

# Final Report

## Team 15

### Portable Wind Turbine



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04/08/16

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## Abstract

Senior Design Team 15 was presented with the project of designing a Portable Wind Turbine and creating a prototype with a budget of \$2,000. A current lack of portable wind energy led to the creation of this project, with the ultimate goal of providing renewable energy in situations such as disaster relief, military applications, research, etc. Constraints, such as a maximum rotational axis height of 2m and design for wind speeds of 4m/s were given to Team 15 to incorporate into the design. Team 15 successfully developed an easy-to-assemble and user friendly Portable Wind Turbine, meeting all constraints given by the project sponsor, while staying within the allocated budget. This report outlines the concept generation, design and fabrication process.

# 1. Introduction

## 1.1 Problem Statement

Team 15 designed a portable wind turbine for the sponsor, Dr. Sungmoon Jung. Dr. Jung desired that the team create a small turbine that can produce enough power to charge a small device, while being easy to transport. The turbine must operate in 4m/s winds, be lightweight, easy to assemble and disassemble, cost under \$2000, and be able to handle a variation of wind and climate conditions at the height of two meters. There is a need for portable, renewable energy. Current small wind turbines cannot produce energy efficiently from 4m/s winds or be relocated easily.

## 1.2 Design Requirements/Constraints

The following are the constraints for the project as defined by the sponsor. Team 15 are to utilizing skills gained in the courses taken in the College of Engineering to come up with the proper performance and design for the portable wind turbine.

- Must be easy to assemble and disassemble
- Structural stability in various locations with different terrains
- Lightweight for portability
- Operational in low wind speeds (4 m/s)
- Height of turbine will be no more than 2m

### 1.2.1 Design Specifications

The following are the design specifications for the portable wind turbine:

1. The turbine must operate in an average wind speed of 4 m/s at a maximum height of 2 m
2. The design must be lightweight. Team 15 desires to keep the total weight under 80lbs
3. The design must be easy to assemble and disassemble.
4. The design has a maximum budget of \$2,000.

### 1.2.2 Performance Specifications

The following are the performance specifications for the portable wind turbine:

1. The power output of the wind turbine will be a minimum of 5 watts.
2. The turbine will be able to handle a variation of wind and climate conditions.
3. The turbine will not break or overturn due to anticipated, reasonable conditions.

4. The turbine will generate enough power to charge a small device such as a cell phone.

### 1.3 Project Objective

Due to the fact that wind speeds are lower at ground level, the two meter, portable turbine will have to utilize energy from only four meter per second winds.

*“Design a lightweight and portable wind turbine that may be easily assembled and produce enough energy at low wind speeds to charge a small device.”*

The objectives of this project are to design a wind turbine that meets the following criteria:

- Produce enough energy to charge a small device.
- Operate at lower wind speeds than current models.
- Assemble more easily than current models.
- Structurally stable on various surfaces and in various situations
- Light enough to allow easy transport.

## 2. Background Research

There are many ways to harness wind energy and take advantage of this natural resource. A portable wind turbine would be a convenience to people who are camping outdoors in places without outlets. The portable wind turbine can also be used for military applications. The most important aspect of the portable wind turbine is to create a convenience to the consumer with a green way of producing energy. The portable wind turbine will be able to generate enough power to charge small devices. Only one current development example exists. The Trinity wind turbine, is a small portable wind turbine that generates about 15 watts in 10 m/hr winds and weighs only 1.4lbs. Not only is the Trinity a one of a kind portable wind turbine but it is also easy to assemble and cheap to buy. This is a good example of the goal for the new portable wind turbine that will be designed by Team 15.2

Although portability is harder to find, Team 15's background research has shown that a variety of small wind turbines already exist and can provide relatively substantial amounts of power. Targeting their research towards existing turbines that are priced closest to their \$2,000 budget constraint, Team 15 found useful information on four miniature wind turbines. Three of these turbines are developed by Southwest Windpower, while a fourth is by AeroVironment. Comparisons of relevant information for each of the turbines are given in Table 1.

**Table 1. Comparison of existing, miniature wind turbines.**

<i>Model</i>	<i>Weight</i>	<i>Price</i>	<i>Spin Up Wind Speed</i>	<i>Power Output (~4m/s Wind)</i>
Southwest Windpower Skystream 3.7	70kg	\$5,399	3.5[Equation]	200W
Southwest Windpower Air X	6kg	\$1163	3.13[Equation]	250W
Southwest Windpower Whisper 500	70kg	\$7,095	3.4[Equation]	500W
AeroVironment Architectural Wind	59kg (Each)	\$134,400 (Incl Install)	2.2[Equation]	25W (Each)

Southwest Windpower's "Xzeres" Skystream 3.7 is a three-bladed, downwind turbine designed and built for grid-connected residential use. The Skystream 3.7 has a blade diameter of 3.72m (12ft) and sweeps an area of 10.7m<sup>2</sup> (115.7ft<sup>2</sup>). The rotor speed is maintained at 50-325rpm during operation using electronic stall regulation with a redundant switch control braking system. Using built in controls and inverters, a gearless alternator and a slotless, brushless permanent magnet, this wind turbine produces energy at an advertised average cost of \$0.99/kWh. The Skystream 3.7 is rated for 2.1kW with 11m/s winds and has a maximum power of 2.6kW. The manufacturer includes a five year warranty for the Skystream 3.7.<sup>3</sup>

Much smaller than the Skystream 3.7, Southwest Windpower's Air X is the world's best-selling small wind turbine and includes a three year warranty from the manufacturer. This 3-blade turbine uses a neodymium alternator and with a diameter of 1.14m (46in) sweeps an area of only 1.64m<sup>2</sup> (17.6ft<sup>2</sup>). Using an electronic torque control braking system, the Air X keeps the rotor under 900rpm during operation. This turbine has both a rated and peak power output of 400W at wind speeds of 12.5m/s.<sup>4</sup>

The Southwest Windpower Whisper 500 is a somewhat atypical turbine design in that it uses only two blades. With a diameter of 4.5m (15ft) these blades sweep over an area of 16.4m<sup>2</sup> (175ft<sup>2</sup>). The Whisper 500 has a rated power of 3kW at 10.5[Equation] and a peak power output of 3.2kW at 12[Equation].<sup>5</sup> This system is designed for off-grid use and regulates its speed using a combination of mechanical over speed protection and side-furling. Southwest Windpower offers a five year warranty for the system and recommends professional installation.<sup>7</sup>

Designed to take advantage of the wind profiles created by building walls in urban settings, the AeroVironment Architectural Wind uses a five bladed design. These blades create a diameter of approximately 1m (3ft) and each turbine has a rated power of 1kW. One distinguishing feature of the AeroVironment design is that its systems are sold in arrays of 12 turbines and includes installation. Aesthetic turbine hoods can be added for an additional price.

## 3. Concept Generation

Several concepts were generated for each of the major sections of the Portable Wind Turbine: the base, the body and the blades. These concepts are discussed below.

### 3.1 Concept Generation for Body and Base

#### 3.1.1 Turbine Body

After developing three potential concepts for the blades of the turbine, Team 15 moved on to brainstorming body types for the turbine. Similar for the blades, the team will also need to develop a method of joining the selected body of the turbine to the nacelle. This attachment must allow the nacelle to safely and easily detach as well as turn freely to align to the wind while attached. The first of the concepts for the body of the turbine actually completely eliminates the body in a “bodiless” wind turbine.



**Figure 1. Bodiless wind turbine concept.**

Shown in Figure 1. Bodiless wind turbine concept. using a four-legged base, the bodiless design concept sits the nacelle of the turbine directly onto the base of the turbine. The elimination of the body of the turbine has several potential advantages such as greatly increasing the portability of the design by reducing both the weight and the total number of parts that are needed.

Secondly, Team 15 developed a cylindrical body concept for the wind turbine. Similar to the bodies of full scale turbines, the cylindrical shape would give strength and rigidity to the turbine body. Team 15's concept is constructed of several cylinders with decreasing diameter. This design would allow the body to collapse into itself for added portability, while being able to expand to the maximum height of 2m. A basic CAD model of this design is shown in Figure 2. Cylindrical turbine body concept.



**Figure 2. Cylindrical turbine body concept.**

The final design for the body proposed by members of Team 15 was a cross style body, shown in Figure 3. Cross turbine body concept. This design would be able to fold onto itself, becoming flat, for easier transportation. The design also includes cut-outs from all sides in order to reduce the weight and thus the portability of the design. In order to avoid interference between the blades of the turbine (should the standard or hybrid blade concepts be selected) and the body of the turbine, the cross design is tapered as it extends upwards from the ground. Although this design would provide a sturdy midsection for the portable wind turbine, the long, flat, triangular shape that is formed when the design is folded onto itself would be very awkward to transport.



**Figure 3. Cross turbine body concept.**

### 3.1.2 Turbine Base

Finally, Team 15 developed design concepts for the base of the turbine. The base of the turbine will be the section below the body. The first concept proposed was a tripod based design. An example of a professional grade video camera tripod is shown in Figure 4. A professional grade video camera tripod.<sup>10</sup>

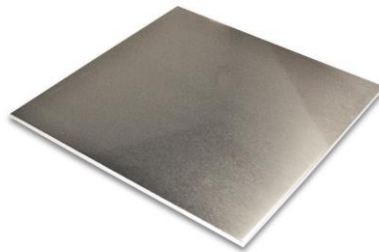


**Figure 4. A professional grade video camera tripod.<sup>10</sup>**

Clearly, designing a tripod base would rely on Team 15 being able to design a portable wind turbine with a nacelle light enough to be supported by the tripods. The design concept of telescoping legs for the tripod base would aid in the ease of assembly for Team 15's wind turbine.

This concept has several advantages in that tripods are designed to be extremely compact and portable.

The next, and arguably simplest, concept proposed by members of Team 15 was a solid plate for the base of the turbine. An example of this simple concept can be seen in Figure 5. A plate similar to what would be used as a solid base



**Figure 5. A plate similar to what would be used as a solid base.**

This concept would rely on the size and weight of the base plate in order to stabilize the portable wind turbine. Obviously the major disadvantage of this design concept is that, since it relies on large size and high weight to function, it would significantly detract from the portability of the turbine.

## 3.2 Concept Generation for Mounting Systems

In order to facilitate the set up and break down of the Portable Wind Turbine, Team 15 decided to develop several project-specific methods of attaching the turbine blades to the rotating alternator shaft as well as attaching the entire nacelle to the base of the turbine.

### 3.2.1 Nacelle Mounting System

Several methods were considered as options for attaching the nacelle of the turbine to the Portable Wind Turbine base. As stated by the project sponsor, whatever the design, it must be simple and easy to use for any user. Initially Team 15 considered a simple pin with a retainer through two concentric cylinder to attach the nacelle to the base. This idea was quickly discarded, however,

since it would lock the nacelle in one direction and not allow it to rotate freely, relative to the base, if the wind changed direction.

Moving forward from this idea, the Team ultimately settled on the adaptation of a steering wheel quick release system to use as a mount for the turbine nacelle. After considering the many different types of steering wheel quick releases that are available, Team 15 selected a flange style, hex-shaft quick release. An example of this style of quick release can be seen in Figure 6, with a CAD representation of the assembly concept in Figure 7.



**Figure 6. Quick release with mounting bolts.**



**Figure 7. CAD model of quick release concept.**

In this design concept, the quick release head would be bolted to the bottom of the turbine nacelle. This would allow the nacelle to be easily placed onto the hex-head which would be welded to a shaft, fit into two sleeve bearings. These bearings, mounted into the top of the base would allow the nacelle to freely rotate with changing wind speeds while the quick release system would allow the user to very easily attach or remove the nacelle from the base as required.

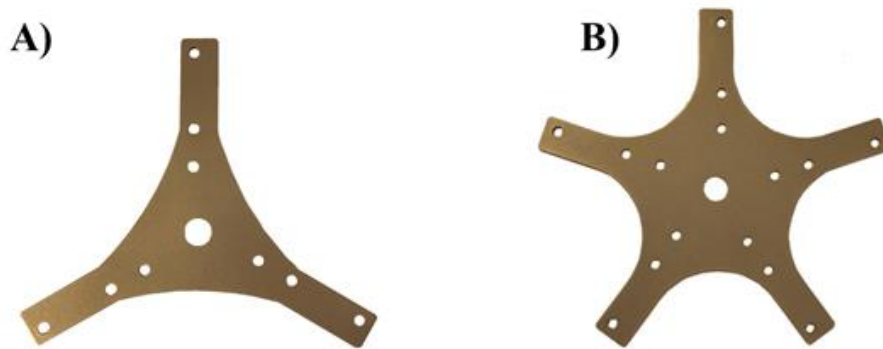
### 3.2.2 Blade Mounting System

Two essential components of the Portable design are the blades and the way in which they are mounted. One of the constraints of the project was that Team 15 should use off-the-shelf wind turbine blades in the Portable Wind Turbine design. UV-stabilized polycarbonate blades were chosen for this application. Blades made from this material would withstand abuse better than the aluminum blades since aluminum could potentially be permanently deformed. Also the UV-stabilized polycarbonate blades will reduce the overall weight of the final design. The airfoil of the blades is a thin under-cambered profile, this shape is practical for low-speed aerodynamic applications such as the Portable Wind Turbines, where high lift force is desired at low flow speeds and corresponding Reynold's Number. An image of the ordered blades from Windy Nation is provided below in Figure 8.



**Figure 8. Blades that will be mounted on the hub.**

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.

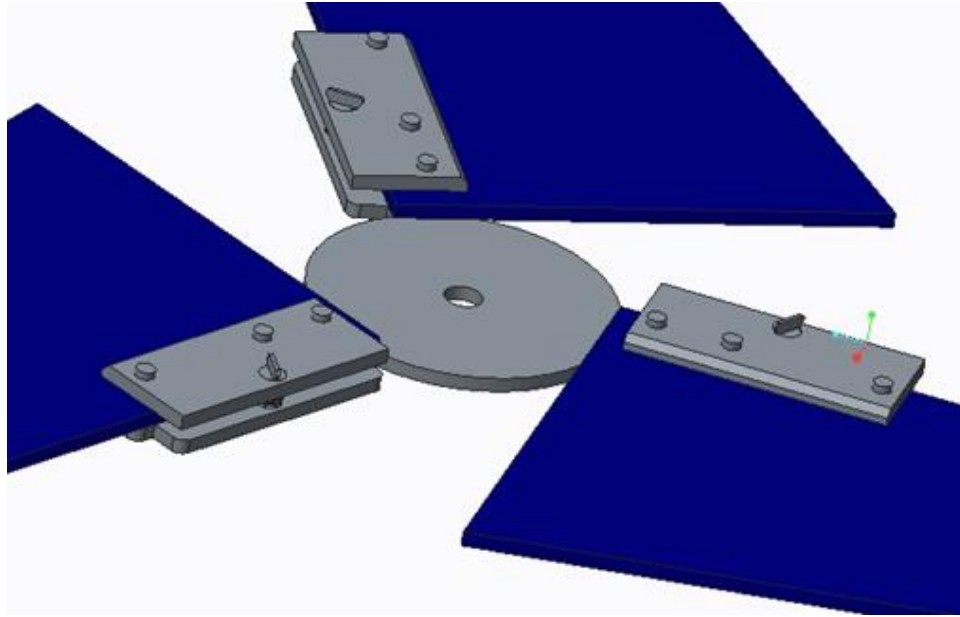


**Figure 9. Standard hubs from Windy Nation. (A) is for 3 blade systems (B) is for 5 blade systems.**

An innovative way to attach and remove the blades from the assembly was needed to increase portability of the wind turbine. In the early stages of the Portable wind turbines design, it was assumed that a standard 3-blade wind turbine hub as pictured in Figure 9(A) would be used as this would be the easiest option, since it required no further manufacturing or fabrication. In this design instead of using conventional bolts and screws to attach the blades, plastic fasteners or “snap screws” would be used in order to provide easy and quick assembly. However after analyzing this design, the strength of the fasteners was deemed questionable. The design was re-updated to include a mounting piece for the shaft on the alternator however once the alternator arrived it was discovered that it already utilized a clamp to secure the hub to the alternator.

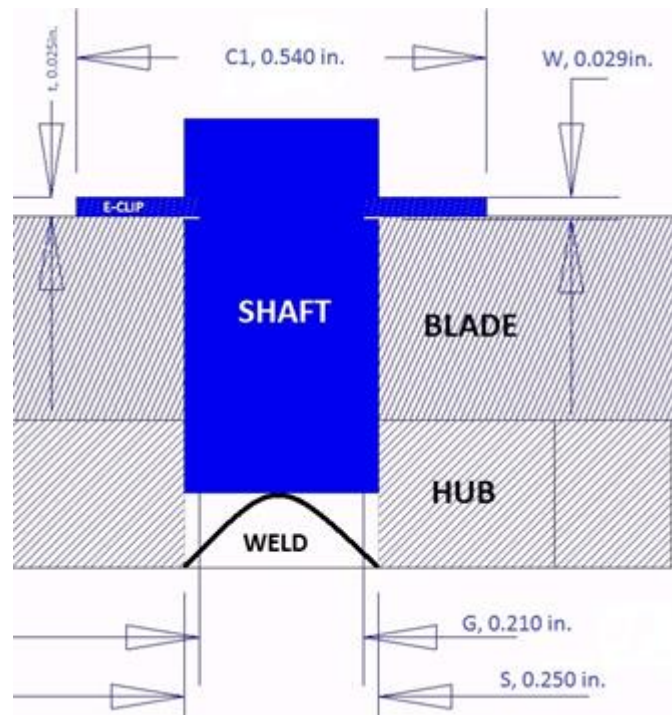
To completely eliminate the need for tools a custom blade mounting hub with retaining mechanisms was designed in Creo Parametric. There were initially two concepts to mount the blades using the custom hub the first used clamps along with thumb screws to secure the blades.

A hub was designed for this application and is pictured below in Figure 10. The hub would require additional extruded material where the blades base will rest so the top portion of the clamp could be placed on top the blade and be secured with the thumb screws. The design also required shafts to act as support pins for the clamp. However this design added unnecessary weight to the design and would significantly alter the aerodynamic profile (airfoil) of the blades.



**Figure 10. Initial blade mounting concept for the Portable Wind Turbine.**

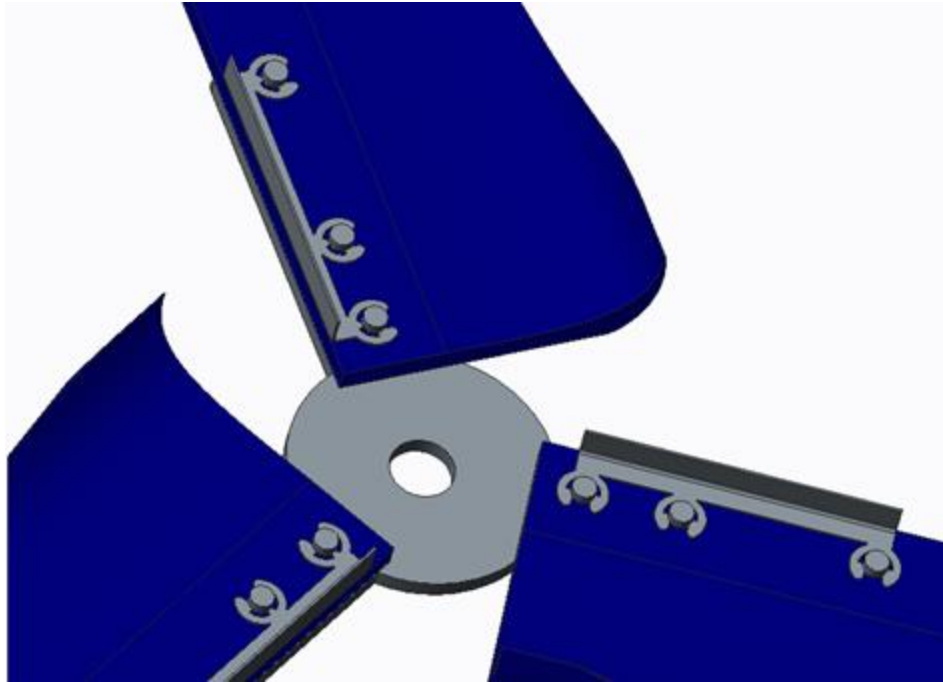
The second design utilized a custom e-clip with welded grooved shafts in the hub to secure the blades. This design would reduce the part count for the blade mounting down to 4, and was considerably lighter than the previous. The design for the e-clip was based on standard e-clip design for a shaft of 0.25 inches. All required parameters to design the clip were provided by Arcon Ring and Specility, including the free ring diameters, clip thickness, proper retaining groove width, and all corresponding tolerances. A cross section of the e-clip, with some of the mentioned dimensions is below in Figure 11.



**Figure 11. Cross-section of the e-clip and shaft for the secondary design concept along with corresponding dimensions.**

When designing a retaining ring there are four main parameters that need to be considered. Those are the load capacities of the ring and groove, the edge margin of the shaft or the amount of material above the groove on the shaft, the installation stress the e-clip experiences, and the rotational capacity of the clips. Additional loading situations that could be taken into consideration are the dynamic thrust load capacities of the e-clip including impact load or vibration loading. The equations are mostly dependent on clip dimensions, material properties of the clip and groove, as well as safety factors. Samples of the calculations can be found in Appendix A.

A CAD representation of the second blade mounting design is given below in Figure 12. After meeting with the machinist that would create the e-clip it was realized that the 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.



**Figure 12. Assembled view of the secondary design concept.**

### 3.3 Concept for Electrical Systems

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 safe and efficiently charge the battery for the consumer

## 4. Final Design

### 4.1 Base Design

After closely analyzing all design concepts for the base and body of the wind turbine, a design was chosen that will simply be referred to as the base of the turbine. The alternative that was selected for the base of the turbine was a long, aluminum tube, the neck, connected to a tripod-like section, the legs, as shown in Figure 13. The tripod-like section is composed of three legs, each with two telescoping aluminum tubes. This will provide for a sturdy base while still minimizing number and size of parts, while the telescoping design will aid in the ease of assembly and disassembly. This neck concept was selected to be a part of the turbine body to provide more space for the blades to spin, without hitting the tripod legs. It also aids in a minimization of size and number of parts. This helps both in decreasing the weight and improving portability. Team 15 decided to minimize the height of the telescoping legs and maximize the neck length. Again, all of this included will allow free spinning of the blades, increase portability, decrease weight, and allow assembly for any user.



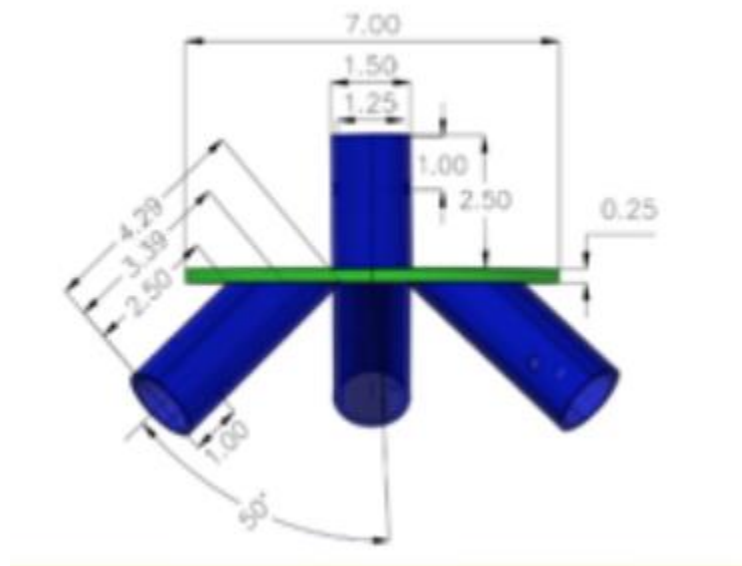
**Figure 13. Final body selection for the Portable Wind Turbine.**

The telescoping tripod base legs will lock in place with a simple clamp shown in Figure 14. This will allow for quick and easy connection of the leg tubes. The use of clamps gives flexibility in the length of the tripod legs on sloped or flat surfaces. Choosing a clamp instead of a pin to adjust for leg length eliminates the need of numerous holes throughout the length of the legs if a pin were to be used. Also, the clamps have simple adjustable strength allowing them to lock in place tighter.



**Figure 14. Tube clamp.**

The legs and neck will be connected by a welded piece of aluminum and aluminum tube pieces referred to as the leg and neck connection, or the welded plate. This is shown in Figure 15. The welds give this connection enough strength to resist failure. Also the bottom three tube pieces give the legs a set angle. This connection allows quick and easy assembly for the user.



**Figure 15. Leg and neck connection.**

The legs and neck are connected to the leg and neck connection with a retainer pin as shown in Figure 16. The pin selection for the base is very important considering it will be one of the most vulnerable places for failure. Using a pin made out of steel will be the most efficient way to account for these failures because of the strength of the material.



**Figure 16. Pin with locking retainer.**

The legs of the turbine are attached to all terrain feet as shown in Figure 17. At the bottom of each of the legs is a threaded hole where these feet can easily be attached and taken off. This allows for quick and easy assembly for the user. By using these feet, the turbine can stand on almost any terrain type. The larger surface area allows for stability on sand or softer soil while the rubber of the feet resist sliding on smoother surfaces.

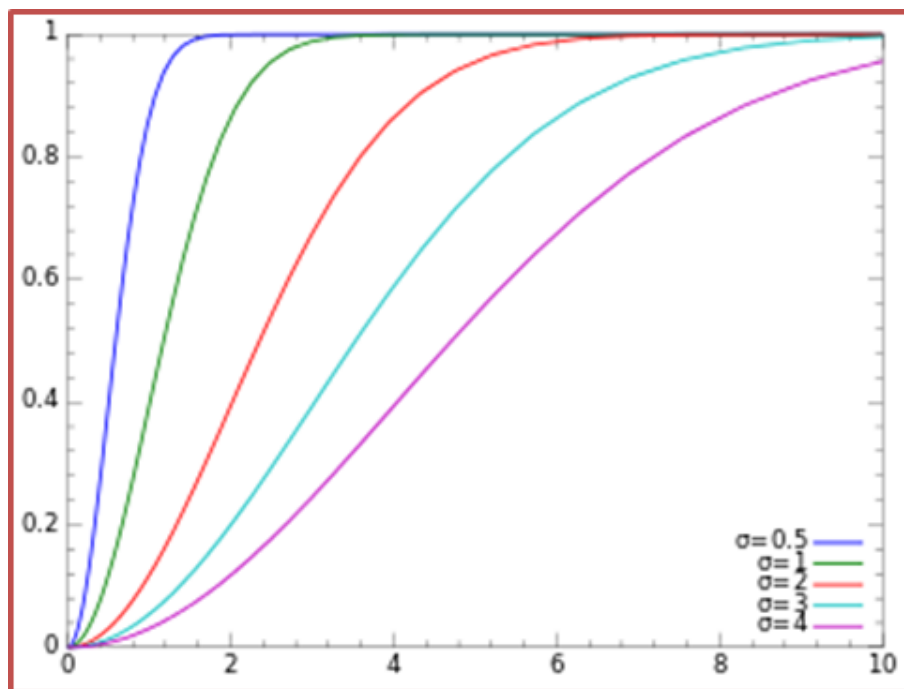


**Figure 17. Base feet.**

The base was designed to withstand 4 m/s wind speeds and not overturn. Because of this, an anchor or anchoring system was not included in the design of the wind turbine. However, if wind speed is too great, the user has the ability to use their own anchoring system and anchor the legs to the ground or cable off the legs to a nearby tree or other stable object. This will provide more resistance to overturning.

## 4.2 Calculations for Base

In designing the base for the portable wind turbine there are many issues to consider. The failures of the parts are very important. For the aluminum tubing the bending, buckling and shearing of the material need to be evaluated. This means that the tubing of the base needs to be strong enough to hold the nacelle and blades of the turbine as well as accounting for the wind loads on the base. The pins in the tubing also need to be evaluated for shearing. Another concern with the design of the base includes stability against overturning. To do this the Rayleigh wind distribution and a sloped surface will be assumed. The Rayleigh Chart shows the distribution of wind speeds that can be anticipated from several average wind speeds. Since the speed of wind fluctuates at any given location, the actual wind speed at a location which has the design speed of four m/s can be predicted based on the lowest of the five lines in Figure 18. Though the average wind speed is four m/s, there is a one percent chance that the wind fluctuates up to 10 m/s. In this case, the additional wind could cause a failure of the turbine due to overturning or failure of the individual parts. Therefore, some of the calculations for the base and the body will include accounting for ten m/s winds. An accidental bump on the turbine base also needs to be evaluated in case the consumer bumps into it. For this an 8 inch offset will be assumed.

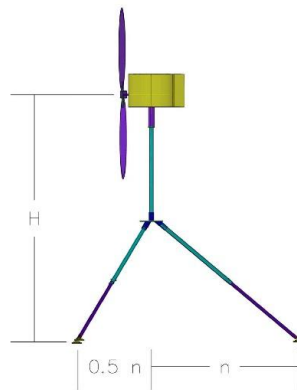


**Figure 18. Rayleigh Distribution Chart.**

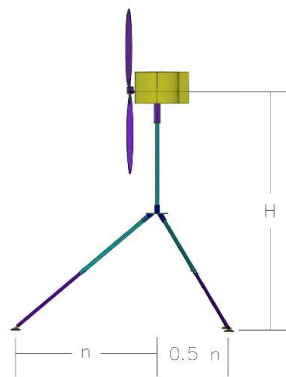
### 4.2.1 Overturning:

The turbine's base needs to be designed so it can reliably withstand the force of the wind without fear of it falling over, or overturning. The turbine is designed for wind speeds averaging 4 m/s, so the base needs to be able to resist that resulting driving moment at any direction, with or without the use of an external anchoring system. Then, the next step is to resist the winds determined through the Rayleigh Distribution to be very rare. The turbine should be able to withstand wind speeds close to this goal of 10 m/s.

Analyzing the moment due to the wind that must be resisted was crucial in determining the required width of the base. There were two scenarios that had to be analyzed in order to understand the stability of the turbine under the most efficient and least efficient orientations. Figure 19, below, shows the most efficient scenario and Figure 20 shows the least efficient scenario with respect to the stability of the turbines against overturning.



**Figure 19. Efficient**



**Figure 20. Inefficient**

$$W_{Min} = \frac{2F_W H}{L \sin \phi} = \frac{F_W H}{n} \text{ or } \frac{F_W H}{0.5n}$$

$$F_W = \frac{W_T L \sin \phi}{2H} = \frac{W_T n}{H} \text{ or } \frac{W_T (0.5n)}{H}$$

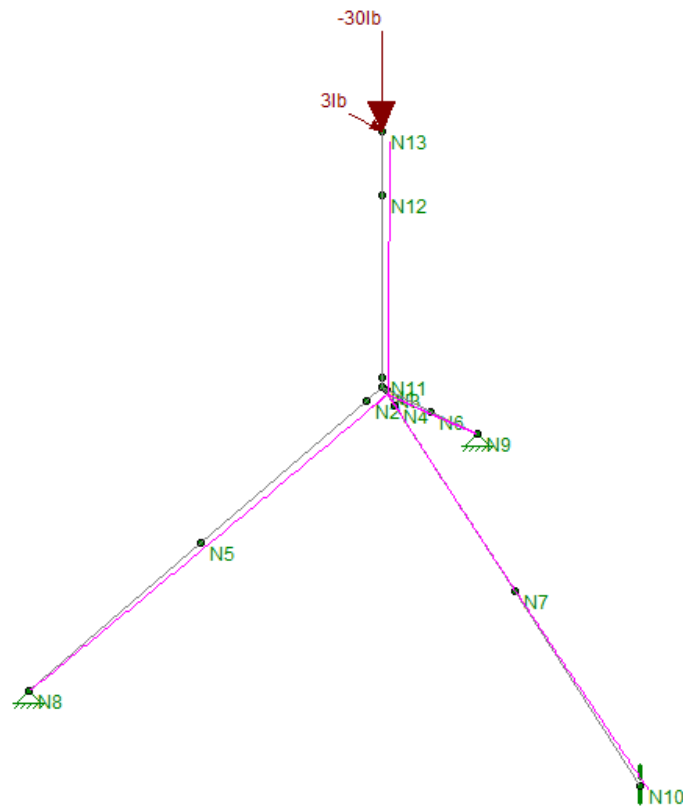
If  $W_T = 30lb$  and the overturning axis is the minimum distance, as shown in Figure 19, then  $F_W = 6.55 \frac{m}{s}$  (14.7 mph).

If  $W_T = 30lb$  and the over turning axis is over the extended foot, as shown in Figure 20, then  $F_W = 9.26 \frac{m}{s}$  (20.8 mph).

These values show that the turbine is stable under normal conditions (close to 4 m/s) under any orientation and that, when oriented efficiently, it can withstand close to the wind speed determined from the Rayleigh Distribution. Of course, the stability of the turbine can be drastically increased through the use of an anchoring system. Larger wind speeds could be utilized and orientation of the turbine could become less critical if the turbine were to be anchored. The base might seem wide, though the width is necessary for resisting the fluctuating wind forces that might be experienced.

#### 4.2.2 Stress (Axial and Bending):

The aluminum tubing that the three legs and the neck sections are composed of will be subject to both axial stresses and bending stresses. These stresses, in combination with each other, could cause failure to the turbine. To ensure that the members of the turbine have adequate strength, these stresses were analyzed with both hand calculations and computer calculations. The hand calculations gave the following equations with the following resulting values. The computer analysis was completed through the program RISA 3D. The results and images from this program are also shown below. Figure 21 represents the displacement diagram of the base when the wind load and self-weight are applied. The wind is flowing in the positive X direction and all of the wind load is going towards node N10 in the image.



**Figure 21. Risa Deflection.**

$$\sigma_{Neck} = \left( \frac{(H - L \cos \phi) F_W \frac{d_0}{2}}{\left( \frac{\pi(d_0^4 - d_i^4)}{64} \right)} \right) + \left( \frac{4W_N}{\pi(d_0^2 - d_i^2)} \right)$$

4 m/s - Max Stress in Neck-

Equation Value: 0.19 ksi

RISA 3D Value 1.29 ksi

10 m/s – Max Stress in Neck-

Equation Value: 0.71 ksi

RISA 3D Value: 7.88

$$\sigma_{legsroller} = \left( \frac{\left( W_T + 2F_W \frac{H}{L \sin \phi} \right) L \sin \phi d_0}{3} \frac{64}{2 \pi (d_0^4 - d_i^4)} \right) + \left( \frac{4 \left( W_T + 2F_W \frac{H}{L \sin \phi} \right) \cos \phi}{3 \pi (d_0^2 - d_i^2)} \right)$$

4 m/s – Max Stress in Legs-

Equation Value: 6.98 ksi

RISA 3D Value: 6.65 ksi

10 m/s – Max Stress in Legs-

Equation Value: 16.92 ksi

RISA 3D Value: 15.31

$$\sigma_{legs-pin} = \left( \left( \frac{F_W \cos \phi - \left( W_T + 2F_W \frac{H}{L \sin \phi} \right) \sin \phi}{3} \right) L \frac{d_0}{2} \frac{64}{\pi (d_0^4 - d_i^4)} \right) + \left( \frac{4 \left( W_T + 2F_W \frac{H}{L \sin \phi} \right) \cos \phi}{3 \pi (d_0^2 - d_i^2)} \right)$$

4 m/s – Max Stress in Legs-

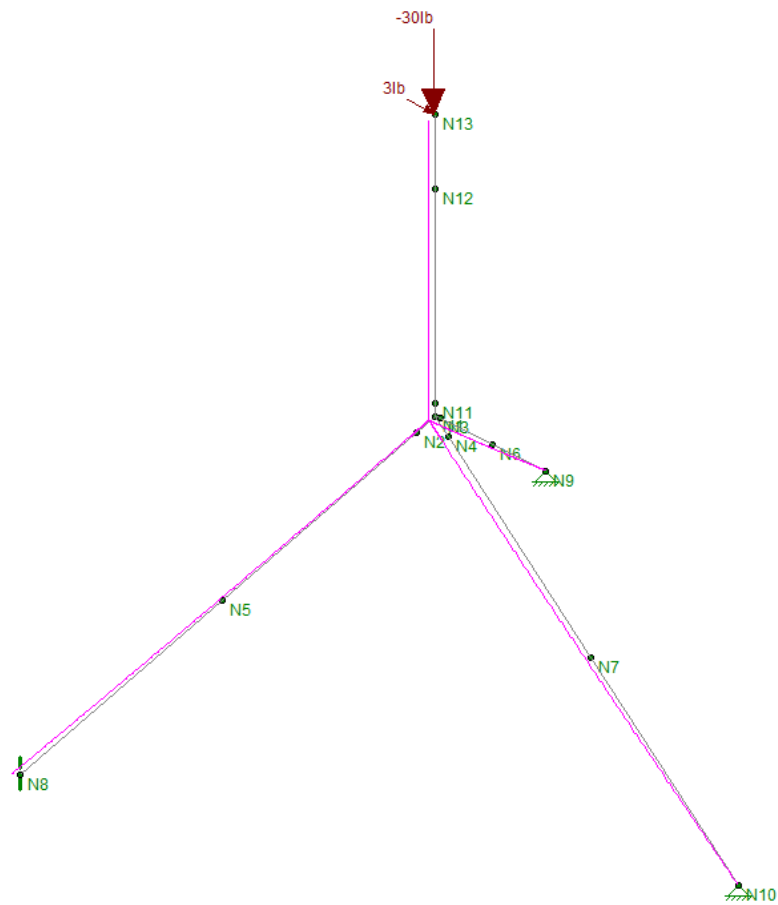
Equation Value: 6.87 ksi

RISA 3D Value: 4.13 ksi

10 m/s – Max Stress in Legs-

Equation Value: 16.25 ksi

RISA 3D Value: 7.88 ksi



**Figure 22. Risa deflection in second case**

There are some differences between the hand calculations and the RISA 3D values. When doing the analysis by hand, it was possible to calculate the stresses on the members with a one pin and two roller situation. The RISA 3D program only allowed for there to be two pins and one roller to complete the analysis for the base, and this is the cause of the difference in analysis between the computer program and hand calculations. The RISA 3D given stresses equal to be about half of the hand done calculations, which is understandable with different boundary conditions. Figure 22 represents the deflection diagram of the base in the second condition where the support of the leg receiving the majority of the wind load was set as a pin, rather than a roller.

The analysis for the stresses in the legs were split into two parts. The reaction of the feet of the turbine with the ground resulted in different reactions throughout the members. The first scenario was for when the extended foot of the turbine was treated as a roller. This means that it was

expected to slide across the ground surface while the other two feet stayed in place. The second scenario was for when the extended foot of the turbine was treated as a pin while the other two feet were treated as pins. This scenario resulted in lower maximum stresses than had resulted in the first scenario. Also, the values from RISA 3D varied more in the analysis of the second scenario. This is because the program requires additional restraints for stability against rotation when the support reactions consist of two rollers and a pin rather than two pins and a roller.

For the stress of the neck section, the calculated values for the stress in the neck varied significantly from the values given from RISA. This is because RISA uses the total change in orientation of the individual members due to the effects from the displacement of the other members in order to calculate the stresses. While the stresses in the neck section were insignificant in the calculated, upright and un-displaced position, they were very large when the member was displaced and oriented at an angle to the vertical. These values will represent the maximum and minimum stress values for both of the wind speed situations.

For each of the equations, the most efficient and least efficient scenarios that were discussed in the preceding Overturning Section were analyzed again. The stresses were maximized in the legs, however, in the more efficient of the two scenarios with respect to overturning; when one leg is extended in the direction opposing the wind, rather than two. The equations and values of this scenario were the ones used in determining the maximum stresses and are therefore the ones shown above. The assumed wind speed of 4 m/s and the goal wind speed of 10 m/s were analyzed again as well.

The members had to be selected based on their calculated internal stresses being adequately below the yield stress of their material. The type of aluminum selected had a yield stress of 35 ksi, which provided an upper limit for the members. This value, paired with the derived stress equations and RISA 3D stress values, was used to determine whether the outer and inner diameters of the tubing options were adequate.

### 4.2.3 Buckling:

The aluminum members of the base were also checked against buckling. Buckling would occur due to axial forces resulting from the combination of the wind on the blades and weight of the turbine. The derived equations and values with respect to buckling are shown below.

$$W_{Max} = \frac{\left( \frac{\pi^2 EI}{k^2 L_{leg\ seg.}^2} \right) - \left( \frac{2F_W}{3 \sin \phi} \right)}{3 \cos \phi}$$

Max Weight for Legs: 3350 lb

$$W_{Max} = \frac{\pi^2 EI}{k^2 L_{neck}^2}$$

Max Weight for Neck: 1640 lb

The weight of the turbine that would cause buckling under assumed wind loads (4 m/s and 10 m/s) was derived to determine the equations shown above. This maximum weight is the weight of the turbine allowed before buckling could occur. Since the allowable weights calculated are significantly larger than the actual expected weight of the turbine, buckling is said to be negligible for this design.

### 4.2.4 Shearing:

The members of the base of the turbine were also checked against the possibility of shearing. The pins in the legs and neck of the tubing could shear if the force is too large or the pins are too small. The pins could also cause shearing to the tubing if the force is too large or if the cross sectional area is too small.

$$\tau = \frac{V}{A}$$

$$\tau_{tube} = \frac{V}{d_{pin} L_{leg\ seg.}} = \frac{W_T}{d_{pin} L_{leg\ seg.}}$$

$$\tau_{pin} = \frac{V}{\left(\frac{\pi(d_{pin}^2)}{4}\right)} = \frac{W_T}{\left(\frac{\pi(d_{pin}^2)}{4}\right)}$$

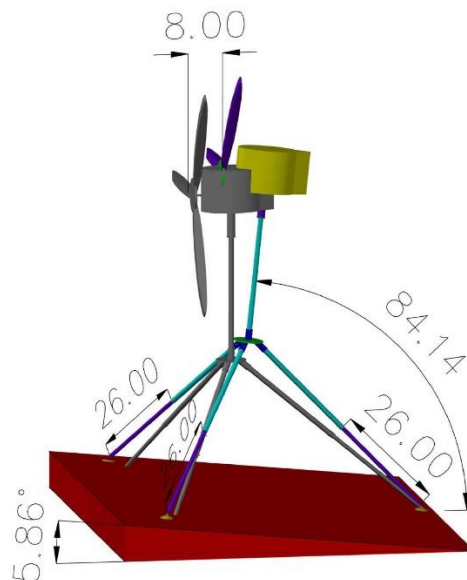
Pin: 2.45 ksi

Tube: 0.24 ksi

The values for shear stress for the selected members were significantly smaller than the yield stress of the aluminum in the tubing (35 ksi) and the yield stress of the steel in the pins (60 ksi). This shows that the chances of failure due to shearing is negligible for this design. As a note, the maximum shear force was determined to occur at the connection of the neck section to the welded plate. At this connection, the maximum shear force is about equal to the weight of the parts supported by it.

#### 4.2.5 Bump:

An assumption made during the design of the turbine was that the turbine might be bumped while in use by someone nearby or by something else within its vicinity. The bump was assumed to offset the turbine by a maximum of 8 inches measured from the center of the nacelle in the horizontal direction. An illustration of this is shown below in Figure 23 as well as the corresponding equations and values.



**Figure 23. Bump case**

$$W_{Min} = \frac{F_W \left( H \cos \theta + \frac{L}{2} \sin \phi \sin \theta \right)}{\left( \frac{L}{2} \sin \phi \cos \theta - H \sin \theta \right)}$$

$$F_{W_{Max}} = \frac{W_T \left( \frac{L}{2} \sin \phi \cos \theta - H \sin \theta \right)}{\left( H \cos \theta + \frac{L}{2} \sin \phi \sin \theta \right)}$$

$$\theta = \sin^{-1} \left( \frac{\text{Offset Distance}}{H + \frac{L}{2} \sin \phi} \right)$$

Orientation 1:

Max Angle: 11.02 degrees

Max Displacement: 19.00 inches

Orientation 2:

Max Angle: 9.10 degrees

Max Displacement: 15.73 inches

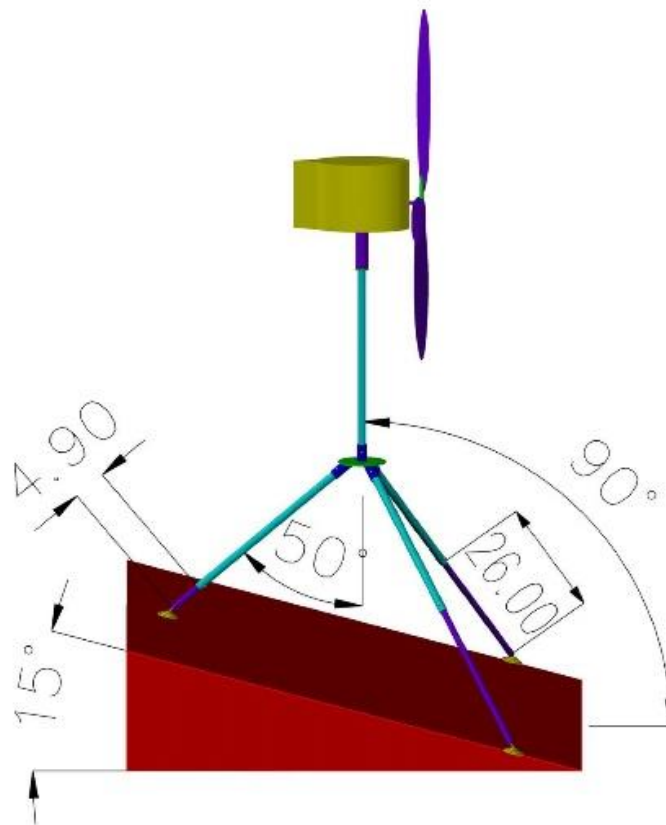
These values show that the turbine is more than adequately designed to withstand this assumed displacement under the assumed 4m/s wind load. The equations were derived to show the minimum weight of the nacelle that would be required for a specified offset, or a maximum wind speed that could be coupled with this offset. Given a specific wind speed and weight assumption, the maximum bump displacement and resulting offset angle was determined, as shown above. This maximum angle and distance was determined for both axes again, to account for varying orientations of the turbine. These values were significantly greater than the goals that were set, which shows that the turbine should not fail due to a casual bump.

#### 4.2.6 Adjustment for slope:

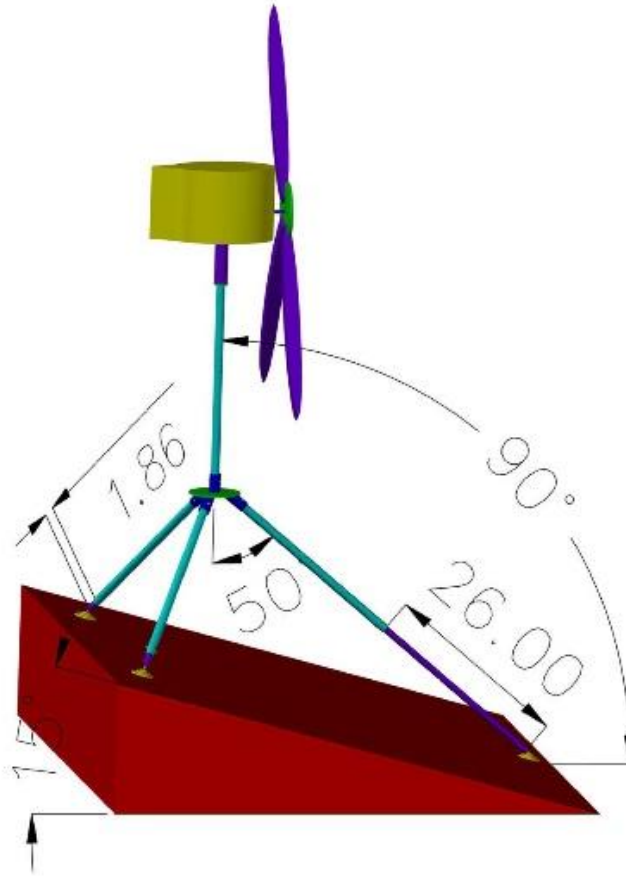
The slope of the surface that the turbine might be placed on could vary greatly. We assumed that this slope could reach up to 15 degrees. Under the turbine dimensions and loads assumed, the turbine would not be able to resist overturning reliably for any surface greater than 9 degrees unless

the legs were allowed to adjust. The turbine would also be able to operate more efficiently if the nacelle were able to remain leveled. The legs were designed to telescope for these reasons.

In designing the turbine, the angle of the legs needed to be determined. The angle was determined to be fixed for multiple reasons, though the main reason was ease of assembly. The angle needed to be maximized for stability against overturning, though it was restricted by the amount the legs could telescope to accommodate for a sloped surface. Under the assumed slope of 15 degrees, the total leg length of 54 inches, and the adjustable length of the legs of 26 inches, the following angle was determined.



**Figure 24. Set up angle in Case 1**



**Figure 25. Set up angle in Case 2.**

$$\frac{3 \times L \times \sin\left(\tan^{-1}\left(\frac{\tan \phi}{2}\right)\right) \times \tan \theta \times \sin(90 - \theta)}{\sin\left(90 + \theta - \tan^{-1}\left(\frac{\tan \phi}{2}\right)\right)} = \Delta L$$

$$\frac{3 \times L \times \sin(\phi) \times \tan \theta \times \sin(90 - \theta)}{\sin(90 + \theta - \phi)} = \Delta L$$

Orientation 1: 60.5 degrees

Orientation 2: 55.4 degrees

The images and equations above show how the fixed angle of the legs was determined. Both of the orientations (most efficient and least efficient) required their own equation and both were used to determine the angle. Though the maximum angle was calculated to be close to 55 degrees, an angle of 50 degrees was selected. This conservative angle was selected in order to account for

several factors. These factors include: manufacturing tolerances, variation of actual leg length and adjustable length from assumed, and possibly a slope slightly greater than 15 degrees. With the addition of the feet and the welded connection plate, the actual leg length becomes slightly larger than the assumed, which reduces the maximum allowable angle of the legs. Also, the clamps used to telescope the legs might not allow the full 26 inch adjustable length. This would also decrease the allowable angle of the legs.

Maximum Slope Adjustment Allowed:

Orientation 1: 20.6 degrees

Orientation 2: 17.1 degrees

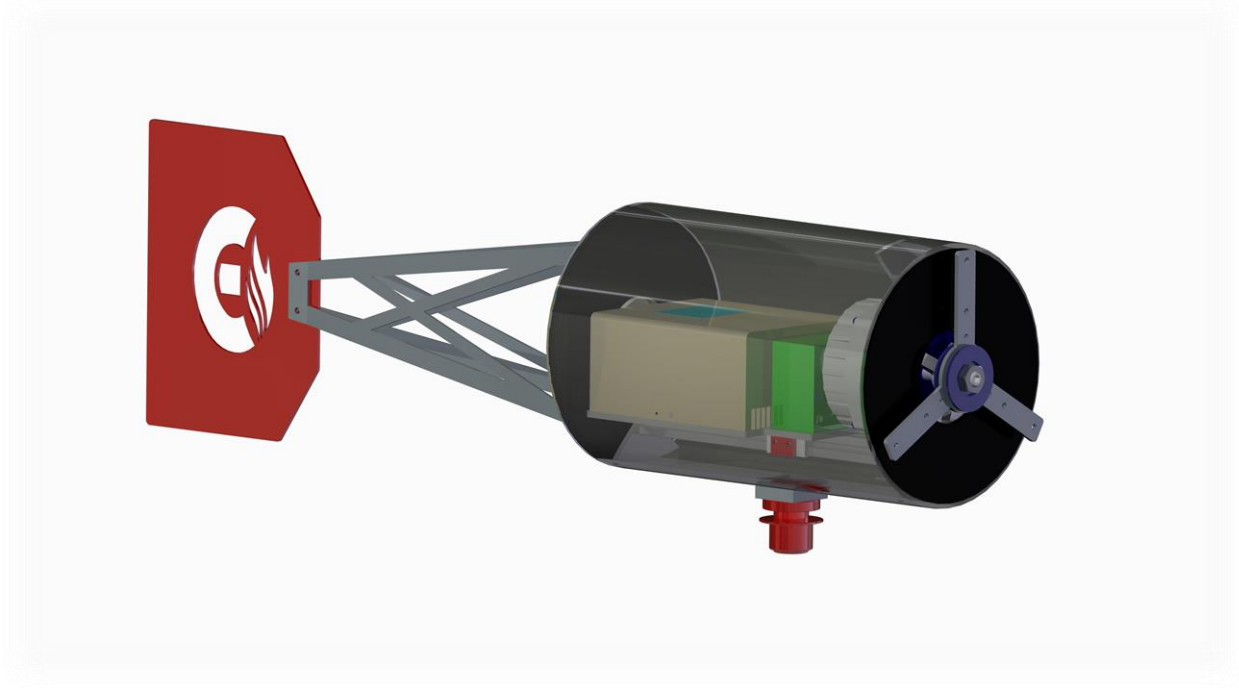
By rearranging the preceding equations, the maximum slope that the turbine's base can adjust for and still stay leveled was calculated. The values for this are listed above and it was noted that each of them exceed the goal of 15 degrees. Orientation 1 and 2, shown above, are the same that were used previously.

## 4.3 Nacelle Design

Several aspects were considered when design the nacelle of the Portable Wind Turbine. Obviously, all electrical components must be able to fit inside of the nacelle body and must there be protected from the elements. Along with this, it was required by the project definition that the turbine be easy to assemble, disassemble and operate for any user. To meet this requirement, special consideration was given to the design of the nacelle structure and mounting as well as the method of mounting the turbine blades.

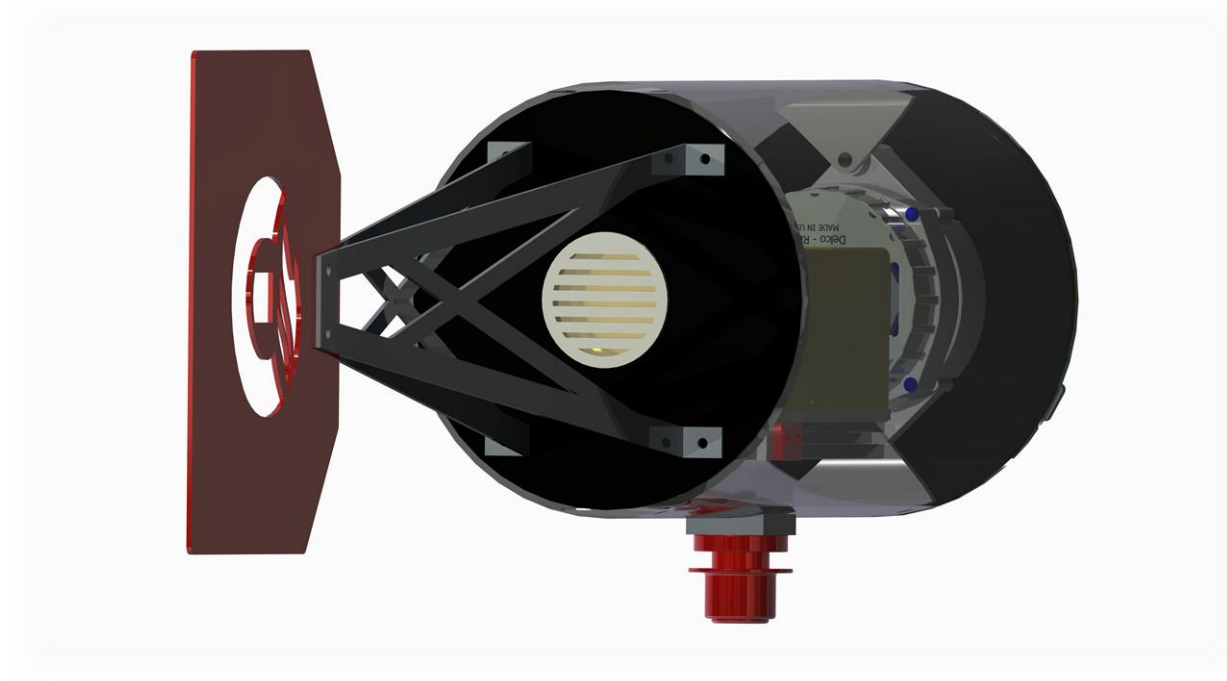
### 4.3.1 Nacelle Structure Design

In order to contain the electrical components of the Portable Wind Turbine, it was required that Team 15 develop a nacelle. Although a square nacelle body would have been a somewhat more efficient use of space, Team 15 settled on a round design for the nacelle of the turbine. The CAD render of this design can be seen in Figure 26.



**Figure 26. CAD model of the nacelle design.**

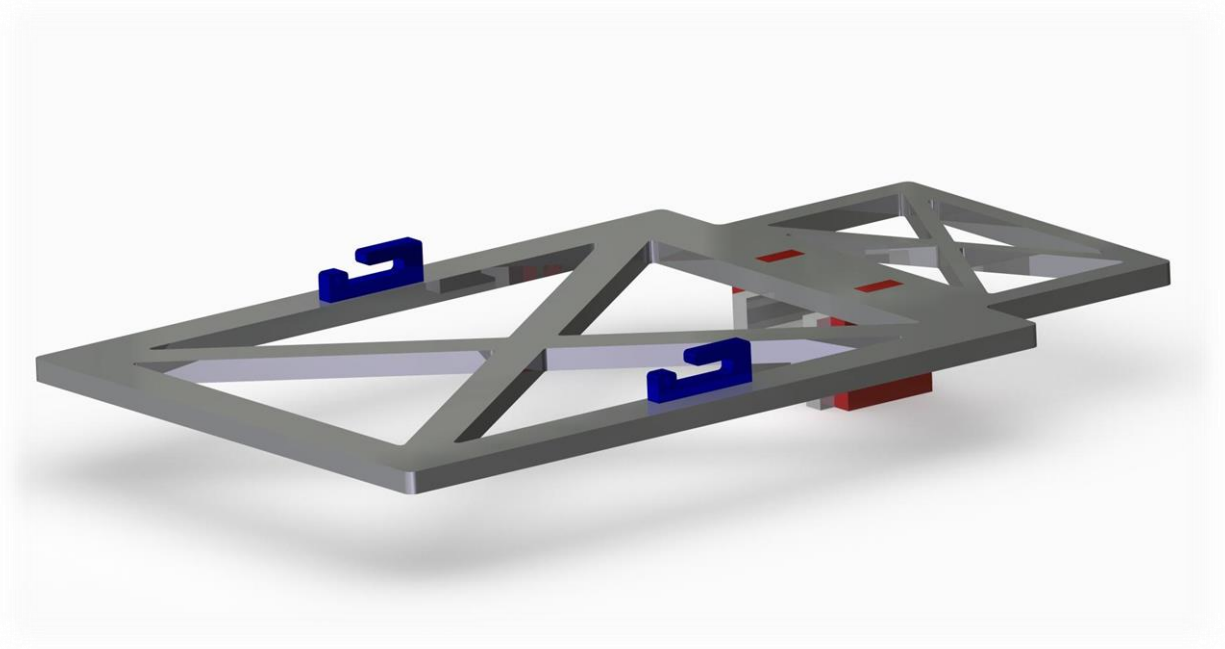
As well as being much more aesthetically pleasing than the square, box-like design initially considered, the “wasted” space in the interior of this design was actually helpful to Team 15. The major defining factors for the size of the nacelle were the alternator and charge controller. Obviously, since the Portable Wind Turbine will be generating power, there will also be heat created by the electrical components. The added space in the interior of the turbine nacelle allows more space for this heat to dissipate from the electronic components in the nacelle. In order to aid in the heat dissipation process, a louver vent was added to the rear end cap of the nacelle design, as seen in Figure 27.



**Figure 27. Louver vent in rear of nacelle.**

Combined with the opening in the front end cap (seen in Figure 26) this louver vent would allow air to flow through the length of the nacelle while in operation, cooling the internal electrical components. Team 15 recognized that the opening in the front end cap created a vulnerability of the design to the elements and decided to research methods of preventing water from entering this opening while still allowing air flow and rotation of the alternator shaft.

The next challenge in the design of the turbine nacelle was the mounting of the electrical components to the interior of the tube-shaped nacelle casing. Design for the mounting of the alternator was a simple task, and mounting tabs were quickly created that could be welded to the interior of the tube. In order to allow for the mounting of the charge controller and battery, while still allowing the user to access and change the charge controller settings and replace the battery if necessary, a sliding mechanism was created. This sliding mount, seen in Figure 28, would be mounted on a rail of 80/20 aluminum using aluminum sliders. Tabs would be used to secure the charge controller to the sliding mount plate, and a simple nylon strap to secure the light-weight battery. The Delrin sliders would securely hold the sliding plate on the 80/20 rail, but still allow the user to pull these electrical components out of the back of the turbine to perform any actions that they desired.



**Figure 28. Sliding mount for charge controller and battery.**

This sliding design also led to the design for the method of attaching the front and rear end caps to the main body of the nacelle using draw hasps. An example of such a hasp can be seen in Figure 29.



**Figure 29. Draw hasp for attaching end caps to nacelle.**

Such an attachment system would allow the user to easily remove the rear (and front if required) end cap to access the internals of the Portable Wind Turbine Nacelle.

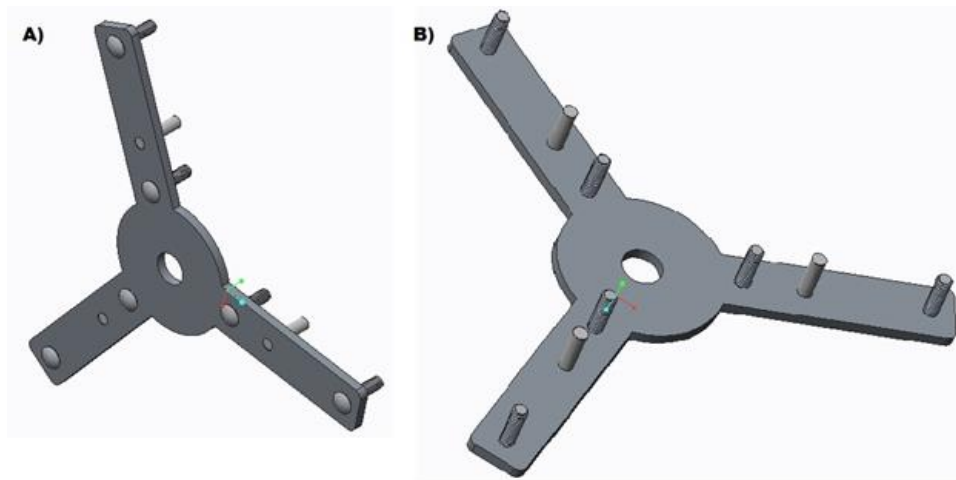
Apart from the Delrin end caps (and of course the internal electrical components), the entire nacelle design would be fabricated from aluminum sheet. Although plastics were initially considered, it was determined that the use of aluminum would result in a significantly stronger and more durable design for the same weight in material. For many of the components, the use of aluminum was also a cheaper option than if plastic had been used.

### 4.3.2 Quick Release Mounting System Design

As mentioned previously, Team 15 had selected a hex-shaft mount, flange style steering wheel quick release in order to mount the nacelle to the base of the Portable Wind Turbine. Following this selection process, the only further design required was to select sleeve bearings that would be able to be fit into the tubing of the turbine base design and allow for the nacelle to freely rotate on the quick release shaft. This task was quickly accomplished via McMaster. The loading and rotational stresses and fatigues usually needed to be evaluated in a bearing application were considered negligible in this application because of the relatively low weight of the nacelle and the extremely low rotations per minute that would be encountered from changing wind directions.

### 4.3.3 Blade Mounting System Design

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 not altered significantly from the second design, the only change that was made is the welded shafts were not included. The final design was simplified significantly from the second and will use the same custom hub design. To retain the blades to the hub self-locking wing nuts, bumper bolts, and dowel pins will be used. Figure 30 displays an image of the hub that will be used in the final design. The image displays how the bumper bolts will be welded into the top and bottom holes in the hub 3 inches apart from one another. Bumper bolts were chosen for the design due to the fact they could be purchased locally as opposed to threaded rods and bumper bolts would sit flush along the backside of the hub. The dowel pins will be press fit and welded into the central holes of the hub and will act as support pins for the blades.



**Figure 30. Original hub design with dowel pins included.**

This design was altered one final time where the dowel pins were removed to allow for easy machining. The final design is given below in Figure 31. As can be seen in the figure the central dowel pins were removed and additional bumper bolts were placed into these holes.



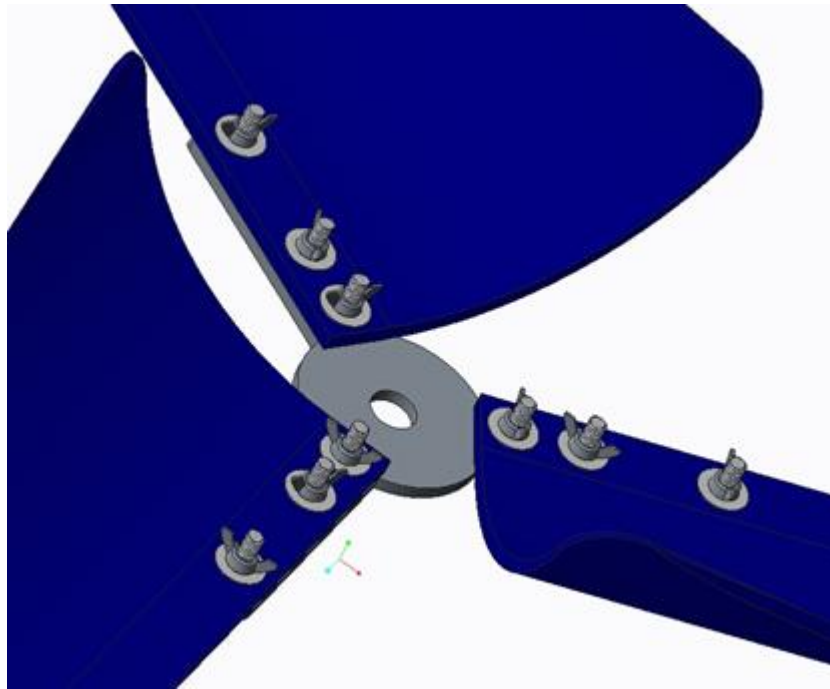
**Figure 31. Final hub assembly that will be used to mount the blades to the Portable Wind Turbine Prototype.**

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. 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 9.5 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. The machine hub is shown in Figure 32.



**Figure 32. Machine hub for blade mounting.**

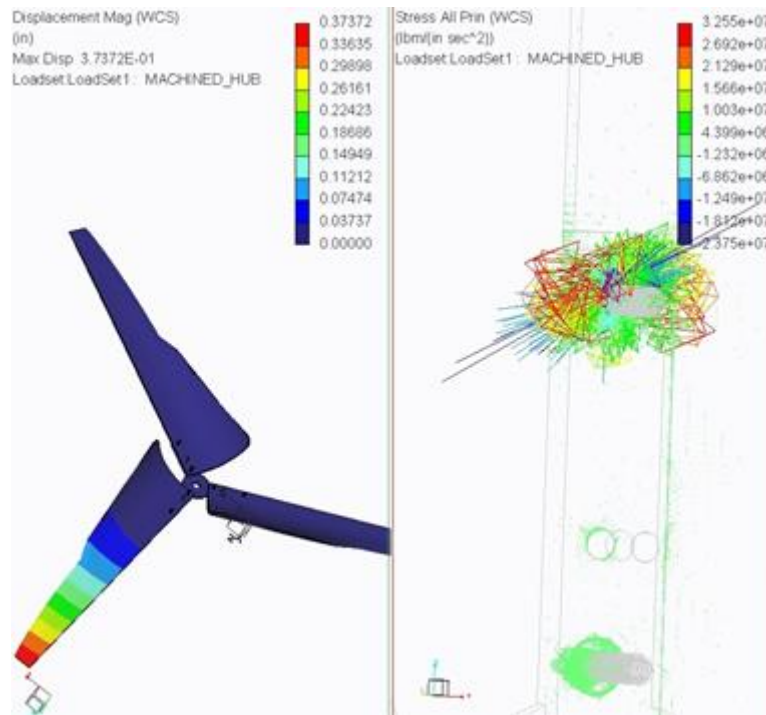
Below in Figure 33 is an image of the CAD assembly of the blade mounting system. As can be seen in the image the wing nuts are what secures the 3 UV-stabilized polycarbonate blades to the hub. The blades ordered from Windy Nation would usually include 9 stainless steel bolts, locking nuts, and washers. The new mounting system will include 9 self-locking nylon insert wing nuts and 9 general purpose flat washers. The self-locking wing nuts will have a nylon insert to increase the pressure and keep the blades from vibrating loose. The wing nuts and washers are standard where the wing nuts are 1/4-20 Grade 2 Zinc Plated Zamac Nylon Insert Wing Nuts, the washers are 8 1/4" x 0.734" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washers. According to imperial torque charts for locking nut fasteners, the average minimum assembly torque for hex sizes 7/16-1/2 in. ranges from 23 to 37.5 ft-lb. These are normally used to fasten the blades to the hub. Research concerning wing nut torque revealed that for a 5/16" wing nut the average torque for a male was about 3.3 ft-lb for a male and 2.5 ft-lb for a female, which will be suitable for this application.



**Figure 33. Final CAD blade mounting assembly representation.**

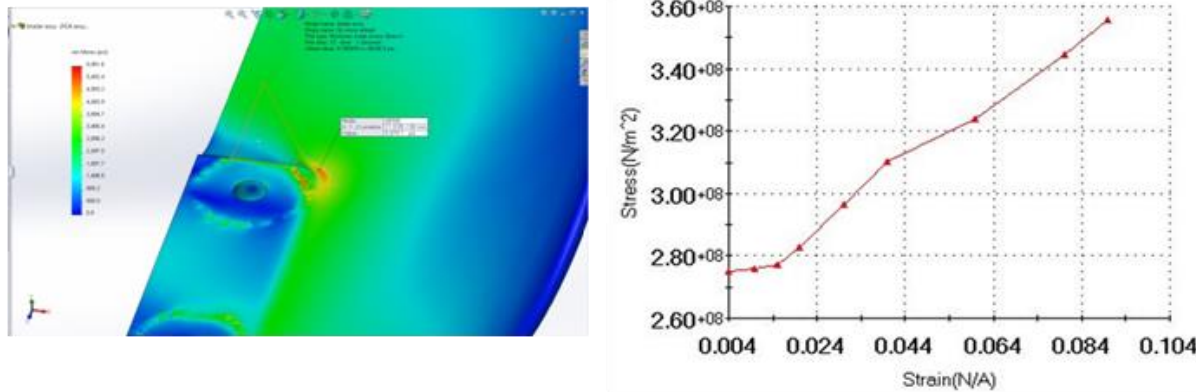
Below Figure 34 shows the FEA performed on blades that were created in Creo Parametric. The blades take the general shape of the blade, and are not exact duplicates. The load was only applied

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 34. FEA performed in Creo Parametric for the blades and attachment.**

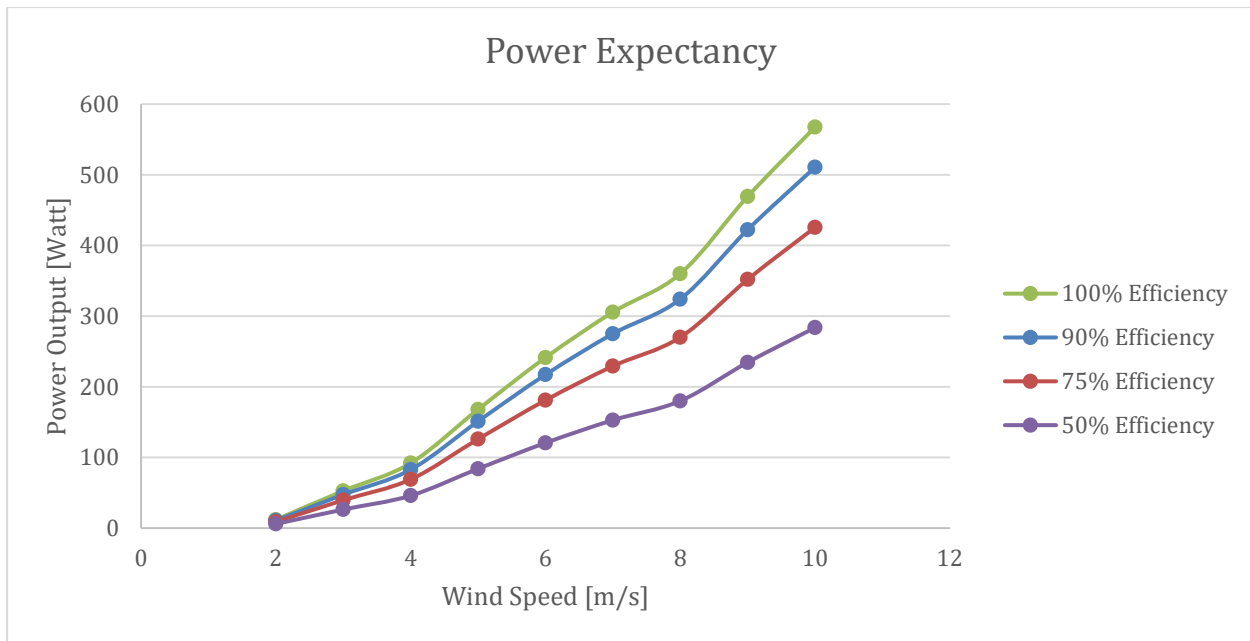
Figure 34 also contains the max stress point for the blades. Figure 35 is an image of FEA provided by Windy Nation. The image has fairly low resolution, but what can be seen from the image is the max stress point which lies along the base of the blades where the hub attaches. Specifically the up most hole for attaching, notice that in Figure 35 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 up most wing nut on each blade, as this point is the most likely to fail.



**Figure 35. Finite Element analysis provided by Windy Nation.**

## 4.4 Electrical Component Selection

Per the project description, the Portable Wind Turbine must be able to charge a battery, and be able to charge a small mobile device. It was pivotal in the selection of the electrical components to make sure everything was compatible, as well as efficient. As it turned out to be an iterative process, the first component selected was an alternator. Team 15 selected the WindBlue DC-540 alternator. As will be explained in Section 4.4, the selected blades have a specific TSR, or tip to speed ratio. With the blade specific TSR, Team 15 understood that under the conditions of 4 m/s wind speeds, the blades would output roughly 250 rotations per minute. That meant the alternator would need to output a decent amount of power at relatively low speeds, and that is why the WindBlue DC-540 was selected. Figure 36 below shows what expected power outputs should be based on wind speeds.

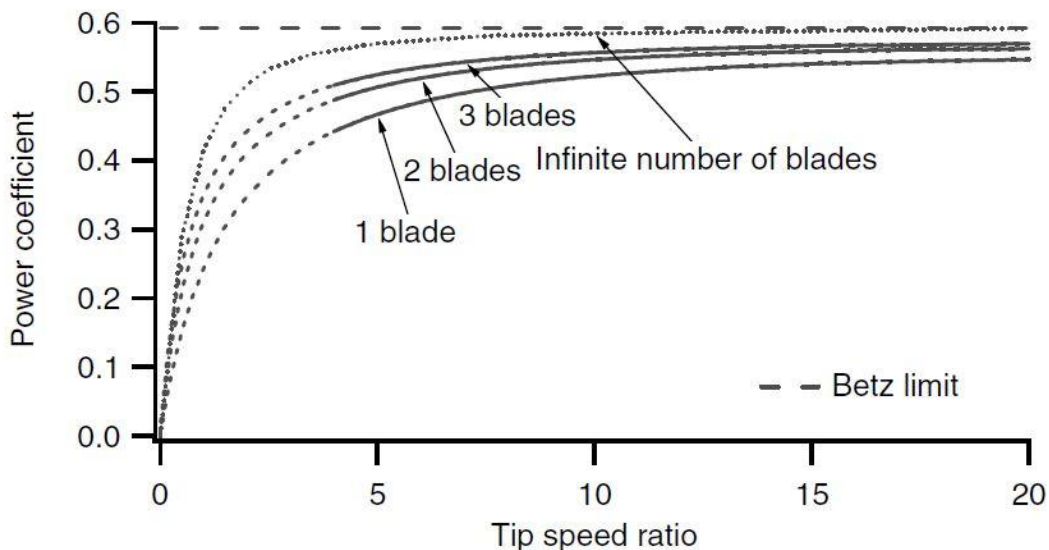


**Figure 36. Power expectancy of the Porable Wind Turbine**

After the alternator was selected, it was time to determine the battery type to be used. Keeping in mind safety as well as ease of use for the consumer, Team 15 selected a 12-volt Lithium Iron Phosphate battery. These batteries are ideal for long lives, and hold a significant amount of power in them. With only a 12-volt battery selected, it became immediately apparent that there could be overcharging that could possibly lead to turbine or user injury. To combat that, a charge controller was added to the circuit. This WindyNation TrakMax charge controller works at 12, 24, or 48 volts, and is very easy for the user to operate if needed. The charge controller is used for a couple different reasons. First and foremost, it is used as a safety feature to prevent overcharging of the battery. Once the battery is full, the charge controller diverts the inputted power away from the battery as heat. As shown in the figure above, if the wind speeds pick up, the power outputted by the alternator can be up to a factor of 10 or 20 times the nominal battery voltage. The charge controller helps keep that nominal voltage regulated. Simultaneously, the wind speeds decrease for a short period of time, the charge controller actually holds a charge similar to a capacitor and is able to let out some of that charge if the alternator is not outputting enough power. Finally, the charge controller does one final thing. The TrakMax is able to direct the flow of current, or rather block the flow from traveling in unwanted directions. This just means that if the wind dies down, the battery does not begin to charge the motor to rotate the blades.

## 4.4 Blade Selection

Blade selection was something Team 15 managed to do with little trouble. The first task was to decide which type of blades Team 15 wanted. Two designs were ultimately chosen to decide between, helix blades that the rotational axis is perpendicular to the wind and a traditional blade system where rotation is parallel to the wind direction. After some preliminary research, the traditional turbine blades were selected. Furthermore, while doing research on blades Team 15 discovered something very interesting known as the Betz Limit. This is represented in the figure below, but essentially the Betz limit says that as the number of blades increases, the efficiency actually maxes out at about 59%.



**Figure 37. Blade efficiency versus Tip Speed Ratio as a function of number of blades.**

With one of the design specifications being easy assembly and portability, the team made the decision to use 3 blades on the turbine. This was not only efficient, but it brought the cost of parts down as well as the number of parts the consumer would have to carry as well as put together.

A significant value comes with the selected blades and that is known as the tip speed ratio (TSR) as mentioned in the previous section. The TSR is the ratio of the tangential speed at the tip of the blade to the actual wind speed. This particular TSR is 4.8. That value, along with the blade length, was significant in determining which alternator to select because it directly correlates the wind

speed to the expected input angular velocity. This is extrapolated to selecting our battery; the battery is determined by the alternator, and the alternator by the input angular velocity, and the angular velocity by this blade-specific TSR.

## 4.5 Turbine Assembly

With the design of all the individual components completed, the design of the assembly of the full Portable Wind Turbine was a simple task for Team 15, thanks to the ease-of-use methods developed by the team for the assembly of the turbine. Despite difficulties with some software compatibility issues encountered when switching between different CAD programs used by the mechanical and civil engineering students, a full model of the Portable Wind Turbine was created in Creo Parametric 2.0. A render of the full design can be seen in Figure 38.



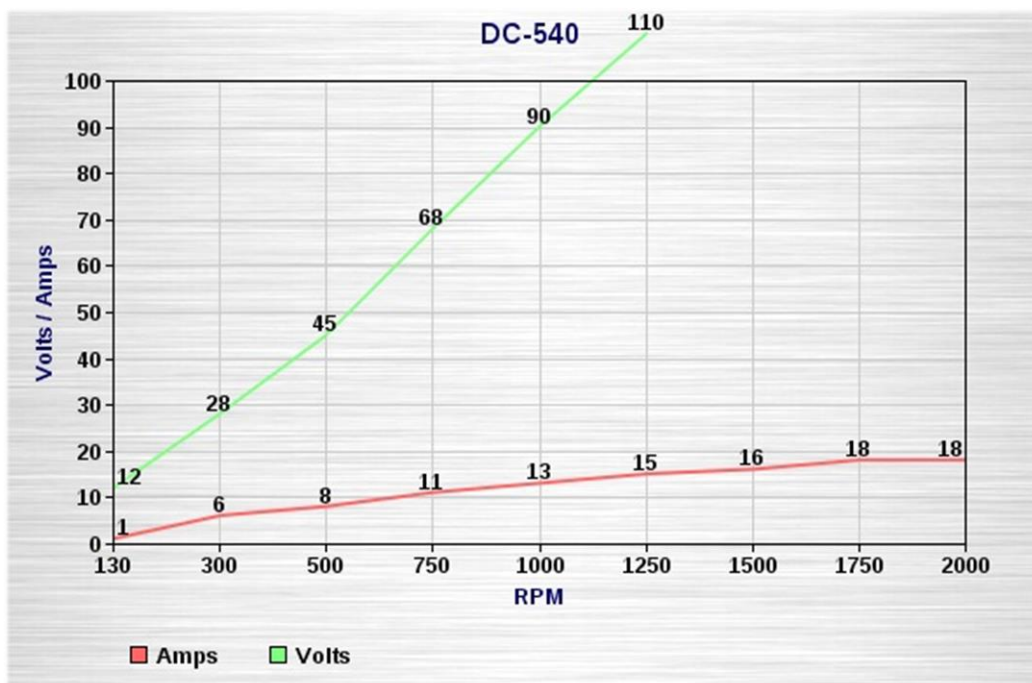
**Figure 38. Complete Portable Wind Turbine render**

## 5. Proof of Design

Before the wind turbine could be assembled, Team 15 needed to create a proof of design; something that says this is a conceivable idea and can work. Team 15 essentially split this proof of design into two parts: Power generation and proper wind speed locations.

### 5.1 Power Generation

The idea of turning mechanical energy in the wind into electrical energy to store in a battery or charge a device is not only plausible, but Team 15 found a way to do it safely, timely, and portably. The success of the turbine was measured by the amount of power it is able to generate, so the Team made sure to make the most efficient turbine possible. Designed to operate at wind speeds of roughly 4 m/s (10mph) and expected to output at least 5 watts of power, Team 15 had to select a proper alternator to do the trick. As discussed in the electrical component section above, the WindBlue DC-540 alternator was chosen. Shown below in the figure is a representation of what voltages and what currents are outputted by the alternator at different angular velocities.



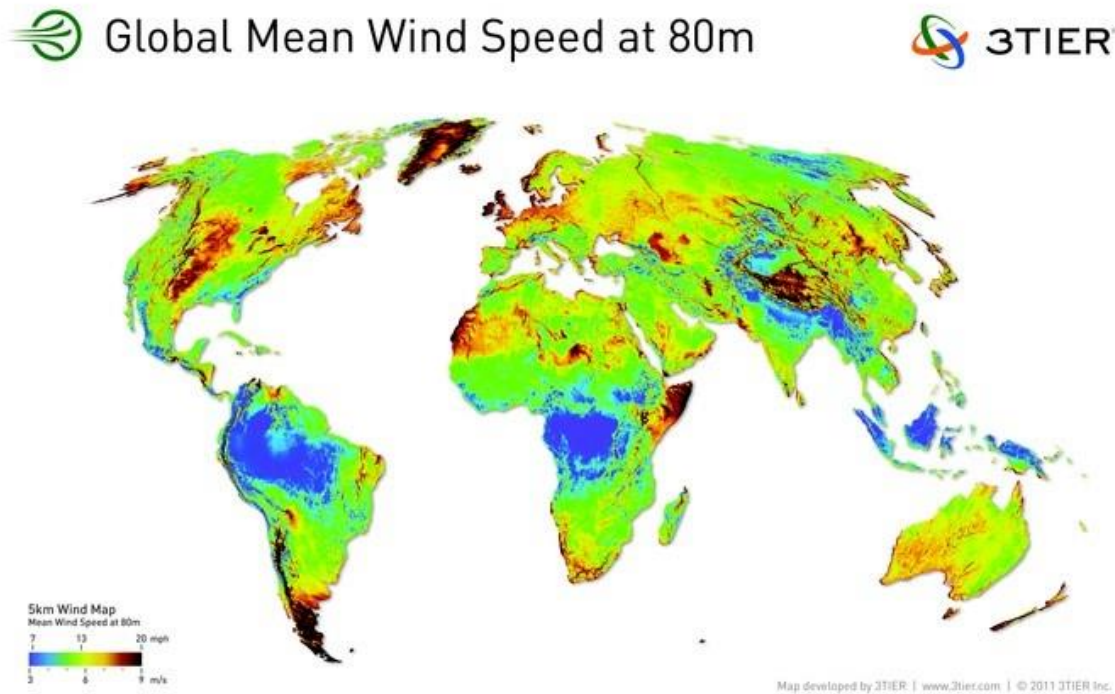
**Figure 39. Voltage and amperage output of DC-540 alternator**

The DC-540 is designed by the manufacturer for low speed winds and is able to output upwards of 250+ watts of power. To determine the power output, simply multiply current and voltage. For example, at 300 revolutions per minute, the alternator is outputting roughly 170 watts of power. This is well over what is required by the project, and with the charge controller being used to safely release excess power as heat, the worry of a battery overcharging or exploding becomes moot.

The obvious most difficult task is to change the energy from mechanical energy in the wind to an electrical energy a consumer can use to charge a mobile device. With the alternator handling that bulk of work, the design for power storage became the next big venture. As discussed in the Electrical Components Selection, Team 15 chose a 12 volt Lithium Iron Phosphate battery. This was used for its simplicity in this particular circuit and for its shelf life.

## 5.2 Wind Locations

The location of where a wind turbine is placed is crucial to generate enough power to operate efficiently. Different areas around the world experience different wind speeds at different heights due to vegetation, construction, and local wind patterns. Team 15's portable wind turbine is designed to operate at wind speeds of around 4m/s (8.95 mph). Because of the portability factor, this wind turbine is to have a height of 2 meters. Team 15 researched areas around the world where this product can be marketed and used efficiently to generate enough power to charge small devices. Figure 40 displays the average wind speeds around the globe at 80 meters from the ground surface<sup>8</sup>.



**Figure 40. Global wind speeds**

Wind speed increases with height in a logarithmic fashion. Because of this, the wind at 2 meters off the ground is much less than the speeds at 80 meters. The equation below is the log wind profile ratio and represents what the velocity at height 1 would be based on the velocity at height 2.

$$V_1 = V_2 \frac{\ln\left(\frac{Z_1}{Z_0}\right)}{\ln\left(\frac{Z_2}{Z_0}\right)}$$

In the above equation,  $Z_2$  is the elevation of the unknown wind speed.  $V_2$  correlates with  $Z_2$  and is the wind speed at that elevation.  $Z_1$  is the elevation of the known wind speed.  $V_1$  correlates with  $Z_1$  and is the wind speed at that elevation. For this project,  $Z_1$  is taken as 2 m,  $Z_2$  as 80 m,  $V_1$  as 4 m/s and  $V_2$  will be the wind speed at 80 m off the ground. The last variable,  $Z_0$ , is the surface roughness length and is chosen based on the desired environment.  $Z_0$  was chosen based on a wind flow and landscape description of “rough”, stating there are natural crops and obstacles such as buildings or mountains. Looking at these conditions,  $Z_0$  is considered 0.25 m. Since there is not an

exact way to calculate the speeds around the globe at such a low altitude, the team decided to use the known average of 4 m/s at 2 meters off the ground to solve for what wind speeds to look for at 80 meters high. Using the log wind profile ratio, a wind speed of 11.1 m/s (24.8 mph) at 80 meters off the ground will correlate to a wind speed of 4 m/s at 2 meters off the ground. The yellow on the map shows areas where the average wind speed is 13 mph and the dark red shows areas of 26 mph. The red and orange coloring on Figure 40 displays areas around the world where Team 15's Portable Wind Turbine can be marketed and used efficiently. The yellow areas on the map display areas around the globe where the Portable Wind Turbine can sometimes be used if the wind speed is above the average for that area. However, if the terrain in the chosen area is more open, such as a desert or a beach, it is more susceptible to having higher wind speeds at a lower elevation due to minimal obstructions.  $Z_0$  for this type of open landscape is 0.03 m. Using the log wind profile ratio equation, the wind speed at 80 m off the ground correlating to a wind speed of 4 m/s at 2 m off the ground would be 7.5 m/s (16.8 mph). So for these landscapes and terrains, areas on the map designated by a green or yellow color would also have an optimal wind speed for Team 15's wind turbine to operate efficiently.

Team 15 took a closer look at where the wind turbine could operate efficiently in the United States. Figure 41. Average wind speeds in the United States at 80m shows the wind speeds in the U.S. at 80 m off the ground. Again, using the log wind profile ratio, the correlating wind speeds at this elevation were calculated against the 4 m/s wind speed at 2m off the ground. The regions in Figure 41. Average wind speeds in the United States at 80m designated by the purple coloring are areas with optimal average wind speeds. It was determined that the mountainous region in the center of the United States was the best location for wind speed for Team 15's wind turbine to operate efficiently.

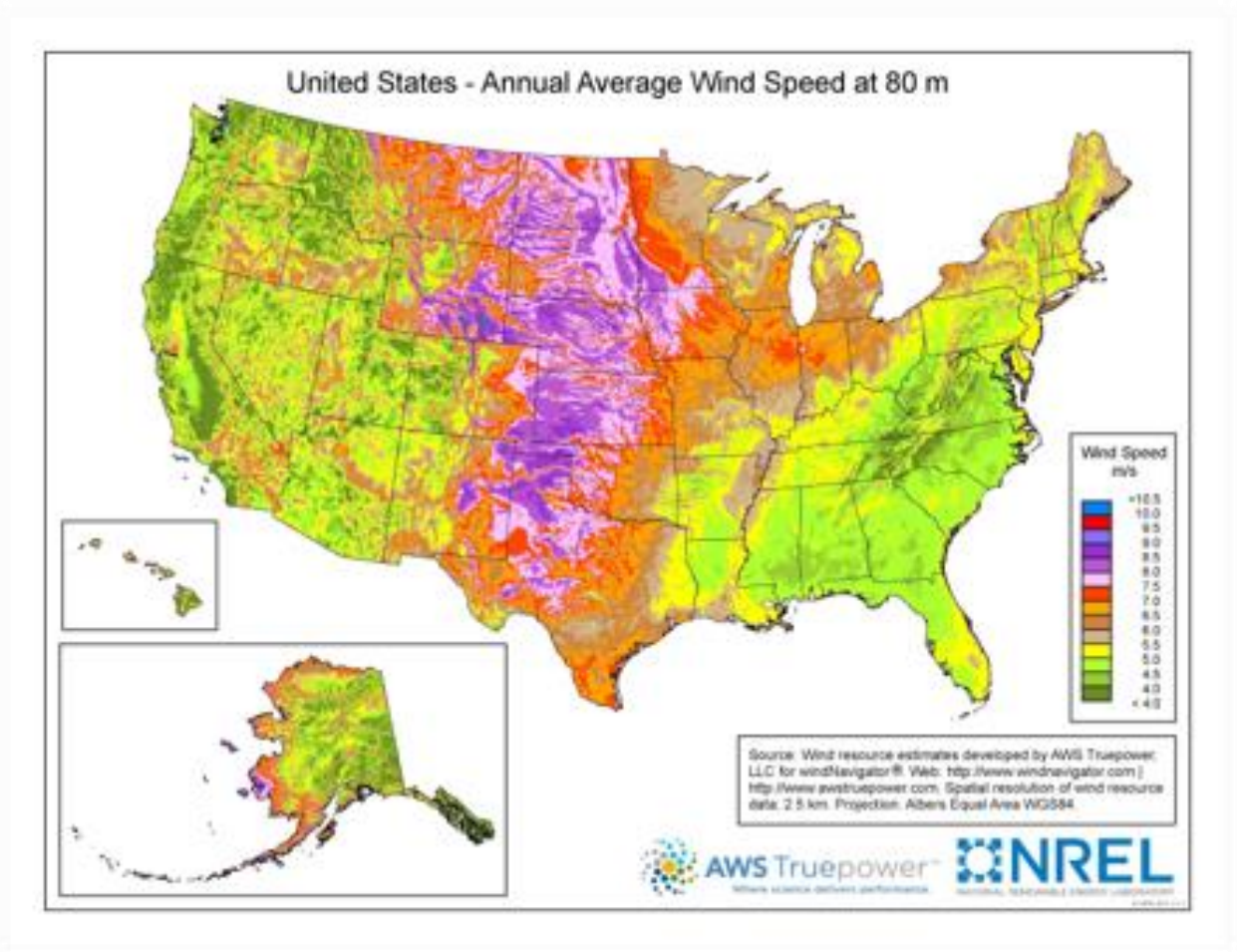


Figure 41. Average wind speeds in the United States at 80m.

## 6. Economics

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 48% of the budget. The portioning of the budget can be seen in Figure 15 in a 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.

### 6.1 Base Costs

The costs for the base are listed in Table 2. The materials chosen were to optimize the portability and construction of the base. Aluminum tubing and sheet metal was chosen because it was a strong material with the best economic value. Aluminum was also readily available with many tubing sizing options. The total cost for the base is \$366.19.

**Table 2. Cost of materials for the base of the turbine.**

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

Nylon Tubing	\$30.71
<b>Total Cost</b>	<b>\$366.19</b>

## 6.2 Nacelle Costs

The costs associated with the nacelle of the Portable Wind Turbine Prototype fall into two main categories: The costs of the structure of the nacelle and the costs of the electrical components. These two sections are discussed below.

### 6.2.1 Nacelle Structure Costs

As discussed, the structure of the nacelle was fabricated almost exclusively from aluminum sheet metal. An outline of the expenses for all structural components is outlined below in Table 3. The blades are also included in this table for reference.

**Table 3. Cost of materials for the nacelle.**

<b>Part</b>	<b>Cost</b>
1/4" Aluminum sheet(2)	\$152.82
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
<b>Total Cost</b>	<b>\$371.98</b>

### 6.2.1 Electrical Component Costs

The electrical components were the singularly most expensive components of the Portable Wind Turbine. The costs of these components can be seen in Table 4.

**Table 4. Cost of electrical components.**

<b>Part</b>	<b>Cost</b>
Alternator	\$239.00
Charge Controller	\$199.99
Battery	\$76.54
USB	\$12.99
<b>Total</b>	<b>\$528.52</b>

### 6.2.3 Blade Costs

The blades for the Portable Wind Turbine were ordered from WindyNation. The fact that 3-blades were used instead of 5 reduced overall spending. Machining of the parts did not affect the budget as it was provided by the college of engineering. Material for the e-clip design was ordered however these materials were not used in the final design. Costs concerning the material for the blade mounting system and blades are given below in Table 5.

**Table 5. Blade and blade mounting system costs.**

<b>Component</b>	<b>Cost</b>
Blades	\$57
Hub Material (1095 Spring Steel)	\$49.95
Washers, Wing Nuts, Bumper Bolts	\$5
<b>Total</b>	<b>\$111.95</b>

### 6.3 Packaging Costs

In order to increase portability of the turbine, a carrying case needed to be selected. The parts of the turbine would need to be transported together efficiently and without the risk of damage. The case selected needs to be large enough to hold all of the parts of the disassembled turbine and to provide enough space between them to ensure adequate protection. The case needs to be sturdy as to prevent damage to the parts or to the case itself in conditions that may be suboptimal. It also needs to be designed in a way that would make transportation of the entire system as easy as possible for the consumer. These are the reasons that we came to the decisions of choosing the Pelican Storm iM3075 for a price of \$378.36. The cost was a little high, though it is both worth the cost due to quality and it would be cheaper if produced in bulk instead of for a prototype. The case meets or exceeds all of our requirements of it and will ensure ease in transporting and protecting the parts.

### 6.4 Operational and Maintenance Costs

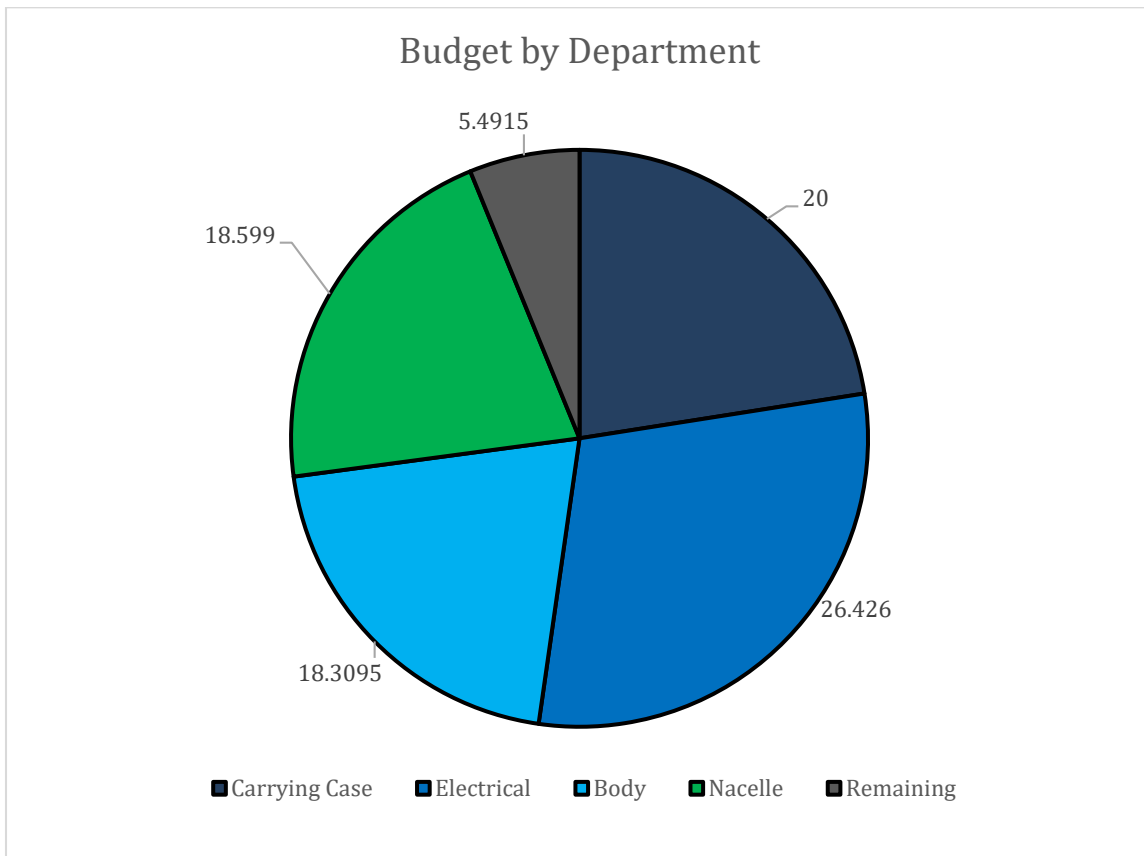
There are not many operational or maintenance costs required with the portable wind turbine. The turbine uses the concept of renewable energy, operating on its own to harness energy from the wind. If any parts on the portable wind turbine rust or break due to long term wear, maintenance costs can include the buying of new materials. These costs can be seen in the tables from section

### 6.5 Cost Summary

Team 15 started the year with a budget of \$2,000. As stated previously, safety, portability, and power generation are all important factors in building this wind turbine. That being said, Team 15 felt confident in the organization of funds throughout the project to hit each of those goals. Below, in Table 6, is a representation of the funds by physical department: Body, Nacelle, Electrical Components, and Carrying Case. In the first table, each department is laid out showing a master total. Below that, Figure 42 shows what percentage of the total budget was dedicated to each department.

**Table 6. Cost summary**

Body	\$366.19
Nacelle Material	\$371.98
Electrical Components	\$528.52
Carrying Case	\$378.36
Shipping and Tax	\$253.83
<b><u>Total</u></b>	<b><u>\$1,898.88</u></b>



**Figure 42. Pie chart of usage of funding by Team 15**

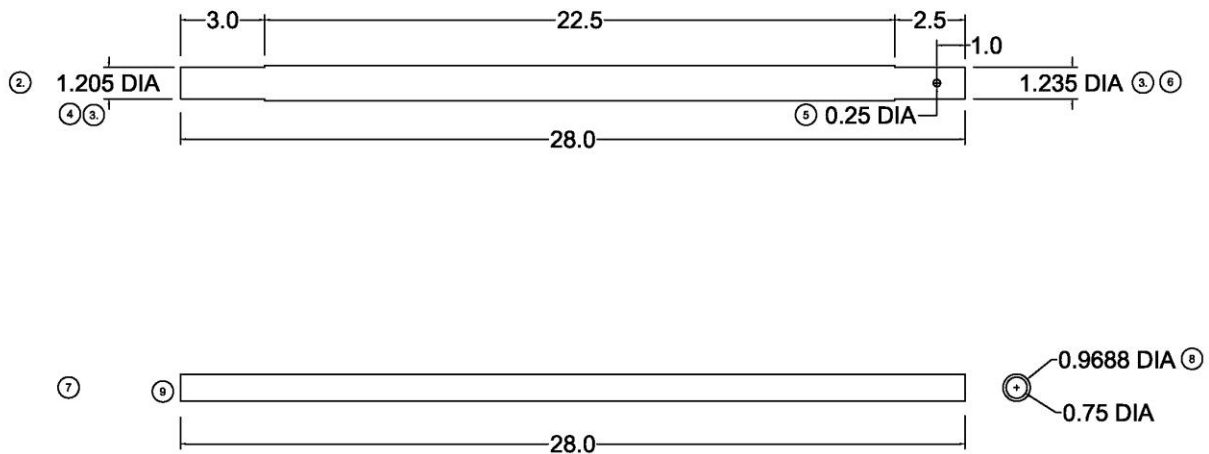
## 7. Turbine Prototype

### 7.1 Base Fabrication/Assembly

#### 7.1.1 Base Fabrication

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 43.

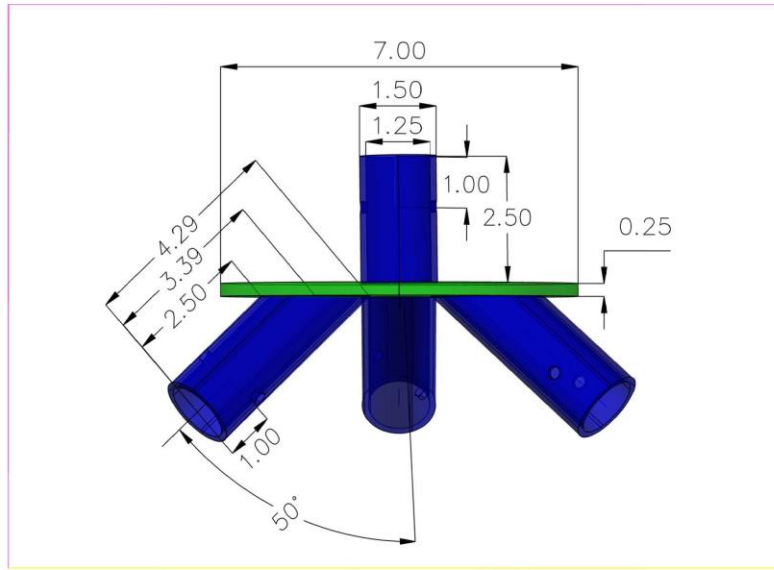


**Notes:**

- 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.

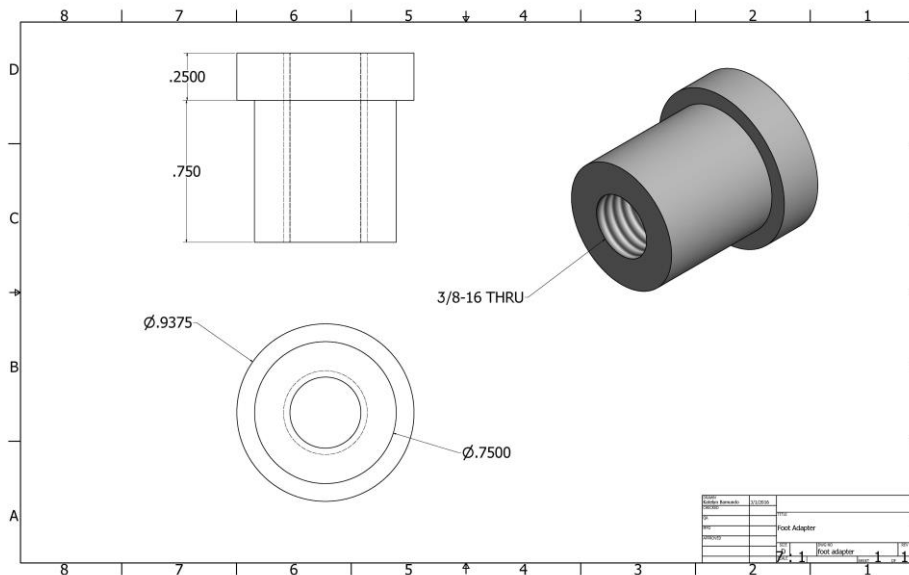
**Figure 43. The drawings for the aluminum tubing for the base.**

The plate was cut to the desired diameter, then four of the short tube sections were welded into place. This is depicted in Figure 44.



**Figure 44. 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 45.



**Figure 45. Drawings for the threaded inserts of the base.**

## 7.1.2 Base Assembly

The assembly of the base of the turbine is depicted in Figures 46 and 47. The parts for the base will be located inside the carrying case along with the other parts of the turbine while being transported. After the parts have been removed from the case, the parts should be organized. There should be three small 28-inch tube sections (A), four large 28-inch tube sections (B), three clamps (C), four pins (D), the welded plate (E), and three feet (F) for the base. No additional parts or tools are needed for the assembly of the base. Figure 48 shows the turbine completely assembled.

The four larger tubes should be inserted into the welded plate so that the holes in the tubes are aligned with the holes in the plate. Between the insertions of each of the tubes, a pin should be pushed through the holes and latched. After all four of the larger tubes have been inserted into the weld plate and each of them have been secured by pins, the clamps and smaller tubes can be utilized.

There are two sides to the plate. The side of the plate with three tubes protruding from it (not one) will be the focus of this step. The three clamps should be fastened onto the end of the three tubes on this side of the plate. They will be fastened simply by sliding snugly into place. After this is completed, the three smaller tubes should be slid into the clamps, into the larger tubes. Then the clamps should be both tightened and closed. Make sure in this step that the tubes are oriented in the correct direction. The side of the small tubes without inserts should be the one entering the large tubes.

Finally, the three feet can be screwed into the bottoms of the smaller tubes through clockwise hand rotations. The threaded end of the feet should screw into the small tubes' inserts with ease. In disassembly, the parts should be disassembled in reversed order, then inserted back into their case.

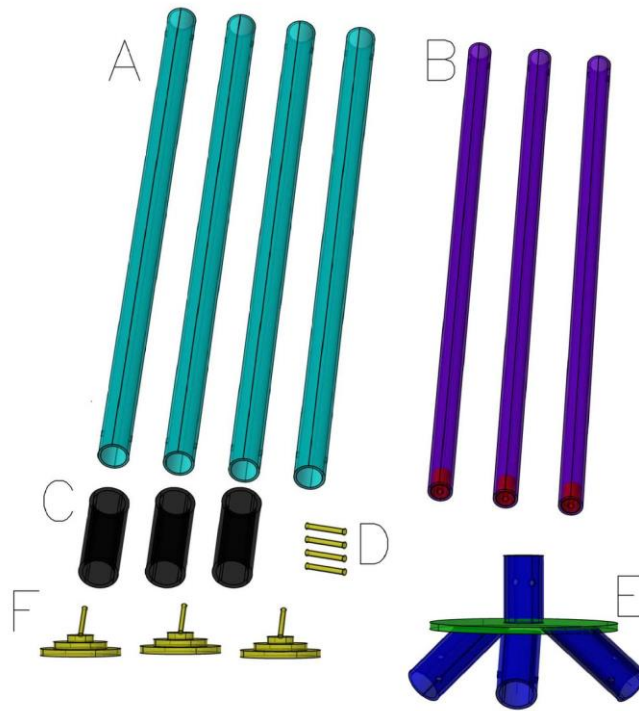


Figure 46. The components of the base

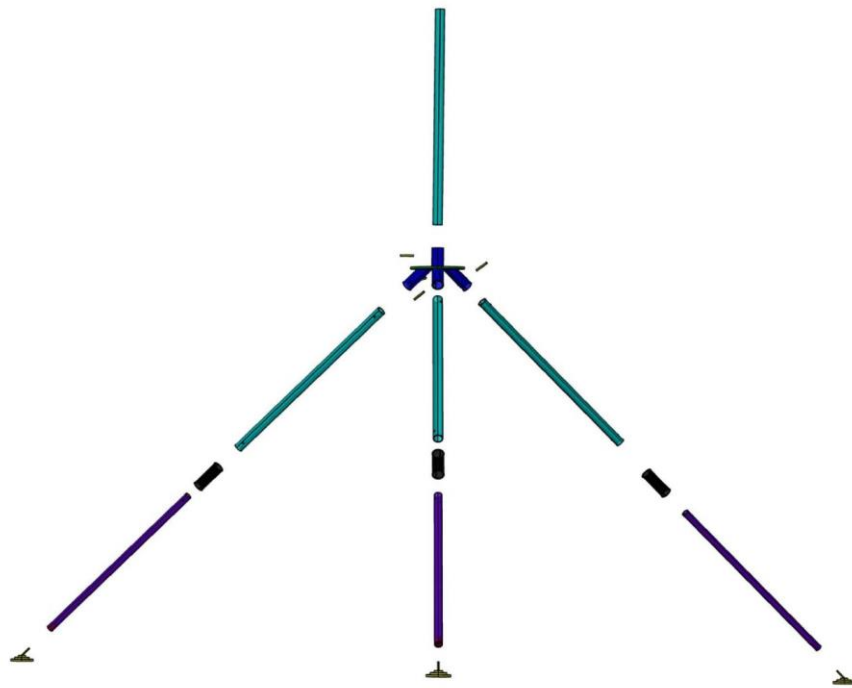
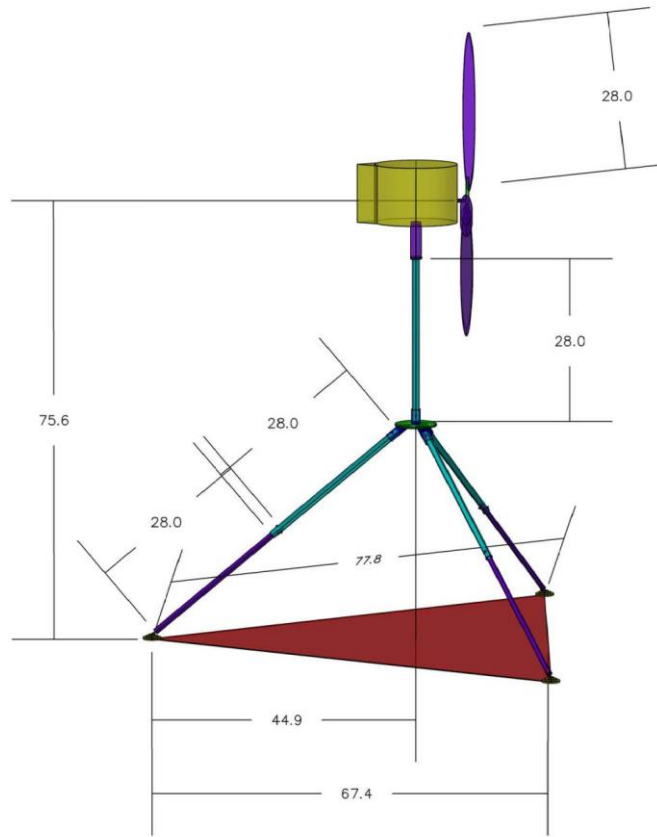


Figure 47. The assembly of the base.



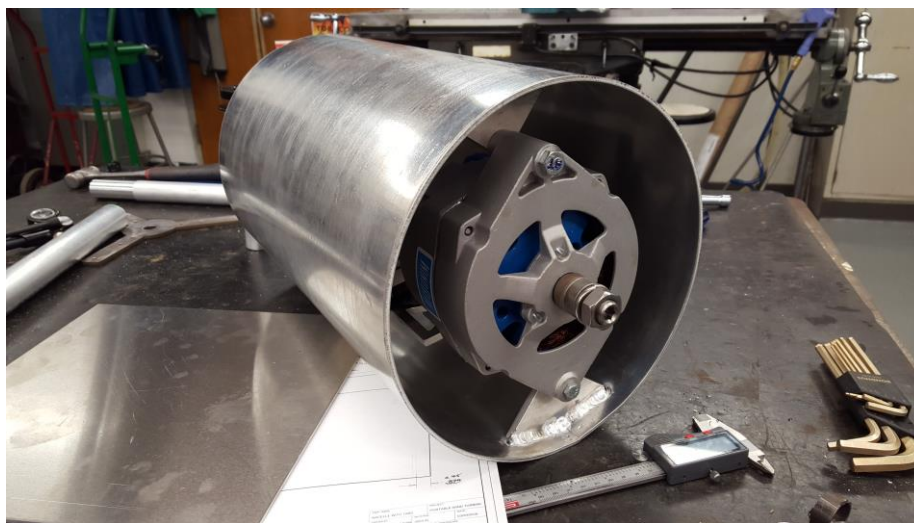
**Figure 48. Base set up and dimensions.**

## 7.2 Nacelle Fabrication/Assembly

The fabrication and assembly of the Portable Wind Turbine nacelle was performed almost entirely in the FAMU-FSU College of Engineering Machine Shop. Engineering drawings for all parts created can be seen in Appendix B. The water jet, CNC mill, manual mill, drill press, hand drill, band saw, TIG welder and various hand tools were all used in the completion of the Portable Wind Turbine Prototype.

The only component that was not created in the Machine Shop was the round tube that comprised the main body of the nacelle. Upon sourcing an aluminum tube of the required inner diameter to fit the charge controller and alternator, Team 15 discovered that the cost would be nearly \$400. Suitable plastic tubing of the required size was similarly priced. An alternative was found in Kelly Sheet Metal. For under \$100, Kelly Sheet Metal was able to cut and roll a sheet of 3003 aluminum into the required inner diameter tube for the main body of the nacelle.

Upon receiving the nacelle body from Kelly Sheet Metal, the seam of the sheet was welded to finish the creation of the tube. The inner diameter of the tube was then re-measured to check for accuracy and the mounting tabs for the alternator and the 80/20 aluminum rail were cut from a sheet of 6061 aluminum using the water jet. The 80/20 aluminum rail was cut to size using the band saw. A mounting jig was created to properly place the tabs in the interior of the nacelle tube, and they were welded in place. Figure 49 shows the nacelle tube on the shop table with its internal components.



**Figure 49. Nacelle fabrication in progress.**

With the mounting tabs securely welded to the interior of the nacelle, the 80/20 rail was able to be mounted along the bottom of the nacelle. The sliding plate mount and accompanying tabs for the charge controller and battery were then cut from 0.25in thick 6061 aluminum sheet using the water jet. The tabs for the charge controller and Delrin sliders were then welded to the sliding plate and the charge controller was mounted to this assembly. The Delrin sliders were quickly created using the CNC mill, tapped and mounted to the sliding assembly and the entire assembly was placed on the 80/20 aluminum rail in the nacelle.

Next the tail vane blade and boom were cut from 6061 aluminum sheets using the waterjet. A thickness of 0.080in was used for the blade of the tail vane while a thickness of 0.090in was used for the boom supports. The ends of the boom supports were then bent to the appropriate angle and secured to the tail vane blade. The tail vane assembly can be seen in Figure 50.



**Figure 50. Tail vane assembly held by a team member in the FAMU-FSU College of Engineering Machine shop.**

Following the fabrication of the tail vane, the Delrin end caps were created for the nacelle using the CNC mill. This was a straight forward process, only requiring verification of the 3D CAD models prior to beginning the machining in the CNC. The rear end cap also required tapping of four holes for the mounting of the tail vane booms.

The final component of the nacelle requiring fabrication was an adapter to be mounted on the bottom of the tube. This adapter would create a flat surface, allowing the quick release system to be securely mounted to the otherwise curved surface. At the writing of time of this report, this final component is still being manufactured in the FAMU-FSU College of Engineering Machine Shop. It will require the five components of the box-like adapter (four sides and bottom) to be cut using the water jet and then welded together and to the underside of the nacelle tubing. Following this the Portable Wind Turbine prototype will be completely assembled.

## 8. Considerations for Environment, Safety and Ethics

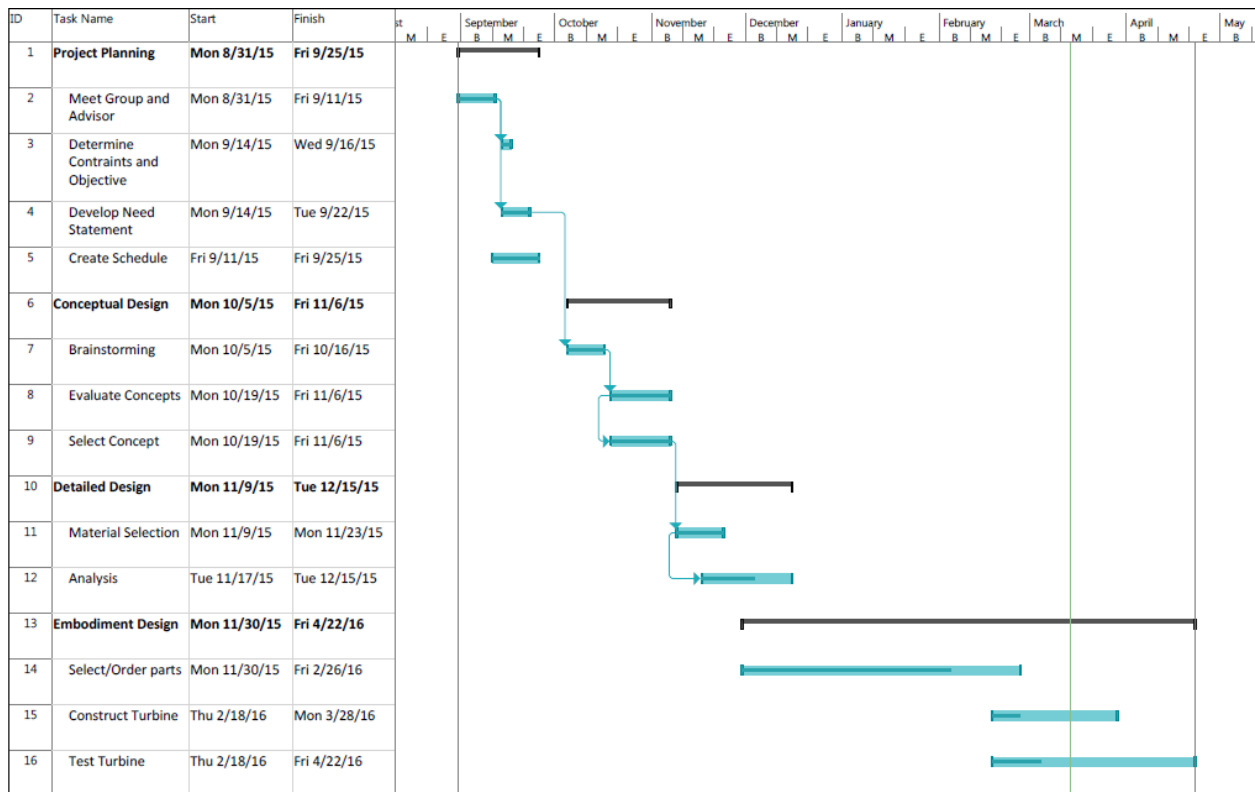
The design includes safety features in order to prevent injury to the operator during assembly and disassembly. Also, the turbine as a whole is designed well enough to prevent it from falling, even in situations where the ground is not level or there is severe weather. If there is an extreme case of wind or slope, the user has the option to anchor the turbine to the ground to completely secure it from falling. Finally, a visual operational manual is included so that people not familiar with the turbine will be able to set it up correctly, easily and safely.

The purpose of the portable wind turbine is to find a new, creative way to generate renewable energy. This is an alternative to the burning of gasoline or the using up of other natural resources to generate electricity, which makes the turbine environmentally friendly. Also, the turbine also does not have a direct or lasting effect on other people in the area where the turbine is being operated.

## 9. Project Management

### 9.1 Schedule

In order to plan the two semester long project, Team 15 developed a basic Gantt chart to create a visual representation of the different tasks that needed to be completed. The Gantt chart used by Team 15 can be seen below in Figure 51.



**Figure 51. Team 15's Gantt Chart**

This Gantt chart helped the team get a broader view of the project, including both completed tasks and upcoming tasks. It was also a valuable learning experience for the team, emphasizes the necessity of proper planning and accurate assessment of time required to complete tasks.

### 9.2 Resources

Both the civil engineering students and the mechanical engineering students utilized the FAMU-FSU College of Engineering machine shop in order to fabricate parts for the Portable Wind Turbine Prototype. The services utilized at the machine shop included use of the water jet, the CNC, the

drill press and welding. The civil engineering students also attempted to use the structures laboratory in order to test the capabilities of the clamps that were selected for the telescoping legs. Unfortunately, the team was not able to perform these tests because the machinery in the structures lab is accurate only when measuring forces much greater than those that the clamps would experience in this application. In order to test the selected alternator, the mechanical engineering students utilized one of the many electrical engineering laboratories at the FAMU-FSU College of Engineering. This testing confirmed that the alternator met (and even exceeded) the specifications provided by the manufacturer.

### 9.3 Procurement

Several manufacturers and suppliers were used for the procurement of the materials necessary for the fabrication of the Portable Wind Turbine Prototype. All purchases were completed through the Mechanical Engineering Department, which will receive reimbursement from the Civil and Environmental Engineering Department at the conclusion of the Spring 2016 semester. The majority of the purchases were made from McMaster-Carr.

Accounting for all purchases made by Team 15, the Portable Wind Turbine Prototype consumed approximately 95% of the budget allotted by the project sponsor. By successfully keeping costs within the budget, Senior Design Team 15 ensured that future teams would have sufficient funding to continue improving and refining the Portable Wind Turbine design.

### 9.4 Communications

Team 15 used several methods of communication throughout the course of the project. The primary method of communication was through the group messaging GroupMe app that the team members installed on each of their personal cell phones. This app allowed instant communication between the team and ensured that all members of the team would see the message.

E-mail was also used for information that was not time sensitive, or for when an official record of the communication was desired. This method of distance communication was also the only method of communication used between the team, Dr. Gupta and the team's advisors. In addition to a method of communication, e-mail was also used for quick, small file transfer.

For transferring large files and storing records and documents that all team members might require access to, Team 15 set up a shared folder in Microsoft's OneDrive cloud service. This allowed easy uploading and downloading of important files at any location and also facilitated the creation and simultaneous editing by all team members of the team's deliverables.

In addition to electronic communications, the team had weekly in-person meetings with their advisor, Dr. Jung. As with all teams in the senior design program, the team also participated in the Staff Meetings set up by Dr. Gupta. Both of these meetings allowed the advisor and Dr. Gupta to be updated on the team's progress ensure that the team was moving along the right track towards the completion of the project as desired by the sponsor.

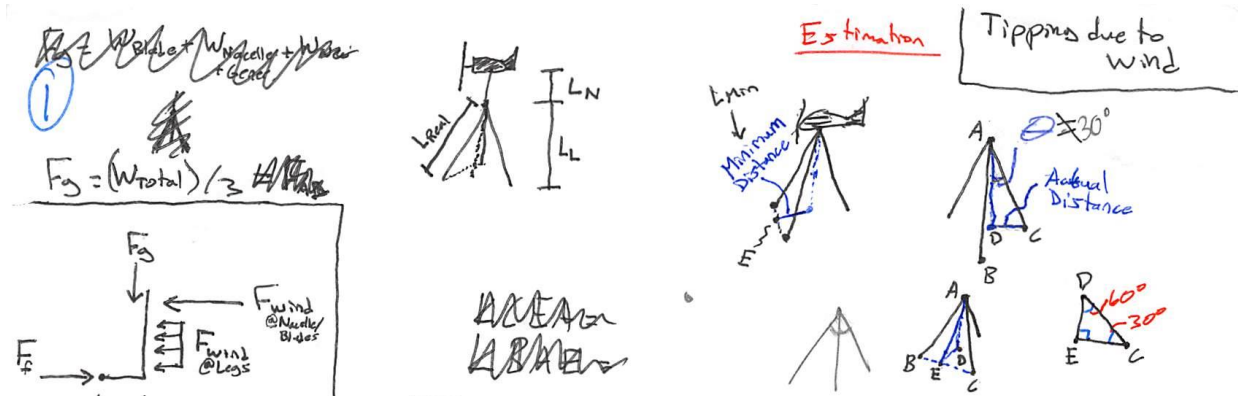
## 10. Conclusion

As the project comes to a close, looking back there were a lot of mountains to climb and obstacles to overcome, the biggest being the power generation and storage, cost, and time management. Time management was key to completing this project in a timely manner. Cost was of significant importance because, arguably, the most important constraint of the project was to spend no more than \$2,000. Team 15 finished the project, including a durable, shock proof and waterproof case to carry the turbine, at about 90% of the total given budget. This leaves sufficient funding for future senior design teams to continue improving and refining the design of the Portable Wind Turbine. As far as power generation was concerned, establishing success is difficult currently. Each member of the electrical components has been tested individually, however the power generation abilities of the turbine as a whole were not verified because the team was not able to experience the wind speeds locally. Team 15 plans on testing the turbine in the coming week in different locations to establish the efficiency as a whole for the project. For future work, based off testing results, there are two recommendations to be made. First, try to make the joint where the legs meet collapsible; the ability to extend and collapse the telescopic legs is great and should continue to be implemented, however the ability to leave the legs in and fold on themselves would allow users to leave the pins in for short movements. Second, the wiring of the electrical components have a built in factor of safety for the wiring chosen. That being said, adding a fuse to the circuit would improve the safety specifications for the system as well as user safety.

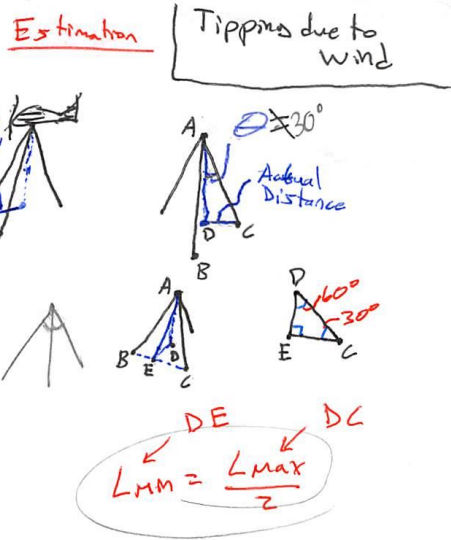
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# Appendix A: Mathematical Analysis



$$\begin{aligned}
 L_{AD} &= L_L \\
 L_{AB} &= \frac{L_{AD}}{\cos(\theta)} = L_{Real} \\
 L_{DE} &= L_{DC} \cdot \cos\left(\frac{120}{2}\right) \\
 L_{DC} &= L_L \cdot \tan(\theta) = L_{Max} \\
 L_{DE} &= \frac{L_L \cdot \tan(\theta)}{2} = L_{Min} \\
 L_{AE} &= \left( L_L^2 + \left( \frac{L_L \cdot \tan(\theta)}{2} \right)^2 \right)^{1/2} \\
 L_{AE} &= \frac{1}{2} L_L (4 + \tan^2(\theta))^{1/2}
 \end{aligned}$$



11b = 4.45 N  
 $F_g = \text{Weight Nacelle + Blades}$

$\sigma_{Bending} = \frac{M \cdot c}{I}$   
 - look online at strength specs of materials

$$(F_g \cdot L_{min}) \geq \left( F_{wind @ N\&B} \cdot L_L + F_{wind @ Legs} \cdot \frac{L_L}{2} \right)$$

$$\begin{aligned}
 F_{wind @ legs} &= \frac{1}{2} \cdot \rho \cdot A_L \cdot \vec{V}^2 \\
 F_{wind @ N\&B} &= \frac{4}{9} \cdot \rho \cdot A_B \cdot \vec{V}^2 \\
 \frac{c}{I} &= \frac{R \cdot 4}{\pi(R^3 - r^3)} \\
 \sigma_{Bending} &\approx 11000 \text{ psi (value for Al tube)}
 \end{aligned}$$

$$A_B = \pi \cdot r^2 = \pi (28 \text{ in})^2 = 2463 \text{ m}^2 = 1.589 \text{ m}^2$$

$\rho = 1.225 \text{ kg/m}^3$   
 $\vec{V} = 4 \text{ m/s}$

$$F_{wind @ N\&B} = \frac{4}{9} \cdot 1.225 \text{ kg/m}^3 \cdot 1.589 \text{ m}^2 \cdot (4 \text{ m/s})^2 = 13.04 \text{ N}$$

$\approx 14 \text{ N}$   
 $L_{min} = [(14 \text{ N})(2 \text{ m}) + (2 \text{ N})(1 \text{ m})] / F_g$

$A_L = \sum A_{segments}$   
 $A_{segment} = (L_{real})(\text{diameter})$  And 3 sections  
 Assume: 2ft sections at about 1in diameter (3cm)  
 $A_{segment} = (6.67 \text{ m})(0.03 \text{ m}) = 0.02 \text{ m}^2$

$F_{wind @ legs} = \frac{1}{2} \cdot 1.225 \frac{\text{kg}}{\text{m}^3} \cdot 0.02 \text{ m}^2 \cdot (4 \frac{\text{m}}{\text{s}})^2 \cdot 3$  3 segments  
 $= 0.588 \text{ N}$  ← -6ft tall  
 -3cm average dia  
 -conservative Estimation

$\approx 2 \text{ N}$  (3 legs) (52m)  
 if  $F_g = 10 \text{ lbs}$   $L_{min} = 67 \text{ cm}$  (26m)  
 if  $F_g = 20 \text{ lbs}$   $L_{min} = 34 \text{ cm}$  (13m)

②

Estimation Failing due to wind due to Bending

Neck Region (FA)

$$N_{max} = -W_{N\&B}$$

$$V_{max} = F_{wind @ legs} + F_{wind @ N\&B}$$

$$M_{max} = (F_{wind @ N\&B})(L_N + 3.5m) + (F_{wind @ legs} \cdot \frac{L_N}{2})$$

$$M_{max} = 14N \cdot (L_N + 0.08m) + (\frac{L_N^2}{2}) \cdot (4 m/s)^2 \cdot 1.225 kg/m^3 \cdot \frac{1}{2}$$

$$[N \cdot m] = (L_N + 0.08) \cdot 14 + L_N^2 \cdot 4.9$$

$F_{wind @ N\&B} =$

$F_{wind @ legs @ A} =$

Legs Region (AL)

$\theta$  typically = 30°

$F_{wind @ legs @ C} = 13.84N \approx 14N$

$F_{wind @ N\&B} = TBA. Est. = 2N$

$M_{max @ C} = \frac{1}{3} [ (F_{wind @ N\&B})(L_N + L_L) + (F_{wind @ legs @ C})(\frac{L_N + L_L}{2}) \pm \frac{W_{N\&B}}{3} \cdot \sin(\theta) \cdot L_{max} ]$

$N_{@C} = (V_{max} + F_{wind @ legs @ C}) \cdot \sin(\theta) + (\frac{M_{max}}{3}) \cdot \cos(\theta)$

$V_{@C} = (V_{max} + F_{wind @ legs @ C}) \cdot \cos(\theta) + (\frac{M_{max}}{3}) \cdot \sin(\theta)$

Assuming Even distributed over 3 legs.

$M_{max} = [14N \cdot 2m + 2N \cdot 1m \pm F_g \cdot \sin(\theta) \cdot L_{max}] / 3$

$[N \cdot m] = [30N \cdot m \pm F_g \cdot \sin(\theta) \cdot L_{max}] / 3$

if  $F_g = 10 lbs$   $M_{max} = 20 N \cdot m$

if  $F_g = 20 lbs$   $M_{max} = 20 N \cdot m$

Same since  $L_{max}/2$  and  $F_g/2$

Assume 30°, Forces evenly distrib. between 3 legs.  $L_{max}$  from other page

4

1. Overtopping

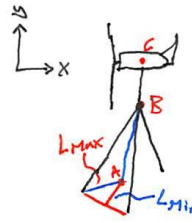
$$F_R = F_{wind} @ NBR$$

$$F_L = F_{wind} @ Legs \& Neck$$

$W_N$  = Weight Needle  
 ~~$W_{neck}$~~   
 $A_B$  = Area of blades

$W_L$  = Weight of each leg

$A_L$  = Area of legs + Neck Tubing



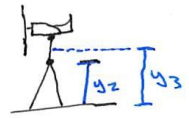
$$F_B = \frac{4}{9} \cdot \rho_{air} \cdot A_B \cdot \vec{v}^2$$

$$F_L = \frac{1}{2} \cdot \rho_{air} \cdot A_L \cdot \vec{v}^2 \cdot C_d$$

$C_d \approx 1 \leftarrow$  Chart: Reynolds # vs.  $C_d$

$$L_{min} = \frac{\int_A F_B dy + \int_A F_L dy}{(W_N + W_{neck} + 3W_L)}$$

$$W_N + W_{neck} + 3W_L = W_T$$



$$L_{min} = \frac{H \cdot \frac{W_T \cdot \sin\theta + F_B \cdot \cos\theta}{W_T \cdot \cos\theta - F_B \cdot \sin\theta} + \dots}{\dots}$$

$$\frac{H \cdot W_T \cdot \sin\theta + F_L \cdot \cos\theta \cdot y}{W_T \cdot \cos\theta - F_L \cdot \sin\theta}$$



$$L_{min} = \frac{H \cdot F_B \cdot \cos\theta + F_L \cdot \cos\theta \cdot y + 2H \cdot W_T \cdot \sin\theta}{W_T \cdot \cos\theta - F_B \cdot \sin\theta}$$

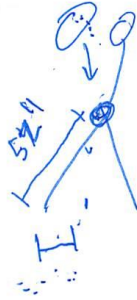
~~Wrong~~

$$L_{min} = \frac{H \cdot F_B \cdot \cos\theta + y \cdot F_L \cdot \cos\theta + (H \cdot W_N + \frac{y_2}{2} \cdot W_L + y_3 \cdot W_{neck}) \cdot \sin\theta}{W_T \cdot \cos\theta - (F_B + F_L) \cdot \sin\theta}$$

~~$L_{min} =$~~

5

0.017m



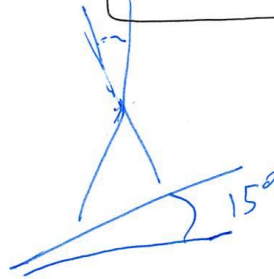
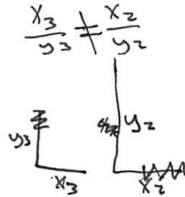
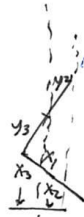
$$F_1 \cdot x_1 = F_2 \cdot y_1 + F_3 \cdot y_2$$

$$x_1 = \frac{F_2 \cdot y_1 + F_3 \cdot y_2}{F_1}$$

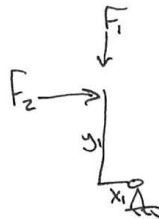
$$x_3 = x_2 \cdot \cos \theta - y_2 \cdot \sin \theta$$

$$x_2 = x_1 \cdot \cos \theta - y_1 \cdot \sin \theta$$

$$y_2 = y_1 \cdot \cos \theta + x_1 \cdot \sin \theta$$

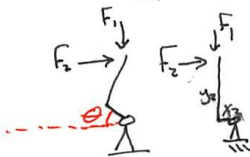


$\theta_1 = 60^\circ$   
 $x_1 = x_2$



$$F_1 \cdot x_1 = F_2 \cdot y_1$$

$$x_1 = \frac{F_2 \cdot y_1}{F_1} = L_{MM}$$



$$F_1 \cdot x_2 = F_2 \cdot y_2$$

$$x_2 = x_1 \cdot \cos(\theta) - y_1 \cdot \sin(\theta)$$

$$y_2 = y_1 \cdot \cos(\theta) + x_1 \cdot \sin(\theta)$$

$$x_1 = \frac{x_2 + y_2 \cdot \sin \theta}{\cos \theta}$$

$$x_1 = \frac{x_2 + y_1 \cdot \sin \theta}{\cos \theta}$$

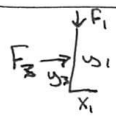
$$x_1 = \frac{y_2 - y_1 \cdot \cos \theta}{\sin \theta}$$



$$F_1 \cdot (x_1 \cdot \cos(\theta) - y_1 \cdot \sin(\theta)) = F_2 \cdot (y_1 \cdot \cos \theta + x_1 \cdot \sin \theta)$$

$$x_1 \cdot (F_1 \cdot \cos \theta - F_2 \cdot \sin \theta) = F_2 \cdot y_1 \cdot (F_1 \cdot \sin \theta + F_2 \cdot \cos \theta)$$

$$x_1 = y_1 \cdot \frac{(F_1 \cdot \sin \theta + F_2 \cdot \cos \theta)}{(F_1 \cdot \cos \theta - F_2 \cdot \sin \theta)} = L_{MM}$$



$$x_2 = x_1 \cdot \cos \theta - y_1 \cdot \sin \theta$$

$$y_2 = y_3 \cdot \cos \theta + x_1 \cdot \sin \theta$$

$$x_1 = \frac{F_2 \cdot y_3}{F_1}$$

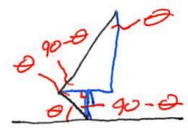
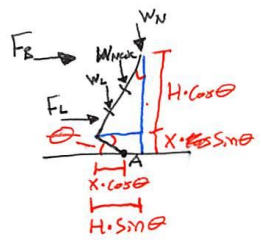
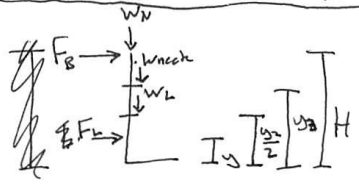
$$x_3 = \frac{y_1 \cdot F_1 \cdot \sin \theta + F_2 \cdot \cos(\theta) \cdot y_3}{F_1 \cdot \cos \theta - F_2 \cdot \sin \theta}$$

6

Assume:  $\frac{y_2}{2} = \bar{y}$  of legs = center of mass of legs

$$F_L \cdot x_1 \cdot \cos\theta - F_L \cdot y_2 \cdot \sin\theta + F_L \cdot x_1 \cdot \cos\theta - F_L \cdot y_2 \cdot \sin\theta$$

$$L_{min} \left[ \frac{W_L}{2} \cos\theta \right] = H \cdot F_B \cdot \cos\theta + y_2 \cdot F_L \cdot \cos\theta$$



$$\sum M_{Az} = 0 = W_L \cdot \left( x_1 \cdot \cos\theta - \frac{y_2}{2} \cdot \sin\theta \right) + W_{neck} \cdot \left( x_1 \cdot \cos\theta - y_2 \cdot \sin\theta \right) + W_N \cdot \left( x_1 \cdot \cos\theta - H \cdot \sin\theta \right) - F_L \cdot \left( y_2 \cdot \cos\theta + x_1 \cdot \sin\theta \right) - F_B \cdot \left( H \cdot \cos\theta + x_1 \cdot \sin\theta \right)$$

$$x_1 \left( W_L \cdot \cos\theta + W_{neck} \cdot \cos\theta + W_N \cdot \cos\theta - F_L \cdot \sin\theta - F_B \cdot \sin\theta \right) = \frac{y_2}{2} \cdot \sin\theta \cdot W_L + W_{neck} \cdot \sin\theta \cdot y_2 + W_N \cdot H \cdot \sin\theta + F_L \cdot y_2 \cdot \cos\theta + F_B \cdot H \cdot \cos\theta$$

$y_2 = n$        $y_3 = q$       (ps. 9)      Tilt over Axis 1

$$x_1 = \frac{\left( \frac{y_2}{2} \cdot W_L + W_{neck} \cdot y_2 + W_N \cdot H \right) \sin\theta + \left( F_L \cdot y_2 + F_B \cdot H \right) \cos\theta}{W_T \cdot \cos\theta - \sin\theta \cdot (F_L + F_B)} = L_{min}$$

$$F_L = \frac{1}{2} \rho_{air} \cdot A_L \cdot \vec{v}^2 \cdot C_d \quad F_B = \frac{4}{9} \cdot \rho_{air} \cdot A_B \cdot \vec{v}^2$$

~~Reps pg 4-6~~      Reps 8 and 9 4th

- Legs, Neck, & Nacelle all separated ( $y_2/2$  for wind and for self weight)
- Re-define all variables
- Problem 2 solve for variables
- Set equal
- Solve for 4 situations individually
- then together

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## 2. Bending in Legs

Buckling

$$P_{cr} = \frac{\pi^2 EI}{L_{eff}^2}$$

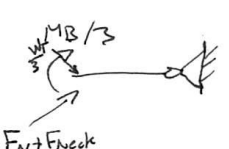
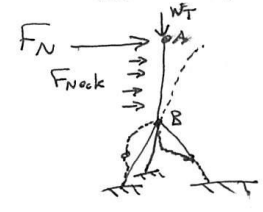
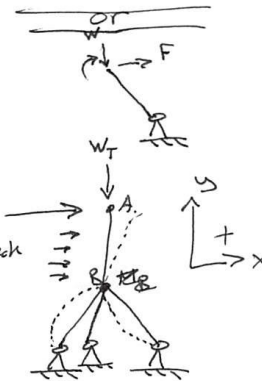
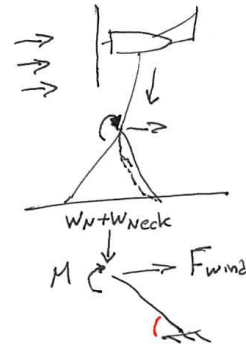
$L_{eff}$  = effective length  
=  $K \cdot L$

Bending

$$\sigma_{cr} = \frac{Mc}{I}$$

$$I = 0.78 (r_o^4 - r_i^4) = \frac{\pi}{4} \cdot (r_o^4 - r_i^4)$$

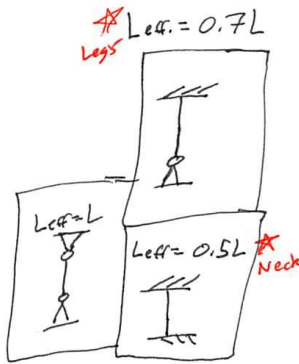
$$c = r_o$$



$$M_B = F_N \cdot L_{AB} + F_{neck} \cdot L_{AB} / 2$$

$$M_o = r \times F$$

$$P_o = \hat{A} \cdot \hat{F}$$



self weight ~~of tower~~

$M_o = \frac{1}{2} \cdot W_T \cdot m$

$P_{neck} = W_T$

$P_{legs} = \frac{n \cdot W_T}{3n} \text{ or } \frac{W_T}{3n} \cdot (m^2 + n^2)$

$\sigma_{cr} = \frac{W_T \cdot m \cdot r_o \cdot 4}{3 \cdot \pi \cdot (r_o^4 - r_i^4)}$

$m = \frac{\sigma_{cr} \cdot 3 \cdot \pi \cdot (r_o^4 - r_i^4)}{W_T \cdot r_o \cdot 4}$

$L_{eff} = 0.7L$

$P_{cr} = \frac{\pi^2 EI}{L_{eff}^2} = \frac{\pi^2 EI}{3(n^2 + m^2)}$

$L^2 = n^2 + m^2$

$L_{eff} = (n^2 + m^2) \cdot 0.7^2$

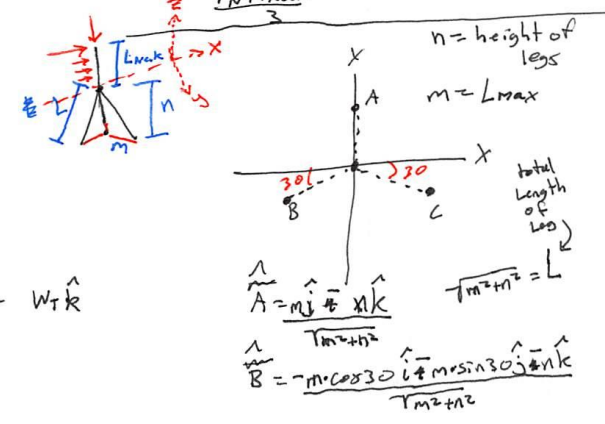
$\frac{\pi^2 EI \cdot 3}{W_T \cdot 0.49} = \frac{n^2 + m^2}{n^2 + m^2} = n^2 + m^2$

$\left[ \frac{\pi^2 EI \cdot 3}{W_T \cdot 0.49 \cdot n} - n^2 \right]^{1/2} = m = L_{max}$

$\frac{\pi^2 EI \cdot 4}{W_T \cdot 0.49 \cdot n} = L_{neck}$

minimum  $L_{max}$  value due to legs buckling

$\left[ \frac{\pi^2 EI \cdot 3}{W_T \cdot 0.49} - n^2 \right]^{1/2} = m$

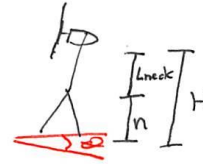


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$$L_{neck} = \frac{\pi^2 EI \cdot 4}{W_N} = H - n$$

$$n = H - \frac{\pi^2 EI \cdot 4}{W_N}$$

Minimum height of legs due to neck buckling



$$\frac{M_c}{I} = \sigma_{cr}$$

$$c = r_o$$

$$I = \frac{\pi}{4} (r_o^4 - r_i^4)$$

$W_N = W_N$   
 $F_B = F_N$

$$M = F_B \cdot L_{neck} \cdot \cos \theta + W_N \cdot L_{neck} \cdot \sin \theta$$

Axis 1 + Axis 2

$$\sigma_{cr, Neck} = \frac{(F_B \cdot L_{neck} \cdot \cos \theta + W_N \cdot L_{neck} \cdot \sin \theta) \cdot r_o \cdot 4}{\pi (r_o^4 - r_i^4)}$$

$$L_{neck} = \frac{(\sigma_{cr, Neck}) \cdot \pi \cdot (r_o^4 - r_i^4)}{4 \cdot r_o \cdot (W_N \cdot \sin \theta + F_B \cdot \cos \theta)} = H - n$$

$$n = H - \frac{\sigma_{cr} \cdot \pi \cdot (r_o^4 - r_i^4)}{4 \cdot r_o \cdot (W_N \sin \theta + F_B \cos \theta)}$$

Axis 1 + Axis 2  
Pg. 10

Minimum height of legs due to neck Bending

$$L_{max} = \left( n_o^2 \cdot \tan^2 \left( \tan^{-1} \left( \frac{m_o}{2n_o} \right) - \theta \right) + \frac{3m_o^2}{4} \right)^{1/2}$$

$L_{max}$  at an angle  $\theta$  relative to  $L_{max}$  at flat  
 $L_{max} = m$

$$\tan \left( \tan^{-1} \left( \frac{L_{min}}{n_o} \right) + \theta \right) \cdot 2n_o = m_o$$

$L_{max}$  required at flat surfaces given  $L_{min}$  at sloped surface ( $\theta$ ) required.

tilt over x-axis (Axis 1)

horizontal

Level Ground:  $L_{max} = 2L_{min}$

$$L_{min} = n \cdot \tan \phi_2$$

$$L_{max} = n \cdot \tan \phi$$

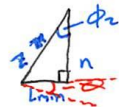
$$n = \left( n_o^2 \cdot \tan^2 \left( \tan^{-1} \left( \frac{m_o}{2n_o} \right) - \theta \right) + \frac{3m_o^2}{4} \right)^{1/2}$$

$$L_{min} = \left( n_o^2 \cdot \tan^2 \left( \tan^{-1} \left( \frac{m_o}{2n_o} \right) - \theta \right) + \frac{3m_o^2}{4} \right)^{1/2} \cdot \sin \theta$$

$$n = \tan(\phi_2 - \theta) = L_{min}$$

$$L_{min} = n_o \cdot \tan \left( \tan^{-1} \left( \frac{m_o}{2n_o} \right) - \theta \right)$$

$L_{min}$  at an angle (relative to  $L_{min}$  Flat)



$$\phi_2 = \phi_2 - \theta$$

$$\phi_2 = \tan^{-1} \left( \frac{L_{min}}{n_o} \right)$$

$L_{min}$  is constant

$$\phi = \tan^{-1} \left( \frac{m_o}{n} \right)$$

$$L_{max} = (L_{min}^2 + x^2)^{1/2}$$

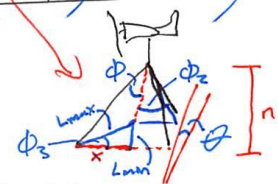
$$x = m_o \cdot \cos(30) = \frac{\sqrt{3}}{2} m_o$$

Axis constant  
 $x = \text{constant}$   
 $L_{min} = L_{min, Flat}$

$$\tan^{-1} \left( \frac{m_o}{n} \right) = \phi \rightarrow n = \frac{m_o}{\tan(\phi)}$$

$$\tan^{-1} \left( \frac{L_{min}}{n} \right) = \phi_2 \rightarrow n = \frac{L_{min}}{\tan(\phi_2)}$$

$$\frac{L_{min}}{m} = \frac{\tan^{-1}(\phi_2)}{\tan^{-1}(\phi)}$$



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$$W_T = W_L + W_N + W_{Neck}$$

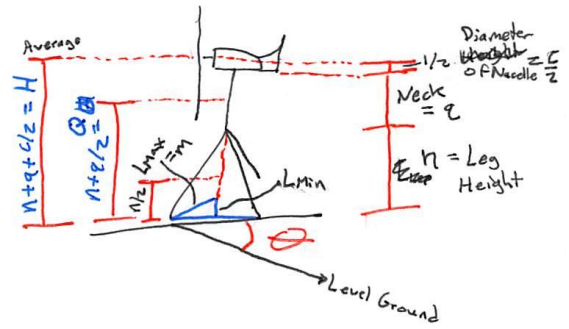
$W_L$  = Weight of Legs (total of the 3)

~~W<sub>N</sub>~~

$W_N$  = Weight of Nacelle and Blades

$W_{Neck}$  = Weight of neck, (includes weight of welded attachment plates)

$F$  = force due to wind (same subscripts)



1. Overturning Equations

$$L_{min} = \frac{\left( \frac{n_0}{2} \cdot W_L + W_{Neck} \cdot Q + W_N \cdot H \right) \cdot \sin \theta + \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H \right) \cdot \cos \theta}{W_T \cdot \cos \theta - F_T \cdot \sin \theta}$$

at slope surface

$$L_{max} = m_0 = \left[ \tan \left( \theta + \tan^{-1} \left( \frac{L_{min}}{n_0} \right) \right) \right] \cdot 2 \cdot n_0$$

at flat surface (required) minimum

- Given:  $L_{min}$  at sloped surface  $L_{min}$
- Height of legs on flat surface  $n_0$
- Slope (Maximum)  $\theta$

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Failure due to bending  
2. Legs

$$\sigma_{cr \text{ legs}} = \frac{M \cdot c}{I}$$

$$M_{\text{due to weight}} = \frac{B \cdot W_T}{3} \cdot m \quad A. \frac{W_T \cdot m}{6}$$

$M_{\text{due to wind}} = (\text{Maximum})$

$$B. F_N \cdot H + F_{\text{neck}} \cdot Q + F_L \cdot n/2 \text{ or } F_T \cdot n/3$$

$$A. [(F_N + F_{\text{neck}}) \cdot n/3] / 2$$

$$M_T = \left[ \frac{W_T}{3} \cdot m \pm (F_N + F_{\text{neck}}) \cdot n/3 \right] / 2$$

$$\sigma_{cr \text{ legs}} = \frac{r_o \cdot 4}{\pi \cdot (r_o^4 - r_i^4)} \cdot \frac{W_T \cdot m \pm (F_N + F_{\text{neck}}) \cdot n/3}{3 \cdot 2} + F_L/2$$

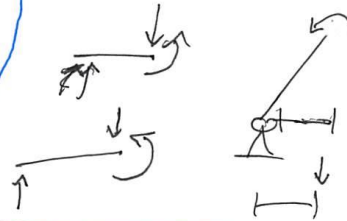
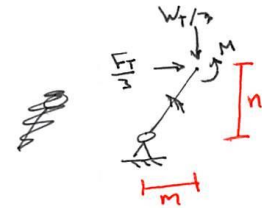
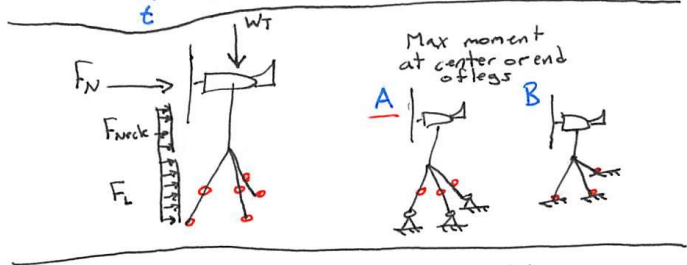
$$m = \left[ \frac{\sigma_{\text{allow}} \cdot 3 \cdot \pi \cdot (r_o^4 - r_i^4)}{2 \cdot 4 \cdot r_o} + \frac{(F_N + F_{\text{neck}}) \cdot n}{\tan} \right] / W_T$$

Maximum  $L_{\text{max}}$  due to bending in legs on level ground

~~$M_T$~~   ~~$M_T$~~



$c = r_o$  ← of smallest leg tubing  
 $I = \frac{\pi}{4} \cdot (r_o^4 - r_i^4)$  ←



3. Neck

$$\sigma_{cr \text{ neck}} = \frac{M \cdot c}{I}$$

$c = r_o \quad I = \frac{\pi}{4} (r_o^4 - r_i^4)$

$$M = F_N \cdot (q + q/2) \cdot \cos \theta + F_{\text{neck}} \cdot q/2 \cdot \cos \theta + W_N \cdot (q + q/2) \cdot \sin \theta + W_{\text{neck}} \cdot q/2 \cdot \sin \theta$$

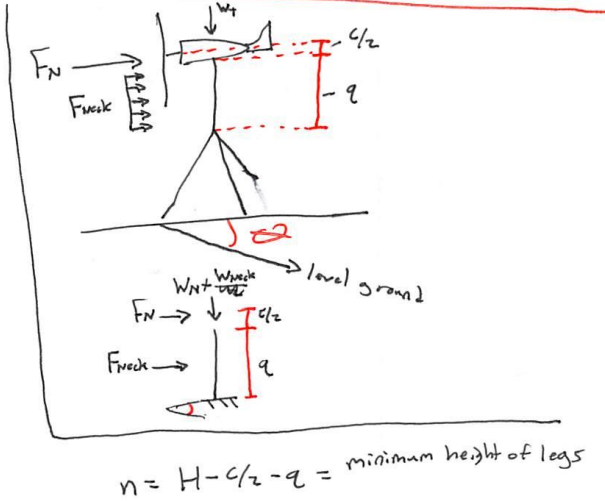
$$M = \cos \theta \cdot [F_N (q + q/2) + F_{\text{neck}} (q/2)] + \sin \theta \cdot [W_N (q + q/2) + W_{\text{neck}} (q/2)]$$

$$\sigma_{cr \text{ neck}} = \frac{r_o \cdot 4}{\pi (r_o^4 - r_i^4)} \cdot M$$

$$\left[ \frac{\sigma_{\text{allow}} \cdot \pi \cdot (r_o^4 - r_i^4)}{r_o \cdot 4} - (F_N \cdot \frac{q}{2} \cdot \cos \theta + W_N \cdot \frac{q}{2} \cdot \sin \theta) \right] = q$$

$$F_N \cdot \cos \theta + F_{\text{neck}} \cdot \frac{\cos \theta}{2} + W_N \cdot \sin \theta + W_{\text{neck}} \cdot \frac{\sin \theta}{2}$$

Maximum Length of Neck due to Bending

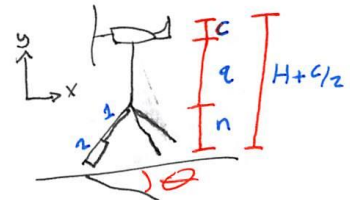
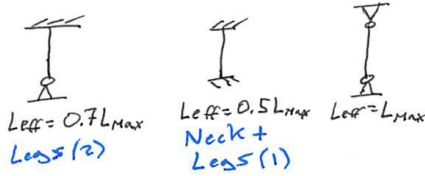


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Failure due to Buckling

$$P_{cr} = \frac{\pi^2 EI}{L_{eff}^2}$$

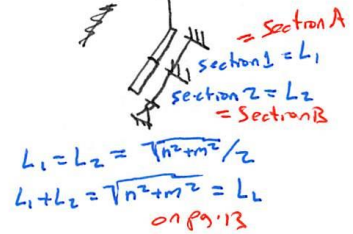
$$L_{eff} = \left[ \frac{\pi^2 EI}{P_{cr}} \right]^{1/2}$$



$$L_{eff} = \left[ \frac{\pi^2 \cdot E \cdot \frac{\pi}{4} (r_o^4 - r_i^4)}{P_{cr}} \right]^{1/2} = \frac{1}{2} \left[ \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{P_{cr}} \right]^{1/2}$$

$P_{neck} = W_N + W_{neck}$

$$L_{neck\_max} = \left( \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{W_N + W_{neck}} \right)^{1/2}$$



$$L_{L1\_max}^A = \left( \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{P_{L1}} \right)^{1/2}$$

$$L_{L2\_max}^B = \frac{1}{1.4} \left( \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{P_{L2}} \right)^{1/2}$$

$P_{L1} = P_{L2} - W_{L1} \rightarrow P_{L1} \approx P_{L2} \rightarrow P_L$

$P_L = (W_N + W_{neck}) / 3$  on flat ground in y direction

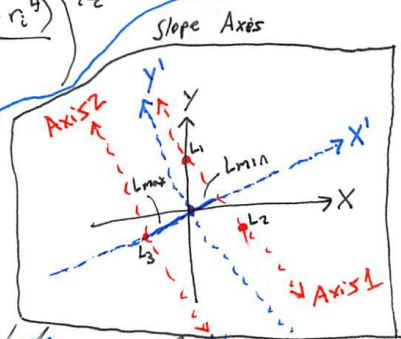
$P_L = \frac{W_N + W_{neck}}{3} \cdot \frac{\sqrt{n^2 + m^2}}{n}$  on flat ground

~~$P_L = \frac{W_N + W_{neck}}{3} \cdot \frac{\sqrt{n^2 + m^2}}{n} \cdot (1 + 2 \cdot \sin \theta)$~~   
 ~~$= \frac{W_N}{3} \cdot \frac{\sqrt{n^2 + m^2}}{n} \cdot \sin^{-1} \left( \frac{m}{\sqrt{n^2 + m^2}} \right) + \dots$~~

evaluate  $P_L$  for  $\theta$  (tower axis perpendicular to  $L_{max}$  line) instead of x axis

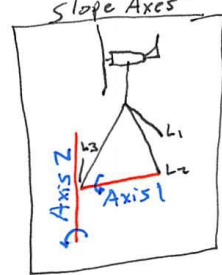
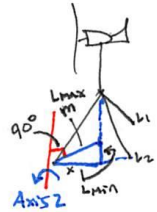
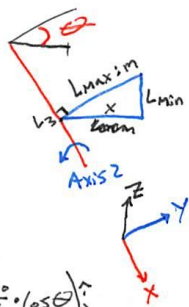
Then use dot product to solve for max force in  $L_{1/2}$  cable

possibly solve all calculations for tilt angle  $\theta$  axis = 0 axis perpendicular to  $L_{max}$  line?



Axis 2 - Vectors

$\vec{W}_N = -W_N \hat{k}$   
 $\vec{W}_{neck} = -W_{neck} \hat{k}$   
 $\vec{W}_{L1} = W_{L1} \hat{k}$   
 $\vec{F}_T = F_T \cdot (-\hat{j}) = -F_T \hat{j}$



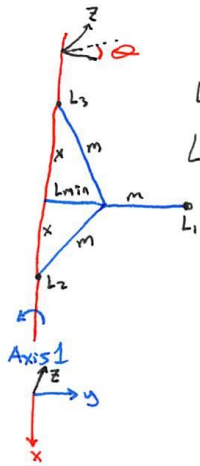
$m = m_0 \cdot \cos \theta$   
 $\hat{L}_2 = \left( \frac{\sqrt{3}}{2} \cdot m_0 \right) \hat{i} + \left( H \cdot \sin \theta + \frac{m_0}{2} \cdot \cos \theta \right) \hat{j} - \left( H \cdot \cos \theta + \frac{m_0}{2} \cdot \sin \theta \right) \hat{k}$   
 Direction from  $W_N$  to  $L_2$

$\hat{L}_2 = \frac{[ (H \cdot \sin \theta - m_0 \cdot \cos \theta) \hat{j} + (H \cdot \cos \theta + m_0 \cdot \sin \theta) \hat{k} ]}{\sqrt{H^2 + m_0^2}}$   
 Direction from  $W_N$  to  $L_2$   
 $\hat{L}_1$  is same as  $\hat{L}_2$  except  $\hat{i}$  is negative

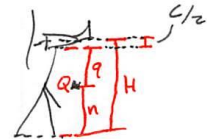
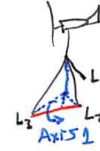
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Axis 1 - Vectors

F = Wind  
 W = Self-weight  
 $\vec{F}_T = F_T \hat{j}$   
 $\vec{F}_R = -F_T \hat{j}$   
 $\vec{W}_T = -W_T \cdot \hat{k}$



$L_{min} \neq m/2$   
 $L_{min_0} = m_0/2$   
 $\hat{L}_2 = \hat{L}_3$  except  $\hat{i}$  is negative



[z=H] Direction from  $W_N$  ( $F_N$ )  
~~Direction from  $W_N$  ( $F_N$ )~~

$$\hat{L}_3 = \frac{\left(-\frac{T_3}{2} m_0\right) \hat{i} - (H \cdot \sin \theta - \frac{m_0}{2} \cdot \cos \theta) \hat{j} - (H \cdot \cos \theta + (m_0/2) \cdot \sin \theta) \hat{k}}{(H^2 + m_0^2)^{1/2}}$$

except  $\hat{L}_1 = \frac{(m_0 \cdot \cos \theta) \hat{j} - (H \cdot \cos \theta + m_0 \cdot \sin \theta) \hat{k}}{(H^2 + m_0^2)^{1/2}}$

[z=Q] Direction from  $W_{neck}$  ( $F_{neck}$ )

[z=n/2] Same as  $W_N$  except  $H \rightarrow Q$ ,  $Q = n + e/2$   
 Direction from  $W_L$  ( $F_L$ )  
 $H \rightarrow n/2$

Wind Forces

$$F_N = \frac{1}{2} \cdot \rho_{air} \cdot A_{Blades} \cdot \vec{V}^2$$

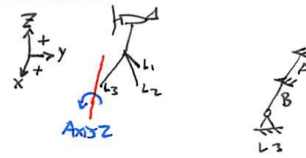
$$F_L = \frac{1}{2} \cdot \rho_{air} \cdot A_L \cdot \vec{V}^2 \cdot C_d$$

$$F_{neck} = \frac{1}{2} \cdot \rho_{air} \cdot A_{neck} \cdot \vec{V}^2 \cdot C_d$$

$C_d \approx 1$  ← Reynolds # vs  $C_d$  Chart

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Failure due to Buckling - continued



$$P_{L3} = (L3)_z \cdot \frac{\pi^2 EI}{L3 \cdot k} \quad L1 = L2 \quad P_{L1} = P_{L2}$$

$$\uparrow \sum F_z = 0 = -W_N + (L3)_z + (L2)_z + (L1)_z - W_L - W_{weck}$$

$$\sum F_x = 0 = (L1)_x + (L2)_x + (L3)_x \quad \sum F_y = 0 = (L1)_y + (L2)_y + (L3)_y$$

$$X: L1 \left( \frac{\sqrt{3}}{2} m_0 \right) - L2 \left( \frac{\sqrt{3}}{2} m_0 \right) + L3 \left( \frac{\sqrt{3}}{2} m_0 \right) = 0 \rightarrow L1 = L2$$

$$Y: L1 (H \cdot \sin \theta + \frac{m_0}{2} \cdot \cos \theta) + L2 (H \cdot \sin \theta + \frac{m_0}{2} \cdot \cos \theta) + L3 (H \cdot \sin \theta - m_0 \cdot \cos \theta) = 0$$

$$L1 (2H \cdot \sin \theta + m_0 \cdot \cos \theta) = L2 (m_0 \cdot \cos \theta - H \cdot \sin \theta)$$

$$L3 = L1 \left( \frac{m_0 \cdot \cos \theta + 2H \cdot \sin \theta}{m_0 \cdot \cos \theta - H \cdot \sin \theta} \right) \text{ for } W_N \text{ and } F_N \text{ (Not } W_{weck}, W_L) \leftarrow \text{Similar though}$$

$$Z: W_N \cdot \overline{H^2 + m_0^2} = (2H \cdot \cos \theta - m_0 \cdot \sin \theta) L1 + (H \cdot \cos \theta + m_0 \cdot \sin \theta) L3$$

$$W_N \cdot \overline{H^2 + m_0^2} = \left[ (2H \cdot \cos \theta - m_0 \cdot \sin \theta) \left( \frac{m_0 \cdot \cos \theta + 2H \cdot \sin \theta}{m_0 \cdot \cos \theta - H \cdot \sin \theta} \right) + (H \cdot \cos \theta + m_0 \cdot \sin \theta) \right] \cdot L3$$

$$P_{L3} = L3 = \left[ \frac{W_N \cdot (H^2 + m_0^2)}{H \cdot \cos \theta + m_0 \cdot \sin \theta} \right] \cdot \left[ \frac{m_0 \cdot \cos \theta + 2H \cdot \sin \theta}{(2H \cdot \cos \theta - m_0 \cdot \sin \theta)(m_0 \cdot \cos \theta - H \cdot \sin \theta) + (H \cdot \cos \theta + m_0 \cdot \sin \theta)(m_0 \cdot \cos \theta + 2H \cdot \sin \theta)} \right]$$

$$+ \left[ \frac{W_{weck} \cdot (\varrho^2 + m_0^2)}{\varrho \cdot \cos \theta + m_0 \cdot \sin \theta} \right] \cdot \left[ \frac{m_0 \cdot \cos \theta + 2\varrho \cdot \sin \theta}{(2\varrho \cdot \cos \theta - m_0 \cdot \sin \theta)(m_0 \cdot \cos \theta - \varrho \cdot \sin \theta) + (\varrho \cdot \cos \theta + m_0 \cdot \sin \theta)(m_0 \cdot \cos \theta + 2\varrho \cdot \sin \theta)} \right]$$

$$+ \left[ \frac{W_L \cdot \left( \left( \frac{n}{2} \right)^2 + m_0^2 \right)}{\left( \frac{n}{2} \right) \cdot \cos \theta + m_0 \cdot \sin \theta} \right] \cdot \left[ \frac{m_0 \cdot \cos \theta + n \cdot \sin \theta}{\left( \frac{n}{2} \cdot \cos \theta - m_0 \cdot \sin \theta \right)(m_0 \cdot \cos \theta - \frac{n}{2} \cdot \sin \theta) + \left( \frac{n}{2} \cdot \cos \theta + m_0 \cdot \sin \theta \right)(m_0 \cdot \cos \theta + n \cdot \sin \theta)} \right]$$

$$L_L = \sqrt{m_0^2 + H^2} = L_A + L_B$$

$$L_{Amax} = \left( \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{P_{L3}} \right)^{1/2}$$

$$L_{Bmax} = \frac{1}{1.4} \left( \frac{\pi^3 \cdot E \cdot (r_o^4 - r_i^4)}{P_{L3}} \right)^{1/2}$$

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Bending in Legs - At. Angle

$$\sigma_{cr} = \frac{M_c}{I} = \frac{r_o \cdot y}{\pi(r_o^4 - r_i^4)} \cdot M$$

$$\vec{M} = \vec{r} \times \vec{P}$$

$$\vec{P}$$

$$\vec{W}_N = W_N \cdot \hat{k}$$

$$\vec{W}_{neck} = W_{neck} \cdot \hat{k}$$

$$\vec{W}_L = W_L \cdot \hat{k}$$

$$\vec{F}_N = F_N \cdot \hat{j}$$

$$\vec{F}_{neck} = F_{neck} \cdot \hat{j}$$

$$\vec{F}_{result} = F_{result} \cdot \hat{j}$$

$$\vec{F}$$

$$\sqrt{m^2 + H^2}$$

$$\sqrt{m^2 + a^2}$$

$$\sqrt{m^2 + \frac{w^2}{4}}$$

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Overturning Equation - Given  $m$ , Solve for  $W_N$ .

$$m_{0min} = 2n \tan \left( \theta + \tan^{-1} \left( \frac{1}{n_0} \left( \frac{n_0}{2} \cdot W_L + Q \cdot W_{Neck} + H \cdot W_N \right) \frac{\sin \theta}{W_N \cdot \cos \theta - F_T \cdot \sin \theta} + \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H \right) \cdot \cos \theta \right) \right)$$

$$\tan^{-1} \left( \frac{m_0}{2 \cdot n_0} \right) - \theta = x \rightarrow \frac{\tan(x) \cdot n_0}{\cos \theta \cdot \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H \right)}$$

$$n_0 \cdot \tan(x) = \frac{\left( \frac{n_0}{2} \cdot W_L \right) \cdot \sin \theta + Q \cdot W_{Neck} \cdot \sin \theta + H \cdot W_N \cdot \sin \theta + \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H \right) \cdot \cos \theta}{W_N \cdot \cos \theta + \left( W_L + W_{Neck} \right) \cdot \cos \theta - F_T \cdot \sin \theta}$$

$$W_N \cdot \cos \theta \cdot n_0 \cdot \tan(x) = \left( \frac{n_0}{2} W_L + Q \cdot W_{Neck} \right) \cdot \sin \theta + \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H \right) \cdot \cos \theta + W_N \cdot H \cdot \sin \theta - \left[ \left( W_L + W_{Neck} \right) \cdot \cos \theta - F_T \cdot \sin \theta \right] \cdot n_0 \cdot \tan(x)$$

$$W_N = \frac{\left[ \left( \frac{n_0}{2} \cdot W_L + Q \cdot W_{Neck} + F_T \cdot \sin \theta \right) \cdot n_0 \cdot \tan(x) + \left( F_L \cdot \frac{n_0}{2} + F_{Neck} \cdot Q + F_N \cdot H - \left( W_L + W_{Neck} \right) \cdot n_0 \cdot \tan(x) \right) \cdot \cos \theta \right]}{\left[ \cos \theta \cdot n_0 \cdot \tan(x) - H \cdot \sin \theta \right]}$$

Determining  $W_{Nmin}$  for 2 scenarios (and all 4 loadings)

- Diameter of least = 1inch (item # 4NTF2) = 0.0254m
- 28in Member
- $W_L = W_{Neck} = 0.0143 \text{ lb/in}$  (online metals.com/calculator, cfm)  $\times 175.13 = \text{N/m}$
- $\phi = 30^\circ$   $\rightarrow$   $\frac{c}{2} = 4m$
- 2m. overlap of members

- 1 4m/s  $0^\circ$
- 2 10m/s  $0^\circ$
- 3 4m/s  $15^\circ$
- 4 5.7  $^\circ + 15^\circ$
- 5 10m/s,  $20.7^\circ$  worst case scenario

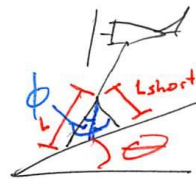
1	$L = 28 \text{ in} = 0.711 \text{ m}$	$m = 14 \text{ m} = 0.356 \text{ m}$	$n = 24.25 \text{ in} = 0.616 \text{ m}$	$Q = 51.25 \text{ m} = 1.30 \text{ m}$	$H = (78.25 + 4/2) \text{ in} = 82.25 \text{ m} = 2.084 \text{ m}$
2	$L = 54 \text{ in} = 1.37 \text{ m}$	$m = 27 \text{ in} = 0.686 \text{ m}$	$n = 46.77 \text{ in} = 1.19 \text{ m}$	$Q = 60.77 \text{ m} = 1.54 \text{ m}$	$H = (74.77 + 4) \text{ in} = 78.77 \text{ in} = 2.004 \text{ m}$

$W_{Nmin}(N)$

1	1. 150N	33.88lb
2	1. 32.54N	7.315lb
3	516.86N	116lb
4	0N	0lb

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$\phi = ?$   
Goal: Maximize  $\phi$



$\theta = 15^\circ$

$L - L' = \Delta L$   
 $0 \leq \Delta L \leq 26 \text{ in}$

$L = (28 \text{ in}) \cdot 2 - z \text{ in}$   
 $= 54 \text{ in}$

$H_L = L \cdot \cos \phi$

~~$H_L - H'_L = z \cdot \tan \theta$~~

$\phi_2 = 180 - [90 - \phi - \theta] - \phi$   
 $= 90 + \theta$

$\theta_2 = 90 - \theta$

$\theta_3 = 180 - (90 - \theta) - \phi$

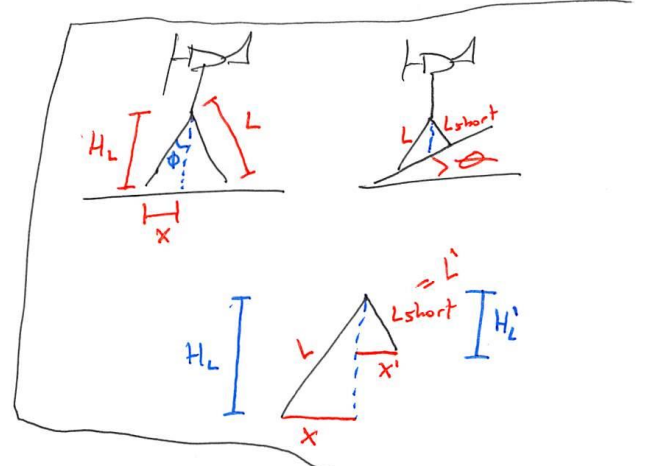
$\theta_3 = 90 + \theta - \phi$

$L - L' = \frac{y_2}{\sin \theta_3} \cdot \sin \theta_4$

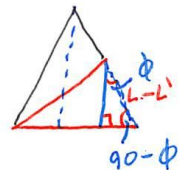
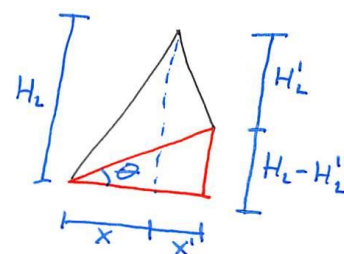
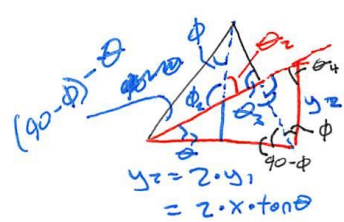
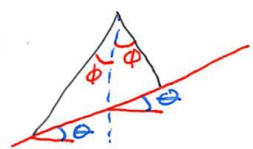
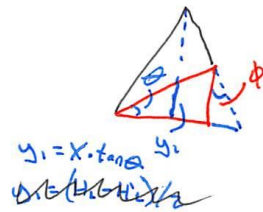
$L - L' = \frac{z \cdot x \cdot \tan(\theta)}{\sin(90 + \theta - \phi)} \cdot \sin(90 - \theta)$

$L - L' = \frac{z \cdot L \cdot \sin \phi \cdot \tan(\theta) \cdot \sin(90 - \theta)}{\sin(90 + \theta - \phi)}$

for  $\theta = 15^\circ$ ,  $L = 54 \text{ in}$ ,  $L' = 28 \text{ in}$ ,  
 $\phi = 44.8^\circ$  [used excel]



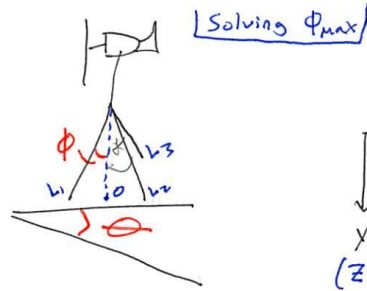
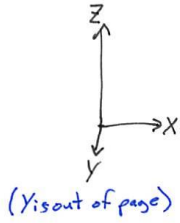
$180 - (90 - \theta + \phi) - \theta$   
 $90 - \theta$



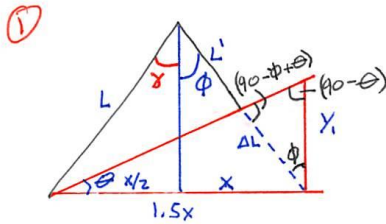
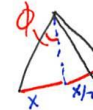
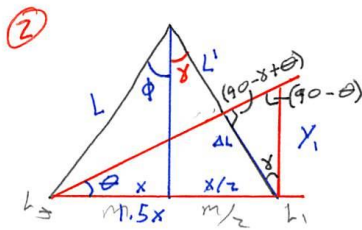
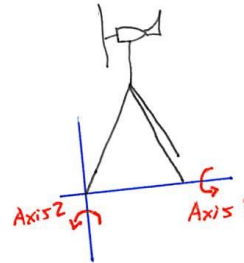
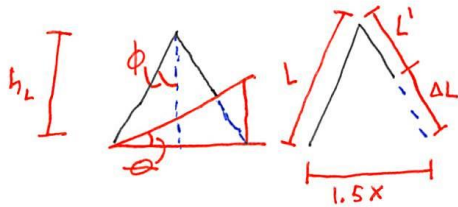
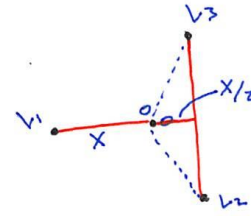
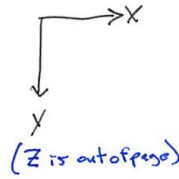
$H_L - H'_L = (L - L') \cdot \cos \phi$   
 $[a^2 = b^2 + c^2 - 2bc \cdot \cos A]$   
 $\frac{a}{\sin A} = \frac{b}{\sin B}$

$\theta_4 = 180 - \phi - (90 + \theta - \phi)$   
 $\theta_4 = 90 - \theta$   
 $x = L \cdot \sin \phi$

18



When  $\theta = 0$



$$\tan(\phi) = \frac{x}{h_L}$$

$$\tan(\gamma) = \frac{x/2}{h_L} = \frac{\tan \phi}{2}$$

$$\gamma = \tan^{-1}\left(\frac{\tan \phi}{2}\right)$$

$$Y_1 = 1.5x \cdot \tan \theta \quad x = L \cdot \sin \phi = 2L \cdot \sin \gamma$$

$$Y_1 = 1.5 \cdot L \cdot \sin \phi \cdot \tan \theta$$

$$Y_1 = 3 \cdot L \cdot \sin \gamma \cdot \tan \theta$$

Law of sines:

2

$$\frac{\Delta L}{\sin(90-\theta)} = \frac{Y_1}{\sin(90-\gamma+\theta)}$$

$$\Delta L = \frac{3 \cdot L \cdot \sin \gamma \cdot \tan \theta \cdot \sin(90-\theta)}{\sin(90-\gamma+\theta)}$$

$$\frac{3 \cdot L \cdot \sin\left(\tan^{-1}\left(\frac{\tan \phi}{2}\right)\right) \cdot \tan \theta \cdot \sin(90-\theta)}{\sin(90+\theta - \tan^{-1}\left(\frac{\tan \phi}{2}\right))} = \Delta L$$

1

$$\frac{\Delta L}{\sin(90-\theta)} = \frac{Y_1}{\sin(90-\phi+\theta)}$$

$$\Delta L = \frac{1.5 \cdot L \cdot \sin \phi \cdot \tan \theta \cdot \sin(90-\theta)}{\sin(90-\phi+\theta)}$$

For  $\theta = 15^\circ, L = 54 \text{ in}, \Delta L = 26 \text{ in}:$

1  $\phi_{max} = 60.45^\circ$

2  $\phi_{max} = 55.44^\circ$

19

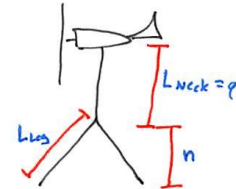
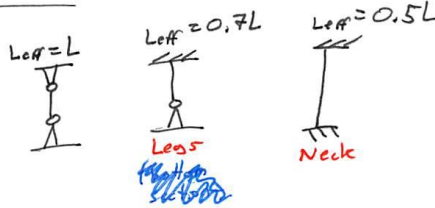
Max Buckling

$$P_{cr} = \frac{\pi^2 EI}{(L_{eff})^2}$$

$$\frac{P_{cr}}{A} = \sigma_{cr}$$

$$A = \frac{\pi}{4} (d_o^2 - d_i^2) \quad I = \frac{\pi (d_o^4 - d_i^4)}{64}$$

$$L_{eff, leg} = 0.7L \quad L_{eff, neck} = 0.5L$$



~~W<sub>n</sub>~~

$$P_{cr} = W_n$$

$$W_{n, max} = \frac{\pi^2 \cdot E \cdot (\pi \cdot (d_o^4 - d_i^4))}{64 \cdot L^2 \cdot (0.25 \text{ or } 0.49)}$$

$$W_{n, leg, max} = \frac{\pi^3 \cdot E \cdot (d_o^4 - d_i^4)}{31.36 \cdot L^2}$$

$$W_{n, neck, max} = \frac{\pi^3 \cdot E \cdot (d_o^4 - d_i^4)}{16 \cdot L^2}$$

L = (segment length vertical component of leg)

L = Length of neck segment

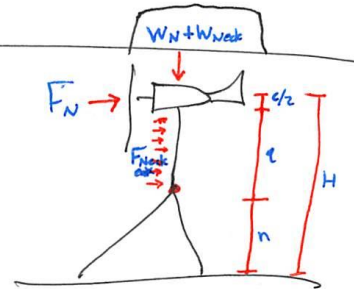
Neck Bending

$$\sigma = \frac{M \cdot c}{I} + \frac{F}{A}$$

$$\sigma_{neck} = \frac{F_N \cdot (H-n) \cdot d_o \cdot 32}{\pi (d_o^4 - d_i^4)} + \frac{F_N \cdot 4}{\pi (d_o^2 - d_i^2)}$$

$$M = F_N \cdot (H-n) \text{ when upright}$$

$$c = \frac{d_o}{2}$$



Pin-hole spacing

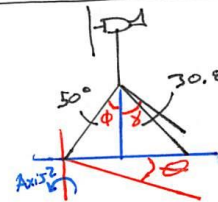
$$\Delta L = \frac{3L \cdot \sin(\tan^{-1}(\frac{\tan \phi}{2})) \cdot \tan \theta \cdot \sin(90 - \theta)}{\sin(90 + \theta - \tan^{-1}(\frac{\tan \phi}{2}))}$$

$$\phi = 50^\circ$$

$$\Delta L = \frac{3 \cdot L \cdot \tan \theta \cdot \sin(90 - \theta) \cdot 0.512}{\sin(59.21 + \theta)}$$

$$\Delta L_{Axis 2} = \frac{1.536 \cdot \tan \theta \cdot \sin(90 - \theta)}{\sin(59.21 + \theta)} \cdot L$$

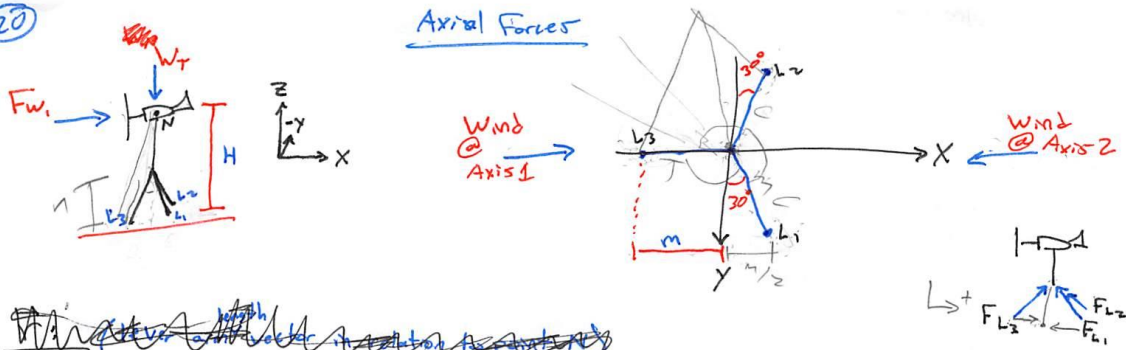
Relationship between leg adjustment and slope of turbine.



Axis 2 maximizes slope - ΔL relationship

$$\Delta L_{Axis 1} = \frac{1.15 \cdot \tan \theta \cdot \sin(90 - \theta)}{\sin(40 + \theta)} \cdot L$$

20



~~Analysis of the forces and moments acting on the turbine tower.~~

$L_{3z} = L_{2z} = L_{1z} = -H \hat{k}$   
 $L_{3x} = -m \hat{i}$      $L_{2x} = \frac{m}{2} \hat{i} = L_{1x}$   
 $L_{3y} = 0$      $L_{2y} = -\frac{\sqrt{3}}{2} m \hat{j}$      $L_{1y} = \frac{\sqrt{3}}{2} m \hat{j}$

$\vec{F}_w = (F_w \cdot \hat{i})$      $\vec{W}_T = -(W_T \cdot \hat{k})$   
For Axis 1

$L = \sqrt{m^2 + H^2} = \bar{r}$

$\vec{F}_w = -\bar{F}_w \cdot \hat{i}$   
For Axis 2

$\vec{L}_3 = -\bar{L}_3 (-m \hat{i}, H \hat{k})$      $\vec{L}_2 = -\bar{L}_2 (\frac{m}{2} \hat{i}, -\frac{\sqrt{3}}{2} m \hat{j}, -H \hat{k})$   
 $\vec{L}_1 = -\bar{L}_1 (\frac{m}{2} \hat{i}, \frac{\sqrt{3}m}{2} \hat{j}, -H \hat{k})$

$\pm \Sigma F_x = 0 = \bar{F}_w + \bar{L}_3 \cdot \frac{m}{L} - \bar{L}_1 \cdot \frac{m}{2L} - \bar{L}_2 \cdot \frac{m}{2L}$      $F_w \cdot \frac{\sqrt{m^2 + H^2}}{m} = -\bar{L}_3 + \bar{L}_1$  Axis 1

$\pm \Sigma F_y = 0 = -\bar{L}_1 \cdot \frac{\sqrt{3}m}{2L} + \bar{L}_2 \cdot \frac{\sqrt{3}m}{2L}$      $\bar{L}_1 = \bar{L}_2$

$\pm \Sigma F_z = 0 = -W_T + (\frac{H}{L})(\bar{L}_3 + \bar{L}_2 + \bar{L}_1)$      $\bar{L}_1 + \bar{L}_2 + \bar{L}_3 = W_T \cdot \frac{\sqrt{m^2 + H^2}}{H} = 2\bar{L}_1 + \bar{L}_3$

$F_w \cdot \frac{\sqrt{m^2 + H^2}}{m} = -\bar{L}_1 + \bar{L}_3$  Axis 2

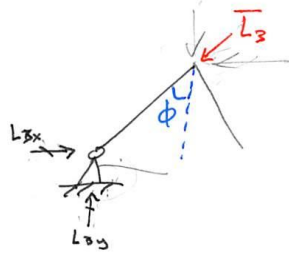
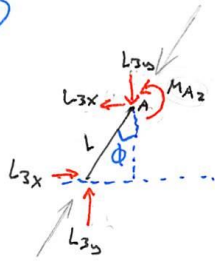
$\bar{L}_3 = \left( F_w \cdot \frac{\sqrt{m^2 + H^2}}{m} + \frac{W_T \cdot \sqrt{m^2 + H^2}}{2 \cdot H} \right) / 1.5$  Axis 2

$\bar{L}_3 = \left( W_T \cdot \frac{\sqrt{m^2 + H^2}}{2 \cdot H} + 2 F_w \cdot \frac{\sqrt{m^2 + H^2}}{m} \right) / 3$  Axis 1

$\bar{L}_3 = \frac{W_T \cdot \sqrt{m^2 + H^2}}{3H} + \frac{2 \cdot F_w \cdot \sqrt{m^2 + H^2}}{3m}$

$\bar{L}_1 = \bar{L}_2$   
 $= \frac{W_T \cdot \sqrt{m^2 + H^2}}{3 \cdot H} + \frac{F_w \cdot \sqrt{m^2 + H^2}}{3 \cdot m}$

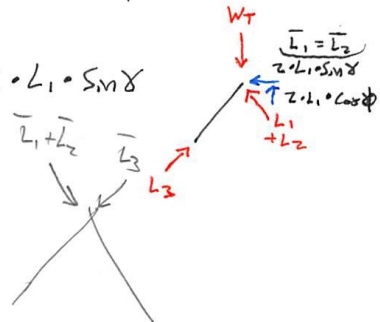
(21)



$$\bar{L}_{3y} = \bar{L}_3 \cdot \cos \phi$$

$$\bar{L}_{3x} = \bar{L}_3 \cdot \sin \phi$$

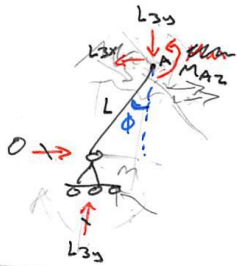
$$L_{3x} = 2 \cdot L_1 \cdot \sin \delta$$



$$\sum M_{Az} = 0 = M_{Az} + L_{3x} \cdot (L \cdot \cos \phi) - L_{3y} \cdot (L \cdot \sin \phi)$$

$$M_{Az} = L_{3y} \cdot L \cdot \sin \phi$$

$$M_{Az} = 0 \quad \text{Pin Support}$$



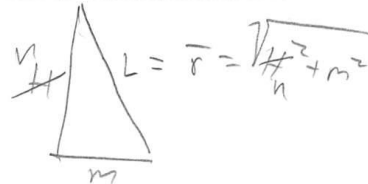
$$\sum M_{Az} = 0 = M_{Az} - L_{3y} \cdot (L \cdot \sin \phi)$$

$$M_{Az} = L_{3y} \cdot L \cdot \sin \phi$$

$$M_{Az} = \bar{L}_3 \cdot \cos \phi \cdot m \quad \text{Roller Support}$$

$$L \cdot \sin \phi = m$$

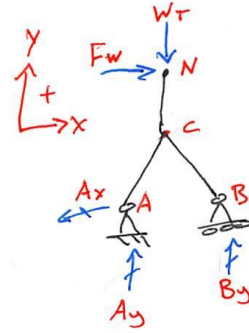
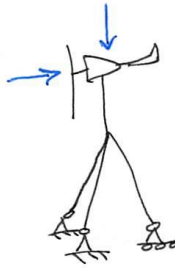
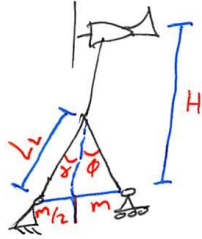
$$\sqrt{\left(\frac{m}{2}\right)^2 + \left(\frac{\sqrt{3}m}{2}\right)^2} + n^2 = \sqrt{m^2 + n^2}$$



$$\frac{H \hat{k} + m \hat{i}}{\sqrt{H^2 + m^2}} = \hat{L}_3$$

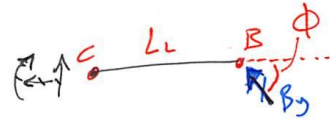
$$\hat{F} = \frac{(F_x \hat{i} + F_y \hat{j} + F_z \hat{k})}{\sqrt{F_x^2 + F_y^2 + F_z^2}}$$

22 Case 3



$$\sum M_{Az} = B_y \cdot (1.5m) - W_t \cdot (0.5m) - F_w \cdot H = 0$$

$$B_y = \frac{W_t}{3} + \frac{2 \cdot F_w \cdot H}{3m}$$



$$\text{Shear} = B_y \cdot \sin \phi$$

$$= \left( \frac{W_t + 2 \cdot F_w \cdot H/m}{3} \right) \cdot \sin \phi$$

$$M_{max} = \text{Shear} \cdot L_L$$

$$= \frac{W_t + 2 \cdot F_w \cdot H/m}{3} \cdot \sin \phi \cdot L_L$$

556 lb.in

Plug & Chug

Assume:  $W_t = 301b$  (133.4N)  
 $\vec{V}_w = 4m/s$   
 $H = 2m$   
 $\phi = 50^\circ$

Smallest pipe  $d_i = 1''$   
 $d_o = 1.25'' - 1/16'' = 1.1875''$   
 $L_L = 54in = 1.37m$  (Cut to telescope)

$$\sigma_{Bend} = \frac{M \cdot c}{I} \quad c = \frac{d_o}{2} = 0.5938in$$

$$I = \frac{\pi(r_o^4 - r_i^4)}{4} = \frac{\pi(d_o^4 - d_i^4)}{64}$$

$$I = 0.04852 [in^4]$$

$$\sigma_{Bend} = \frac{566.5 [lb \cdot in] \cdot 0.5938 [in]}{0.04852 [in^4]} = 6933.0 lb/in^2$$

$$\sigma_{Total} = \sigma_{Bend} + \sigma_{Axial} = 6,933 lb/in^2 + 27.35 lb/in^2 = 6960 psi$$

$= 6.96 ksi$

$$m = \sin(\phi) \cdot L_L = \sin(50^\circ) \cdot 1.37m = 1.05m$$

$$F_w = (1/4) \rho \cdot A_B \cdot \vec{V}^2 = \frac{1}{4} \cdot 1.225 \frac{kg}{m^3} \cdot 1.5m^2 \cdot (4m/s)^2$$

$$= 13.1 [N] \quad (2.94 lb)$$

$$M_{max} = \frac{(133.4 [N] + 2 \cdot 13.1 [N]) \cdot 2 [m]}{3} \cdot \sin(50^\circ) \cdot 1.37m$$

$$M_{max} = 64 [N \cdot m] \quad (566.5 [lb \cdot in])$$

$$\text{Shear} = \frac{566.5 [lb \cdot in]}{54 [in]} = 10.5 [lb]$$

$$\text{Axial } \sigma = F/A$$

$$= \frac{W_t + 2 \cdot F_w \cdot H/m}{\pi(d_o^2 - d_i^2)/4}$$

$$\sigma_{Axial} = \frac{(W_t + 2 \cdot F_w \cdot H/m) \cdot \cos \phi}{\pi(d_o^2 - d_i^2)/4}$$

$$\sigma_{Axial} = 27.35 lb/in^2$$

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$$\sigma_{\text{Max Legs}} = \left( \frac{W_T + 2 \cdot F_w \cdot \frac{H}{m}}{3} \right) \cdot \sin \phi \cdot L_L \cdot \left( \frac{d_o}{2} \right) \cdot \left( \frac{64}{\pi(d_o^4 - d_i^4)} \right) + \left( \frac{W_T + 2 \cdot F_w \cdot \frac{H}{m}}{3 \cdot \pi \cdot (d_o^2 - d_i^2)} \right) \cdot 4 \cdot \cos \phi$$

Axial Stress

could be simplified a little

$$\sigma_{\text{Max legs}} = \left( \frac{W_T + 2 \cdot F_w \cdot \frac{H}{m}}{3} \right) \left( \frac{4 \cdot \cos \phi}{\pi(d_o^2 - d_i^2)} + \frac{\sin \phi \cdot L_L \cdot d_o \cdot 32}{\pi(d_o^4 - d_i^4)} \right)$$

$$\sigma_{\text{avg}} = \frac{M_{\text{max}} \cdot c}{I} + \frac{P_{\text{axial}}}{A}$$

$$\sigma_{\text{MAX Neck}} = \frac{(H - L_L \cdot \sin \phi \cdot \cos \phi) \cdot F_w \cdot \frac{d_o}{2}}{\pi(d_o^4 - d_i^4) / 4} + \frac{W_n \cdot 4}{\pi(d_o^2 - d_i^2)}$$

$$\sigma_{\text{MAX Neck}} = \frac{2 \cdot (H - L_L \cdot \cos \phi) \cdot F_w \cdot d_o}{\pi(d_o^4 - d_i^4)} + \frac{4 \cdot W_n}{\pi \cdot (d_o^2 - d_i^2)}$$

$$P_{\text{cr leg}} = \frac{\pi^2 \cdot E \cdot I}{31.36 \cdot (L_{\text{leg}})^2} = \frac{\pi^2 \cdot E \cdot I}{\pi^2 \cdot (3) \cdot (3.6)^2} = \frac{\pi^2 \cdot E \cdot I}{12.96}$$

$$P_{\text{cr neck}} = \frac{\pi^2 \cdot E \cdot I}{16 \cdot (L_{\text{neck}})^2} = \frac{\pi^2 \cdot E \cdot I}{16 \cdot (L_{\text{neck}})^2}$$

Buckling

$$P_{\text{cr}} = \frac{\pi^2 \cdot E \cdot I}{k^2 L^2}$$

Per = Axial Force

$$= \frac{W_T \cdot L_L}{3n} + \frac{2 \cdot F_w \cdot L_L}{3m}$$

$$W_T \text{ leg max} = \left( \frac{\pi^2 \cdot E \cdot I}{0.49(L_{\text{leg}})^2} - \frac{2 \cdot F_w \cdot L_L}{3m} \right) \cdot \left( \frac{3n}{L_L} \right)$$

$$W_T \text{ Neck max} = \frac{\pi^2 \cdot E \cdot I \cdot 4}{(L_{\text{neck}})^2}$$

Per =  $W_n \text{ neck max}$

$$M_z = (\cos \phi \cdot F_w - \sin \phi \cdot W_T) \cdot L_L$$

$$A_z = \cos \phi \cdot W_T + \sin \phi \cdot F_w$$

$$P_{\text{cr leg}} = \cos \phi \cdot W_T + \sin \phi \cdot F_w$$

$$W_T \text{ leg max} = \left( \frac{\pi^2 \cdot E \cdot I}{0.49(L_{\text{leg}})^2} - F_w \cdot \sin \phi \right) / \cos \phi$$

$$k_{\text{leg}} = 0.7$$

$$k_{\text{neck}} = 0.5$$

1. Solve indeterminate structure for "normal stress" <sup>max.</sup>
2. Check that roller + pin can be added for worst case
3. Calculate stress for bump bump.
4. Calculate deflections.

$$\delta = \frac{PL^3}{3EI}$$

$$P = \frac{38EI}{L^3} = \frac{3\delta_1 \cdot E \cdot I_1}{L_1^3} + \frac{3\delta_2 \cdot E \cdot I_2}{L_2^3}$$

$$L_1 = L_2 = 27.1 \text{ m} \quad E = 10,000 \text{ ksi}$$

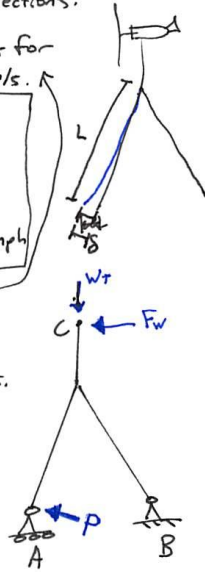
$$I_1 = \quad \quad \quad I_2 =$$

5. Calculate stresses for 4 m/s, 6.5 m/s, 9.2 m/s.

14.6 mph  
 m/s  
 6.5 m/s  $\cdot T_2$   
 = 9.2 m/s = 20.7 mph

then find max wind before failure.

6. Calculate Shear Stress.

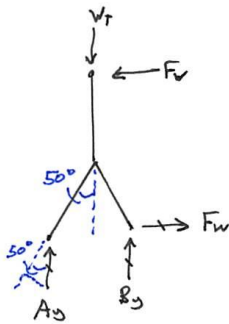


$$\sum M_B = 0$$

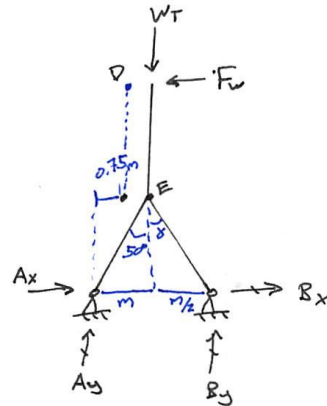
$$= A_y \cdot (1.5m) + F_w \cdot H + W_t \cdot 0.5m$$

$$A_y = \frac{2 \cdot F_w \cdot H + W_t \cdot m}{3 \cdot m}$$

$$A_y \cdot \sin \phi = P$$



$$P_{\text{both}} = 2 \cdot 5m(50) \cdot \left( \frac{2 \cdot F_w \cdot H}{3m} + \frac{W_t}{3} \right) - F_w \cdot \cos 50$$



$$A_y + B_y = W_t$$

$$A_x + B_x = F_w$$

When  $B_x = 0$   
 $A_x = F_w$

$$\frac{(A_x + B_x) \cdot H + B_y \cdot m/2}{m} = A_y$$

$$\frac{F_w \cdot H + (W_t - A_y) \cdot m/2}{m} = A_y$$

$$\frac{F_w \cdot H + W_t \cdot m/2}{1.5 \cdot m} = A_y$$

$$W_t \cdot m/2 + F_w \cdot H - A_y \cdot 1.5m$$

$$(A_x + B_x) \cdot H + 0.75m \cdot B_y - 0.75m \cdot A_y - 0.25m \cdot W_t$$

$$4 \cdot F_w \cdot H + 3 \cdot m \cdot B_y = 3 \cdot m \cdot A_y + m \cdot W_t$$

$$A_y \cdot m = A_x \cdot m \Rightarrow A_x = A_y \cdot \frac{\sin 50}{\cos 50}$$

$$\frac{(A_x + B_x) \cdot H + W_t \cdot m/2}{m} = \frac{A_y \cdot \cos 50}{\sin 50} \cdot A_y$$

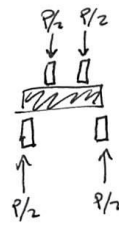
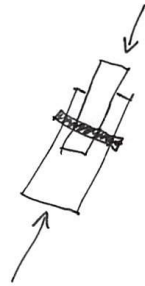
$$A_y \left( 1 + \frac{H \cdot \sin 50}{m \cdot \cos 50} \right) = \frac{B_x \cdot H + W_t \cdot m/2}{m}$$

$$A_y \left( 1 - \frac{H \cdot \sin 50}{m \cdot \cos 50} \right) = \frac{B_x \cdot \frac{\sin 50}{\cos 50} \cdot H + W_t \cdot m/2}{m}$$

$$A_y \cdot m - A_y \cdot H \cdot \frac{\sin 50}{\cos 50} = B_x \cdot H/2 \cdot \frac{\sin 50}{\cos 50} + W_t \cdot m/2$$

$$A_y \cdot m = (A_y + B_y/2) \cdot H \cdot \tan 50 + W_t \cdot m/2$$

$$A_y \cdot \sin 50 - A_x \cdot \cos 50 = P = \left( \frac{2 \cdot F_w \cdot H}{3m} + \frac{W_t}{3} \right) - F_w \cdot \cos 50$$



$$F_N = \frac{4}{9} \cdot \bar{v}^2 \cdot \rho \cdot A_B$$

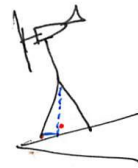
$$= 0.22481 \frac{lb}{ft^2}$$

$$\tau = \frac{F}{A}$$

$$A_{pin} = \frac{\pi r^2}{2}$$

$$A_{tube} = \frac{\pi}{4} (D_o^2 - D_i^2) \cdot L$$

of "do"



$$W_T \cdot m \geq F_w \cdot H \leftarrow \text{level ground}$$

$$\left[ \tan \left( \tan^{-1} \left( \frac{m}{2n} \right) - \theta \right) \cdot n \right] = \frac{W_N \cdot H \cdot \sin \theta + F_N \cdot H \cdot \cos \theta}{W_T \cdot \cos \theta - F_T \cdot \sin \theta}$$

The changing Distance of L<sub>min</sub> dep. on  $\theta$

~~Handwritten scribbles~~

~~Handwritten scribbles~~



$$\left( \frac{m_o}{2} - H \cdot \sin \theta \right) \cdot (W_T \cos \theta - F_T \sin \theta) = W_N \cdot H \cdot \sin \theta + F_N \cdot H \cdot \cos \theta + m \cdot \sin \theta$$

$$W_N \left( \frac{m_o}{2} - H \cdot \sin \theta \right) = F_N (H \cdot \cos \theta + \frac{m_o}{2} \cdot \sin \theta)$$

$$W_{N_{min}} = \frac{F_N (H \cdot \cos \theta + \frac{m_o}{2} \cdot \sin \theta)}{\left( \frac{m_o}{2} \cdot \cos \theta - H \cdot \sin \theta \right)}$$

such a offset at Noelle

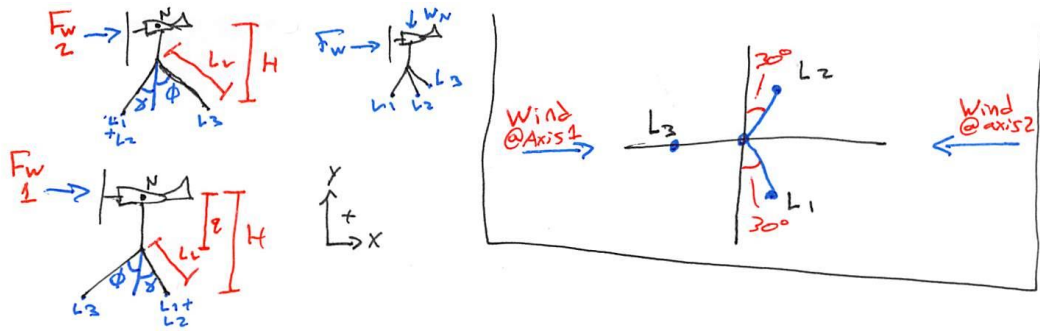
~~offset~~

$$m \cdot \sin \theta + H \cdot \sin \theta = \text{offset}$$

$$\theta = \sin^{-1} \left( \frac{\text{offset}}{m+H} \right)$$

or

$$\theta = \sin^{-1} \left( \frac{\text{offset}}{m/2+H} \right)$$



Axis 1:

$$\rightarrow \sum F_x = F_{w1} + F_{L3x} - F_{L1x} - F_{L2x} = 0$$

$$\bar{F}_{L1} = \bar{F}_{L2}$$

$$\uparrow \sum F_y = 0 = -W_n + F_{L3y} + F_{L1y} + F_{L2y}$$

~~$$\sum M_{N2} = 0 = F_{L3x} \cdot q - 2 \cdot F_{L1x} \cdot q$$~~

$$F_{L3x} = \bar{F}_{L3} \cdot \sin \phi$$

$$F_{L2x} = \bar{F}_{L2} \cdot \sin \gamma$$

$$F_{L1x} = \bar{F}_{L1} \cdot \sin \gamma$$

$$F_{L3y} = \bar{F}_{L3} \cdot \cos \phi$$

$$F_{L2y} = \bar{F}_{L2} \cdot \cos \phi$$

$$F_{L1y} = \bar{F}_{L1} \cdot \cos \phi$$

$$F_{w1} = 2 \cdot F_{L1} \cdot \sin \gamma - F_{L2} \cdot \sin \phi$$

$$\frac{W_n}{\cos \phi} = 2 \cdot F_{L1} + F_{L2}$$

$$F_{L2} \cdot \sin \phi = 2 \cdot F_{L1} \cdot \sin \gamma \rightarrow F_{L1} = F_{L2} \cdot \frac{\sin \phi}{2 \sin \gamma}$$

$$\frac{W_n}{\cos \phi} = F_{L2} \left( 1 + \frac{\sin \phi}{\sin \gamma} \right) \rightarrow F_{L2} = \left( \frac{W_n}{\cos \phi} \right) \left( \frac{\sin \gamma}{\sin \gamma + \sin \phi} \right)$$

~~$$F_{w1} = 0$$~~

## RISA

Pipe - SmallestR3D  
Users Guide

$$d_o = 1'' - \frac{1}{16}'' = 0.9375''$$

$$d_i = 0.75''$$

$$t = \frac{d_o - d_i}{2} = 0.09375''$$

$$A = \frac{\pi}{4} (0.9375^2 - 0.75^2) \approx 0.2485 \text{ in}^2$$

$$I = 0.0224$$

$$S = \frac{I}{c} = \frac{I \cdot 2}{d_o} \approx 0.0478 = Z$$

Pipe - Mid

$$d_o = 1.25'' - \frac{1}{16}'' = 1.1875'' \quad d_i = 1''$$

$$t = 0.09375''$$

$$A = \frac{\pi}{4} (1.1875^2 - 1^2) = 0.3221 \text{ in}^2$$

$$Z = 0.0817 \text{ in}^3$$

$$I = 0.0485 \text{ in}^4$$

Pipe - Large

$$d_o = 1.5'' \quad d_i = 1.25'' \quad t = \frac{1}{8}'' = 0.125''$$

$$A = \frac{\pi}{4} (1.5^2 - 1.25^2) = 0.540 \text{ in}^2$$

$$I = 0.1287 \text{ in}^4$$

$$Z = 0.1716 \text{ in}^3$$

Database: AISC

Using 36 ksi  
SteelAluminum in RISA 9.0  
not RISA 7.0

$$E_{\text{Alum}} = 10,000 \text{ ksi}$$

$$E_{\text{Steel}} = 29,000 \text{ ksi}$$

$$F_{y \text{ Alum}} = 35 \text{ ksi}$$

$$F_{y \text{ Steel}} = 36 \text{ ksi}$$

## Calculations for Blade Mounting

### LOAD CAPACITIES

$$D_s := 0.25\text{in}$$

Shaft Diameter

$$t := 0.025\text{in}$$

E-clip thickness

$$S_s := 80000\text{psi}$$

Shear strength of clip material

$$K_r := 3$$

Factor of Safety recommended for retaining ring

$$K_g := 2$$

Factor of Safety recommended for groove

$$P_r := \frac{D_s \cdot t \cdot S_s \cdot \pi}{K_r} = 523.599\text{ lbf}$$

Allowable thrust based on ring shear, theoretical amount of load the ring can withstand before it shears

$$S_y := 100000\text{psi}$$

Yield Strength of groove material, High Strength 1144 Medium Carbon Steel Rod

$$d := 0.04\text{in}$$

Depth of groove

$$P_g := \frac{D_s \cdot d \cdot S_y \cdot \pi}{K_g}$$

Theoretical amount of load a groove can withstand before it deforms and fails

$$P_g = 1.571 \times 10^3 \text{ lbf}$$

$$P_g > P_r$$

**EDGE MARGIN**

Ring grooves located near the end of a shaft should have an adequate edge margin to maximize strength. Usually calculated as 3 times the groove depth.

$D_G := 0.210\text{in}$  Groove diameter, based on 0.25in. shaft

$P := 11\text{bf}$  Load, weight of blades

$$Z_s := \frac{K_g \cdot 3 \cdot P}{S_y \cdot D_G \cdot \pi} = 9.095 \times 10^{-5} \cdot \text{in} \quad \text{Shear}$$

$$Z_b := \left( \frac{K_g \cdot 6 \cdot d \cdot P}{S_y \cdot D_G \cdot \pi} \right)^{\frac{1}{2}} = 2.697 \times 10^{-3} \cdot \text{in} \quad \text{Bending}$$

Therefore the minimum edge margin, Z should be 0.02697 in., 0.1 in was chosen.

**INSTALLATION STRESS, FOR EXTERNAL RINGS**

$b := 0.086\text{in}$  Radial wall

$E := 30000000\text{psi}$  Modulus of Elasticity of clip material, 1095 spring steel

$D_I := 0.207\text{in}$  Free Inside Diameter

$S_T := 99400\text{psi}$  Tensile Strength of clip material, 1095 spring steel

$$S_E := \frac{E \cdot b \cdot (D_s - D_I)}{(D_I + b) \cdot (D_s + b)} \quad \text{Stress due to expansion}$$

$$S_E = 1.127 \times 10^6 \cdot \text{psi}$$

80% of Tensile Strength of spring steel is 79520 psi, The installation stress is 72840 psi, therefore permanent set is not expected.

**ROTATIONAL CAPACITY**

$$I := \frac{(t \cdot b^3)}{12} = 1.325 \times 10^{-6} \cdot \text{in}^4$$

Moment of Inertia

Multiple turn factor

$$n = 1, \text{ for 1 turn}$$

Number of turns

$$Y := 1.909$$

Multiple Turn Factor

$$A := (t \cdot b) - (.12) \cdot t^2 = 2.075 \times 10^{-3} \cdot \text{in}^2$$

Cross-sectional Area

$$R_M := \frac{(D_I + b)}{2} = 0.146 \cdot \text{in}$$

Mean free radius

$$g := 386.4 \frac{\text{in}}{\text{s}^2}$$

Gravitational Acceleration

$$\gamma := 0.283 \frac{\text{lb}}{\text{in}^3}$$

Material Density

$$\text{Cling} := D_G - D_I = 3 \times 10^{-3} \cdot \text{in}$$

$$V := \frac{\text{Cling}}{2} = 1.5 \times 10^{-3} \cdot \text{in}$$

$$N := \left[ \frac{3600 \cdot V \cdot E \cdot I \cdot g}{(4\pi^2) \cdot Y \cdot \gamma \cdot A \cdot R_M^5} \right]^{\frac{1}{2}}$$

Rotational Capacity

$$N = 1.591 \times 10^6 \cdot \text{rpm}$$

**DYNAMIC THRUS LOADS****IMPACT LOADING**

Safe impact load capacity of the ring

$$l_r := \frac{P_r \cdot t}{2} = 6.545 \text{ in}\cdot\text{lbf}$$

Safe impact load capacity of the groove

$$l_g := \frac{P_g \cdot d}{2} = 31.416 \text{ in}\cdot\text{lbf}$$

# Appendix B: Design CAD

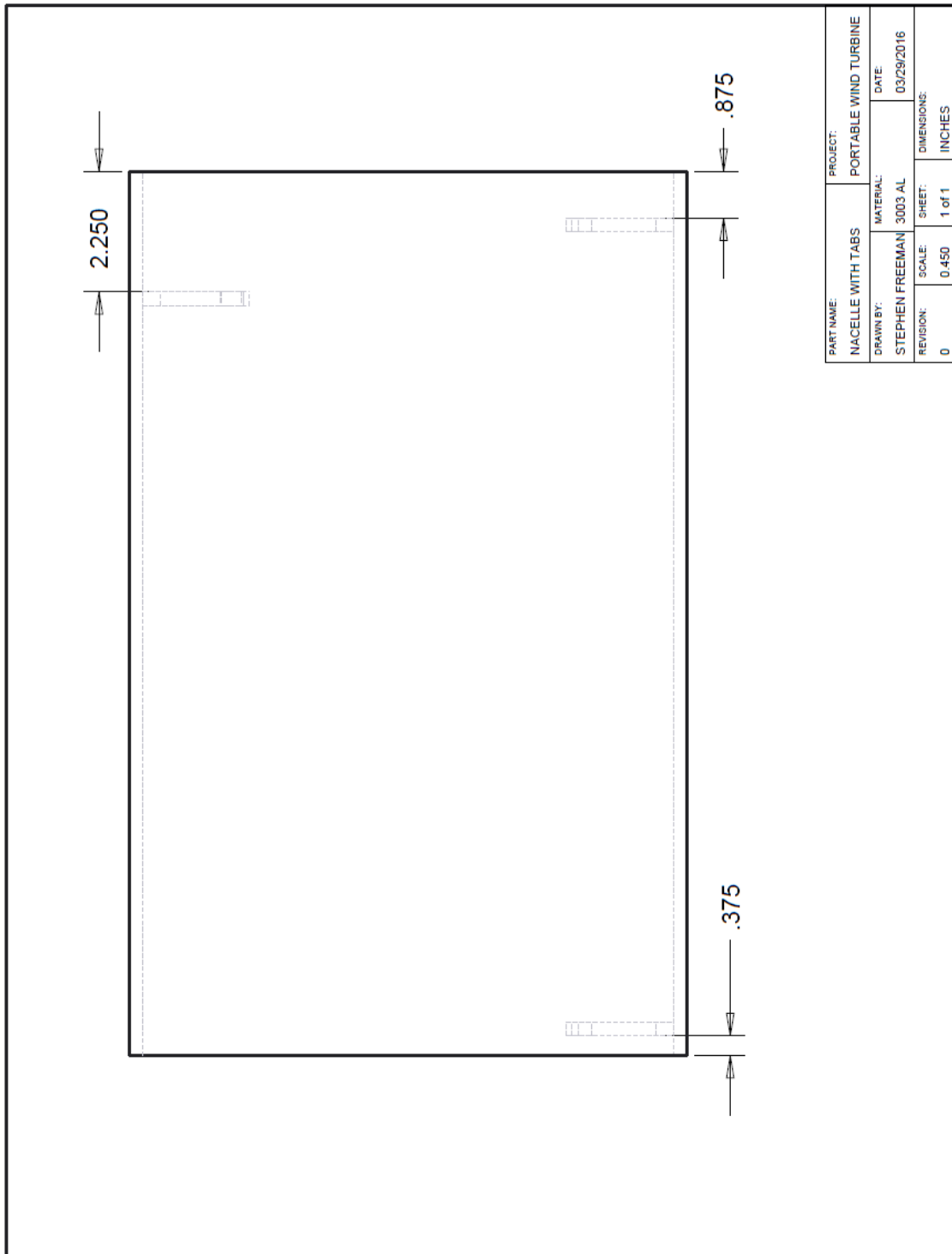


Figure 52. Tab placement in nacelle tube.

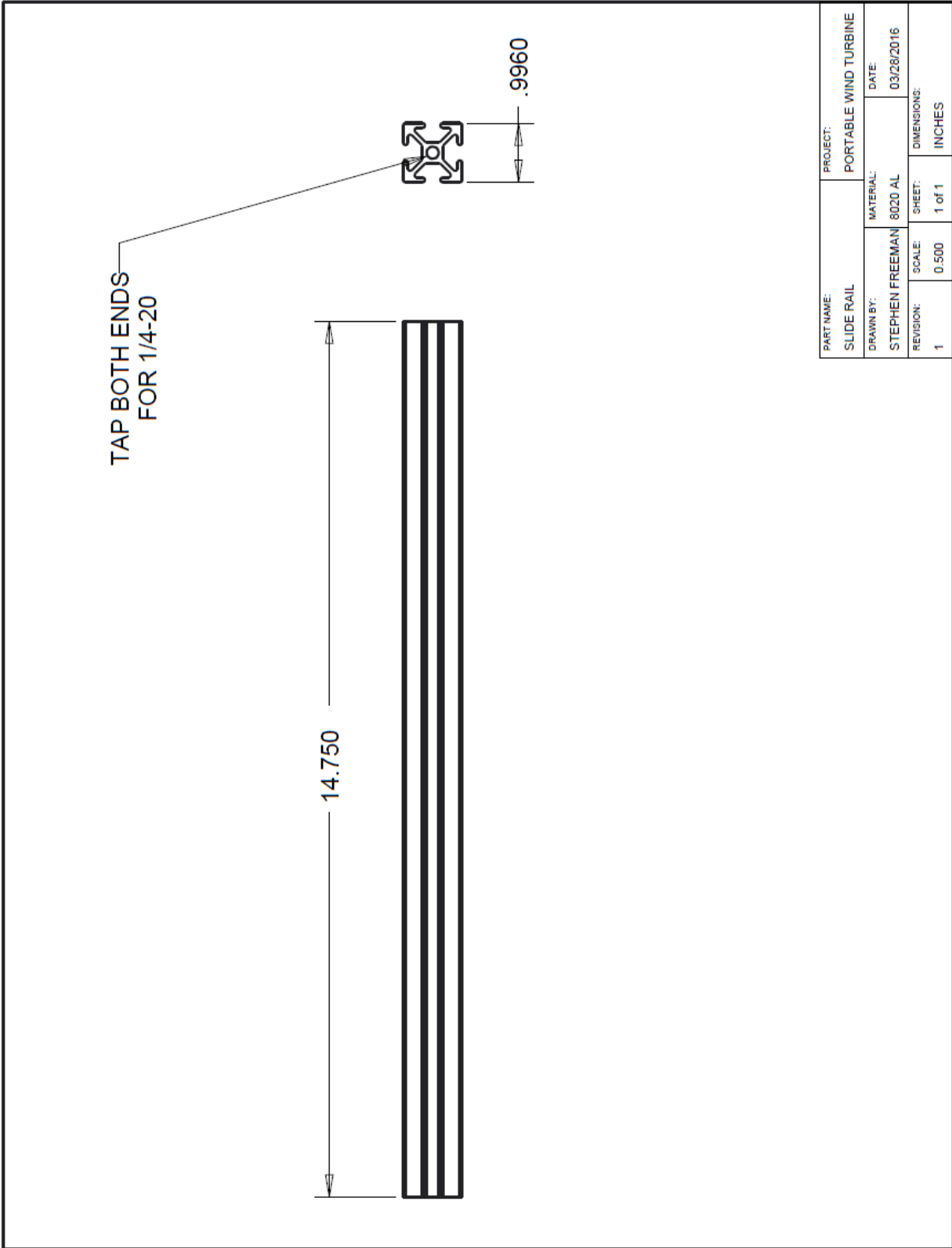


Figure 53. 80/20 aluminum rail.

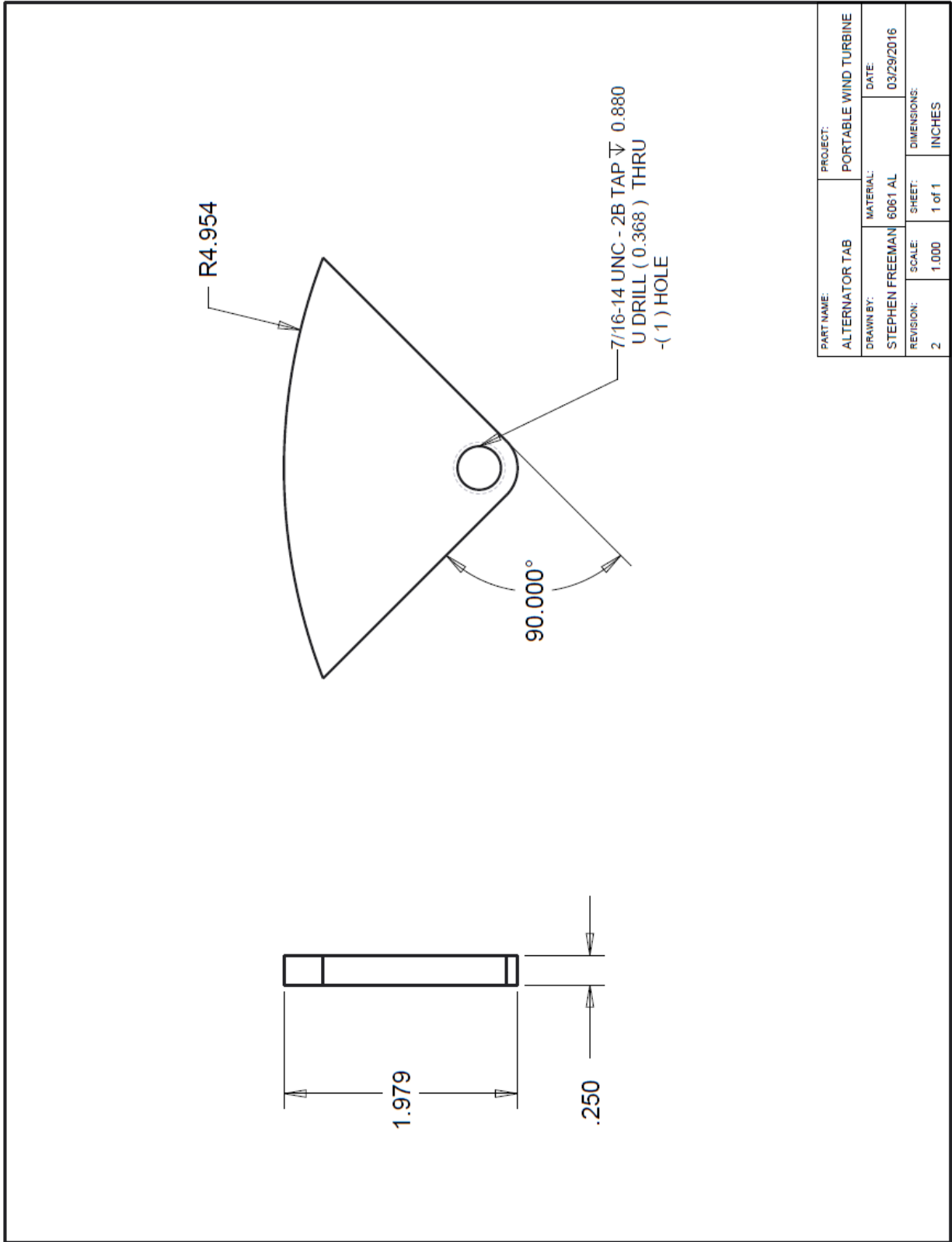


Figure 54. Mounting tab 1.

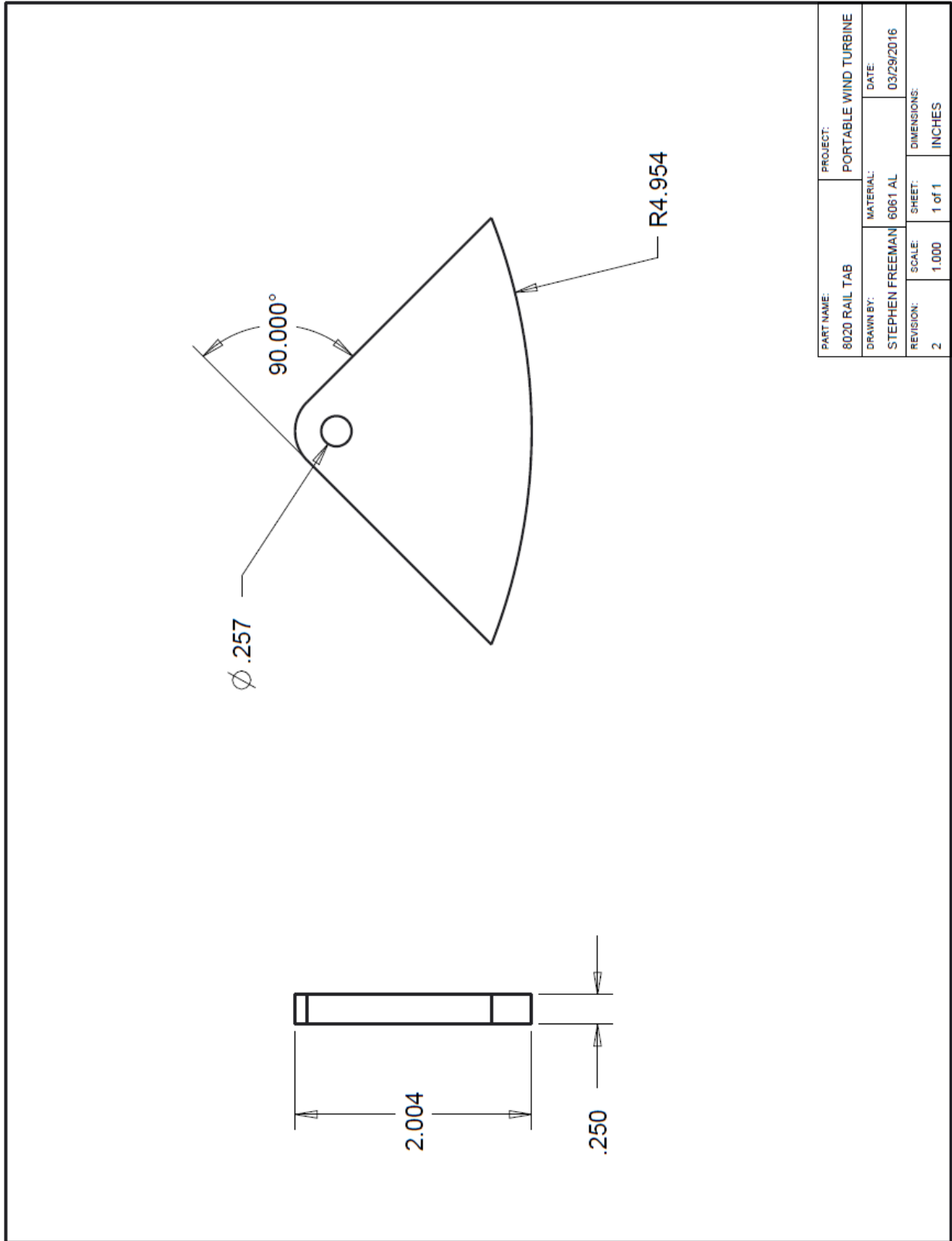


Figure 55. Mounting tabs 2 and 3.

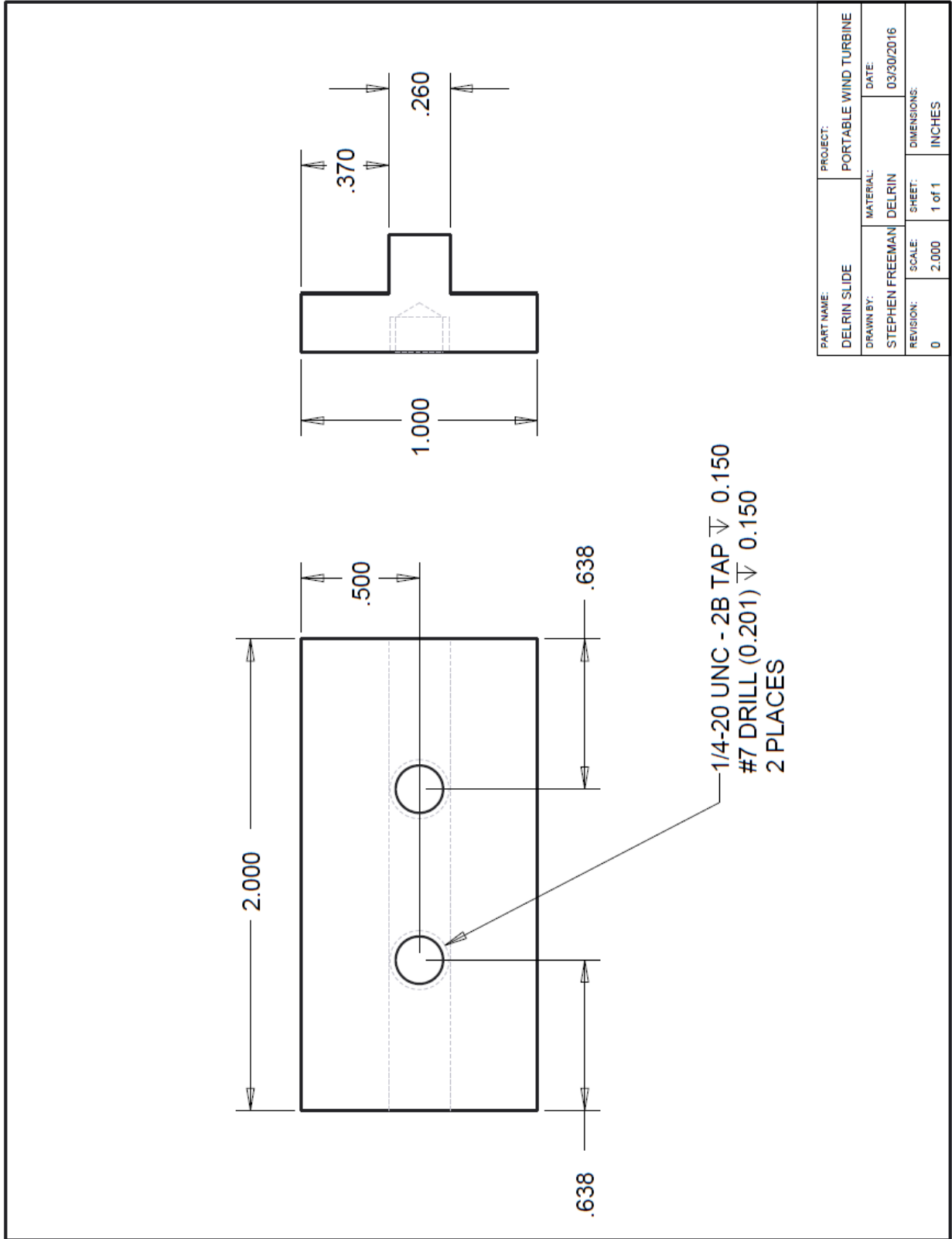


Figure 56. Delrin sliders.

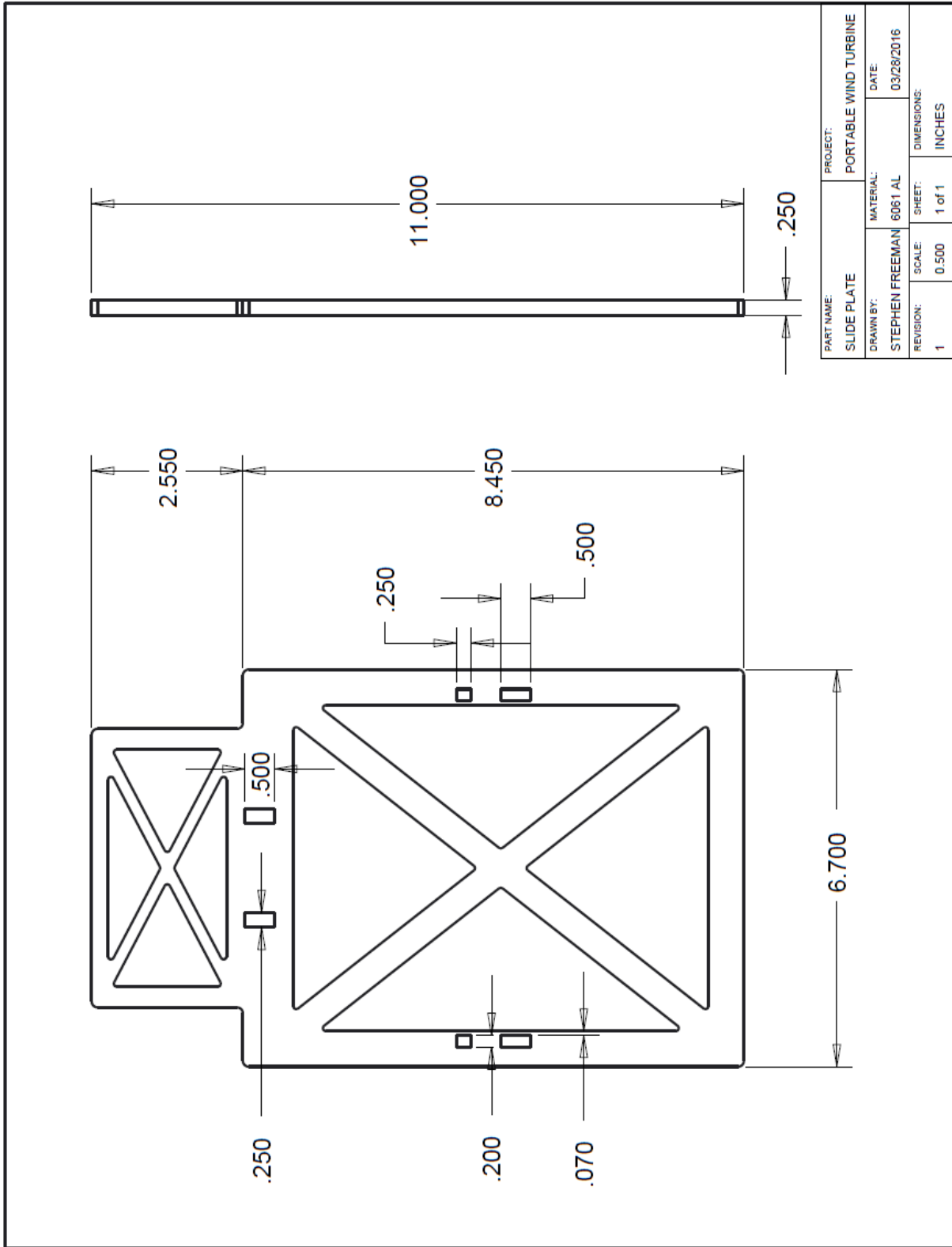


Figure 57. Sliding plate for electrical components.

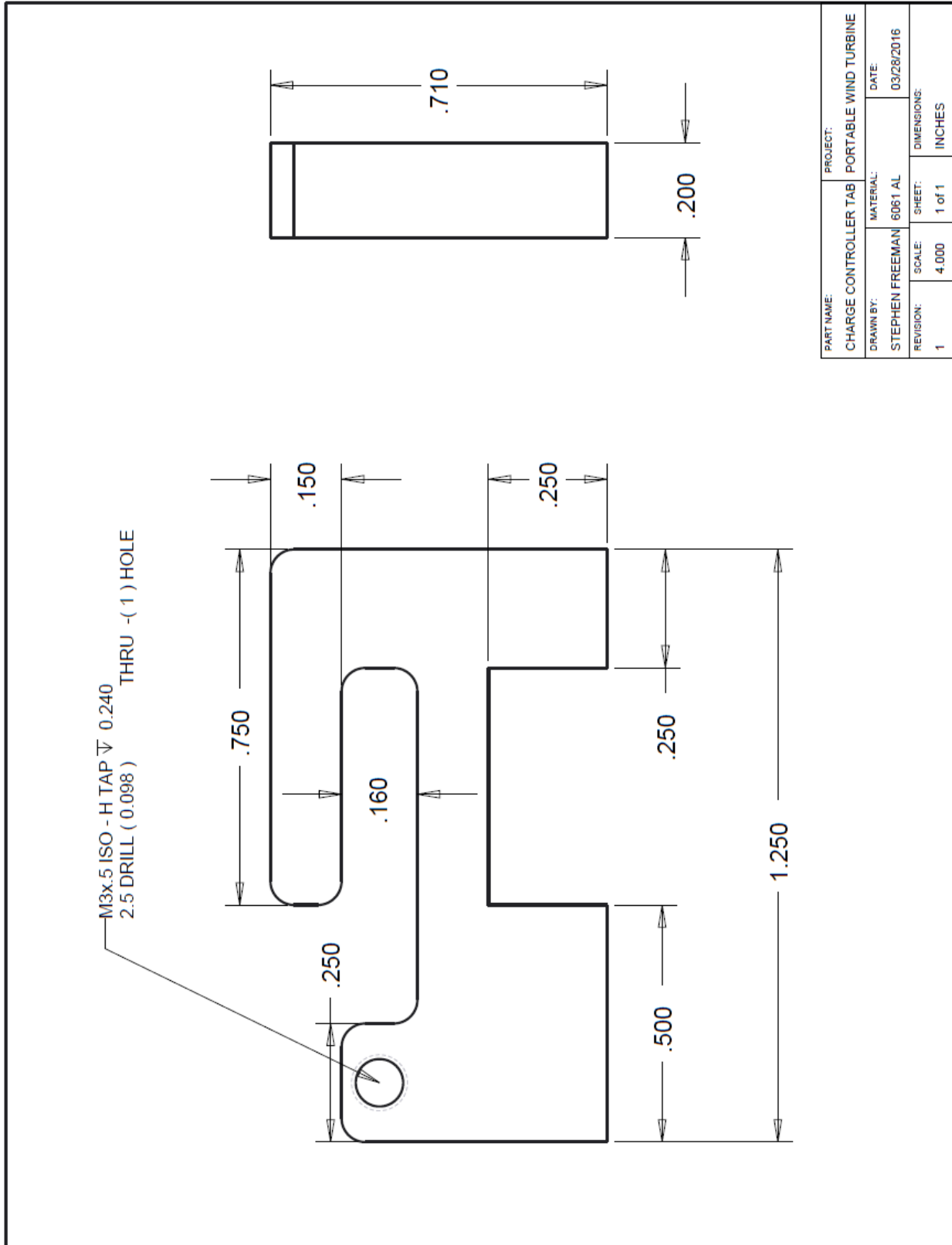


Figure 58. Mounting tabs for charge controller.

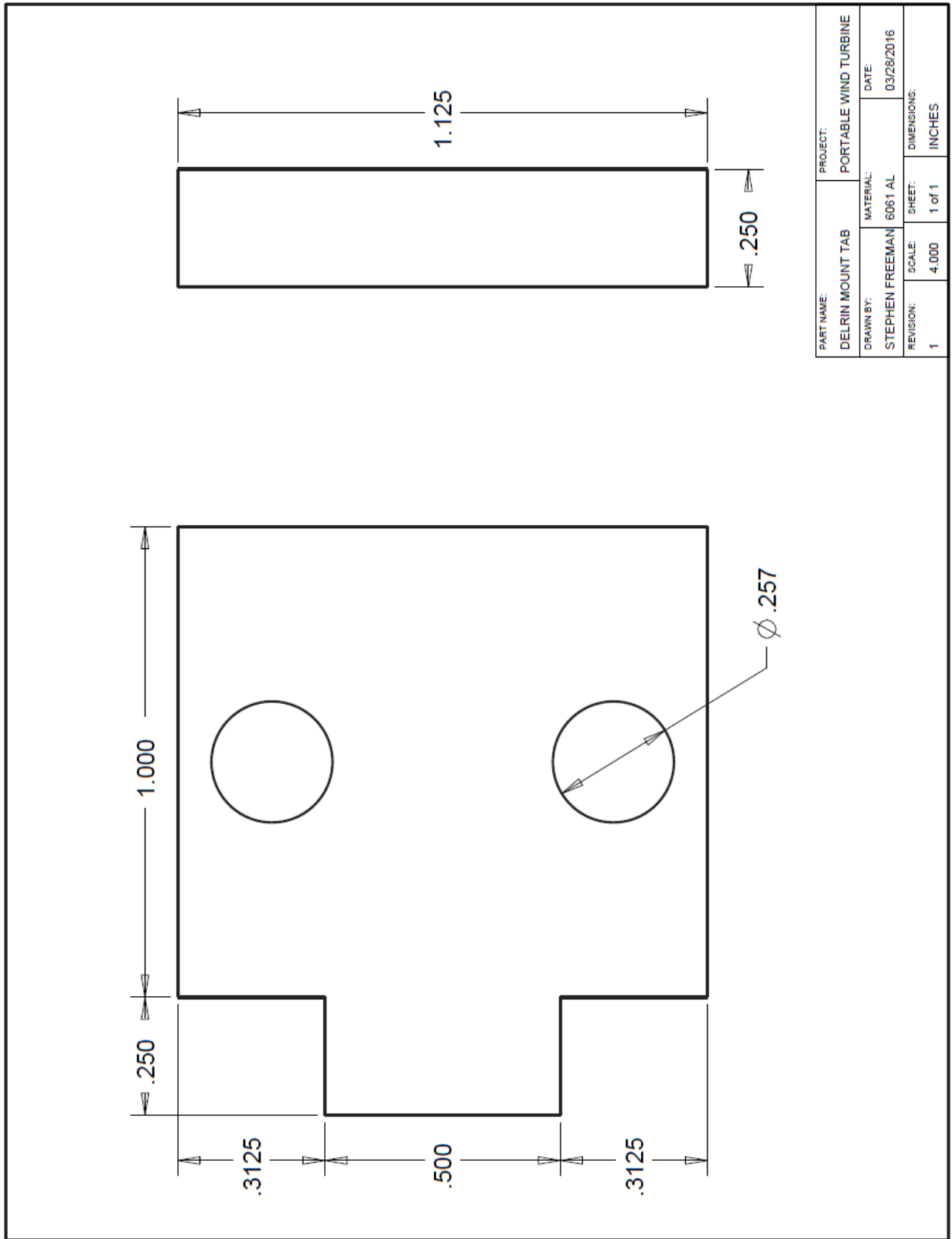
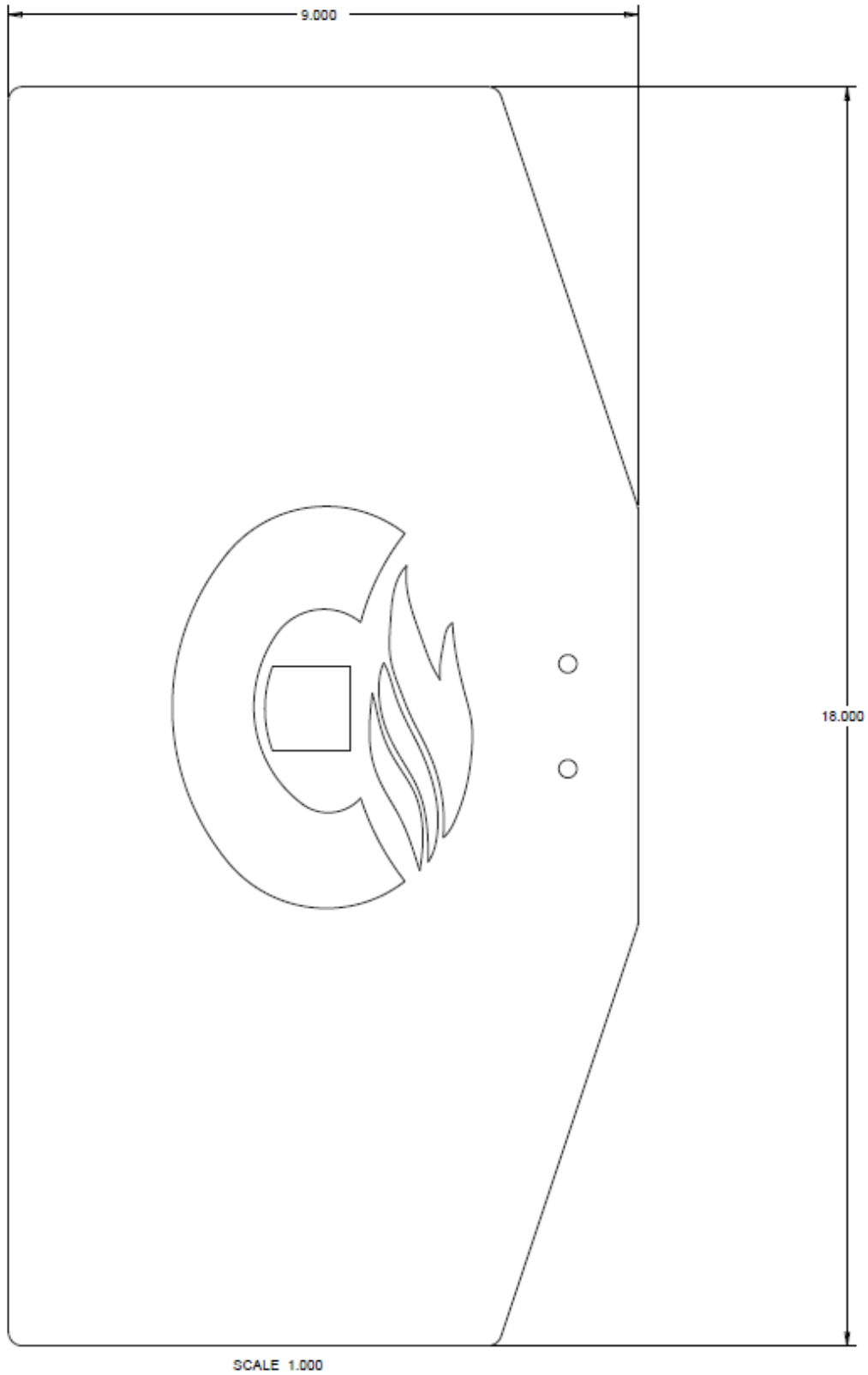
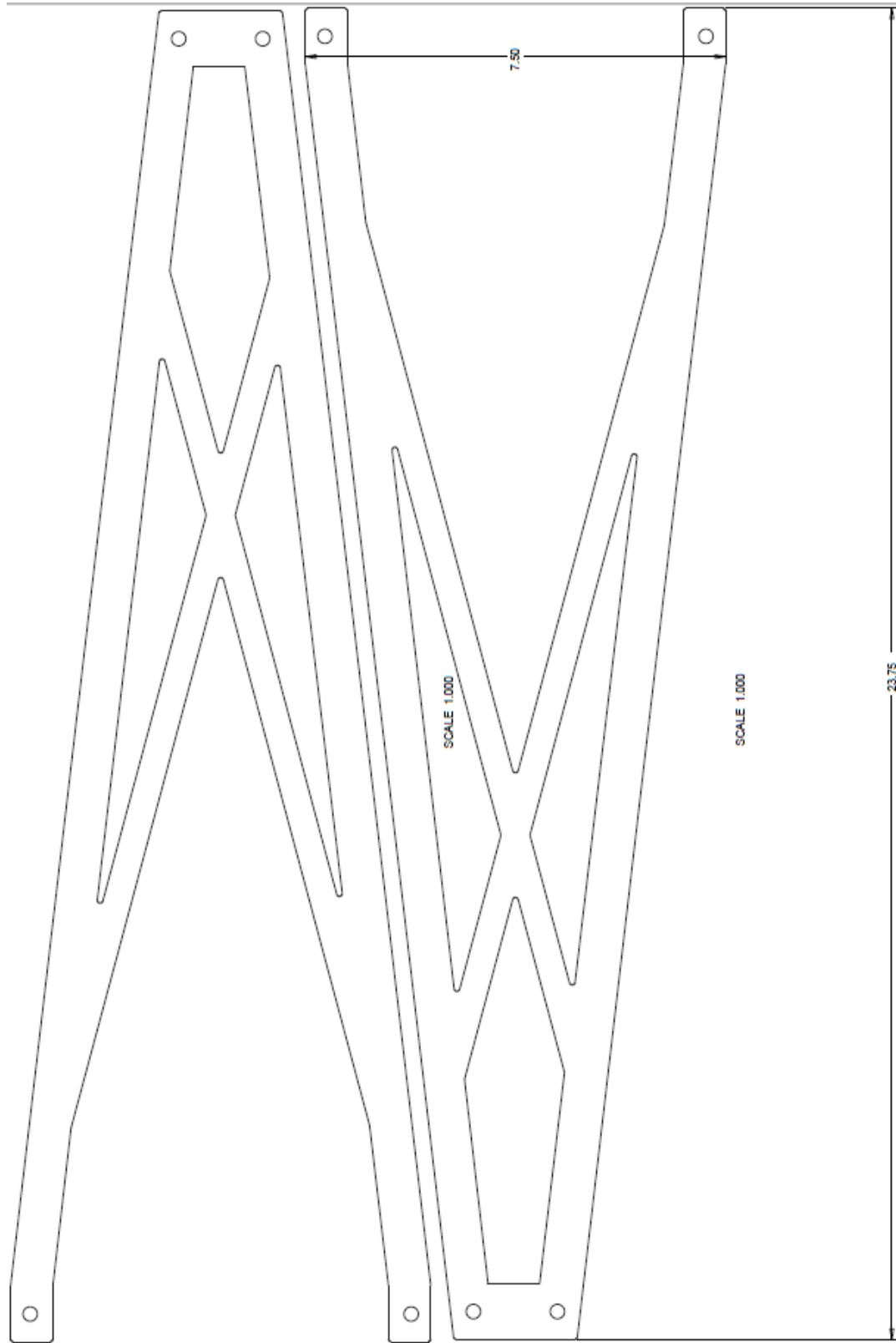


Figure 59. Mounting tabs for Delrin sliders.



**Figure 60. Tail vane blade rough drawing for DXF confirmation.**



**Figure 61. Tail vane boom rough drawing for DXF confirmation.**

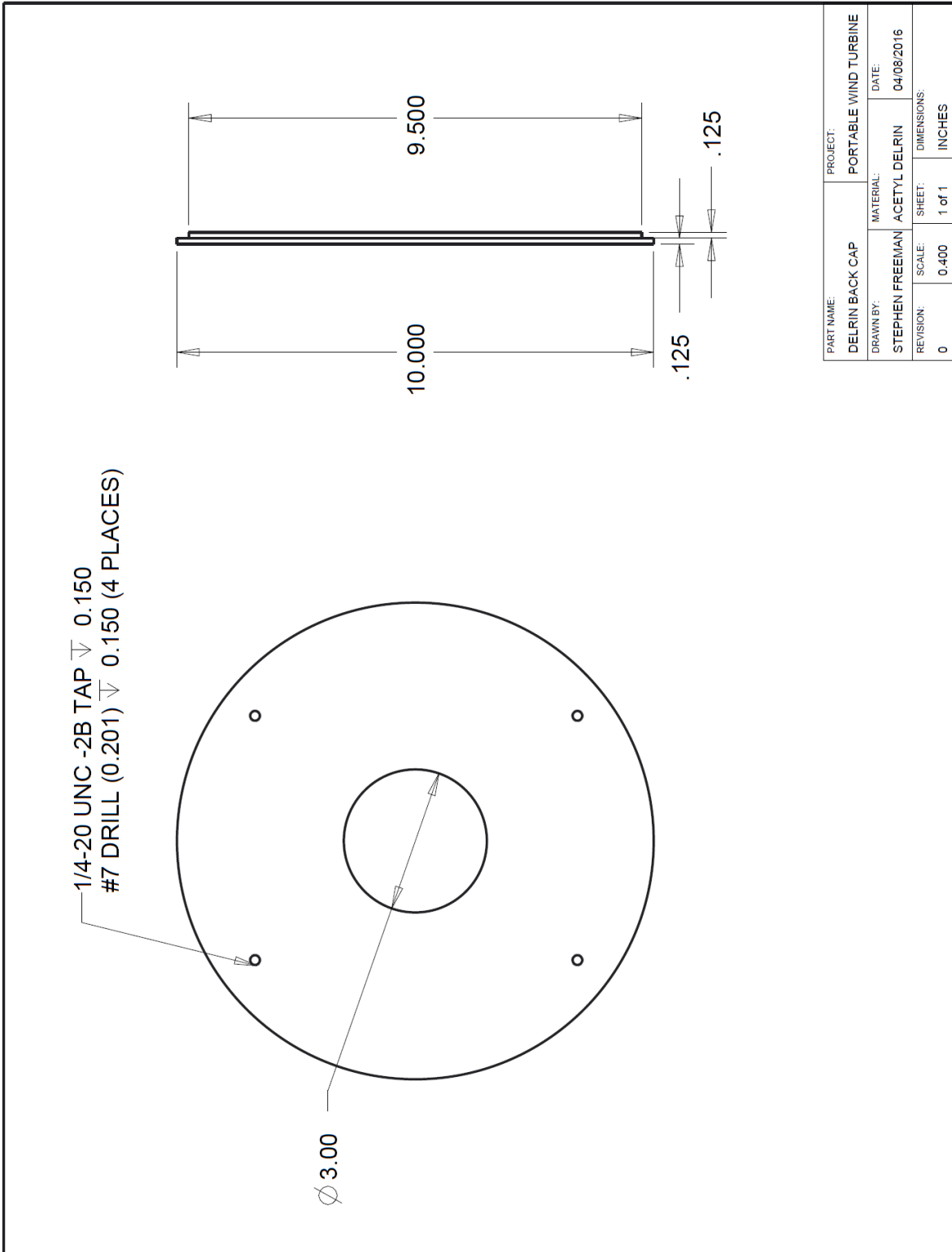


Figure 62. Delrin end plate (front is identical but without tapped holes)

## Appendix C: Prototype Purchases List

### Department of Mechanical Engineering

#### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 01/25/2016

Professor's Name: Dr. Nikhil Gupta

Team No./Project: 15/Portable Wind Turbine

Vendor Name: Bicknell Racing Product

Vendor Website: <http://www.bicknellracingproducts.com/catalog2/index.php?p=product&id=1661>

Your Name: Stephen Freeman

Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
Complete 5/8" Bore Weld On Quick Release Assembly - Aluminum Rim, Hex Shaft Type - Black Anodized	1	\$39.67	\$54.15

**SUB TOTAL:** \$54.15

\* Include units if other than single item (e.g. 2 dozen)

**Purpose:**

Attachment system for turbine nacelle to body.

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 63. Purchase order 1 completed by Team 15

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 01/25/2016

Professor's Name: Dr. Nikhil Gupta

Team No./Project: 15/Portable Wind Turbine

Vendor Name: McMaster // RockWestComposites // BHPhotoVideo

Vendor Website: McMaster // RockWestComposites // BHPhotoVideo

Your Name: Stephen Freeman

Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
9246K11	1	\$14.80	\$14.80
9056K37	2	\$36.40	\$72.80
9056K36	2	\$30.25	\$60.50
9056K38	1	\$21.16	\$21.16
9043K57	1	\$49.95	\$49.95
9043K48	1	\$29.03	\$29.03
=====			
Telescoping Clamp	3	\$27.99	\$83.97
=====			
All Terrain Gitzo Feet	1	\$69.95	\$69.65

**SUB TOTAL: \$402.16**

\* Include units if other than single item (e.g. 2 dozen)

Purpose:

Parts for Nacelle Base and Blade Mounting

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 64. Purchase order 2 completed by Team 15.

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 03/10/2016

Professor's Name: Dr. Nikhil Gupta

Team No./Project: 15/Portable Wind Turbine

Vendor Name:

Vendor Website:

Your Name: Stephen Freeman

Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
WindyNation - TrakMax 30L LCD MPPT 30A Solar Charge Controller	1	\$199.99	\$199.99
Amazon - Battery Tender BTL09A120C Lithium Iron Phosphate Battery	1	\$76.54	\$76.54
McMaster - 1688K26	2	\$3.20	\$6.40
McMaster - 8920K195	1	\$6.94	\$6.94
McMaster - 98416A012	6	\$2.05	\$12.30

**SUB TOTAL: \$302.17**

\* Include units if other than single item (e.g. 2 dozen)

Purpose:

Materials for turbine construction

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 65. Purchase order 3 completed by Team 15.

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 03/21/2016  
 Professor's Name: Dr. Nikhil Gupta  
 Team No./Project: 15/Portable Wind Turbine  
 Vendor Name: McMaster  
 Vendor Website: mcmaster..com  
 Your Name: Stephen Freeman  
 Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
1/4" AL Sheet - 8975K443	2	\$17.91	\$35.82
1/8" AL Sheet - 89015K18	1	\$28.56	\$28.56
Delrin Block - 8739K51	1	\$19.98	\$19.98
Pin - 98416A012	1	\$2.05	\$2.05

**SUB TOTAL: \$86.41**

\* Include units if other than single item (e.g. 2 dozen)

Purpose:  
 Materials for interior of nacelle

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 66. Purchase order 4 completed by Team 15.

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 03/23/2016  
 Professor's Name: Dr. Nikhil Gupta  
 Team No./Project: 15/Portable Wind Turbine  
 Vendor Name: McMaster  
 Vendor Website: www.mcmaster.com  
 Your Name: Stephen Freeman  
 Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
0.025" 1095 Spring Steel - 9043K42	1	\$18.30	\$18.30
1/4" 1144 Carbon Steel Rod - 6628K224	1	\$0.98	\$0.98
1" 6061 AL Rod - 8974K13	1	\$5.32	\$5.32

**SUB TOTAL:** \$24.60

\* Include units if other than single item (e.g. 2 dozen)

**Purpose:**  
 Raw material for machining for various components

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 67. Purchase order 5 completed by Team 15.

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 03/30/2016

Professor's Name: Dr. Nikhil Gupta

Team No./Project: 15/Portable Wind Turbine

Vendor Name: Amazon/E-Plastics

Vendor Website: amazon.com // eplastics.com

Your Name: Stephen Freeman

Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
3in Screen Louver	1	\$8.80	\$8.80
0.625"x12"x12" Delrin (Black)	2		\$59.46
Pelican Storm iM3075	1	\$378.32	\$378.32
Screen Shots of Websites Attached			

**SUB TOTAL: \$446.58**

\* Include units if other than single item (e.g. 2 dozen)

Purpose:  
Materials for nacelle end caps

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 68. Purchase order 6 completed by Team 15.

## Department of Mechanical Engineering

### Purchase Order Request

Please Fill In All Information

INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date: 04/03/2016

Professor's Name: Dr. Nikhil Gupta

Team No./Project: 15/Portable Wind Turbine

Vendor Name: McMaster

Vendor Website: mcmaster.com

Your Name: Stephen Freeman

Your Email: sef12e@my.fsu.edu

Item Description (include item #)	Quantity*	Unit Price	Total Cost
24"x24" 0.125" AL Sheet	1	\$79.97	\$79.97
1 1/4" OD, 1" ID Nylon Tube	1	\$22.49	\$22.49
1" OD, 15/16" ID Nylon Tube	1	\$8.22	\$8.22
12"x24" 0.080" AL Sheet	1	\$32.80	\$32.80
24"x24" 0.090" AL Sheet	1	\$64.74	\$64.74
Pins w/ Retainer	2	\$2.05	\$4.10

SUB TOTAL: \$212.32

\* Include units if other than single item (e.g. 2 dozen)

Purpose:

Materials for nacelle end caps

Attach additional pages as needed. Attach quotes or copies of catalog pages whenever possible.

Figure 69. Purchase order 7 completed by Team 15.

## Appendix D: Design For Manufacturing, Reliability and Economics

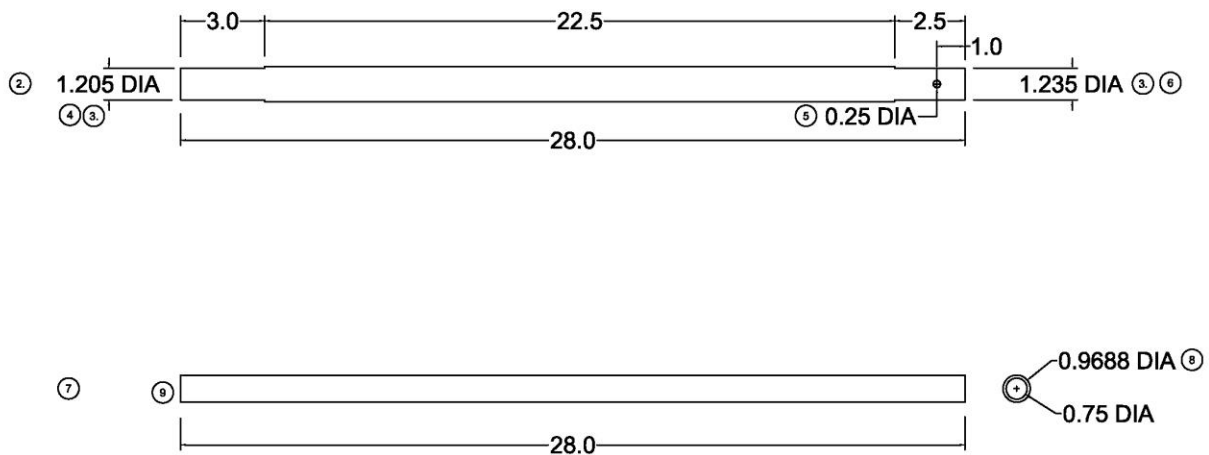
The following pages contain the previously completed report on the Design for Manufacturing, Reliability and Economics of the Portable Wind Turbine project.

# 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.

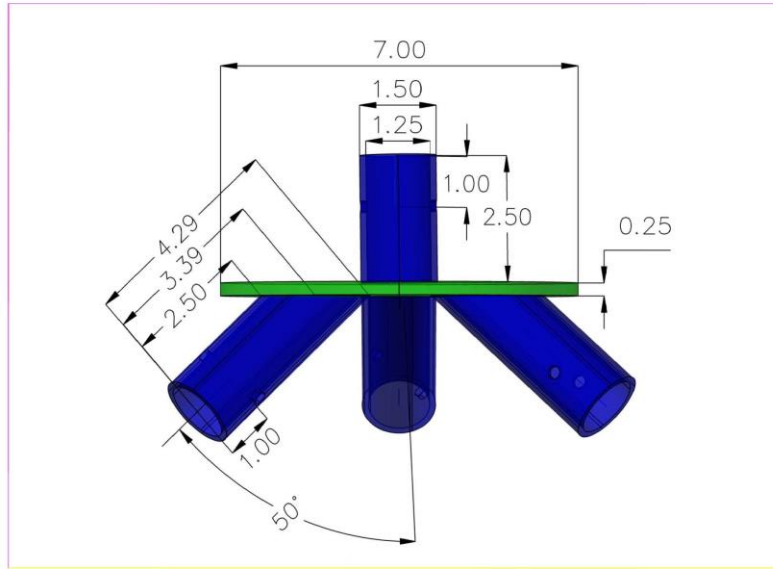


**Notes:**

- 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.

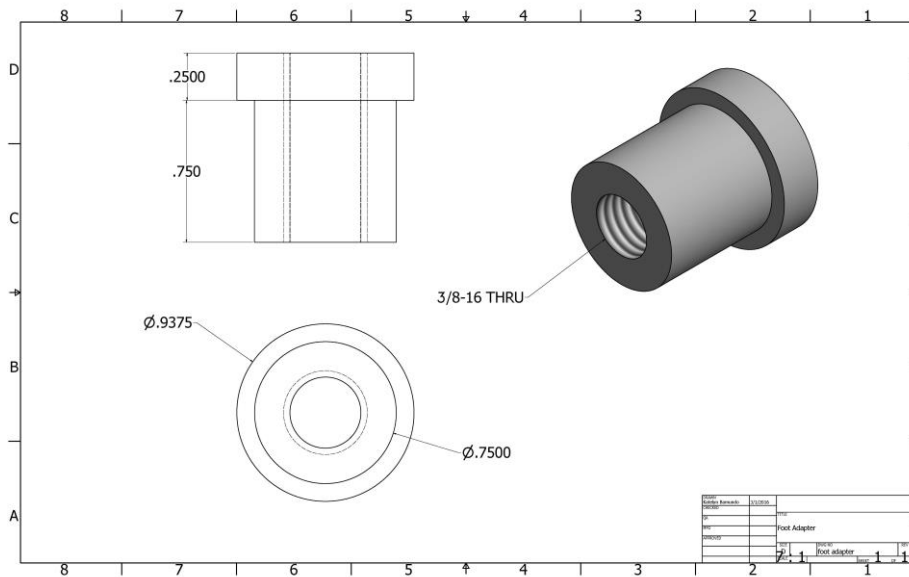
**Figure 1. The drawings for the aluminum tubing for the base.**

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.**

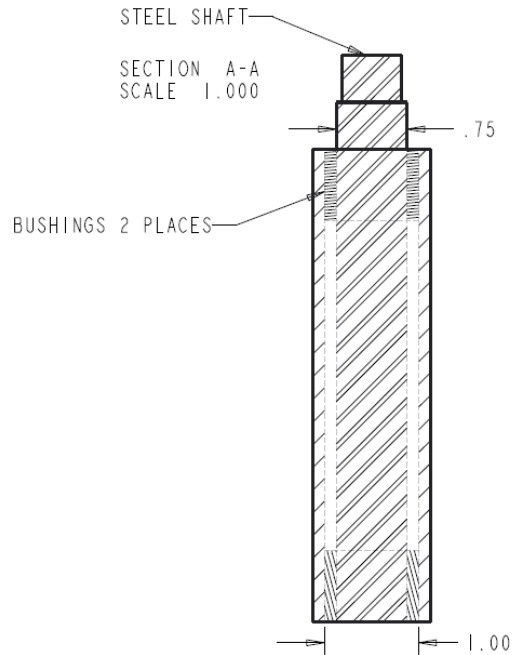
## 1.2 Nacelle

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.



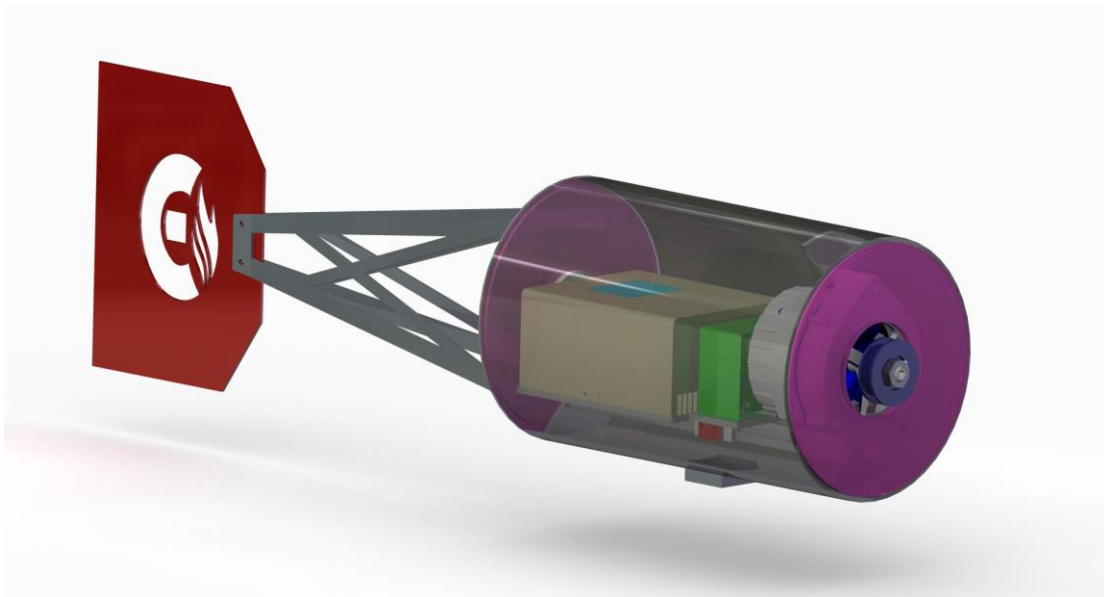
**Figure 4. Quick release system that joins the nacelle to the base.**

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.



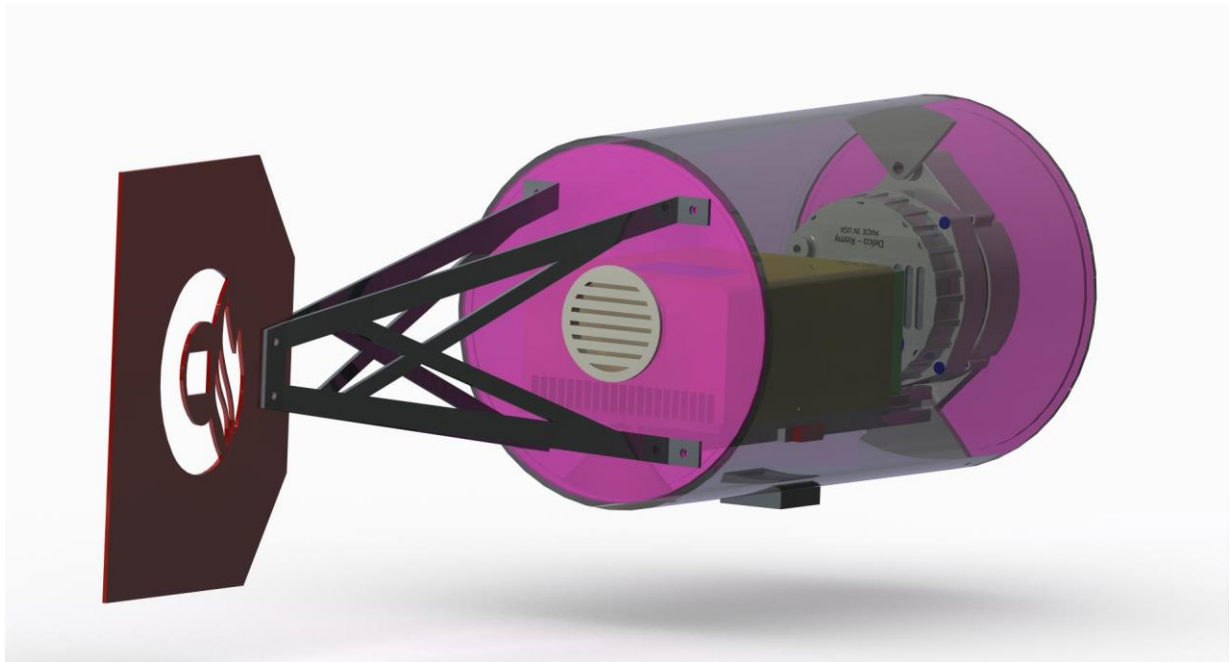
**Figure 5. Cross section of the system allowing free rotation of the nacelle.**

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.

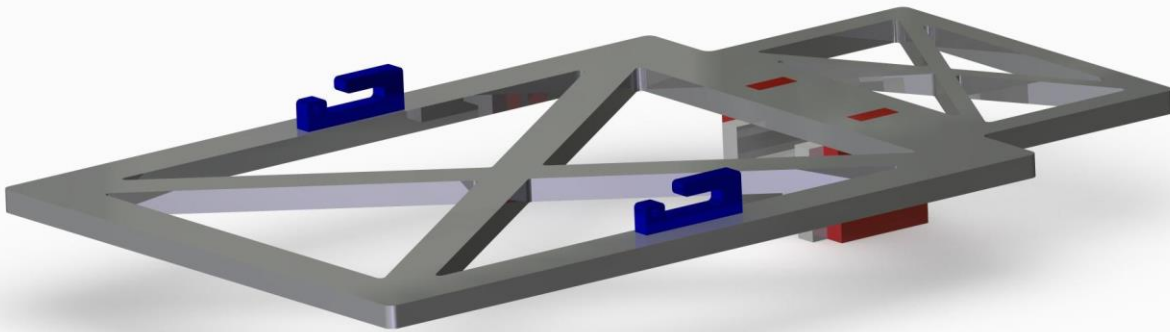


**Figure 7. The rear end of the nacelle.**

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.



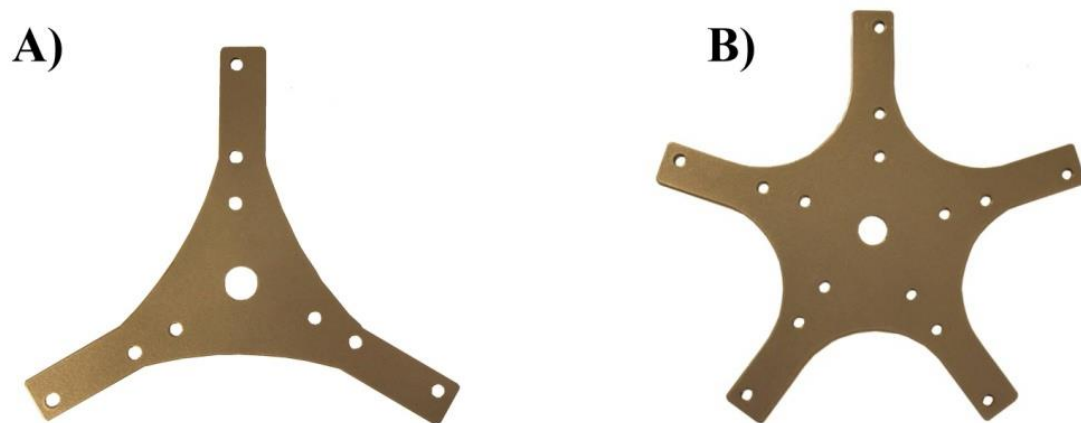
**Figure 8. The carriage system that holds the charge controller and battery.**

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.

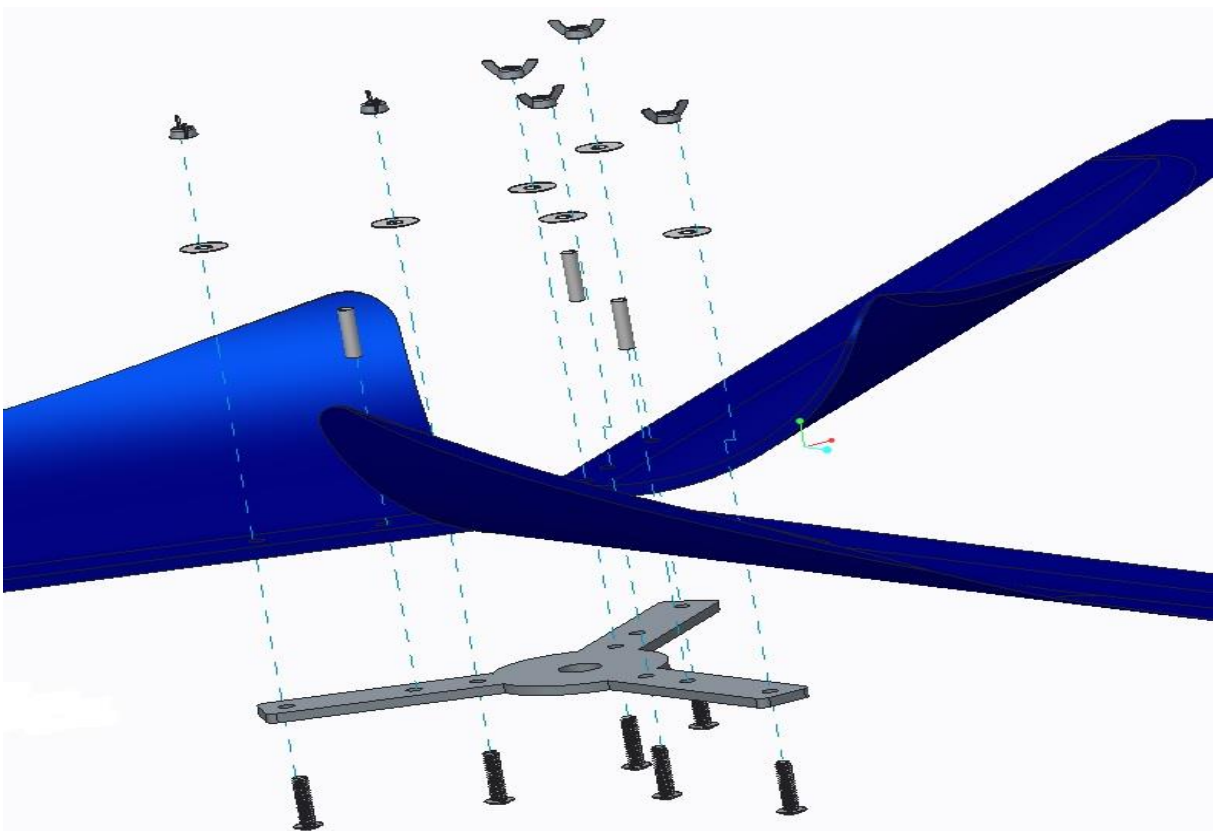


**Figure 10. Hub designed to mount blades to the alternator shaft.**

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

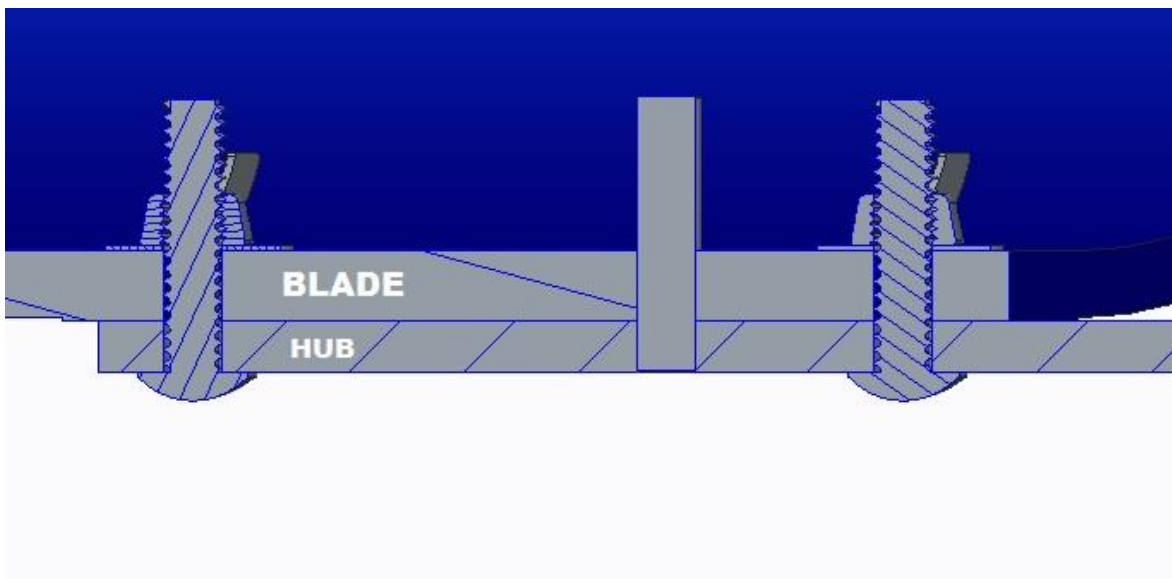
The only significant concern, and was addressed, was the components overheating in the nacelle due to the release of heat from the charge controller specifically. Since the charge controller will be regulating the power output to the battery, excess power will be released through the heat fins built 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

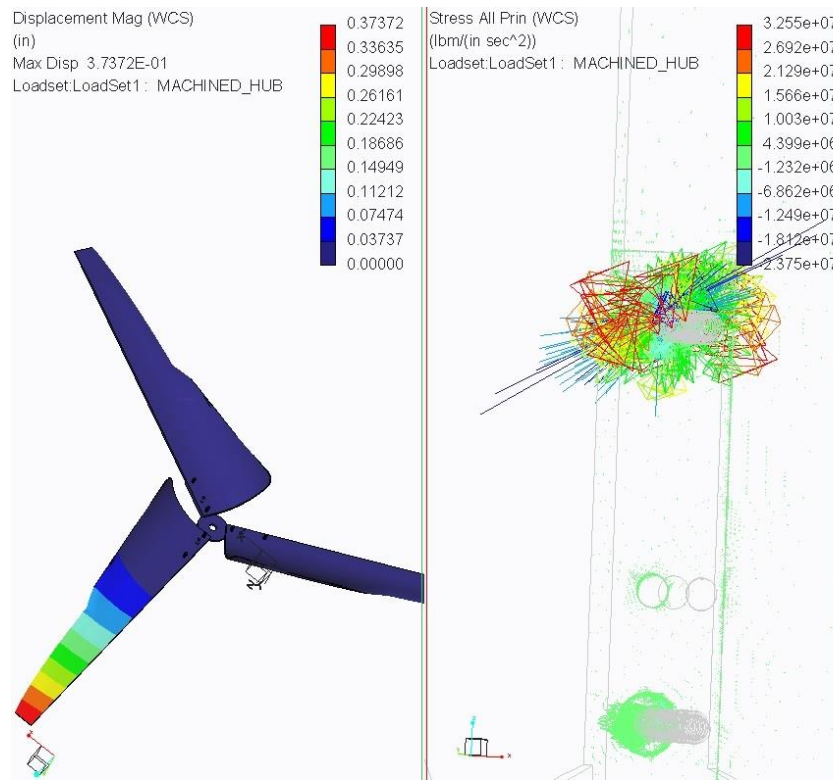
the wing nut when installing the blades possibly causing the blades to crack at the base. The compressive strength for the UV-Stabilized polycarbonate is about 80 MPa. To avoid the possibility of cracking, the stainless steel washer will increase the surface area of contact on the blade which will increase 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.



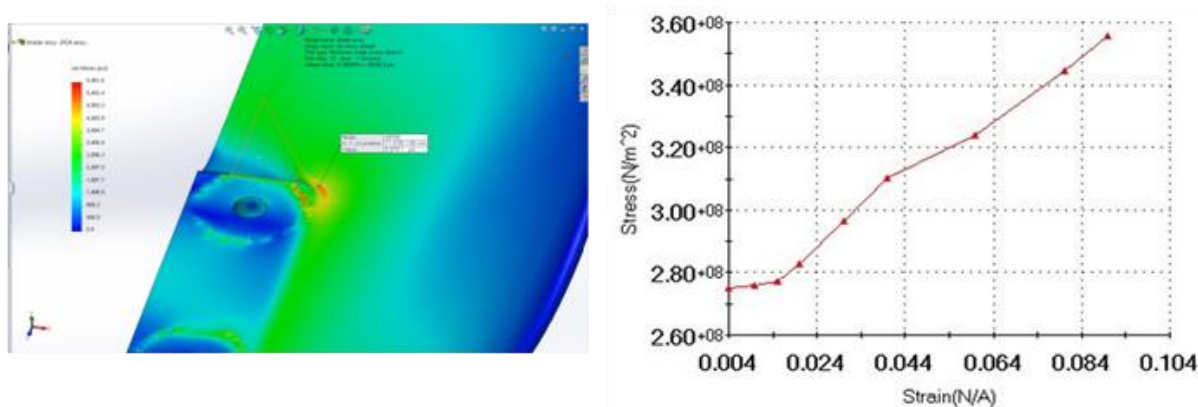
**Figure 12. Cross section view of the blade system at the base of the blade.**

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

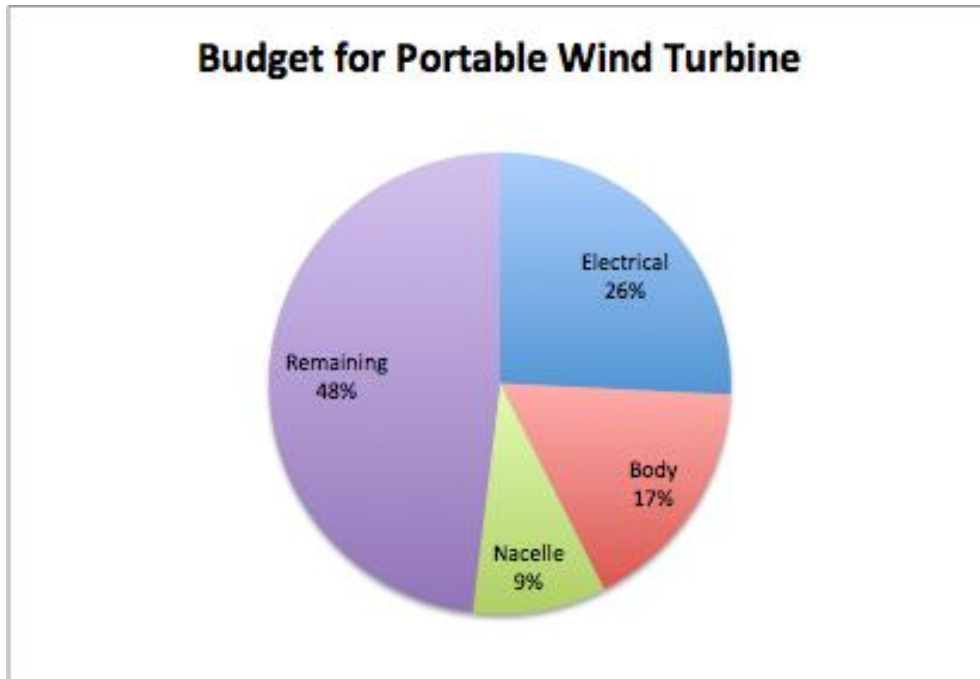
### 3.1 Power Generation

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.**

<b>Part</b>	<b>Cost</b>
Alternator	\$239.00
Charge Controller	\$199.99
Battery	\$76.54
<b>Total</b>	<b>\$515.53</b>

**Table 2. Cost of materials for the nacelle.**

<b>Part</b>	<b>Cost</b>
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
<b>Total Cost</b>	<b>\$272.89</b>

**Table 3. Cost of materials for the body.**

<b>Part</b>	<b>Cost</b>
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
<b>Total Cost</b>	<b>\$335.48</b>

## 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.

## Appendix E: Operational Manual

The following pages contain the previously completed Operational Manual for the Portable Wind Turbine Prototype.

# 1. Functional Analysis

## 1.1 Base

The base of the Portable Wind Turbine was designed to carry the weight of the blades and nacelle as well as being easily assembled and disassembled for any user. The base is 2 meters tall and can charge a small electronic device. The size of the legs of the base were minimized while the neck section was maximized for the purpose of easy transportation. The base for the portable wind turbine is made out of Standard 6061 Aluminum tubing with a yield strength of 35 KSI, which will be strong enough to withstand the weight of the entire turbine and additional wind loads. The tower is separated into separate sections. All parts are shown in Figure 1 in the Appendix. First are the telescoping leg sections, these can be shown in Figure 1 Sections (A) and (B). These will be connected with a clamp to adjust for any length of the legs determined by the terrain which can be seen in Figure 1 Section (C). At the bottom of the legs will be an all-terrain foot which can be seen in Figure 1 Section (F). This foot will be screwed into the bottom of each tube closest to the ground. The all-terrain foot will accommodate for the angle of the legs to remain the same on all surfaces. The next piece of equipment for the tower will include the connection of the neck to the legs which can be seen in Figure 1 Section (E). This connection is also made out of 6061 aluminum tubing and sheet metal. The tubes for the legs will slide into the connection and will be placed together with pins which can be seen in Figure 1 Section (D). The neck section is made with the same tubing as the legs and will then be connected with pins to the connection piece. The assembly of the base with specified parts can be seen in Figure 2 in the Appendix.

## 1.2 Nacelle

The nacelle is essentially the housing for the electrical components. The nacelle sits above the base and attaches to the body through the quick-release mechanism that was implemented. This allows for easy assembly and disassembly. The nacelle was designed to maintain a dry atmosphere for the components, while also allowing for air to flow through to help avoid any overheating that might occur. The components inside the nacelle are comprised of a battery, charge controller, diodes, and an alternator. The alternator converts the mechanical energy from the wind to electrical energy that can be stored in a battery and used to charge a mobile device. This electrical energy is

passed through wires to the charge controller. The charge controller acts as a filter to maintain a level output of voltages to charge the battery. If the alternator is outputting more voltage than the battery needs, the charge controller filters the excess. The charge controller is even capable of briefly adding power when the wind slows down for short periods of time. The charge controller outputs the regulated power to charge the battery. The diodes are placed throughout the circuit to safeguard that the current only flows in the correct direction. The alternator is connected to the blade shaft.

### 1.3 Blades

Two essential components of the wind turbine design are the blades and the way in which they are mounted. Ultimately a company called Windy Nation was chosen to source the blades from. Windy Nation provides much more information about their products than many other suppliers and the company is based in the United States, lowering the lead time for receiving the blades and facilitating communication between the supplier and consumer. Windy Nation offers two options in each of three categories for wind turbine blades. These options can be seen in Table 1.

**Table 1. Blade options offered by Windy Nation.**

<i>Category</i>	<i>Option 1</i>	<i>Option 2</i>
<i>Blade Material</i>	Aluminum	UV-stabilized polycarbonate
<i>Blade Length</i>	28in	35in
<i>Number of Blades</i>	3	5

UV-stabilized polycarbonate blades were chosen for this application. Blades made from this material would withstand abuse better than the aluminum blades since aluminum could potentially be permanently deformed. Also the UV-stabilized polycarbonate blades reduced the overall weight of the final design. The airfoil of the blades is a thin under-cambered profile, this shape is practical for low-speed aerodynamic applications such as the Portable Wind Turbines, where high lift force is desired at low flow speeds and corresponding Reynold's Number.

To completely eliminate or reduce the need for tools a custom blade mounting hub with retaining mechanisms was designed in Creo Parametric. The final design uses self-locking wing nuts, bumper bolts, and dowel pins will be used to attach the blades.

## 2. Project/Product Specifications

### 2.1 Base

The base of the turbine was split into a neck and three connected leg segments. The length of the neck was maximized while the leg lengths were minimized in order to decrease size and number and size of parts while increasing portability. Additionally to increase portability, each of the leg and neck segments have two telescoping aluminum tubes. This ability allows adjustment of the leg height for any change in ground slope up to fifteen degrees. These telescoping segments are held tightly in place with the help of a clamp. These clamps allow quick and easy use for the operator. Designing the tower out of aluminum allowed for lighter weight material in order to be transported easier. The hub height of the turbine is 2 meters. This allows the wind turbine to receive enough wind speed to generate enough power to charge small electronic devices. The exact dimensions of the tower can be seen in Figure 3 of the appendix.

### 2.2 Nacelle

The nacelle is responsible for protecting the integrity of the most significant components of the turbine, the alternator. In order to charge or power anything, the alternator must be able to efficiently convert the mechanical energy of the wind to electrical energy that can be stored in a battery. The team selected a WindBlue Power DC-540 alternator. With the target goal of being able to charge a 5 watt device, the WindBlue alternator shows what currents and voltages are outputted based on rpm. With the tip-to-speed ratio of the selected blades under the influence of 4 m/s (~10 mph) wind speeds, the expected rpm is to be around 190 rpms. As represented in Figure 4 in the Appendix, this gives a projected ~25 watts of power. While this is significantly higher than is required to charge a device of only 5 watts, there is expected losses as well as the power flowing through the charge controller, which will also be regulated. The charge controller selected, the Windy Nation TrakMax, enables the user to adjust the desired output voltage according to the battery connected (in this case the battery is 12 volts and that would be the standard on the controller). The 12 volt battery selected was a Battery Tender lithium iron phosphate battery. All of this fits snug inside the nacelle. A final feature added to the nacelle was the ability to have the

charge controller slide out of the back when a panel is opened. This removal is for the ease of the consumer if they need to adjust the power regulation.

## 2.3 Blades

The specifications for the blades ordered from Windy Nation used for the Portable Wind Turbine are given below in Table 2. The company website provided all information in the table, although it should be noted that the exact airfoil specifications of the blades are unknown, however the general airfoil shape is known and is mentioned in the table. Also the wind swept diameter will vary slightly since the mounting hub is not the standard one that is typically included with the blades. Windy Nation also states that the blades are rated to handle 70mph (31.3 m/s) wind speeds with a safety factor of 2, which is suitable for the Portable Wind Turbine that will operate in wind speeds of 4 m/s. Figure 5, in the Appendix, displays the dimensions for the blades.

**Table 2. Product information for the blades.**

<b>Material</b>	UV-stabilized Polycarbonate
<b>Length</b>	28in.
<b>Airfoil</b>	Under-cambered
<b>Swept Diameter</b>	59in.
<b>Weight</b>	0.704 lb

As previously mentioned the mounting system for the blades was designed in Creo Parametric and then cut using a water jet. The wing nuts and washers are standard where the wing nuts are 1/4-20 Grade 2 Zinc Plated Zamac Nylon Insert Wing Nuts, the washers are 1/4" x 0.734" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washers, and the bumper bolts are stainless steel capped pan head bumper bolts. According to imperial torque charts for locking nut fasteners, the average minimum assembly torque for hex sizes 7/16-1/2 in. ranges from 23 to 37.5 ft-lb. These are normally used to fasten the blades to the hub. Research concerning wing nut torque revealed that for a 5/16" wing nut the average torque for a male was about 3.3 ft-lb for a male and 2.5 ft-lb for a female.

## 3. Product Assembly

### 3.1 Base

The assembly of the base of the turbine is depicted in Figures 1 and 2 in the appendix. The parts for the base will be located inside the carrying case along with the other parts of the turbine while being transported. After the parts have been removed from the case, the parts should be organized. There should be three small 28-inch tube sections (A), four large 28-inch tube sections (B), three clamps(C), four pins (D), the welded plate (E), and three feet (F) for the base. No additional parts or tools are needed for the assembly of the base.

The four larger tubes should be inserted into the welded plate so that the holes in the tubes are aligned with the holes in the plate. Between the insertions of each of the tubes, a pin should be pushed through the holes and latched. After all four of the larger tubes have been inserted into the weld plate and each of them have been secured by pins, the clamps and smaller tubes can be utilized.

There are two sides to the plate. The side of the plate with three tubes protruding from it (not one) will be the focus of this step. The three clamps should be fastened onto the end of the three tubes on this side of the plate. They will be fastened simply by sliding snugly into place. After this is completed, the three smaller tubes should be slid into the clamps, into the larger tubes. Then the clamps should be both tightened and closed. Make sure in this step that the tubes are oriented in the correct direction. The side of the small tubes without inserts should be the one entering the large tubes.

Finally, the three feet can be screwed into the bottoms of the smaller tubes through clockwise hand rotations. The threaded end of the feet should screw into the small tubes' inserts with ease. In disassembly, the parts should be disassembled in reversed order, then inserted back into their case.

### 3.2 Nacelle

The nacelle is one of the few parts of the turbine that the user has little to no assembly on. The nacelle will come as one unit with everything inside. The charge controller will be removable, but on first arrival will be inside the nacelle with the other electrical components. The only assembly

required is to use the quick-release mechanism that has been added to the system, which also requires minimal effort. Simply squeeze on the flanges and pull to remove the nacelle, or placed on. This quick release system is shown in Figure 4 of the Appendix.

### 3.3 Blades

The blades should be removed carefully from the foam packaging. The hub will already be attached to the alternator and will be retained using the standard bolt and screw used to secure the hub clamp. The user should then ensure that the 8 stainless steel washers and self-locking wing nuts are present, take 6 of each out of the package and set them aside. There are 2 extra wing nuts and washers included for replacement. Once the user has assured that all parts for assembly are present, take the alternator and hub assembly and position it with the threads of the bumper bolts facing up. Then one at a time take a blade and align the mounting holes in the blade with the screws and pin on the face of the hub, do this with the curved side of the blade facing up. Once aligned set the blade down onto the hub so that the threaded bolts and pins go through holes. The user should then proceed to place one washer on each of the threaded bolts, while holding down the blade with one hand and along the flat side of the blade near the base. Once the washers are set, while still securing the blade with one hand grab one wing nut and screw it onto the bumper bolt until the blade is secure, do this for each both wing nuts on each blade. Rotate the hub with blades attached carefully when screwing on the wing nuts. The user should make sure not to over torque the wing nut to prevent damaging the blade, specifically the upmost wingnut.

## 4. Operation Instructions

The operation of the portable wind turbine depends on the ability of the user to place all of the pieces together. Once this is done the turbine can work in the desired location to generate power. To maintain the parts of the turbine, make sure the individual parts have not been broken or worn down. All parts are necessary for the operation of the turbine.

### **Startup**

After the connections made between the base, nacelle and blades are completed the turbine can operate properly to charge the desired small device. The legs of the base also need to be adjusted for the slope of the chosen terrain and the terrain must be a solid ground in which the turbine stands properly with no tilts.

### **Operation**

Once the turbine is properly assembled and placed on a stable ground the user can plug in their small desired device to be powered.

### **Shut Down**

After the wind turbine has served its purpose it can be disassembled. This is done by taking apart the pieces of the tower, nacelle and blades. Once the turbine is disassembled, they should be placed in the casing provided and can be carried conveniently offsite.

## 5. Troubleshooting

### **Leg or neck segments are sliding and not staying in place.**

Make sure clamps are tightened securely.

### **If the charge controller fails.**

Refer to the Windy Nation TrakMax 30L LCD MPPT 30A Charge Controller manual under Reference 1.

### **Small electronic device is not being charged.**

Check to see that the USB is completely plugged in to the USB port on the nacelle.

### **If pin connectors or telescoping legs do not properly match or slide.**

Check to see if the connections can be adjusted without damaging the pins or leg segments. If not, contact manufacturer to receive new parts.

## 6. Regular Maintenance

Minimal maintenance is required for the Portable Wind Turbine prototype since there are a minimum of moving parts in the design.

Overtime, the lubricated brass bushings in the neck of the turbine that allow free rotation of the turbine nacelle with changing wind directions may wear out. This will be indicated by a failure of the turbine to passively reorient the nacelle to keep the blades facing into the wind. If this occurs:

- 1) Remove the collar that connects the quick release hex-head to the rest of the base of the turbine.
- 2) Use an Allen key to remove the bolt holding the rotating shaft in place
- 3) Press out the brass bushings
- 4) Purchase replacement bushings from: <http://www.mcmaster.com/#standard-sleeve-bearings/=11sb5sv> (Part Number 1688K26)
- 5) Press the new bushings into the tube
- 6) Reassemble the turbine base

## 7. Replacement Parts

Should parts of the Portable Wind Turbine become damaged, the best method of replacement is by contacting the manufacturer. If this is not an option, the following sources can be used for replacement of individual components of the Portable Wind Turbine:

- All aluminum and Delrin materials can be sourced from [www.mcmaster.com](http://www.mcmaster.com) (although some minimal machining may be required if purchasing raw materials).
- All fasteners (such as bolts and washers) can be purchased from a local hardware store or [www.fastenal.com](http://www.fastenal.com)
- Replacement turbine blades can be purchased from Windy Nation at: <http://www.windynation.com/Blade-Sets/28-inch-HyperSpin-P-Series-Wind-Turbine-Blades-Set-of-3/-/172?p=YzE9MTM=>
- Replacement feet for the base can be purchased from B&H Photo and Video at: [http://www.bhphotovideo.com/c/product/326243-REG/Gitzo\\_G1220\\_130B3\\_G1220\\_130B3\\_All\\_Terrain\\_Shoes.html](http://www.bhphotovideo.com/c/product/326243-REG/Gitzo_G1220_130B3_G1220_130B3_All_Terrain_Shoes.html)
- Replacement clamps for the telescoping legs can be purchased from RockWest Composites at: <https://www.rockwestcomposites.com/bonding-telescoping-clamp>
- A replacement charge controller can be purchased from Windy Nation at: <http://www.windynation.com/Charge-Controllers/WindyNation/TrakMax-30L-LCD-MPPT-30A-Solar-Charge-Controller-Regulator-12-24-48-Volt/-/1247?p=YzE9MTc=>
- A replacement internal battery can be purchased at: [http://www.amazon.com/Battery-Tender-BTL09A120C-Lithium-Phosphate/dp/B00F9LPIAC?ie=UTF8&refRID=1BCZJBPP0NR43KP7NSVG&ref\\_ybh\\_a\\_27](http://www.amazon.com/Battery-Tender-BTL09A120C-Lithium-Phosphate/dp/B00F9LPIAC?ie=UTF8&refRID=1BCZJBPP0NR43KP7NSVG&ref_ybh_a_27)
- A replacement alternator may be purchased at: [http://www.windbluepower.com/Permanent\\_Magnet\\_Alternator\\_Wind\\_Blue\\_Low\\_Wind\\_p/dc-540.htm](http://www.windbluepower.com/Permanent_Magnet_Alternator_Wind_Blue_Low_Wind_p/dc-540.htm)

## Biography

- **Katelyn Bamundo** is a senior in the Department of Civil Engineering at Florida State University. Katelyn is the Head Civil Engineer of Team 15. During her time at Florida State University, she has worked as an engineering intern at Universal Orlando.
- **Stephen Freeman** is the Vice President of the FAMU-FSU Society of Automotive Engineers and has worked at ASC-NHMFL and interned at Toyota Motor Sales in Torrance, CA. Currently working as an Undergraduate Research Assistant at AME, he has accepted a full-time offer from Toyota and will relocate to California after graduation.
- **Matthew Hutchisson** is a senior in Civil Engineering, focusing in structures. He has worked as an intern at Reynolds Smith and Hills and plans on attending graduate school before starting career.
- **Stephanie McLellan** is a senior in the Department of Civil Engineering. Stephanie was an intern at Turner Construction Company in Miami, FL and worked on building the American Express Headquarters in Sunrise, Florida. Stephanie has accepted a full time offer with Turner Construction Company and will relocate to Miami, FL after graduation.
- **Garrett Rosenthal** is a sixth year senior studying Mechanical Engineering at Florida State University. When not studying for classes, he enjoys participating in the university's intramural sports program and networking with his peers.
- **Rishad Walker** worked as a Project Engineer for Exp. Energy Services this past summer, gaining experience in Interstate Natural Gas and Crude Oil Transmission Pipeline Routing. Rishad plans to complete the Fundamentals of Engineering exam prior to his graduation, with later plans of receiving a Professional Engineering License.