

University of Alaska Fairbanks  
Collegiate 2014  
Technical Report

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## Turbine Overview

Our turbine will need to be able to withstand the rigorous conditions of field performance and the stress that accompanies high wind speeds. At the same time, low wind speed performance is critical to being functional in variable environments. To meet these standards the blade design will be optimized for a wide range of wind speeds and the drivetrain will have a low rotational mass to facilitate low cut in speeds.

The system is able to hold up to sudden changes in the wind speed and has an emergency stop. Testing of the overall wind turbine assembly was done in a custom built wind tunnel that was used to not only optimize component properties, but to perform destruction tests to assure that the turbine is functional and safe at very high wind speeds.

## Blade Design Techniques and Methods

Primary blade design was accomplished through means of using third party software, such as MATLAB and Microsoft Excel, to do intensive and iterative calculations. Equations and methodology were obtained from Manwell's book, *Wind Energy Explained: Theory, Design and Application*.

The primary method of modeling the blades is done using Solidworks. Flow simulations within Solidworks help to provide some preliminary data to compare for when real-time testing in the reconstructed wind turbine is done with the prototyped blades. The blade design and model will be modified pending test data from the wind tunnel.

The following process was how the blades for the wind turbine were designed. Predetermined values for different aspects of the overall wind turbine were used to determine what the values of critical variables for the calculation and design of the wind turbine. The number of blades,  $n$ , was chosen

to be 3. The cut in speed, or wind speed at which our blades would start to generate power, for our turbine was picked to be 2.3 m/s (5.14 mph). Using the cut in speed (CIS), the tip speed ratio (TSR) was found to be 4.89.

$$TSR = \frac{(R_T) * V}{CIS}$$

Where  $R_T$  is the radius of the rotor in m,  $V$  is the speed needed to start power generation in rad/s, and CIS is the desired wind speed for power generation to occur in m/s.  $R_T$  was taken to be .215 m and the RPM at cut in was 500 RPM or 52.359 rad/s.

Depending on how many iterations are being used, the TSR, and radius will have to be found for every different section. For the radius, simply take the section number, beginning from one, and multiply it by the fraction of the radius and divided by the total number of iterations. The local TSR can be found by multiplying the overall TSR by the local section number divided by the total number of sections.

Once the TSR has been found then  $\phi$ , the angle of relative wind is calculated for each section using equation 3.111 on page 134 of Manwell's *Wind Energy Explained: Theory, Design and Application*.

$$\phi = \frac{2}{3} \arctan\left(\frac{1}{TSR}\right)$$

The blade cross section S822 was chosen because the thickness of the blades was relatively higher compared to the chord length (CI), making it ideal for small turbines made out of relatively weak material. The cross section also has very good performances characteristics at the low wind speeds the

turbine will be operating at. The angle of attack was chosen such that the CL/CD ratio was at its maximum; this was around an angle of attack of 9.25 degrees. The process from this point is about pitching the angle of the blade such that as the blade travels through the air, it will experience this alpha design.

The section chord length for each section is calculated using Equation 3.112 on page 134

$$C = \frac{8\pi R_T}{nC_{l,design}}(1 - \cos(\varphi))$$

Then using Equations 3.113 and 3.114 on pages 134, the twist angle of the blade can be calculated. It is also necessary to generate the  $C_{l\_alpha}$ , and  $C_{l\_0}$  information, by making a graph of the  $C_l$  vs  $\alpha$  near the angle of attack chosen, approximating and generating a trend line using excel. The slope of that line is  $C_{l\_alpha}$ , and the intercept is  $C_{l\_0}$ .

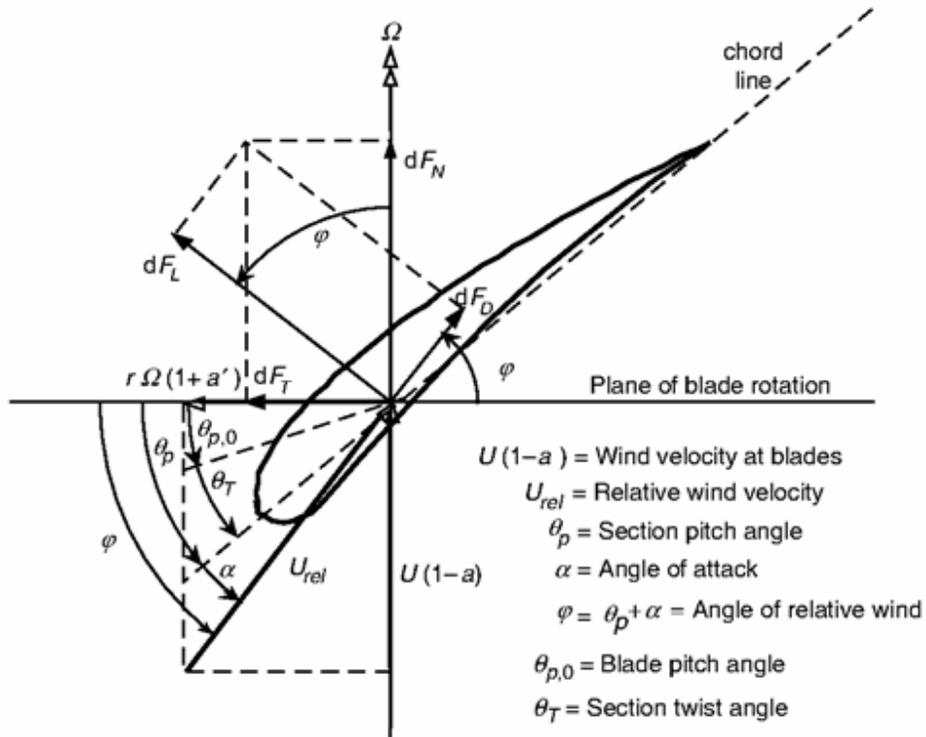


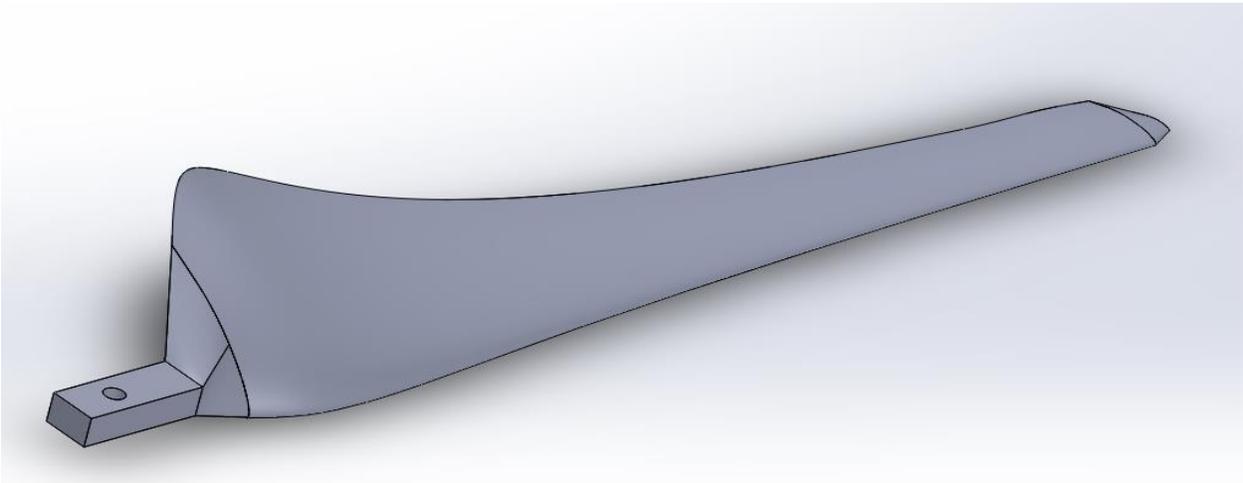
Figure 1: Shows the different variables that need to be calculated.

Figure 1 shows the plane of motion, and the incoming wind velocity perpendicular to the blades rotation. The angle of relative wind shows what wind velocity the blade experiences as it is moving. The goal of this process is to find the section pitch angle such that the alpha in the diagram is the alpha design we have chosen.

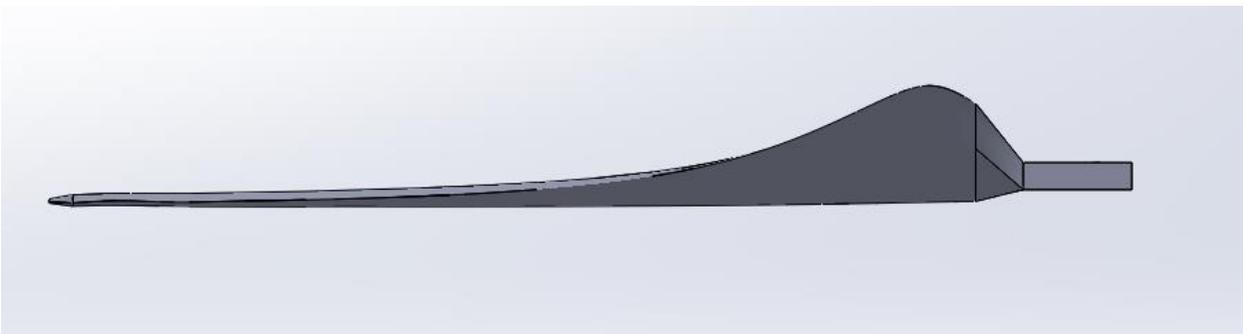
The process of optimizing this number is explained on page 135; this process needs to be applied to each and every section. The inputs for this method are the radius of the blades, the Overall TSR,  $Cl_0$ ,  $Cl_{\alpha}$ , number Blades, the local radius, local chord length, local twist angle, and the tip pitch angle. Once constructed in the excel solver the  $Cl$  from the lift curve and from the momentum theory will be compared. Once the Fractional difference is equal to zero, the alpha has been optimized. For each section the local data will have to be changed, and alpha will be optimized for each section

The excel program that this was built in has a goal seek function that can be used to find the answer. This can be done by setting the fractional difference to zero by changing the "guess alpha"

value. If the initial value is not very close to the final answer, it may choose a large negative number which solves the equations. To avoid this, our answer is set initially to the alpha design. The optimized value will then be close to that one. Often the fractional difference will be very close to zero; in this case the value must be manually changed until the fractional difference is zero.



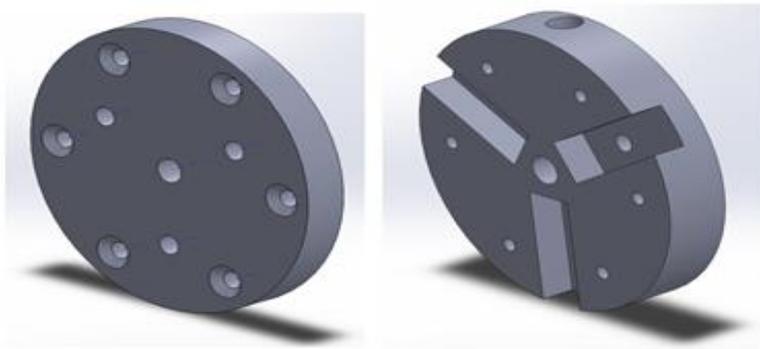
**Figure 2: Top view of turbine blade**



**Figure 3: Side view of turbine blade**

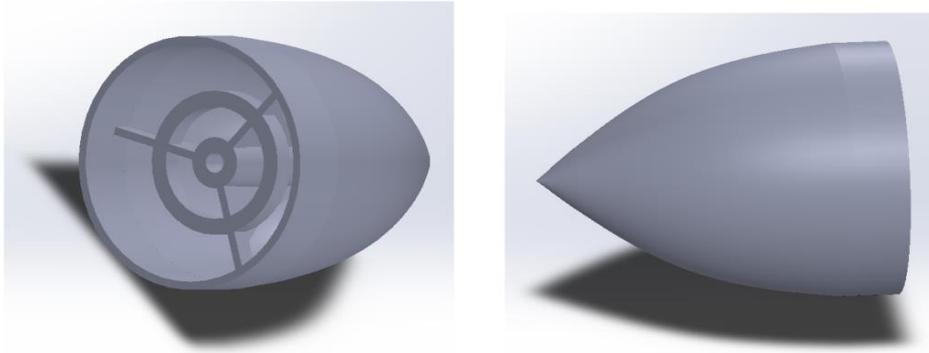
## Hub Design Techniques and Methods

For quick blade assembly and disassembly, the hub design, shown in Figure 1, utilizes a series of slots and pins. The hub will contain three slots for which three blades can be inserted in. A hole, perpendicular to the slot, will be placed near the end of the slot. A flat hub cap, shown on the right, will then be placed over the main body to secure the blades in the slots. With a hole at the end of the blade, a pin, placed within the hole in the hub, will slide through the hole of the blade, locking the blade in place. The screwed on nosecone, located behind the pin, will then secure the pin in place and ultimately the blades in place. The connection of the hub to the low speed shaft then will be made using a set screw located on the side of the hub. Operations to construct the hub were performed using a lathe and a vertical drill press. Starting with 2 and ¼ inch round aluminum 6061 – T6 stock, the hub was cut to the 2 inch diameter as specified. The slots and holes for the pins and screws were then made using the vertical drill press.



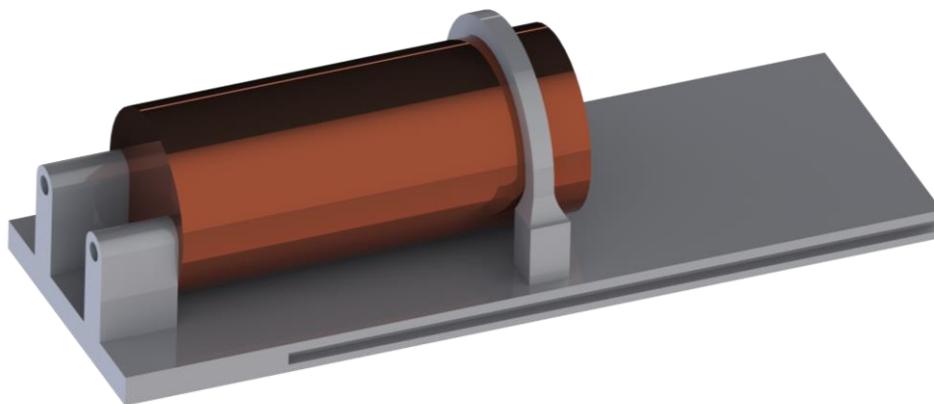
**Figure 4: Hub Cap (left), Main Hub Body (right).**

The nose cone, shown in Figure 5, was primarily designed to hold the blade securing pins. To accomplish this task, a support bracket, located inside the nosecone, was created to press against the pins as the nosecone was screwed on the main portion of the hub. The outer portion of the nosecone was shaped parabolically in order to minimize fluid resistance and redirect the fluid toward the blades. The nosecone will be printed with high density plastic ABS using the Stratysis Fortus 250mc 3D printer.



**Figure 5: Inner View of Nosecone (left), Outer View of Nosecone (right)**

The chassis of the turbine functions to provide a platform to mount the various components of the turbine. As shown in Figure 6, the chassis consists of a flat plate, two support towers, and a horseshoe shaped arch. The support towers will secure the gearbox to the platform using the preexisting holes. The horseshoe shaped arch will wrap around the generator securing it to the platform. All components of the chassis will also be printed with high density ABS plastic using the Stratasys Fortus 250mc 3D printer.



**Figure 6: Motor and Chassis Assembly.**

The brake design involves a setup consisting of four links, a servo, hinges, and two curved brake pads. Shown in Figure 7, a servo, mounted on a bracket connected to the frame of the turbine, will engage a pair of links hinged to a second link on each side. With pins fixed to a bracket behind the hub, the second links then engage brake pads which will directly slow the rotational motion of the hub.

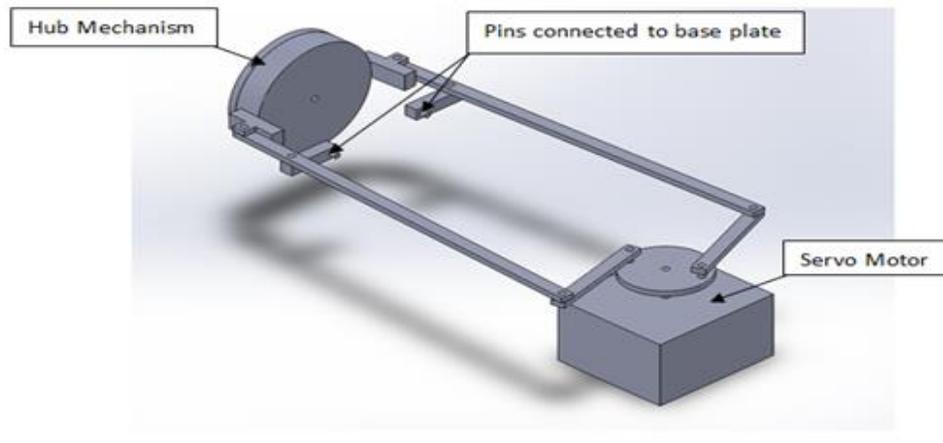


Figure 7: Servo Brake Design

Comparing previous brake concepts, the servo brake design is clearly simpler and requires fewer parts. The caliper and drum brake design, which were originally proposed, both require many small complex parts which require precision and accuracy in fabrication. In addition, the hydraulic system, used to drive the caliper and drum, require an extensive amount of fabrication. Due to the complexities associated with caliper and drum brake system, the servo brake design has been adopted as the primary design to be used for the braking system.

In addition, the mechanical brake system will be integrated with an electronic brake, as explained in Figure 11. The switch to activate the servo will also be wired to a relay which will short the output leads from the generator. While a majority of the braking can be accomplished through the electronic brake, the mechanical brake will provide additional braking as well as ensuring the brake system is fail safe.

## Electrical System

The Electrical System plays a simple yet critical role of rectifying the three phase motor to a clean DC signal. A DC/DC converter will be used in conjunction with the rectifier to regulate the output voltage to the desired voltage of 5V. The DC/DC converter will also be used to achieve a low turn on voltage by boosting the low input voltage to the desired regulated voltage.

The electrical system for the wind turbine will consist of three main sub systems as shown in the figure below.

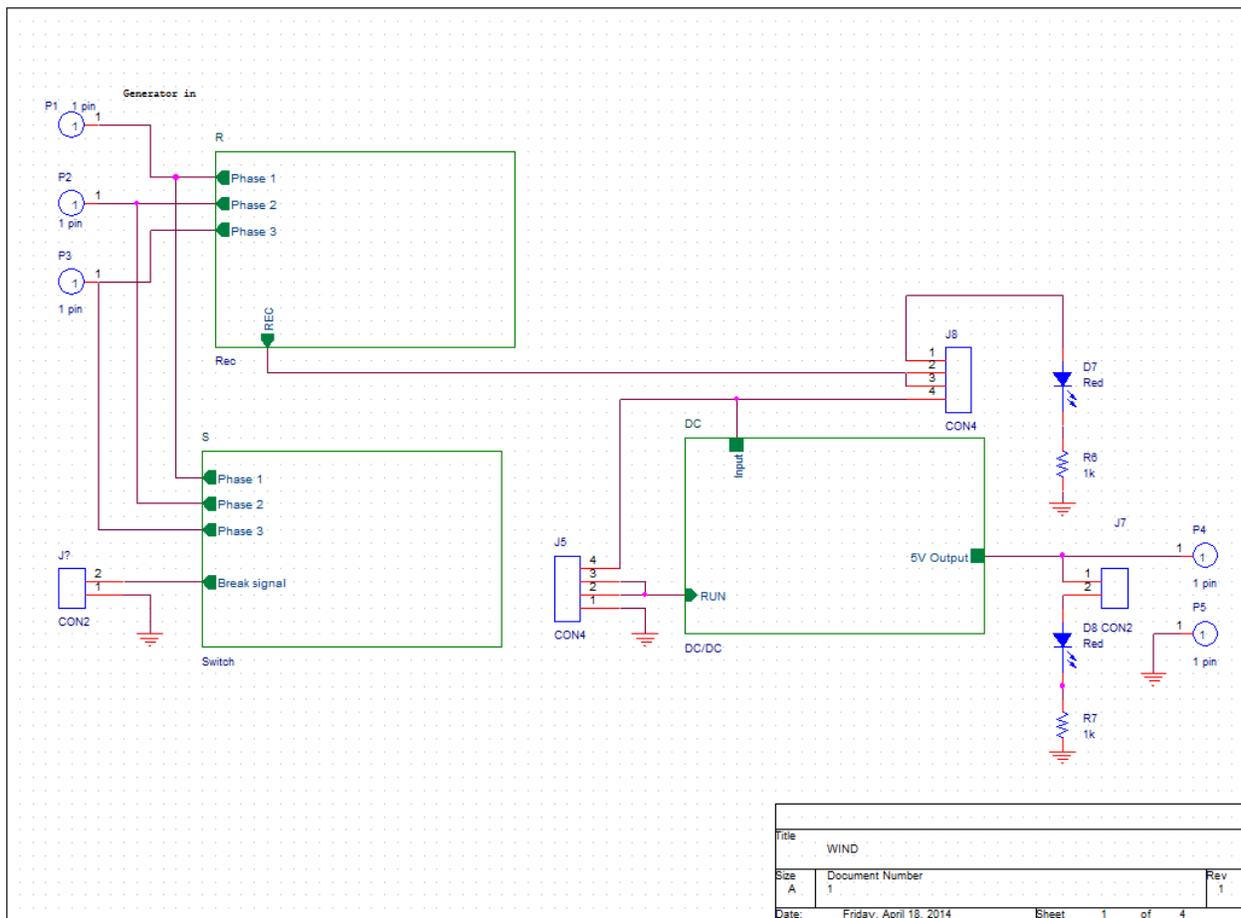


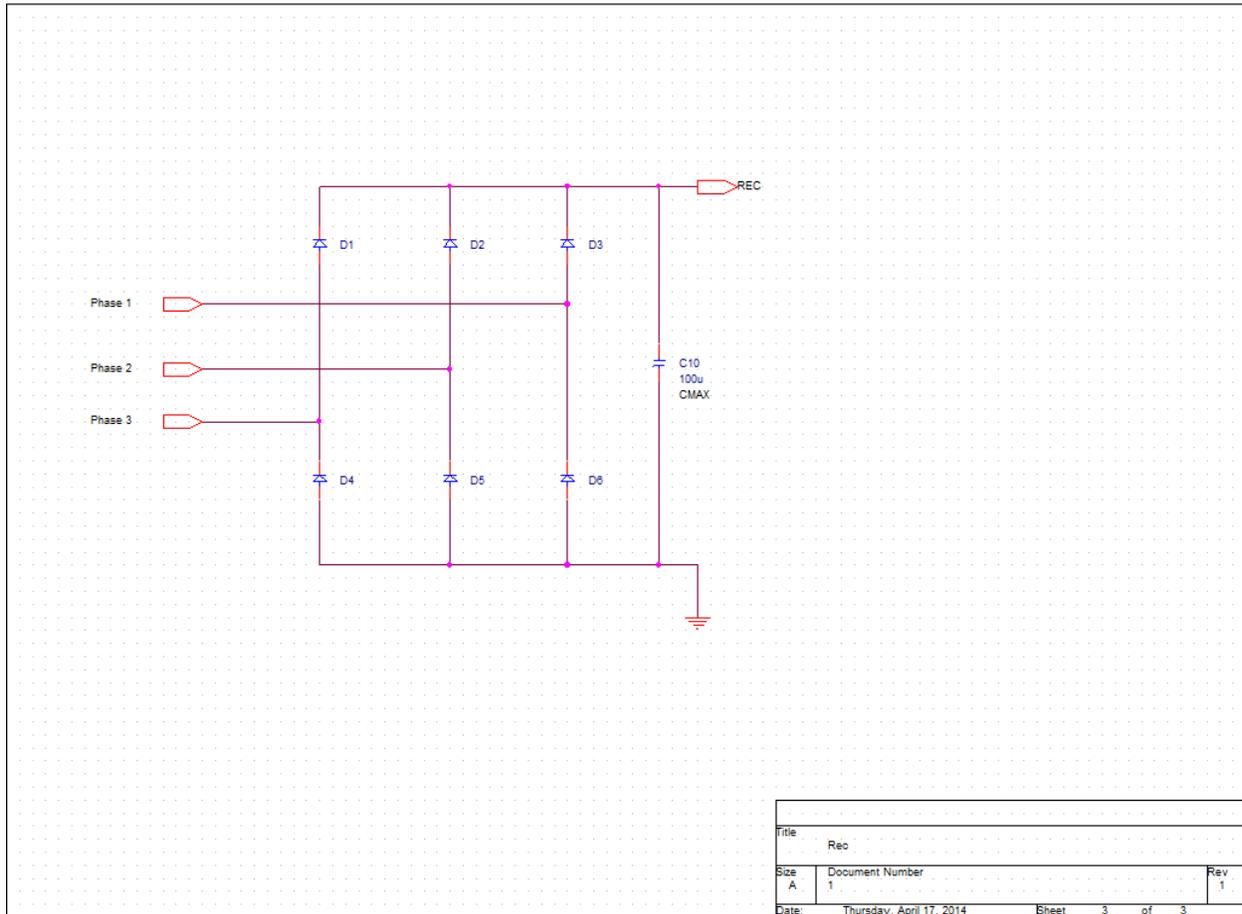
Figure 8: Schematic subsystem over view.

### System Requirements

- EE-001 The GPMG5225 brushless DC motor shall be used for power generation and will be the only source for the electrical system at start up (no batteries, or caps pre-charged).
- EE-002 The turbines output will be regulated as efficiently as possible to a value of 5 volts as specified by the rules document provided for the competition (pg. 40).
- EE-003 The turbine needs to maintain a minimum power rating of 10W for a given wind speed in between 5-14 m/s.
- EE-004 The turbine will break under critical wind speeds.

### System Makeup:

## Rectifier



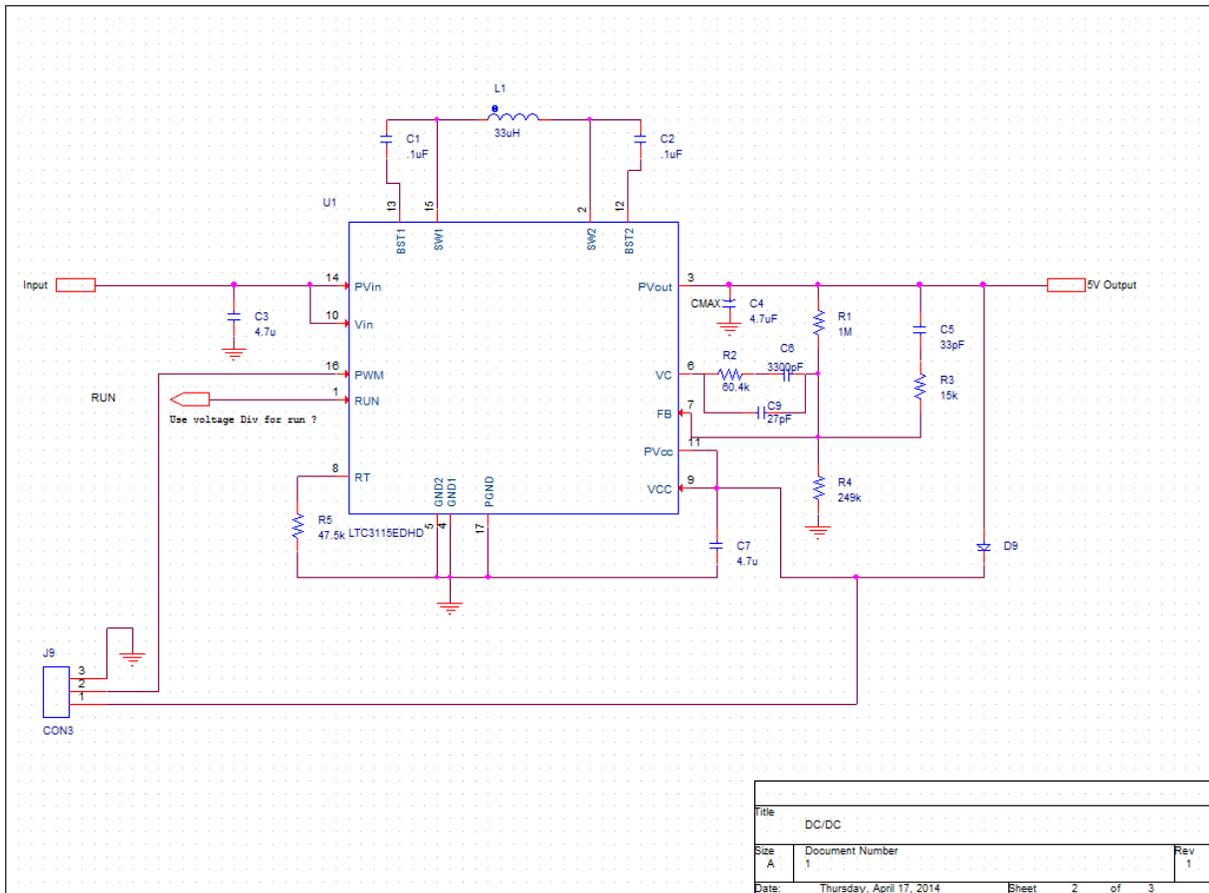
**Figure 9: Three Phase Rectifier Circuit.**

Using the rectifier circuit presented in Figure 9; Schottky diodes, given their low turn on voltage are used. The perspective Schottky diode APT30S20BG-ND is used.

## Buck-Boost DC/DC Converter

A Buck-Boost DC/DC converter is used to convert the rectified input DC voltage to a regulated output DC voltage of 5V. An LTC3115-1 DC/DC converter chip by Linear Technology was chosen for the design. A typical application design was followed in the design for the DC/DC Converter. The LTC3115-1

is connected to the output of the rectifier than being able to regulate the input voltage to a 5V output voltage.



**Figure 10: Typical Application DC/DC Converter Schematic**

The Buck-Boost DC/DC Converter can take in a voltage from a range of 2.7V to 40V and will regulate an output voltage of 5V as well as giving an output of 1A when the input voltage is greater than 3.6V and 2A when the input voltage is greater than 6V. A maximum power rating of 10W can be achieved by this chip. This chip was chosen due to its wide range of input voltage and it was able to meet the output power requirement.

## Break Relay

By shorting all the phases of the generator together with a user controlled relay we will aid the mechanical break in slowing the turbine when needed.

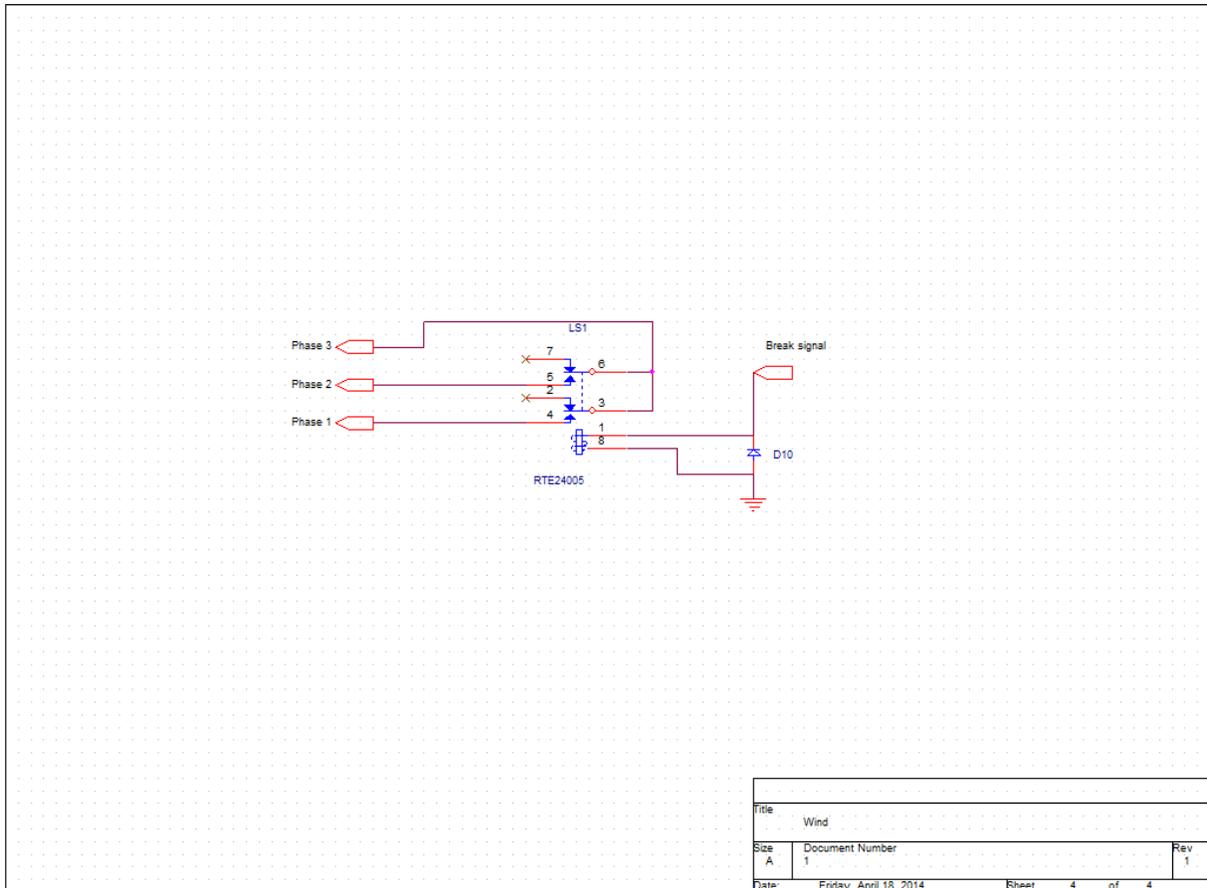


Figure 11: Brake relay schematic.

## Wind Tunnel Design & Fabrication

Engineering resources are limited in Alaska, and it quickly became apparent that there was not a wind tunnel suitable to our needs accessible within the state. This left the team with two options: mount a testing platform on a motorized vehicle capable of obtaining the wind speed equivalent needed with some amount of accuracy, or use the power section from an existing tunnel and fabricate a flow section to suitable specs. In the interior of Alaska, winter temps frequently drop to -40 degrees Fahrenheit, and winds are unpredictable. These factors combined with air density differences make outdoor testing virtually impossible.

Standardized iterative processes were followed to optimize the dimensions of the wind tunnel, as shown in Figure 12. It was decided that an open circuit system would be the easiest to fabricate and model accurately.

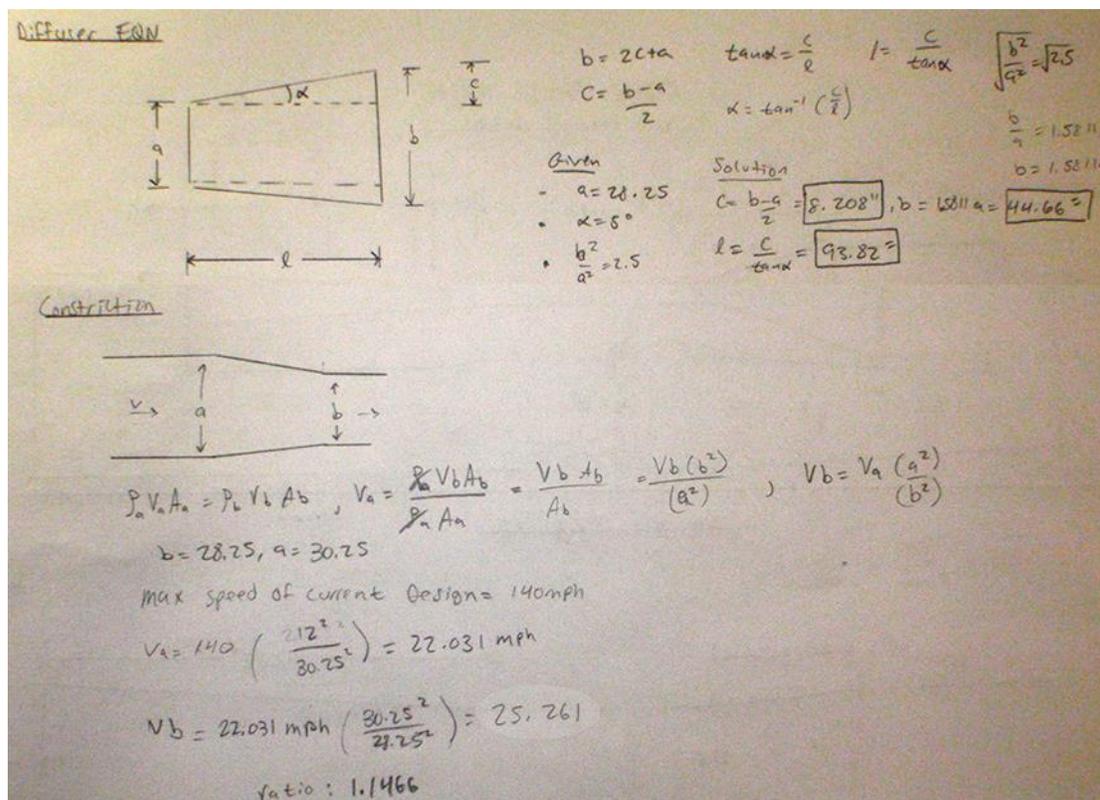
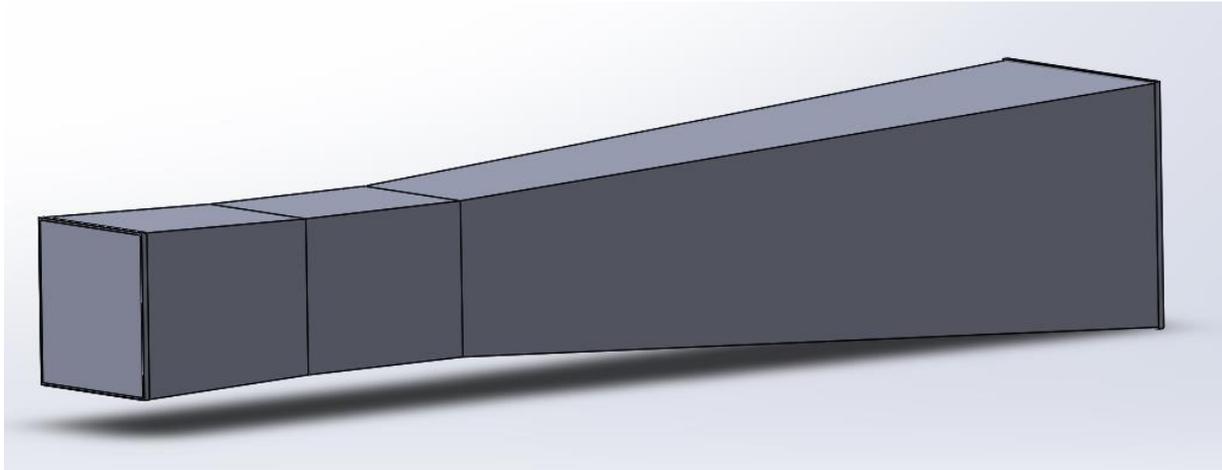


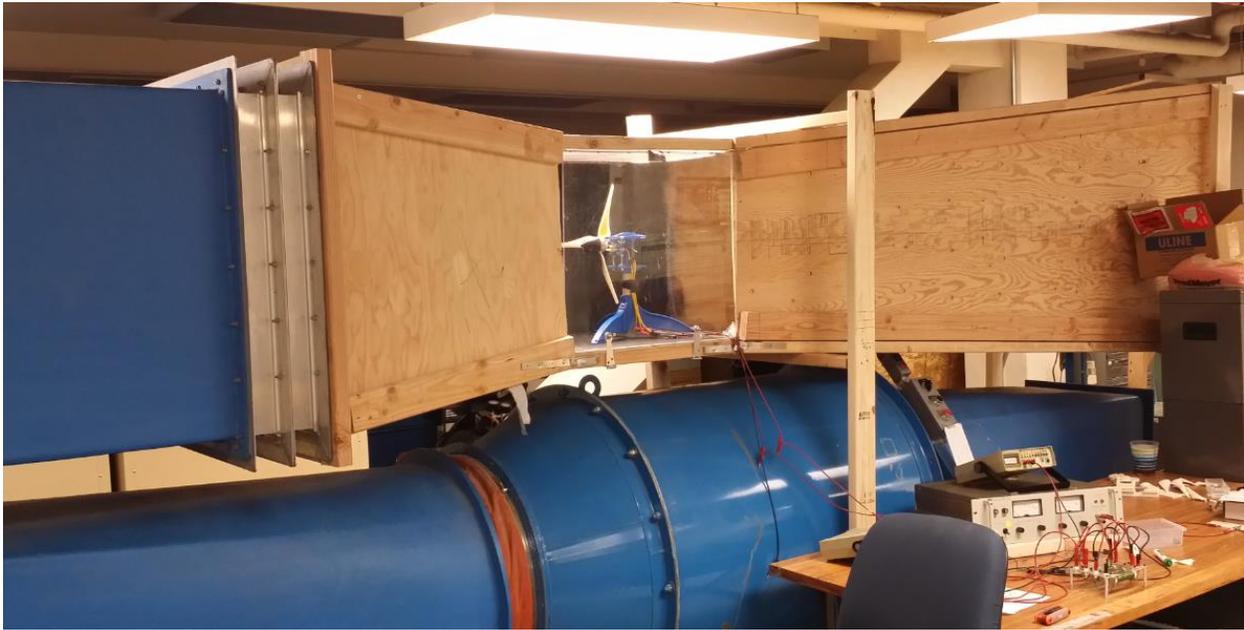
Figure 12: Wind tunnel dimension calculations

The optimized dimensions were then used to create a 3 dimensional model in SolidWorks (Figure 13) and tested using a fluid flow simulation. From that point the model was exported to sheet metal and the dimensions of each individual piece were calculated.



**Figure 13: Wind tunnel concept**

Materials to be used for the construction of the wind tunnel came under heavy discussion. Using sheet metal was thought to be the cleanest option offering the lowest amount of drag, but would require highly skilled labor and have high associated costs. Due to various group members background in wood working, it was decided that plywood and 2"x4" studs would be the cheapest and least labor intensive option. It was also decided that the drag and turbulence created by the rough surface of the lumber could be offset by increasing the scale of the tunnel and sanding its inside surfaces.



**Figure 14: Completed wind tunnel, Alaskan style**

## Testing

With the completion of the wind tunnel, the Alaska team now had testing capabilities in house. A test stand was fabricated to house the motor and gearbox and provide attachment points to route electrical components. The test stand and components were placed in the wind tunnel, and an anemometer mounted to determine accurate wind speeds. An oscilloscope was connected between two leads of the generator and used measure the frequency of rotation. A digital multi-meter was used to measure voltage output, and a resistor pack served the purpose of a variable load bank. The wind speed and corresponding RPMs were used to determine which one of our blade designs had the optimum performance we required. The power curve was formulated from the voltage reading and the current reading, plotted against the corresponding wind speed, as shown in Figure 15.

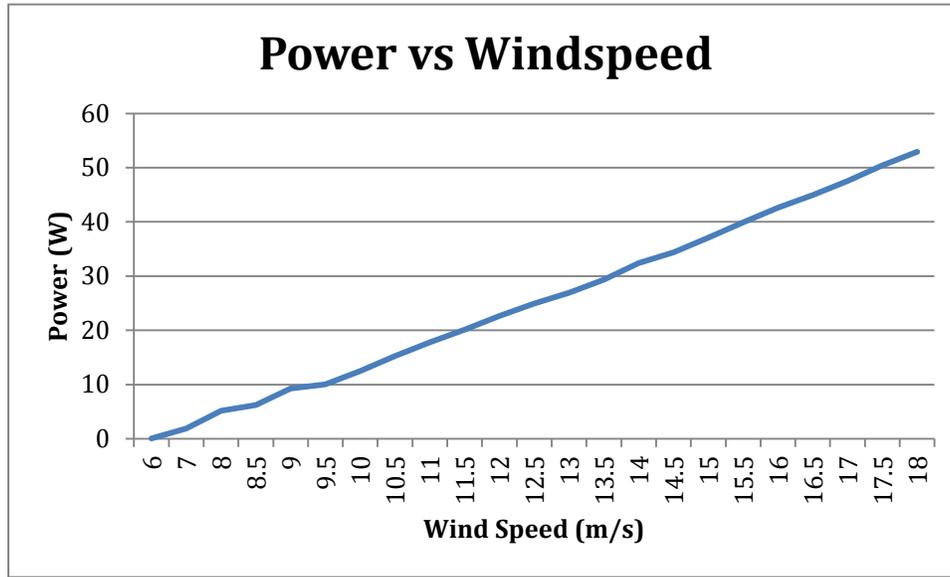


Figure 15: Power curve found using rectifier only

The power curve in Figure 15 does not have a specific power rating, as the current and voltage continue to rise as the speed increases.

## Completed Design

The final design, as shown in **Error! Reference source not found.**, is a compilation of all components as a working product. A test stand was designed and fabricated to match the specs needed for testing. A nacelle is modeled to house the electrical and mechanical components, as well as provide a mounting point for the hub/drivetrain assembly. The brake components are contained within the nacelle, and a fin has been added along the top edge for directional control when in field use. The top nacelle/fin assembly slides off the base plate easily for access to the internal components and maintenance where required. The blades are easily removable by hand by unscrewing the front nose cone and sliding them off the hub.



Figure 16: Final Turbine Design

## References/Appendix

Manwell, J. F., J. G. McGowan, and Anthony L. Rogers. *Wind Energy Explained: Theory, Design and Application*. Chichester: Wiley, 2002. Print.

<http://airfoiltools.com/airfoil/details?airfoil=s823-nr>