Design for Manufacturing, Reliability, and Economics Report

Team 25

Taller Wind Turbine for Low Wind Speed Regions

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ABSTRACT

Current wind turbines are not effective to use in Florida because the average wind speed is too low to provide adequate power. This problem has led to the need for a taller wind turbine that can be used in low wind speed regions. The team cannot construct the final design due to size and budget constraints, so a small-scale representation was constructed instead. This report outlines the manufacturing, reliability, and economics of the wind turbine designed for use in the southeastern United States. The report also covers the manufacturing, reliability, and economics of the small-scale representation the team built in order to display the key components of the design. An in-depth analysis and description of all the team has done will be fully documented in the final report submitted April 10, 2015.

ACKNOWLEDGMENTS

There were several individuals that have helped us throughout this semester. Without help from these people the project would not have made as much progress as it has. We are very thankful for the time they took out of their busy schedules in order to instruct us and make sure we understood how to fix our problem before they let us go. Dr. Sungmoon Jung allowed the group to work on this very exciting project and always made time to attend biweekly meetings and answer any questions we had. Dr. Jung has always been extremely positive even when the team has been confused or stuck on a topic related to the project. Dr. Kunihiko Taira has been an excellent mentor and helped us with approaching the design of the wind turbine blades and always provided great ideas that we had not considered. Dr. Powell at the Center for Ocean and Atmospheric Studies helped us understand how to find the wind speed at different heights and good sites to build the turbine. Dr. Hollis has been very helpful in the modeling of the wind turbine blades in Pro Engineer. Dr. Atul introduced the team to the FAST software that is essential to determining the power output from our designed turbine. The senior design instructors, Dr. Shih and Dr. Gupta have provided guidance on deliverables and helpful feedback to make sure the team stays on track.

1. Introduction

The goal of this project is to design a wind turbine that is viable for use in the southeastern United States because current wind turbines are not effective in these regions. The team designed a full-scale wind turbine that could be used in south Florida and produce enough energy to be cost-effective. It is impossible for the team to create this design for a prototype so the team designed a small-scale representation of the full-scale design that displays the areas that the team focused on, specifically the blades and tower construction. This report outlines the process for manufacturing the small-scale design of the wind turbine. It also covers the reliability concerns of the tower and how to ensure the final tower fulfills the requirements of the project and will not fail. This reports also covers the costs associated with the construction of the full-scale wind turbine and the small-scale representation.

2. Design for Manufacturing

The wind turbine designed for this project is 157.5 meters tall with blades approximately 61.5 meters long. As it would be highly unrealistic to construct a full-scale prototype for this design, a small-scale representation of the design was constructed. The following subsections will describe the manufacturing process of the full-scale wind turbine and the manufacturing process of the small-scale wind turbine.

2.1 Manufacturing of Full-Scale Wind Turbine

2.1.1 Tower

The first governing criterion for the tower's design was the hub height. In order to reach sufficient energy production rates, the tower would need to be at least 50% taller than the typical, tubular steel tower of 80-90 meters. In order to achieve this height in a non-traditional manner which would allow for equal or comparable usage of materials, the team decided to design a steel-lattice frame tower. The steel truss frame required a compromise in terms of efficiency of construction, but allowed for the required hub height to be met, making sustainable energy production possible. At 157.5 meters, our tower's hub height nearly doubled that of the typical National Renewable Energy Laboratory (NREL) tower, which is 80m.

Before achieving full success of design, structural analyses were required. The sponsor explained that in order to prove the effectiveness of our design, the tower's weight would need to be no more than 10-15% larger than that of an 80 meter tubular tower. After multiple iterations, a few members continued to fail at approximately 40 meters from the base of the tower. Finally, it was decided that the base of the tower must be widened to withstand the large amount of moment in the tower, which had been the cause of failure along with limited sizes of steel sections. After widening the base to a diameter of approximately 27 meters, failures ceased to occur thanks to an increased lateral component in the base's geometry. Then, after running additional optimizations and iterations, the tower's weight dropped to a sufficient weight of about 300 tons.

2.1.2 Blades

The manufacturing method that would be used is similar throughout the top wind turbine blade manufacturers in the industry. Building a wind turbine blade begins with a two-piece mold of the shell. Figure 1 shows a wind turbine blade mold.

Figure 1. Blade manufacturing process

A layer of gel coat is applied to the mold. Gel coat will make up the outer layer of the blade, which is to protect the blade from the outdoor elements. Next, layers of glass and epoxy will line the mold. A Styrene Acrylonitrile (SAN) foam core will be placed in the mold followed by additional layers of glass and epoxy. The blade will then be vacuum bagged for the resin to cure. The shell is known as a sandwich structure. Additional layers will be added to the root of the blade for added strength. The spar or structural member will be prefabricated out of aluminum and placed into the mold, which will be followed by heat curing.

2.2 Manufacturing of Small-Scale Wind Turbine

2.2.1 Tower

The tower prototype is approximately 8.5 feet tall, consisting of three sections. Although, the full-scale tower contains twenty sections, it was decided that three typical sections would suffice to represent the general geometry of the tower. The upper two sections are 2 feet, 9 inches tall while the bottom section is 3 feet tall. At either end of each section, a custom connection is used. This connection consists of a heptagonal ring with plugs on the top and/or bottom where the columns slide in to be connected. A total of four rings were fabricated to be used in this design. The entire heptagonal ring connection is made up of 1-inch square hollow structural steel (HSS) tubes. The columns are made of ¾-inch square HSS tubes, while the bracing is made of ½-inch steel angle. The columns and bracing are connected to the plugs with steel bolts.

In order to fabricate the prototype, the steel was prepared, measured and cut to the correct dimensions. To create the connections, each of the sides of the heptagonal ring were cut so that when placed next to each other, they formed a heptagon. Each location between two consecutive members of the ring was welded to create one continuous shape.

Each of the heptagonal rings varies in diameter due to the widening of the tower from top to bottom. The outside diameter of the uppermost ring measures 8 inches while the outside diameter of the ring located at the base measures over 2 feet. After the heptagonal rings were prepared, the plugs to be attached to the rings were cut and grinded down to the correct angle so that when placed flat against the surface, the plug would line up with the incoming column. Each of these plugs were then welded to the corresponding vertex of the heptagonal ring to create one whole connection. The plugs were cut to be 2 ½ inches long to provide sufficient area for bolted connections to both the columns and the bracing at those locations. The complete heptagonal ring is shown in Figure 2 connecting the lower and upper columns.

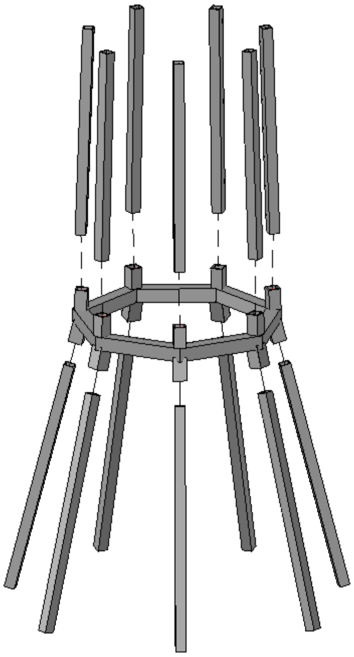


Figure 2. Exploded view of tower connection

In order to fabricate the columns of the tower, they were cut to the desired dimensions. The columns located in the upper two sections are 2-feet, 7-inches in length, while the columns in the bottom section are 2-feet, 11-inches in length.

The bracing is connected to the plugs, where the columns are also connected. The tower will be braced at every section. After the entire tower is assembled, fabric will be wrapped around the entire tower. In order to attach the fabric to the tower, Velcro will be used. The majority of the fabric will be opaque white, while a portion will be transparent to allow the inside structure of the tower to be seen.

The actual time it took to prepare, measure, and cut the steel for the tower was close to the expected time. Overall, this process took a total of 15 hours spanning over five days. However, there was a delay in obtaining welding services to complete the heptagonal ring connections. Once the welding is done, the assembly of the tower should take no more than twenty minutes. The fabric wrap has yet to be made due to a delay in ordering the material. However, once the material arrives, it should only take a day to sew the fabric together and attach the Velcro so that the fabric fits taut around the tower.

Overall, the tower prototype is a simplified version of the full-scale tower design. Given the time and monetary constraints, it was unrealistic to create an exact replica of the full-scale design. Although it would have been possible to add the internal bracing component to the prototype, it was added to the design after the material for the prototype had already been ordered. Therefore, there was an insufficient amount of steel to include the internal bracing in the prototype. Otherwise, the tower prototype effectively represents the full-scale design. If any of the components had been removed, the tower would not be stable or comparable to the full-scale design.

2.2.2 Blades and Nacelle

The three foot blades were 3D printed in four sections, each section nine inches long. The blades were printed in sections rather than as one piece due to the limitations of the 3D printer used. Epoxy putty was used to connect each section of the blade. The blade was then wrapped in e-glass, a type of fiberglass, which was applied by means of an epoxy and hardener mixture. Standard wind turbines have over a hundred layers of fabric; however, this amount of fabric was unnecessary for the small-scale prototype. The prototype blades were wrapped with fiberglass until appropriate blade strength and stiffness was achieved. These characteristics were achieved once the blades had been wrapped in two layers of fiberglass. The excess fiberglass along the edges of the blades was trimmed off and the blades were sanded to provide a smooth finish. Once the blades were smooth, a coat of primer followed by several layers of white paint was applied. This made the blades aesthetically pleasing as well as a closer representation of the full-scale wind turbine.

In order to ensure the epoxy was fully cured the team waited a minimum of 24 hours between each application. Fiberglass was applied on three blades at a time so it took a total of four days to apply two layers on each side of the three blades. The blades were finished in the same time that the team felt it would take.

The scaling of the turbine blades from 61.5 meters to 3 feet meant that a lot of the complexity of the full-scale design could not be incorporated into the prototype blades. A lot of the design in the Fall semester was focused on developing an innovative interior spar that would strengthen the blades from bending under load. But scaling the design down meant that they could not be included in the prototype because the 3D printer did not have the resolution to print the interior of the blade. So the team decided to fill the interior of the blades when printing to ensure they were strong enough. With the lower printing resolution, the 3D printer still had difficulties printing the trailing edge of the airfoil which can be seen below in Figure 3. This was corrected by sanding the blades down before fiberglass was applied as explained above.

Figure 3. Chipping of 3D printed blades

Creating a nacelle for the full-scale design was not included in the project description. But for the prototype a nacelle is required in order attach the blades to the tower and generate electricity so the team developed a simple nacelle early in the Spring semester. The nacelle design can be seen below in Figure 4.

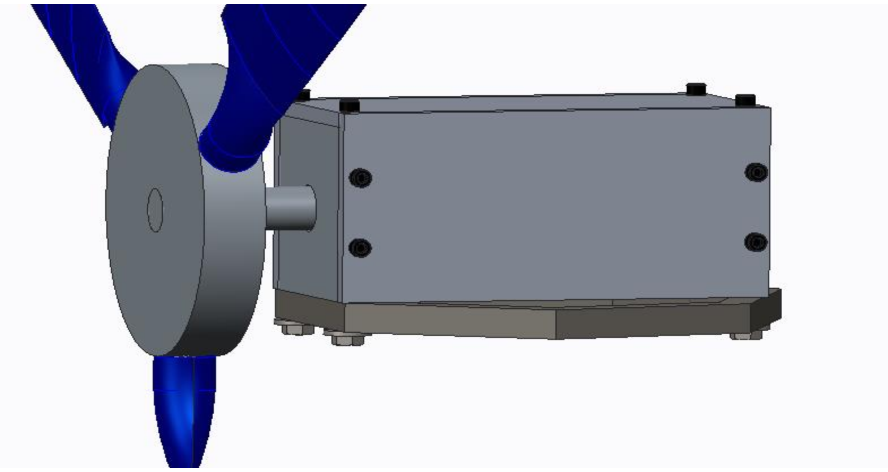


Figure 4. Creo model of nacelle

The nacelle is made out of Aluminum 6061 and is used to attach the blades to the tower. The blades are interconnected to the motor by a rotor and shaft that run through a series of bearings which allow the system to be rotated easily. The shaft is connected to a motor with a roll pin to secure no losses between the motor and shaft. The motor, which is back driven by the spinning shaft, will generate electricity. The nacelle is assembled with 10-24 bolts and ¼-20 bolts to secure it to the top of the tower. To show how the parts of the nacelle and blades connect an exploded view of the design can be seen below in Figure 5.

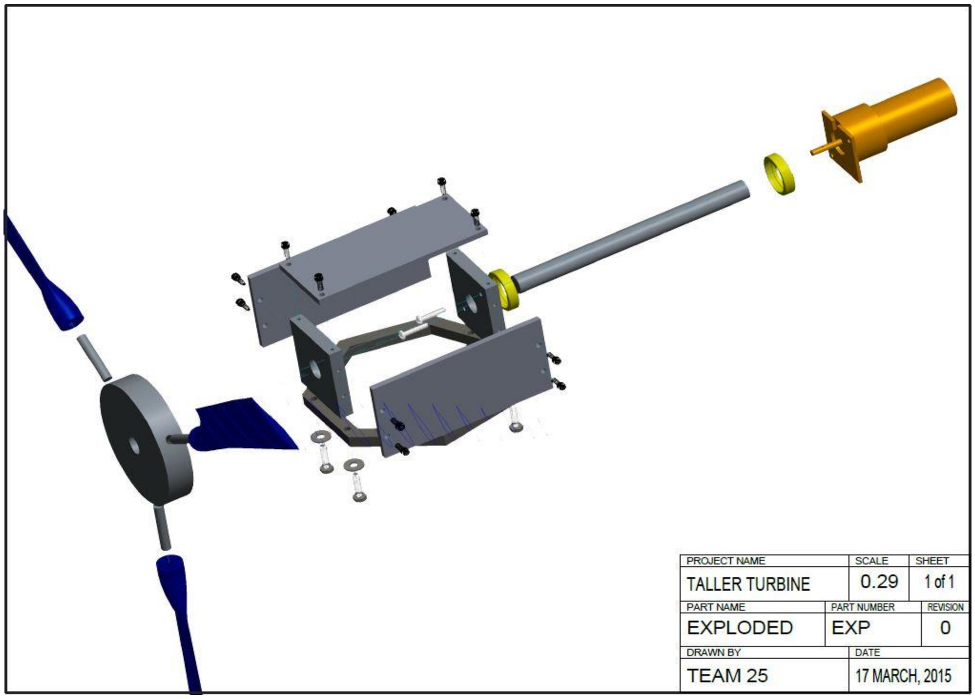


Figure 5. Nacelle exploded view

The nacelle was machined in the machine shop in the FAMU-FSU College of Engineering and the team assembled the pieces together. The machine shop was behind schedule which caused a long waiting period for the parts to be machined, but the actual assembly of the nacelle was finished in one day and can be seen in Figure 6.

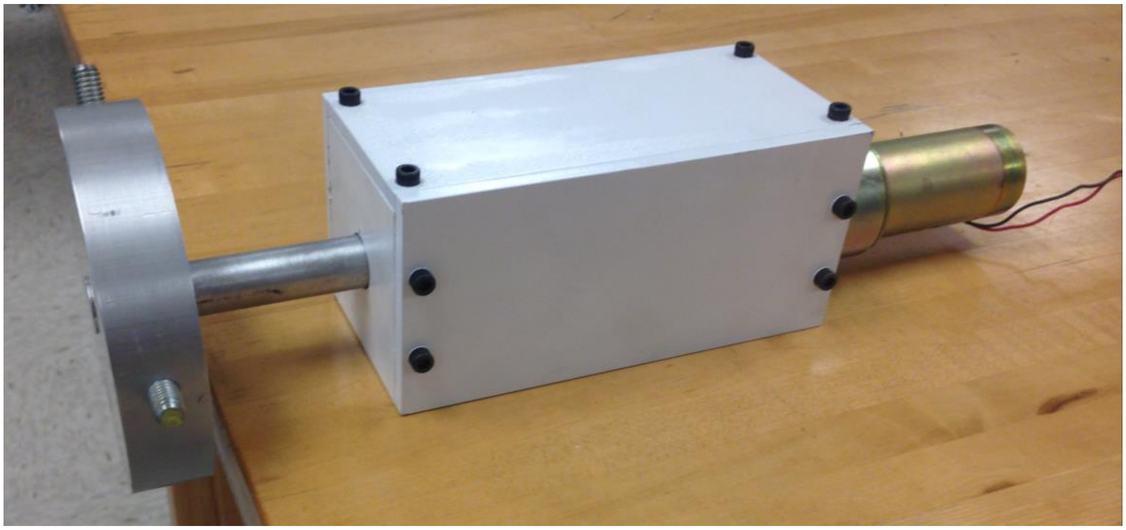


Figure 6. Assembled prototype nacelle

The design of the nacelle was very simplistic because it was not a part of the original project requirements. The design could have been more complex by including a system to sense wind direction and rotate the blades to be perpendicular to the wind direction. This would have added extensive work that the sponsor did not want the team to focus on due to time and money constraints.

3. Design for Reliability

3.1 Reliability of Full-Scale Wind Turbine

3.1.2 Reliability Concerns for Tower

One initial drawback to our lattice frame design was the lack of insulation within the tower. The team liked the design because it could increase the hub height, decrease material usage, and even reduce undesirable wind loading on the structure's walls. It was concluded that the tower would need to be insulated with an architectural fabric. This insulation would keep unwanted moisture away from the structural steel of the tower and the mechanical and electrical components of the nacelle and rotor. Due to our widened base design sufficient insulated room was available to store the generator within the tower itself. As an additional precaution all structural steel will be painted to resist corrosion. Maintenance of the tower itself would then be limited to visual inspections to ensure no unexpected corrosion is taking place, along with inspections on all bolts and connections.

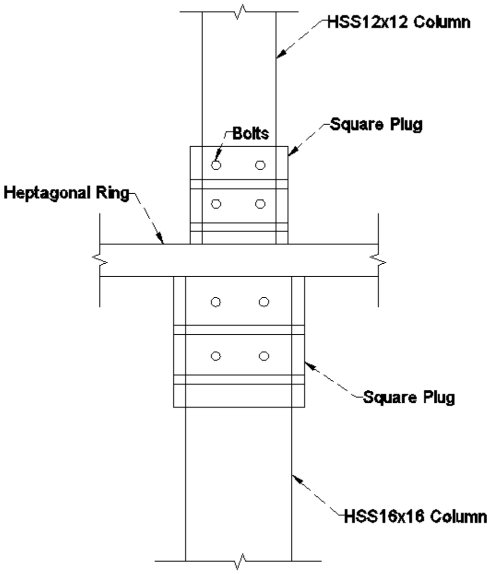


Figure 7. Full scale tower connection design

The connections, shown in Figure 7, were made simplified through use of HSS shapes. Thorough connection design and plug welds were utilized to allow for "male-to-female" slip fits. Not only will this allow for a faster assembly process, but it will also ensure that all vertical load bearing members will be supported by directly bearing upon one another. In theory, every bolt will not carry any load. Therefore they will serve as additional safety factors to the design, unless yielding were to occur.

3.1.3 Reliability Concerns for Blades

The main reliability concerns for the blades are cracks or fracture that occur during transportation and operation. Because of the size of the blades a small force at one end of the blade will generate a large moment at the other end. This moment can cause large loads on the E-glass and internal structure of the blades. During transportation it is possible that the jostling of the trucks or carelessness while driving would place a large load on the blade which could cause fracture of the fiberglass or fracture of the bracing spar. In order to prevent this, drivers must be well qualified and experienced with transporting large pieces of equipment like wind turbine blades to ensure they arrive safely to the construction site. The other concern for the blades is failure during the operation of the wind turbine. After the final design was complete, the blade was tested in Creo with an applied load twice of what would be expected in Florida. On average a 60 meter turbine blade deflects 2.5 meters. Upon finite element analysis the designed spar deflected only 1.15 meters, which is well below the average deflection. The spar is only a portion of the blades strength, consequently it is proved that our design will be much stronger than typical turbines. This can be seen below in Figure 8.

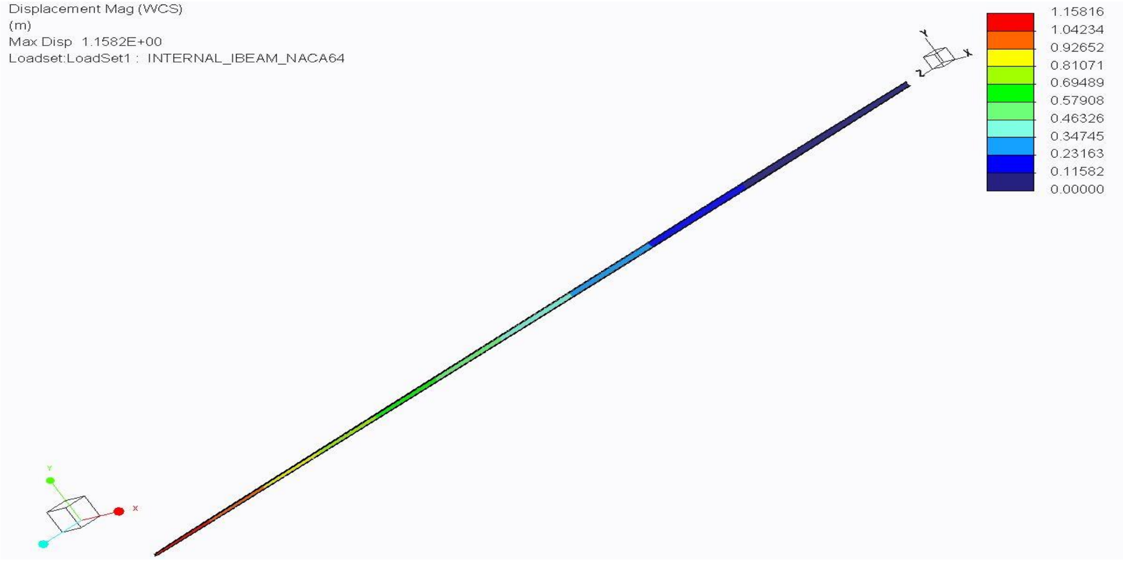


Figure 8. Turbine blade deflection under load in meters

From Figure 8 it can be seen that the root of the blade, on the right, is shaded purple and has no deflection while the blade tip, in red, has deflected the maximum amount of 1.15 meters.

3.2 Reliability of Small-Scale Wind Turbine

The reliability concerns of the small-scale representation of the final design can be split into two parts, the tower and the blades.

3.2.1 Reliability Concerns for Tower

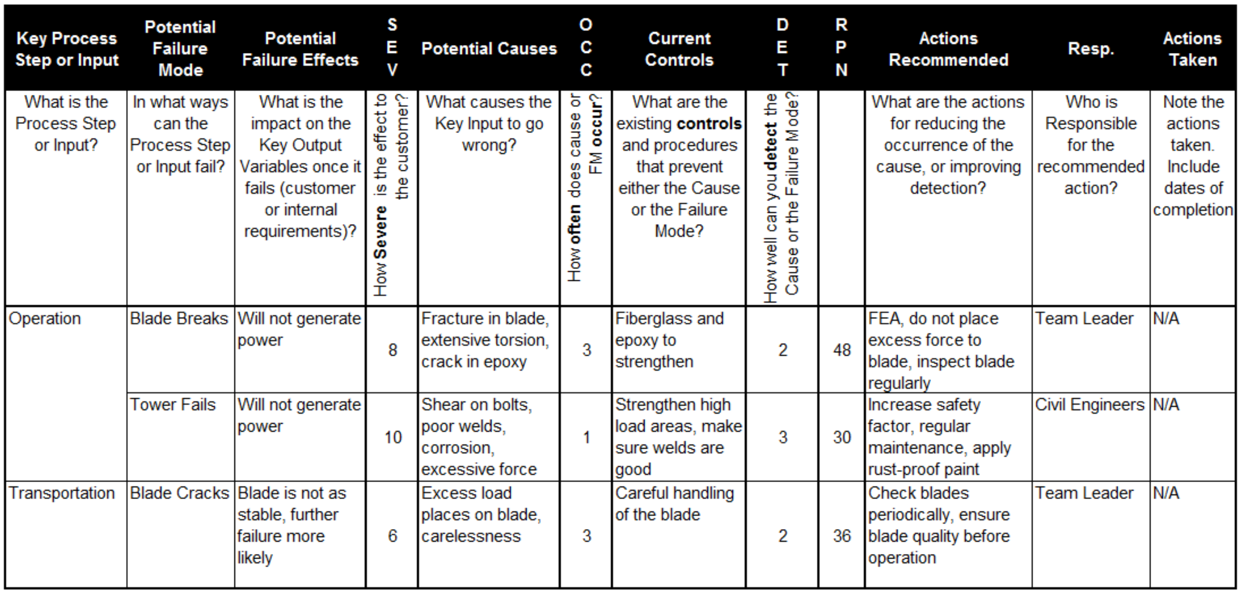
There are two main causes for a structure to experience failure which are defects in the material or insufficient design. In terms of the design, the tower prototype should be able to withstand multiple uses as long as the members are placed properly and the connections are secure. Since the tower is made of structural steel and the blades are relatively light, the tower is not expected to fail due to excessive loading. Considering material failure there is a slight possibility that the steel may include weak points as a result of poor manufacturing. However, there is no preventative solutions to material defects unless they are visually apparent. Nonetheless, there are several reliability concerns for the tower over time. There is the possibility of corrosion within the steel. This can be prevented by applying protective coatings on the steel surfaces at least once a year. Another concern may be local failure at the connections. If there are unexpected high stresses in areas where connections are placed, then the connection may break weakening the entire tower as a result. In order to prevent local failures at the connections, the bolts will be given plenty of tear-out distance and high-grade bolts will be used. Also, the welds will be examined as much as possible to ensure that they are strong enough to carry the anticipated loads. Apart from the steel, the fabric wrapped around the tower has the possibility of tearing or unraveling if it comes in contact with a sharp object or experiences excessive stretching. However, unless it comes into contact with the moving blades, a tear in the fabric is only a visual defect and has no effect on the functionality of the prototype.

3.2.2 Reliability Concerns for Blades

One of the main reliability concerns for the blades is that they will fail during operation of the system. There are several points of possible failure for the blades. As discussed in Section 2.2.2 the multiple sections of the blades had to be connected using epoxy putty. This connection was strengthened by wrapping the blades in two layers of fiberglass. The full-scale blades lack these failure points. It is possible that high stress applications on the small-scale blades will cause the epoxy putty to deform, resulting in the blades failing at the connection between the sections. This will be accounted for by handling the blades with caution and making sure there is never a large point load placed on the blades. The other main failure point of the blades is the connection between the blades and the rotor of the nacelle. The blades will be connected to the rotor with a piece of all-thread that is tapped into both the rotor and root of the blade. It is highly unlikely that this connection will fail, although if the blade is pulled away from the rotor or excess torsion is applied to the blade the thread inside the root of the blades could strip causing the blades to fall off the all-thread. The blades are printed out of ABS plastic which means the threads will not be as strong as those in the Al6061 rotor and all-thread. This failure mode will be prevented by not applying excess loads to the blades at the connection point and ensuring that the all-thread is fully screwed into the connection before operation of the small-scale representation.

The failure mode effect analysis can be seen below in Table 1. This table displays multiple ways that the design could possibly fail throughout its lifetime, as well as recommended actions that should be taken to prevent these failures from occurring.

Table 1. Failure Mode Effect Analysis



Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion
Operation	Blade Breaks	Will not generate power	8	Fracture in blade, extensive torsion, crack in epoxy	3	Fiberglass and epoxy to strengthen	2	48	FEA, do not place excess force to blade, inspect blade regularly	Team Leader	N/A
	Tower Fails	Will not generate power	10	Shear on bolts, poor welds, corrosion, excessive force	1	Strengthen high load areas, make sure welds are good	3	30	Increase safety factor, regular maintenance, apply rust-proof paint	Civil Engineers	N/A
Transportation	Blade Cracks	Blade is not as stable, further failure more likely	6	Excess load places on blade, carelessness	3	Careful handling of the blade	2	36	Check blades periodically, ensure blade quality before operation	Team Leader	N/A

4. Design for Economics

4.1 Economics of Full-Scale Wind Turbine

The economics of the full-scale wind turbine was made through a series of equations and estimations. This economics consist of calculating power generation capabilities, the wind at the target site, and the cost of building and running the wind turbine. From these calculations the levelized cost of energy is calculated, which can be compared to the current standard for wind turbines in the United States.

4.1.1 Power Generation

Using the wind speeds at the target site, the power generation was calculated. Figure 9 displays a histogram with the average hourly power generated per year.

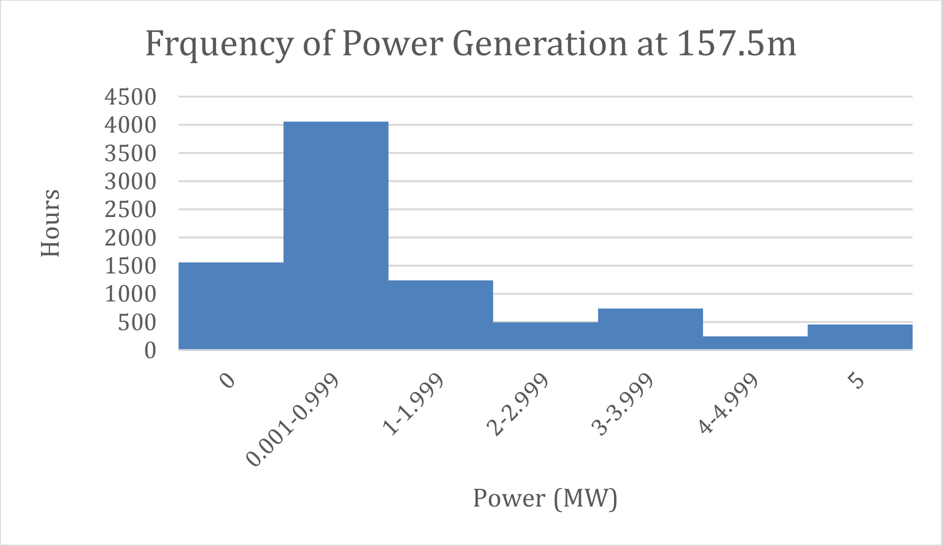


Figure 9. Power generation histogram

Figure 9 shows that 63.9% of the time, the wind turbine would have been generating less than 1 MW of power. Additionally, the plot shows the wind turbine would have been running at its maximum rated power 5.2% of the time. After these findings, it may be worth looking into reducing the rated power of the wind turbine to 2, 3, or 4 MW generator. Furthermore, the energy was calculated for the year to be 10,786 MW*h.

4.1.2 Costs

Blade Cost

The cost of the blades were estimated based on *GLWN's* study *U.S. Wind Energy Manufacturing and Supply Chain: A Competitive Analysis*. [4] The total cost of a set of 61.5m blades is approximately $363,710. This was based off materials, labor, burden, SGA (sales, general, administrative), engineering, logistics, and profit which is in Table 2.

Table 2- Cost of Blades

Item	Cost ($)
Materials	147,825
Labor	31,300
Burden	64,165
S.G.A	36,494
Engineering	14,597
Logistics	45,000
Profit	24,329
Total	363,710

The blades used for the design are similar to the "standard" blades used in this study. The main difference between blades is the spar. The estimation in table 2 was based off a fiberglass sandwich structure spar with two beams. The spar used in the design is composed of three aluminum beams. It was estimated the burden cost would increase while the material cost would decrease using this design. Therefore, the cost difference would be negligible and the total standard cost would be used for the design in the cost analysis.

Tower Cost

The cost of the tower is a function of the steel material, architectural fabric, and the assembly costs related to each. The steel material, at 300 tons, was estimated to cost about $780/ton for a total of

$234,000. The construction method of the tower varies from that of a typical tubular wind turbine. Therefore, alternative methods were used along with NREL data in estimating the anticipated construction costs.

The upper sections of the lattice tower are designed to be fabricated before arrival on site to allow for a rapid assembly method similar to that of a typical steel tubular tower. Equations from *NREL Turbine Design Cost and Scaling Model* were employed to scale the cost of the assembly and installation of the upper portion of the tower. [1] The cost is scaled based on the total height of the upper sections and the rotor diameter including the blades. The final estimate without material costs is $110,000.

The lower portion of the tower is the widened base which must be assembled on site. This assembly method can be compared to that of a steel truss bridge. Since the geometry and assembly method would be very similar, the only scaling necessary would account for the varying dimensions between the bridge and the tower. Cost estimates on the construction of a pedestrian steel truss bridge are obtained from *RSMeans Heavy Construction Cost Data 2012*. [2] The final estimate for the cost of assembly is $211,000.

The costs of a PVC-coated polyester fabric were found from the *Architectural Record* and includes the cost of installation. [3] This fabric is ideal to last the lifetime of the wind turbine, but at $40 per square foot it is much too costly to be considered. It would cost over $1 million just for the fabric. Therefore, after considering other fabric alternatives, the most efficient option would be to use LDPE (Low Density Polyethylene) coated HDPE (High Density Polyethylene) woven membrane, which is high-strength, light-weight, and fire retardant but needs to be replaced after 10-15 years. The cost of this fabric is closer to $12 per square foot which comes to a total of $442,800.

Similar to the lower portion of the tower, the foundation costs were estimated using the *RSMeans Heavy Construction Cost Data 2012*. [2] The reinforced concrete foundation is considered to be a circular spread footing with a 23-meter diameter. The foundation cost is estimated to be about $240,000 which includes excavation, material, and equipment. The total cost of the foundation and the tower, including material, equipment, and labor, comes to $1,178,000.

Additional Components

There are many components involved in building a wind turbine. The cost of these additional components are in Table 3. These values come from *NREL Turbine Design Cost and Scaling Model.* [1]

Table 3. Additional Component Cost of Wind Turbine

Item	**Cost ($)**
Hub Cost	95,706
Total Pitch System Cost	183,552
Nose Cone Cost	10,084
Low Speed Shaft Cost	115,753
Total Bearing Cost	95,050
Brake/Coupling Cost	9,947
Generator Cost	1,096,650
Variable Speed Electronics Cost	395,000
Yaw Drive and Bearing Cost	113,954
Main Frame Cost	66,010
Electrical Connections Cost	200,000
Hydraulic and Cooling Systems Cost	60,000
Nacelle Cover	61,535
Control, Safety System, Condition Monitoring Cost	35,001
Road, Civil Work Cost	256,450
Electrical Interface/Connections Cost	432,250
Engineering Permits Cost	125,050
Additional	1,750,000
TOTAL	5,101,990

Leasing Land

When building wind farms, it is most common to lease sections of agricultural land. Since, wind turbines only require approximately 3-5 acres per site much of the land remains usable for farming. After looking at multiple recent wind farm contracts, the cost ranged from $1500 to $5000 per MW per year. [5] The site locations included states from all around the country except for the south east. Taking into account the wind speeds in Belle Glade would be considered a low speed region nationally, it was estimated the leasing cost would be around $2500 per MW per year.

Operational and Maintenance Cost

Operations and maintenance involves keeping the wind turbine running effectively after construction. Some of the tasks include turbine and blade failure, monitoring and control systems, safety, repowering, wind monitoring, and site security. Based off NREL, it is estimated the fixed and variable operational and maintenance costs are approximately \$10 per MW per year. [1]

Cost Summary

The best way to see the profitability of the wind turbine is to calculate the levelized cost of energy (LCOE) which is the present value of the total cost divided by the energy produced of the project lifetime. For this value it was estimated the project would have a lifetime of 20 years. Table 4 shows the estimated cost over 20 years based on the capital, leasing, operation, and maintenance costs.

Table 4- Total Cost Over 20 Years

Item	**Cost ($)**
Blades	363,710
Tower/Foundation	1,178,000
Additional Components	5,101,990
Lease	250,000
O & M	1,000,000
Total	7,893,770

The estimation of the power generation was done by multiplying one year of power generation by 20 years. Then to account for scheduled maintenances, that number was multiplied by 98%. The total power generated with this design and location site would be approximately 211,401 $MW * h$. Combining the total cost with the total power generation yields a levelized cost of energy of \$37 per $MW * h$. The target number for levelized cost of energy in the wind industry ranges between \$36 per $MW * h$ to \$72 per $MW * h$. According to this number, the turbine would be very profitable. However in real application the efficiency would decrease with wear which would lead to a small increase in the levelized cost of energy.

4.2 Economics of Small-Scale Wind Turbine

The team was given $2,000 to build a small-scale representation of the wind turbine designed. After purchasing all of the materials the team spent $1,443.66 leaving $556.34 in the budget. Of the money spent, approximately $850 were spent by the mechanical engineering students on materials used for the wind turbine blade construction while approximately $595 were spent by the civil engineering students on materials used for the wind turbine tower construction.

The small-scale wind turbine produced by the team is very unique to this project, therefore there are no similar products on the market. Due to the fact a cost comparison of the money spent by the team on the small-scale representation cannot be compared to anything in industry.

Below, Figure 10 displays a pie chart of the project expenditures. It can be seen that 72% of the budget has been spent, while 28% remains.

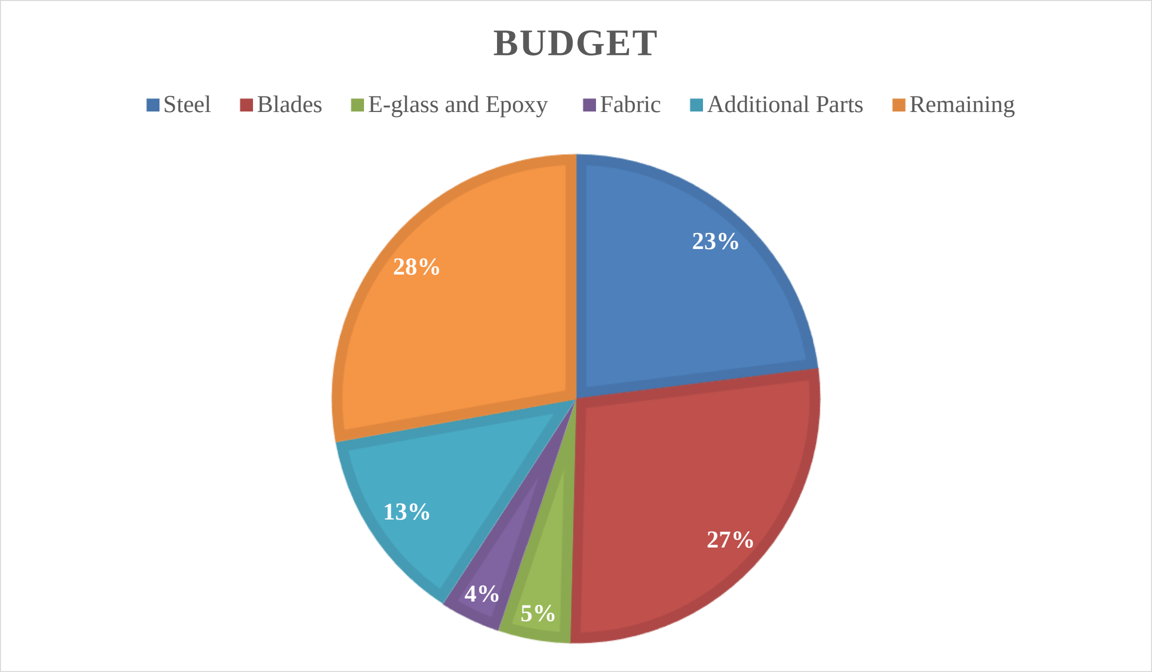


Figure 10. Pie chart of project budget

5. Conclusion

The goal of this project is to design a taller wind turbine that is cost-effective for use in low wind speed regions, specifically the southeastern United States. The team has completed the final designs and this report outlines how the final design of the small-scale turbine representation will be constructed. The team has analyzed the way the design is most likely to fail and developed methods to prevent this failure. The total and breakdown costs of the full-scale turbine was calculated. The budget of the small-scale turbine is also discussed in this report and after completion of the final design, the team will have 28% of the original budget remaining. This is large enough to account for any unforeseen circumstances that may present themselves before the end of the semester. The team is on track to finish the project before the final presentation.

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