

Design for Manufacturing/Reliability and Economics

Team 15

Portable Wind Turbine



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Abstract

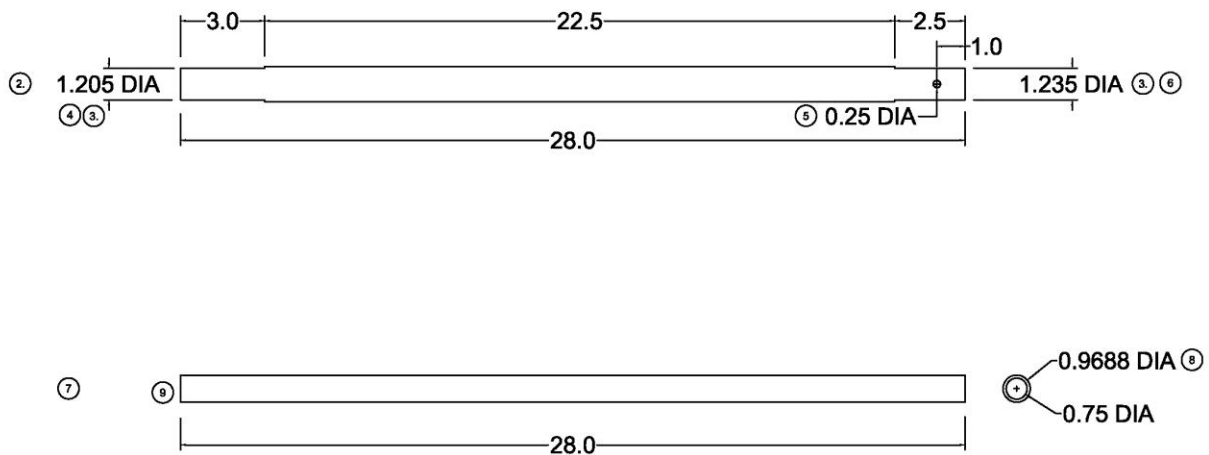
As part of the project statement, Team 15 constructed a Portable Wind Turbine. This report outlines the manufacturing processes that went into the construction of the Portable Wind Turbine prototype, as well as addressing any reliability concerns and the economics of the design. Constructed mostly from aluminum, the Portable Wind Turbine prototype attempted a light weight, user friendly construction while still maintaining a durable exterior. As with any prototype, the design faces several reliability concerns which are addressed in this report. The cost of production of the prototype, which was within the allotted \$2,000 budget, and the estimated efficiency of the power output of the design are also addressed.

1. Design for Manufacturing

1.1 Base

The manufacturing required of the base consisted of machining and welding aluminum tubing, sheet metal, and rods. The clamps, feet, and pins were purchased and not altered. All of the aluminum materials, however, were modified.

The aluminum tubing was cut into sections, then cut down in outer diameter to meet requirements. Then, holes were drilled into the tubing to allow for pins. This is depicted in Figure 1.



Notes:

- ① All units are in inches.
- ② This 1.25 inch O.D. (1.0 inch I.D.) tube needs to be machined into 4 of these 28 inch sections.
- ③ This shaved diameter is not to scale. Drawn larger to be seen.
- ④ This outer diameter is tentative. This part of the tube needs to fit inside the clamp.
- ⑤ Hole for 0.25 DIA pin.
- ⑥ This outer diameter is tentative. This part of the tube is to slide into a 1.25 I.D. tube (the welded plate). Must be a tight fit but have room to slide on and off. This fit needs to be tighter than ⑧
- ⑦ This 1 inch O.D. tube needs to be machined into 3 of these 28 inch sections.
- ⑧ This DIA was originally 1 inch. This shaved diameter is tentative. It must telescope inside the big tube with I.D. 1.0 inch.
- ⑨ 1 machined "foot adapter" needs to be welded into each of these 3 sections.

Figure 1. The drawings for the aluminum tubing for the base.

The plate was cut to the desired diameter, then four of the short tube sections were welded into place. This is depicted in Figure 2.

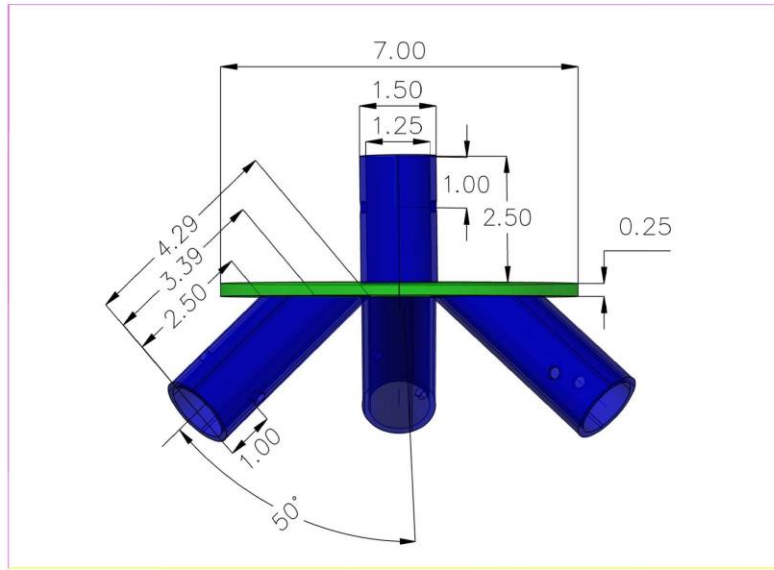


Figure 2. The drawing for the tube joining section of the base.

Inserts were created from aluminum rods and welded inside the end of each of the small tubes. These were threaded inside to allow for the feet to attach. The inserts are depicted in Figure 3.

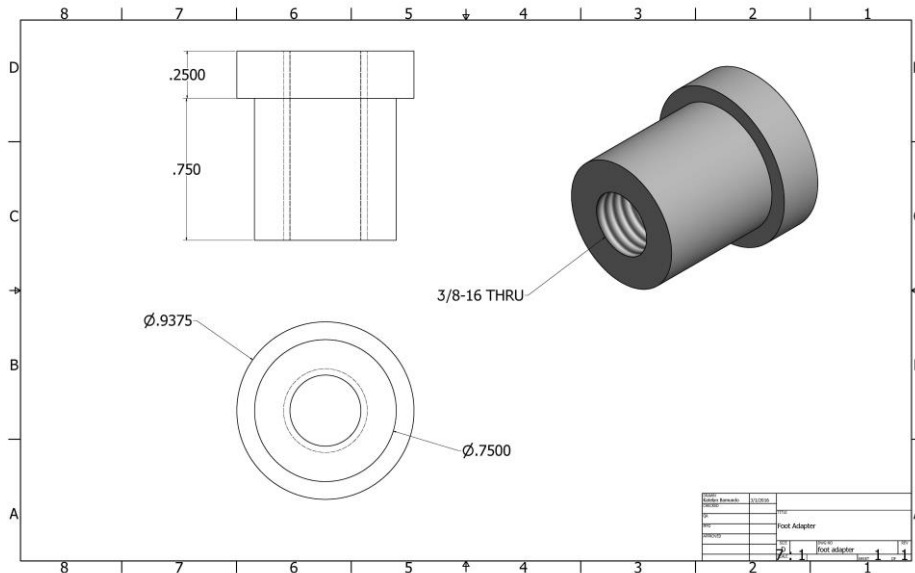


Figure 3. Drawings for the threaded inserts of the base.

1.2 Nacelle

Between the base and the nacelle of the turbine a simple steering wheel quick release system was adapted from a racing application to allow for easy removal of the nacelle from the base. This system can be seen in Figure 4.



Figure 4. Quick release system that joins the nacelle to the base.

In order to allow for free rotation of the nacelle with changing wind directions, the mating shaft of the quick release was fit into two (2) oil impregnated sleeve bearings which were in turn fit into the top most tube of the turbine base. Optimal for the very low RPMs seen by the turbine when rotating to adapt to changing wind directions, these lubricated bushings provide excellent performance with little to no maintenance required. The cross sectional view drawing of the quick release shaft through the two bushings can be seen in Figure 5.

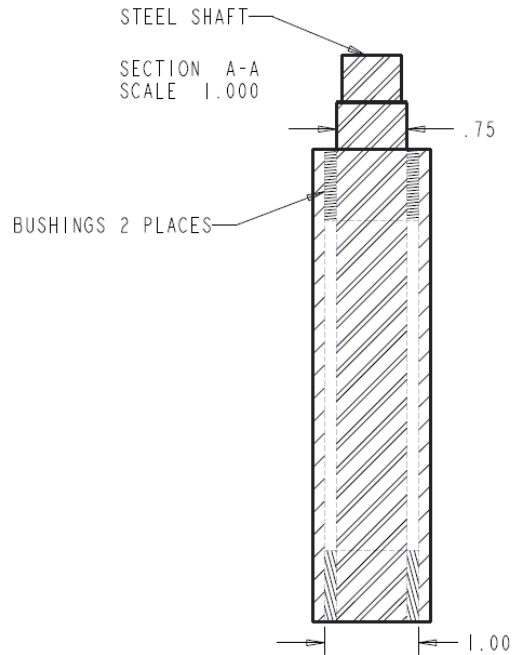


Figure 5. Cross section of the system allowing free rotation of the nacelle.

The nacelle was designed to encase the electronic components of the Portable Wind Turbine, protecting them from the environment while still allowing the user to access the electrical components if needed. Figure 6 shows the nacelle with transparent shading used for the main tubing and end caps in order to allow for viewing of the interior components.

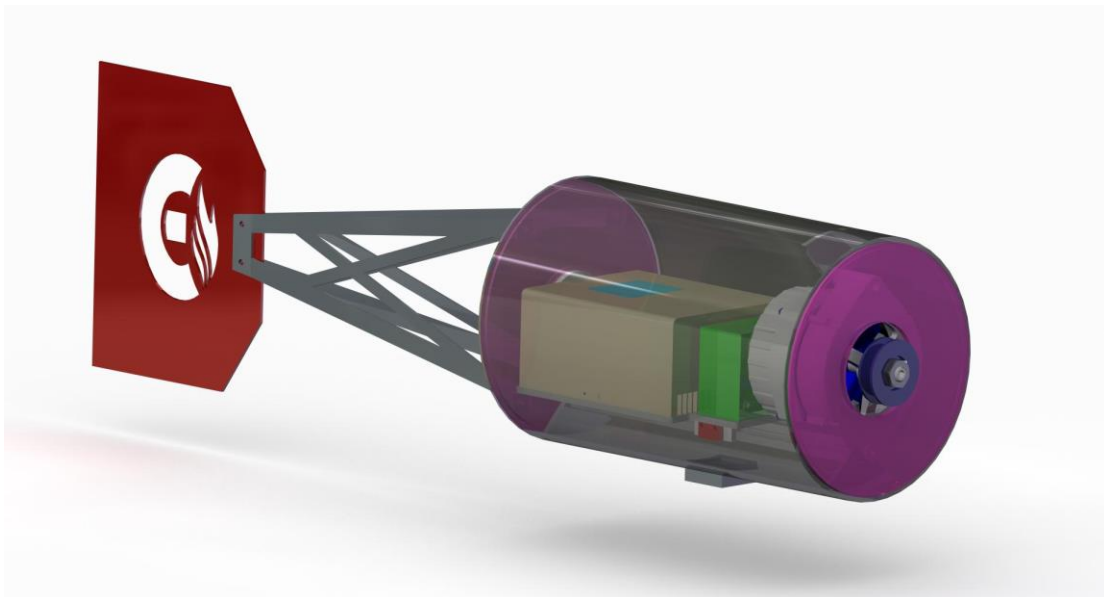


Figure 6. The Portable Wind Turbine nacelle

The outer body of the nacelle tube was constructed of 0.125in thick, 3003 aluminum sheet. The sheet was rolled into a 10in outer diameter, 16.75in long tube and welded along the seam. The end caps for the tube were created from 0.500in thick acetal Delrin, cut to fit the tube ends using the water jet. A rubber gasket was cut by hand and added to each of these Delrin end caps in order to help prevent any leakage of rain water into the interior of the nacelle housing. The end caps were then secured to the tube using simple clips. Both end caps had a circular hole removed from the middle. In the front this allows the shaft for the alternator to pass through. A breathable, water-resistant covering was then added to this hole to protect the interior of the nacelle from rain water. As shown in Figure 7, the back end cap of the nacelle had a louver vent fitted into the hole in order to prevent rain water from entering the nacelle, while still allowing for cooling of the electrical components.

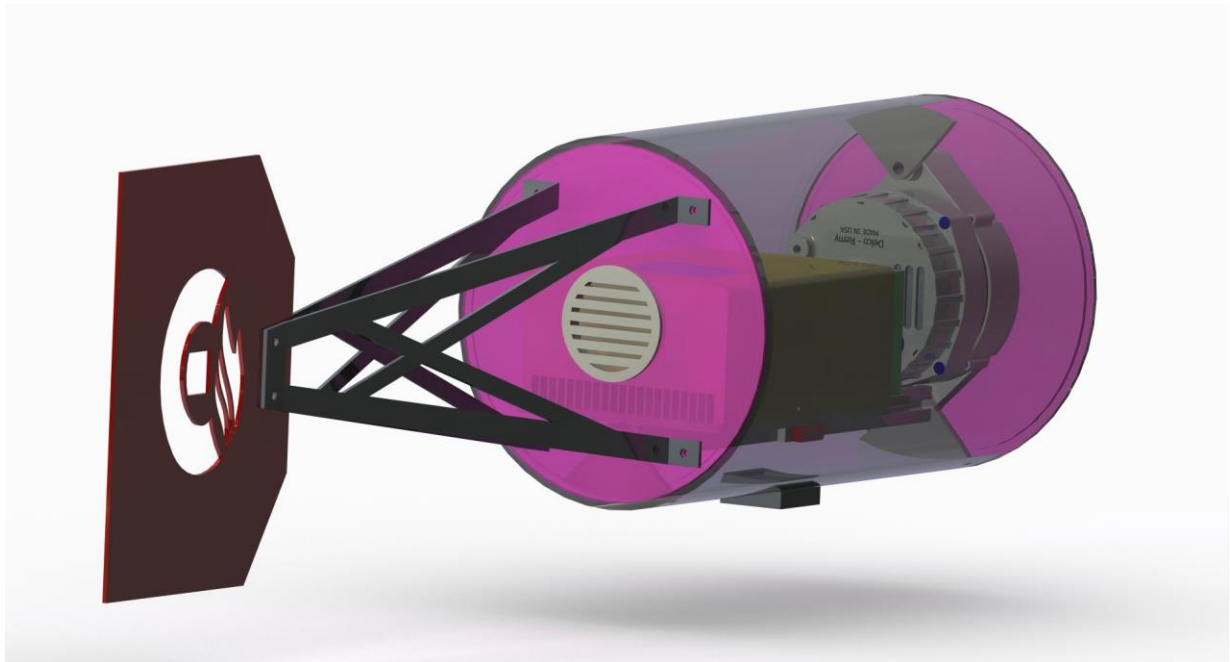


Figure 7. The rear end of the nacelle.

The back end cap was also tapped and threaded with four holes for the mounting of the tail vane. This tail vane was entirely comprised of 1/16in aluminum sheet and was cut on the water jet. It was secured together and to the back end of the nacelle using standard 1/4-20 bolts.

The interior of the nacelle was constructed in such a way that the user could easily access the electrical components if needed, without the need to disassemble the entire nacelle. Tabs were

water jet from 0.25in thick, 6061 aluminum sheet and welded into place in order to mount the alternator and a 14.75in length of 8020 aluminum to the inside of the previously created nacelle tube. The alternator and the 8020 aluminum rail were secured to these tabs using two (2) 1/4-20 bolts, a single 3/8-16 bolt and three (3) appropriately sized washers. Using acetal Delrin sliders created by the CNC, a carriage assembly was mounted to the 8020 aluminum rail in order to allow for the electrical components to slide out of the back of the Portable Wind Turbine nacelle when the rear end cap was removed by the user. The Delrin sliders were secured to the carriage assembly using four (4) 1/4-20 bolts and four (4) appropriately sized washers. This carriage system can be seen in Figure 8.

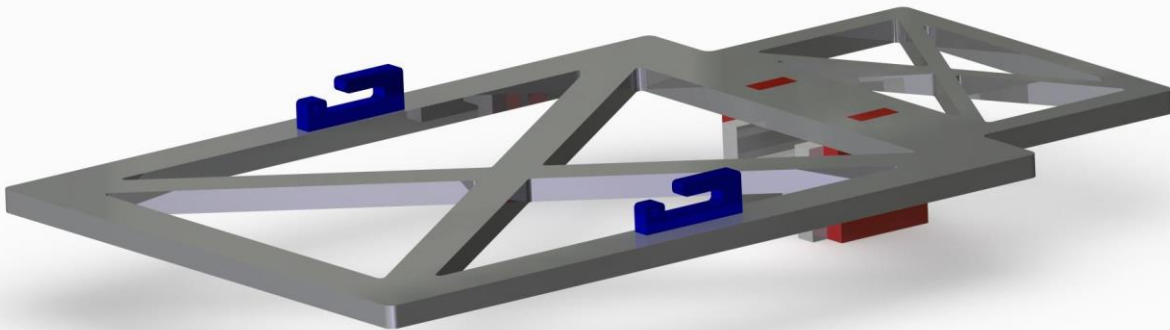


Figure 8. The carriage system that holds the charge controller and battery.

Mounting tabs were created to secure the charge controller to this carriage assembly as well as to secure the assembly to the Delrin sliders. All of these components were cut from a single sheet of 0.25in thick, 6061 aluminum sheet using the water jet.

1.3 Blades

The blades for the Portable Wind Turbine were ordered directly from a company called Windy Nation. The blades selected are HyperSpin P-Series Wind Turbine Blades, the blades are made from UV-stabilized polycarbonate which was selected over aluminum based on material properties and reliability concerns. There is not much information known regarding the exact manufacturing process of the blades for the Portable Wind Turbine as they were ordered directly from Windy Nation. It is known that Polycarbonates are thermoplastic polymers that are naturally transparent. Essentially the material has phenyl and methyl groups on its molecular chain which contribute to a molecular stiffness in the polycarbonate. The low mobility of the molecules results in good thermal resistance but high viscosity during processing. Polycarbonates are strong, tough materials and have good thermal resistance. The UV-stabilization will assist in protecting the blade against long term degradation effects from ultraviolet radiation. The airfoil, or shape of the cross section of the blade resembles that mostly of that of an under-cambered profile. As small scale wind turbines begin to become more popular, the under-cambered shape becomes more desired. The reason this shape is becoming more desirable is due to the fact that this shape is suitable for applications that where low velocity fluid steams are present, and a large lift force on the blades is essential.

In order to design a blade mounting system that would be easy to assemble and increase portability, current blade mounting systems were researched and inspected. It was discovered that many smaller wind turbines use a standard wind turbine hub which is blade dependent, such as the ones shown in Figure 9. These hubs are standard and may be ordered from multiple companies. The ones shown in the figure are provided by Windy Nation, where the hubs overall diameter, thickness, and material type depends on the blades selected for the application, however the central hole comes in two standard alternator shaft sizes, those diameters being 1in or 17mm.

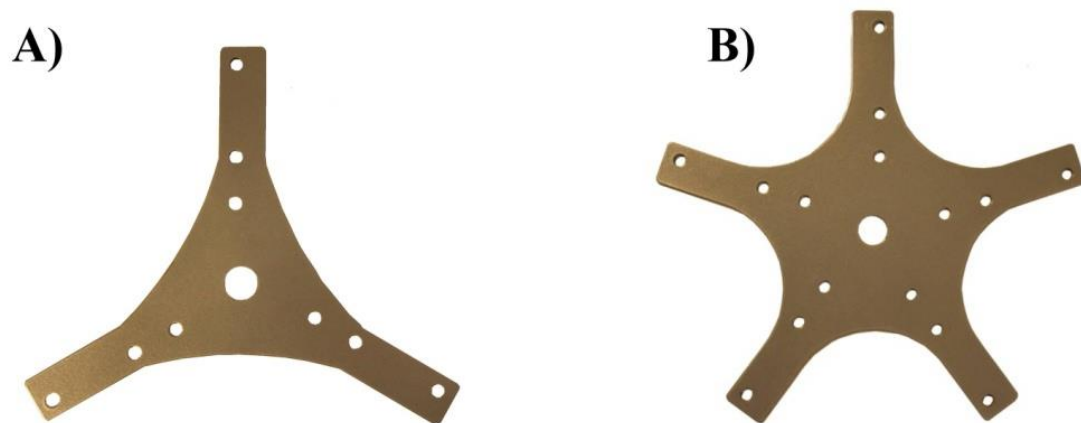


Figure 9. a) Standard wind turbine hub used for 3-blade turbines b) Standard wind turbine hub used for 5-blade wind turbines.

It was decided that a custom hub would be designed so that retaining devices could be used in unison with it to eliminate the use of tools during assembly of the Portable Wind Turbine. The hub was designed in Creo Parametric and was machined in the FAMU-FSU College of Engineering machine shop using the water jet. The material selected for the hub is 1095 spring steel. Figure 10 shows the completed hub.



Figure 10. Hub designed to mount blades to the alternator shaft.

The standard hubs are usually made of stainless steel however spring steel was chosen for this application under the assumption that e-clips and shafts would be used, where spring steel is the typical material for e-clip design. Purchasing the same material for all parts helped to reduce the cost of the design. The Wind Blue Power DC-540 alternator selected for the Portable Wind Turbine has a standard 17mm mounting shaft. Unlike the standard hubs pictured above the holes are not offset to one side, this design aspect was added so that the blades could be mounted with the curve facing in or out. However the metal ordered for the hub only had a width of 8 inches the original hub diameter was approximately 9 inches so the design was scaled to fit for the ordered metal, to save time and money. This meant that the blades would no longer be able to be mounted with the curve facing in or out, but was restricted to mounting the blade with the blade out.

There were initially two concepts to mount the blades using the custom hub the first used pressure clamps along with thumb screws to secure the blades however this design added unnecessary weight to the design and would significantly alter the aerodynamic profile (airfoil) of the blades. The second utilized a custom e-clip with grooved shafts to secure the blades, however this design had lots of uncertainties in the blades' thickness ranging from 0.253in to 0.255in, it was essential for all dimensions to be exact to ensure that the blades would be retained with enough force to prevent them from falling off the assembly. Due to these large chances of error this design was also discarded.

Below in Figure 11 is an image of the exploded view of the blade mounting system for the Portable Wind Turbine. The figure displays where each of the selected parts for the design will be located. The bumper bolts will be welded after being inserted into the top and bottom holes on each of the 3 sides of the hub. The dowel pins were press fit and welded at approximately 0.008 in. from the back of the hub in each of the remaining central holes. The bumper bolts, self-locking wing nuts, and stainless steel washers were all ordered from Fastenal.

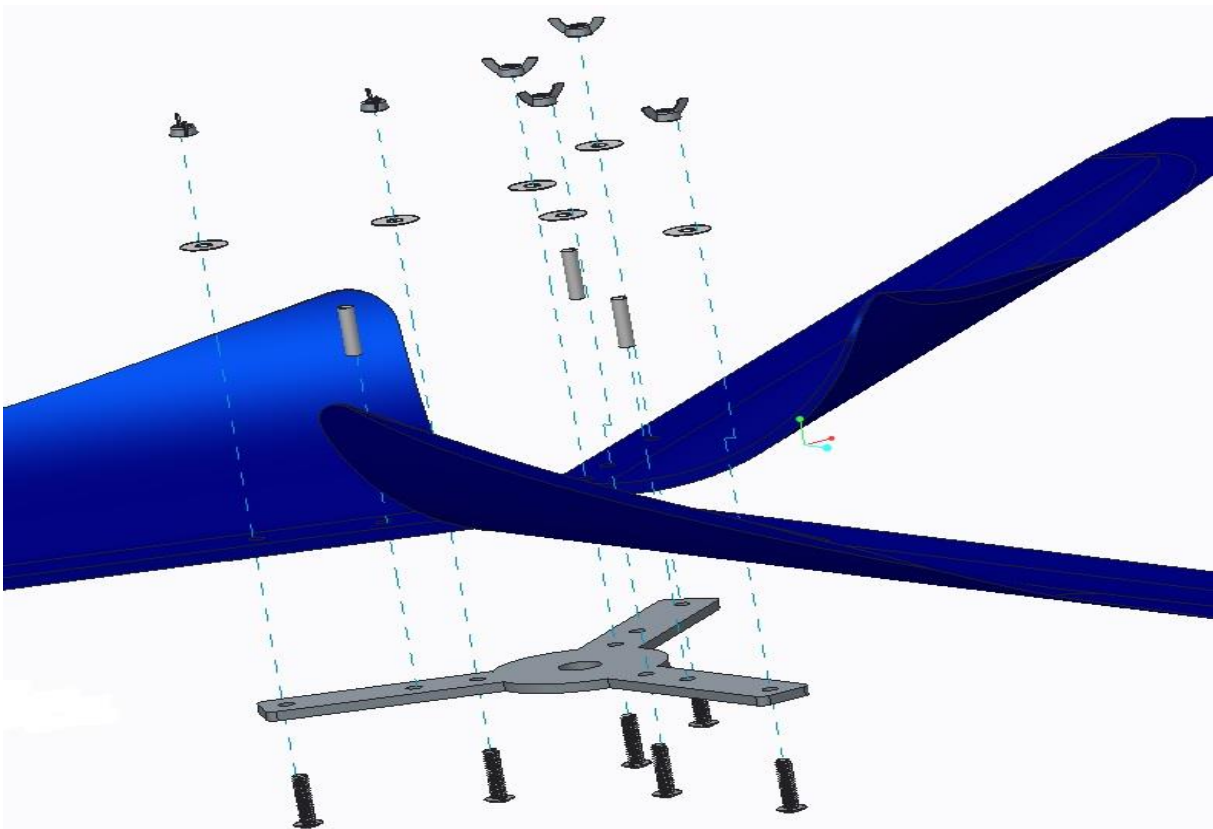


Figure 11. Exploded view of the blade mounting assembly.

2. Design for Reliability

2.1 Reliability Concerns for Tower

Some failures of the turbine structure may be due to design or to the materials themselves. In terms of design, the base will stay standing if it was placed together correctly by the user. All clamps must be securely tightened. Since the base is made of aluminum and the weight of the nacelle and blades are minimized, failure of the tower due to self-weight or buckling of the legs or neck is not likely. The base of the wind turbine was designed to allow for a 15 degree sloped surface as well as any accidental bump of the members. Wind speeds at the hub height of 2 meters off the ground are not likely to be large enough to overturn the wind turbine and cause the tower to fail. However, if wind conditions are extreme, the additional use of cables may help to secure the tower. Material failure is not likely unless there are visual defects in the aluminum tubing. An excessive encounter with water or salt overtime may begin to corrode the aluminum. To prevent this, the base can be applied with a protective coating. Failure at the connections between members in the legs and neck may occur. This can be prevented by periodically checking that the clamps are tightened securely. The strong pins will drastically reduce the possibility of the material shearing. Examination of the welds will ensure their reliability.

2.2 Reliability Concerns for Nacelle

The only significant concern, and was addressed, was the components overheating in the nacelle due to the release of heat from the charge controller specifically. Since the charge controller will be regulating the power output to the battery, excess power will be released through the heat fins built into the back. This was alleviated by adding slits to the front and back of the nacelle, allowing for air flow throughout, but simultaneously not compromising the safety of the electrical components against rain or moisture.

2.3 Reliability Concerns for Blades and Attachment

A majority of the reliability concerns for the blades and attachment for the Portable Wind Turbine, will be when the user installs the blade onto the hub and when the Portable Wind Turbine is in use. As previously mentioned one of the reliability concerns is if the user applies too much torque on

the wing nut when installing the blades possibly causing the blades to crack at the base. The compressive strength for the UV-Stabilized polycarbonate is about 80 MPa. To avoid the possibility of cracking, the stainless steel washer will increase the surface area of contact on the blade which will increase the amount of required force to crack, when torquing down the wingnut, the user should never reach the required amount of torque to crack. To completely avoid this issue the user should be sure only to tighten until the blade is secure.

A load was applied along the edge and curvature of the blade to simulate a large wind load being applied to the blade for further analysis. A cross section where the blade will be retained to the hub is provided below in Figure 12. The shear through the bolts was the largest concern for the blade mounting system while the Portable Wind Turbine is in use.

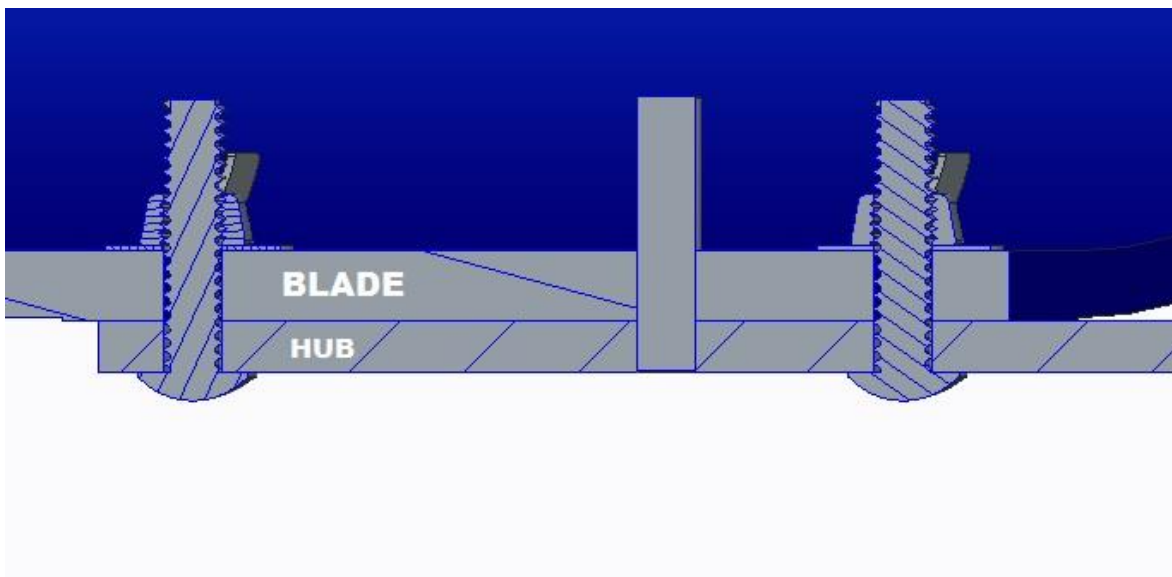


Figure 12. Cross section view of the blade system at the base of the blade.

Below in Figure 13 shows the FEA performed on blades that were created in Creo Parametric. The blades take the general shape of the blade, and are not exact duplicates. The load was only applied to one blade and the center of the hub was given a pin constraint. Note the option for UV-stabilized polycarbonate was not available for material selection in Creo Parametric so PVC was selected for the analysis. Also the load was exceptionally large (10lbs), however as shown in the even with such a large load the max displacement of the blades was near the end of the blade with a maximum displacement of 0.0374 in., whereas there was little to no displacement at the base where the blades attach.

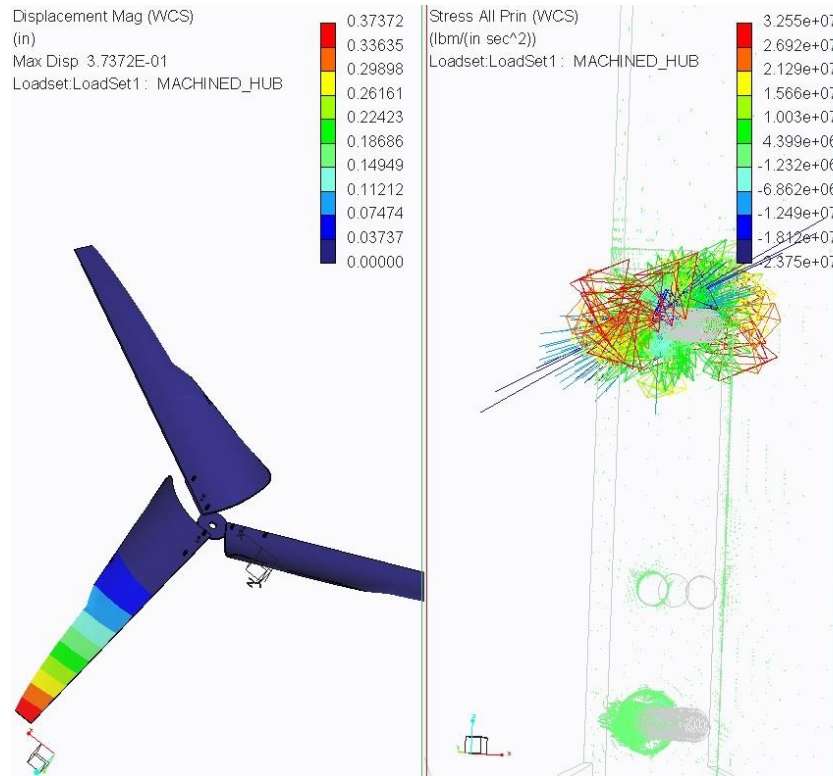


Figure 13. FEA performed in Creo Parametric for the blades and attachment.

Figure 13 also contains the max stress point for the blades. Figure 13 is an image of FEA provided by Windy Nation. The image has fairly low resolution, but what can be seen from the image is the max stress point which lies along the base of the blades where the hub attaches. Specifically the upmost hole for attaching, notice that in Figure 12 the max stress point lies in the same position which reassures the analysis performed above. To compensate for this large stress the user should be careful when securing the upmost wing nut on each blade, as this point is the most likely to fail.

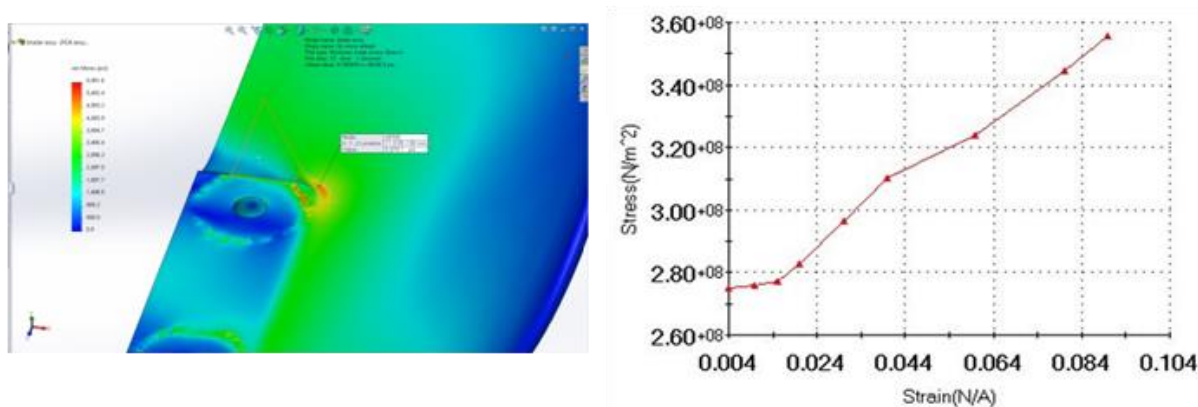


Figure 14. Finite Element Analysis provided by Windy Nation

3. Design for Economics

3.1 Power Generation

The scope of the project was for a user to be able to charge a device up to 5 watts of power. With the wind speeds averaging 4 m/s, the alternator will rotate at ~190 rpms. According to the company website, as well as testing in a lab locally, the alternator will output ~25 watts of power at that angular velocity. This is excessively more than is needed, yet it is alright. It is important to note three things with the power generation being high: there will be expected natural losses, the wind will slow down at times, and the charge controller will regulate the power output to the battery to avoid overcharging. The charge controller will ensure the power output to charge the battery is the correct amount to safely and efficiently charge the battery for the consumer.

3.2 Costs

The total budget of the Portable Wind Turbine was set at \$2000. From this \$2000, 17% was used for the tower, 26% was used for the electrical components and 9% was used for the nacelle. This leaves a remaining of 48% of the budget, these values can be seen in Figure 15 represented by the pie chart. The total cost for the electrical portion of the turbine was \$513.53. The total cost for the body was \$335.48 and the total cost for the nacelle was \$186.97. The individual costs for the electrical components can be seen in Table 1. The individual costs for the parts for the body can be seen in Table 2 and the costs for the parts of the nacelle can be seen in Table 3.

Since this portable wind turbine is a new prototype, any consumer can buy these products and create the turbine on their own. These parts were chosen in accordance with the \$2000 budget and many more materials can be found and used.

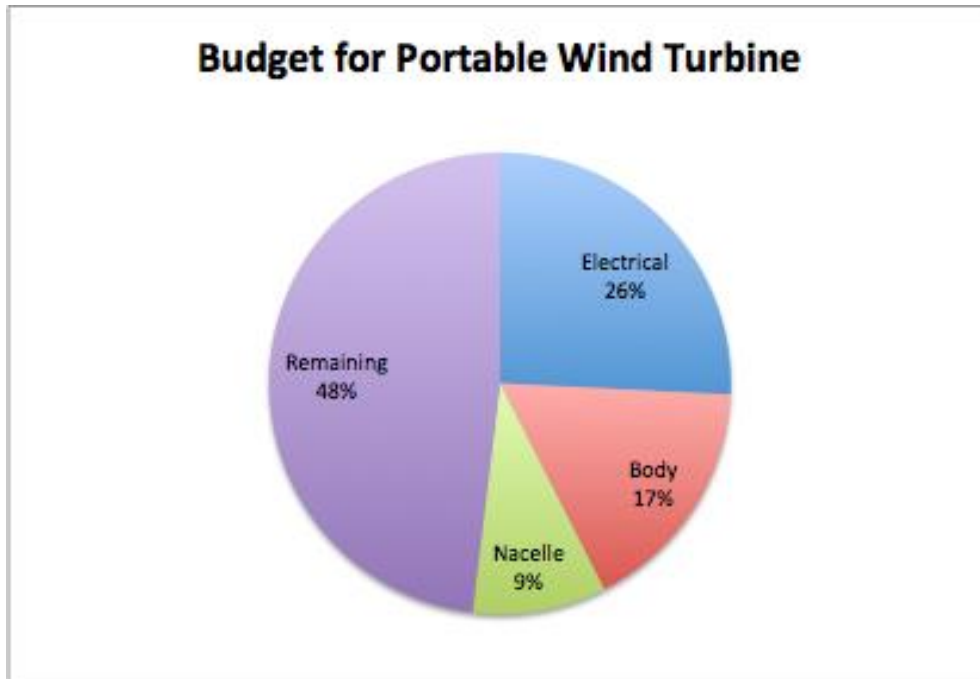


Figure 15. The budget usage of the Portable Wind Turbine

Table 1. Cost of electrical components.

Part	Cost
Alternator	\$239.00
Charge Controller	\$199.99
Battery	\$76.54
Total	\$515.53

Table 2. Cost of materials for the nacelle.

Part	Cost
1/4" Aluminum sheet (2)	\$35.82
1/16" Aluminum sheet (2)	\$28.56
1/8" Aluminum sheet rolled into tube	\$80.00
Delrin	\$19.98
Steel Rod 3/4"	\$6.94
Quick Release	\$39.67
Blades	\$54.98
Bushings	\$6.94
Total Cost	\$272.89

Table 3. Cost of materials for the body.

Part	Cost
All Terrain Feet	\$69.95
Clamps	\$83.97
Aluminum Plate 0.25"	\$14.80
Aluminum Tube 1-1/4"	\$72.80
Aluminum Tube 1"	\$60.50
Aluminum Tube 1-1/2"	\$21.16
Pins	\$12.30
Total Cost	\$335.48

4. Conclusion

The Portable Wind Turbine prototype was created within the budget constraint of \$2,000 outlined by the project sponsor. Similar material thicknesses, bolts and threading were used in as many locations as possible in order to reduce the total number of different parts and materials that needed to be purchased, therefore reducing the cost of the design. Automated, quick cutting procedures, such as the water jet, were also used whenever possible in order to reduce machining time and the costs associated. By using an almost entirely aluminum design, the team was able to maintain the durability of the prototype while still keeping the weight of the design relatively low. Several user friendly features, such as the slide mechanism to allow for access to the electrical components inside the nacelle, were included in the design in order to facilitate its use and allow for a wider user base.