Wind Turbine Structure and Fan Blade Development Process

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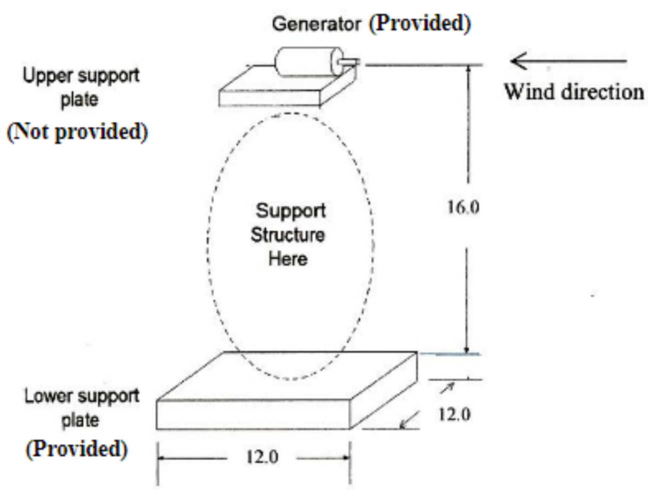
Project Summary

The E26 turbine project consists of two main design goals to complete an overarching objective. With the groups having to create a blade design and a tower to support the blade; they are given some requirements for both the tower and the blade. The tower is required to support a motor and a blade, have a volume less than 16in^3, be scaled appropriately, and resist stress. Additionally, the blade's diameter should not exceed 6.0 inches. As seen in Fig.1, the group is given an ABS plate to glue the tower onto for testing. This also means the tower must support itself and can not rely on the plate through fasteners.



(Figure 1: Project Description and Requirements)

With this context, the objectives of this project are quite clear. The blade must be efficient in creating power. While the tower must be sturdy and resist the stress placed upon it through tests. The project will be tested to see how many RPMs the blade will produce, the structural stability of the tower, and the amount of power created through the attached DC motor.

This means that our group needed to consider multiple factors to produce an effective design. Each component of the scaled down wind turbine our group worked on had all the necessary components required of it. We knew this as we ran our tower through stiffness tests in CAD and researched our blade design thoroughly. Our tower was successful in producing a peak power at .75 Watts, with a deflection of 1.56mm. Our turbine's weight was also in consideration at CAD weight of 308g (with blade) and a final real weight at 263g (with blade). Creating a stiffness to weight ratio of 6.29. Meaning that our design had fulfilled all of the criteria necessary and performed within the expected range.

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Introduction

Historical Introduction

Wind power has been utilized by humanity for more than a millenia with the first practical uses of windmills being recorded as early as the 7th century in Sistan, a region in Iran bordering Afghanistan. For centuries wind power was utilized in agriculture to refine grains like wheat, barley, oats, and rice into flour, a refined product which was easier to store and less perishable. With the invention of the steam engine, most large farming operations replaced their windmills with much more practical steam engine mills which could operate regardless of the wind conditions present. In 1887 Charles F. Bush, an American Scientist, made history by creating the first automatic wind turbine to generate electricity. Despite the invention being promising, utilizing wind for generating electricity was much more expensive than coal use so the invention gained very little popularity. Wind power was first utilized in the commercial market starting around the 1970's with the rise of fossil fuel prices, but was only marginally employed. However, fast forward to today and the world is in an entirely different situation. Currently the world is in a race against time with the climate crisis, and wind power is one of the most promising solutions to our problems. The world's electricity is primarily generated through the burning of fossil fuels like coal and methane, which both increase the concentration of greenhouse gasses threatening the future of humanity. As a result of our uncertain future, humanity must strive to decrease its Carbon Emissions as rapidly as possible. Across much of the developed world wind energy is the most promising alternative to fossil fuels due to its reliability and cleanliness. Wind power has seen an eruption of use in the United States, Europe, and China and is projected to only grow with time due to the decarbonization plans in these countries. Moreover, unlike solar power, wind power is much more dependable due to the fact that wind blows during all hours of the day. However, fossil fuel industries across the world are resisting the use of green technologies through lobbying and many other tactics which have slowed the transition to renewables. Wind power is the most promising tool to solve the complicated and controversial issue of Clean Electricity in the world.

Technical Introduction

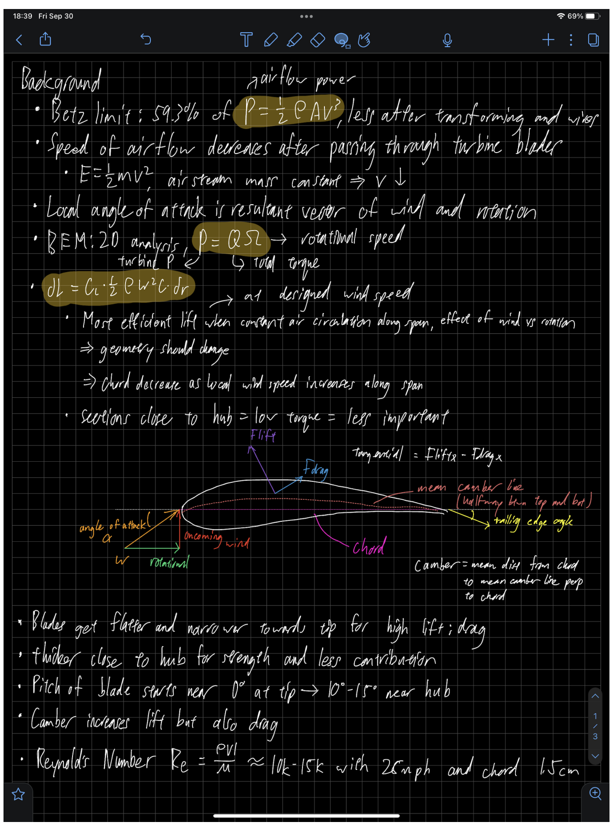
The mechanics of a Wind Turbine are actually quite simple compared to that of other methods of generating electricity. The first key component of a wind turbine is the foundation, which is built into the earth to keep the structure of the Wind Turbine in place during heavy winds exerting extreme forces on the tower. These foundations are traditionally built with cement which is bolted to the turbine tower. The next crucial component is the tower which extends hundreds of meters in the air in order to elevate the generator component of the tower high enough for optimal power generation. The structure of the tower must be sturdy enough to remain upright and withstand the force of the wind hitting it. Next there are the moving components of the blades and hub. Each blade catches the wind and is designed to rotate the hub. Blades are designed to be lightweight but sturdy enough to not flex while rotating. Finally, in the internals of the wind turbine lies the gearbox and generator. The gear box is connected to the main axle of the hub and transmits power to a fast moving shaft, which moves wires around magnets or magnets around wires to generate electricity. Wind turbines also have several crucial safety mechanisms built into them in order to prevent disasters caused by high wind speeds.

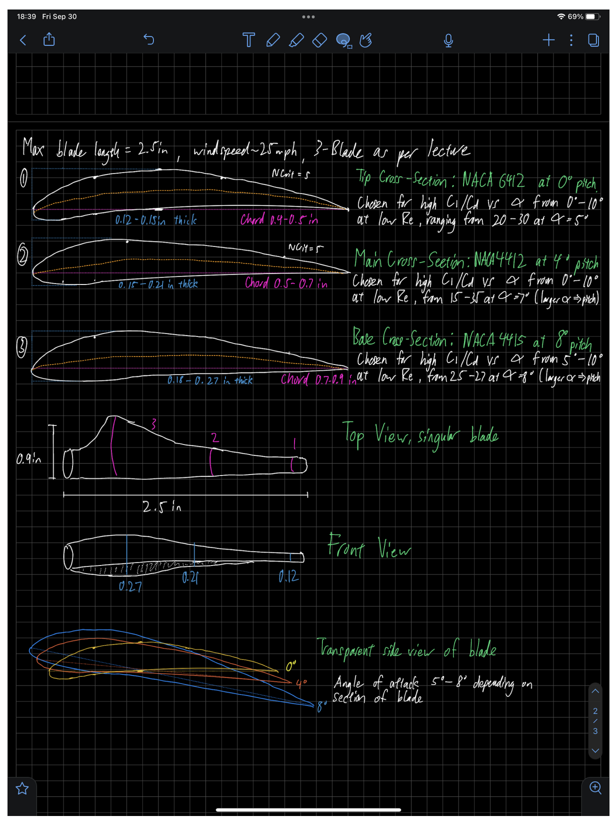
Design

Blade Design

The blade design was the first step to build the wind turbine. Each member of the team did individual research on factors that would impact blade performance such as angle of attack, angle of twist, blade profile, and the number of blades. All group members settled on a 3-blade design but chose different parameters for the angle of attack and angle of twist. Seeing that most blades at the tip had an attack angle of 0 degrees, the attack and twist angle parameters were combined.

Each group member sketched out a blade profile design including parameters for the angle of twist from the hub to the tip of the blade. The parameters used in the final blade design were taken from these sketches:



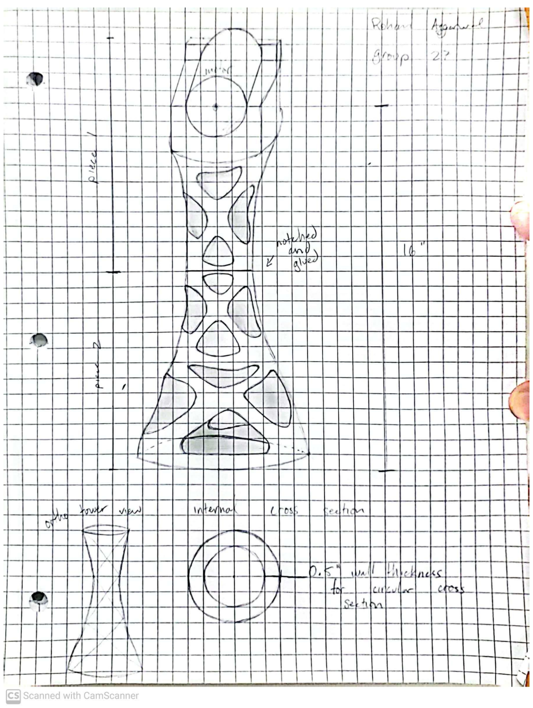


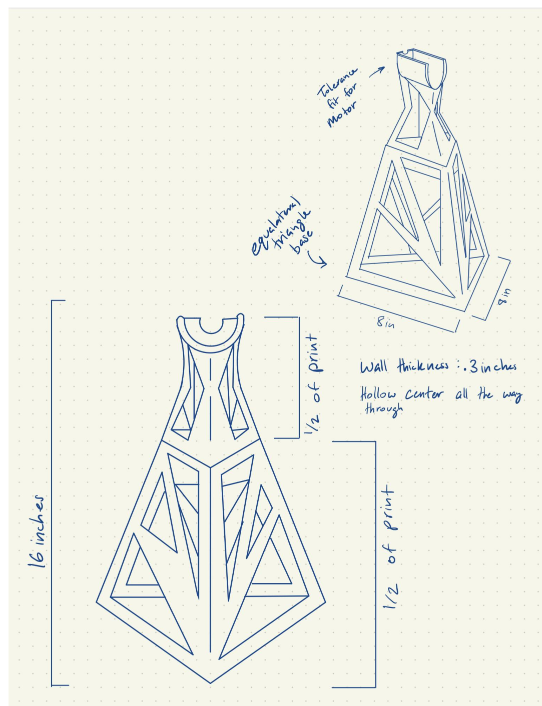
(Figure 2: Blade Research and Concept) (Figure 3: Blade Shape Proposal)

The final blade design had an angle of twist of 8 degrees with 2 cross sections lofted together. We mainly used extrusions to create the shape. The three blade design minimized weight and allowed for a wider blade with more surface area to generate power with. Since the weight of the blade was estimated to be 9g in CAD, there seemed little reason to worry about the potential drag from the larger surface area as the high wind speed in testing would far overpower the air resistance from the blade’s rotation.

Tower Design

Our tower was kept simple. During the design process the team unanimously decided that triangles would be a key shape in the tower pattern. Other than stress considerations, we also thought about how to model our tower. This train of thought led to the use of lofts and extrusions as our team was comfortable with those tools in solidworks. The software itself was also instrumental to the design of the tower. These considerations and reliance on solidworks can be seen in our team sketches and other designs.

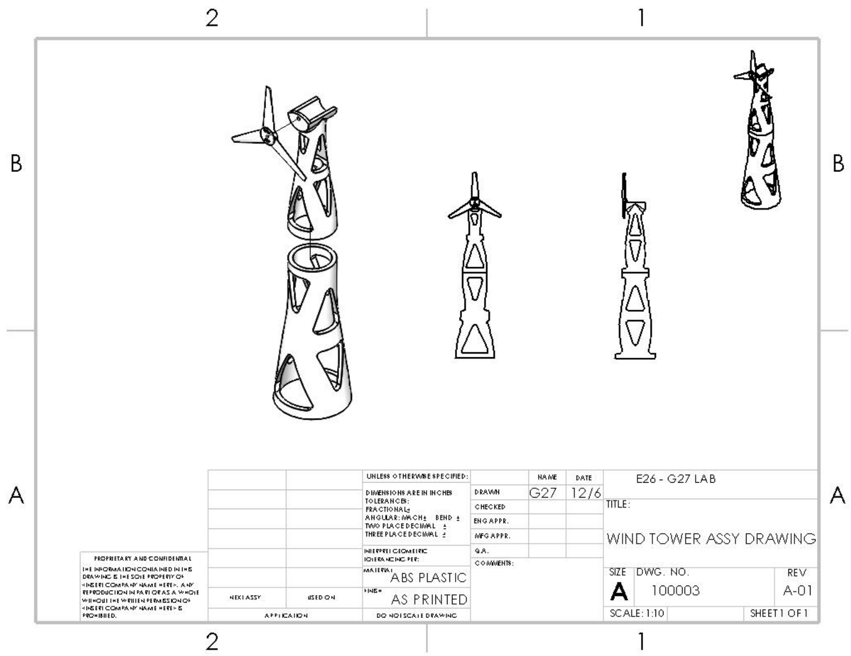




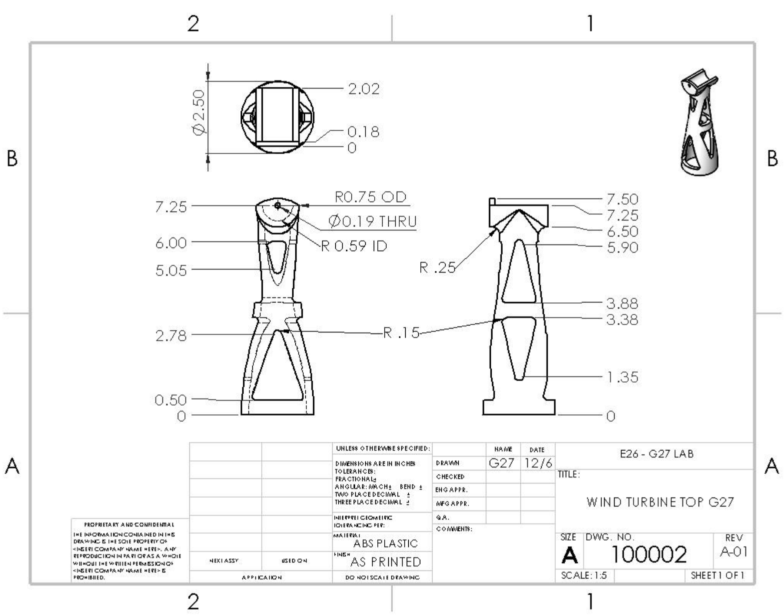
(Figures 4 and 5: Wind Tower Proposal sketches)

Once we had a rough idea of what we wanted, each group member attempted a design. We would combine teammates' ideas into our own model during this process. With the use of a decision matrix and comparison of stress testing through CAD software, we chose a tower. Our results and design can be seen below.

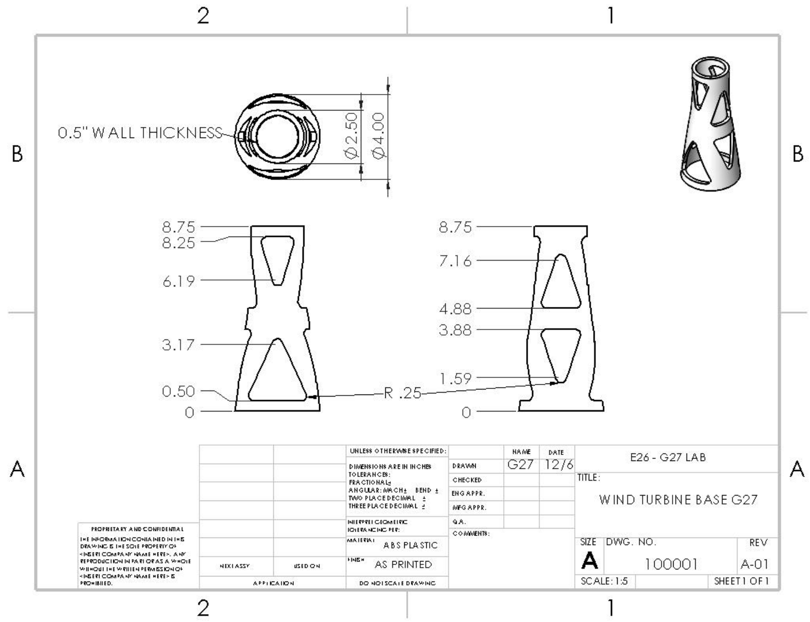
CAD Drawings and Continuation of Tower Design Process



(Figure 6: 3D assembly Drawing of Final Wind tower Design and exploded view)



(Figure 7: 2D Part Drawing for Upper Section of Wind Tower)



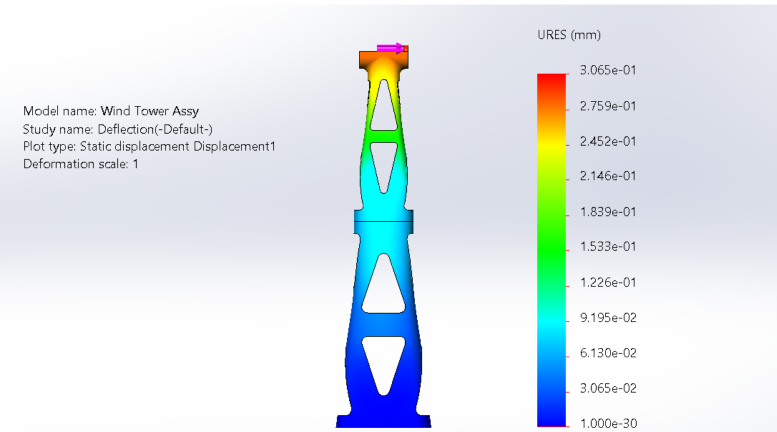
(Figure 8: 2D Part Drawing for Lower section of Wind Tower)

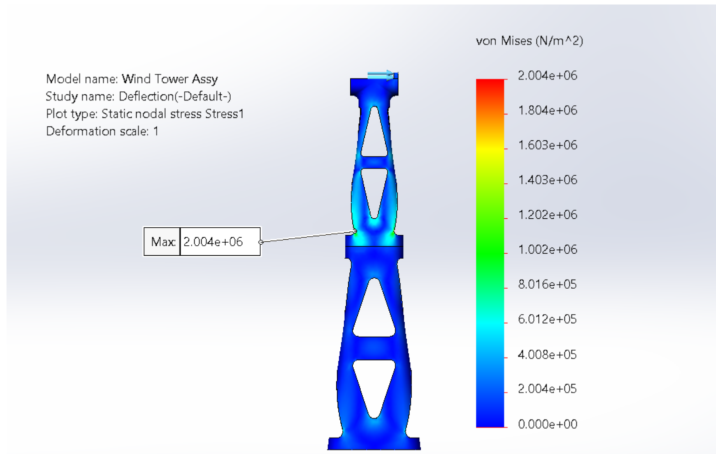
These CAD drawings depict our final tower choice. Once we had picked a tower, we ran simulations to revise our model. We utilized Finite Element Analysis (FEA's) which can be used to see how a structure reacts to external forces. To conduct an accurate simulation, the tower needed to be subjected to the same load scenario it would be presented with in testing. This required a fixture at the bottom of the tower and a fixture holding the two sections of the tower together. After the tower was fixed in place, load was applied to the motor housing hole to simulate the weight on a pulley during testing. Multiple load cases were run on the tower to ensure it could withstand any potential test. Results are below.

Finite Element Analysis Simulation

FEA Analysis and Plots of Tower

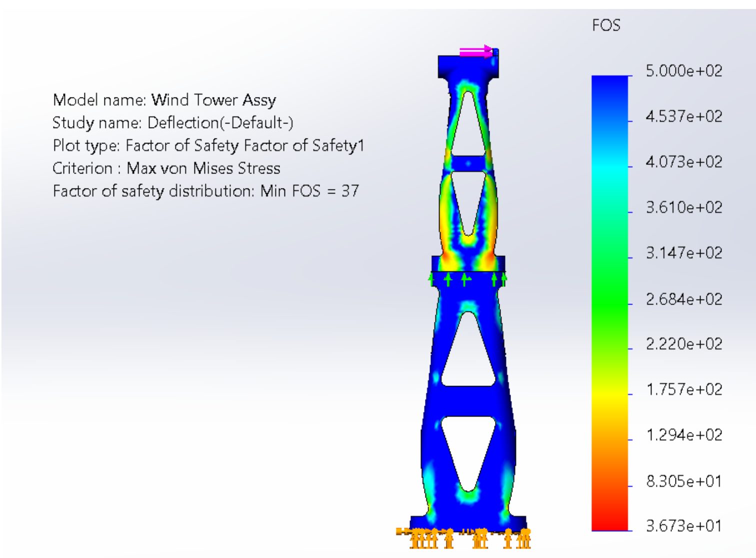
9.8N of Force (1kg):





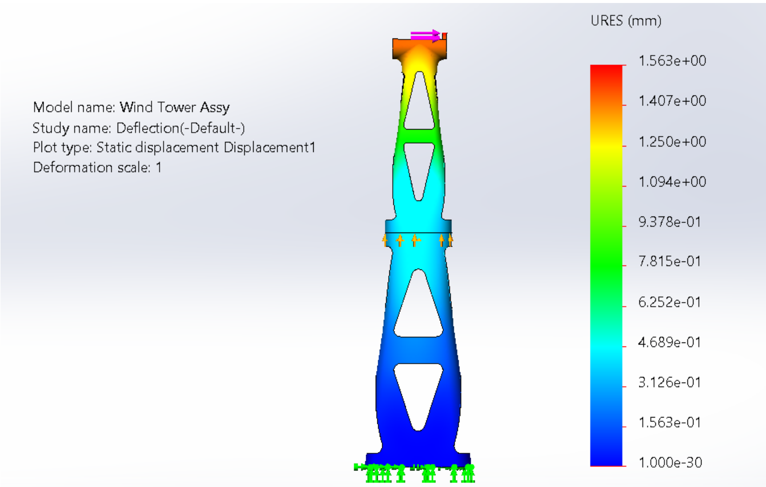
(Figure 9: Predicted Displacement of 0.31mm)

(Figure 10: Peak Stress (von Mises) of 2.004e+06)

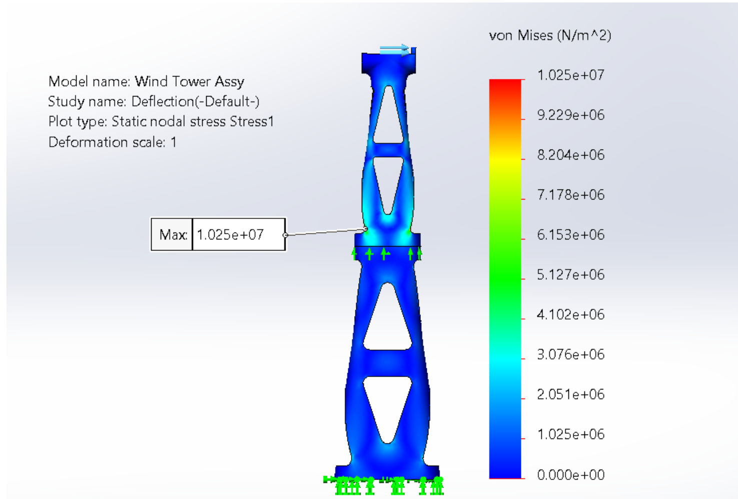


(Figure 11: Minimum Factor of Safety = 37 under 1kg load)

15N of Force (1.53kg):

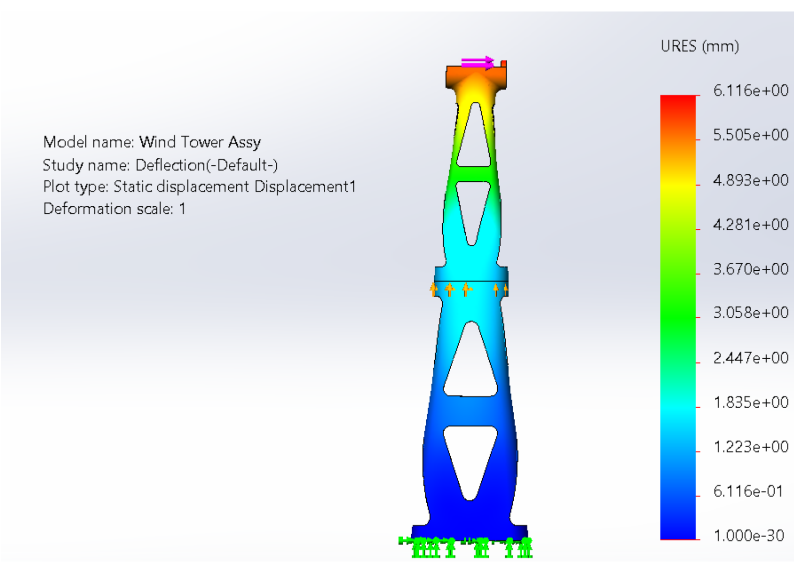


(Figure 12: Predicted Displacement of 1.56mm)

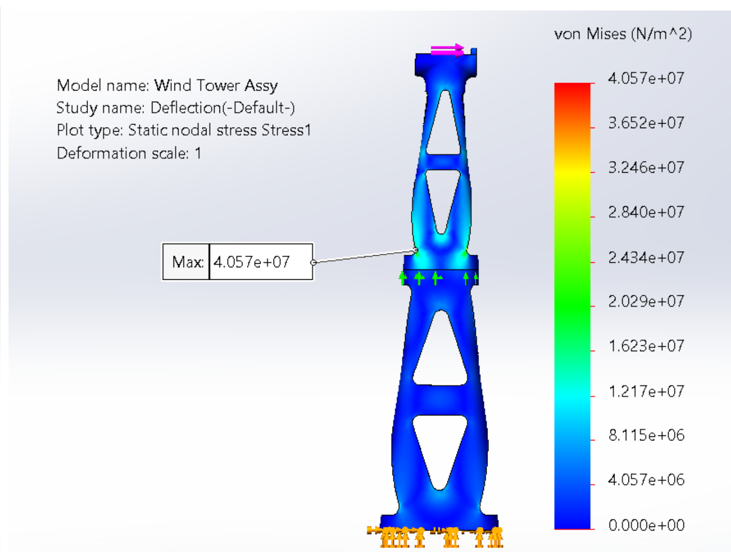


(Figure 13: Peak Stress (von Mises) of 1.025e+07)

196N of Force (20kg):

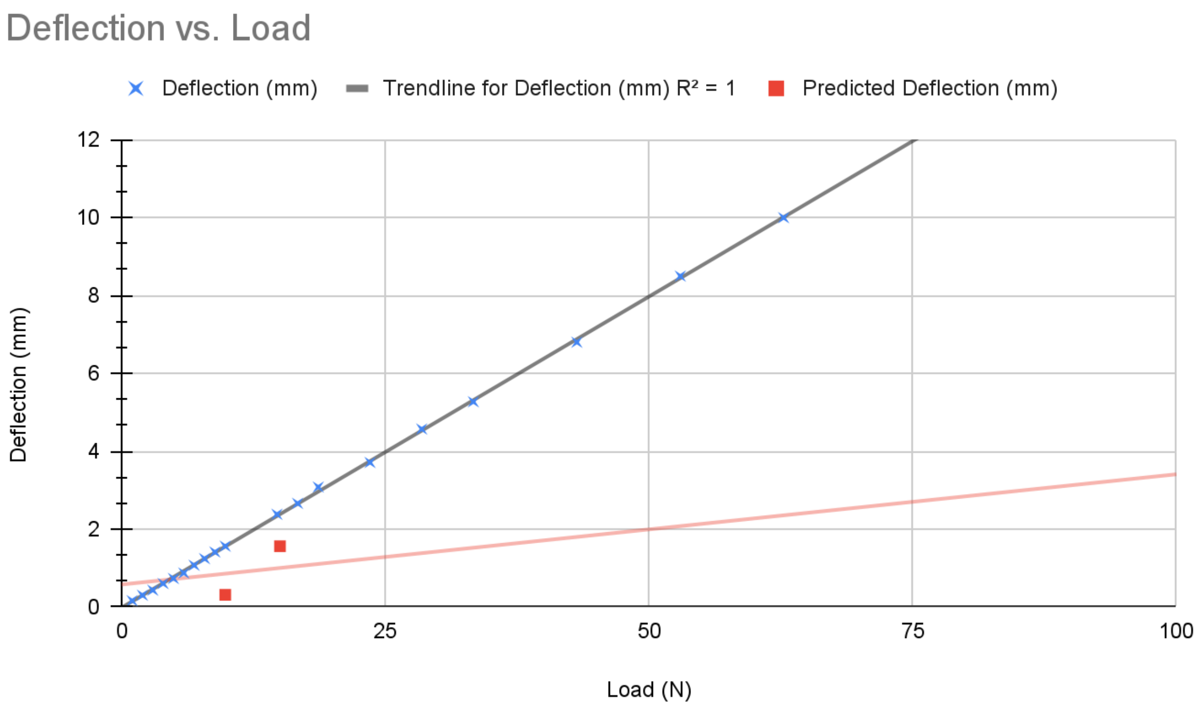


(Figure 14: Predicted Displacement of 6.11mm)



(Figure 15: Peak Stress (von Mises) of 4.057e+07)

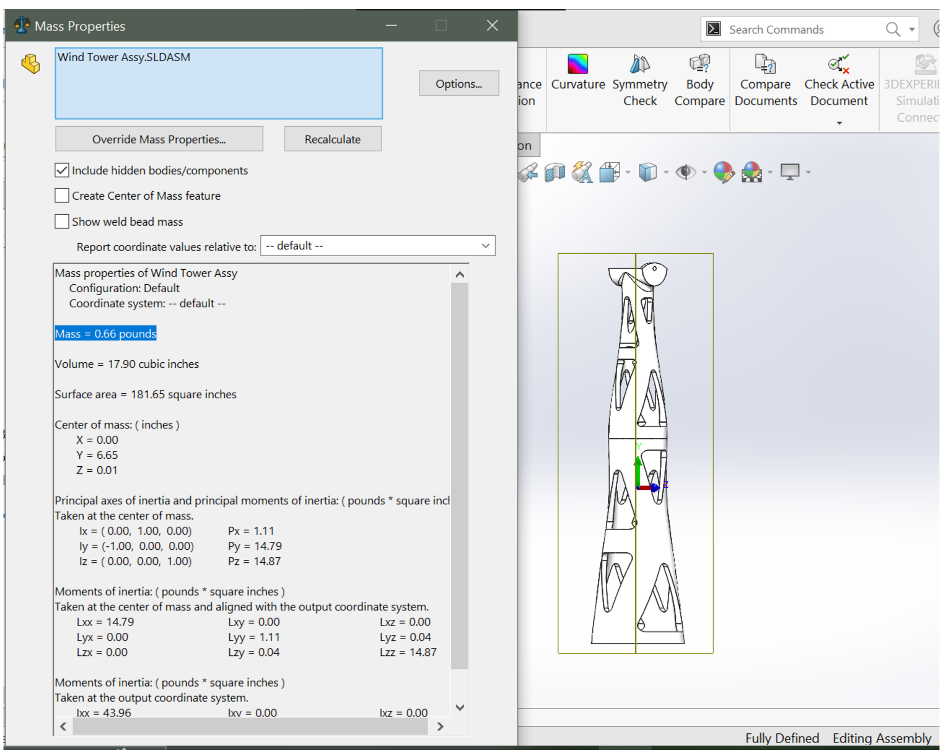
As shown in figure 9, the tower had a minimum factor of safety of 37 under a 1kg load scenario, so the group continued running simulations at higher loads to estimate the stiffness and deflection up to 20kg of force on the tower (figures 12 and 13). Below is a comparison of the simulated and actual deflection results.



(Figure 16: Comparison of Deflection during real test (blue) and FEA simulation (red))

FEA v. Results Comparison

As illustrated in figure 16, the FEA simulations did not accurately predict the deflection of the wind tower under load. Real deflection of the tower was significantly higher than that of the simulations. This may be due to a discrepancy between the material properties of the ABS plastic in the SOLIDWORKS materials library and the actual material properties of the printed ABS plastic that the tower was ultimately made of. Another potential discrepancy is the actual weight of the tower compared to estimated weight in CAD. The tower weighed in at 263g while CAD predicted 308g (Figure 17 below). However, the tower remained stiff and showed no signs of nearing failure even under high load scenarios. There was not enough time to test the yield force of the tower. Ultimately we ended with a Stiffness to Weight Ratio of 6.29.

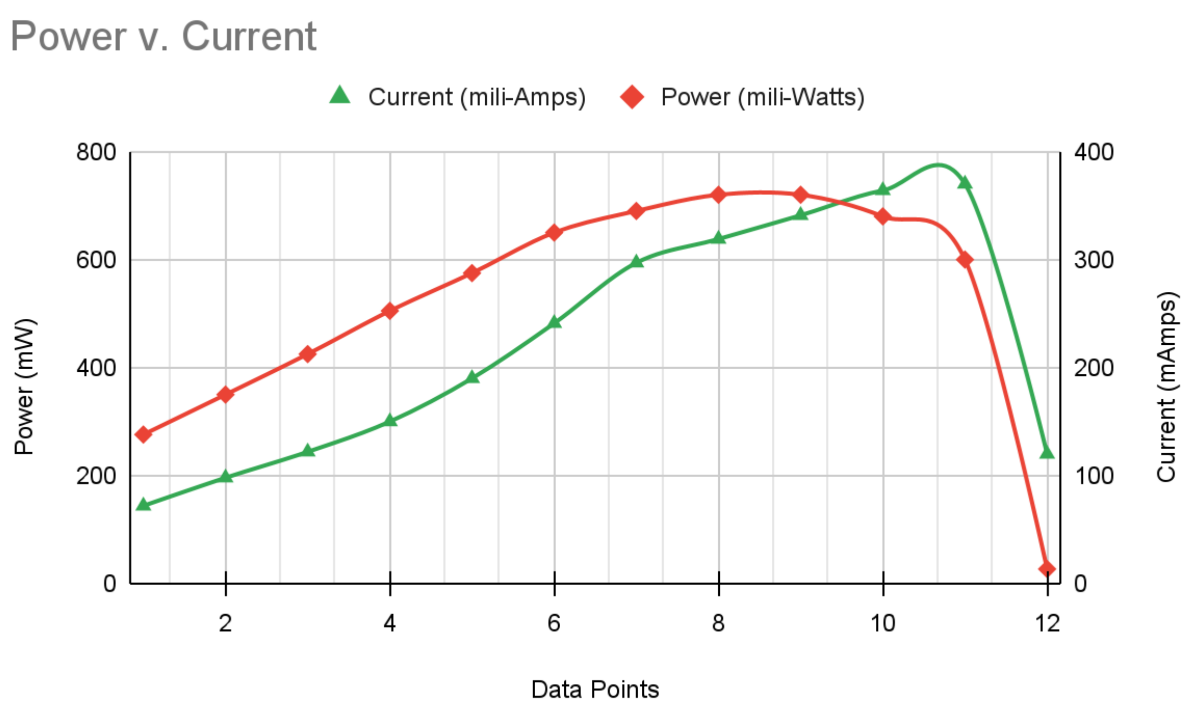


(Figure 17: weight of tower in CAD)

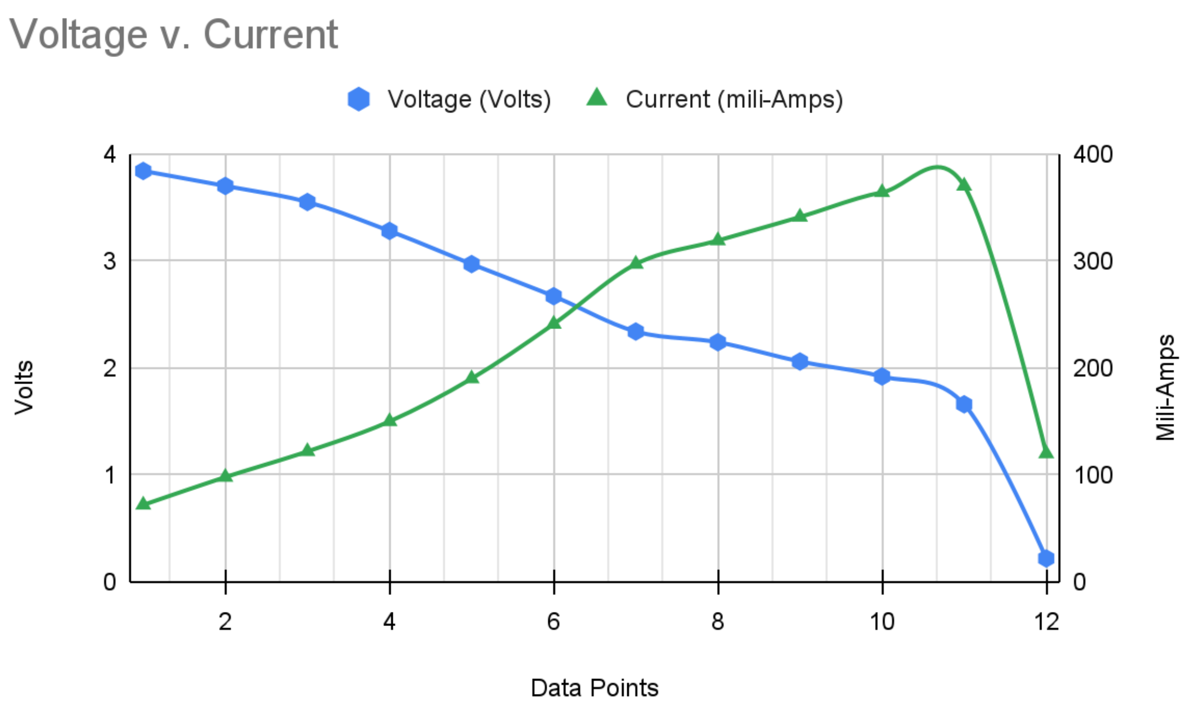
Results

Blade Performance

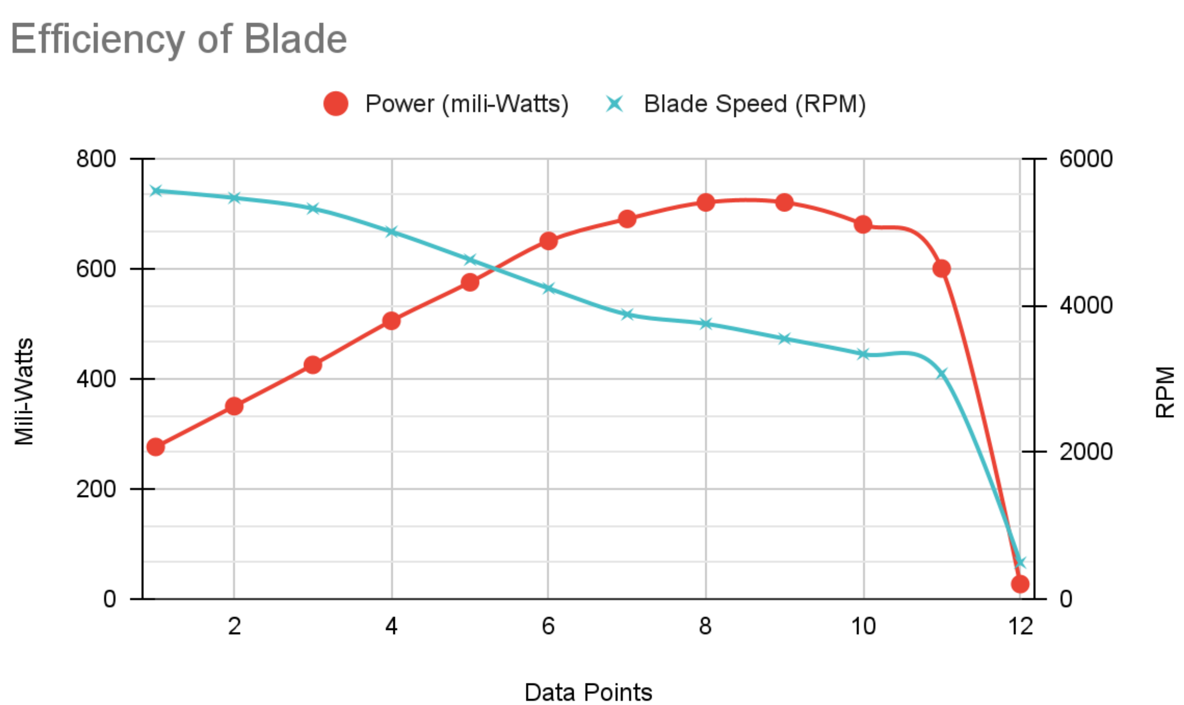
To test the power output of the blade, it was attached to a motor housed at the top of the tower which would serve as a generator. The motor was connected to potentiometers that controlled resistance and sensors that provided information on the Voltage, Current, and Power output of the turbine. A high power fan blew air at approximately 25mph at the blade. To test the maximum power output of the blade, data was collected with the motor at no internal resistance. Then, incrementally, resistance was increased using the potentiometers and the power output was recorded. This was done until the power began to decline and the blade stalled due to high internal resistance that the wind could no longer overcome. Results are shown below.



(Figure 18: Plot of Power output versus Current over the course of the test)



(Figure 19: Plot of Voltage versus Current over the course of the test)



(Figure 20: Power output versus Blade speed over the course of the test)

The results of the test showed that the blade could produce a maximum of 0.75Watts of power with 25 mph wind. As the current (resistance) increased power of the blade increased until peak power was achieved. With additional resistance, the power output began to decrease until it quickly dropped off in a stall. The blade was most efficient at approximately 3500 revolutions per minute as seen in Figure 20.

Conclusion

The design process of our project incorporated CAD modeling, simulations, and research. Initially, our group conducted research on the factors that make a wind turbine successful in power generation and structural stability. We designed several towers and blade designs in SolidWorks, all while adhering to manufacturing limitations, and ran simulations to determine which would best meet our needs.

As a result of our design process, the structure fully met project objectives. The design of the blade allowed for moderately efficient power generation. Additionally, the tower design was relatively sturdy, especially compared to class averages.

Recommendation for future work

In our project, we measured the power generated by wind turbines and stiffness by measuring the displacement of the tower when pulled by 1 kg. Our wind turbine has successfully generated power of 0.75W and did not break even when it was pulled by more than 6 kg, but it is also true that our wind turbine was not exceptionally good compared to others. To improve on both measurements, we found some suggestions to improve the wind blade design for power, the tower design for stiffness, and one more fun idea.

Firstly, we should improve our blade design. Our blade design could improve with increasing difference between the top and bottom length to increase the air pressure difference. The time for the wind to reach from the start to the end of the edge would be the same on both the top and bottom sides, so having more of a difference would increase the difference in speed, increasing the lift. We can also create a smoother edge on both the contacts to increase the use of wind. We could also bend the tip of our blade to decrease the vortex-like airplane blade. Nowadays, planes usually bend the wingtip to decrease the vortex and drag. If we could bend the tip of a blade, we could decrease the drag, slowing the wind blade. Moreover, the angle of the twist should change as well. The angle of twist should be around 5 to 10 degrees; however, we could have given more of the angle of a twist near the center where the area of air contact is higher compared to the edge of the blade. Currently, our angle of twist is contact throughout with around an angle of 10 degrees. We could have done a 3-degree angle of change around the edge and a 7-degree angle of change near the center. Finally, we could increase the area of the air contact area. We believe it would have been better to increase the air contact of the blade after seeing that there seems to be a high correlation between the power generated and the size of the wind turbine. For example, there is an increase in air contact by increasing the width of the blade.

Secondly, the tower design can improve further to increase the tower stiffness. The inner support structure could have given stronger support. For example, a central pillar connects with the wall of the tower to resist the bent. In addition, we could have used more of a triangular-based shape. Using a more triangular-based shape would allow us to use more of the other volume to build a towering wall thicker or pillar as I mentioned earlier. Thirdly, we could have organized the cheese hole more organized way so that it can resist more of the pull and become stiff. For example, when the edge of the triangle meets, we could have made the corner of the triangular hole smoother using a fillet tool, so that the joint will be stiffer than the current design and can support the weight. We could also create a three-central on the wall that would transfer the force vertically.

One fun idea is that we could hollow out the wall of the tower. Hollowing out the wall would allow us to build more structure to give extra stiffness to the tower while allowing the 3d printer to build its support system to build the 3d design.