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Propelling Into the Future: Wind Turbine Design for Hala Industries

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Introduction

Our company, Grizzly Renewable Company (GRC), works to construct affordable, aesthetically pleasing, and highly functional structures. This specific project, the Design-Build Project, asked us to create a wind turbine. Structural requirements were given, and we were told to create an operational wind turbine made up of a tower that can withstand lateral forces and blades that can produce a high voltage. This project required designing, redesigning, testing, and learning from failure. The project promoted teamwork, trial and error, and the iterative design process. Our company, GRC, worked hard to brainstorm, plan out, sketch and design each prototype. We looked for cost-effective ways to enhance our designs, and create a sturdy, successful tower. Both team members, Rachel Cuneo and Gisselle Robleto, worked on the tower and blades. Rachel created the initial design for the blades, and constructed the final tower design. Gisselle made the initial tower and created the final blade prototype. As a team, we learned how to work with one another, bounce ideas off the other person, and come up with solutions using both of our knowledge. We learned how to use failure as a building block towards progress, understanding our mistakes, and brainstorming ways to create the best final product possible. At GRC we work to put the iterative design process to life and are constantly striving for the best. We constantly work to improve each time we create a product, learning and growing as we go.

Design Prototypes

The preliminary blade design included six separate blades arranged with a slight angle. These blades were flat and made primarily of popsicle sticks and construction paper. Figure 2.1 shows the sketch of the design. The main inspiration for our first iteration of the blade stemmed from looking at basic ceiling fan blades. These blades serve a very similar purpose to the ones we were creating, therefore, observing the shapes and sizes of these blades helped us generate our own design. This initial design worked, and adjusting the angles the blades were set at greatly enhanced the performance of the design. Additionally, using 6 blades instead of 3 helped increase the average volts produced; however, the addition of these blades made the prototype fairly heavy.

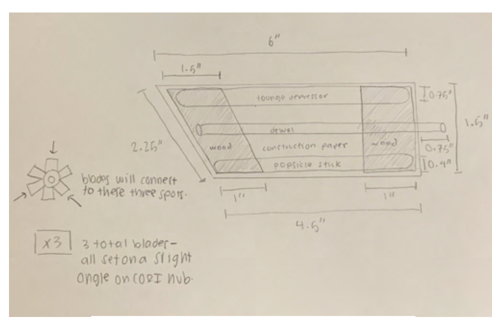

Figure 2.1 Initial Blade Design

Redesigning the blades allowed us to focus on the weak points in our initial design. The amount of popsicle sticks used to support each blade made the preliminary design-heavy, and therefore the blades did not spin as fast as we aimed for. Additionally, we realized that having fewer blades would reduce the weight of the prototype. Therefore, when we designed our final blades, we created 3 instead of 6. We used fewer popsicle sticks as support, and instead, we strengthened the final blades by folding the paper that made up the majority of the prototype. We used similar blade angles to our initial design because that was one of the main factors of our first design's success. The last difference between our two iterations was that the final design's blades were curved. This allowed wind to pick up the blades easier and therefore spin faster. The blades had to be between 4 and 12 inches, and use only the materials provided. Additionally, in order to be functional, the blades had to produce over 0.1 volts during testing. Between our two designs, the average volts produced was 0.1385. Figures 2.2 and 2.3 show our two prototypes, and the changes that were made between the two. Figure 2.2 is the preliminary design, while Figure 2.3 is our final design.

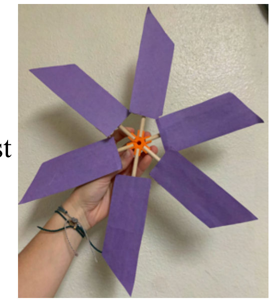

Figure 2.2 Initial Blade Prototype

Figure 2.3 Final Blade Prototype

The preliminary design of the tower was created using our fundamental knowledge of how beams and columns work. We set up a 12 x 12 inch base, where each corner of this base supported a column set at a slight inwards angle. These columns all pointed towards the center of the tower creating strong continuous support up all four sides. Beams were used along the outside to connect these columns, and on the bottom layer of the tower, 8 straight columns were used to support the beams. Finally, the top of the tower consisted of four smaller upright columns that were all connected at the top by beams along the outside. We knew that the column and beams would work with one another to support the structure as a whole, and having a strong base would help support the rest of the tower. Figure 2.4 sho\ws our preliminary design sketch for the tower.

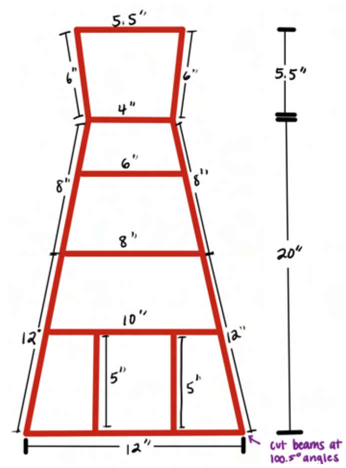

Figure 2.4 Design Sketch

During the preliminary design testing, we saw that the tower failed at the top, right where the continuous, slightly angled column supports connected with the straight columns. Identifying that spot as our main problem, we approached the redesign with the main internet of fixing the top half of the tower. Because of how strong it was, the bottom half of the tower stayed the same, and we modeled the top half after it. We continued the angled supports on the four corners all the way up to the very top of the tower, giving the tower a stronger, continuous frame. This eliminated the failure point of the initial tower because there was no change in direction of the columns that made up the four corners of the tower. Additionally, we added vertical columns as support on the third story of the tower, replicating those on the bottom story. This was to add additional support to the top of the tower, in the same way that the bottom was supported. All of these iterations created a strong final design that was able to withstand more weight than the initial tower. The tower prototypes had to have a base of under 16 x 16 inches, and an opening of 4 inches to provide room for an elevator. The tower was to only be built using the provided CORI Beams, and could not exceed a height of 26 inches tall. Additionally, to meet minimum requirements, the tower had to withstand a lateral force of 8 lbs. Our initial prototype withstood 14.536 lbs, and our final design withstood 19.873 lbs. Figures 2.5 and 2.6 show the two constructed prototypes. Figure 2.5 is our initial prototype, and Figure 2.6 is our final prototype.

Figure 2.5 Initial Prototype

Figure 2.6 Final Prototype

Aesthetics and Construction

The aesthetic goals of our design were simple. We strived towards a sleek, symmetrical, and simplistic prototype. Our wind turbine tower was painted all white, giving it a nice uniform look. The design of the tower is the same from bottom to top, adding to the symmetrical and clean aesthetic. Column supports are located on the first and third story of the tower, not only aiding in the support and strength of the prototype but also keeping a uniform design that spans across the entire tower. The tower was made out of the CORI Beams, Our final blade prototype fit into our aesthetic goals as we created a simple, aerodynamic design. We made the blades all one dark color to stand out against the tower. We mainly used construction paper for the blade prototype, to give it a lightweight yet powerful design. During our construction, we built the tower from the bottom up, replicating each of the four stories as the tower reached its final height. It was challenging to keep the continuous nature of the tower from bottom to top, as the top floors were smaller and harder to create. Additionally, painting the tower white gave it a clean and uniform appearance that really pulled it all together. It was challenging to create blades that were both aesthetically pleasing as well as functional. We tried different shapes and designs, but the one that both looked and worked the best was the oval, curved blades we used in our final product. Connecting the blades to the tower really solidified the structure, bringing it together as both an aesthetically pleasing and strong wind turbine. Figure 3.1 shows the final tower and blades connected: the complete wind turbine.

Figure 3.1 Wind Turbine

Experimental Methods & Results

The testing procedure for the tower was set up to analyze how much force the "top floor" of the tower could withstand before major failure. The minimum lateral load requirement needed to be reached was 8lbs. The tower's base was secured with clamps, the pulley system was used for the lateral load, and the MTS machine was connected to a computer to collect data. The initial prototype of our tower had a very strong base but the "top floor" was the part that seemed likely to fail. This was because of the angled connection to the previous CORI beam; it was not as strong as the rest that followed one single direction. Figure 4.1 depicts when the prototype failed. This prototype was able to withstand 14.536 lbf and failed at the predicted failure point. With the second prototype, the only difference was the part that failed last time. We replaced it to have CORI beams along one direction on all 4 sides. This was to ensure the connections were stronger than before. We predicted that the failure would be in the middle portion of the tower because although it was stronger than the initial prototype, it still was connected with adhesives instead of being a single CORI beam. This prototype failed at the part we predicted but withstood a lateral load of 19.873 lbf. Figure 4.2 portrays the part where the final prototype failed. Both of the prototypes' failure mechanism was rupture. Moreover, the graph shown in Figure 4.3 illustrates the force laterally loaded (y-axis) and the displacement (x-axis). Since prototype 2's plot is much steeper than prototype 1's, it signifies that prototype 2 is stronger as it withstood more force compared to prototype 1.

Figure 4.1 Initial Tower

Figure 4.2 Final Tower

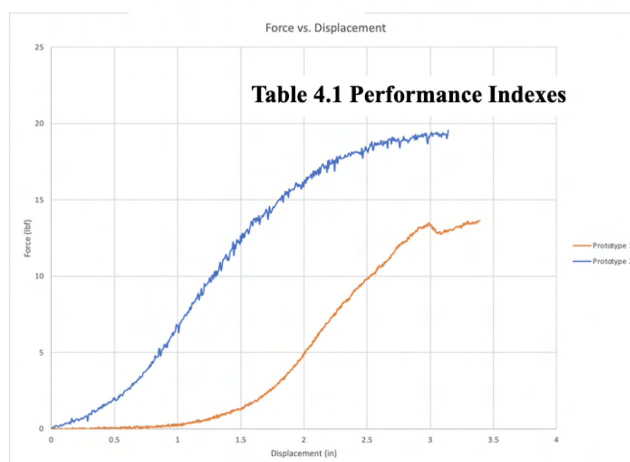

Table 4.1 Performance Indexes

Figure 4.3 Graph

The testing procedure for the blades was set up to check if the blades met the 0.100V requirement. There was a 3 ft distance between the CORI hub and the center of the fan (put on the lowest setting). The initial prototype of the blades resulted in 0.147V and produced a performance index of 0.551. The main concern here was that the blades were too heavy. So, for the second prototype, a lighter design was provided and resulted in 0.133V and produced a PI of 0.431. Although the energy output did not increase in the second prototype, the weight was significantly lighter than the initial prototype. The amount of blades also changed from 6 to 3 and we realized that less blades meant a smaller surface area and therefore, less energy produced. If another iteration was done, we would've had 6 blades on the lighter design for the wind to hit more of the blades and therefore, produce more energy.

The performance index (PI) for the tower was calculated by multiplying the lateral force resisted by the tower before failure in pounds by the height of the tower, and dividing that number by 25 times the weight of the tower squared. This yielded a tower PI of 14.047 for our initial design and 14.565 for our final design. The PI for the blades was calculated by squaring the Blade voltage reading in volts and multiplying that number by the height of the tower. This gave us a PI of 0.55 and 0.43 on the initial and final prototype, respectively. Understanding the factors that play into the PI equation helps maximize the results. For example, having a taller tower would grant a higher PI for both the tower and blades, because it is included in the numerator of the equations. Likewise, having a lighter tower would increase the PI of the tower because this value is included in the denominator of the equation. Another important factor in raising the PI of both the tower and blades is making sure that the blades reach a high voltage and the tower withstands a high lateral force. Both of these numbers prove a high strength and strong performance, factoring into the PI. The final prototype of our tower withstood a higher lateral force than the initial prototype, allowing for a higher PI index. This proves the equations and significance of the numerical values included.

for Blades and Tower Prototypes

Blade Prototype	Volts (V)	Height (in)	PI
1	0.147	25.5	0.551
2	0.13	25.5	0.431

Tower Prototype	Force (lbf)	Height (in)	Weight (lbf)	PI
1	14.536	25.5	1.027	14.048
2	19.873	25.5	1.180	11.727

<u>Structural Analysis</u>

Many forces are considered to affect the wind turbine based on its design. During the testing, the lateral loads emulated wind forces acting on the structure causing axial loads on the beams and transverse loads on the columns. The reason that the structure failed in both attempts was that the bending caused tension in the lower beams and resulted in rupture. The beams parallel to the forces acting on the structure experience axial loads, while those perpendicular to the forces experience transverse loads. The equation for stress, $\sigma = \frac{F}{A}$, helps analyze the impact on the structure. Specifically, the F in the equation expresses the force (lateral load) and the A represents the area of the cross-section.

The maximum moment at the base of our final tower was 499 lbf *in. This was calculated using the equation $M = F * D = (19.567\ lbf)(25.5\ in)$. The data used to calculate the maximum moments was found in the graphs. The maximum moment of the beam at the top of the final tower was calculated by the equation $M = \frac{F*D}{4}$ and resulted in 124.7 lbf*in. The maximum deflection at the top of the final tower was found to be 1.37 inches by using the equation, $\Delta = \frac{FL^3}{48EI}$. Here, the F, L, and E were given so the moment of inertia needed to be calculated ($I = \frac{bd^3}{12} - \frac{b_1(d_1)^3}{12} = 0.00636 in^4$). Knowing all the variables, the maximum deflection was able to be found, $\Delta = \frac{(19.567\ lbf)(4\ in)^3}{48(3000\ \frac{lbf}{in^2})(0.00636\ in^4)} = 1.37\ in$. The same equations were used to find the calculations of the initial tower. The maximum moment of the initial tower was $M = (13.630 lbf)(25.5 in)$ =348 lbf*in. The maximum moment at the top of the initial tower was $M = \frac{(13.630 lbf)(25.5\ in)}{4} = 86.9\ lbf * in$. The maximum deflection at the top of the initial tower was calculated to be $\Delta = \frac{(13.630\ lbf)(4\ in)^3}{48(3000\ \frac{lbf}{in^2})(0.00636\ in^4)}$= 0.95 in.

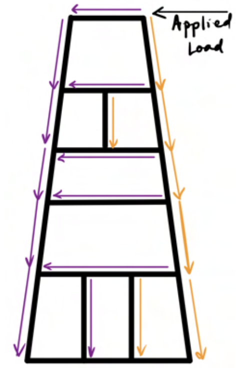

Figure 5.1 Applied Load Diagram

When the wind load was applied to the blades, it caused a lateral load that pushes against the blades to create energy. Figure 5.1 depicts the possible load paths of the structure. The orange highlighted arrows depict the beams that are in tension while the purple ones depict the beams that are in compression. The initial load is transferred to the top beams and the columns. The top beams experience compression while the columns experience tension. Since the force causes the tower to elongate, the components on the side of the tower would all experience tension. The components opposite from the force experience compression since the applied load causes shortening on that side of the tower.

<u>Conclusions</u>

This project enabled us to understand and experience the engineering design process.
When a concept is learned it isn't fully understood until you can put it into practice. We learned the importance of analyzing the initial design and how to improve it. One recommendation to teams in the future would definitely be to know the simple properties of the materials they utilize (whether it is flexible, sturdy, etc). Some challenges faced for this project included time constraints, differences in schedules, and the initial designs. We overcame these challenges by making sure to communicate effectively and establish tentative plans for each week. One of the main struggles was the fact that we had to work over the break because many times there are distracting factors that impact our work. If we could start over again, we would definitely set up more times to meet up and improve the tower and blade prototypes; having the knowledge we have now we understand how the testing works and the limitations of our prototypes. The concept of the design process can not only be extended to future careers in structural engineering but can also allow for the development of research papers in other courses. Another concept that can be extended in structural engineering is the lateral force-resisting systems; understanding how moment frames, bracing, and shear walls work as well as their benefits/limitations. Overall, this project effectively established how we could use the concepts learned to create; in this case, a wind turbine.

Acknowledgments: Thank you to the teaching team for helping aid in our design process.

References: Referenced Lecture Notes (Week 1, 2, 5) for Technical Report