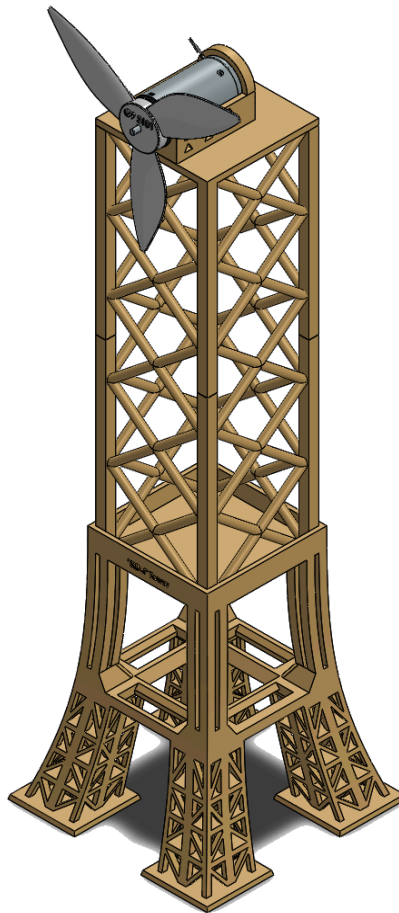


University of California, Berkeley
Department of Mechanical Engineering
ENGIN 26 - Three-Dimensional Modeling for Design

Design, Optimization, and Testing of Wind Turbine with Multi-Objective Optimized Blades and an Eiffel Tower-Inspired Structure



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Project Summary

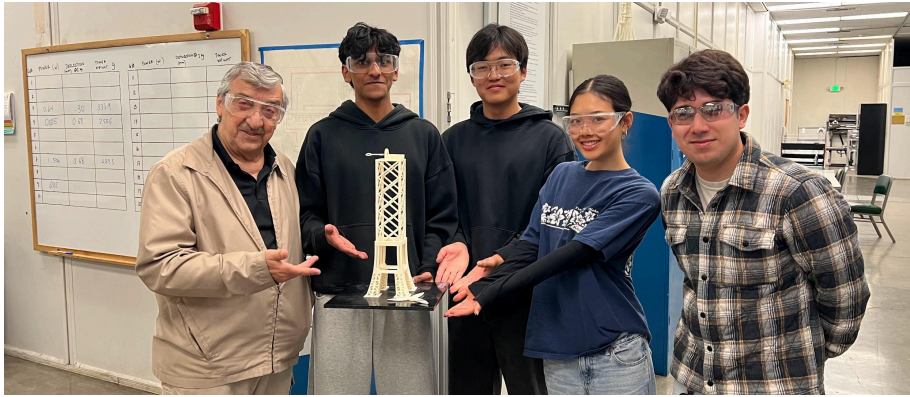


Figure #: Proud Project-mates + Professor Youssefi Holding our Eiffel Tower Wind Turbine

The goal of this project was to design, optimize, assemble, and test a small-scale wind turbine. Our work focused on two main areas: improving the aerodynamic performance of the rotor blades and designing a lightweight but structurally stable tower. The project combined computational optimization, CAD modeling, finite element analysis (FEA), fabrication, and physical testing.

The rotor blades were designed using a custom Python optimization framework that uses XFOIL aerodynamic analysis, Blade Element Momentum (BEM) theory, and multi-objective optimization techniques. Different blade geometries were evaluated by adjusting parameters such as blade twist, chord distribution, angle of attack, and tip-speed ratio before selecting a final three-bladed NACA 23012 rotor configuration.

For the tower, our group designed a tapered lattice structure inspired by the Eiffel Tower because of its structural efficiency and visual appearance. FEA simulations in SolidWorks showed low displacement under loading conditions, while experimental testing produced highly linear structural behavior with an R^2 value of approximately 0.995 and an estimated stiffness of about 99N/mm. During the destruction test, the tower failed near the glued connection between the thinner upper section and heavier lower base section, identifying the bonded region as the primary stress concentration point.

Although our final rotor design was unable to generate measurable electrical power, it was still able to achieve some rotational motion under wind loading. Testing with a successful reference rotor provided by Professor Kourosh Youssefi achieved a peak power output of approximately 1.374 W at 5441 rpm. Overall, the project demonstrated strong structural performance from the tower while also highlighting the importance of blade geometry and manufacturing accuracy in small-scale wind turbine systems.

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Introduction

Background on Wind Turbine Systems

Wind turbines are an important source of renewable energy because they generate electricity without producing harmful emissions from fossil fuels. As the demand for cleaner and more sustainable energy continues to increase, engineers play a major role in designing systems that are both efficient and structurally reliable. Wind turbines work by converting the kinetic energy of moving air into electrical energy. When wind blows against the turbine blades, the blades begin to spin. This spinning motion turns a shaft connected to a generator, which then produces electricity. The main parts of a wind turbine include the blades, rotor, generator, and tower, which work together to convert wind energy into electricity. The primary goal of this project was to work as a team to design and build a wind turbine model while learning more about the engineering design process. Throughout the project, our group developed ideas for the turbine design, created a 3D model in SolidWorks, and performed simulations to analyze factors such as stress, displacement, and overall structural performance under loading conditions. The development of modern wind turbine technology is the result of many years of engineering advancements, beginning with early wind-powered machines and continuing to the large-scale energy systems used today.

The development of wind turbines has taken place over many centuries as engineers continued to improve the ability to convert wind into useful energy (National Grid, 2024). Some of the earliest uses of wind power date back to around 200 BC in China (UTI Editorial Team, 2024), where wind-driven water pumps were used for farming and irrigation. Later, windmills became common throughout Europe and the Americas, where they were used for tasks such as pumping water, grinding grain, and cutting wood. The advancement of electricity in the late nineteenth century greatly expanded the purpose of wind-powered machines. In 1887, Scottish engineer James Blyth designed one of the first wind turbines capable of generating electricity for a home (Garisto, 2022). Over time, improvements in materials, aerodynamics, and electrical systems allowed wind turbines to become larger, more efficient, and more reliable for energy production.

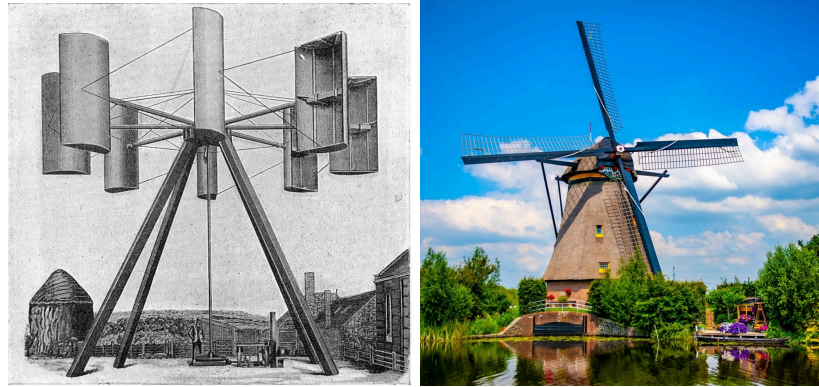


Figure 1 & 2: James Blyth's turbine(left), 1740 Kinderdijk Dutch Windmill (right)

Modern wind turbines are now used around the world as an important source of clean and renewable energy. In the United States, wind energy has grown quickly as the country works to reduce its dependence on fossil fuels such as oil and coal. States like California have invested heavily in wind farms and other renewable energy systems to help provide cleaner electricity for homes and businesses (American Clean Power, 2024). Today, there are two main types of wind turbines: Horizontal Axis Wind Turbines (HAWTs), which are the large three-blade turbines commonly seen in wind farms, and Vertical Axis Wind Turbines (VAWTs), which rotate vertically and can work well in areas with changing wind directions. As technology continues to improve, wind turbines are becoming more efficient and more widely used throughout the world. The continued growth of wind energy shows how engineering and renewable technology can help create a cleaner and more sustainable future.



Figure 3 & 4: HAWT Wind Farm (left), VAWT turbine (right)

Project Objectives and Constraints

The main objective of this project was to design and optimize a small-scale wind turbine while understanding the advantages and disadvantages of different blade designs. Throughout the design process, our group focused on improving the turbine's performance

by testing three main factors: the number of blades, the blade profile, and the angle of attack. Understanding how lift and drag affect turbine blades was an important part of the design process. Wind turbine blades are designed to generate lift, which creates the rotational motion needed to spin the rotor and produce electricity. As wind flows across the blade, air pressure changes on each side of the blade, creating lift and drag forces. Lift acts as the main driving force that turns the blades, while drag creates resistance against the motion (U.S Department of Energy, 2023). A successful blade design must balance these two forces in order to maximize efficiency and rotational speed.

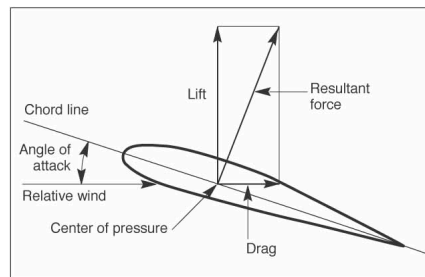


Figure 5: Lift, drag, and angle of attack

The project also included several engineering and manufacturing constraints that affected the final design. The lower support platform was provided as a 12 × 12 inch ABS plastic plate, and the motor was provided to act as the generator. The maximum rotor swept diameter could not exceed 6 inches, meaning the blade length from the center of the hub to the tip could not be greater than 3 inches. A CAD model of the rotor hub was also provided and could not be modified. In addition, all parts had to be fabricated using 3D printing and fit within the printer build size of 9 × 9 × 9 inches. These constraints limited the overall turbine size and required careful consideration of blade dimensions and manufacturability during the design process.

Design Methodology

Our group chose to use a three-blade design for the wind turbine because it balances efficiency, stability, and overall performance. During lecture, Professor Youssefi explained that turbines with an odd number of blades generally perform better because they are more balanced and stable during rotation. The lecture also showed that adding more blades increases efficiency, but the improvement becomes smaller with each additional blade. For example, going from one blade to two blades increases efficiency by about 6%, while going from two blades to three blades only increases efficiency by about 3%. This demonstrates that the benefits begin to level off as more blades are added. Based on these engineering considerations, a three-blade design was selected. This decision was also supported by a lecture from Massachusetts Institute of Technology on Wind Power Fundamentals, which

identified two and three-blade turbines as the most efficient and commonly used designs in modern wind turbine systems.

The angle of attack determines how the air flows over the blade and affects how much lift and drag the blade produces. Choosing the correct angle is important because if the angle is too small, the blade will not create enough lift to efficiently spin the turbine. If the angle is too large, drag increases and the blade becomes more likely to stall, which reduces performance. Our group selected an angle of attack of 3.86° because it provided a good balance between lift and drag while maintaining stable performance. This angle also falls within the commonly recommended design range of about 3° to 8° used in wind turbine engineering (U.S Department of Energy).

Twist was added to the blade because the airflow angle changes along the length of the blade. Near the center of the rotor, the blade moves more slowly and requires a larger blade angle to maintain effective lift, while the outer sections move faster and require a smaller angle. Because of this, the blade was designed with a twist of approximately 9° to help maintain efficient airflow and more consistent aerodynamic performance across the blade. In theory this should've allowed the turbine to generate lift more effectively along the full span of the rotor and improve overall rotational efficiency, but in reality the results showed something else.

After researching different airfoil designs, our group selected the NACA 23012 airfoil blade profile because it provided a good balance between performance and structural strength. The airfoil shape affects the amount of lift and drag produced by the blade, which directly impacts how efficiently the wind turbine operates. Through modeling and simulation, the NACA 23012 profile showed strong aerodynamic performance while keeping structural stress lower than some other designs (Martinez Garcia, 2026). The profile also worked well with the selected angle of attack, helping the blades generate enough lift while reducing unnecessary drag and bending forces. Based on these results, the NACA 23012 profile was chosen as the best overall option for the final turbine design.

For the tower design, we focused on creating a structure that was lightweight, stable, and able to satisfy all project constraints. Our group chose to model the tower after the Eiffel Tower because we thought it would be interesting and visually appealing to build from scratch. However, due to material and manufacturing constraints, we could not include all of the detailed features of the real structure. The tower height had to position the motor shaft exactly 16 inches above the platform, and the structure had to be radially symmetrical with at least three contact points for stability. All parts also had to fit within the $9 \times 9 \times 9$ inch 3D printer build size, use less than 17 in^3 of printed material and support volume, and be printed in at least two separate pieces that were later glued together. These constraints

required our group to balance structural strength, stability, manufacturability, and appearance throughout the design process.

Wind Turbine Blade Design

Optimizing Blade Profile Parameters

The wind turbine rotor blade was designed using a custom computational optimization framework developed in Python (Martinez Garcia, 2026). The framework uses XFOIL aerodynamic analysis, Blade Element Momentum (BEM) theory, and multi-objective optimization techniques to generate an efficient rotor geometry as shown to be effective in prior experiments (Li et al., 2023).

The optimizer defined each blade candidate using a design vector containing the airfoil profile, blade count, tip-speed ratio, design angle of attack, hub-radius ratio, chord scaling factor, and twist scaling factor. These parameters were iteratively modified throughout the optimization process to evaluate how geometric changes influenced rotor performance. An NSGA-II style evolutionary algorithm was used to generate and rank blade candidates using non-dominated sorting and Pareto-front selection.

Aerodynamic analysis relied heavily on XFOIL, which generated lift and drag coefficient polar data for multiple Reynolds number conditions. These aerodynamic coefficients were then integrated into the Blade Element Momentum solver to estimate rotor torque, power coefficient C_p , thrust loading, and root bending moment for each candidate blade geometry.

The blade geometry was generated by discretizing the blade into multiple radial sections extending from the hub to the tip. For each section, the optimizer calculated the local inflow angle, chord length, and twist angle required to maintain favorable aerodynamic loading across the blade span. The resulting geometry featured larger twist angles near the blade root and progressively reduced twist toward the blade tip.

The local blade geometry was generated using the following relationships:

$$\lambda_r = \lambda \frac{r}{R}$$

$$\phi_{des}(r) \approx \frac{2}{3} \tan^{-1} \left(\frac{1}{\lambda_r} \right)$$

$$\theta(r) = s_t (\phi_{des}(r) - \alpha_d - \beta_{pitch})$$

$$c(r) = s_c \left(\frac{8\pi r \sin(\phi_{des})}{BC_{l,des} \lambda_r} \right)$$

In these equations, λ_r represents the local tip-speed ratio, ϕ_{des} is the design inflow angle, $\theta(r)$ is the local twist angle, and $c(r)$ is the local chord length. These equations allowed the optimization framework to directly generate the blade chord and twist distributions from aerodynamic performance targets.

The optimization process ultimately selected a three-bladed NACA 23012 rotor configuration as the best compromise solution between aerodynamic efficiency and structural loading.

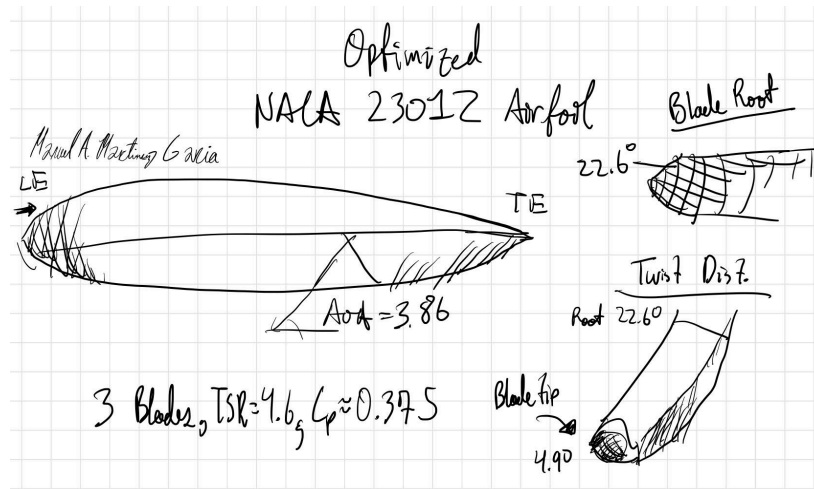


Figure 6: Initial conceptual sketch of the optimized NACA 23012 blade geometry showing blade twist and aerodynamic features.

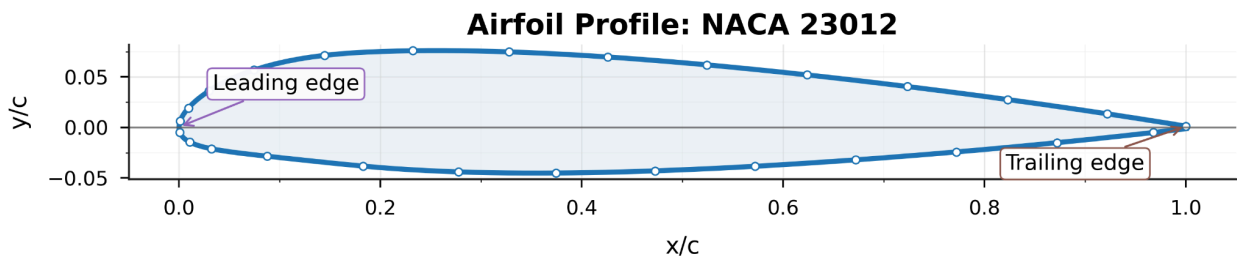


Figure 7: Optimized NACA 23012 airfoil profile generated by the computational optimization pipeline.

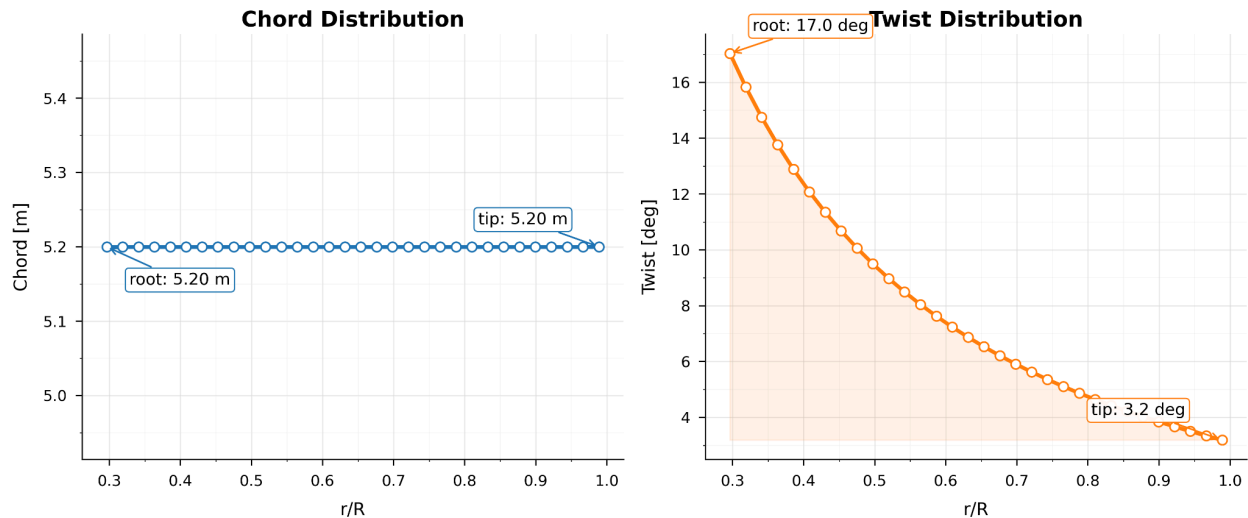


Figure 8: Optimized chord and twist distributions generated using the Blade Element Momentum optimization framework

The optimized blade geometry used a tip-speed ratio near 4.6 and an optimized angle of attack near 3.9° . The twist distribution gradually decreased from root to tip to maintain a more consistent aerodynamic loading condition across the blade span.

Final Rotor Blade Design

After optimization, the generated airfoil geometry was exported directly from the computational pipeline as (x, y) coordinate data. These coordinate files were imported into SolidWorks and converted into spline curves to reconstruct the airfoil cross section. The optimized chord and twist distributions were then incorporated into the CAD model to generate the final blade geometry. Using the provided hub geometry, multiple reference planes were created along the blade span, where the generated airfoil profiles were positioned and scaled accordingly. A loft operation was then used to form the final continuous blade surface and produce the completed turbine blade design.

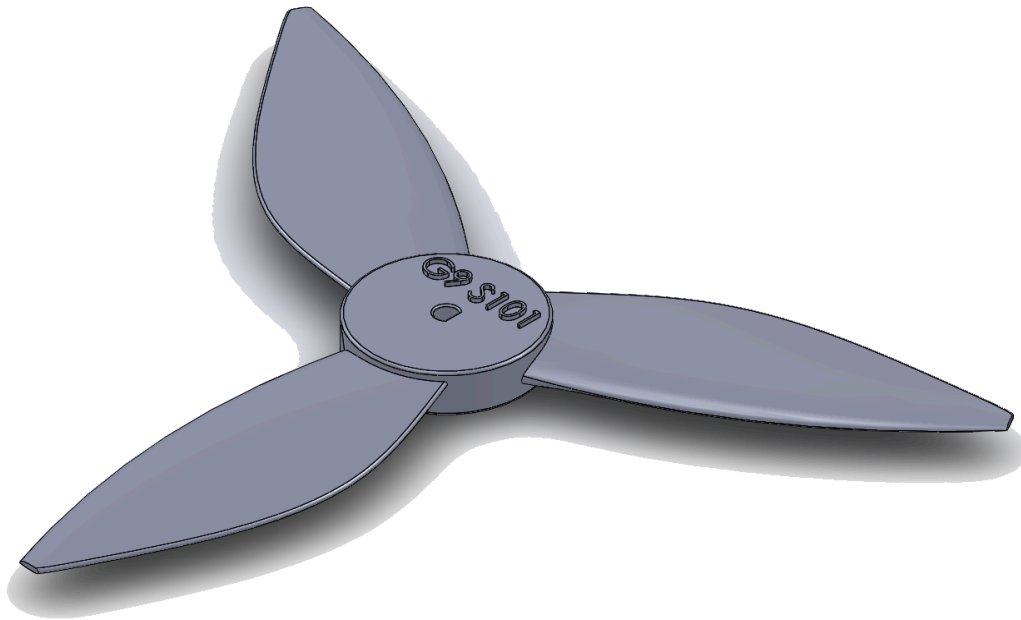


Figure 9: Final Rendered Wind Turbine Rotor with Optimized XFOIL Output

Turbine Tower Design

Tower Design Requirements

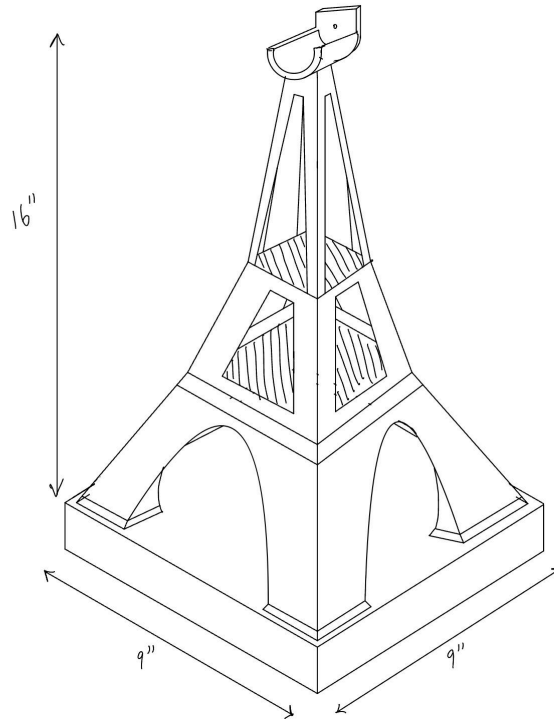


Figure 10: Initial Eiffel Tower Design within Required Constraints

We decided to use the Eiffel Tower as inspiration for our tower design because it is not only visually iconic, but also a proven structurally efficient design. We also found support for this concept in prior case studies (Surya Teja et al., 2022) which shows that complex lattice-style geometries can be effectively fabricated using modern 3D printing technology.

Our initial idea was to maximize the available print volume by splitting the tower into two separate sections that could fit within the printer constraints. These sections were designed to connect together using a LEGO-style interlocking mechanism, allowing the final assembled tower to maintain both structural support and ease of fabrication.

Eiffel Tower Inspired Structural Geometry

Before rendering though, we wanted to get the most accurate (and scalable) dimensions of the Eiffel Tower that we can fit into the parameters of the 3D printer and our model requirements. We ended using the design and calculations from John Hopkins' Perspective on the Evolution of Structures class (John Hopkins University & University of Massachusetts, 2005).

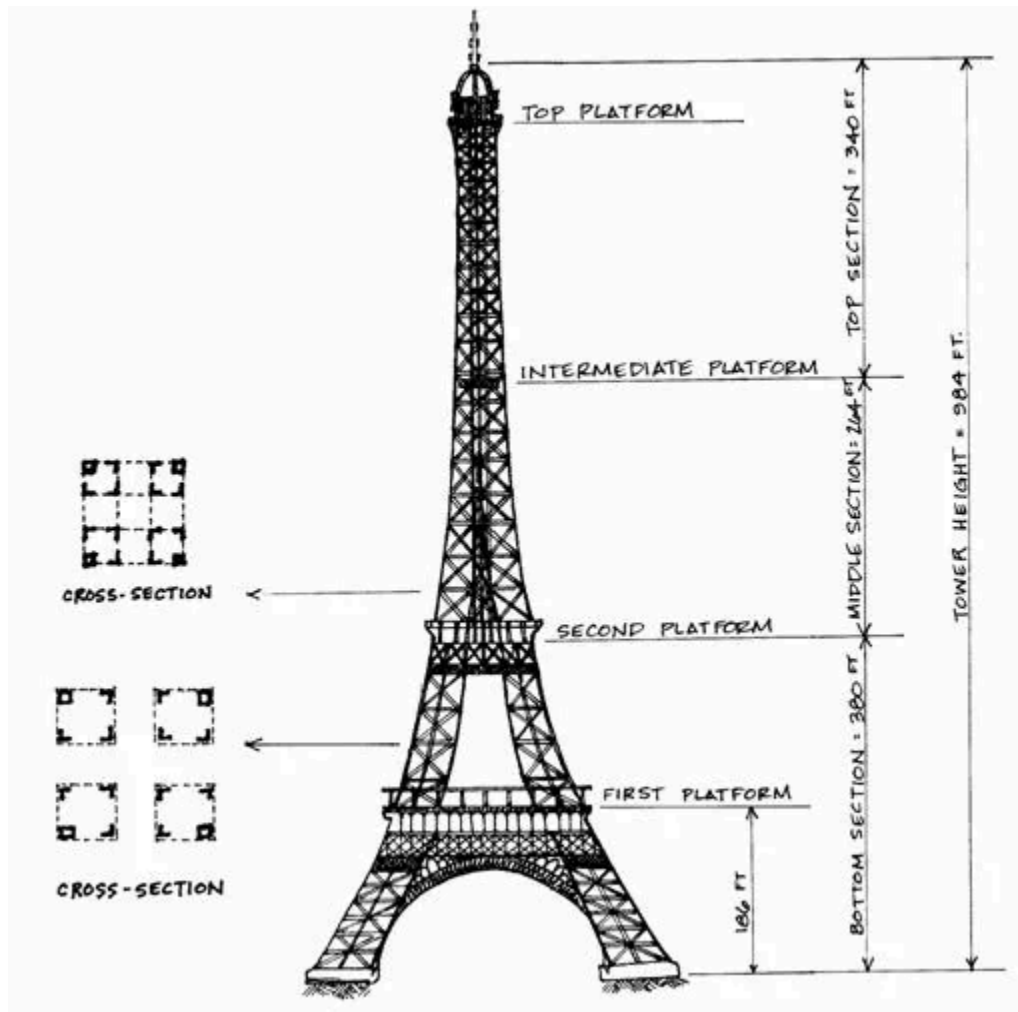


Figure 11: Geometry of Eiffel Tower from JHU's Perspective on the Evolution of Structures

We found this model to be the easiest to scale and interpret and best to use for our model. We quickly found that instead of using 2 platforms it would've been easier to do 3.

Tower Concept Development

As we developed and rendered our model as SolidWorks, more challenges came up especially with our volumetric constraint being way above 17 in^3 despite the lattice cuts. At first, we adjusted the model by reducing the base from 9 inches to 5 inches, which worked well at first, but quickly realized our top platform quickly tapered to 0.

We realized that we had to set a constraint to the top platform to be wide enough to handle any sort of motor housing, thus we went with a conservative $2.5 \text{ in} \times 2.5 \text{ in}$ base to fit any motor housing. This change led to us realizing that the top 2 thirds ended up converging to become a straight line.

Despite this, it wasn't enough. We ended up making a decision where we ended up choosing to stick with the original eiffel tower base, but doing a simple and "standard" version of a lattice tower with X bars since regardless the tower would work best if the top thirds of the tower were straight.

CAD Modeling of the Tower

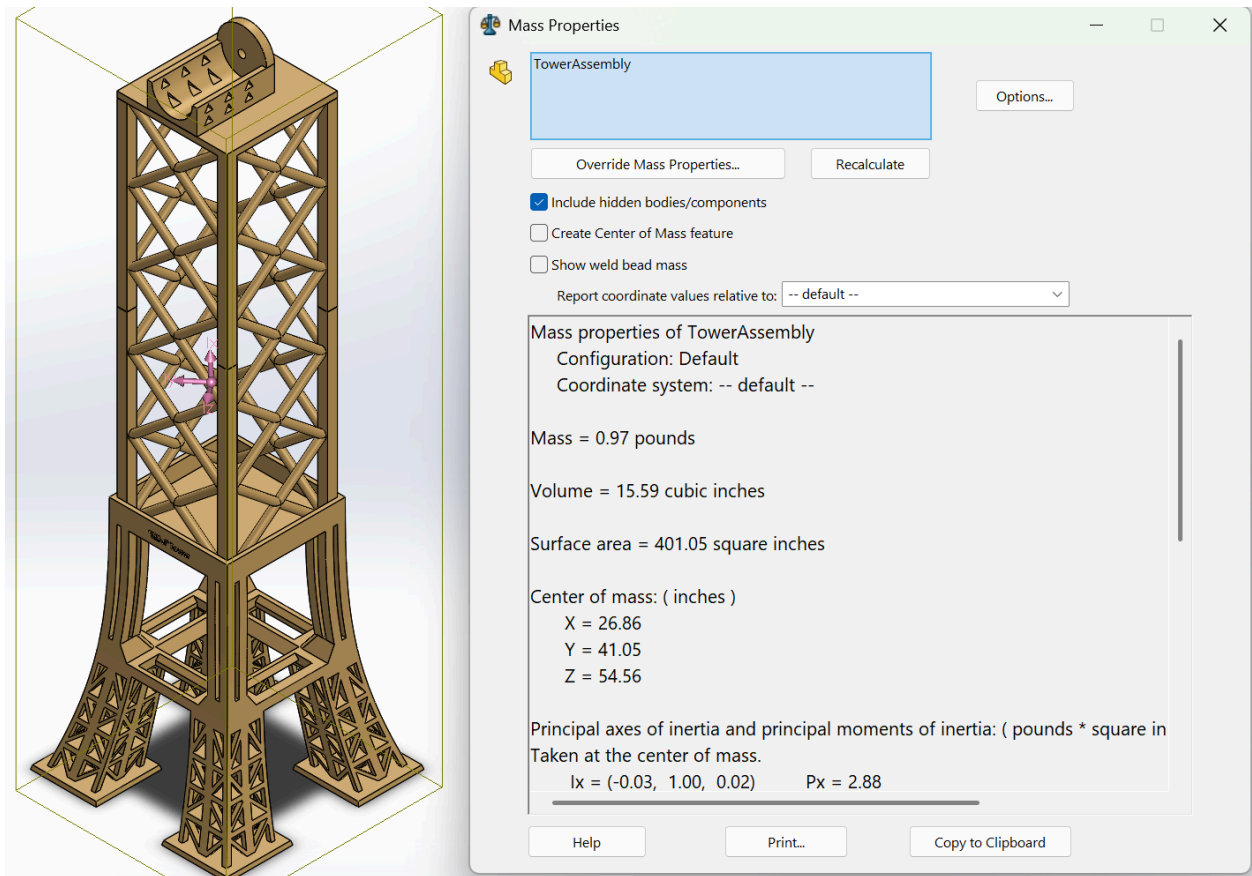
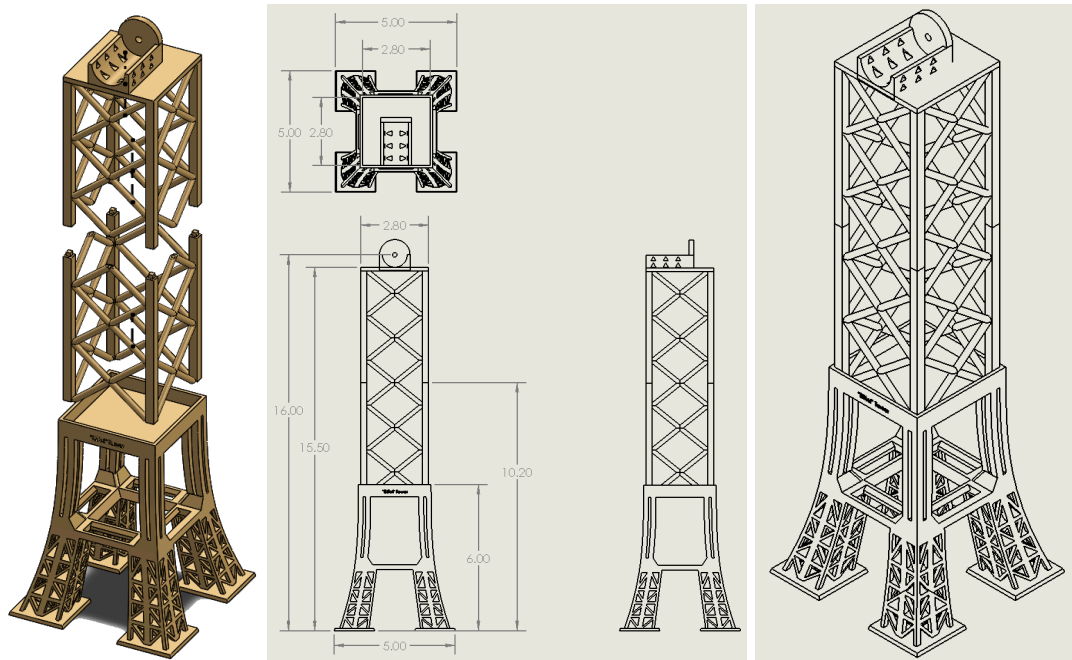


Figure 12: Final Rendered Assembly of Eiffel (Wind Turbine) Tower with Mass Properties Tab



Figures 13, 14, & 15: Exploded View (Left), 2D Drawings (Center), 3D Assembly Drawing (Right)

Theoretical Results

Theoretical Power Generation

The wind turbine power formula calculates the kinetic energy extracted from wind per unit of time. The formula is defined as the following:

$$P = \frac{1}{2} \rho A V^3 C_p \quad \text{such that:}$$

- P (Power) = the electrical power produced in Watts (W).
- ρ (Air Density) $\approx 1.225 \text{ kg/m}^3$ at sea level.
- A (Rotor Swept Area) = the area covered by the blades, calculated as πr^2 .
- V (Wind Speed) = the velocity of the wind in meters per second (m/s).
- C_p (Power Coefficient) = the efficiency of the turbine, indicating how much wind energy is converted into usable power.

In this equation, we can see that the power is directly proportional to air density and rotor area, but proportional to the *cube* of wind speed (Thunder Said Energy, n.d., 1). According to the Betz limit, the maximum power a wind turbine can generate is no more than **59.3%**

of the kinetic energy of the wind. This means that C_p , the power coefficient, cannot exceed 0.593. The typical modern turbines have a power coefficient within the 0.35 to 0.45 range (Thunder Said Energy, n.d., 1). The air density reduces in higher altitude or higher temperatures. For our purposes, we will assume the typical density of 1.225 kg/m^3 .

Our group's wind turbine had a radius of 3 inches, which is 0.0762 meters. This fully constrains the variable of rotor swept area, A , for us as around 0.00203. The maximum wind speed we could set is defined as 25 miles per hour, which is 11.176 meter per second. In order to get the full amount of points, we must achieve a power of at least 2 watts. Redefining the equation as $C_p = \frac{2P}{\rho AV^3}$, we see that we need a power coefficient of around 0.128. Since this is the hypothetical maximum power coefficient, let us redefine the power coefficient as 0.05. The expected resultant power then returns as around 0.78 watts, which is below the criteria for getting maximum points on the power generations requirements of the project. Therefore, the turbine must ideally have an efficiency of 0.128 or above.

Tower Firmness Simulation

To evaluate the structural rigidity of the turbine tower assembly, a static Finite Element Analysis (FEA) simulation was performed in SolidWorks Simulation. We used ABS plastic as our material and applied a fixed constraint at the tower base while a vertical loading condition of approximately 1 kgf was applied near the upper assembly to represent loading from the motor and rotor system. Using this simulation, we are able to evaluate the stress concentration, displacement behavior, and overall structural stability under operating conditions.

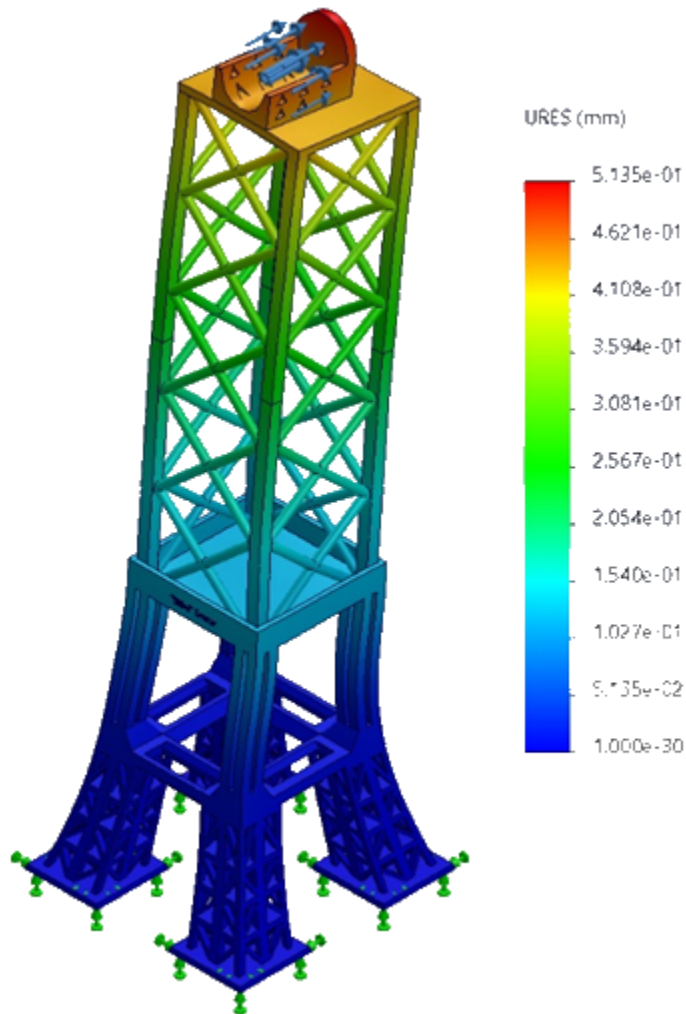
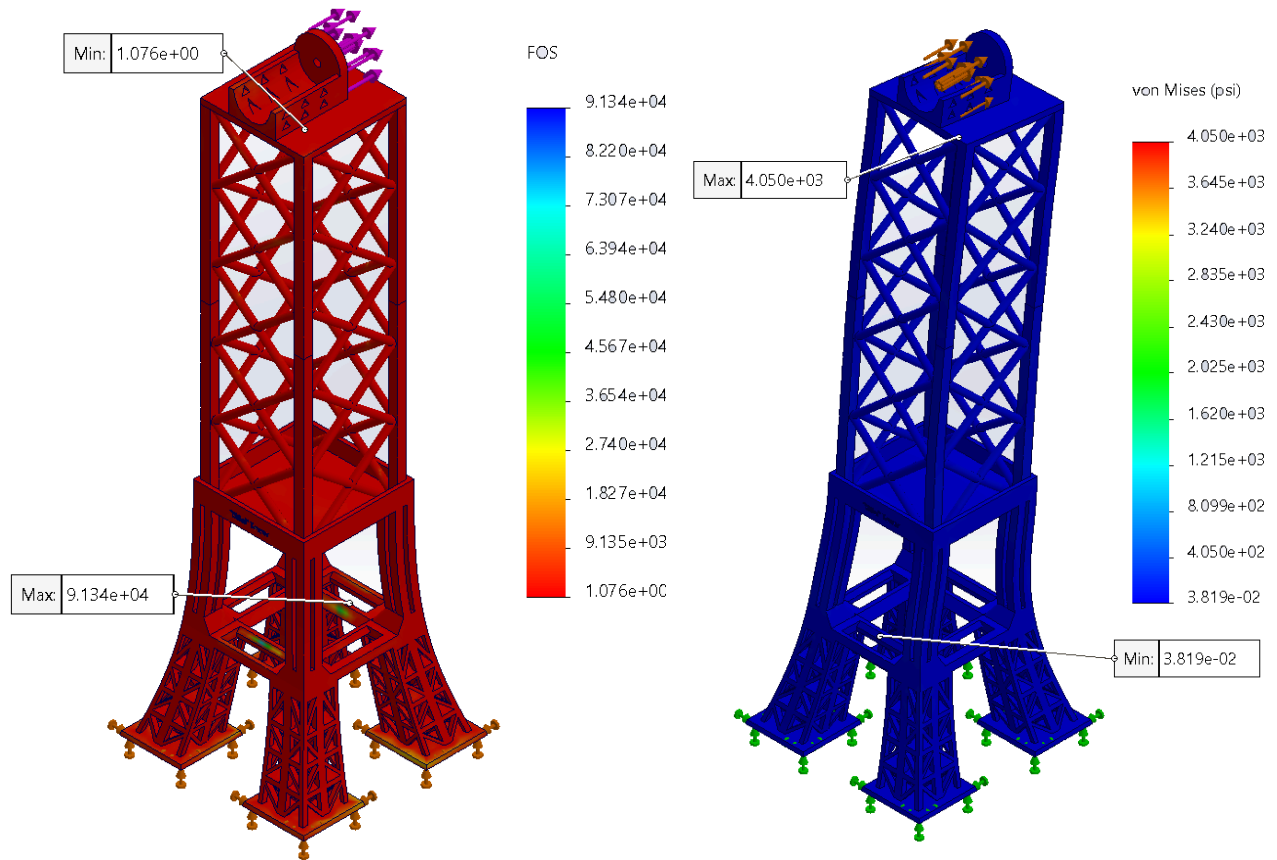


Figure 16: SolidWorks FEA displacement simulation of the turbine tower under applied loading

Results from the stress analysis showed a maximum stress of approximately 2.79×10^7 N/m², while the maximum displacement remained relatively small at approximately 0.51 mm. The results showed that the tower maintained sufficient rigidity under the applied loading conditions and experienced minor deformation throughout the structure.



Figures 17 & 18: SolidWorks FEA results showing tower factor of safety distribution (left) and von Mises stress distribution (right).

The factor of safety and von Mises stress distributions further demonstrate that the tower structure remained well within the material limits under the applied loading conditions. Stress concentrations were primarily localized near the upper mounting region, while the lattice tower geometry is distributing loads effectively throughout the structure, displaying adequate structural stability.

Testing and Results

Power Generation

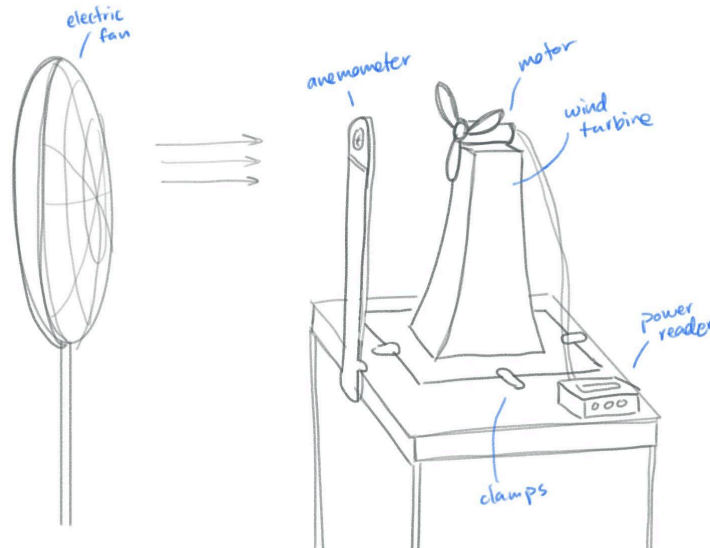


Figure 19: Power Generation Setup performed at Hesse Hall

Equipment

1. Electric fan
2. Anemometer
3. Wind turbine
4. Clamp
5. Motor
6. Power reader

Experimental Setup

1. Turbine Setup: The tower base was firmly clamped to a testing surface and blades were attached to the motor. The motor was attached to a power reader.
2. Wind Speed Calibration: An electric fan was positioned a few meters from the turbine tower. Using an anemometer clamped directly in front of the turbine intake, the distance was adjusted until a consistent wind speed of 25 mph was achieved.
 - a. Our wind turbine blades were unsuccessful and instead thanks to the courtesy of Professor Youssefi we were able to experiment on a prior, successful turbine.
3. Resistance Range Identification: Preliminary tests were conducted by varying the electrical resistance to identify a reasonable resistance range that would achieve maximum power output.

4. Data Acquisition: Using the identified range, resistance was adjusted in 5 Ohm increments. For each increment, the following metrics were recorded: voltage (V), current (mA), power output (mW), blade rotational speed (RPM)

Results

| Voltage (V) | Current (mA) | Power (mW) | Blade Rotational Speed (RPM) |
|-------------|--------------|-------------|------------------------------|
| 4.907 | 95.1 | 466 | 7301 |
| 4.278 | 105.6 | 477 | 7245 |
| 4.18 | 130.2 | 583 | 7020 |
| 4.26 | 169.3 | 730 | 6878 |
| 4.05 | 204.5 | 818 | 6733 |
| 3.71 | 255.8 | 953 | 6535 |
| 3.32 | 336.2 | 1137 | 6046 |
| 3.807 | 452.9 | 1211 | 5359 |
| 2.68 | 407.2 | 1324 | 5309 |
| 2.87 | 482.6 | 1374 | 5441 |
| 2.53 | 496.1 | 1301 | 5298 |
| 2.5 | 498.8 | 1296 | 5204 |
| 2.87 | 482.6 | 1374 | 5441 |

Table 1: Table of Results from In-Person Experimentation Across 12 Data Points

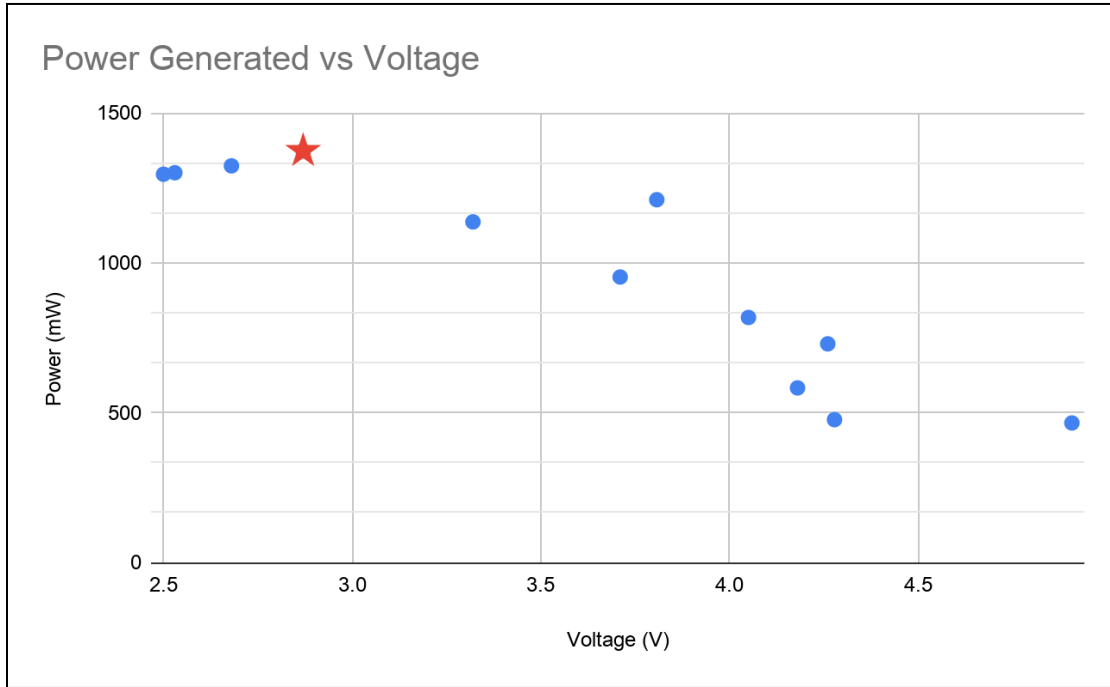


Figure 20: Plot of Power over Voltage with Max Power labeled at $P(V=2.87) = 1374 \text{ mWatt}$

Peak power generation was 1.374 Watts which came from 2.87 volts, 482.6 mAmp resistance, and a Blade Rotational Speed of 5441 rpm.

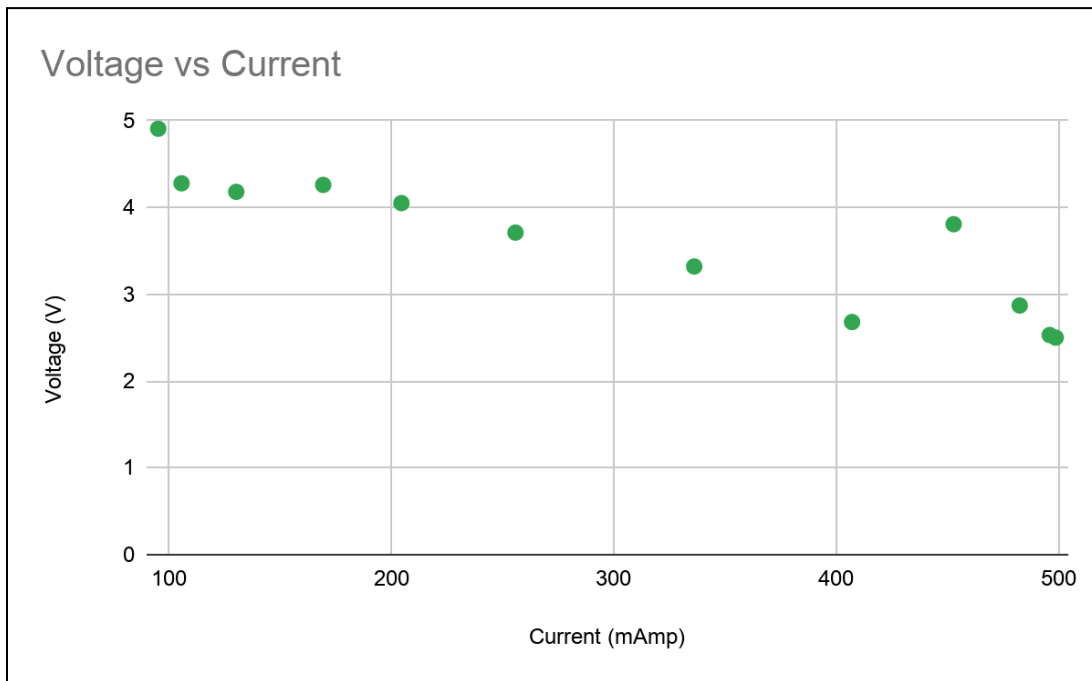


Figure 21: Plot of Voltage over Current

Structural Testing

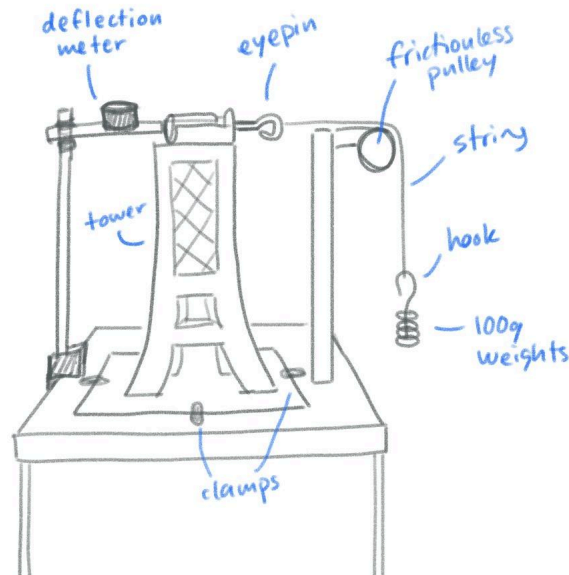


Figure 22: Stress Testing Tower Setup Performed at Hesse Hall

Equipment

1. String
2. 100g Hook
3. Nine 100g weights
4. Deflection meter
5. Eye pin
6. Frictionless pulley
7. Clamps
8. Tower

Experimental Setup

1. Clamp tower to table and attach string to eye pin attached to motor housing. Lay the string over a frictionless pulley.
2. Set up a deflection meter to be in light contact with the other end of the motor housing.
3. Attach 100g hook and record deflection. Continue adding 100g weights and recording data until all 1kg of weights are attached.

Results

| Load (N) | Deflection (mm) |
|----------|-----------------|
| 9.81 | 0.07 |
| 19.62 | 0.16 |

| | |
|-------|------|
| 29.43 | 0.23 |
| 39.24 | 0.31 |
| 49.05 | 0.41 |
| 58.86 | 0.52 |
| 68.67 | 0.63 |
| 78.48 | 0.74 |
| 88.29 | 0.86 |
| 98.1 | 0.96 |

Table 2: Deflection Results as we increased stress by 100g up to 1kg

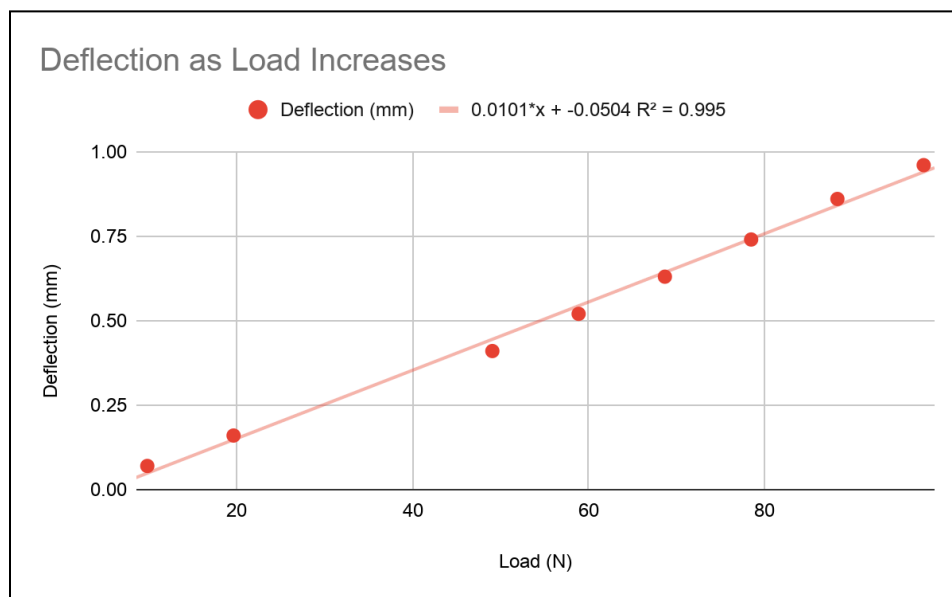


Figure 23: Plot from Testing in Hesse Hall, $R^2 \approx 1$ implies linear correlation (slope of $1.01E-02$ mm/N)

Comparison Between Theoretical and Experimental Results

The experimental power generation results showed that the turbine achieved a maximum electrical power output of 1.374 W at approximately 2.87 V and 482.6 mA. Using the measured peak power, the corresponding power coefficient was estimated to be approximately 0.088, or about 15% of the theoretical Betz limit of 0.593. While this is below the efficiency range typically observed in large commercial wind turbines, the result is reasonable given the small rotor size, lower Reynolds number flow regime, and limitations associated with 3D-printed blade manufacturing. The power curve also demonstrated a distinct peak operating region, indicating that the turbine was able to effectively convert wind energy into usable electrical power under the tested conditions.

The theoretical analysis predicted that achieving the project target of 2 W would require a minimum power coefficient of approximately 0.128 under the maximum available wind speed of 25 mph. Based on a more conservative estimated efficiency of $C_p = 0.05$, the expected power generation was approximately 0.78 W. The experimentally measured peak power of 1.374 W exceeded this conservative estimate, suggesting that the final turbine design performed better than initially anticipated, although it still remained below the theoretical target required for maximum project scoring.

The structural evaluation also showed strong agreement between theoretical and experimental results. SolidWorks FEA predicted a maximum tower displacement of approximately 0.51 mm under an applied loading condition near 1 kgf. Experimental testing produced a maximum measured displacement of approximately 0.96 mm at 98.1 N, while maintaining a highly linear load-deflection relationship with an R^2 value of 0.995. The near-linear trend confirms that the tower remained within the elastic deformation region throughout testing and behaved consistently with the assumptions used in the simulation model. Overall, both the computational and experimental analyses demonstrated that the turbine tower maintained sufficient rigidity and structural stability under expected operating loads.

Conclusion

Although our final rotor design was not able to generate measurable electrical power, it was still able to achieve some rotational motion under wind loading. After testing, we found that the blade geometry was likely not well matched to the actual operating conditions of the turbine. The blades had a relatively low twist and angle of attack, which made it difficult for them to efficiently capture airflow and generate enough torque to spin at high speeds. In addition, the fabricated blades appeared flatter than expected compared to the original CAD model, which likely further reduced performance.

Professor Youssefi provided us with a functional rotor for comparison, which performed much better during testing. Compared to our design, this rotor used a thinner blade profile with a stronger twist and angle of attack, allowing it to spin significantly faster and successfully generate electrical power. This comparison helped us better understand how important blade geometry and startup behavior are to overall wind turbine performance.

Despite the issues with the rotor, the tower itself performed very well during testing. The tower was able to withstand loads of up to 1 kg without structural failure, showing strong rigidity for its size and material. As more force was applied, the tower displacement

followed a very linear trend with an R^2 value of about 0.995. From the load-deflection relationship, we estimated the tower stiffness to be about 99 N/mm, showing stable and predictable structural behavior throughout testing.

After completing the main tests, we also performed a destruction test on the tower to better understand its structural limits and observe how failure would occur. During this test, the tower ultimately failed near the connection point where the thinner upper section was superglued to the heavier lower base section. This suggested that the bonded transition region acted as the primary stress concentration point under high loading. Throughout testing, the displacement versus force data collected by the testing machine also followed a very linear trend, further supporting the consistency and predictability of the tower's structural behavior. Overall, while the rotor design still needs improvement, the tower design itself was successful and demonstrated strong structural performance.

Recommendations for Future Work

During the physical testing of the wind turbine, we noticed that the blade had difficulty spinning even under the maximum wind speed setting. We believe that this was mainly due to the low twist magnitude of the blades. The twist setting on the blade was approximately 9 degrees in SolidWorks, which likely limited the blade's ability to efficiently capture airflow and generate torque. After receiving the manufactured blade from the Hesse Machine Shop, we also noticed that the blade appeared flatter than expected compared to the original CAD model. This made the blade more resistant to rotational movement when wind was blowing directly toward the front of the turbine. If we had increased the twist value to around 12 to 15 degrees, we believe the rotor would have performed better during testing.

Additionally, our group ultimately shortened the blade radius slightly to ensure the design remained within the 3-inch size constraint. Since the power generated by a wind turbine is strongly related to the swept area of the rotor, maximizing the allowable blade radius may have improved the final power output. Future work could also include additional aerodynamic validation and testing to better match the computational design with the physical turbine performance.

During the initial planning stage of the tower, our group wanted to prioritize creativity alongside the practical performance of the structure. Because of this, we adopted a design inspired by the Eiffel Tower. While the final tower performed well structurally, there are several ways the design could be further optimized in future iterations. With the help of iterative FEA simulations, each version of the tower could be evaluated and refined to

identify redundant structural members, reduce overall material usage, and decrease tower weight while still maintaining sufficient rigidity and strength.

Another possible improvement would involve optimizing the top platform geometry to more closely match the dimensions of the motor housing. In the final design, the top platform used a simple flat surface with additional buffer space to ensure secure motor mounting. Future designs could taper the upper platform more precisely around the motor housing, reducing unnecessary material usage and lowering the overall structural weight while still maintaining stability and support.

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