Department of Energy
Collegiate Wind Competition

Written Report
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Arctic Winds
University of Alaska Fairbanks

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Aerodynamics and Structure

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Executive Summary

Arctic Winds LLC is a small company comprised of four employees. The company found its roots at the University of Alaska Fairbanks as the senior design project of college students. These students would go on to create a local business that would produce the *Turbo Spirit 1000*. This small wind turbine is targeted for rural Alaska residences that seek emergency power for small electronics. The turbine is rated to produce 12 Watts of power at 8 m/s winds. The *Turbo Spirit 1000* has a price point of $500 and was built to be the “Cadillac” of wind turbines.

To design such a turbine three teams of engineers were formed. These teams included Aerodynamics, Gearbox and Brake, and the Control and Power Systems. Highlights of the Aerodynamics team is that when designing the blades of the turbine, a combination of MATLAB and QBlade software was used to optimize the blade geometry. The blades can be constructed out of ABS or sapele wood. The gearbox of the turbine features a gear ratio of 3.75 and uses a timing belt and pulley. This configuration allows for easy maintenance and long life.

For speed control, a rotor and caliper brake system was developed. This system can be used to regulate shaft speed and to stop the turbine. The caliper uses bicycle brake pads that are easy and affordable to replace.

The Control and Power System was designed around an Arduino micro controller that would be able to use sensors to monitor turbine characteristics. With this data, the control system is able to manipulate the brake to regulate the shaft speed and power output of the wind turbine.

The deployment strategy for the *Turbo Spirit 1000* primarily consists of placing the wind turbine in local stores located in Fairbanks, AK. The target consumer would be those who are environmentally conscience in addition to those who may live off the grid and seek alternative energy sources. With each turbine comes a guide for site selection and turbine placement. In addition to selling turbines Arctic Winds will also offer consulting services for site placement of turbines for those who wish to purchase this service.

Business Plan

Business Overview

Arctic Winds LLC seeks to develop a 45 cm or smaller wind turbine that can produce 12 watts of power reliability in adverse conditions. Traditionally batteries and small gasoline or diesel generators have been used for backup power during times when there are power outages or storms. This turbine system would only be meant to power small electronics or emergency communications equipment, such as a HAM radio or satellite phone.

The company is modeled after a traditional small business. Arctic Winds LLC seeks to strive for quality over quantity. Traditionally, small businesses in Alaska strive on local support and tourism. Arctic Winds LLC hopes to manufacture the turbine primarily from components that can be ordered from other parts of the United States and assemble them in a shop in Fairbanks, AK.

Wind energy is a fragile market and there have been many efforts in Alaska to increase the amount of wind turbines. Previous ventures by the Department of Energy to build wind turbines have ended with little success. Issues encountered primarily pertained to the challenges of shipping and erecting large turbines in remote locations. These previous ventures influenced Arctic Winds decision to produce a small wind turbine that is easy to install and is intended to not supply a household's entire power needs, but instead be used for emergency power.

Value Proposition

Current market analysis shows that similar turbines on the market range from $300 - $3000 in cost. The Arctic Winds Turbine will be priced at approximately $500 MSRP. Commonly Alaskan's prefer items that are made in Alaska. This is because Alaskan made items are usually of high quality and are designed to operate in Alaska's harsh climate.

The turbine is also appealing to many Alaskan's because it is designed as an emergency power source. Often in Alaska, power can be unstable or unreliable. The peace of mind of having a backup energy source to power cell phones of flashlights is very appealing to both urban and rural households.

Environmentally, the wind turbine would aid in reducing the waste from using non rechargeable batteries.

Market Opportunity

- Target Market:

nalysis of the market shows that there is a lack of options for small turbines that operate in cold climates. The team's initial target market is households located in rural Alaska. Below are numbers of potential customers.

Total Market: Rural and Urban Alaska from the 2010 Census [1]
306,967 Total Households
182,989 are considered Urban
123,978 are considered Rural

Typically consumer products are expected to have between 2 and 6 percent market penetration [2]. For Arctic Winds our projected market share will be between 2500 and 7400 households. Current wind turbines are large and sophisticated to install and have performance issues in cold regions. The Arctic Winds turbine has been designed to be a “Cadillac” of wind turbines. We emphasize reliable robust performance instead of lower costs. Advertising in rural areas will be accomplished using conventional methods such as television and radio.

- Market Forecast:

For Alaska, there are many factors that could influence the market for wind energy. One of these factors are Government Incentive Programs, if the government subsidizes renewable wind energy, the general public will become more interested due to the smaller personal initial investment that is required. Oil prices, are another major factor in that influences the renewable energy market. When oil prices are low the general demand for renewables decreases due to them becoming less economically viable option. In Alaska oil prices also play a large part in the overall strength of the economy, so when oil prices are low the overall economy suffers, causing consumers to have less spending money and therefore a smaller propensity to spend. However, when oil prices increase, the opposite occurs and renewables become a very viable option. The table below outlines the most of the major factors that affect the wind energy market in Alaska.

In general Alaska’s rural market will be more resilient to changes in demand for wind energy compared to the urban population. This resilience to change is due to many of Alaska’s rural communities being on their own micro electrical grids that are not connected to main grid that connects the major urban populations in the middle of the state. This isolation makes emergency power applications much more appealing, thus creating a slightly greater and more consistent demand.

Table 1: Factors that Influence Market

Factor	**Influence**
Government Incentive Programs	AREF Can provide grants to install renewables
Oil Prices	Low oil prices makes renewable energy less economical and weaken Alaska’s Economy
Solar Energy Prices	Wind energy cannot compete on the same economic level as solar energy since prices have decreased in manufacturing.
Innovations in Wind Technology	New innovations in generators can help to lower the cost of wind turbines

- Current Solutions and Pricing Strategy

Current competitors for small wind turbines include ABS Alaskan. These turbines produce 50W-200W, and have a price range of $600-$1300 [3]. In addition gasoline generators are expensive on the order of over $1000 [4]. Based on these price ranges Arctic Winds felt that small turbine priced at $500 would be competitive for the projected market.

In addition to price, the Arctic Winds turbine price takes into account that it will be a high quality turbine produced in Alaska. In addition because the system is installed by the homeowner, there are no costs associated with installation.

- Public Education

When introducing a new product in the renewable energy theater, it is important to educate the market. Informing the public of how valuable and convenient wind energy can be will aid in sales. This will be accomplished by performing outreach events with UAF through open houses such as Engineering Week.

Management Team

As a small business Arctic Winds LLC has a very simple company structure and staff. The company is a partnership between two prospective entrepreneurs, the general manager and manufacturing engineer. The roles and responsibilities of each position are outlined below.

- General Manager / Financial Officer

The primary role of the general manager is to manage the financial assets and normal operations of the company. In addition the general manager leads company in new ventures and is the front man for communications between customers. Keeps blow and bitch stacks separate

- Manufacturing Engineer / Technician

The manufacturing engineer is in charge of research and development of turbine products. In addition to designing the turbines he will also be assisting in the assembly of the products. For any technical issues that arise with turbines that have been sold to customers, the manufacturing engineer will act as the field technician for repairs and service.

- General Laborer

The general laborer assists the manufacturing engineer in turbine assembly and service. The general laborer is also responsible for transporting the product. Other duties include shop maintenance and assisting the where needed.

- Intern/Office Assistant/General Laborer

The intern acts as the office clerk responsible for menial job duties such as answering phone calls and filing paperwork. In addition to office work the intern will be responsible for coffee and getting donuts for customers who visit the office.

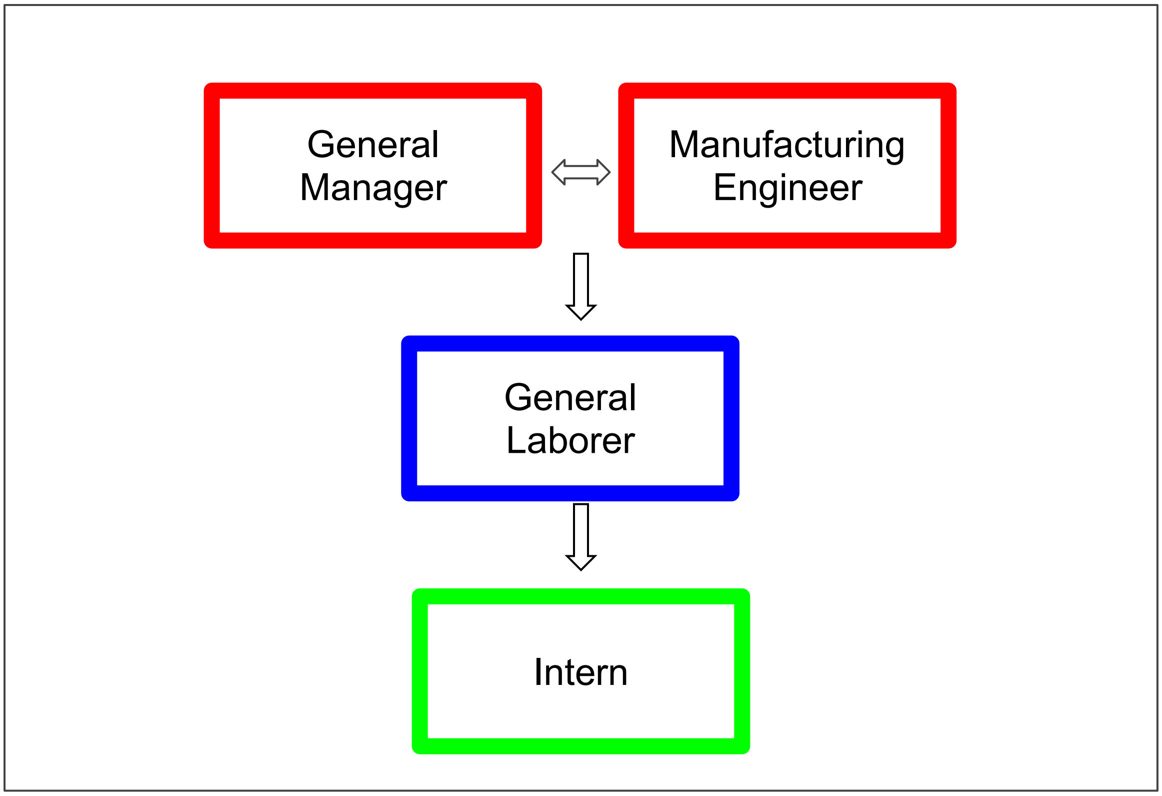

Figure 1: Company Structure Diagram

Development and Operations

- Product development

Initial research and development was conducted by a team of 12 engineering students located at the University of Alaska Fairbanks. The small wind turbine acted as the student's senior design. The students were divided into three sub teams that developed the turbine blades, gearbox, and control system. Once the initial prototype was completed and a final product developed, two of the students carried the business on and became the general manager and manufacturing engineer of Arctic Winds LLC.

- Manufacturing and Distribution

Manufacturing for the wind turbine components will be sub contracted out to other companies. These parts will then be shipped to the Fairbanks office, where they will be assembled into fully functioning wind turbines.

Small white vans will be used for the distribution of the product directly to customers and to local retailers. Customers that live remotely, in the "bush" will have their products shipped to them via USPS Flat Rate Boxes.

Small businesses strive on the help and support of other small businesses. We seek to ask local businesses that sell outdoor recreational equipment or have an emphasis in sustainability to advertise and carry our turbine products. Prospective local stores in Fairbanks would be Beaver Sports and REI. The actual distribution of the turbine is outlined in the Deployment Strategy.

- Product Specifications

The first turbine model to be sold by Arctic Winds is the *Turbo Spirit 1000*. The turbine will have a 45 cm rotor diameter with built in speed control. *The Turbo Spirit 1000* will feature automatic shut off in the event of high wind speeds that might damage the turbine and in the event that the load system is lost. The turbine will output 12 Watts at 8 m/s. The battery or load system is dependent upon what the user wants the system to power.

The mounting base is also dependent on the user's needs. The turbine is supplied with a two foot tower that can be mounted to the roof of a home or can be extended and mounted to a concrete base.

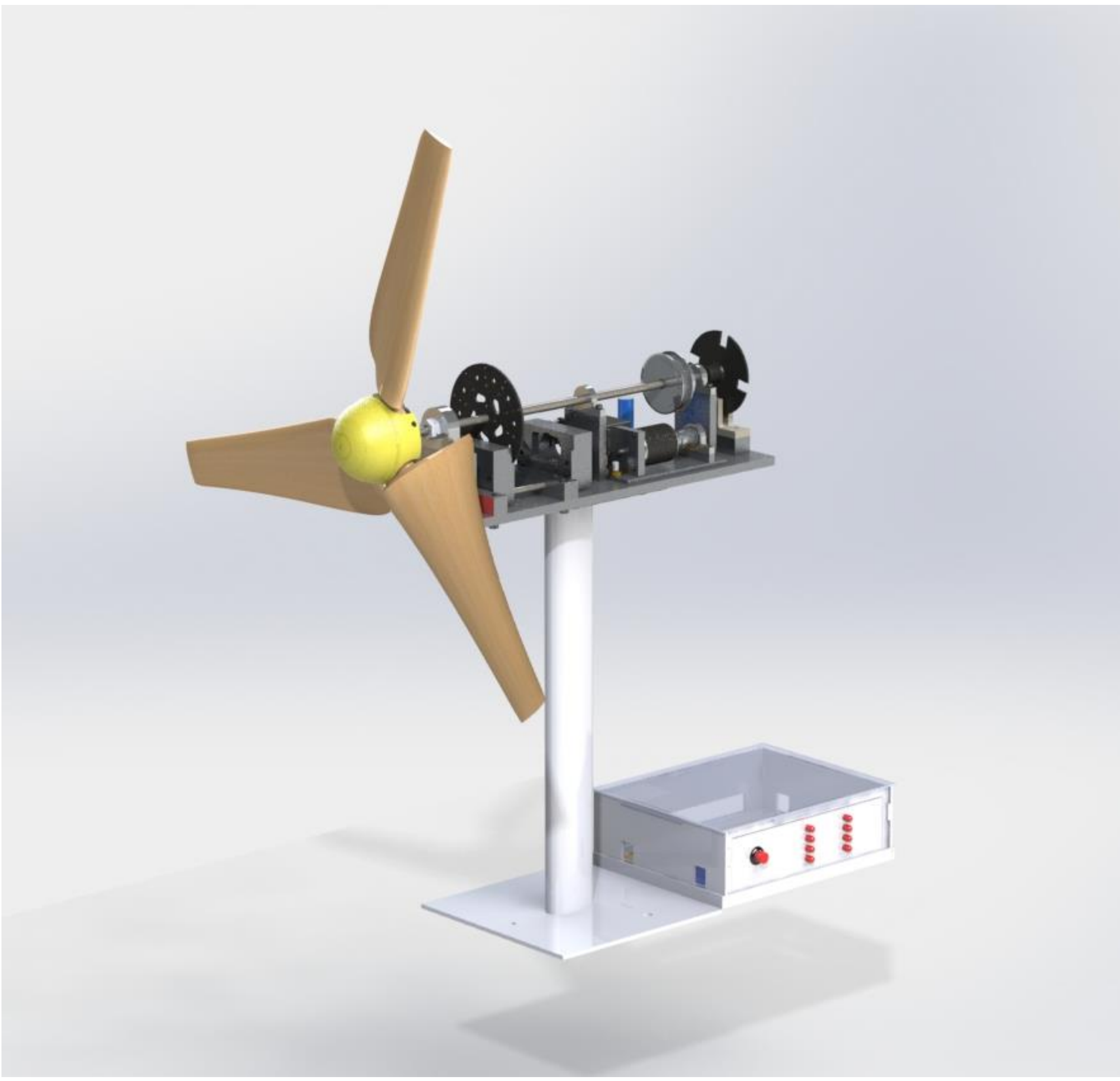

Figure 2: *Turbo Spirit 1000*

Financial Analysis

To start off few initial assumptions were made in order to establish a foundation for the financial analysis to begin. The first assumption is that the business is starting with initial funding of $32,000, after purchasing of equipment and materials for the production of twenty turbines. We felt this was valid assumption because the money is coming from the owners unused college funds. The second assumption made was the company has no mortgage; this is because the facilities will be rented on a monthly basis. Lastly a 2 % initial market penetration was assumed based upon research that was completed. [2].

Nearly all companies are most vulnerable during the startup stage. In order to analyze and mitigate risks, a SWOT analysis was performed. Below is a table displays the strengths, weaknesses, opportunities, and threats that influence Arctic Winds.

Table 2: SWOT Analysis

Strengths Lean Specialized Staff Limited Bureaucracy Strong Owner Involvement	**Weaknesses** Lack of Business Experience Start Up Company High Operating Costs in Alaska
Opportunities Growing Need for Alternative Energy Public Awareness About Wind	**Threats** Low Oil Prices New Competitors Certification Permitting

Starting with strengths Arctic Winds has an advantage because it is a small company. Having a small staff and limited bureaucracy allows for the employees to work with more freedom. Being a small company gives it a family feeling, allowing employees to become invested in their work. In the General Manager and Manufacturing Engineer are the owners of the company and are heavily involved with each aspect of the company.

The weaknesses of Arctic Winds starts with the lack of experience associated with entrepreneurs coming straight from college starting a company. To mitigate this risk the company has sought the knowledge and experience of other small companies in the interior. Research and asking those who have worked around alternative energy are paramount. The final weakness comes from operating a company in Alaska. Heating and electricity costs are high for operating a shop in a cold region. Using day/night thermostats along offsetting heating costs with a wood/waste oil furnace have been proposed solutions.

With challenge also comes opportunity. The growing need for supplemental systems to offset costs or for energy security has helped to fuel the alternative energy market. Power production in Alaska is limited and power outages are a reality during snow and ice storms. A small wind turbine that could provide power during these scenarios is attractive to buyers.

Threats the oppose Arctic Winds are numerous. With recent oil prices decreasing the need for alternative energy has dropped. In addition there have been other small wind turbine companies from other countries that have competitive price points. As an ambitious company Arctic Winds seeks to use this lull in the market to its advantage and increase inventory to be prepared when the market revives. The final threat is certification and permitting. Passing the Small Wind Turbine testing standards can be challenging and may also impede the company. In addition acquiring the proper licenses for a business in Alaska can be expensive.

Pro-forma financial statements are shown in Table 3, 4, and 5.

Table 3: Balance Sheet

	January	February	March	April	May	June	July	August	September	October	November	December
Current Assets												
Cash	$32,000.00	$25,651.42	$19,927.84	$15,037.59	$10,980.68	$7,757.10	$5,366.85	$3,809.94	$3,086.36	$3,196.11	$4,139.20	$5,915.62
Inventories	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Other	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Security Deposit	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Total	$44,000.00	$37,651.42	$31,927.84	$27,037.59	$22,980.68	$19,757.10	$17,366.85	$15,809.94	$15,086.36	$15,196.11	$16,139.20	$17,915.62
Fixed Assets												
Equipment	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Equity and Other Investments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Less Accumulated Depreciation												
Total	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Total Assets	$54,000.00	$47,651.42	$41,927.84	$37,037.59	$32,980.68	$29,757.10	$27,366.85	$25,809.94	$25,086.36	$25,196.11	$26,139.20	$27,915.62
Current Liabilities												
Acounts Payable	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Notes Payable	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Long-Term Liabilities												
Mortages	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Owner Equity												
Total	$54,000.00	$47,651.42	$41,927.84	$37,037.59	$32,980.68	$29,757.10	$27,366.85	$25,809.94	$25,086.36	$25,196.11	$26,139.20	$27,915.62
Total Liabilities and Stakeholder Equity	$54,000.00	$47,651.42	$41,927.84	$37,037.59	$32,980.68	$29,757.10	$27,366.85	$25,809.94	$25,086.36	$25,196.11	$26,139.20	$27,915.62

Table 4: Income Statement

	January	February	March	April	May	June	July	August	September	October	November	December
Revenue												
Turbines Sold	4	8	13	17	21	25	29	33	38	42	46	50
Total Sales	$2,083.33	$4,166.67	$6,250.00	$8,333.33	$10,416.67	$12,500.00	$14,583.33	$16,666.67	$18,750.00	$20,833.33	$22,916.67	$25,000.00
Material	$1,041.67	$2,083.33	$3,125.00	$4,166.67	$5,208.33	$6,250.00	$7,291.67	$8,333.33	$9,375.00	$10,416.67	$11,458.33	$12,500.00
Labor	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00	$3,450.00
Costs of Goods Sold	$4,491.67	$5,533.33	$6,575.00	$7,616.67	$8,658.33	$9,700.00	$10,741.67	$11,783.33	$12,825.00	$13,866.67	$14,908.33	$15,950.00
Gross Profit	($2,408.33)	($1,366.67)	($325.00)	$716.67	$1,758.33	$2,800.00	$3,841.67	$4,883.33	$5,925.00	$6,966.67	$8,008.33	$9,050.00
Expenses												
Insurance	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00	$575.00
Rent	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Utilities	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53	$810.53
Maintenance	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
Taxes	$1,057.26	($599.97)	($142.68)	$314.62	$771.91	$1,229.20	$1,686.49	$2,143.78	$2,601.08	$3,058.37	$3,515.66	$3,972.95
Telephone	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00
Vehicle/Travel	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00	$95.00
Total Expenses	$4,287.79	$2,630.56	$3,087.86	$3,545.15	$4,002.44	$4,459.73	$4,917.02	$5,374.31	$5,831.61	$6,288.90	$6,746.19	$7,203.48
Net Income	($6,696.12)	($3,997.23)	($3,412.86)	($2,828.48)	($2,244.11)	($1,659.73)	($1,075.36)	($490.98)	$93.40	$677.77	$1,262.15	$1,846.52

Table 5: Cash Flow

	January	February	March	April	May	June	July	August	September	October	November	December
Current Assets												
Cash	$32,000.00	$25,651.42	$19,927.84	$15,037.59	$10,980.68	$7,757.10	$5,366.85	$3,809.94	$3,086.36	$3,196.11	$4,139.20	$5,915.62
Inventories	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Other	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Security Deposit	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Total	$44,000.00	$37,651.42	$31,927.84	$27,037.59	$22,980.68	$19,757.10	$17,366.85	$15,809.94	$15,086.36	$15,196.11	$16,139.20	$17,915.62
Fixed Assets												
Equipment	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Equity and Other Investments	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Less Accumulated Depreciation												
Total	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
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Current Liabilities												
Acounts Payable	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Notes Payable	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Long-Term Liabilities												
Mortages	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Owner Equity												
Total	$54,000.00	$47,651.42	$41,927.84	$37,037.59	$32,980.68	$29,757.10	$27,366.85	$25,809.94	$25,086.36	$25,196.11	$26,139.20	$27,915.62
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Technical Design

Introduction

For this turbine we have divided the turbine into three subsystems: aerodynamics, gearbox, and controls. The aerodynamics group worked mainly with the hub, the blades, and the nosecone. The gearbox team focuses on converting power from the blades to the generator, as well as designing the brake to control the shaft speed. A gearbox housing was designed to contain the gearbox and electrical components. It will convert the spinning mechanical energy from the gearbox into electrical power. The controls team will monitor the turbine characteristics and use these reading to control the turbine.

Objectives

The main objectives of the turbine consist of performance, safety, and durability. Performance of the turbine will focus on a low cut in wind speed as well as a maximum coefficient of performance when lower wind speeds are present. The turbine must be able to regulate RPM, via the brake, and produce constant power. To protect the system various safety features have been implemented. An emergency brake will be used to shut down the system when the turbine is disconnected from the load. The system is also equipped with fuses to prevent the power output from destroying the electrical components. To ensure that the turbine is durable, the roots of the blades are designed for a strong connection to the hub. This concept was also used when designing the gearbox, since those components are the most prone to fail.

Design Overview

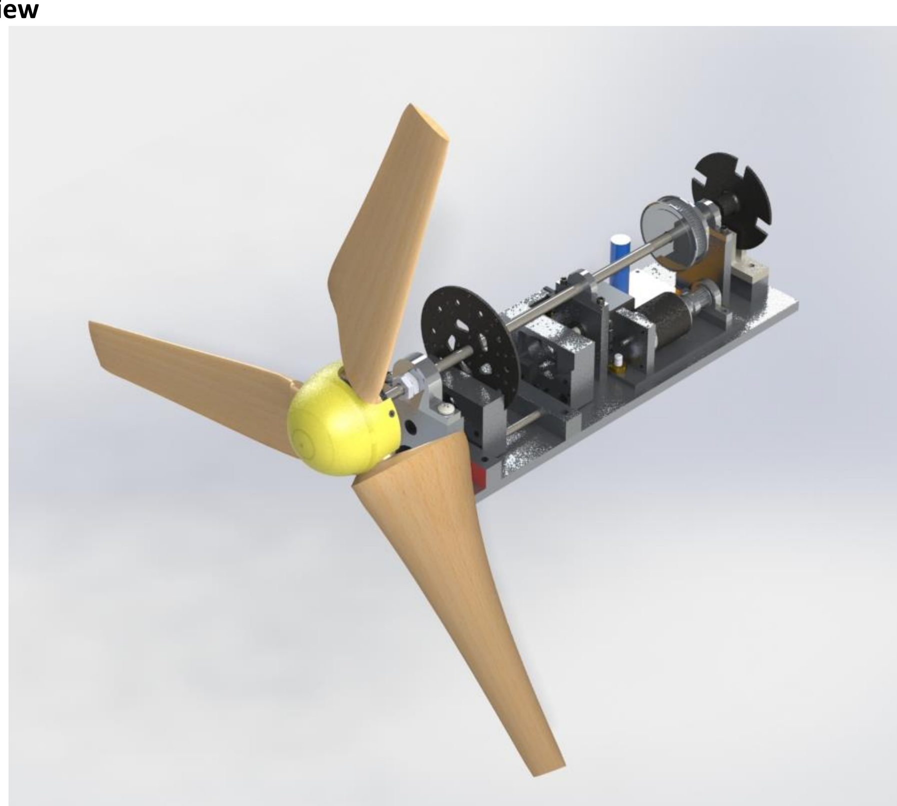


Figure 3: Gearbox and Rotor

Figure 3 shown above displays the final design of our turbine. The turbine consists of three subsystems which include: blades, gearbox, and power controls. Teams of 2 - 4 people were assigned to design each subsystem.

- Aerodynamic Systems
- Rotor
- Hub

The hub uses a modified slotted dovetail root system to fix the blades to the rotor assembly. The root was designed to account for the available manufacturing equipment's ability to produce the necessary geometry and to reduce the overall stress concentrations in the blade root. Autodesk Inventor was used to adjust the design to reduce stress concentrations. Finite element analysis was used to analyze the loads on the hub at predicted maximum rotation. According to the EN 61400-2 standards, the centrifugal force is the primary load on the hub while the other forces are negligible [5]. The hub and hubcap are made of aluminum 6061-T6 and production models would be anodized to offer corrosion resistance. Alternative offerings would include stainless steel for coastal and nautical applications.
A Shaftloc single-end style fastener was chosen to mate the hub to the shaft because it is an effective and obtainable part and its geometry fits seamlessly into the hub design as seen in Figure 3. The Shaftloc applies pressure to the hub and the shaft as the two parts of the shaft lock screw in together. The use of a Shaftloc fastener simplifies the assembly process and end-user maintenance as the rotor can be installed or removed as one piece by an individual.

Blades

The blades were designed using a generalized rotor design procedure as outlined in *Wind Energy Explained* by Manwell, Gowan, and Rogers and is based on Blade Momentum Theory and Blade Element Theory. The algorithm requires the number of blades, a Tip-to-Speed Ratio (TSR), and an airfoil [6]. The number of blades was determined by examining the efficiency of energy extraction as a function of the number of blades and evaluating design considerations such as cost and technical complexity. Analysis from Wind Energy Explained showed that while increasing the number of blades increases maximum efficiency, the returns per a blade diminish significantly after four blades (Figure 4). A three blade design was chosen as an optimal balance between economy, design simplicity, and efficiency. NREL S series airfoils were chosen for initial designs because the series was developed specifically for small wind turbines. The S833, S834, and S835 were selected because the airfoils were specifically designed for rotors of one to three meters [7]. TSR of 4, 5, and 6 were initially chosen based on the comparison of TSR and power coefficients. After prototype testing and analysis on how TSR affects the chord length, a TSR of 4 was chosen to aid in obtaining a low cut in speed and limiting the mass of the blades.

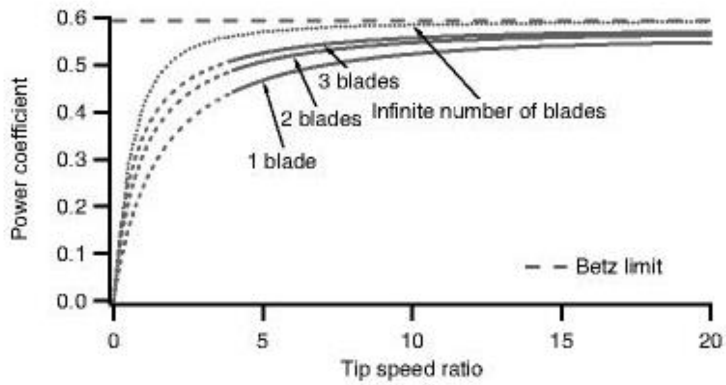


Figure 4: Comparison of Number of Blades

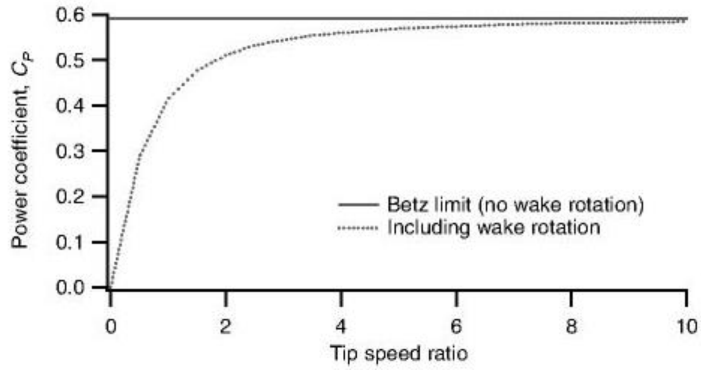


Figure 5: Betz Limit

A MATLAB script was written to evaluate multiple blade configurations using the generalized rotor design algorithm. The script requires hub and rotor diameters, TSR, and airfoil data. The required airfoil data includes the coefficient of lift (C_L) as a function of angle of attack (AOA) and coefficient of drag (C_D) as a function of AOA. NREL has not published empirical data for the S series. Instead, predicted data using the XFOIL module of QBlade was referenced. The data was then extrapolated to include the C_L and C_D values for 360 degrees. This was done using QBlade's extrapolation module. The script determines the ideal airfoil geometry for each section and then optimizes the section using the angle and axial induction factors. After computing each blade and the corresponding coefficient of performance, the script determines which blade configuration produces the maximum coefficient and outputs a text file with the necessary parameters to construct the blade. The blade geometry was then imported into QBlade which then optimized the geometry using to approach the Schmitz limit.

The optimized geometry generated from QBlade was then used to construct the blade in SolidWorks. To create the blades, the SolidWorks model exported an STL file which was then used to construct the blades through additive manufacturing using a Fortus 20mc printer. The printing material used was Acrylonitrile-Butadiene-Styrene (ABS) due to availability. A process to make the blades out of sapele wood using a CNC milling center is currently be developed at the time of writing.

Nose cone

A nose cone was developed to slide over the hub. The primary objective of the nose cone was to decrease the force induced by drag onto the structure. To fulfill this objective without drastically altering the airflow around the rotor, a rounded nose cone was chosen. The secondary objective was to improve the aesthetics of the turbine. While not a critical technical objective, the secondary objective was considered to increase marketability of the turbine.

In order to mitigate the nose cone's impact the performance of the rotor, the nose cone was designed with additive manufacturing in mind. The nose cone is mostly hollow except for three support structures inside to decrease weight and volume. The nose cone is attached to the rotor with friction around the hub perimeter and with alignment pegs that fit into the hub cap.

Gearbox and Brake Systems

To design the gearbox and braking system it had to be determined how much torque the blades would produce. This is important because the gearbox has to withstand the stress that is produced by the torque and the braking system has to stop that much torque. The maximum torque is calculated by the following process.

The theoretical power that can be extracted from the wind can be calculated with the following equation.

$$Power = 0.5\rho C_p A_{Blades} V^3 [6]$$

$\rho = air\ density$

$C_p = power\ coefficient$

$A_{blades} = Cross\ sectional\ area\ of\ blades$

$V = air\ velocity$

This equation assumes the blades are 59% efficient in the energy extraction of the wind, which is called the Betz Limit. The Betz Limit is the theoretical max efficiency for blades, as the Carnot cycle is for heat engines [5]. In reality the blades will probably only be around 20%-35% percent efficient. Therefore this will be the worst case scenario and a safety factor was created during the process. The torque is the value we need and that can be calculated by the following equation

$$Torque = \frac{Power}{2\pi(\frac{rpm}{60})}\ [6]$$

As seen by this equation the two variables are power and rpms. The power can be calculated by the first equation and the rpms are determined by this next equation.

$$rpm = \frac{tip\ speed \cdot 30}{r\pi}$$

$$tip\ speed\ ratio = ratio\ of\ speed\ of\ the\ blade\ tips\ compared\ to\ the\ upstream\ wind\ velocity$$
$$r = radius\ of\ blades$$

All of the variables here were known except the TSR at that time, but it was determined for small turbines that tip speeds between 4 and 6 are the optimum. Looking at both tip speeds it was

determined that the tip speed of 4 produced more torque so this value was used in order to produce a torque value that would theoretically be the greatest.
The torque was calculated to be 1 N-m or (8.8 inch pounds) at the maximum wind speed of 18 m/s. This value is the greatest amount of torque that could possibly be seen and has a safety factor of between 2 and 3.

Gearbox

- Constraints

Durability was the key consideration in the design process of the gearbox. In a wind turbine the gearbox is the generally the first part to fail. The gearbox has to be made so that it will be reliable and last as long as possible with little maintenance. Another consideration was the desire to design the gearbox with off-the-shelf components. This allows for the turbine to be easily manufactured. The parts were ordered from Stock Drive Products/Sterling Instrument (Sdp-Si) as they specialize in miniature components.

- Design

To design the gearbox, preliminary calculations were performed from theoretical values to get the maximum rpm, power, and torque that would potentially be expected. The gearbox type that was chosen was a timing belt and pulley system. This system was chosen because of the flexibility that it offered in the designing process. By having a timing belt and pulley system it allowed us to change the belt and pulley for a different gear ratio without having to change the location of the shafts. The timing belt and pulley system is efficient, cost effective and has low maintenance when designed properly. The worst malfunction that could happen would be that the belt would strip out. In this case it would be more cost effective to replace a belt instead of several gears.

Several gear ratios were selected for initial testing; 3.25, 3.75, 4.5. These values were chosen to give a range of gear ratios to optimize. The gear ratio was dependent on the generator chosen as well as the efficiency of the blades. Testing was held to decide on the optimum gear sizes. Initial gear sizes were chosen based upon the wind speed range and the generator chosen by the power systems team. A final gear ratio of 3.75 was decided upon.

The belt was selected by calculating the rpms of the high speed shaft as well as how much torque the blades could theoretically produce. After preliminary calculations a 2mm pitch, GT2 6mm wide belt was chosen as it was capable of operating at the high rpms that we needed. This belt had a rating of 14,000 rpms and it was able to operate within the max torque range of 8.8 inch pounds. At this high rpm range there was a suggested minimum number of grooves in the pulley which was 16. Therefore, the size of the small high speed pulley was chosen based on that. The low speed pulley was chosen to provide the correct gear ratio, 3.75 to 1. Also taken into consideration was the requirement for how many teeth of the pulley were in mesh. Six teeth in mesh is the recommended minimum amount to prevent the belt from slipping and from having too much force on each individual tooth. Therefore, the length of the belt was chosen to provide enough teeth in mesh and so that each gear ratio would have the same center to center distance.

A wind turbine shaft has both a static moment and a dynamic torque acting on it during operation, thus both must be accounted for when designing a shaft. The shaft diameter was determined based upon the diameter required for the pulley but the following equation was used to perform a check to make sure the shaft could withstand the forces on it. The torsional stress ended up being 2800 psi which is far lower than the yielding stress for stainless steels.

$$\tau = \frac{Tr}{J} = \frac{T\left(\frac{d}{2}\right)}{\frac{\pi d^4}{32}} \text{ [8]}$$

$d = diameter\ of\ shaft$

$\tau = torsional\ stress$

$T = torque$

$J = polar\ moment\ of\ inertia$

The pulleys and belts apply forces axially through the shaft as it rotates. This causes deflection and stress through the shaft. A basic shaft layout of both the input and output shaft should be made so that the location of the pulleys and bearings are located at the ends of the shaft.

Brake System

- Constraints

The braking system is one of the main components of the wind turbine. It will be used to not only stop the wind turbine blades, but it will also be used to regulate the speed. Regulating the power output will be accomplished by using the brake to regulate the rotational speed of the generator. Regulating the speed will also ensure that the wind turbine generator will not see critical failure at higher wind speeds. The brake will also need an emergency brake that can be applied if the turbine is disconnected from the load. During this process, the brake will be powered only by the power that is currently being produced by the blades.

- Initial Design: Magnetic Brake

The initial idea for the brake was to try to design a magnetic brake that used the interference between magnetic fields to create stopping power. The magnetic brake would essentially be a disk with permanent magnets embedded into it, which is then attached to the low speed shaft of the wind turbine. Permanent magnets will also be embedded into the caliper. This will then allow a magnetic interaction to occur between the disk and caliper. The closer the caliper is to the disk, the more resistance the magnets will allow, which will then slow down and eventually stop the blades.
The team first wanted to use a magnetic brake to allow the braking system to be frictionless, creating no wear on the parts. The testing set up for the preliminary brake system was a rail system combined with a lead screw attached to the caliper (Figure 6). However, during preliminary tests the magnet's interactions were causing vibrations in the parts. It was also hard to control the spacing between the magnets at closer distances due to greater attraction force.

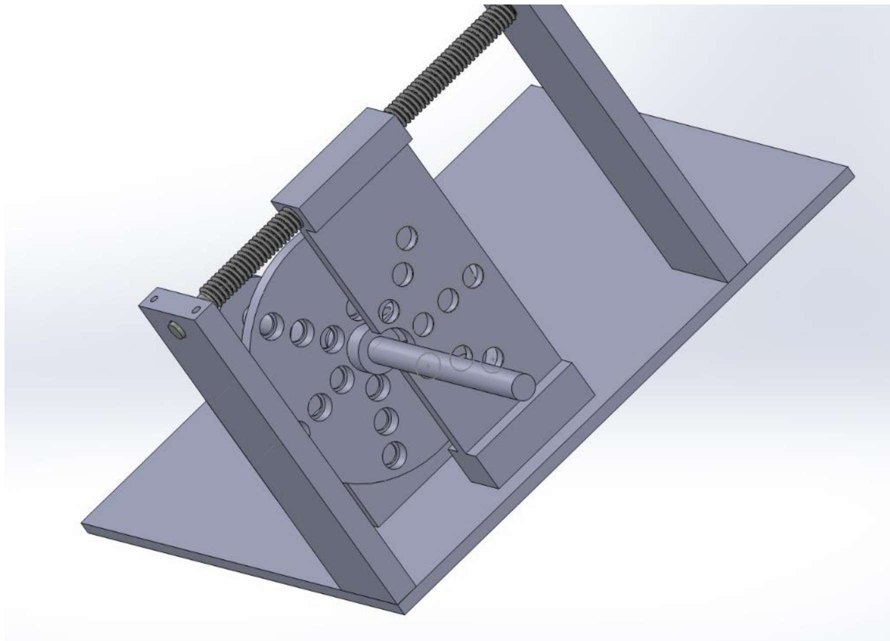


Figure 6: Magnetic Brake

The team's first initial design for the braking system was to solely rely on using the magnetic brake. A disk and caliper design was drawn up in SolidWorks and 3D printed. Preliminary tests were performed and the magnetic brake caliper was altered multiple times. Through testing, the team realized how the orientation of the magnets was very important and a final orientation was designed. After the designs were finalized, the parts were machined out of aluminum as well as a platform to secure all the components of the braking system and gearbox. Once a system was designed to linearly move the caliper in and out, the team realized that the magnets caused a lot of "chatter" in the braking system. Therefore, a design change for the brake was needed.

- Design Change: Friction Brake

The changes to design a more conventional friction brake over a magnetic break were made for a couple of reasons. First being that the theory behind the magnetic brakes is not strong enough to make adequate assumptions from magnetic fields that are interacting very close to one another. Thus, these brake designs come mostly from a lot of trial and error during testing. Due to time constraints and the large amount of testing trial and error did not fit in with the scope and time frame of the project. To counter this designing a friction brake is a much more refined process, allowing for calculations to be performed. This allows for the team to more easily demonstrate the technical knowledge we have gained in school and also saves time with having to perform less iterations of prototyping to obtain a working product.

The friction brake design entails a servo motor that rotates a power screw through a fixed hole in the caliper. Having the screw rotate through a fixed hole will cause the screw to be pulled through the hole and pushing a brake pad up against a rotor that is attached to the low speed shaft. This can be seen in Figure 7, where the small black box is the servo, which is connected to the lead screw via pins. The lead screw is then inserted into the caliper, which linearly actuates the brake pad against a rotor.

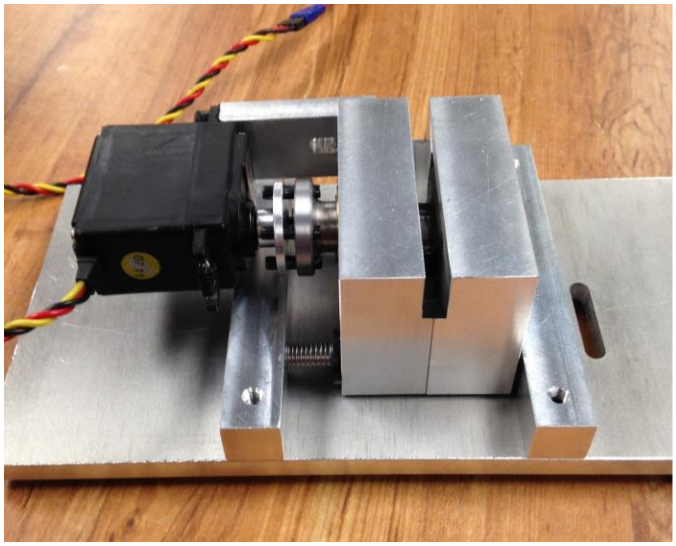


Figure 7: Friction Brake Design

For the designed braking system, a set of resin bike brake pads selected due to their availability, low cost, and size. Resin pads are made of organic fibers that are bonded together with resin. In general resin pads offer a slightly higher initial coefficient of friction than other braking materials but at the cost of slight faster wear rates. When designing brakes, it is common to use 50 percent of the test coefficients as a factor of safety. A generally accepted value of the coefficient of friction for this material is between 0.3-0.4, so for the design it was approximated as 0.15.
The total force that needs to be applied to the brake pad to stop the rotation can be calculated using the following relationship.

$$F = \frac{T}{\mu n\left(\frac{D_{disk}}{2} - \frac{L_{pad}}{2}\right)}$$

$F = Force$ $\quad$ $n = number\ of\ pads$

$T = torque$ $\quad$ $D = Dimaeter\ of\ rotor$

$\mu = coeff.friction$ $\quad$ $L = length\ or\ radius\ of\ brake\ pad$

Using this relationship to generate a plot of the force vs rotor diameter in Figure 8, it is clear to see that the required force on the brake pads is significantly decreased with rotor size. In an ideal world it would be great to have a large rotor so that far less force would have to be supplied and thus a smaller servo that consumes less power could be used. However due to the size constraints that are involved with the project a 3-inch rotor was selected. This means that the braking system needs to be able to apply approximately 26.22 lbs. of force on the pads.

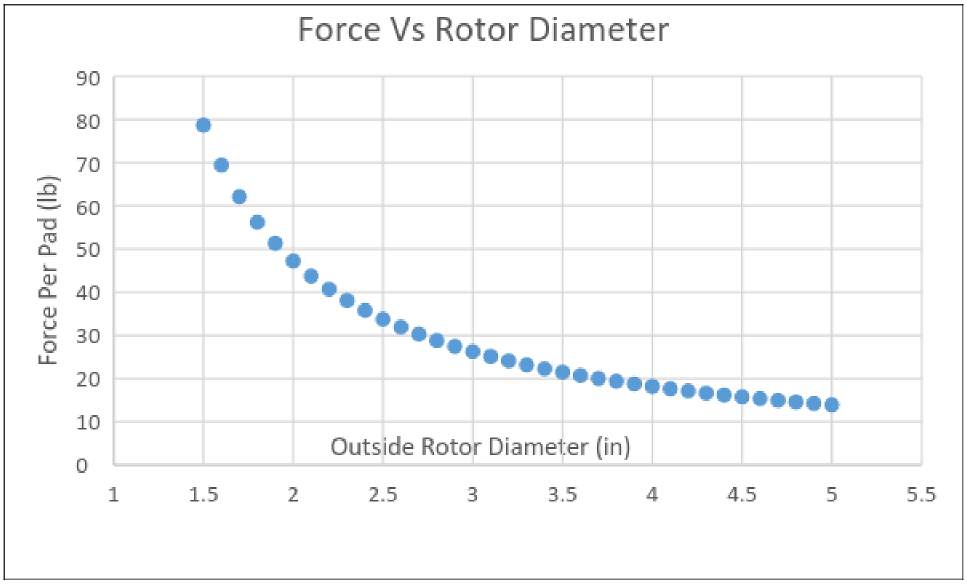


Figure 8: Force vs. Rotor Diameter

When choosing a material for the brake rotor, some important factors were taken into account. These factors include cost, availability, hardness, thermal properties and corrosion resistance. The rotor was initially made out of a stainless steel, however when machining the steel, it warped making the rotor not perfectly straight. Therefore, the team decided to choose to manufacture the brake rotor out of cast iron, because of its resistance to deform when machining.

For the design the screw will be used as a power screw that is going to convert the rotary motion of the servo into linear motion to exert a force on the brake pads. The screw mechanism was chosen for the design because of its relative simplicity and ease of manufacturing, its mechanical advantage, and its ability to be self-locking. A screw that is self-locking means that it will hold its position unless a positive torque is acting upon it. This feature is important for the design so that the brake stays engaged when power is lost during the competition. To calculate the necessary torque needed to create the 26.22 lbs. of force needed the following relationship was used.

$$T = \frac{W d_m}{2} \frac{f \pi d_m + L \cos \alpha_n}{\pi d_m \cos \alpha_n - f L} + \frac{W f_c d_c}{2} \quad [8]$$

$T = torque$	$\alpha_n = thread\ angle$
$W = lift\ load$	$d_c = diameter\ of\ colar$
$L = lead\ of\ screw$	$f = coeff.friction\ threads$
$d_m = mean\ diameter\ of\ screw$	$f_c = coeff.friction\ collar$

The calculation yielded a result of maximum torque of 58.83 oz in. This is the max torque that should have to be produced by the servo to create enough force to stop the turbine in an 18 m/s wind.

The generator selected for the turbine was a Turnigy 2217 brushless DC motor. Although motors such as these are labeled "DC" in reality they produce or are power in three-phase AC. The generator produces a three-phase AC current that is then routed to a rectifier that will convert the signal into single phase direct current. To use the motor as a generator, the shaft of it is connected to the high speed shaft of the gearbox. This particular motor is rated for 11.1 V, 22 A, and 860 RPM/Volt. It was chosen because it had the potential to produce a moderate amount of voltage at low RPM. The target production power of the turbine was initially set at 10 W because of CWC requirements. Theoretically the generator should be able to produce 10 V at 8,600 RPM. In order to produce 20 W the load had to be designed in order to draw an appropriate amount of current. The generator selection governed the design of the gearbox and aerodynamics sub teams because the generator determined the shaft speed targets.

To control the entire system, a microcontroller will be used, specifically an Arduino Uno. The microcontroller will be taking various inputs from sensors and send outputs to the brake. Microcontrollers have been known to be used for such applications.

The sensors will be reading shaft speed, voltage, and current. Shaft speed will be read using a tachometer attached to the low speed shaft. The tachometer consists of an infrared emitter and a photodiode. How it works is that there is a disk located on the shaft that has a notch. On one side of the disk the IR emitter is positioned and on the other side the phototransistor is positioned. As the disk rotates with the shaft it will allow light to pass through the notch; the microcontroller can then count how many times the photodiode is excited and calculate the shaft speed in RPM.

The microcontroller can read voltage directly using its analog pins, however it can only read voltages as high as 5 V. From preliminary calculations it was found that the microcontroller will have to read voltages as high as 15 V or even more. The solution that was selected was to use two resistors in a parallel configuration to divide the voltage being sent to the microcontroller input pins. The values of the resistors are known and the ratio that the voltage is divided can be included in software in order to calculate the actual voltage of the circuit. Figure 9 illustrates what a voltage divider might look like. Voltages will be measured from the rectifier output, the boost output, and across the load.

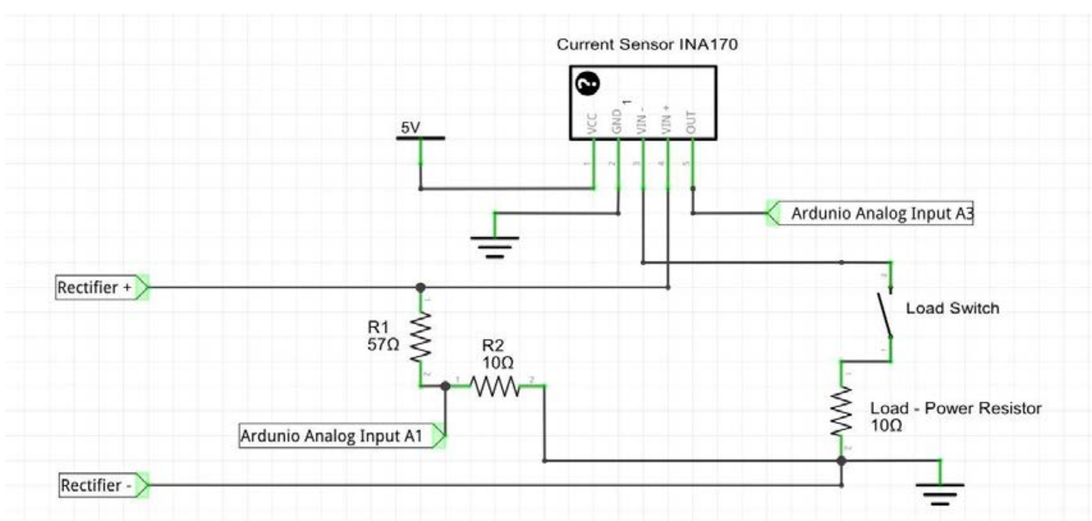


Figure 9: Voltage Divider Circuit

In addition to reading voltage, current will also be measured at the output of the rectifier. This is needed because electrical power cannot be measured directly; it is a function of voltage and current. The microcontroller can use both voltage and current to calculate how much power is being sent to the load. This will aid in determining how efficient the control system is at regulating shaft speed and to ensure that the rated power of the load is not overcome.

During the design phase a boost converter was considered that would take low DC voltages and boost them to high voltages. This would have theoretically allowed the generator to produce more voltage at lower shaft speeds. The benefit of this was that when the turbine first starts to rotate, the control and power system would be able to immediately produce 10V and not have to wait until the turbine reached higher wind speeds. During testing it was found however that the boost converter when used to boost low voltages to higher ranges, such as 3V to 12V, the boost converter created a large load on the generator. It was discovered in order to boost voltage; current would need to increase from the generator output. This in turn caused the generator to rotate slower and the voltage would drop. This was counter-intuitive and the boost converter was removed from the design. It was then decided to regulate voltage via the control system which manipulated the brake; this would keep the generator shaft speed constant, resulting in constant voltage.

The system will utilize a brake to regulate the power output. The braking system will engage to slow down the rpm at wind speeds of 11 m/s and higher. Before this speed the turbine will be producing safe amounts of power for the electrical components to handle. After the turbine is interfacing with higher wind speeds the brake will be applied to regulate the power to a safe level for the components.

The final component of the turbine is the load. Power drawn by the load is a function of voltage and current, the current draw will be determined by the load. What determines the current of a circuit is the amount of current that the load draws. Using ohm's law and Kirchhoff's current law a load resistance can be determined. For the first prototype an 8 ohm power resistor was used. The final design will consist of a 10 ohm resistor and a power sink. The power sink will be charged by the generator and will be used to power the microcontroller and other turbine subsystems when the turbine is not producing power. For the competition, the turbine must be able to completely power itself off of wind energy. This is the purpose of the load, to draw enough current to generate 20 W and to store power to be used later.

The performance of the system will be decreased after the electrical components that are added to the system. The losses across the measuring components and from line loss will be negligible compared to the losses due to the rectifier. The rectifier will have direct voltage drops across the diodes used, this loss is equivalent to .55 volts.

Electrical analysis

The components selected to run the turbine have been chosen to handle the maximum expected output of the system. The Arduino is able to accept power at up to 20 volts and will draw 50 milliamps. If voltages were expected to exceed this voltage then an additional voltage divider would be added to the circuit to protect the Arduino. The pins of the Arduino that will be used to read voltage can only accept up to 5 volts which will be achieved by dividing the voltage from the system to where the readings are taken. The values read on the Arduino side will be adjusted to reflect the real values in the system.

Current will be determined by the draw of the system. The system will draw the current it needs to operate while the excess current will be sent to the load which can handle very large currents. While the load can withstand a large current, most of the components in the system will only withstand amperages of 2 amps. To prevent high currents braking components, fuses have been added to the system to protect the equipment in the case of a current spike.

Control model

The communication between the microcontroller and the related systems can be seen below in the canonical model. The Arduino microcontroller will receive data from generator as RPM, the output of the rectifier as current and voltage, and the voltage drop across the load for power consumption.

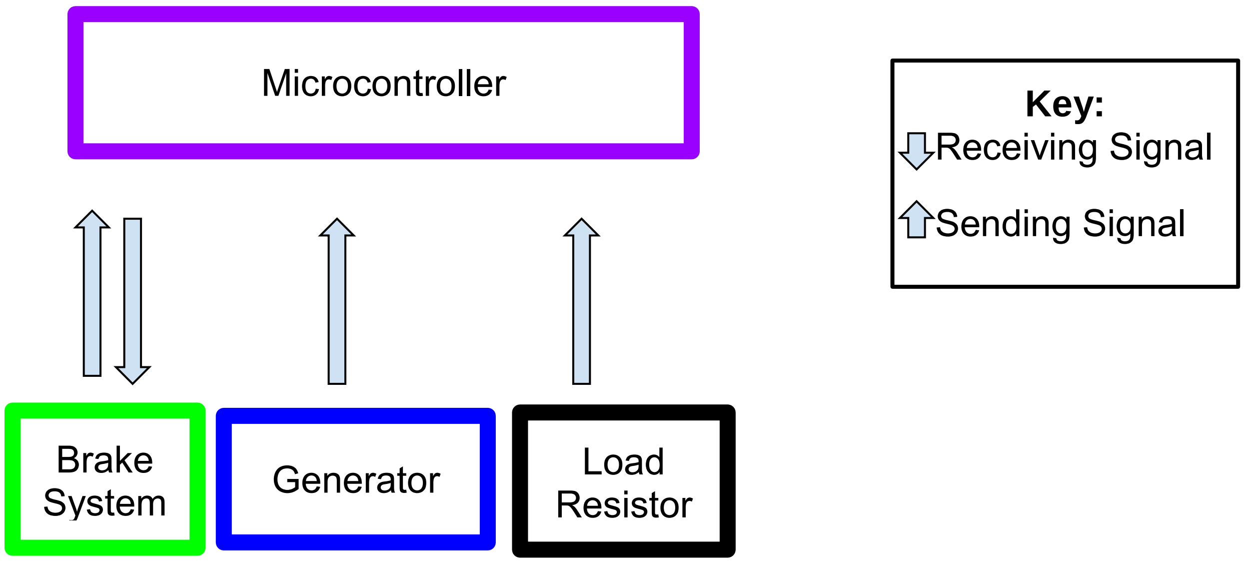
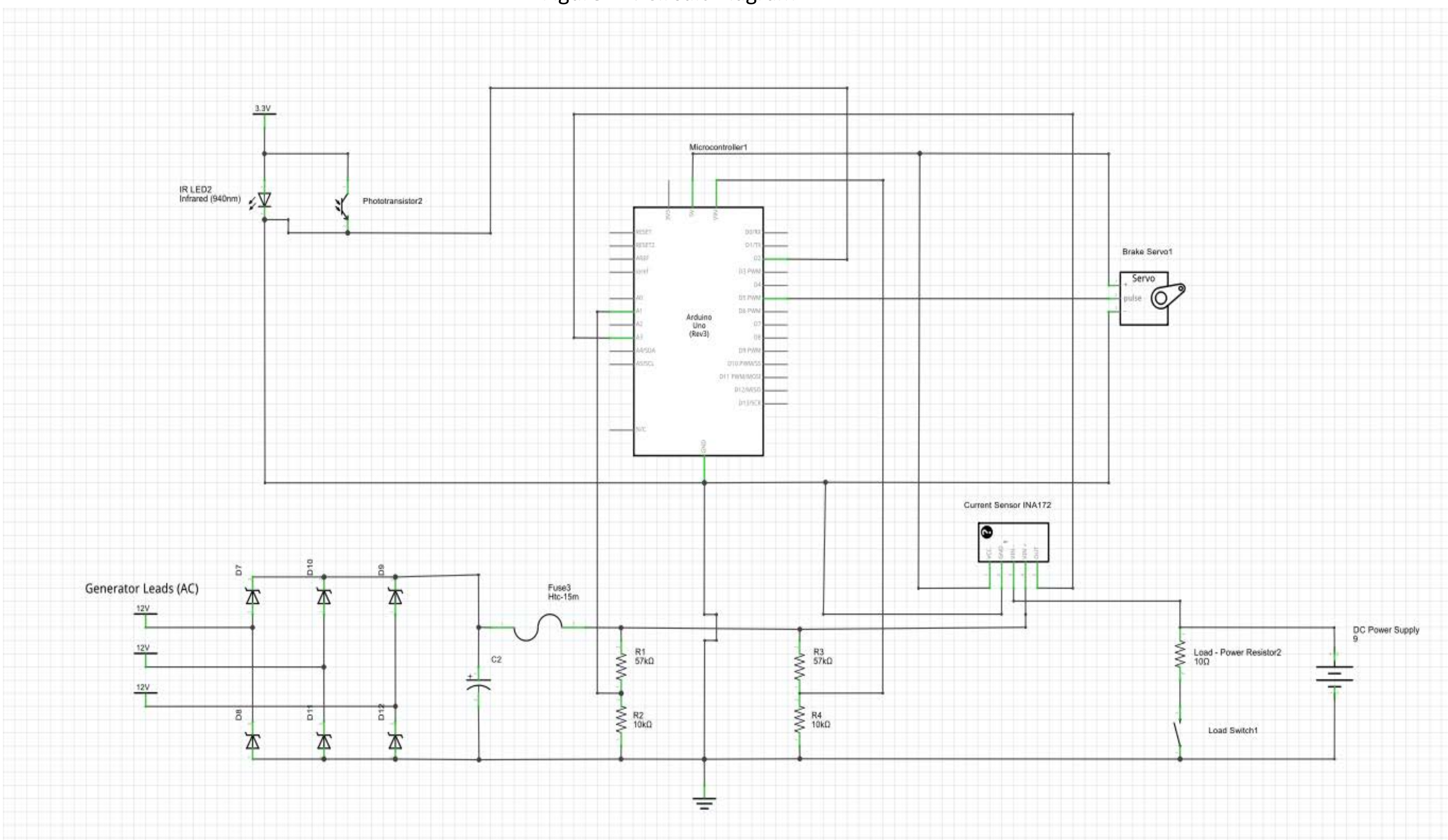


Figure 10: Canonical model

In Figure 12 the circuit diagram is shown. This diagram shows the power input to the rectifier all the way until the output at the load. The measuring devices are shown in this diagram using a shunt, a tachometer, and a voltage divider. The Arduino which is the brain of the turbine is connected to all of the systems in the design. The Arduino outputs values to the 8 LEDs to be shown on a display so that the turbine can be run independently and the values can still be read (Figure 11). The Arduino also controls the servo connected to the brake using a PWM at .94 kHz.

Figure 11: Control Panel

Figure 12: Circuit Diagram



The software is fairly straightforward. The system will check for any conditions that would require it to be turned off, if any of these conditions are met then the system will begin shut down. If these conditions are still met then the system will remain in shut down mode. If however these conditions are not met then the Arduino will continue and measure voltage, current, and RPM. Using the values collected from the measurement tools implemented in the system, the Arduino will adjust the brake correction factor, move the brake and display the results.

The emergency shutdown procedure allows the turbine to be stopped in a controlled fashion. The brake system is still controllable within limited ranges of movement. For example, the servo can move 180 degrees. This moves in a lead screw that moves the pads. Of these only about 40 degrees of movement have any “braking” effect. Using the degrees as reference values, from 50 degrees to 20 degrees is the range in which the brake can be used to control RPM. All the way to 5 degrees translates to the turbine being brought to a complete stop. If the system commanded the servo to 5 degrees from for example 40 degrees, the sudden deceleration would be enough to rip the blades off of the turbine. The emergency stop procedure incrementally moves the brake to 5 degrees from any position in about 3 seconds. This allows for a slow and controlled stop.

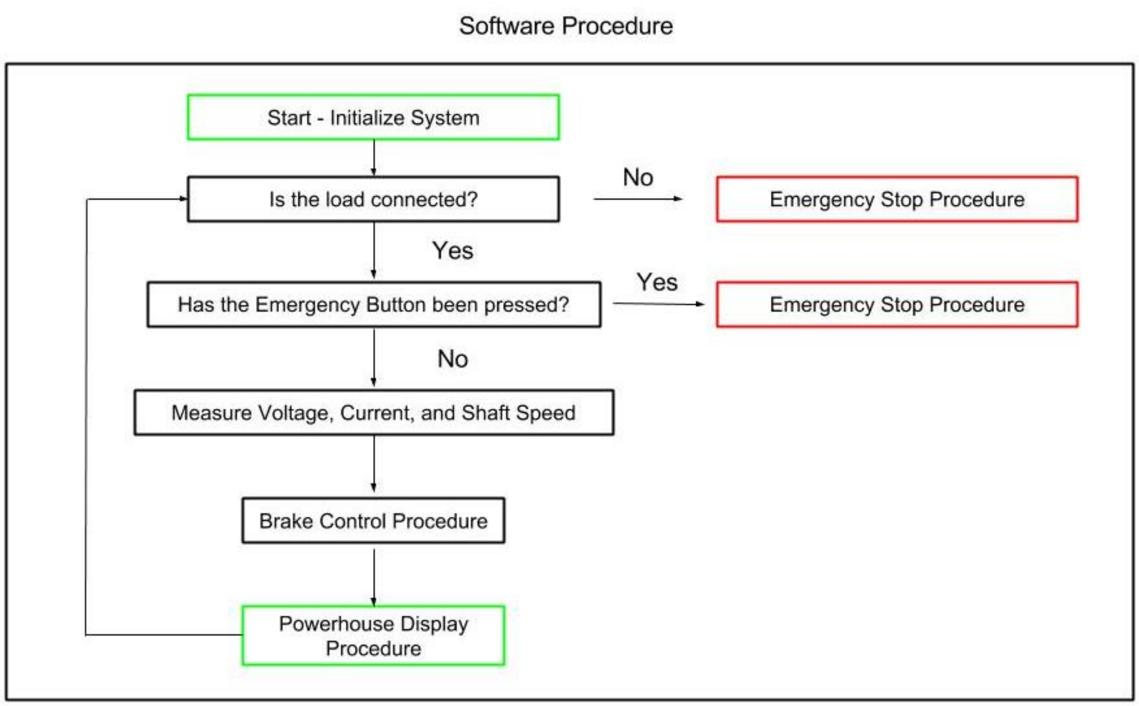


Figure 13: Software Procedure

Once the measurement are taken then the brake system will be adjusted. Using the values collected from the measurement tools implemented in the system, the Arduino will adjust the brake correction factor. The brake correction factor is varied based on the relative gap between the current RPM and the target. Larger gaps will result in higher correction factors. Once the correction factor has been selected then the brake will be adjusted.

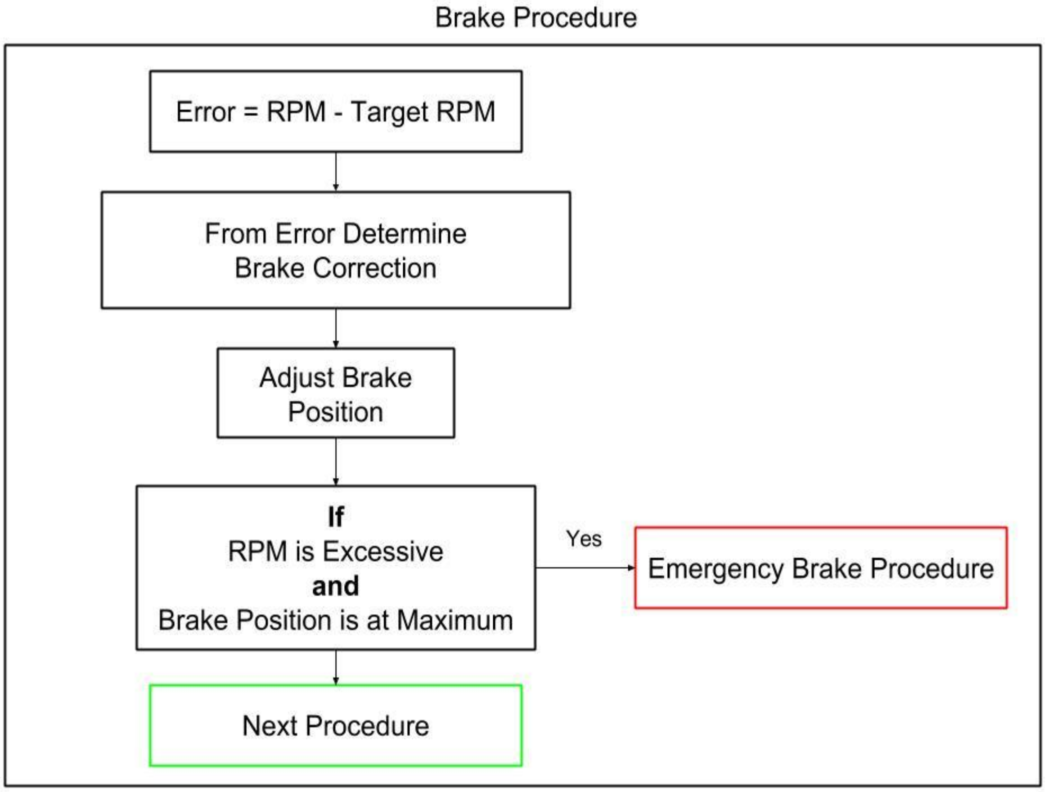


Figure 14: Brake Procedure

Associated Software

- Software Utilized for manufacturing and testing:
  - MATLAB
    - A matrix-based programming language created by MathWorks for engineers and scientists. MATLAB was used to develop and analyze the blade geometry.
  - Excel
    - Microsoft excel was used to perform calculations and generate spreadsheets for the data calculated. This allowed our team to optimize components.
  - Autodesk Inventor
    - A computer-aided design (CAD) program developed by Autodesk for design, visualization, and simulation of parts. Was used to design the first hub before the project standardized software.
  - SolidWorks

A CAD and computer-aided engineering (CAE) program published by Dassault Systèmes SolidWorks was used extensively in the design and analysis of the blades and gearbox and was the primary mechanical design tool. Additionally, this program allowed the team to design and visualize the turbine as an assembly comprised of sub-assemblies which aided in system integration and system design.

  - Cadence

Originally it was intended to use Cadence to design and simulate the control system. However, it was discovered that in order to simulate electronics, the components must exist in the Cadence libraries. The majority of the components for this system were not available within Cadence.

- Fritzing

Fritzing was used to create circuit diagrams and for planning the layout of the project boards.

Results

- Testing Gearbox:

The belt and pulley system has a theoretical potential efficiency of more than 95 percent. The efficiency of the gearbox is important as the power that is generated by the blades is transferred to the generator. When testing the gearbox's efficiency, we were able to get an efficiency of 76%. This value is considerably lower than the expected 95% efficiency; however we believe that the resolution of the equipment used to calculate efficiency was not as high as needed. The method and equipment used was not adequate to determine the real efficiency because the system introduced a lot of extra friction.

The test was performed by hanging a weight from a string wound around the high speed shaft and then weight was applied to in the same manner to the low speed shaft until the shafts started to turn. Efficiency was calculated by multiplying the output weight by the gear ratio and dividing that by the input weight required to start turning the shafts.

$$\eta = T_{output} * \frac{3.75}{T_{input}}$$

$$T = torque = mgR = mass \cdot gravity \cdot radius\ of\ shaft$$

- Power Curve Testing:

The test data was collected for the system to determine a power curve up to the rated RPM of 4000. The data for this test is shown in Table 2. The brake was not used during this test. The rated power 25 watts and rated RPM 4000 were reached at 11 m/s. This test was run up to 11 m/s without using the brake, at which time the test was stopped to preserve the blades. Figure 12 shows the wind speed vs the RPM and Figure 13 shows power vs. wind speed.

Table 6: Wind Tunnel Test Data

Wind Speed (m/s)	Current (A)	Potential (V)	Shaft Speed (RPM)	Power (W)
6.5	0.9	8.2	2145	7.3
7.0	1.0	11.0	2430	11.4
7.5	1.1	10.3	2670	11.3
8.0	1.3	11.0	2820	14.3
8.5	1.3	13.7	2970	17.3
9.0	1.4	12.5	3180	16.8
9.4	1.4	13.3	3400	19.1
10.0	1.5	14.2	3585	21.7
10.6	1.3	17.5	3765	22.7
11.1	2.0	15.7	4000	31.3

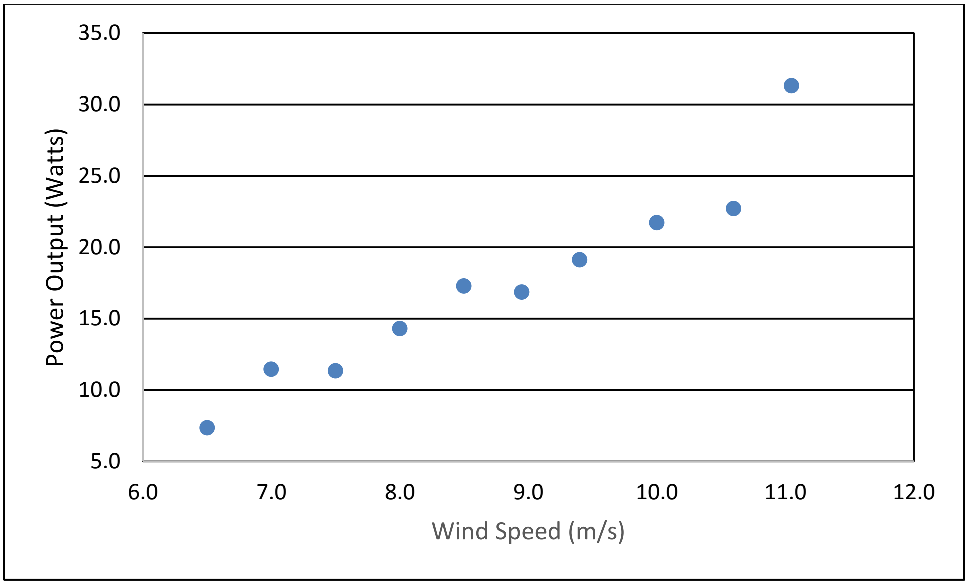


Figure 15: Power Curve

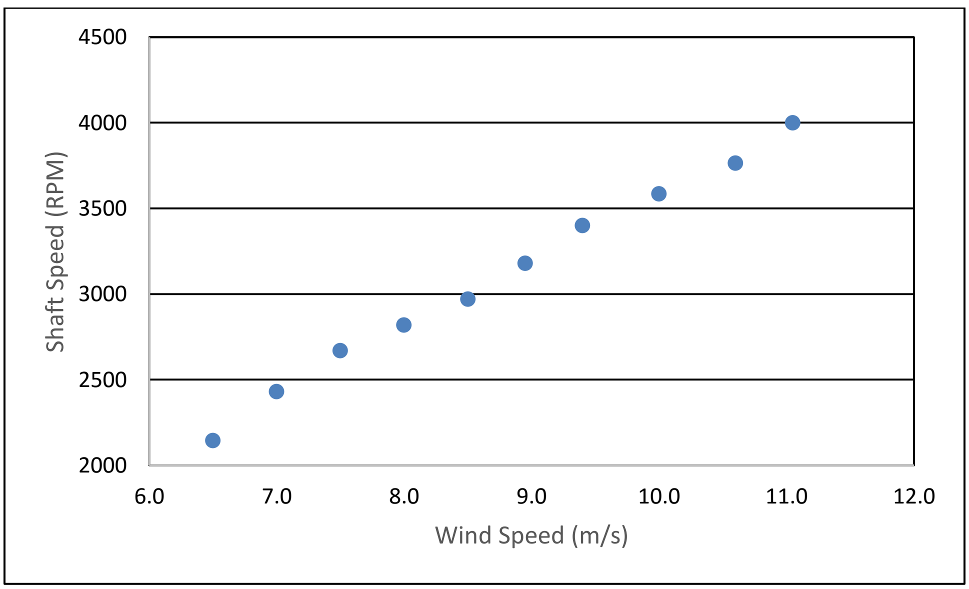


Figure 16: Shaft Speed vs. Wind Speed

Deployment Strategy

A large concern for the success of the product is in how it will get into the hands of consumers. In order to effectively get this product to the target consumer, there will be focus on two main divisions. These divisions are businesses selling the product, and the site evaluation for installation.

By focusing on the placing the product in stores the wind turbine will receive more attention and can become a commonplace item for a residential home. Local businesses such as REI and Beaverspots (outdoor shops located in Fairbanks, Alaska) will endorse this product and allow for the wind turbine to be introduced into the community of Fairbanks. The turbine can be marketed to people who are environmentally conscious and are looking for alternative energy production. A majority of the locals that shop at these outdoor stores are environmentally mindful people. It can be advertised for uses in places such as rural dry cabins, boats, snow machining, or dog sledding. When attaching it to a vehicle the vehicle's motion will enable it to charge something such as a satellite phone or beacon. Advertising the wind turbine as a small versatile power producer should capture the interest of the community. After the product has gained a foothold in the community the business team will reach out to larger stores such as Fred Meyers to give the community better opportunity to purchase the wind turbine. The more environmentally conscious consumers will purchase the wind turbines at the smaller outdoor shops and install them and get more people interested. If more and more people see the wind turbines being installed then they will be more likely to consider purchasing one in passing at the local supermarket. It will be a slow process but in the long run should produce the most sales for a local area.

Wind energy needs to gain popularity in the community, but it also needs to be effective. There will be a short guide, see figure below that is packaged with the wind turbine on how to pick the best direction to install the wind turbine. Also included within the guide will be a phone number for the installation team to come and perform the installation to ensure the optimization of the wind turbines location. This service will cost an additional fee. The wind turbine will be packaged in boxes with clear instructions to build and install the product at the site the consumer chooses. The turbine is designed for residential homes in windy areas but can be used anywhere there is a need for off grid power.

When marketing to rural communities, the community leaders will be contacted to attempt a bulk order for the entire community. This will help in two ways. The first way the bulk order is beneficial is that if the community leaders decide that wind energy is something they want to invest in then, the entire community will receive wind turbines to aid in energy production. The second benefit helps the business. By making bulk sales the business will save on shipping costs and be able to send a team out for installation in a single trip; eliminating the cost of multiple installation trips that would be both expensive for the business as well as the community members in the rural settlement.

Rural communities will be focused on more so than inner city residential homes because there is better opportunity to sell bulk orders as well as install the turbines in effective locations. Rural communities on the coastal regions of Alaska have more opportunity to utilize wind energy because of the coastal winds coming off of the ocean. In these locations the wind turbine is better utilized.

The wind turbine is designed to be easily maintainable and so anyone can repair the turbine if it is in need of a new part. The entire wind turbine comes apart fairly easily and all of the pieces can be replaced. There is also a team that can be called for maintenance issues and they can come and fix any part of the turbine or install a new one for an additional cost.

The cost for the installation and maintenance team will be based on the location of the required maintenance to cut cost to the business. For short distance jobs the cost will be 50% covered by the consumer and 50% covered by the business as well as the cost of the parts for repair. For longer distance jobs the cost to the consumer will be 75% of the cost for the travel of the installation team and the cost of the parts for the repair. This should help keep the cost down for the consumer as well as keep the business running.

Installation guide

You will need

- Compass or GPS
- Map of your area
- A method of measuring wind speed
    - Anemometer
    - Flag
    - Wind sock
- A clear flat space for installing the turbine

1. Orient your map to North
2. Look for valleys or very large obstacles that could impede or funnel wind
3. If there is a certain direction that appears to funnel wind toward your home face in that direction when looking for a place to install the turbine.
4. Find a flat space in the direction of the wind that the turbine could be installed.
5. Use your wind speed measuring device to record some daily data about the wind speed.
6. If the wind speed reaches speeds of 5m/s and higher then this is an ideal location for the wind turbine.
7. If not try to find a different location with higher wind speeds
8. Once a location is selected install the turbine following the installation procedure.
9. If this is too complicated call this number for a installation and optimization estimate 1-907-447-WIND.

Figure 17: Installation Guide

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