Final Report: Fall 2011

Power Generation Through Recycled Materials

EML 4551C – Senior Design – Fall 2011 Deliverable

Team # 7

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Executive Summary

The goal of this project is to take readily available parts from the trash of the “developed world” and create an electrical power generator that runs off renewable resources (wind power, solar power, hydropower, geothermal). The project must also be very cost-efficient as many people in third world countries do not have the financial resources to purchase new systems for green energy production.

Designing a system composed of recycled materials that harnesses these resources requires innovation as well as technical skills. The project is sponsored by Cummins and was proposed based on the book The Boy Who Harnessed the Wind, by William Kamkwamba. The success of this project will prove that there is a great deal that can be done to help both the environment and people in need at a cost that will benefit all parties.

Cummins laid out specific objectives that needed to be met by the final design. The power generation device needed to produce 100 W•h/day, and store a minimum of 300 W•h. In addition, they placed constraints on the cost of the device and the locations where the device would be operational. The total cost to the user for the power generation device could not exceed US $50.00. The total budget that is being provided by Cummins for designing and constructing the designs is US $2000.00. The locations that were to be selected would need to be in third world countries that were 500 km away from each other and 100 km away from an ocean coastline.

It was determined that the renewable resources that were most adequate, due to the cost constraint, were wind energy and water energy. For the concept generation phase it was decided that each concept would follow a similar infrastructure that would contain five main components. The first is a rotational component that changes the potential of the renewable energy source into rotational mechanical energy. The second component is one that will increase the rotational velocity from the rotational component. The next component is an energy conversion component that changes the rotational mechanical energy into electricity, and finally a power storage component that will store that electricity. Four designs were initially generated to solve this problem, though only three were selected for carrying out the construction process. The three are a vertical axis wind turbine (VAWT), a horizontal axis wind turbine (HAWT), and a hydro-electric generator. The fourth design that was eliminated was a Tesla turbine. This was eliminated due to cost, complicated parts as well as a unfeasible scaling for meeting the objectives.

The three designs were analyzed based on a power production standard of 10 W. This standard was selected to take into account wind energy not being available throughout the 24 hours of the day, and to account for losses in power generation while still meeting the objective of 100 W•h/day. The scale was deemed very important because the size would directly impact the cost of the system. Next the wind and water speeds were estimated from the chosen locations. Since wind and water designs were selected, three locations for wind and three locations for water were chosen. The locations chosen for wind exhibited high average wind speeds at relatively low altitudes, and the locations chosen for water had a high flow rates in large rivers.

The necessary sizes of the turbines were calculated using reduced efficiencies as well as inconsistencies in wind flow and water flow. This was necessary to develop a margin and ensure proper meeting of the objectives. Once these sizes were calculated each system was proven possible to build for under the set budget. Since efficiency is not the major concern as long as the power and cost requirements are met, all three designs will be constructed. This will render three fully functional designs that can be implemented in the locations of choice.

The most expensive parts of each system will be the power storage component, and there is little variety to the possible choices. The energy conversion component was initially thought of as being an automotive alternator obtained from a scrap yard; however, due to the high cost, high rpm and over scaled capacity of an alternator, an alternative was researched and selected for use. The alternative is a permanent magnet DC motor, specifically a bicycle dynamo assembly. This allowed for a reduced cost from this component and leaves a greater budget available for the actual design of our power generation device.

The next step includes gathering the parts required from Marpan Recycling Yard, and local junkyards as well as, beginning construction of the systems in early January.

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Project Outline

Problem Statement

Design and construct a power generation device that implements the use of a renewable energy source, and is composed entirely of recycled materials.

Objectives

The following are a list of objectives provided by Cummins that must be met with final design and construction of the power generation device:

- Power generation unit must be capable of generating 100 W•h/day
- Power generation unit must be capable of storing 300 W•h
- Output of unit must be 12 V Direct Current

Constraints

The following constraints must also be satisfied with the design and construction of the power generation system:

- Three geographic locations for implementation of the power generation unit must be selected in third world countries
    - Each location must be 100 Km away from the ocean and 500 Km away from each other
- Final Cost of the power generation kit must be under (US) $50.00
    - Price does not include construction, materials, or labor costs at destination
    - Does not include refurbishment costs for recycled materials

Customer Needs

Justification/Background

In many countries around the world there are people with scarce means of acquiring power. This is mostly due to the lack of financial funds for a centralized power generation facility, or lack of parts that can be combined into a system that can harness energy from natural resources. A power generator would be a very valuable commodity for them and would greatly enhance their standard of living.

With planet Earth's current energy crisis there is a huge surge towards using renewable resources to supply power. Around the globe people are turning to wind, solar and hydro power in order to reduce the amount of carbon emissions they are creating as well as obtain "free" sources of energy. Most common wind applications consist of wind turbines which harness the mechanical energy of wind turning a turbine. Mechanical energy is then converted into electrical energy with the use of either a motor generator or an alternator. Hydropower is another abundant renewable resource that uses falling or moving water to rotate a turbine and produce mechanical energy. This mechanical energy can then be converted into electrical energy, similarly to wind power. Solar power can provide a substantial amount of energy due to the Sun; however, solar photovoltaic cells as well as solar thermal systems are very expensive.

Green energy systems made from new materials have a high cost, and the price is most commonly justified by large scale implementation. For the purpose of this project it is of great importance to provide a small scale device that would be affordable and effective in generating energy. Another advantage of designing the kit in a first world country is the vast majority of trashed or recycled components that are available. These components contain great value that in their current state is overlooked and kept in permanent storage. This abundance in parts is a key element in designing a low cost system.

Product Specifications

The overall layout of the power generation device under development includes five main components for three different designs. The first is a rotating component; which is a wind turbine system, or a hydro-electric paddle wheel. The responsibility of this component is to convert the potential of a renewable source of energy into useful, mechanical energy. The next component is a gearing system; in which a pulley/belt assembly, or spur gear system can be implemented. The third component is an energy conversion device that can convert mechanical energy into electrical energy; a motor generator, dynamo or an automotive alternator. The final component is a storage device; a battery.

Rotational Component

The rotational component of the system will have three forms; one for each of the three designs. They are a vertical axis wind turbine, a horizontal axis wind turbine, and finally a hydro-electric paddle wheel. It is necessary that this component can produce a minimum of 100 W•h/day. Detailed design of these rotational components will be analyzed in the Concept Generation section that follows.

Gearing Assembly

This component of the power generation is required due to the energy conversion process that follows. The rotational velocities of the three designs are not sufficient to directly attach to the alternator, motor or dynamo and generate sufficient power. If using the alternator the ratio will have to be extremely large due to an alternator operating at rotational velocities of over 700 rpm. There are motors that can produce significant power at lower rpm; however, they will still require a stepping down mechanism.

Energy Conversion

The energy conversion component is required to convert rotational mechanical energy into electricity. An automotive alternator, a permanent magnet DC motor, and a bicycle dynamo are capable of successfully performing this task. The component that was selected for implementation onto the designs is discussed in the Concept Generation section under Energy Conversion.

Power Storage

The power storage device is crucial for handling fluctuations in power generation. In order to successfully output a 12 V DC current and store a minimum of 300 W•h an automotive battery contains the capability. The power storage component that will be integrated into the design is analyzed in more detail in the Concept Generation section under Power Storage.

Concept Generation

Geographic Location Analysis

The first step into the concept generation phase was to select the geographic locations where the power generation unit would be implemented. In order to select adequate locations, the amount of natural renewable energy available was taken into consideration. The renewable energy sources that were chosen were wind energy, and water energy. Therefore, the analysis of the locations consisted of finding average wind speeds at reasonable altitudes, as well as average flow rates of major rivers in areas far away from a coastline.

Detailed wind speed data in many third world countries is not readily available; however, there is a global map that highlights countries based on their annual average wind speed. An organization called 3Tier is responsible for publishing this information. They can provide highly detailed information, but the data is quite expensive. The three locations that were selected for wind power are: Faya-Largeau, Chad; Santa Cruz, Bolivia; Sen Monorom, Cambodia. Faya-Largeau, Chad has a local airport that provides accurate information on wind velocities at 10 meters in altitude. The average annual wind speed value is 4.6 m/s. The information for Santa Cruz, Bolivia was provided at no cost from the 3Tier organization, and the annual average wind speed at 10 meters is 3.9 m/s. Sen Monorom, Cambodia was demonstrated by 3Tier to have some of the highest wind speeds; and using the local forecast information from the Titi Tudorancea Bulletin, exhibits an average wind speed of 5.1 m/s. The height in Sen Monorom is not published for this information, but the 3Tier organization groups the location in the same range as the other two locations. Figures 1 and 2 show annual trends for Faya-Largeau and Santa Cruz. Figure 3 was developed from the weekly forecast information available from Sen Monorom.

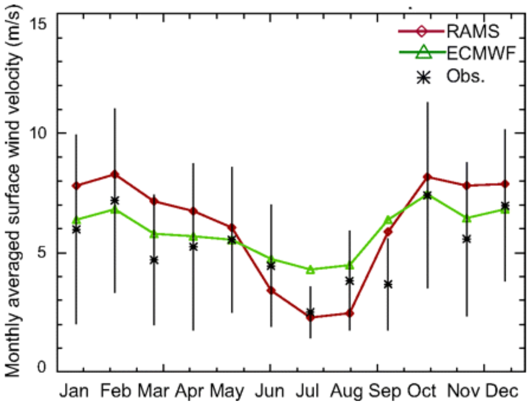


Figure 1 – Faya-Largeau, Chad Annual Average Wind Speed as provided by Proceedings of the National Academy of Sciences of the United States of America organization

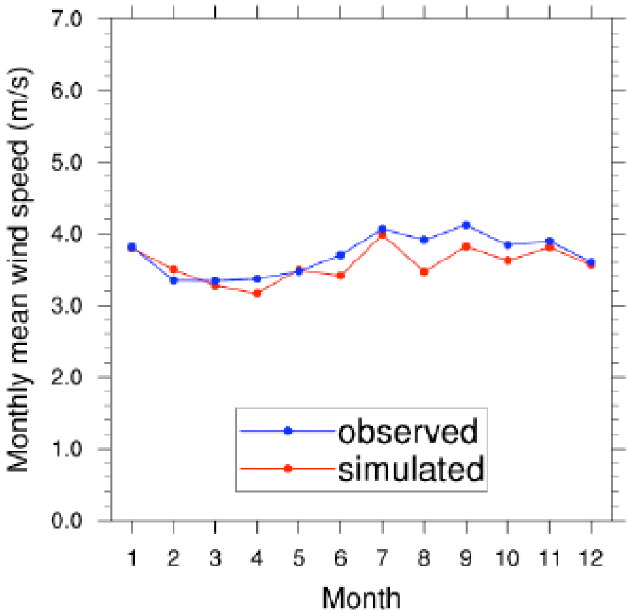


Figure 2 – Santa Cruz, Bolivia Annual Average Wind Speed provided 3Tier Final Report

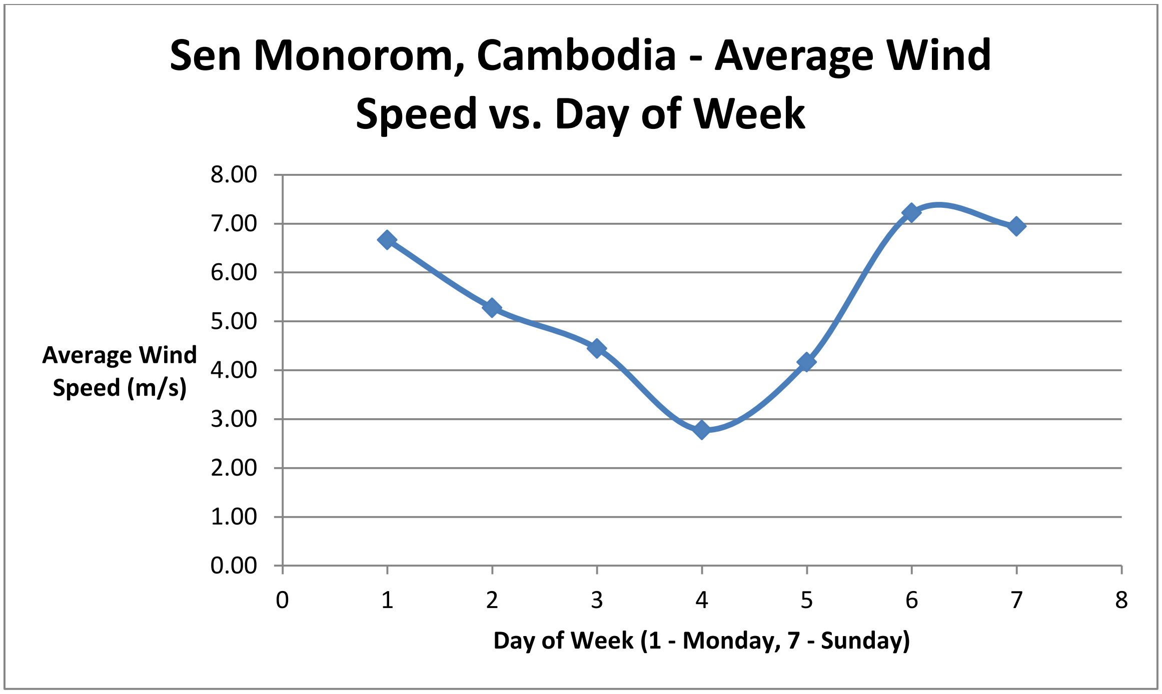
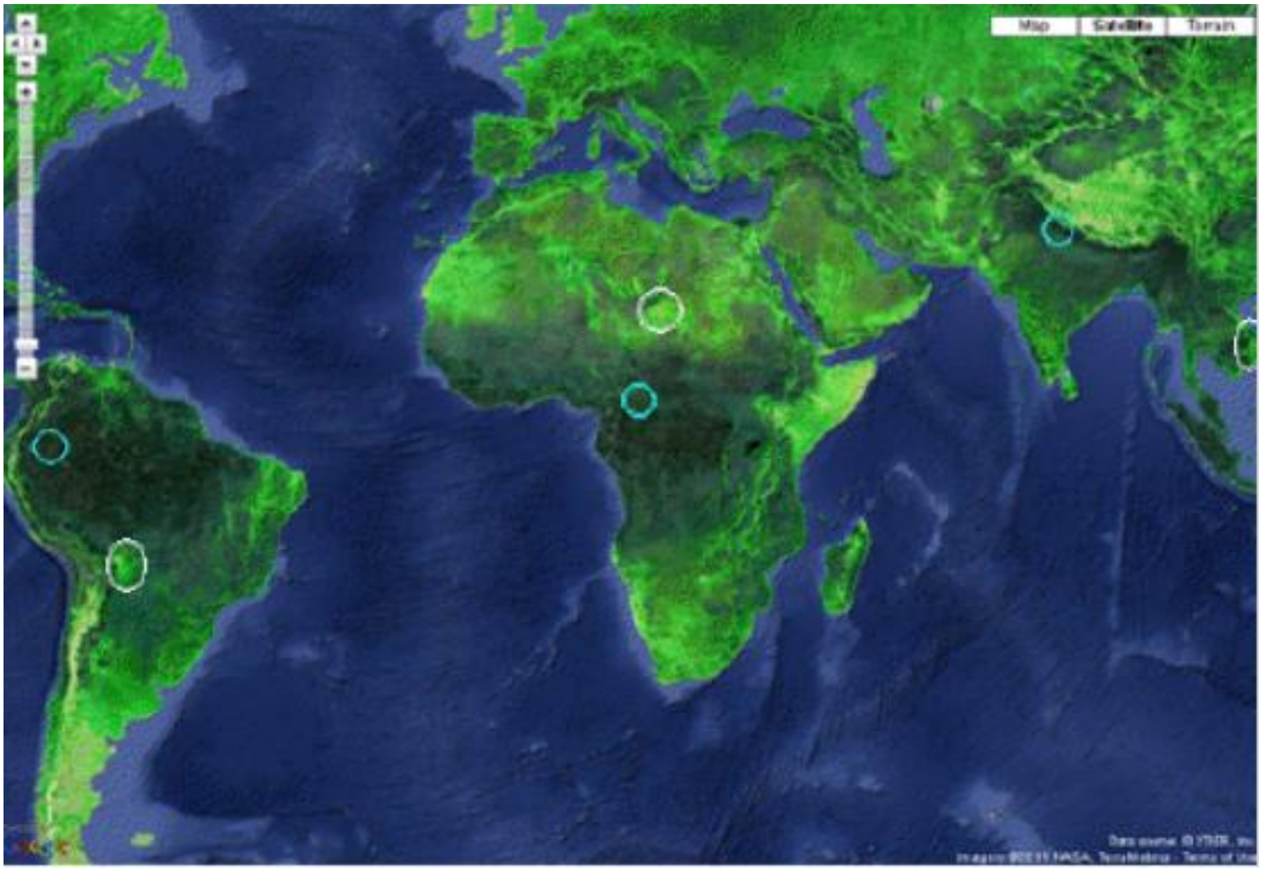


Figure 3 – Sen Monorom, Cambodia – Weekly Average Wind Speed. Data provided by Titi Tudorancea Bulletin Weather Forecast

The water energy locations were chosen based on high volumetric flow rates of rivers. A high flow rate contains a high amount of kinetic energy that can be used directly to spin a turbine, or channeled above a certain height to create a potential head. The three locations chosen were the Atrato River, Colombia; Indus River, Pakistan; Benue River, Cameroon. The average flow in the Atrato River is roughly 2.0 • 10^6 L/s; the average flow for the Indus River is roughly 6.5 • 10^6 L/s; the average flow for the Benue River is roughly 1.75 • 10^5 L/s. These flow rates were taken at locations that were farther than 100 km from the coastlines.

Similarly to the wind speed fluctuations observed in the figures, there are also significant variations in the flow rates of the rivers that will be taken into account for the designs. Ultimately, a velocity threshold will be developed for calculating the total power generated for the three concepts. All six locations are shown in Map 1 below. The wind locations are circled in white, and the water locations are circled in blue.



Map 1 – Global Map – Wind locations are highlighted in white, water locations in blue (3Tier)

Concept Design #1 – Vertical Axis Wind Turbine (VAWT)

A wind turbine uses the mechanical energy of moving wind currents to impart energy onto a turbine, which transfers this energy into rotational kinetic energy. In order to convert this rotational motion into electricity, one must employ an energy conversion device. Once the energy conversion device transforms this mechanical energy into electricity, it is stored in a battery for later use. We will be employing these same basic principles in the design of our systems.

VAWT systems differ from the traditional wind turbines seen in large scale power generation applications. Instead of having a propeller shaped turbine on a horizontal axis, it can have a variety of different turbines mounted on a vertical shaft. This has a huge advantage as it allows the VAWT to be omni-directional whereas the horizontal axis turbine needs to be facing directly into the wind at all times.

There are two basic types of wind turbines: lift and drag based designs. Typically lift designs are used in high wind speed applications as they employ an airfoil design which increases the rotational speed above the speed of the undisturbed wind. This lift technique increases the power production of the system. Since this design will be used in relatively low wind speeds, a drag based design will be ideal.

After extensive research, the Savonius wind turbine design was chosen for the VAWT concept because of its simplicity, high performance coefficient, as well as its ability to run at extremely low wind speeds. As seen in Figure 4**,** the Savonius turbine is simply two cylinders placed facing each other with an offset.

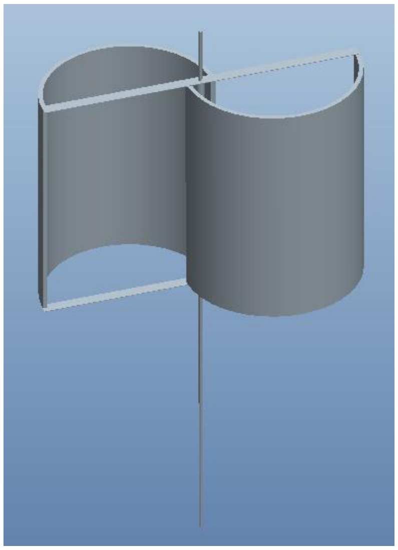
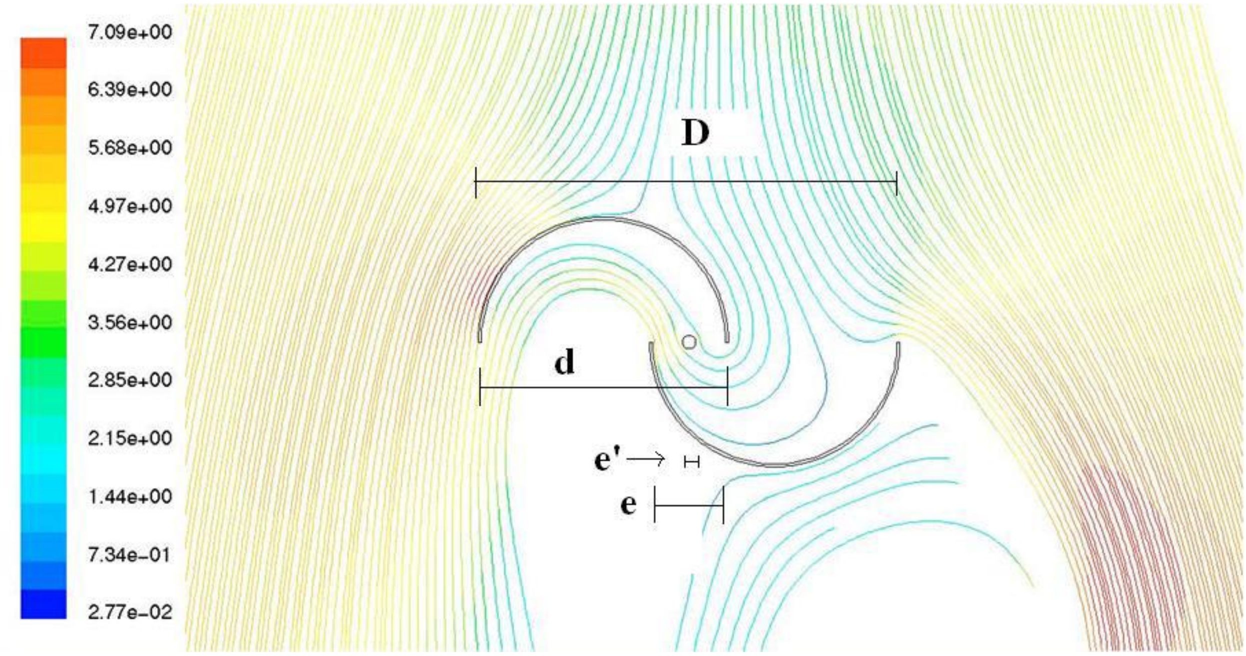


Figure 4 – Savonius VAWT Design Concept #2

The Savonius wind turbine design is known to be a drag based system, although it exhibits flow characteristics because of its design that improves its performance above what a simple drag based turbine can achieve. As seen in Figure 5, the offset of the two turbine blades redirects the flow profile of the wind to travel into the return stroke of the turbine which decreases the net drag experienced by that blade. Also seen in Figure 5 are the units used in the turbine’s dimension calculations.



- **Figure 5 – Static Pressure Flow Field - Jean-Luc Menet1, Nachida Bourabaa2. "INCREASE IN THE SAVONIUS ROTORS EFFICIENCY VIA A PARAMETRIC INVESTIGATION." Web. <http://www.2004ewec.info/files/23_1400_jeanlucmenet_01.pdf>.**

In order to create an idealized Savonius turbine, fairly exact specifications must be followed but the design can be scaled to any size. The following equations have been developed for an ideal Savonius turbine:

—

The aspect ratio which relates the overall height of the system to the diameter seen by the wind is very important as

—

An idealized Savonius turbine will have a power coefficient of approximately 0.3 which means 30% of the energy imparted on the turbine by the wind will be transferred into rotational mechanical energy.

This is fairly high as the theoretical limit declared by Betz' Coefficient is 0.593. As the design specifications to build an ideal turbine are based only on the dimensions of the cylinder chosen, the offset of the two cylinders, and the diameter of the center rotating shaft; the ideal turbine would be very easy to reproduce. It is also safe to say that a device built out of recycled materials could approach this design; therefore, also approaches the power coefficient of an ideal Savonius turbine. For calculation purposes we will assume that a turbine constructed from recycled materials will only produce 80% of the power compared to an ideal turbine.

To reach a power coefficient of 0.3 from a Savonius turbine, the speed of the far rotating edge must match the speed of the undisturbed wind. This relation is called the tip speed ratio and is denoted with the symbol λ. As seen in Figure 6 this power coefficient is only reached at a tip speed ratio of 1. This is generally impossible to accomplish on a drag-based VAWT system. This is because the drag imparted on the returning turbine blade will not allow the turbine to rotate at exactly the same speed as the undisturbed wind. In order to optimize this design, an external wind vane surrounding the turbine has been devised that will block air flow from hitting the return stroke of the turbine as well as direct more air into the power stroke. As the VAWT is omni-directional, the vane must also be omni-directional. The wind vane will be constructed out of a malleable cylinder that is larger than the rotating components of the wind turbine. The cylinder will have slits cut in the outside wall in between the supporting upper and lower structures, as well as have the created strips of material turned at an angle. See Figure 7 for visualization.

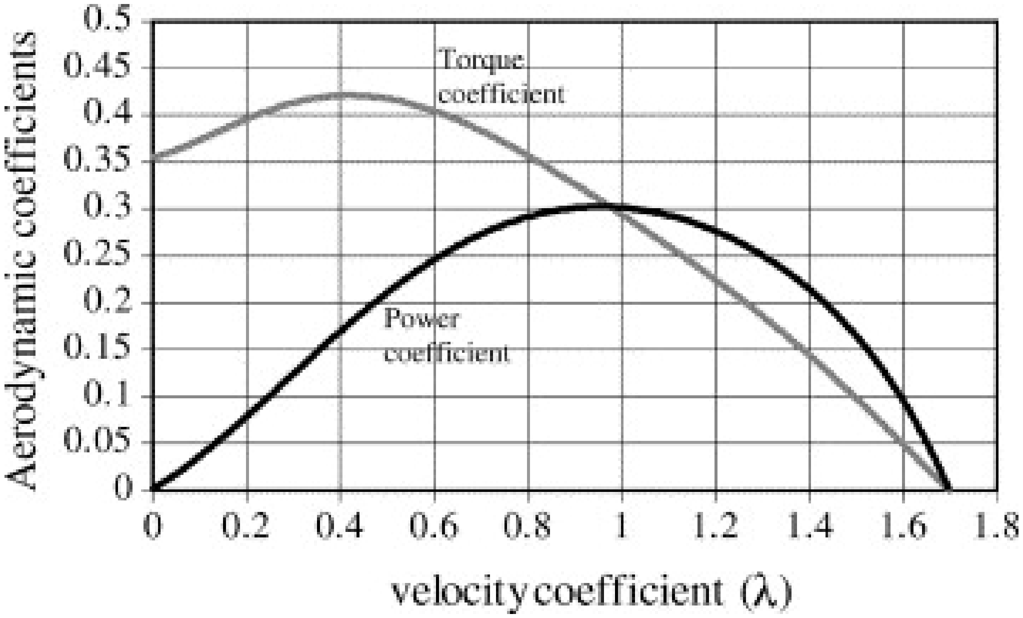


Figure 6 – Savonius Optimization – (Jean-Luc Menet1, Nachida Bourabaa2. "INCREASE IN THE SAVONIUS ROTORS EFFICIENCY VIA A PARAMETRIC INVESTIGATION." Web. <http://www.2004ewec.info/files/23_1400_jeanlucmenet_01.pdf>.)

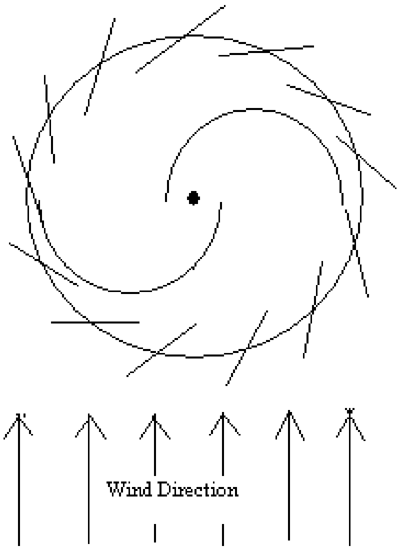


Figure 7 – External Wind Vane Design

An ideal Savonius wind turbine will have at least two steps (turbine stack) stacked on top of one another and attached to the same rotating axis. This provides a few advantages such as allowing the turbine to be self-starting as well as adding the ability to run in even lower wind speed conditions. The two step design will also allow for a greater power output throughout the entire rotation of the turbine, as well as decrease some of the high torque moments seen on the shaft, as seen in Figure 8**.** It has also been proven that endplates on each turbine blade improve performance.

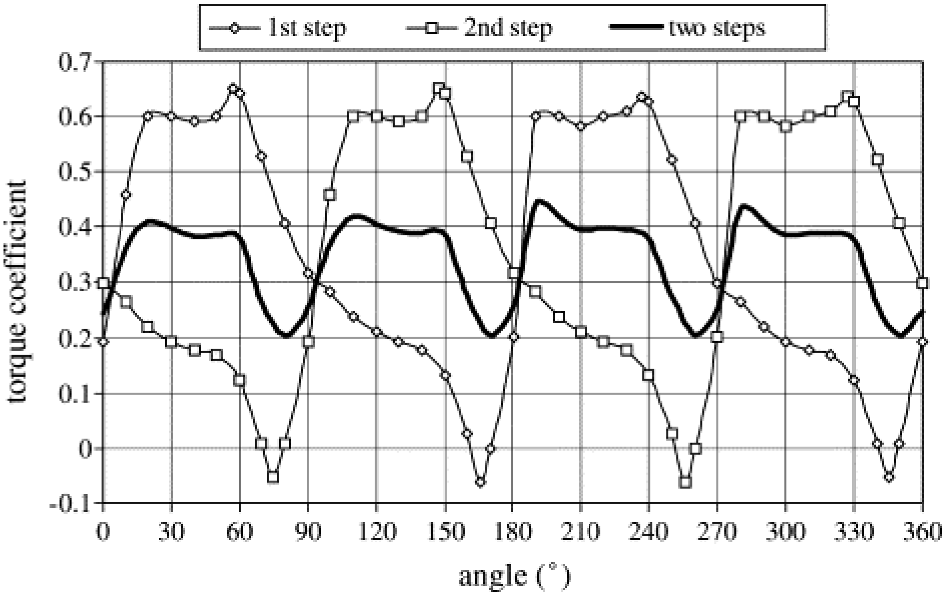


Figure 8 – VAWT Optimization - Jean-Luc Menet1, Nachida Bourabaa2. "INCREASE IN THE SAVONIUS ROTORS EFFICIENCY VIA A PARAMETRIC INVESTIGATION." Web. <http://www.2004ewec.info/files/23_1400_jeanlucmenet_01.pdf>.

As the calculations in Appendix 1 show, the required minimal area to produce 10W is 1.563m^2. 10W was chosen because it will overcompensate for any losses, fouling, or decreased wind speeds that the system may encounter over time. Since materials will come from recycle yards or dumps, this is just a minimum required area and the actual can be anything equal to or larger than this value. All other minimum dimensions are also included in the Appendix. The calculations for possible gearing ratios if using the bicycle dynamo as the power conversion device are provided as well. This shows that no other gearing is required as the ratio of diameter of the bicycle wheel to dynamo wheel diameter is 54:1. Appendix 1 is the design drawing of calculated VAWT dimensions.

Design Concept #2 – Horizontal Axis Wind Turbine

A horizontal-axis wind turbine system can also be implemented as a lift or drag system. Since the VAWT system defined in design concept #1 uses drag physics, the HAWT will be developed as a lift based system. In order to create the lift effect on the turbine blades, PVC will be cut into an approximate airfoil shape. The process can be performed by cutting the PVC into quarters, and drawing straight lines down the lengths of the tube, as well as diagonal, straight lines to one of the ends of the tube. The PVC pipe will then be cut into quarters once again along the straight horizontal lines drawn along its length. The final cut will be made on each piece to keep the diagonal shape drawn throughout each piece of PVC. Examples of the cuts are shown in Figures 9 and 10.

Figure 94 – Sample PVC cuts to approximate airfoil shape. "YourGreenDream - Homemade Solar, Wind and Green Power Diy Projects to Generate Energy. How to Make PVC Windmill Blades." *YourGreenDream - Homemade Solar, Wind and Green Power Diy Projects to Generate Energy.* Web. 07 Dec. 2011. <http://www.yourgreendream.com/diy_pvc_blades.php>.

Figure 10 – Sample PVC cuts to approximate airfoil shape. "YourGreenDream - Homemade Solar, Wind and Green Power Diy Projects to Generate Energy. How to Make PVC Windmill Blades." *YourGreenDream - Homemade Solar, Wind and Green Power Diy Projects to Generate Energy.* Web. 07 Dec. 2011. <http://www.yourgreendream.com/diy_pvc_blades.php>.

The HAWT system that will be constructed will be composed of three airfoil blades, which has been found to be the best compromise of physical strength and rotational speed. The higher the number of blades, the heavier the system becomes and the greater the effect of gyroscopic forces. However, the efficiency also increases with the increase in the number of blades. When researching two-blade systems currently in use for wind generation, the dynamic calculations governing their behavior are very complex and further strengthened the selection of a three-blade design. The three blade design is shown in Figure 11.

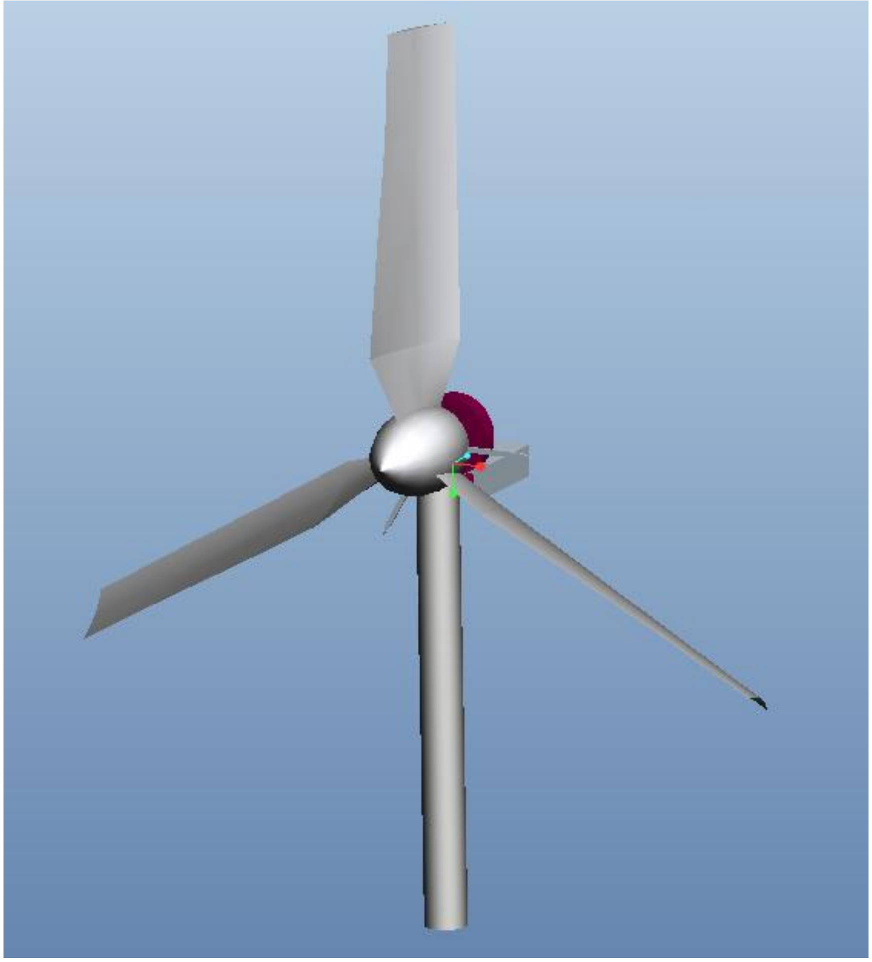


Figure 11 – Design Concept #2 Horizontal Axis Wind Turbine

In order to determine the size of the turbine blades required, data from the National Renewable Energy laboratory was used to estimate the power coefficient of a three-bladed wind turbine design. The ARE442 lift based wind turbine is 7.2 meters in rotor diameter; however, it was the smallest wind turbine with accurate experimental data. A graph comparing the coefficient of power to average wind speed can be observed in Figure 12 for the ARE442.

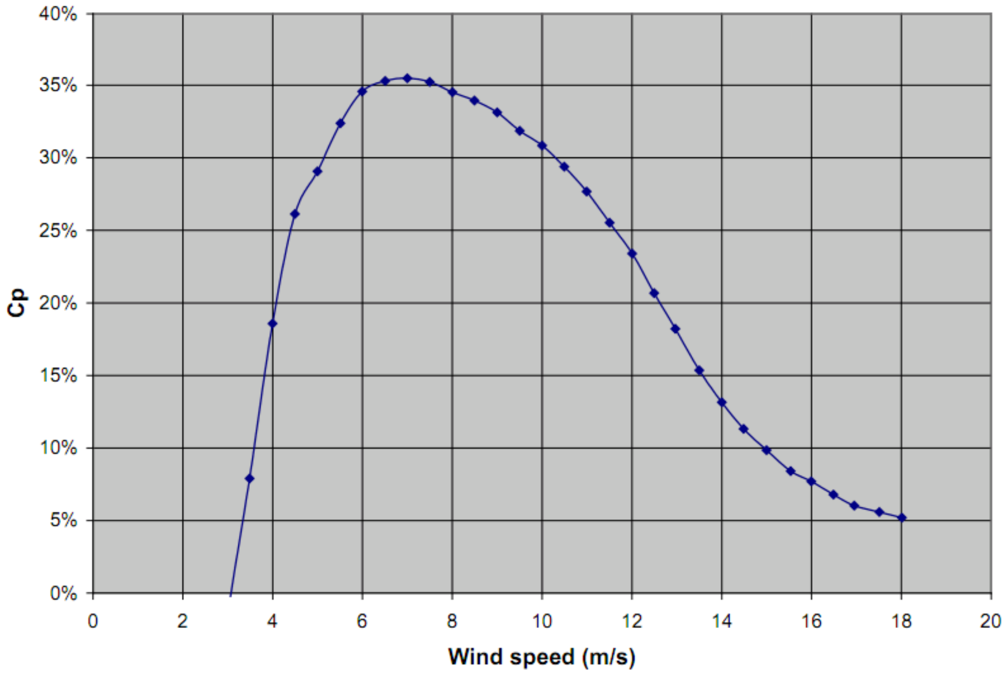


Figure 12 – Coefficient of Performance vs. Wind Speed for ARE442 (NREL) Wind Turbine

Using wind speed data from Faya-Largeau, Chad, an average wind speed of 4 m/s was found at a five meter height. Analyzing this wind velocity, a power coefficient of 19% can be extrapolated from Figure 12. To account for a smaller turbine diameter and an approximate airfoil design, 60% of this 19% was used to carry out the calculations of the design. These imperfections for the wind turbine adjust the power coefficient to a value of 11.4%.

The next consideration that was needed to be examined was the power output requirement of the turbine. In order to achieve the 100 Watts required in one day, and assuming that the 4 m/s is present during a 10-hour period, a minimum power output of 10 W is needed in one hour. Designing for this 10 Watts of power, using Betz Power equation shown below, the area of the turbine was found to be 1.4 m^2. Increasing the margin for error the HAWT turbine blade will have an area of 3.29 m^2. This area accounts for a rotor diameter of roughly 2.05 meters.

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The ρ shown above represents the density of air at near ground level - 1.225 kg/m^3. The η_{belt} stands for the loss in the belt and pulley system that is required if using an automotive alternator. The $\eta_{alternator}$ represents the efficiency loss in using an alternator to convert mechanical energy into electrical energy. Since the alternator and belts will be used and refurbished, the efficiencies were set at 80% for the alternator and 85% for belts.

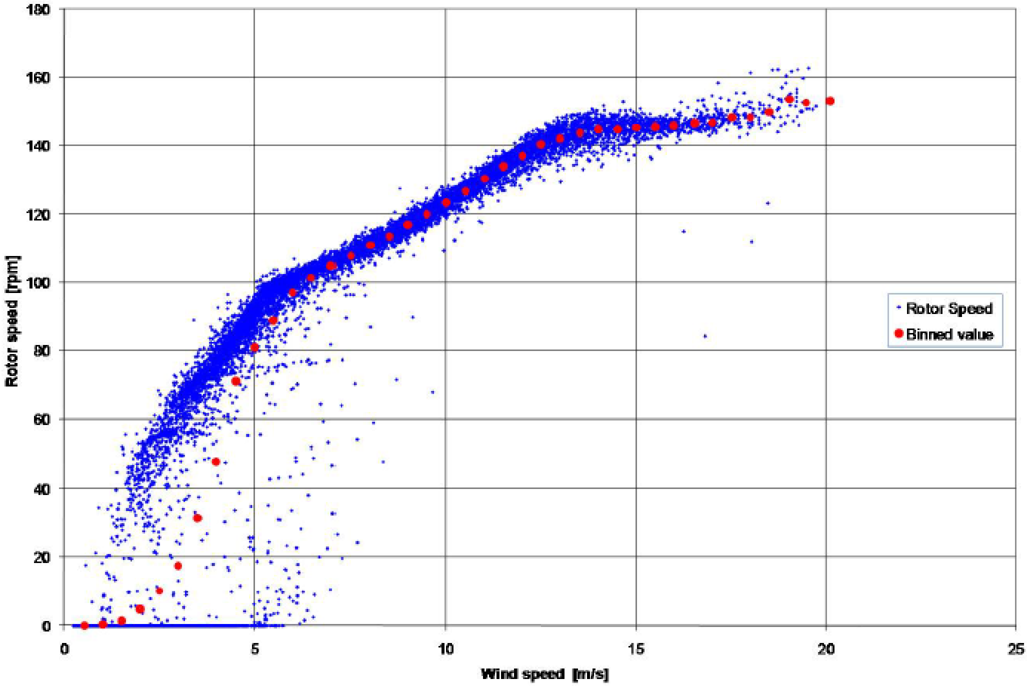


Figure 13 – Rotor Speed vs. Wind Speed for ARE442 (NREL)

Using the belt efficiency, it was necessary to calculate the pulley ratio needed to increase the rotational speed of the wind turbine, to the alternator rotational speed. Using data from the ARE442 turbine shown in Figure 13, an average rotational turbine speed at a 4 m/s wind is 48 rpm. Assuming this same value for design concept 2, the pulley ratio needs to be 15:1.

This was the original design for the HAWT system. However, upon further research, there are a few alternatives to the conversion from mechanical power to electrical power. Permanent magnet DC motors can be used as generators, and some are designed to operate at much lower rpm than alternators, and at the same time maintain a high power generation. A company called Ametek has a variety of permanent magnet DC motors that have proven to be successful in power generation in home-designed wind turbine systems. According to Michael Davis, designer of a home built turbine; an Ametek motor that is rated for 30 Volts at 325 rpm was successful in powering 12 V home appliances.

This significantly reduces the amount of pulley ratio that will be required. The new pulley ratio becomes 8:1. This precise motor may be difficult to find due to its grown popularity in home wind turbine designs. However, there are others available that can be successful in power generation, and can be found in trashed components.

Another option that was analyzed was the bicycle dynamo, a type of permanent magnet DC motor. This was the system developed by William Kamkwamba. William incorporates the back end of a bicycle and uses the sprockets and chain to create a gearing system and increase the rotational speed that the dynamo will see to output voltage. This is the method that has been chosen for the design, due to ease in finding a bicycle assembly and having an incorporated gearing system leading to the dynamo. More information on this power conversion route is given in the Energy Conversion section.

The gearing that will take place with the bicycle assembly will be a 67.5:1 ratio and will cause the dynamo to spin at 3025 rpm. Detailed calculations of this can be seen in the Appendix for the HAWT design.

Design Concept #3: Micro-Hydroelectric Generator

The hydroelectric generator will convert the kinetic energy of the flowing water into rotational mechanical energy through the implementation of a paddle wheel. In order to minimize infrastructure that would otherwise be required to direct flow from a source river, the prototype was designed to anchor in the river. In this way the flowing water of the river will spin the paddle wheel. The paddle wheel selected for this design should be made from light weight, and durable bamboo, and be comprised of 6 fins. These fins will be affixed rotor that in turn is coupled to the shaft. This would cut down on the unit price of the product by using a sustainable resource that is present in many third world countries. A bull pulley connected at the opposite end of the rotating shaft will spin the pinion pulley attached to the dynamo, as illustrated in Figure 14. The gear ratio between the belt driven pulleys will depend upon the incoming flow rate of the water, inertia of the system, and resistance from bearings.

Furthermore, the 12 Volt direct current rectified by a germanium diode from the dynamo will be directed into a battery with a minimum capacity of 300 W•h. This battery will be of the automotive variety and stowed inside the pontoon closest to the paddle wheel. These batteries are abundant in most junkyards. While the individual cost of these used batteries is high, a bulk purchase will reduce the cost by 10%. Also, certain measures will need to be taken to prevent water from coming in contact with the charging system. One way to accomplish this would be to use the insert for a car trunk as a type of shroud to protect the electrical components from water splashing back from the paddle wheel.

Since the flow of all rivers varies throughout the year we based our calculations for power generated as a function of the velocity. By setting the surface area of the paddle wheel in contact with the flowing water to be constant we are able to tabulate the potential power produced. Although there is no actual head since the system actually floats on the surface of the water there is still what is called a gross head. The gross head is based upon the oncoming velocity of water, and is proportional to the vertical distance the water would fall to attain said velocity. Table 1 below demonstrates the mechanical power expected our generator to produce at different flow velocities.

Table 1 - Power Ouput Results – Converts Flowing Kinetic Energy to Head Potential

Power Output (Watts)
Velocity (ft/s)

Gross Head (ft)	3	6	10	15	20
0.139751553	2.993478	5.986957	9.97826087	14.96739	19.95652
0.559006211	11.97391	23.94783	39.91304348	59.86957	79.82609
1.552795031	33.26087	66.52174	110.8695652	166.3043	221.7391
3.49378882	74.83696	149.6739	249.4565217	374.1848	498.913
6.211180124	133.0435	266.087	443.4782609	665.2174	886.9565

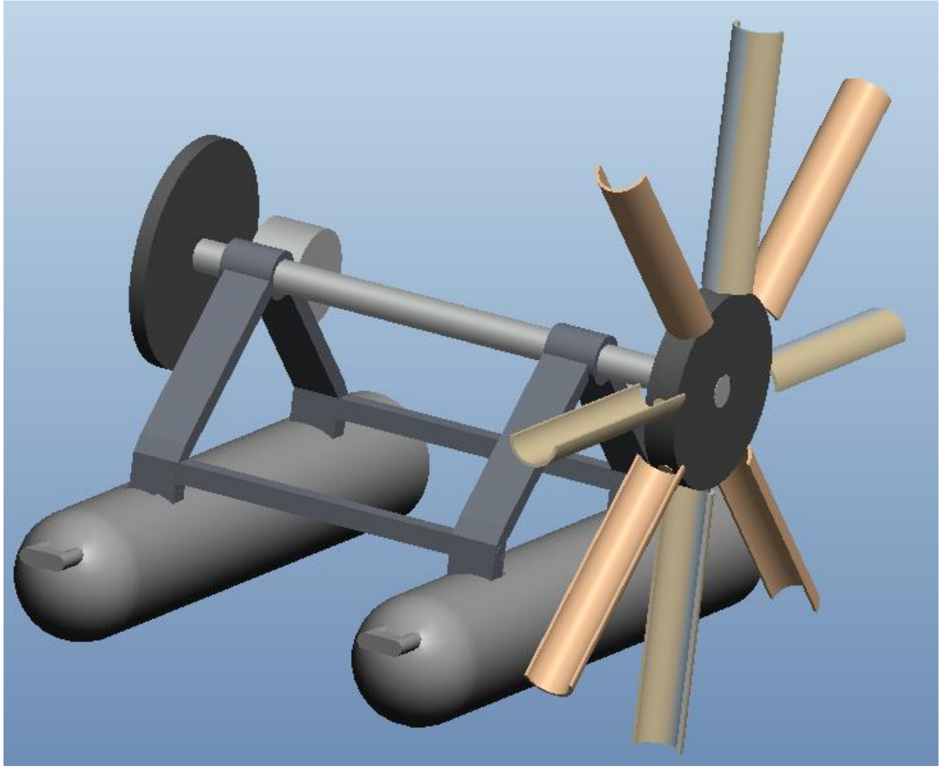


Figure 14 – Micro-Hydroelectric Generator - Illustration of a potential prototype to generate hydroelectric electricity. The paddle wheel sits so 1/3 of the blade is submerged in the flowing water.

Design Concept #4 – Tesla Turbine

The Tesla Turbine was initially designed by Nikola Tesla and works under similar principles as the previous designs. Figure 15, is a basic Tesla turbine design, with half of the casing hidden in order to see the internal working parts. There are four discs spaced apart and mounted on a central rotating axis, which is the mechanical output of the turbine. Water will enter the turbine at the top rectangular section and will collect in between the discs. This collection of water creates a frictional layer that promotes the rotation of the discs in unison and generating mechanical energy. The water circulates and exits the casing when it approaches the holes located at the center of the discs, upon the slowing down of the turbine. During operation, it is imperative that the flow remain laminar throughout the turbine until the exit point as this will maximize the friction and rotational speed. Compact discs (CDs) have been found appropriate for use as the rotating discs in the system. This is due to the acceptable friction coefficient between water and the plastics that make up the compact discs. However, the material strength of the CDs may be low during operation, and a method of controlling the rotational speed may need to be included.

Tesla turbines have been known to have very high operating speeds. When first invented, the lack of material knowledge at the time hindered production. The original discs were made of steel which warped and destroyed the turbines at high operating speeds.

The disadvantages of the Tesla Turbine far outweigh the advantages. First, the parts required to construct this turbine are not widely available in a junkyard. The only plausible materials are compact discs which are inherently fragile. There would also need to be an additional filtering system in order to keep damaging particulates from entering the turbine. Tesla turbines are fairly efficient especially when ideally designed. Nonetheless the turbine size needed to provide the required power would need to be larger than a simple CD case which would in turn increase the stresses on the materials. This size restriction coupled with the lack of reliability of materials and complicated design has eliminated the design from further research and development.

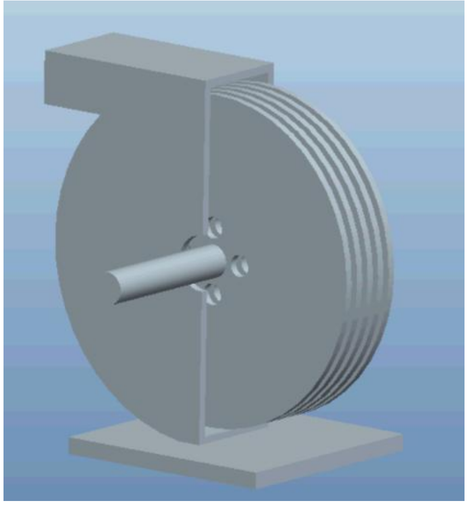


Figure 15 – Tesla Turbine – Internal Working Parts

Energy Conversion

The rotational mechanical energy of the turbine will be transformed into useable electricity by a dynamo. A dynamo consists of a spinning rotor with magnetized coils, this spins inside of another set of stationary coils called a stator. As the rotor spins, the two sets of magnetized coils produce an EMF, and alternating current that has a frequency proportional to the rpm of the rotor.

An alternator from a junk car was first considered to perform this function due to the fact that they are equipped with a voltage regulator, and are abundant in most junkyards. The voltage regulator is important in ensuring that the battery is not destroyed by high voltage, or overcharging. It also converts the alternating current seen by the stator coils into direct current, so a battery can be charged. However, through further research, the alternator was found to be cost prohibitive due to the fact that they retail used for about US $20.00. Given that our unit cost must be under US $50.00; this course of action cannot be justified when other cost effective options are available.

One such option is to us a simple, low power electric motor similar to a bicycle-hub dynamo. Since the dynamo is not equipped with a voltage regulator it will produce an alternating current with voltage varying depending upon how fast the dynamo is being spun. The alternating current being produced by the dynamo can be converted to direct current (required for charging a battery) through the implementation of a Silicon or Germanium Diode. A diode allows current to flow in one direction only by means of a P-N junction. This rectification from the silicon or germanium diode comes with a cost though; typically you can expect a voltage drop of 0.65V or 0.1V respectively. Therefore, a germanium diode should be used in order to reduce losses thereby increasing the systems efficiency. The diode connected to the positive leg of the dynamo will convert A/C to D/C while simultaneously keeping current from the battery from spinning the dynamo. This circuit can be seen below in Figure 16.

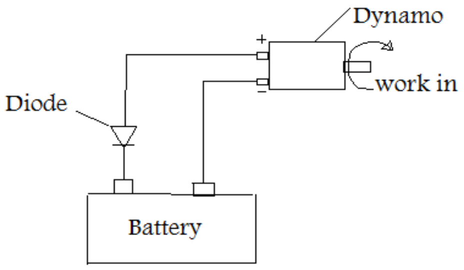


Figure 16 - Illustrates how the diode should be used in the circuit to transform the alternating current produced from the dynamo to direct current so the battery can be charged.

Energy Storage

One of the primary objectives of this project is that our system be capable of storing at least 300 W*hrs. Through research into different types of energy storage, the best way to accomplish this task is by using a standard car battery. Car batteries are typically of the lead acid variety and store electricity chemically. A 12 V, lead-acid battery consists of six cells linked in series, and when fully charged produce 2.1-2.45 V. These batteries typically range between 200-300 A•h. Therefore, a new battery has a potential power storage capacity of 3600 W•h. Since the battery used will not be new but refurbished, it can be assumed that it may only be capable of 70 percent of its original capacity, or 2500 W•h.

A dead battery can be fully charged again in as little as 10 hours if a high charge voltage and current are provided. Ideally, the voltage across a charging battery should be maintained constant at around 13 V. However, for our purposes the voltage to the battery may not be constant, as the incoming wind or water flow may be erratic. Although the battery may cycle between periods of charge and discharge while under use it should not dramatically shorten the life of the battery as long as care is taken to prevent the battery from becoming overcharged. This situation can be prevented by the user simply disconnecting the battery from the charging system during periods of nonuse.

In order to keep power from leaking back out of the battery and actually spinning our dynamo we will need to employ the use of a diode. As discussed in the previous section on energy capture the diode will be connected inline on the positive side of the battery. The diode will serve two purposes; convert the alternating to direct current, and prevent electricity from flowing back out of the battery and into the charging unit.

Water Boiling Wand

As is the case in most third world countries, drinking water free from harmful bacteria and parasites is at a premium. In most cases, boiling the water or merely heating it to 80 degrees Celsius for 20 minutes will make the water safe to drink. In order to solve this dilemma, we propose to include a water sanitizing wand with our kit. The wand works by passing current through a small coil of thin gage copper wire fixed to the end of a wooden handle. The leads from the battery will run through the handle to the heating coil as illustrated in Figure 17.

Through calculations, we have found it is possible to boil up to 4.7 L or sanitize 13 L of water given the battery is fully charged. Hopefully, this will help to provide a sustainable means of providing potable water for a small family.

Figure 17 – Above is a picture of the water sanitizing wand prototype

Cost

There are two places in Tallahassee that have an ample supply of recycled materials needed for the construction of the three concept designs. Prices in Table 2 (below), will be based off the cost of the parts at these establishments.

The first is Pick-n-Pull – Tallahassee, which is a self-service auto parts store. Since the parts are retrieved by the customer, prices are very competitive with the recycled parts market. After consulting with management, large-scale purchases (over $1000) will receive a 10% discount off of advertised rates. Since the prototype will not reach this amount, the parts will cost this project the full amount. However, if the designs were mass-produced, the 10% discount could be implemented into the cost analysis. Assuming that the design will undergo mass production, the discount has been included onto Table 2.

Marpan Recycling is the second business that recycled parts will be procured from. Marpan specializes in handling Class III (construction and demolition) as well as yard waste. Because of the materials that this plant processes, there are many appliances as well as construction materials (pipes, ducts, motors etc…). This makes it an excellent source for many of the required materials for this project. Marpan Recycling deals with bulk materials and all prices are based on weight. The price of metals, (price of metallic appliances) is $300/ton or $0.15/lb. The price of plastics is $0.02/lb. These low prices render the power conversion device (alternator/dynamo) as well as the battery the highest cost components. Table 2, approximates the cost of the designs relative to the total weight. The exact weights are not known; therefore, the values are over-priced to account for a worst-case scenario in cost.

Table 2 – Cost Analysis for Design Concepts #1-3

Cost Analysis	Concept Design #1: VAWT	Concept Design #2: HAWT	Concept Design #3: MHEW
Rotational Component	$2.00	$3.00	$2.00
Supporting Structure	$2.00	$2.00	$10.20
Energy Converter	$10.00	$10.00	$10.00
Gearing Assembly	$2.00	$2.00	$2.00
Bearings	$1.00	$1.00	$1.00
Energy Storage	$19.79	$19.79	$19.79
Battery Cables	$3.59	$3.59	$3.59
Total	$40.38	$41.38	$48.58

In order to support the wind turbine structures, two bearings will be attached to the rotating axis and will be bolted onto a supporting structure that will be built on site. The proposed height is 5m so whether the structure is built on a roof of a building or from the ground is up to the owner. Brackets to support the bearings and weight of the turbine will be supplied. The prices for the supporting structures that are being provided in the kit is included in the cost analysis in Table 2, the rest will be made with locally available parts.

Decision Matrix

The decision matrix for this project (Table 3) analyzes each design against a determined set of requirements. Each design is given a score from one to five based on how well it meets the specification in question. This score is then multiplied to the importance weight of the specification. All scores are then totaled and compared against each other to accurately determine which design best meets the set criteria.

Durability:

The VAWT design received a rating of 5 because of its simplicity and solid construction materials. The turbine blades are the most likely to break and in the VAWT design they are securely fastened and supported. The HAWT design received a rating of 3, because of its PVC turbine blades. They are sturdy but undergo larger gyroscopic forces in higher speeds than the VAWT design. The MHEW received a rating of 3 because of its working fluid, as water tends to wear on materials much faster than wind, especially because its turbines are constructed of bamboo. The Tesla turbine received a rating of 1 because its construction materials (CD’s) are very brittle and prone to wear.

Ease of Assembly:

The VAWT design received a rating of 3 for ease of assembly as the exact dimensions are difficult to replicate without full access to tools. It is also a very large and bulky system with multiple components. The HAWT design received a rating of 5 because assembly is as simple as constructing the supporting structure and bolting the blades to the assembly and attaching them. The MHEW received a rating of 3 because of its need to be water-resistant and well anchored. The Tesla turbine received a rating of 1 because of its complicated design and exact construction specifications in order for it to operate at all.

Cost:

The cost specification is directly related to the cost analysis of each design, which was explained above.

Maintenance:

The VAWT, HAWT, and MHEW designs each received a rating of 3 because of the durability of construction materials. If maintenance is needed on any of these designs it would be very easy to perform. The Tesla turbine received a rating of 1 because it would require constant maintenance and would have to be completely disassembled for any work to be completed on it.

Innovation:

The VAWT, HAWT, and MHEW designs each received a rating of 3 because each system has been used in practice before, but the technology still maintain a level of innovation. The Tesla turbine received a rating of 5 because of its ingenious design as well as complexity.

Second Decision Matrix

The second decision matrix (Table 4) re-analyzes each of the designs with an added specification of efficiency. This is to show that if the designs were based on efficiency the MHEW would win because of its working fluid. Water has much more energy when flowing because it is an incompressible fluid and has a significantly higher density. If the project were to be scaled for a larger power requirement for a low cost, the water wheel would be the most adequate design to choose and implement.

Table 3 – Decision Matrix for the Project

		Concepts							
		VAWT		**HAWT**		**Hydro-electric**		**Tesla**	
Specifications	Importance Weight	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores
Durability	15%	5	0.75	3	0.45	3	0.45	1	0.15
Ease of Assembly	20%	3	0.60	5	1.00	3	0.60	1	0.20
Cost	40%	5	2.00	5	2.00	1	0.40	3	1.20
Maintenance	20%	3	0.60	3	0.60	3	0.60	1	0.20
Innovation	5%	3	0.15	3	0.15	3	0.15	5	0.25
	Score	**19**	**4.10**	**19**	**4.20**	**13**	**2.20**	**11**	**2.0**

Table 4 – Second Decision Matrix including Efficiency

Durability	10%	5	0.50	3	0.30	3	0.30	1	0.10
Ease of Assembly	15%	3	0.45	5	0.45	3	0.45	1	0.15
Cost	30%	3	0.90	3	0.90	5	1.50	3	0.90
Maintenance	15%	3	0.45	3	0.45	3	0.45	1	0.15
Efficiency	30%	1	0.30	1	0.30	5	1.50	1	0.30
	Score	**15**	**2.6**	**15**	**2.4**	**19**	**4.20**	**7**	**1.60**

Results

As described above, the VAWT, HAWT, and MHEW designs will be constructed next semester. They will be designed based on the theoretical calculations provided in Appendix 1, which have proven that the power objectives will be met and the constraints will not be violated. A minimum rotor area was calculated for each. In order to provide for margins for the design, component efficiencies were dropped significantly passed accepted values. These efficiencies were successful in sizing the components accurately.

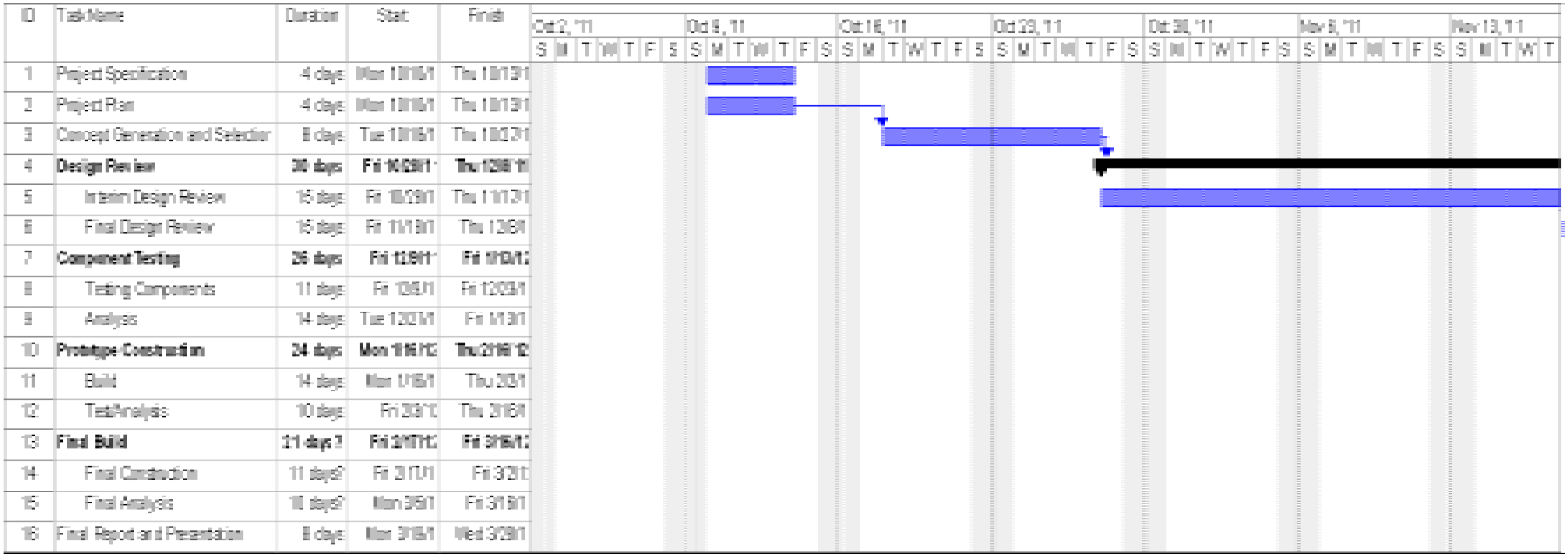
An average wind speed of 4 m/s at a height of 5m was used for the calculations and was based on an estimated boundary layer. Due to this estimation some uncertainty lies in this value. Another assumption that was made on the wind is available for a minimum of ten hours of the day, and is the basis as to the 10 Watt power generation requirement established for the three designs. These 10 Watts of power produced for 10 hours yields the 100 W•h/day objective. There is some uncertainty present in this assumption, but the power generation device will perform adequately in this scenario.

Future Plans/Conclusion

This concludes the design process of the project. Since all three designs are going to be built, it is imperative that construction begins as soon as possible. In the first two weeks of next semester all foreseen parts will be purchased and refurbished if necessary. Construction will begin immediately and should be completed within the second week of January. After initial construction, testing of each design will begin. Iterations of construction and testing may be needed which is crucial for early construction. Each system will be tested at local conditions which will be monitored and any differences in weather will be accounted for.

Multiple DC motors, bicycle dynamos and possibly alternators will be tested to see which are applicable to easy implementation to system. If multiple work, one will be selected as a best option with others as possibilities if resources run out. The same will be conducted for batteries, as there are many options and most hold much more energy than necessary.

As before, Team 7 will continue meeting bi-weekly with Cummins representative Terry Shaw. Terry has provided excellent feedback and suggestions. Staff meetings with our advising professors will also continue and the production of a successful project will be realized at the end of the spring semester.



ID	Task Name	Duration	Start	Finish
1	Project Specification	4 days	Mon 10/10/1	Thu 10/13/1
2	Project Plan	4 days	Mon 10/10/1	Thu 10/13/1
3	Concept Generation and Selection	8 days	Tue 10/18/1	Thu 10/27/1
4	**Design Review**	**30 days**	**Fri 10/28/1**	**Thu 12/8/11**
5	Interim Design Review	15 days	Fri 10/28/1	Thu 11/17/1
6	Final Design Review	15 days	Fri 11/18/1	Thu 12/8/1
7	**Component Testing**	**26 days**	**Fri 12/9/1**	**Fri 1/13/1**
8	Testing Components	11 days	Fri 12/9/1	Fri 12/23/1
9	Analysis	14 days	Tue 12/27/1	Fri 1/13/1
10	**Prototype Construction**	**24 days**	**Mon 1/16/12**	**Thu 2/16/12**
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12	Test/Analysis	10 days	Fri 2/3/1	Thu 2/16/1
13	**Final Build**	**21 days?**	**Fri 2/17/12**	**Fri 3/16/1**
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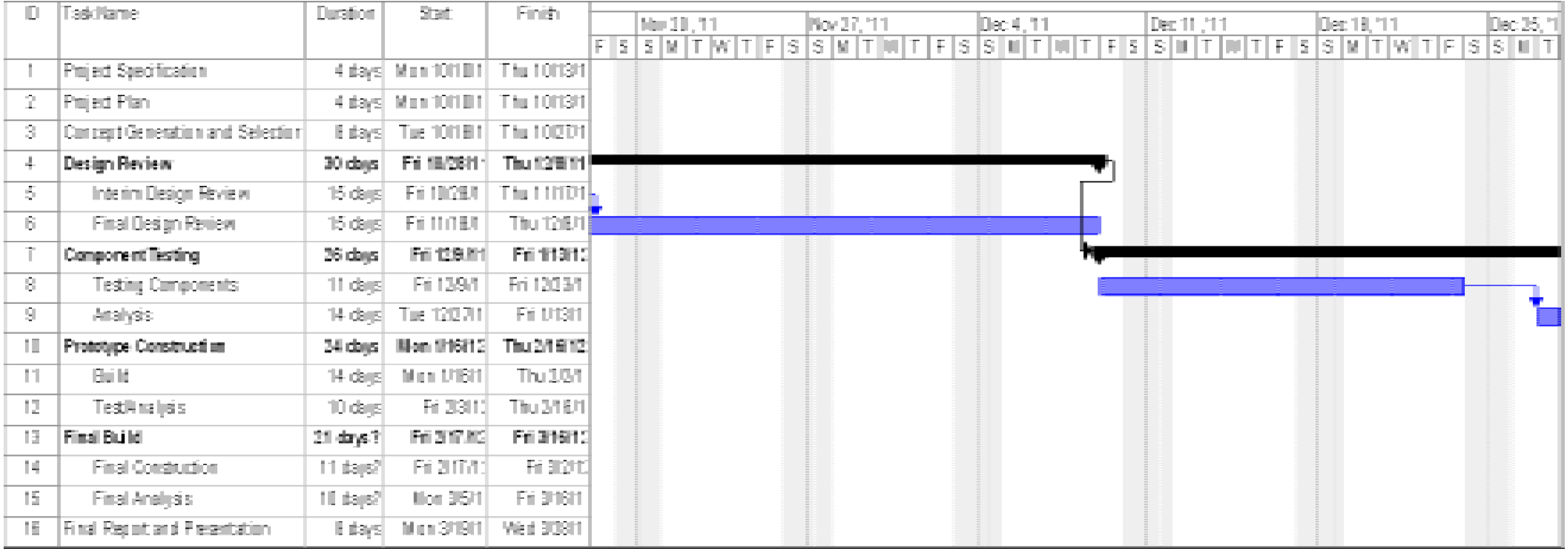
15	Final Analysis	10 days?	Mon 3/5/1	Fri 3/16/1
16	Final Report and Presentation	8 days	Mon 3/19/1	Wed 3/28/1



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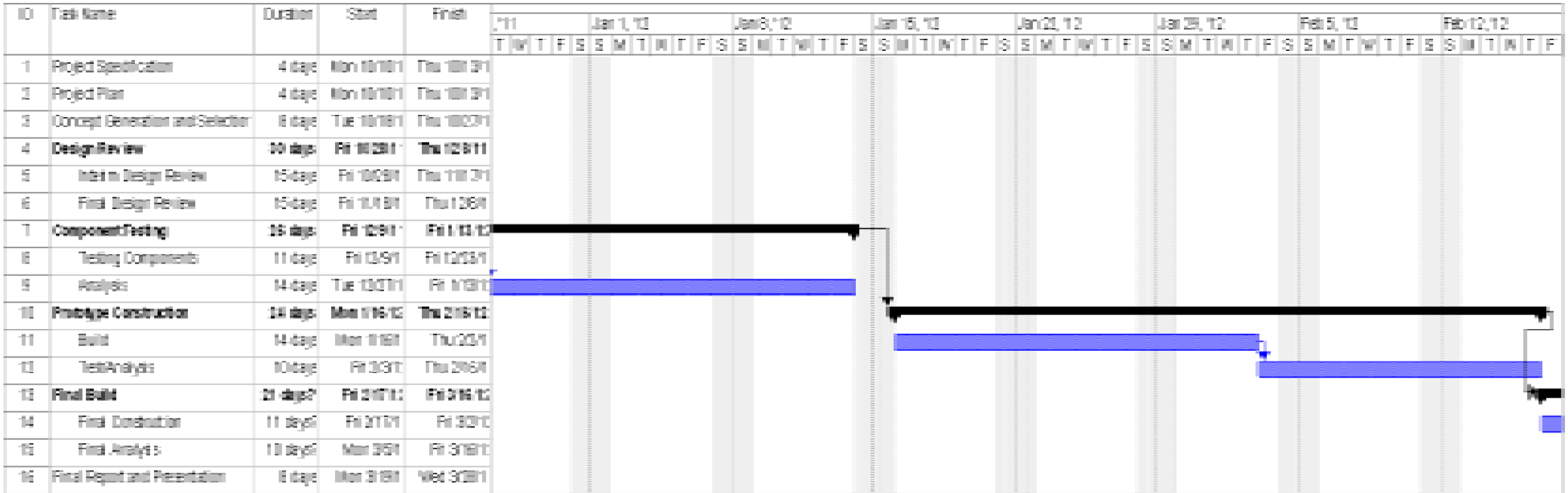

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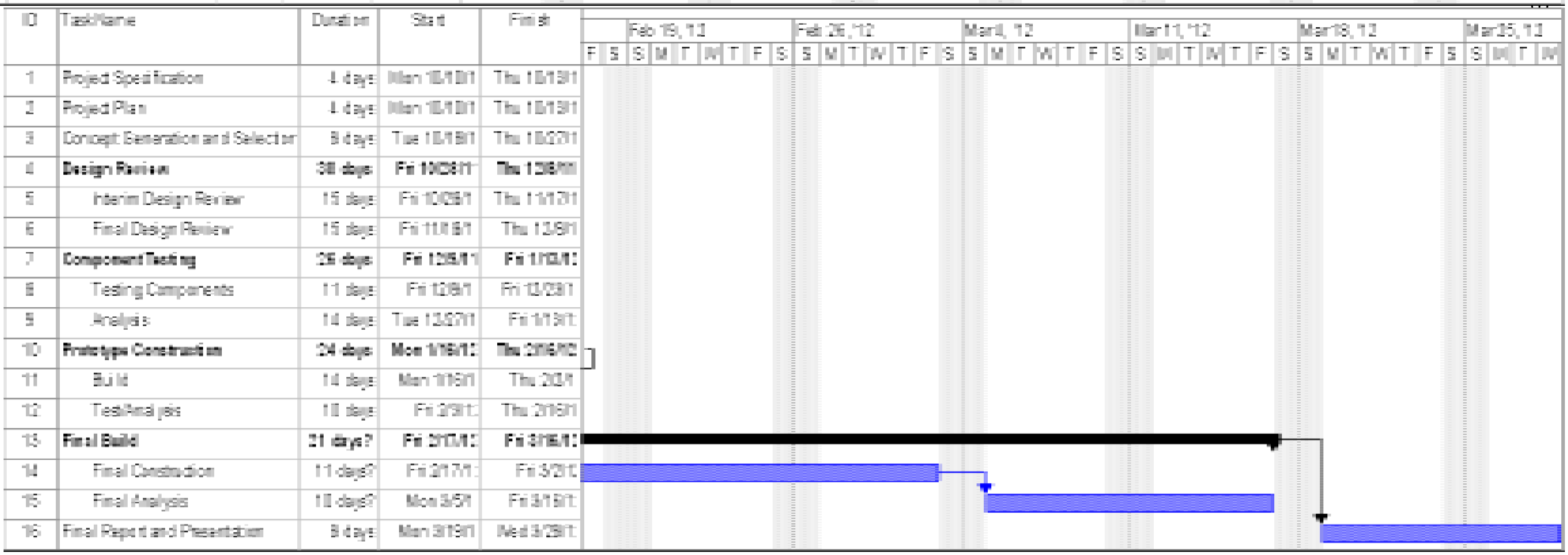

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Appendix 1

VAWT Area Calculations

$C_{p.ideal} := 0.3$	Ideal Savonius Power Coefficient
$V := 4\frac{m}{s}$	Wind Speed
$C_p := 0.8 \cdot C_{p.ideal} = 0.24$	Reduced Turbine Power Coefficient
$\eta_{motor} := 0.8$	Estimated Efficiency of Motor
$\eta_{pulley} := 0.85$	Estimated Efficiency of Pulley
$\rho := 1.225\frac{kg}{m^3}$	Density of Air
$P := 10W$	Power
$D := 1m$	Initiating Diameter of Whole Turbine Assembly
$H := 4 \cdot D$	Ideal Height to Diameter Ratio
$HD := 4D^2 \quad A := HD$ $A := 4D^2 \quad D := \frac{\sqrt{A}}{4}$	Ideal Dimension Derivation Equations
$A := 2 \cdot \frac{P}{\rho \cdot V^3 \cdot \eta_{motor} \cdot \eta_{pulley} \cdot C_p} = 1.563\,m^2$	Minimum Required Area
$D := \sqrt{\frac{A}{4}} = 0.625m$	Minimum Required Diameter of Turbine Assembly
$d := \frac{3}{5}D = 0.375m$	Minimum Required Diameter of Cylinder
$e_{opt} := \frac{d}{6} = 0.063m$	Turbine Offset
$e_{prime} := 0.242d - e_{opt} = 0.028m$	Diameter of Central Axis
$H := 4 \cdot D = 2.501m$	Height of Combined Turbines
$H \cdot D = 1.563m^2$	Check

Gearing Calculations for VAWT

$D_{dynamo} := 0.5in$	Diameter of Dynamo
$D_{wheel} := 27in$	Diameter of Bicycle Wheel
$P_{dynamo} := \pi\ D_{dynamo} = 0.04m$	Perimeter of Dynamo
$P_{wheel} := \pi\ D_{wheel} = 2.155m$	Perimeter of Wheel
$Ratio := \frac{P_{wheel}}{P_{dynamo}} = 54$	Ratio of Perimeters
$\lambda := 0.5$	Tip to Wind Speed Ratio for decreased turbine Cp (See Figure)
$V := \lambda \cdot 4\frac{m}{s} = 2.32\frac{m}{s}$	Velocity of Rotor Tip
$P_{vawt} := \pi\ D$	Perimeter of Rotor Swept Area
$r_{vawt} := \frac{D}{2} = 0.313m$	Radius of Rotor
$\omega_{vawt} := V \cdot \frac{\frac{r_{vawt}}{2}}{r_{vawt}} = 70.88\,rpm$	Angular Velocity of Rotor
$\omega_{dynamo} := \omega_{vawt} \cdot Ratio = 3.828 \times 10^{3} \cdot rpm$	Angular Velocity of Dynamo
$\omega_{dynamo} > 3000rpm$	Check

National Renewable Energy Laboratory (ARE442)

$C_{p\,ARE442} := 0.190$ Power Coefficient of ARE442 turbine, as obtained from Figure X

$D_{rotor} := 7.2m$ Rotor Diameter of ARE442 turbine

$\omega_{rotor} := 48rpm$ Angular Velocity of ARE442 turbine, as obtained from Figure XX

Horizontal Axis Wind Turbine (HAWT)

$P_{gen} := 10.0W$ Power generation requirement

$\eta_{motor} := .80$ Mechanical Efficiency of used motor

$\eta_{belt} := .85$ Mechanical Efficiency of used belt and pulley system

$C_{p\,DC2} := .60 \cdot 0.190$ Power Coefficient of wind turbine

$C_{p\,DC2} = 0.11$

$\rho_{air} := 1.225\frac{kg}{m^3}$ Density of air at sea level

$V_{ave} := 4\frac{m}{s}$ Average Wind Speed at 5 meter height. Faya-Largeau

$$A_{turbine} := \frac{2P_{gen}}{\rho_{air} \cdot V_{ave}^{\;3} \cdot \eta_{motor} \cdot \eta_{belt} \cdot C_{p\,DC2}}$$

$A_{turbine} = 3.29m^2$ Area of turbine

$$D_{rotorDC2} := \sqrt{A_{turbine} \cdot \frac{4}{\pi}}$$

$D_{rotorDC2} = 2.05m$ Rotor Diameter

$$R_{rotor} := \frac{D_{rotorDC2}}{2}$$

$R_{rotor} = 1.02m$ Rotor Radius

Bicycle Dynamo Belt and Pulley System

$D_{dynamo} := 0.4\,in$	Diameter of Dynamo
$D_{wheel} := 27\,in$	Diameter of Bicycle Wheel
$P_{dynamo} := \pi\, D_{dynamo} = 0.03\,m$	Perimeter of Dynamo
$P_{wheel} := \pi\, D_{wheel} = 2.15\,m$	Perimeter of Wheel
$\boxed{Ratio := \frac{P_{wheel}}{P_{dynamo}} = 67.5}$	Ratio of Perimeters
$\omega_{dynamo} := \omega_{rotor} \cdot Ratio = 3240\,rpm$	Angular Velocity of Dynamo
$\omega_{dynamo} > 3000\,rpm$	Check

Energy to Boil Water

$t_{boil} := 10min \qquad \Delta T_{boil} := 75K \qquad m_{water} := 1kg \qquad Cp_{water} := 4187\frac{J}{kg \cdot K} \qquad Power_{available} := 2500W$

$$Q_{boil} := m_{water} \cdot Cp_{water} \cdot \Delta T_{boil} \qquad \boxed{Q_{boil} = 3.14 \times 10^{5} J}$$

$$Power_{boil} := \frac{Q_{boil}}{t_{boil}} \qquad \boxed{Power_{boil} = 523.375W}$$

$$Capacity := \frac{Power_{available}}{Power_{boil}} \qquad \boxed{Capacity = 4.777}$$

Therefore the system has the capacity to boil up to 4.7 liters of water.

Energy to Sanitize Water

$\Delta T_{san} := 55K \qquad t_{san} := 20min$

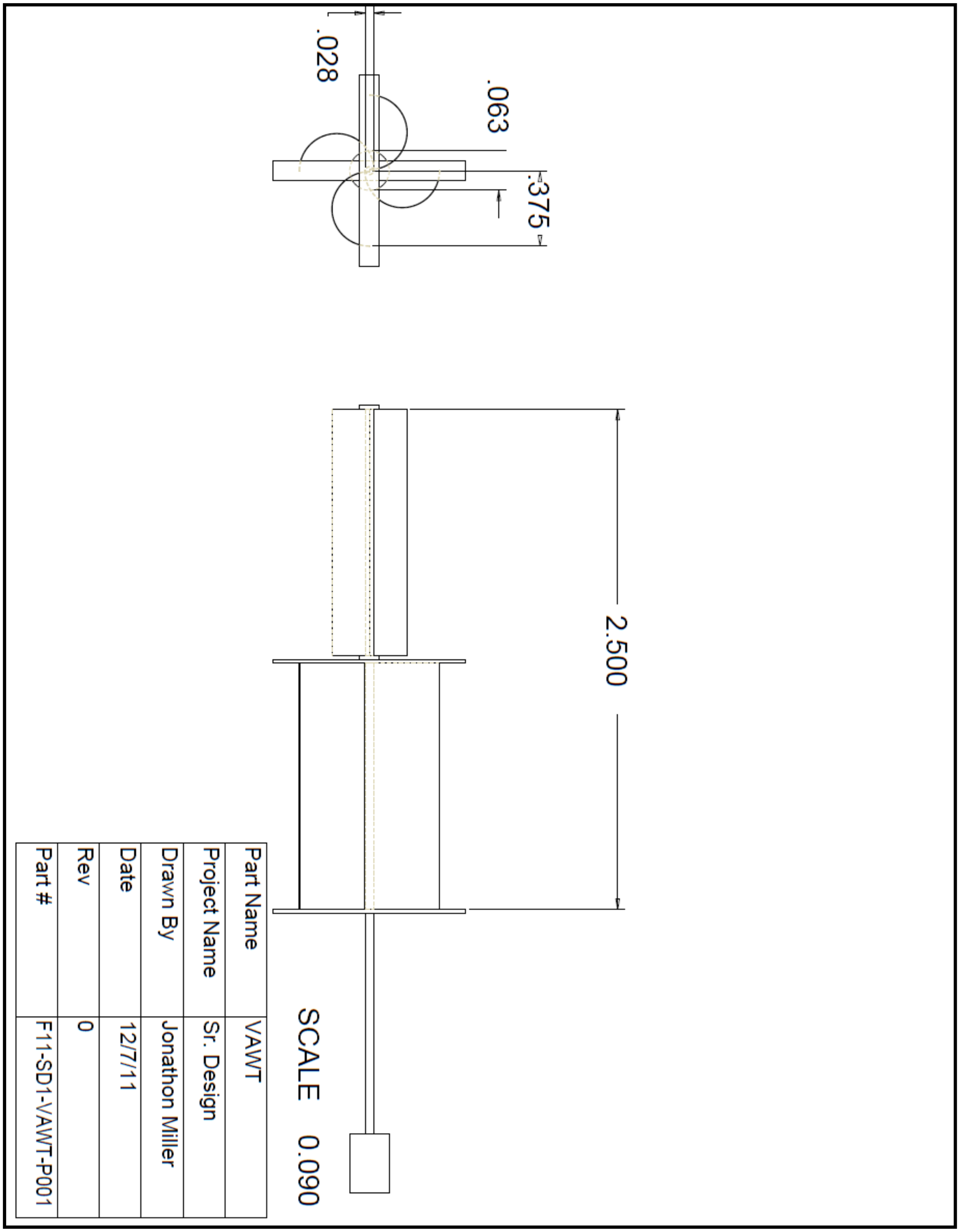
$$Q_{san} := m_{water} \cdot Cp_{water} \cdot \Delta T_{san} \qquad \boxed{Q_{san} = 2.303 \times 10^{5} J}$$

$$Power_{san} := \frac{Q_{san}}{t_{san}} \qquad \boxed{Power_{san} = 191.904W}$$

$$capacity := \frac{Power_{available}}{Power_{san}}$$

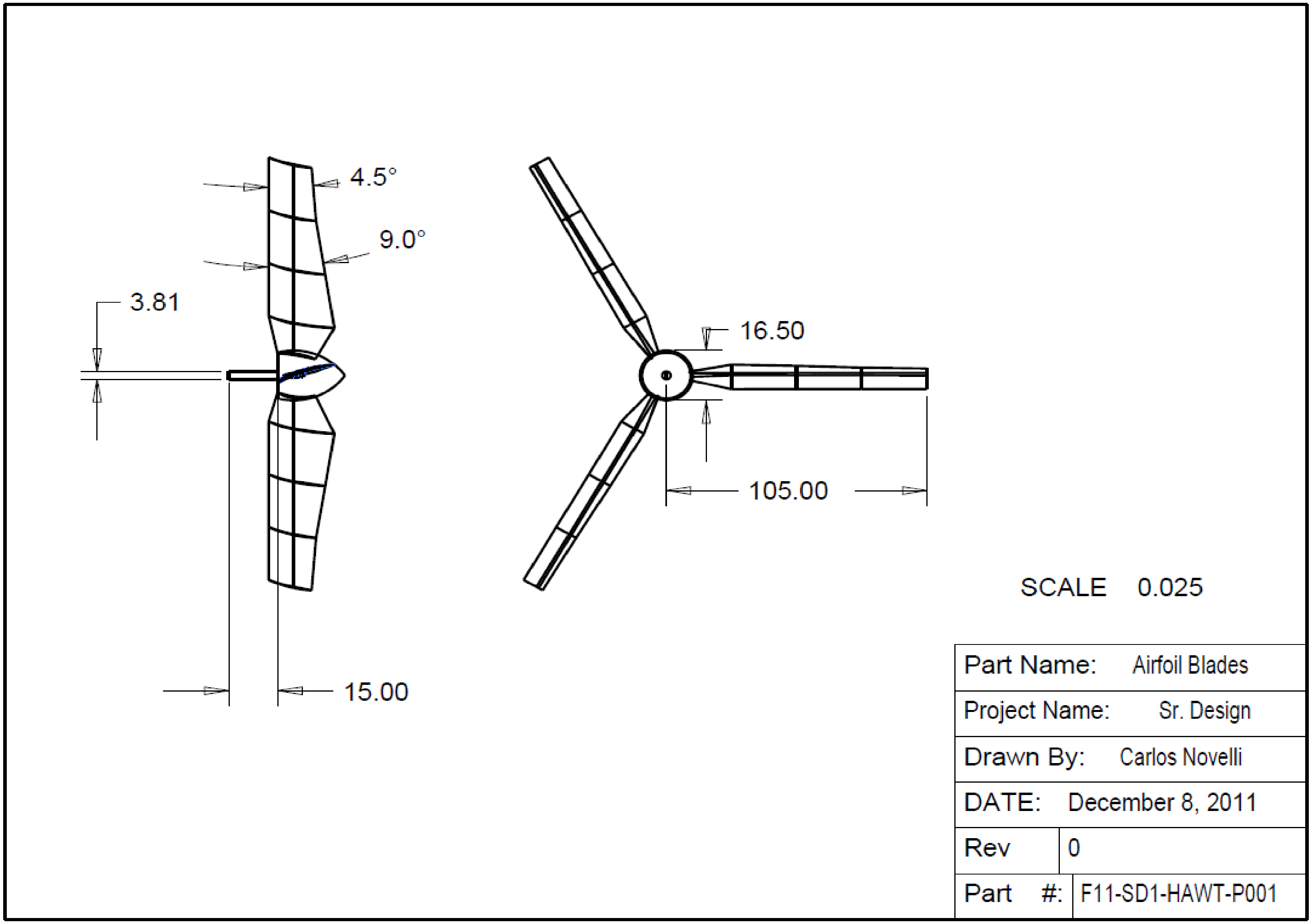
Appendix 2

VAWT Drawing



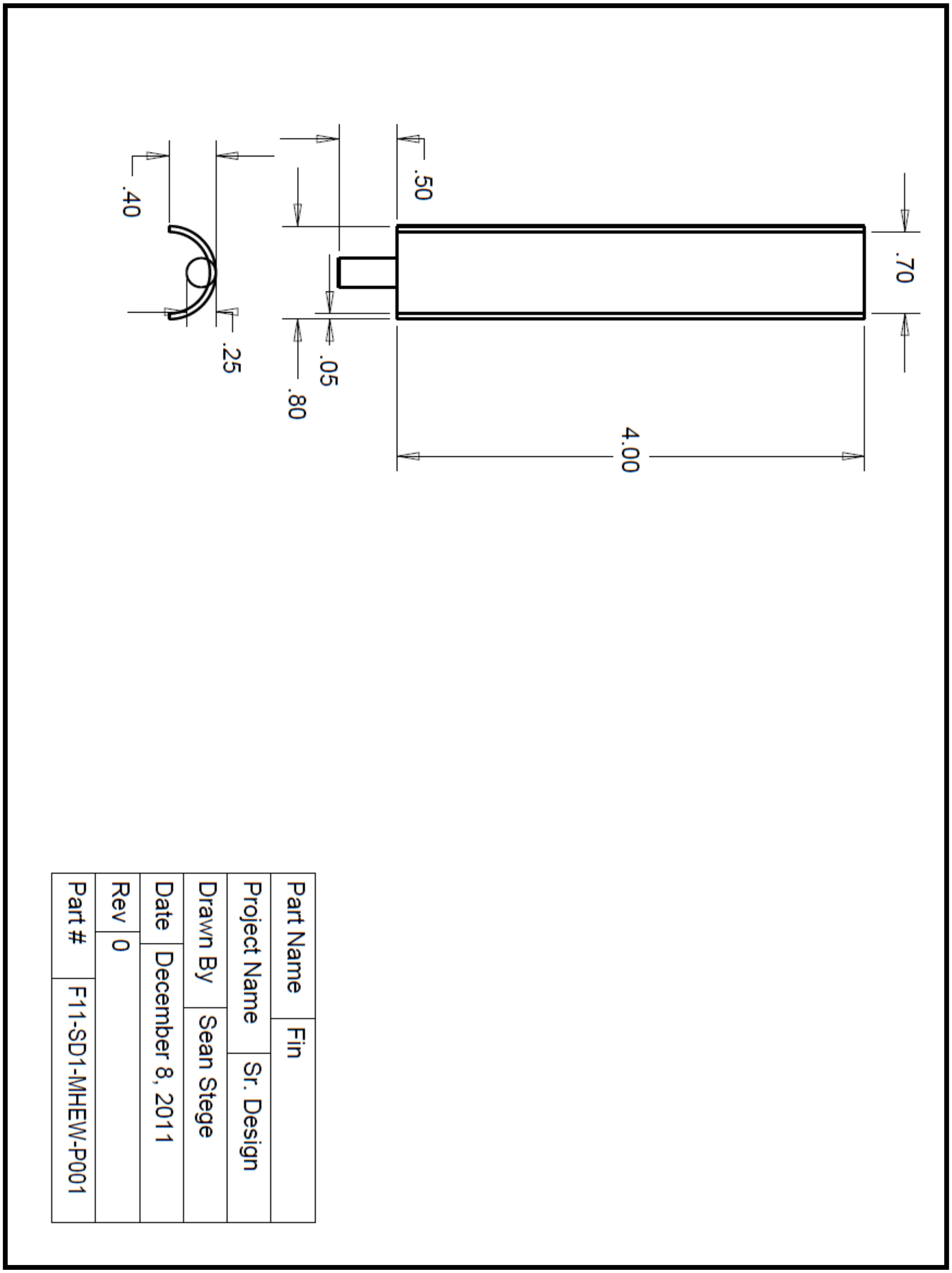
Part Name	VAWT
Project Name	Sr. Design
Drawn By	Jonathon Miller
Date	12/7/11
Rev	0
Part #	F11-SD1-VAWT-P001

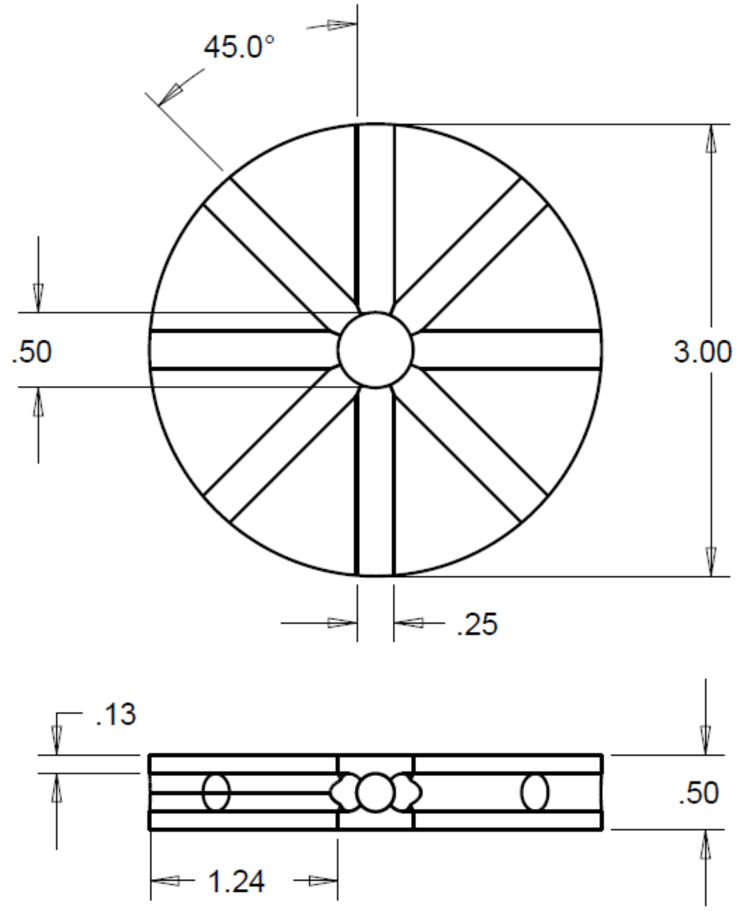
HAWT Drawing



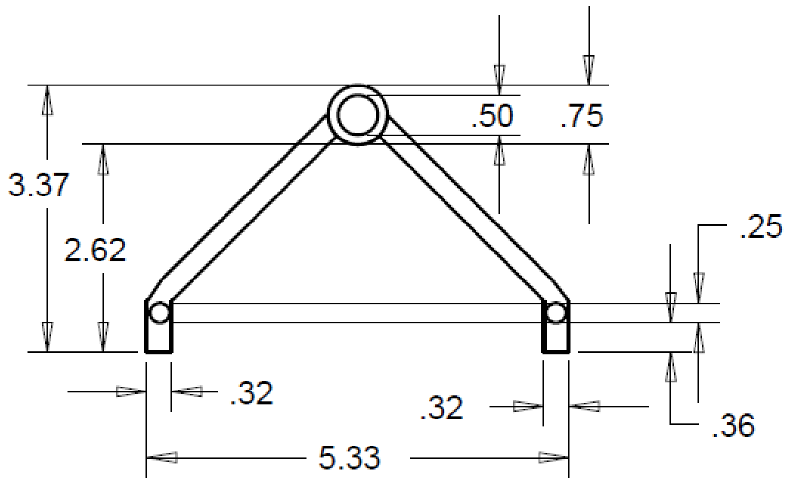
Part Name:	Airfoil Blades
Project Name:	Sr. Design
Drawn By:	Carlos Novelli
DATE:	December 8, 2011
Rev	0
Part #:	F11-SD1-HAWT-P001

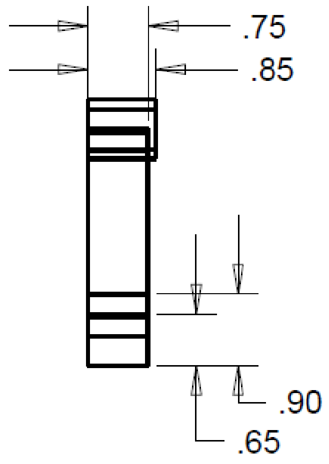
MHEW Drawings

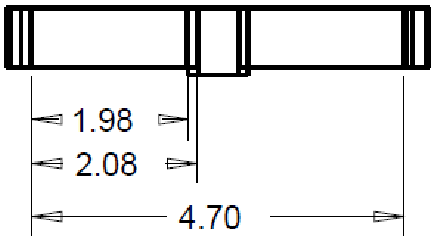




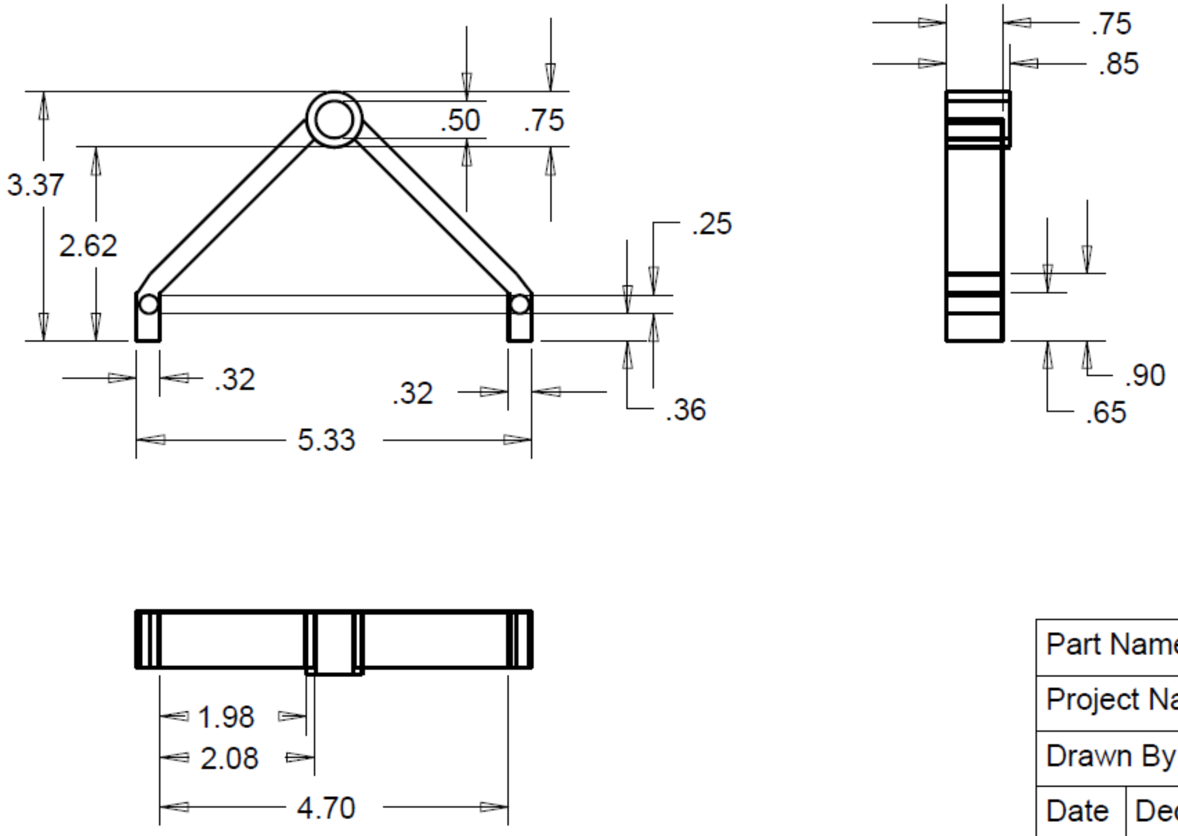
Part Name	Fin Rotor
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P002







Part Name	STRUT
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P003



Part Name	STRUT
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P004