SAN JOSÉ STATE UNIVERSITY

Design of a Solar Assisted Vertical Axis Wind Turbine (SAVAWT)

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Executive Summary

The objective of the Solar Assisted Vertical Axis Wind Turbine (SAVAWT) is to test the proficiency of a hybrid solar-wind system. This project was proposed by Dr. Baldev Krishnan. The SAVAWT is a wind turbine that will power street lamps in San Jose, California. The turbine will spin when there is wind and will generate enough electricity to power a single street light. When there is no wind or the wind is not strong enough to rotate the turbine, the solar panels and battery storage will kick start the turbine to turn and keep spinning to generate the required power. It will generate a minimum of 100 Watts per hour for 10 hours a day. The purpose of this report is to see whether or not a hybrid solar-wind system can be efficient without consuming energy from the grid.

The most common solar-wind systems found in the market consist of a wind turbine and a single solar panel, attached to a tower pole, operating as separate systems. This project is unique because a wind turbine and a solar array consisting of two solar panels will be mounted together using a support frame. Furthermore, a motor will be used to power the turbine from a battery, which will store excess energy from the wind turbine and solar panel, when the wind speed is below the cut-in speed, or initial speed that the turbine begins to produce power.

The energy produced by solar panels shall be stored to the battery for use in an event that wind energy is minimal to rotate the turbine. Such arrangement avoids loss of power due to efficiency of the wind turbine. Moreover, electronic components shall be used that allow for the generator to act as a motor in order to give initial torque for the turbine in a way that could overcome static friction and be able to utilize the lower wind velocity in the presence of dynamic friction.

The task in this project is to study the efficiency of the hybrid solar/wind system and compare it to the standalone turbine. The theory is to prove that the solar panels will help turbine to spin faster and capture more wind, spinning the turbine faster will help to increase the efficiency of the system. There is a significant reasons that the industry is trying to create a better efficiency turbines because they are trying to overcome the climate change problems by relying on renewable energy, wind turbine and solar panels are the main sources of power.
Wind turbine can use as a standalone source of power especially for the third world countries where electricity is not always available.

A serious issue with current wind turbines is being ineffectual since the best turbine has a 30% efficiency. The reason is that there is not enough wind to overcome the cut-in speed, which is defined as the amount of wind needed to overcome the static friction of the turbine.

Acknowledgements

Dr. Baldev Krishan - Owner of patented idea, financial sponsor, and advisor
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Kyle Meininger - Materials and fabrications

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Section I. Introduction

Motivation

The motive of this project is to produce an efficient system that can provide clean renewable energy with no assistance from the electrical grid. Climate change has become pressing issue with series impact to the entire world. Burning fossil fuels for energy causes climate change by releasing carbon dioxide, which traps heat in the atmosphere. Climate change causes a number of problems including extreme temperature conditions, drought, increased precipitation and storm intensity, and a rise in sea-level. Fossil fuels are non-renewable energy sources that will eventually be depleted, and are therefore unsustainable. Despite its negative impact on the environment, fossil fuel energy remains very efficient and cost effective. In order for renewable energy to be widely implemented in place of fossil fuels, its efficiency must compete with fossil fuel energy.

The goal of this project is to harness two renewable energy sources, wind and solar, as system to increase efficiency. Wind turbines have an efficiency much lower than 50%, with some designs resulting in just 5% efficiency. Furthermore, many places experience winds that are below the cut-in speeds for wind turbines, resulting in no power generation. The SAVAWT system intends to utilize energy from its solar panel to kickstart the turbine when wind speeds are low and boost power output when wind speeds are sufficiently high. All excess energy shall be stored in a battery for future use, resulting in an overall more efficient system.

Current Status

Research has been conducted on competing markets. There are hybrid solar-wind systems on the market, however, the two power sources do not work in conjunction, but rather two separate power sources adding together. An idea similar to SAVAWT was prototyped in Spring of 2017 called the "Hybrid Solar-Wind System". The system had not achieve the desired efficiency expected from this hybrid system. Learning from its failures, the SAVAWT will have a flat solar panel arrangement and more efficient wind turbine design. Furthermore, the previous prototype had a rotating solar panel to help cool and clean the solar panel. Testing of the product found that dusty solar panels had a decrease in efficiency of 5.6%-43% depending on the severity of dust cover [1]. Testing also showed that for every 1 degree Celsius of cooling, a .62% increase in efficiency was observed [1]. These observations have influenced the implementation of a rotating solar panel on the SAVAWT.

The SAVAWT was fully assembled and the power output has been tested. The overall system is more stable and appears to be more mechanically efficient. It was concluded that the electrical aspect of the project would need more improvement. In order to make improvements for a better output, future enhancement of the overall design will be needed.

Project Objectives

The main objective of the SAVAWT system is to verify the proof of concept that the output of this hybrid system is better than the output of the standalone turbine. Our goal is to increase the efficiency of the wind turbine by 20%. The system is intended to power streetlights and as such, it shall be secured on top of the light pole. Under this criteria, it is important that the system should produce about 100W of power for 10 hrs each day. Since this system will not be associated with grid power, it is critical that there is always sufficient energy to meet this criteria.

Engineering Specifications

The final project specifications are as follows:

• Combined wind turbine with solar-PV with battery back-up	
• Min. daily output (100W x 10 hrs/day)	1 kWh/day
• Vertical axis wind turbine (VAWT) output	300W max.
• Solar-PV output	~ 50-100 W
• Battery capacity	≥ 2kWh
• Max. total system weight	66 kg
• Max. noise output	50 dB
• Max. total system diameter	1.52 m
• Max. total system height	1.45 m
• Max. production cost	$2500
• Easy installation	
• Easy maintenance	
• Retrofitting capability on existing wind turbines	
• Environmentally sustainable	

Significance of Project, Uniqueness, and Challenges

This project is significant because it can be a stepping stone for a solely renewable energy future. The project is also unique in that it offers a fully off-grid system, an idea that many cities are trying to adopt for municipal lighting. Moreover, remote areas with no access to electric grids can benefit from this project.

An initial challenge for this project was the budget. Wind turbines are very costly and there is a limited market availability for turbines that meet the project specifications. An anticipated challenge is the location of the system. There is concern that in some locations, such as San Jose, CA, wind speeds may not be high enough, even with the kickstarting technology, to sufficiently rotate the turbine. There will also be challenges in implementing the theory within the final project, as it will take various tests to perfect the efficiency of the boosting technology.

Teamwork Roles:

Electrical Team:

1. Henok Mesganaw: leader, circuit design, testing
2. Beniam Ayele: circuit design, testing, data analysis

Mechanical Team:

3. Carlos Franco: co-leader, mechanical design, fabrication, system assembly, testing
4. Suheil Arafeh: mechanical design, fabrication, system assembly, testing
5. Diana Lee: mechanical design and simulations, testing, data analysis
6. Bader Al Durai: purchasing parts, testing, transportation

Section II. Analytical Background

Wind turbines operate on the principle of converting kinetic energy of the wind to mechanical work. The mechanical work produced by the wind turbine is used to rotate the shaft of a generator. The shaft contains copper coils that are tightly wound and the shaft is surrounded by powerful permanent magnets. As the shaft rotates at a high speed, a magnetic field is created that allows a current to flow. The conservation of energy theorem and continuity theorem is applied in order to calculate the power output of the wind turbine where the only energy input is the kinetic energy from the wind, indicated by Eq.1.

$$P_{wind} = \frac{1}{2}\rho A V^3 \qquad (1)$$

The efficiency of wind turbines is normally characterized by the power coefficient (C_p), as shown in Eq.2. The efficiency of the turbine is very important for this project because San Jose is not an ideal environment since the average wind speed is low. Therefore, it is important to generate as much power from the wind as possible to successfully power a street lamp. The efficiency of the wind turbine is determined by dividing the power output of the turbine by the total amount of wind power available.

$$C_P = \frac{P_{turbine}}{P_{wind}} \qquad (2)$$

Where:

P_{wind} = wind power
ρ = air density
A = swept area
V = wind velocity
C_P = power coefficient
$P_{turbine}$ = turbine power

Formulas are retrieved from [12]

The SAVAWT project will be designed to maximize the efficiency of the wind turbine based on the sponsor's recommendation. In this project, the wind turbine will be continuously assisted using a motor that is powered by the solar panels. The objective of this project was to provide a proof of concept that the continuous excitation of the turbine would result in a higher power output due to the v^3 relationship between the wind speed and power.

Section III. Engineering Design

Turbine

There are two kinds of wind turbines: vertical axis wind turbines and the more common horizontal axis wind turbines. Vertical axis wind turbines (VAWTs) have some advantages over horizontal axis wind turbines (HAWTs) that are desired for this project including: smaller diameters, potentially low maintenance costs, ability to take wind from all directions, ability to work with relatively low wind speeds, and environmentally friendly.

The most common types of VAWTs in the market are:

- H-Type
- Helical Savonius
- Rotor Darrieus
- Combined Savonius and Darrieus

In the initial design for this project, a helical Savonius VAWT was chosen due to its small diameters that are suitable for this project. However, Savonius turbines are drag-type turbines and have less efficiency than lift-type turbines. The power output and efficiency are considered to be more important parameters than the diameter for this project, therefore, we switched to an H-type VAWT design.

For the second design of this project, an H-Type VAWT, which is an aerodynamically lift-type turbine, was selected since Savonius (drag) type turbines harness less wind energy than Darrieus (lift) type wind turbines of similar scales *(See **Appendix A**)*. Additionally, the H-Type VAWT has been found to have a higher efficiency compared to other types. Although H-type turbines are typically larger than the desired design specifications for the project, efficiency was the most critical parameter. With this in mind, size specifications were limited by market availability.

For the final design, the chosen wind turbine for this project is a combined Savonius and Darrieus VAWT. This type of VAWT has a high efficiency, but lower cost than the H-Type VAWT. This turbine was also chosen due to the limited market availability of wind turbines in the United States. It is the same turbine the "Hybrid Solar-Wind" team used and has 7 blades. It has a diameter of 1.4m, a height of 1m, and weighs 27kg. (*Images of the turbine and additional specifications of the turbine and its generator can be viewed in **Appendix A***). Table data obtained from references [4]-[8].

Table 1. *Comparison of common H-Type, Savonius Helical, Rotor Darrieus, and the Combined VAWTs*

	H-Type	Helical Savonius	Rotor Darrieus	Combined Savonius and Darrieus

Number of Blades	2-5	2-4	2-3	2-3 Savonius blades 3-4 Darrieus blades
Rotor Material	Aluminum Alloy	Aluminum alloy	Aluminum alloy	Aluminum alloy
Minimum Cut-in Speed (Power production)	3-4 m/s	4 m/s	3.5 m/s	5-9 m/s
Reliability	High	Long cycle life	High	High
Efficiency	Most efficient	Least efficient	Medium	High
Cost	\$300-\$12,000	\$200-\$400	\$250-\$500	\$300-\$600

Solar Panels

The most common types of solar panels on the market are:

- Monocrystalline
- Polycrystalline and
- Thin film solar panels

Table 2. Comparison of Monocrystalline, Polycrystalline, and Thin-Film Solar Panels

	Monocrystalline	**Polycrystalline**	**Thin Film**
Material	High grade Silicon	High grade Silicon	Uses less Silicon; Amorphous silicon
Cost/ W	\$1.589 Most expensive	\$1.418 Expensive	\$0.67 Least expensive
Reliability	Long cycle life 25yrs Warranty	Long cycle life	Flexible; less impacted by high temperature and shading
Temperature	Performed best in standard temperature	Performed best in moderately high temperature	Performed best in high temperature
Efficiency	15-20%	13-16%	7-13%

For this project, the monocrystalline solar panel has been selected because monocrystalline solar panels have the highest efficiency. This is partly because of the higher-grade silicon from which they are made. Consequently, they can be more space efficient compared to other types. In addition, they tend to operate longer than other panel types which can be supported by the common 25-year warranty from manufacturers. Although their performance can suffer if parts of the panel are exposed to shade, dirt, or snow, they tend to be more efficient in warmer temperatures than polycrystalline solar panels. The only downside is that they are the most expensive. **Table 2** compares features of monocrystalline solar panel with other types.

After researching various companies, their products, specifications, and costs, Renogy's two 20W polycrystalline solar panel were selected for this project. The specifications for this solar panel can be found in **Appendix C**. Since dirt and shade can affect their production of power, it was decided that utilizing two panels connected in parallel with the Hybrid Charge Controller was best, as shown in **Figure 14**. The reason for this was for the system to be able to keep supplying some kind of energy even in an instance of one panel being covered. Although the voltage would be higher in a parallel arrangement, MPPT charge controllers are able to accept a higher voltage input while still being able to charge the batter. Since dust particle accumulation on the surface affects the efficiency of the solar panels, it is proposed that the solar panels rotate and be placed above the turbine. The rotation will prevent dust accumulation as well as have a cooling effect, overall boosting the efficiency of the solar panels.

Furthermore, in the previous year's design [1], the solar panels were placed on a rotating hexagonal dome design. However, they found that a flat array produced 2.5 times that of the dome design. Therefore, in this project we have decided to place the solar panels on a flat rotating surface. As you can see in **Appendix E Figure 13**, the solar panels will be placed on a balanced surface made from sheet metal.The support will be placed above the frame, instead of below it like the previous year's design.

Motor

The motor used in this project is the same motor used in the "Hybrid Solar-Wind System" project due to its light weight and customized clutch plate to fit this specific project. The motor is the Manta 12V motor with a 3.5" diameter, 2.1Nm torque, and weighs 8.5lbs. The specifications can be found in **Appendix L.**

Battery

For this project, two types of batteries were considered: the deep cycle lead-acid battery and the lithium-ion battery. A general comparison between lead-acid batteries and lithium-ion batteries indicates the glaring advantages of the Li-ion batteries. **Table 3** compares some battery characteristics according to a comparison by Charlie Messina [4]. Because the budget for this project is limited, cost was a major factor in deciding which battery to use. Also, since the project is designed to store energy generated by the solar panels during the day, overcharging may be an issue. While lithium-ion batteries cannot tolerate overcharging, lead-acid batteries can handle it sufficiently. When the project is ready for light pole implementation, to minimize the weight at the top of the light pole the battery would be placed at the bottom of the lamp pole. This will also lower costs for maintenance by making the battery more accessible. Therefore, the deep cycle lead-acid battery remains the best available option for this type of project.

For the final design, we chose the Duralast Gold Power Sports Battery ETX9. It is a 12V Absorbed Glass Mat (AGM) technology that weighs 7.7lbs. The specifications of this battery can be found in **Appendix F**.

Table 3. Comparison of Lithium-Ion vs Lead-Acid Battery Characteristics

Battery Characteristics	Lithium-Ion	Lead Acid
Weight	⅓ the weight of Lead-Acid	Heavy
Cost	About 5x the price of Lead-Acid	$200
Efficiency	100% in both charge & discharge	Inefficiency leads to loss of 15 amps while charging
Charging Ability	Charges 3x faster	Less efficient
Discharge	100%	80%
Ability to handle over charge	It cannot tolerate	Can handle it perfectly
Cycle Life	5000x more than Lead-Acid	400-500 cycles
Reliability	New	Over 140 years of development
Voltage	Maintain voltage throughout discharge cycle	Voltage drops consistently throughout discharge cycle
Environmental Impact	Cleaner & safer	-

Frame

While the wind turbine and the solar panels are rotating, the frame will remain stationary. According to the previous year senior design report called Hybrid-Solar Wind Turbine [1], T-slot aluminum framing system was used for this design. **Table 4** compares characteristics of T-Slot frames vs. C-Channel frames. T-slot aluminum was chosen because it is light in weight and allows for easy attachment of hardware and components, eliminating the need for welding. The framing allows the solar array to be mounted without putting a weight load on the shaft and turbine below it. T-Slot framing also helps provide more stability. The slots of the framing improve the versatility since wires can be routed through them. For instance, the three wires from the turbine generator can be passed through the slot to connect to the wind turbine charge controller.

For the final design, we have chosen to use a similar design for this project, however, we have added a new additional support compared to the previous year's design. As you can see in **Figure 1 and Appendix H**, the added support will be fixed on top of the frame. Three additional T-Slot 6105-T5 aluminum alloy framing were used. In addition, six corner brackets (with screws) were used to connect three pairs of framing, along with three 90° corner connectors in order to ensure more structure rigidness.

Figure 1. *T-slot Aluminum framing used for final construction* [5]

Table 4. Comparison of T-Slot vs C-Channel Frames

Frame Extrusions	T-Slot	C-Channel
Material	Silver Anodized Aluminum	304 Stainless Steel
Cost/foot	\$7.76 (1 ½”x1 ½”)	\$12.53 (1 ⅝” x 1 ⅝”)
Weight	lightweight	Not lightweight
Stiffness	Medium	High
Versatility	High	Low
Corrosion Resistance	High	Medium

Section IV. Prototype, Fabrication, and Assembly

Shaft

Figure 2. *6061 Aluminum Shaft*

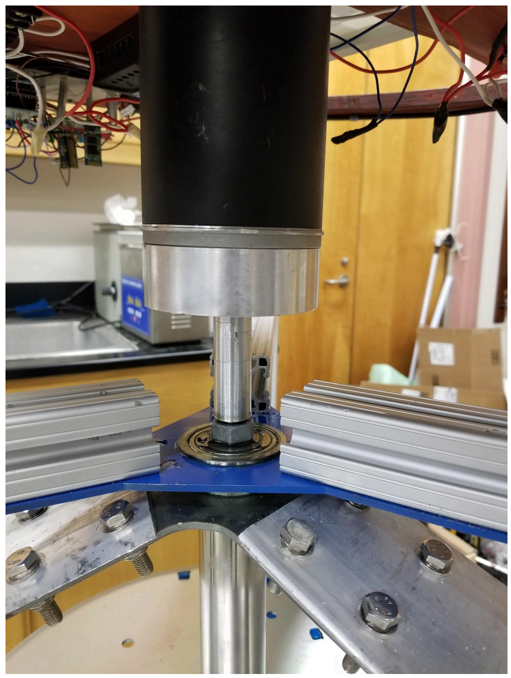

Figure 3. *Engagement mechanism w/ shaft connection*

The previous year's senior project used a pair of two u-joint connectors to transfer torque from the motor to the Aleko turbine [1]. This hindered the turbine performance, due to the shaft misalignment. To solve this issue, a 6061 aluminum shaft was fabricated using the lathe, as shown in Figure 2. A tap and die were used to make threads in order to feed into the threaded insert of the turbine shaft. A hex nut was used in order to prevent the shaft from loosening and to allow for easier removal of shaft in case it was too tight when having to disassemble, shown in Figure 3 above.

It was determined that the shaft actually had some axial load. A stress analysis was conducted on the fabricated shaft since it actually beared some weight of the solar panel system. The maximum stress was found to be 0.497 MPa, much smaller than the yield stress, which was 55.2 MPa. Also, the minimum safety factor was 111. From these results, we concluded that the shaft would not fail. The report of the results of the stress analysis can be found in ***Appendix J***. Further limiting or eliminating this weight on the shaft would increase the efficiency.

Steel Plates and Base Block

As shown in Figure 4, a 1018 steel plate was fabricated using a water jet cutter. Six holes were made to enable the connection to the T-Slot framing using three pairs of T-nut slots. A frictionless flanged ball bearing was press-fitted to enable the transfer of torque from the motor to the Aleko turbine.

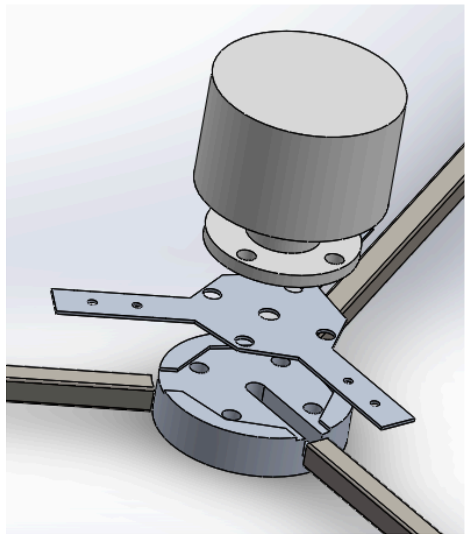

Figure 4. *CAD model of Block-Plate-Frame turbine connection*

Figure 4 shows the 1018 steel plate that was fabricated using a water jet cutter. This was done in order to connect the turbine base with the block using four hex bolts. The center hole on the plate was done in order to pass wires from the turbine alternator into the slot of the base block, which would help keep a leveled system and enable connection to the charge controller. Six holes were made to enable the connection to the T-Slot framing using three pairs of T-nut slots.

In the previous year's design, the turbine load on the steel plate caused stress and bending on the plate due to having limited support directly underneath the turbine base. Therefore, designing this base block would help improve the stability for this project. A 6061 Aluminum base block was fabricated using a mill. A groove for the steel plate to have a flush fit was done to make a stronger and more stable connection with the T-slot framing. The three curved surface contact points of the block were flattened so the T-Slot framing would sit up against the surface more comfortably, as shown in Figure 5. Four holes were made using the drill press and then threaded using a tap and die.

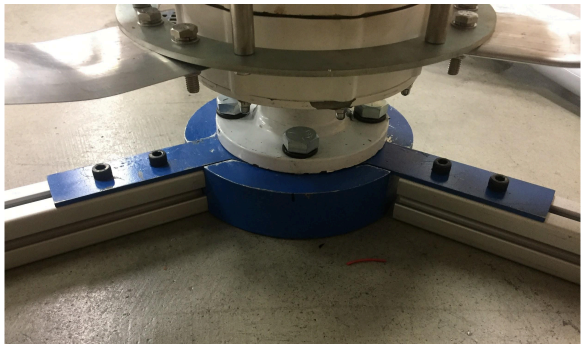

Figure 5. *Block-Plate-Frame turbine connection*

Wooden Frame and FPVC Electronic Components Box

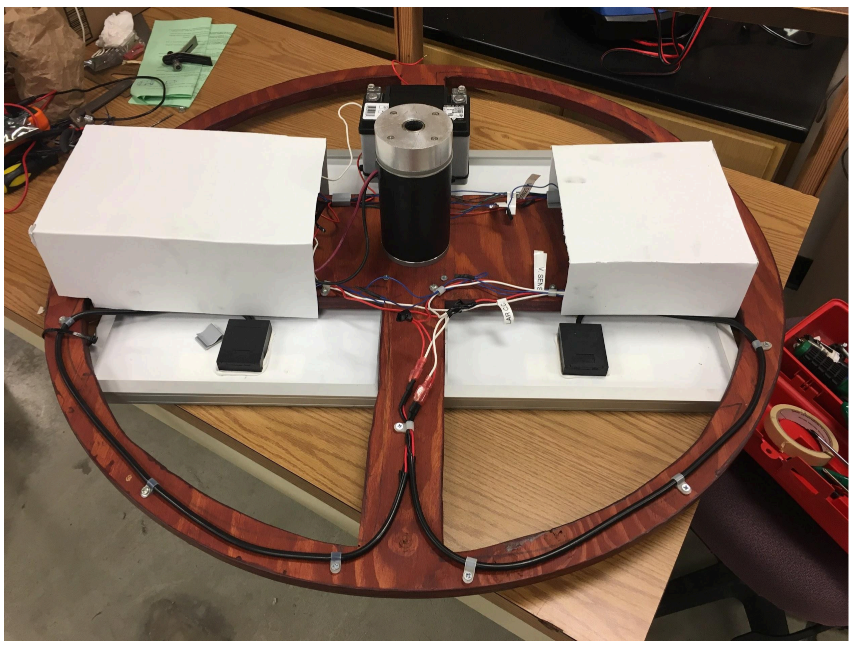

Figure 6. *Plywood frame to support solar panels and electronic components*

A bandsaw was used to fabricate the sanded pine plywood to obtain a diameter of 36 inches, as shown in Figure 6. A jigsaw was later used to remove more material in order to reduce the weight of the turbine system. A portable hand drill enabled the team to secure the motor to the wooden base, the two solar panels, as well as the electronic components. After placing the electronics and circuits on the plywood frame, two FPVC boxes were made in order to house the components. For the ease of removing and placing back on, Velcro was used.

Challenges during Construction and Assembly

During the manufacturing stages of the components a few challenges with the machines arose. During the manufacturing of the aluminum shaft, the lathe's unadjusted chuck was causing our piece to rotate and wobble. This caused a shaft prototype to be defective, such as not having a smoother finish.

While using the mill to make the turbine base, it was concluded that the machine was not leveled completely. This was especially obvious during the first few inconsistent facing passes. Also, the only thing around the shop that was able to hold down the base was a lathe chuck. As a result, even after tracing out pattern on the block there was no indexing tool available to get a correct angle.

Section V. Microcontrollers and Electronic System Interface

The design of the electrical circuit was guided by three important tasks that needed to be accomplished in order to make the project successful. The first task was to channel the generated electrical power from the solar panel and the turbine into their respective charge controllers. The second task was to measure the power generated using sensors. The third task was to control the motor operation and other electronic components. There was a practical need to design two major circuits not only because of the two sources of power generation, but also because of the requirement of the project to rotate the solar panel.

The charge controller for the turbine converted AC to DC and provided consistent voltage to be available for use by load. It placed at the bottom of the frame. Voltage sensors and current sensors were utilized to measure the electric charge generated by the turbine. In order to measure current, a load had to be present, therefore, a small motor attached to the output portion of the circuit design for the turbine allowed for the current to be measured. In addition, the circuit for the turbine had an anemometer sensor fixed to the top of the support frame. These sensors were filtered by a low pass RC circuit after which signals are sent to the Arduino. The data was then collected using a laptop for analysis (see Figure 7). Figure 8 shows actual circuit that was built based on Figure 7.

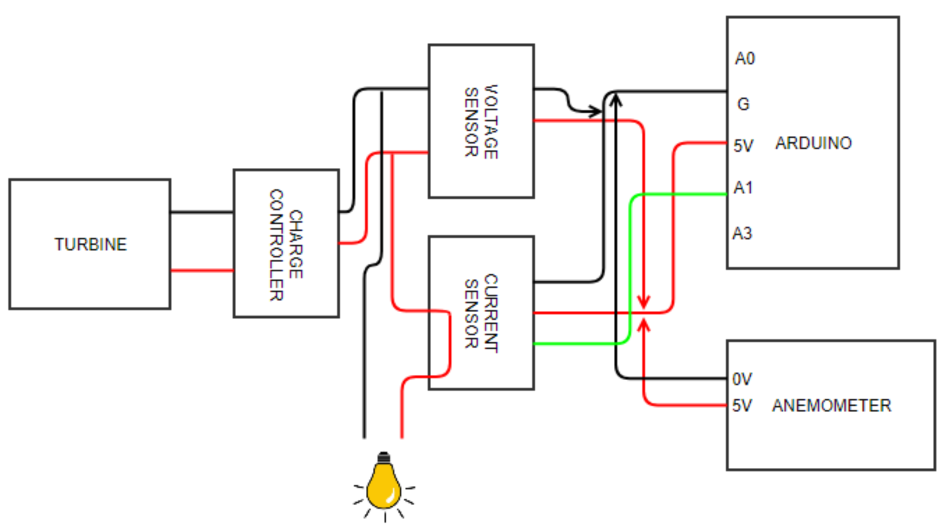

Figure 7. *Block diagram that shows schematics for the circuit design of the turbine*

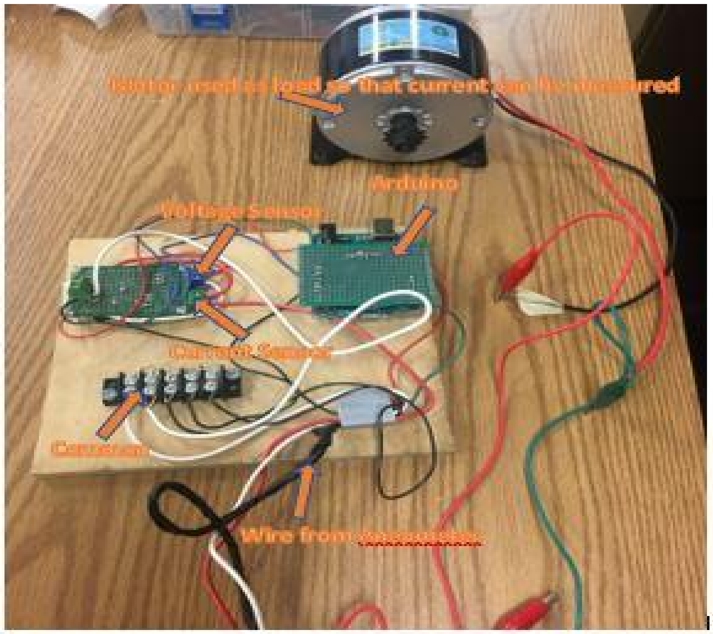

Figure 8. *Circuit that measures the power produced by Turbine*

The circuit design for the solar panel is much more complex than that of the turbine. (see Figures 9 and 10). The complexity has to do with the motor's operation and other electronic components that needed to work together as integrated system. This circuit consisted of two solar panels, a battery, voltage sensors, current sensors, a charge controller, a motor, a motor drive, a bluetooth, an SD card reader, micro SD-card, and an Arduino. The two solar panels were connected in parallel and were directed as input into the solar panel terminal of a charge-controller. The output terminal of the solar panel is connected with a battery while the load terminal of the charge controller was connected with the battery terminal of the motor drive. The motor's positive and ground wires were then connected to the motor-drive.

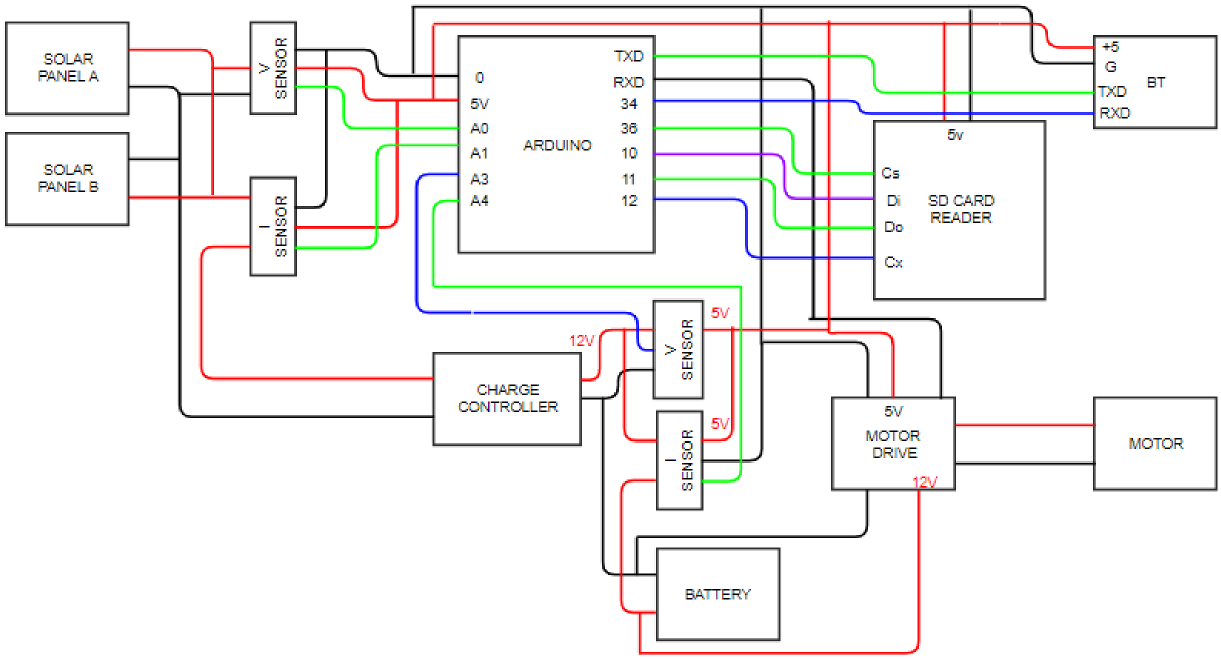

Figure 9. *Block diagram that represented the schematics of the circuit design for the solar panel [*correction: rxd should be connected to txd and vice versa and signal from motor drive should be connected to digital 34]*

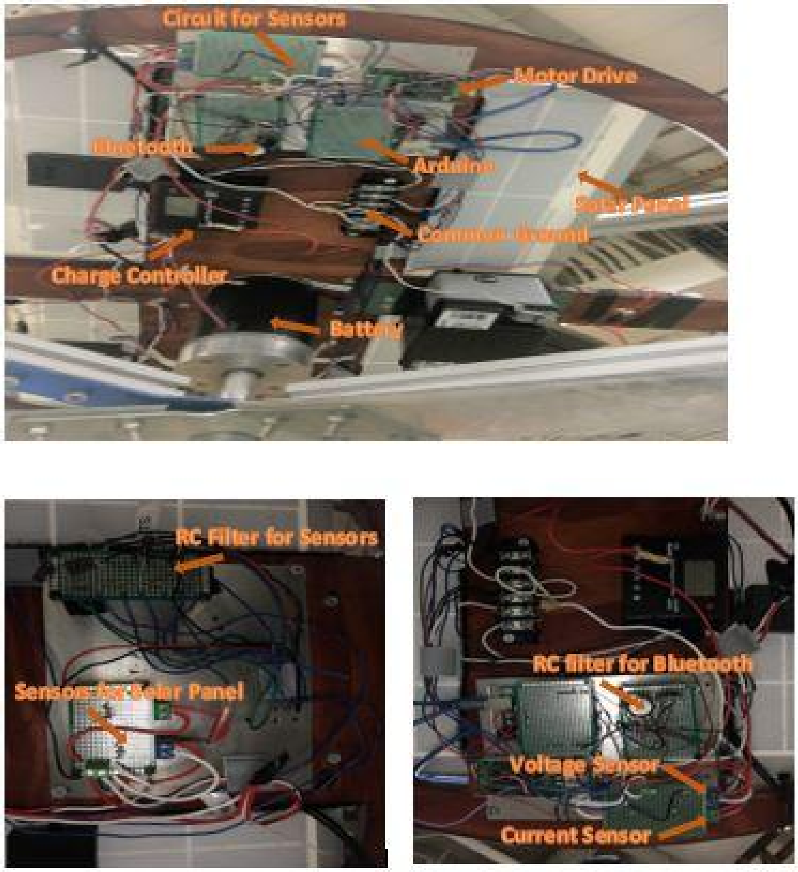

Figure 10. *Circuit for Solar Panel and Motor*

The motor was to be operated at various speeds so as to observe the behavior of the wind turbine as well as observe if there was a significant appreciation of power generation by the wind turbine as speed increased. Therefore, the main function of the motor drive was to run the motor at various speeds while handling the back EMF (electromotive force) generated by the motor during stopping the motor. It also managed some of the excess heat generated by fluctuating current usage of a motor via its built-in capacitor. There were four speeds that were utilized for the motor drive to drive the motor. The duty cycles represented the 25, 50, 75 and 100 percent of total capacity of the battery that represented about 3, 6, 9 and 12 volts respectively. The motor drive received signal from the Arduino for the aforementioned speeds and modulated the voltage supply.

In order to enhance safety and control of the circuit, a switch was introduced between the battery's positive terminal and the solar charge controller. The switch allowed us to shutdown the system manually. Due to the rotation of the wooden plate that supported the solar panels, controlling the motor operation required a wireless communication between our system and a cell phone. Therefore, a bluetooth sensor was used to receive and send data between an Arduino and a Samsung cell phone using an Android app. Once the bluetooth was paired with a cell phone, which was loaded with the Android app, the motor could be stopped and started at the four different speeds mentioned earlier. A low pass RC filter was used by the bluetooth sensor to cancel noise.

The circuit also consists of a voltage sensor and a current sensor to monitor the power generated by the two solar panels. These sensors had low pass RC filters prior to sending signal to the arduino. Moreover, another voltage sensor and current sensor monitored the input to the motor. The data was stored in a micro card reader that was attached to the Arduino for further analysis. In effect, we compare the input power to the motor against the output power produced by the turbine.

Table 5. *Major Electronic Components Used for the Circuit*

Name	**Brand**	**Type**	**Quantity**
Motor	Manta	Manta 12V Motor	1
Motor drive	Dimensions	SyRen 12A	1
Battery	Duracell	*Duralast Gold Power Sports Battery ETX9*	1
Solar panel	Newpowa	Polycrystalline	2
Charge Controller/Solar	HQST	HQST 10A PWM	1
Charge Controller/Wind	-	CD 5.0 12V Wind Charge Controller	1
Voltage Sensor	Allegro	Max 25V Voltage Detector	4
Current Sensor	Allegro	Qunqi ACS712 30A	3
Capacitor	HSC	1micro meter	6
Resistor	HSC	10k resistors	6

Section VI. Testing

The following tests were conducted to analyze the performance of SAVAWT compared to a separated hybrid system, as well as the solar efficiency due to the rotating solar base. (see part of raw data in Appendix O).

1. Power output difference of the integrated hybrid system vs. separate system

The main objective for this project was to analyze the difference in power output of a standalone system, wind power and solar power added, and the integrated hybrid system, wind turbine assisted by solar. This was accomplished by recording the voltage and current output of the generator of the standalone turbine, the voltage and current input to the motor in the integrated system, and the voltage and current output of the generator of the integrated system. The power output from the solar panels varied from 0 to 40W. This power was used to charge the battery which then powered the motor and may be used throughout the day and night. The voltage input from the battery was varied to vary the motor speed. This was accomplished by using a Bluetooth app to change the duty cycle of the motor from 25%, 50%, 75%, and 100% or, in other words, vary the battery input voltage by 12V, 9V, 6V, and 3V. All tests were conducted at Point Reyes Lighthouse, known as the windiest place on the Pacific Coast, despite its reputation, wind speeds did not exceed 7 m/s. The results of these tests are located in the *Results* section.

2. Cooling and Dusting Effects on Solar Panels

Both heat increase and dust buildup can significantly reduce the efficiency of solar panels. One of SAVAWT's goals was to use the motor to not only aid the wind turbine, but to simultaneously increase the solar panel efficiency.

a) Cooling test: The cooling test was performed indoors by placing a Halogen lamp above the solar panels for 7 minutes while stationary and 7 minutes while spinning at 25% duty cycle. Temperatures of the four corners were recorded before and after the 7 minute trial. The averages of these corners were assumed to be the average of the entire panels. The trial time for these tests were limited to the battery's capacity to power the motor without solar charging.

Figure 11. *Solar Panel and Halogen lamp for cooling test*

b) Dusting Test: The dust test was a visual test. In one trial rice was distributed along the solar panels while a camera recorded the results of spinning the turbine from 0 to 100%duty cycle. This was repeated with sugar under the same conditions.

The results for both of the solar tests are located in the *Results* section.

Section VII. Sample Calculations

Power Generated from the Wind

Using Equation 1, the power generated from the wind was determined in **Table 5** at various wind speeds.

Table 6. *Power Generated from Wind (SAVAWT Data)*

Wind Speed (m/s)	1	2	3	4	5	6	7	8	9	10	11
P_{wind} (W)	1.17	9.33	31.49	74.64	145.78	251.9	400.01	597.09	850.16	1166.2	1552.21

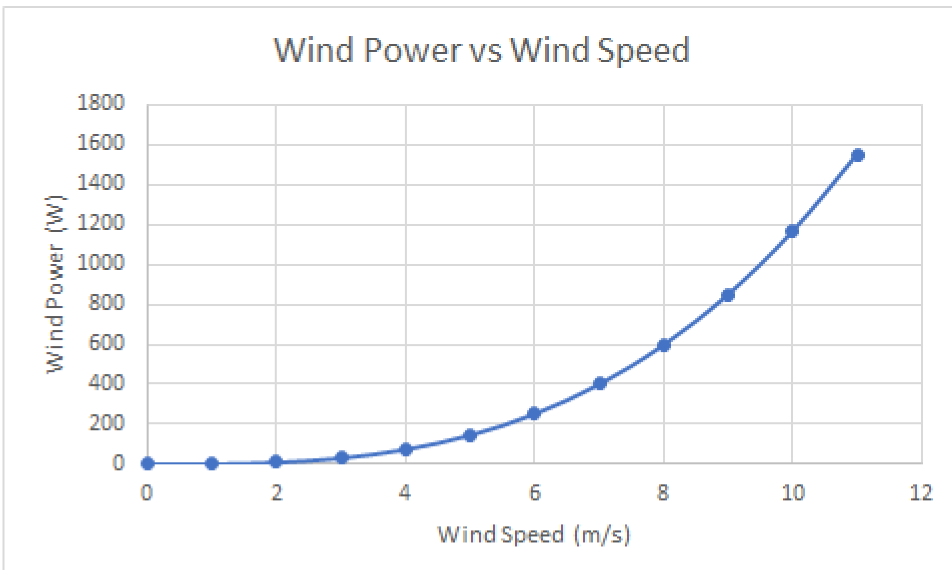

Figure 12. *Power Generated by the Wind at Different Wind Speeds*

Efficiency of the Turbine

The efficiency of the turbine can be found from the power generated by the wind and the power generated by the turbine. For the power generated by the wind, we assumed the wind speed was 4 m/s, which was the average wind speed in San Jose in 2017.

Known parameters:

$$\rho_{air} = 1.225 \text{ kg/m}^3$$

$$V_{air} = 4\, m/s$$

$$D_{turbine} = 1.36 \text{ m}$$

$$h_{turbine} = 1.4 \text{ m}$$

Maximum wind power available at 4 m/s:

$$P_{wind} = \frac{1}{2} * \frac{2}{3} * \rho AV^3 \text{ (for the combined Savonius-Darrieus VAWT)}$$

$$P_{wind} = \frac{1}{2} * \frac{2}{3} * 1.225\text{kg/m^3} * 1.36\text{m} * 1.4\text{m} * (4)^3$$

$$\mathbf{P_{wind} = 86.4 \text{ Watts}}$$

Efficiency of the Standalone Turbine

Parameter provided by the vendor:

$$P_{turbine} = 25 \text{ Watts}$$

Efficiency of the turbine in San Jose, CA:

$$P_{turbine} = \frac{1}{2} C_p \rho AV^3$$

$$C_P = \frac{P_{turbine}}{P_{wind}}$$

$$C_P = \frac{25W}{86.4W} * 100\ \%$$

$$\mathbf{C_P = 28.9\%}$$

Section VIII. Results

Standalone Turbine

During the standalone testing the motor and solar panels were removed from the turbine and data was recorded. The wind speeds during this trial range from about 5 m/s to 7 m/s. The wind power available at these speeds range from 95.2 W to 261 W. Figure 13 below shows the tested power output of the turbine as a solid line and the projected output with the dotted line. The power output ranged from 0 W to .35 W, thus resulting in an efficiency of 0.13%. The results show a cut-in speed of about 5 m/s. As noted by last year's SAWT team, these test concluded that the turbine itself is highly inefficient.

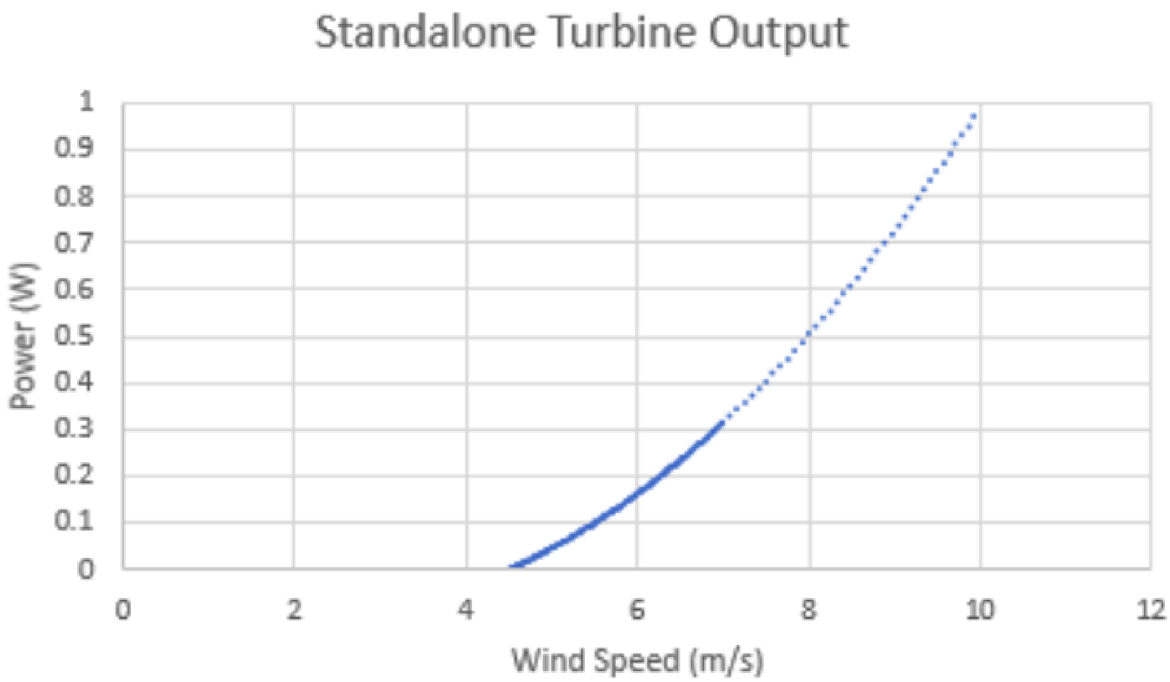

Figure 13. *Standalone Turbine Output*

Integrated Hybrid System

The hybrid tests were conducted at the four duty cycles: 100%, 75%, 50%, and 25%. **Table 6** has the consolidated average data from these tests. At 25% and 50% the hybrid system on average produced less power than the power input from the battery. Figure 15 compares the power output of the vary duty cycles. Individual results and analysis will be discussed in the sections that follow.

Table 7. Averages of Varied Duty Cycle Testing

Duty Cycle	Avg Input Power (W)	Avg Wind Power Available (W)	Avg Power Output (W)	Efficiency (%)
25 %	1.8	52	0.2	0.4
50 %	2.4	51	2.3	6.5
75 %	2.4	39	2.7	8
100 %	2.5	45.2	2.7	7

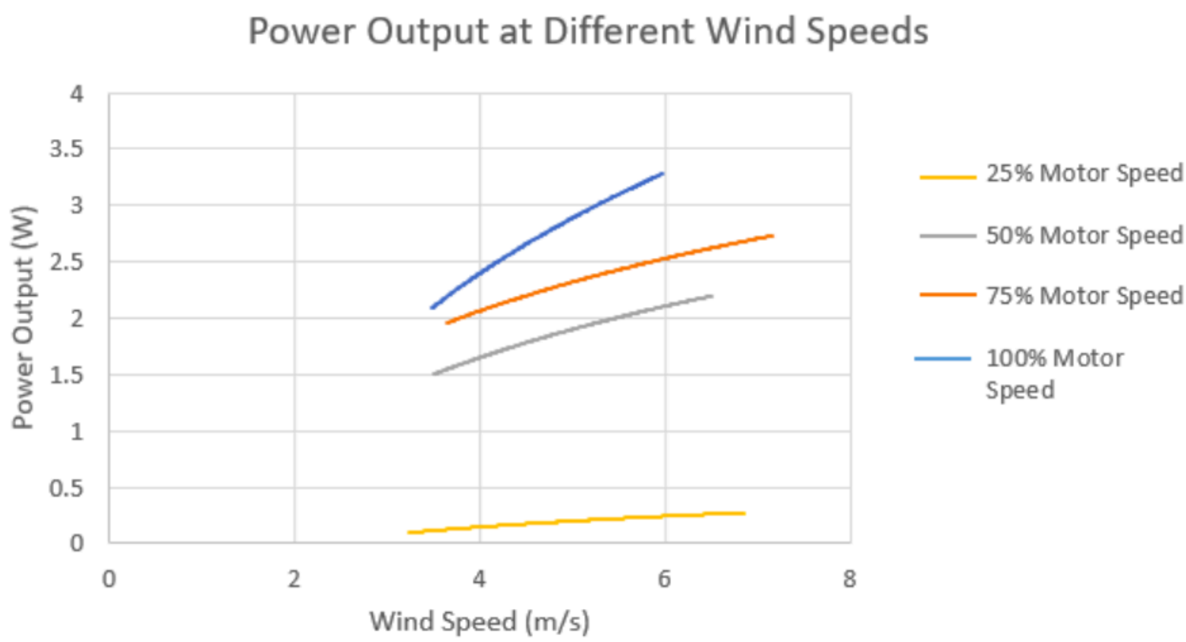

Figure 14. *Power Output at Different Wind Speeds*

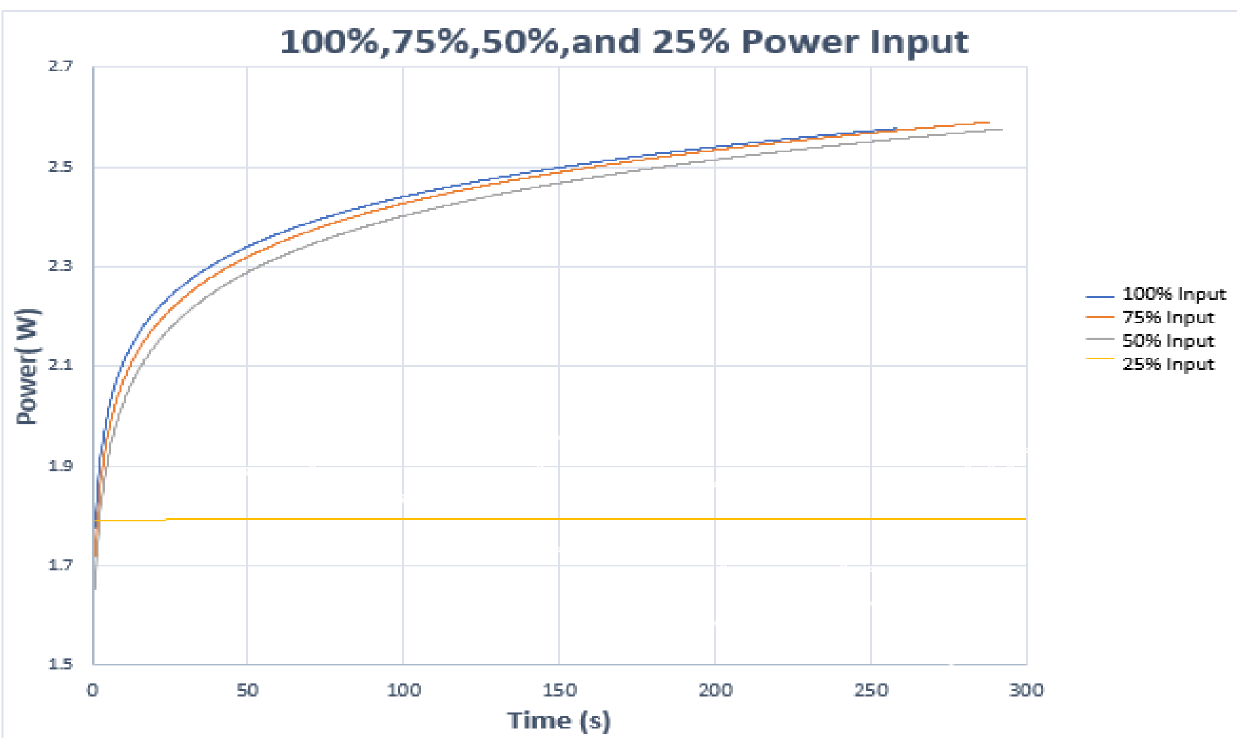

Figure 15. *Power Input for 100,75,50,25 % duty cycles.*

100% Duty Cycle Test Results

The data collected for the 100% duty cycle test is shown **Table 4 and 8**, ***Appendix O***. Initially, the test was designed to give the motor 12V, which is the maximum voltage of the battery. The electrical team was successful in accomplishing this result when testing the motor, but due to the behaviour of motor under load, the data did not show a 12V potential difference. Rather, the current input increased in order to provide enough torque to rotate the load. **Figure 16** and **Figure 17** show the Power Input & Power Output vs. Time and Power Output of Turbine vs. Wind Speed respectively for 100% duty cycle.

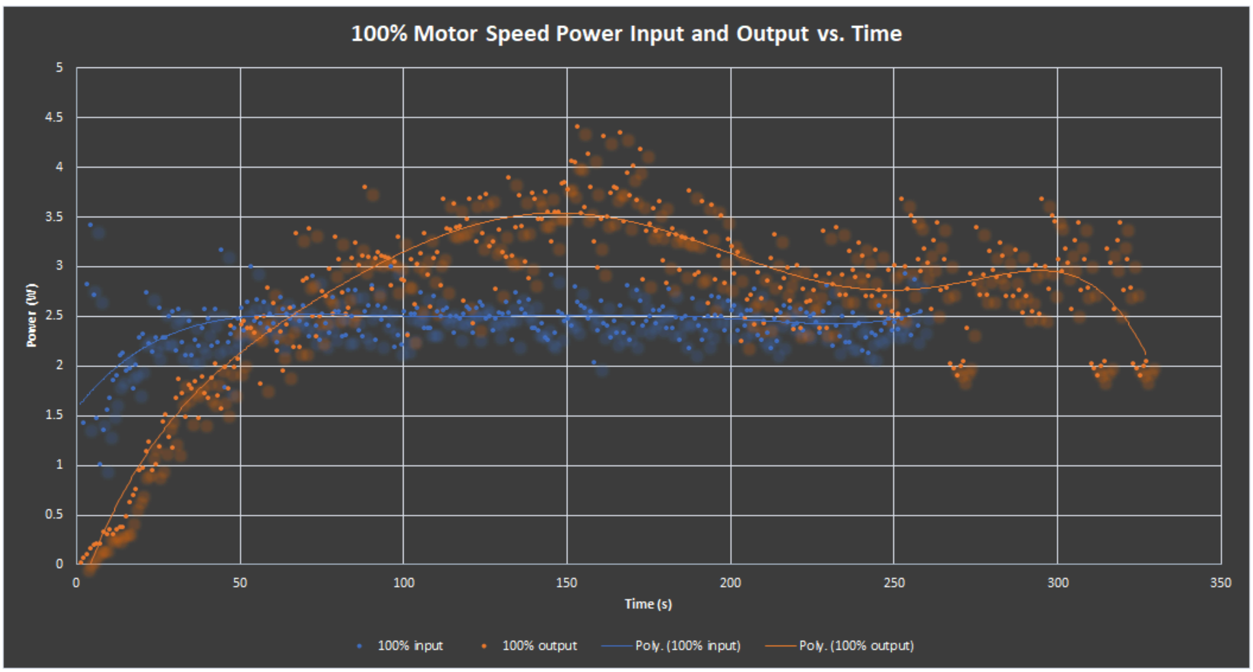

Figure 16. *100% Power Input vs. Power Output*

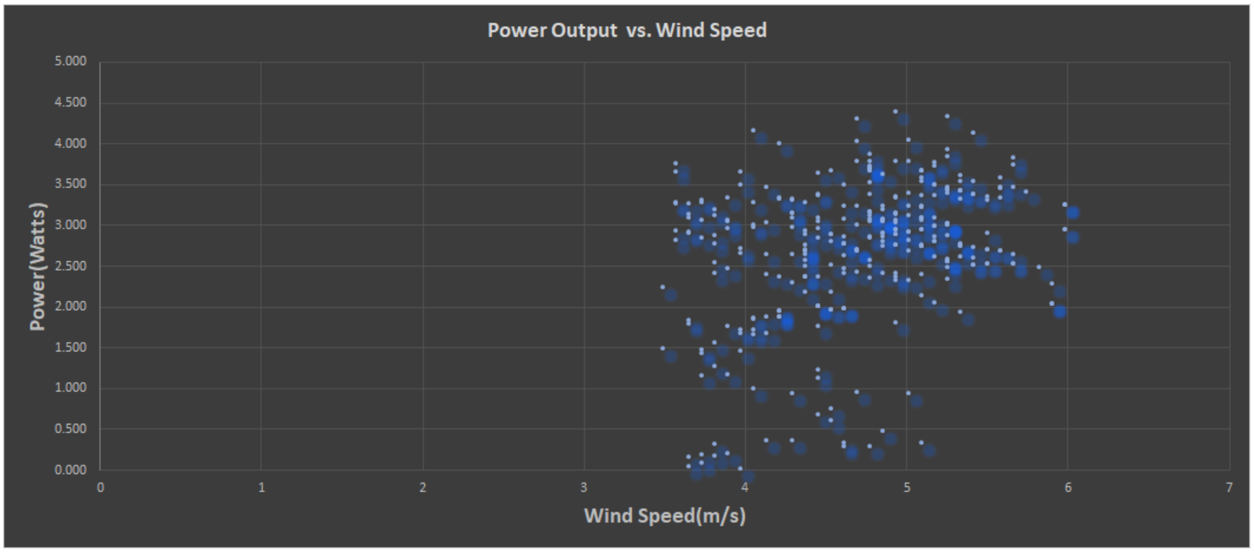

Figure 17. *100% Power Output of Turbine vs. Wind Speed*

75% Duty Cycle Test Results

The data collected for the 75% duty cycle test is shown **Table 3 and 7**, ***Appendix O***. Similar to the situation explained in the 100% duty cycle, load conditions on the motor caused the input voltage to be lower than the expected 9V. **Figure 18 and Figure 19** show the Power Input & Power Output vs. Time and Power Output of Turbine Vs Wind Speed respectively for 75% duty cycle.

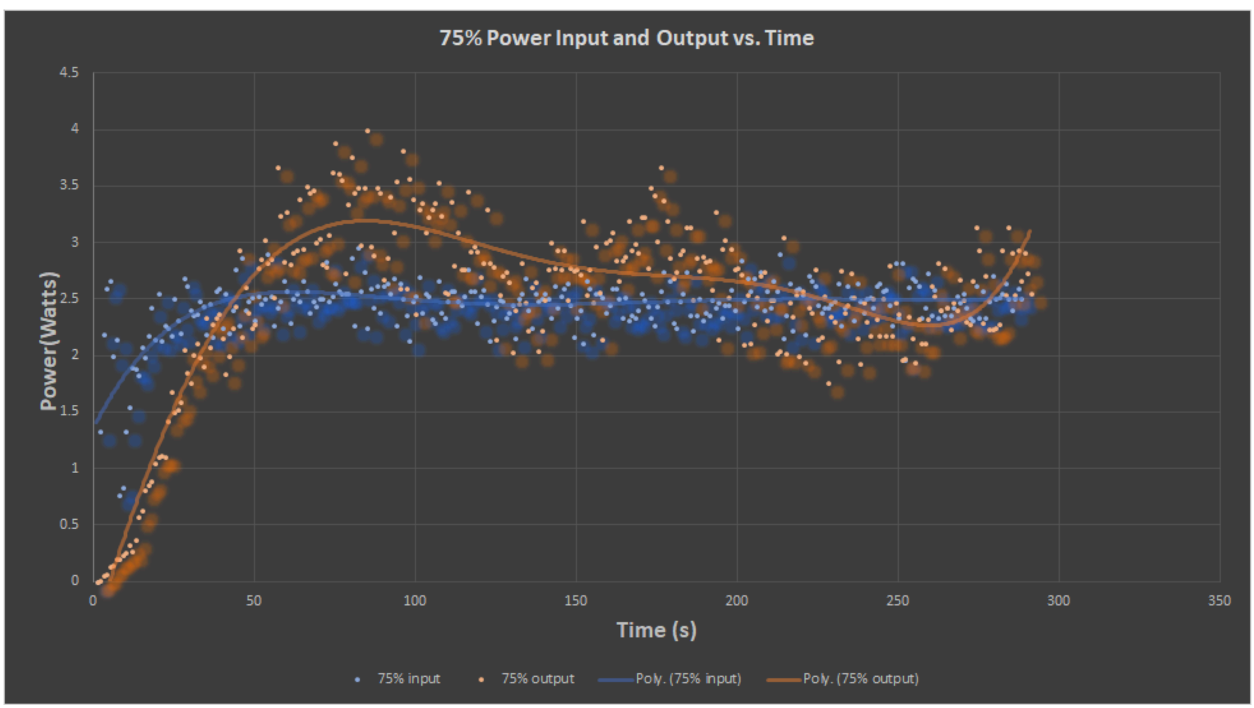

Figure 18. *75% Power Input vs. Power Output*

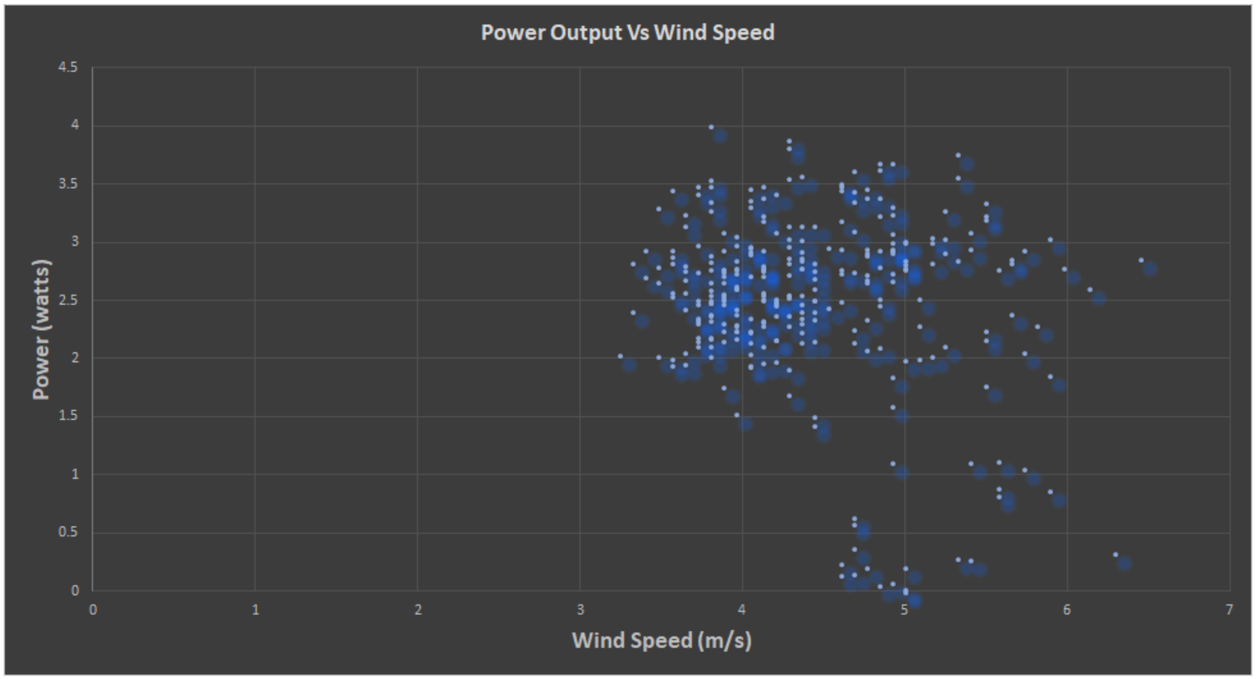

Figure 19. *75% Power Output of Turbine vs. Wind Speed*

50% Test Results

The data collected for the 50% duty cycle test is shown **Table 2 and 6**, ***Appendix O***. This test was designed to give the motor 6V, however, again the load on the motor prevented this. **Figure 20 and Figure 21** show the Power Input & Power output vs. Time and Power Output of Turbine vs. Wind Speed respectively for 50% duty cycle.

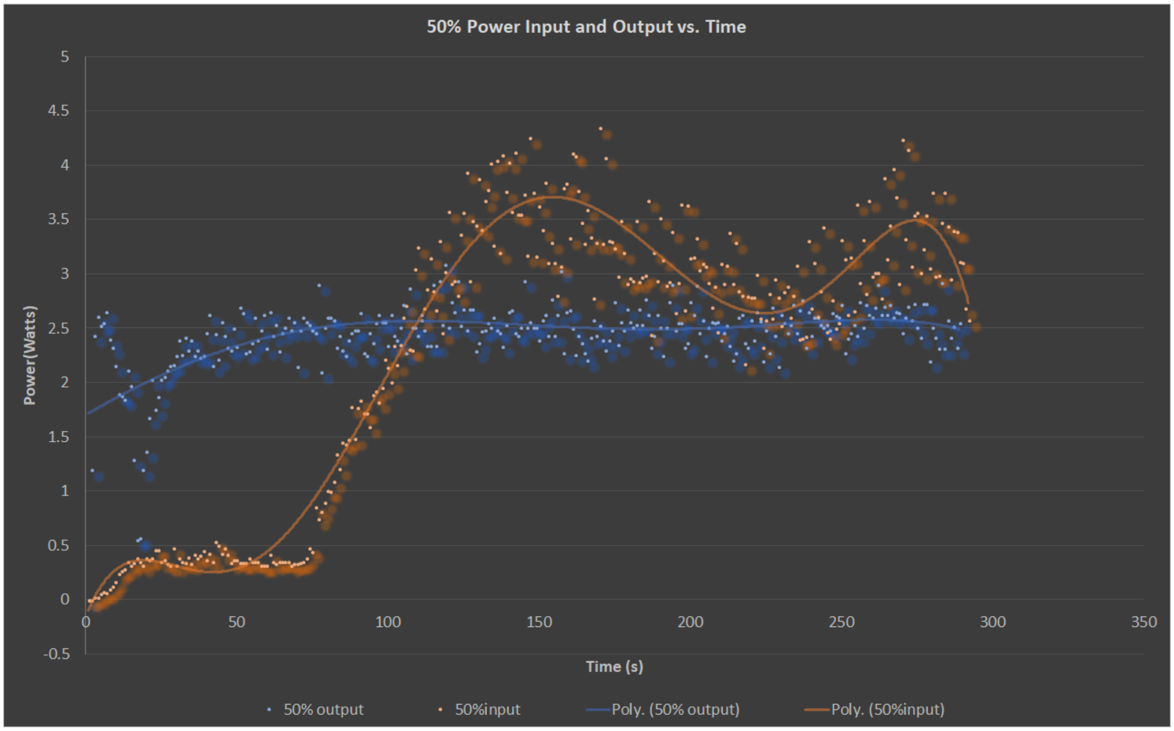

Figure 20. *50% Power Input vs. Power Output*

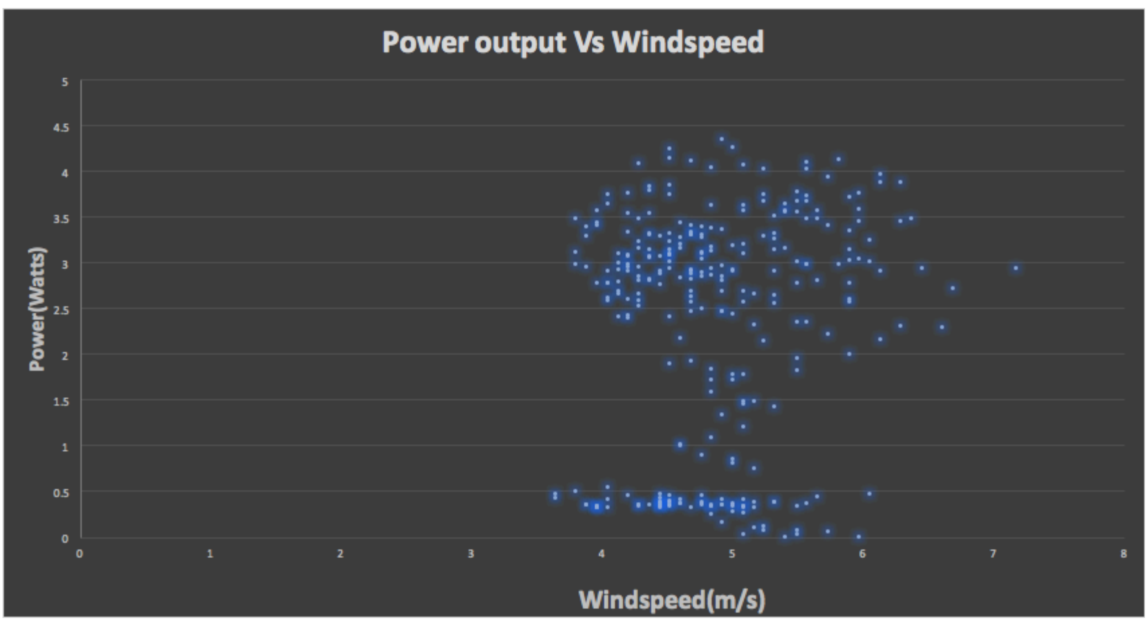

Figure 21. *50% Power Output of Turbine vs. Wind Speed*

25% Test Results

The data collected for the 25% duty cycle test is shown **Table 1 and 5**, ***Appendix O***. This test was designed to give the motor 3V. **Figure 22 and Figure 23** shows the Power Input &

Power Output vs. Time and Power Output of Turbine vs. Wind Speed respectively for 25% duty cycle.

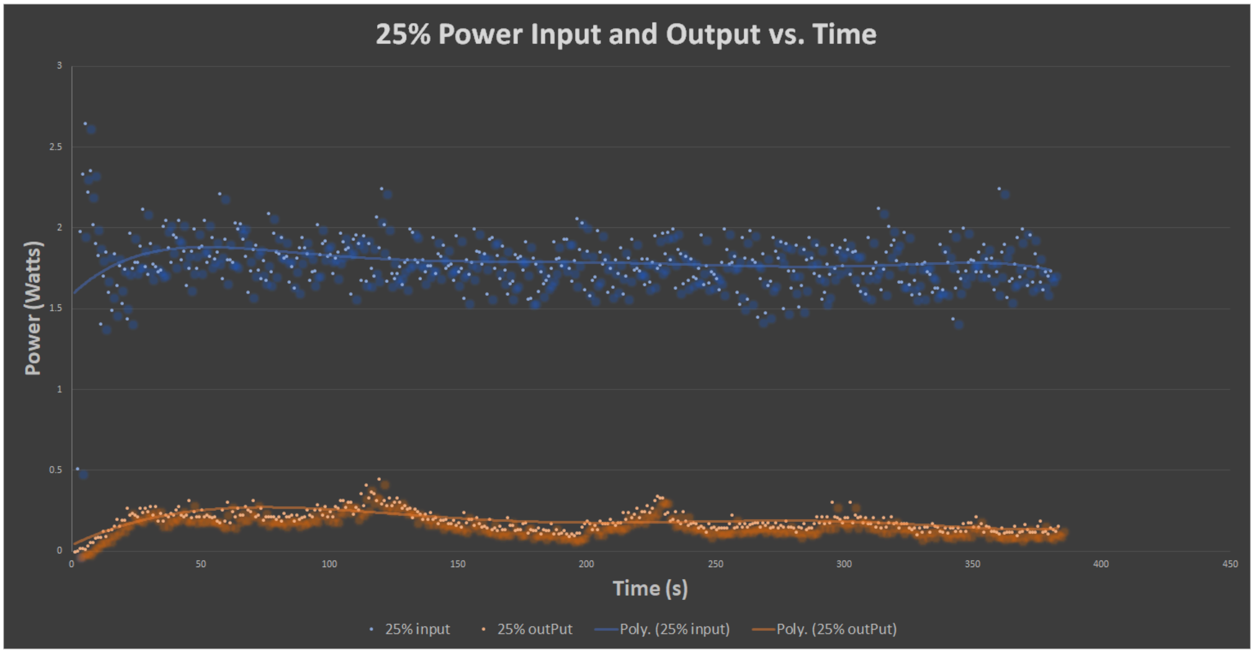

Figure 22. *25% Power Input vs. Power Output*

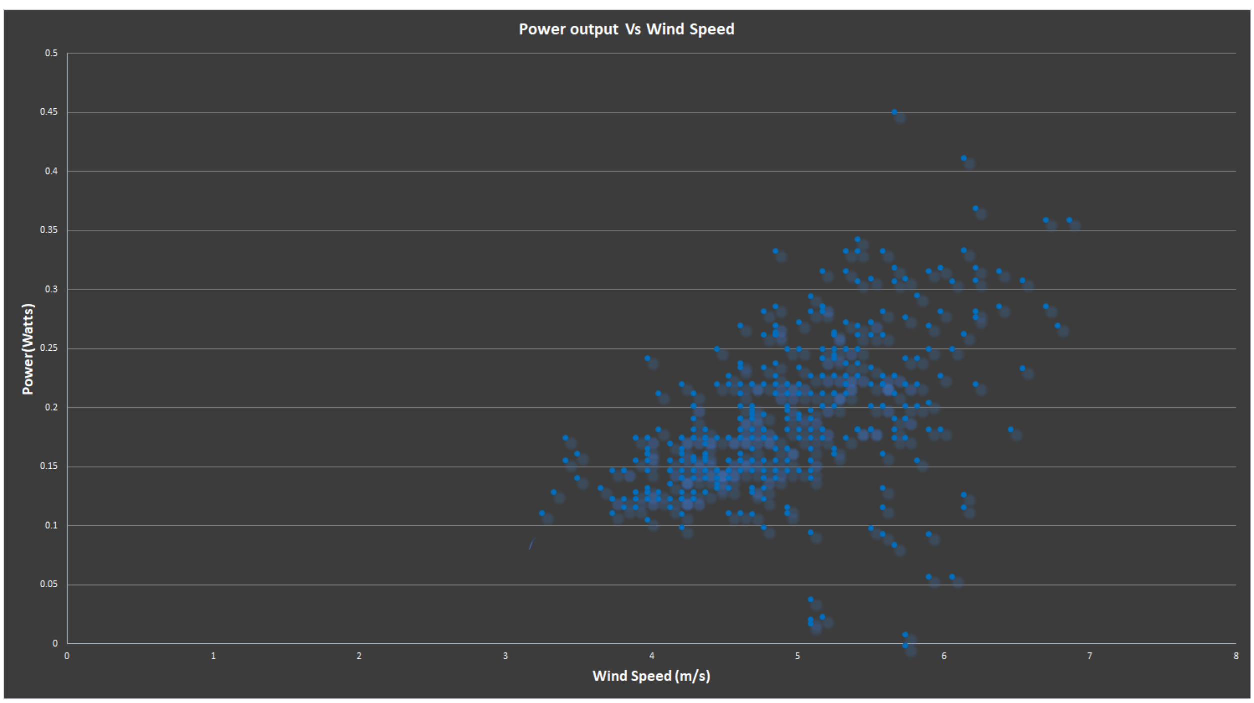

Figure 23. *25% Power Output of Turbine vs. Wind Speed*

Solar Panel Cooling Test Results

The temperature results show that the rotation did have a cooling effect on the solar panels. The Temperature Coefficient of the Solar panels is -.278/℉. After 7 minutes, the spinning solar panels lost about .84% in efficiency from heating, while the stationary solar panels lost about 1.3% in efficiency from heating.

Table 8. Solar Panel Temperature Data

Spinning 7 minutes	Starting Corner Temperatures (℉)				Avg. Starting Temp (℉)	Ending Corner Temperatures				Avg. Ending Temp. (℉)	ΔT(℉)
Trial 1	74.9	73.2	74.4	75.3	74.45	79.2	75.1	77.8	77.5	77.4	2.95
Trial 2	75.0	73.6	75.1	75.3	74.75	79.5	76.4	78.2	77.2	77.825	3.075
Trial 3	75.2	73.4	74.5	75.1	74.55	79.6	75.6	77.9	77.3	77.6	3.05
Trial 4	74.9	73.0	74.9	75.0	74.45	79.7	75.3	77.7	77.2	77.475	3.025
										Overall Average Difference	3.025 ℉
Stationary 7 minutes	Starting Corner Temperatures (℉)				Avg. Starting Temp. (℉)	Ending Corner Temperatures (℉)				Avg. Ending Temp (℉)	ΔT(℉)
Trial 1	75.0	73.6	74.3	75.5	74.6	78.3	79.0	78.1	81.5	79.225	4.625
Trial 2	75.5	74.3	74.5	75.3	74.9	78.6	78.6	78.4	81.4	79.25	4.35
Trial 3	75.1	73.9	74.1	75.6	74.675	78.5	79.2	77.9	82.5	79.525	4.85
Trial 4	75.2	73.8	74.3	75.2	74.625	78.6	78.7	78.3	82.3	79.475	4.85
										Overall Average Difference	4.66875 ℉

Solar Panel Dusting Test Results

The rotating solar panels were able to self remove all the rice in 62 seconds from 0 to 100% duty cycle. In 98 seconds, the rotating solar panels removed 98% of the sugar.

Figure 24. *Solar Panels after about 1 minute between 0% to 100% duty cycle*

Section IX. Conclusions and Future Work

Final Conclusions

The test indicated that at 25% duty cycle, the efficiency of the turbine averaged 0.4% which is very low, 6.5 % for 50, 8% for 75%, and 7 % for 100% duty cycle. Based on the data collected, the team observed the turbine did not completely utilize the available wind power present, rather the turbine used the power supplied to the motor to generate electricity. This was most likely due to ineffective wind turbine blade design. If we look at the power output of the 25% duty cycle, the generated power and hybrid system efficiency was very low due to the motor supplied power not being enough to rotate the turbine or generate power. Thus, we conclude that more test should be conducted after changing the turbine with a more efficient turbine that utilizes the wind power available.

In addition, the team concluded that the initial assumption that the power output of the wind turbine would increase to an exponential point, since the common power graph (**Figure 25**) of the turbine consisted of a cubic function with respect to velocity, was not completely visible. It was important to realize that the v^3 relationship of a wind turbine refers to the wind velocity and not necessarily wind turbine rotational speed. Using the motor to rotate the turbine only increased the turbine speed, however, in a way it could be used to simulate the wind speed's effect on the turbine's rotational speed since natural wind speed would be harder to manipulate. At one point there was a misinterpretation that the law of conservation of energy was being violated since continuous energy used for motor to spin the turbine could not result in more energy produced by turbine. However, the project intended to use the motor in conjunction with the available wind power and during the cubic part of the wind turbine's power graph. In this case it was a matter of net power used in powering the motor to boost the rotation of the turbine and turbine output power due to motor and wind power. Furthermore, the limited high wind speed availability and motor's average efficiency of 80% coupled with efficiency of solar panels and battery reduced the final output of the wind turbine's maximum power output with a maximum theoretical possible efficiency of 59% (Beltze limit).

Finally, the team observed that continuous excitation of turbine through motor requires a lot of energy and the power generated by the solar panels is often times not enough power to support the system. It was also concluded that the system drained the fully charged battery rather quickly, within 4 minutes of operating at 25% duty cycle.

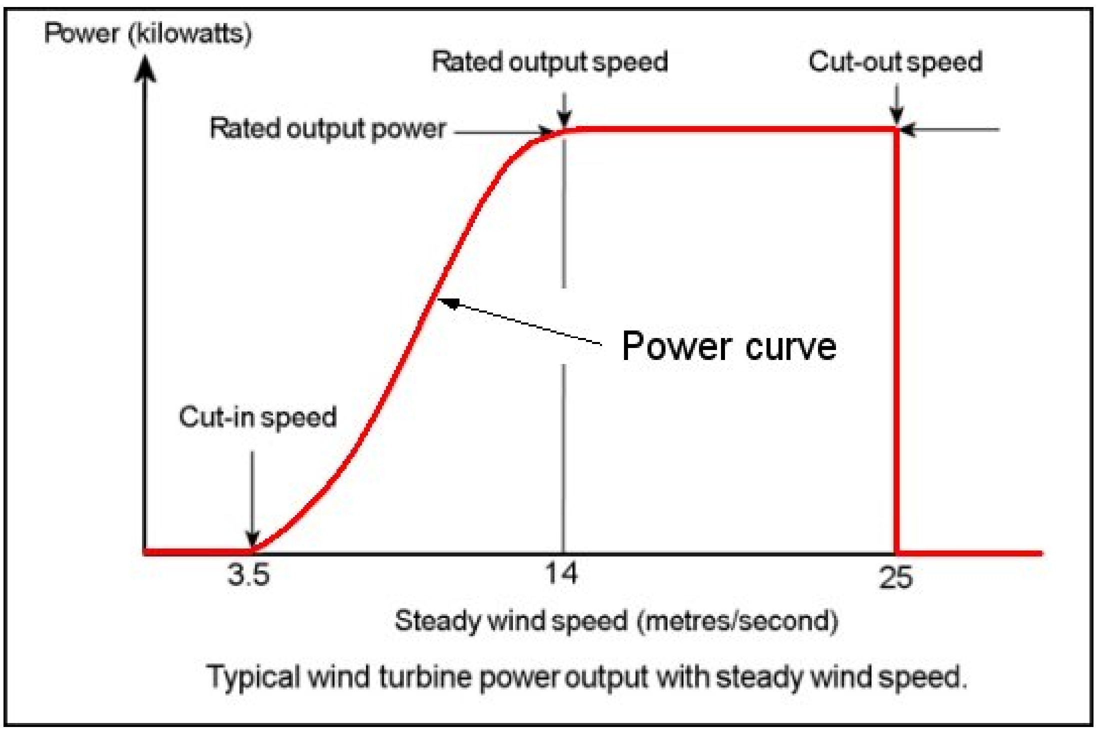

Figure 25. *Common power graph for wind turbines*

Future Work

Using a more efficient turbine with a lower cut-in speed would greatly improve this project. However, we can also reduce the weight of the project by selecting other materials, such as a lighter wind turbine, lighter solar panels, and lighter battery. Also making this project portable by placing wheels under the framing would make it easier to move the project during testing. Additionally, choosing a different motor that can generate more power will help improve this project.

In order to make this project a more viable option for renewable energy, it would be better to use the power generated from the solar panels to only kick start and engage the motor at certain points that will significantly enhanced the wind turbine's efficiency instead of spinning it continuously. This will lower the input power to the system. Also, the newly designed motor-turbine connection of the SAVAWT has considerably less resistance than the SAWT project and can spin freely. A strong kickstart will be able to spin the turbine for a while until a gust of wind picks up.

In addition, using the motor for both solar panel as well as the turbine had caused faster drain of the battery. During starting and increasing motor speed, there is higher use of cranking current due to the demand of larger torque. Therefore, using the motor just for turning the turbine not only increase overall efficiency, but also contributes to the accuracy of the test data. Since the motor power was used for both the solar panel and the turbine, it was difficult to determine the percentage of power use. If rotating the solar panel is critical, a separate motor can be used to achieve that objective. If the SAVAWT shows promise of providing clean renewable energy for street lamps, with further improvements the SAVAWT can be implemented on a larger scale.

Section X. Bill of Materials (BOM)

Bill of Materials									
Item #	Product Name	Product Description	Purchased/ Fabricated	Supplier	Qty	Unit Cost ($)	Total Cost ($)	Source	Purchased?
			Top Section: Solar Panel and Motor						
1	Solar Panel	Newpowa 20W 12V Poly Solar Panels	Purchased	Amazon	2	$42.98	$85.96	p/B00W813E4I/ref=sr_	Yes
2	Solar Charge Controller	HQST 10A PWM Solar Panel Regulator	Previous Project	Amazon	1	$17.99	$0.00	Previous Project	Yes, Previous Group
3	Motor Battery	12 V 7.2 AH rechargable	Purchased	Amazon	1	$20.12	$20.12	C/ref=sr_1_9?s=autom	Yes
4	Motor Drive	SyRen 10A Regenerative Motor Driver	Purchased	Amazon	1	$52.99	$52.99	ef=sr_1_cc_1?s=aps&i	Yes
5	Motor Driver	SyRen 10A Regenerative Motor Driver	Purchased	Amazon	2	$49.99	$99.98	/B00CJ0BD2S/ref=od_	Yes
6	Arduino	Arduino Uno R3 Microcontroller	Purchased	Amazon	1	$23.64	$23.64	08GRTSV6/ref=oh_aui	Yes
7	Arduino Battery	5 V Battery	Purchased	Amazon	1	$12.99	$12.99	TF8&pd_rd_i=B00L9F9	Yes
8	Current Sensor	Qunqi 5PCS ACS712 30A Range Current Sensor Module for Arduino	Purchased	Amazon	2	$16.99	$33.98	77GLTV8N/ref=oh_aui	Yes
9	Voltage Sensor	5PCS Max 25V Voltage Detector Range 3 Terminal Sensor Module for Arduino	Purchased	Amazon	2	$6.99	$13.98	076Q27P59/ref=oh_aui	Yes
10	TF Card Shield	HiLetgo Stackable SD Card and TF Card Shield for Arduino UNO R3 Arduino Mega 2560	Purchased	Amazon	1	$6.99	$6.99	006LRR0IQ/ref=oh_aui	Yes
11	Bluetooth Module	Bluetooth	Purchased	Amazon	1	$10.00	$10.00	KSAF6/ref=sr_1_2_ssi	Yes
12	Switch	Smart Wi-Fi Light Switch In-Wall	Purchased	Amazon	1	$22.00	$22.00	on/dp/B073TRS6KC/re	Yes
13	Rectifier Diode	50 V 1A General Purpose Rectifier Diode	Purchased	Jameco Electronics	10	$0.12	$1.20	OG&gclid=CjwKCAjAk4	Yes
14	1 µF Capacitor	RC filter	Purchased	Amazon	2	$5.98	$11.96		Yes
15	10 kΩ Resistor	RC filter	Purchased	Amazon	1	$8.54	$8.54		Yes
						Total:	$404.33		
			Bottom section: Turbine						
16	Turbine	300W 12V Three-Phase Vertical Axis Turbine	Previous Project	Aleko	1	$489.00	$0.00	Vertical-AC-Wind-Gene	Yes, Previous Group
17	Turbine Charge Controller	CD 5.0 12V Wind Charge Controller	Previous Project	Aleko	1	$59.00	$0.00	Wind-Charge-Controlle	Yes, Previous Group
18	Anemometer	Wind Speed Sensor w/ Analog Voltage Output	Previous Project	Adafruit	1	$44.95	$0.00	ww.adafruit.com/produ	Yes, Previous Group
19	Flanged Ball Bearing	Flanged Frictionless Bearing 35mmx55mmx10mm Shielded Bearing	Purchased	VXB	1	$25.99	$25.99	F6907ZZ-Flanged-35x5	Yes
						Total:	$25.99		
			Frame/Hardware						
20	Round Bars	6061 Aluminum Round Bar	Purchased/Fabricated	Campbell Metal Supply	2	$50.00	$100.00	bellmetal.com/products	Yes
21	Cylindrical Plates	6061 Aluminum Cylindrical Plate	Purchased/Fabricated	Campbell Metal Supply	2	$0.00	$0.00	bellmetal.com/products	Yes
22	Sanded Plywood	3/4 in. x 4 ft. x 4 ft. BC Sanded Pine Plywood	Purchased/Fabricated	Home Depot	1	$30.80	$30.80	https://www.homedepo	Yes
23	Steel Plates	1/8" 1018 Steel Plate	Purchased/Fabricated	In House	3	$0.00	$0.00	SJSU	Yes
24	T-Slotted Framing	-	Previous Project	80/20 Inc	3	$19.50	$0.00	Previous Project	Yes, Previous Group
25	T-Slotted Framing	Single Rail, Silver, 1-1/2" High x 1-1/2" Wide, Hollow	Purchased	McMaster Carr	3	$21.79	$65.37	https://www.mcmaster.	Yes
26	Corner Brackets	Corner Bracket for 1-1/2" High Single Rail, Silver	Purchased	McMaster Carr	6	$9.74	$58.44	https://www.mcmaster.	Yes
27	Corner Connectors	90 degree Inside Corner Connectors	Purchased	80/20 Inc	3	$6.30	$18.90	https://8020.net/shop/3	Yes
28	Connectors	22-18 AWG .250 Tab Fully Insulated Nylon M Disconnect, Pack of 10	Purchased	Frys	2	$2.79	$5.58	https://www.frys.com/p	Yes
29	Connectors	22-18 AWG Vinyl Butt Connectors, Pack of 20	Purchased	Frys	3	$2.49	$7.47	https://www.frys.com/p	Yes
30	Ring Terminals	12-10 AWG Insulated Ring Terminals #8 Stud, Pack of 14	Purchased	Frys	1	$2.49	$2.49	https://www.frys.com/p	Yes
31	FM Vinyl Bullet	22-18 AWG .157 Diameter Vinyl FM Bullet, Pack of 7	Purchased	Frys	2	$2.79	$5.58	https://www.frys.com/s	Yes
32	Vinyl M Bullet	22-18 AWG .157 Diameter Vinyl M Bullets, Pack of 19	Purchased	Frys	1	$2.79	$2.79	https://www.frys.com/p	Yes
33	Black Wires	16AWG 24' Black Primary Wire	Purchased	Home Depot	1	$5.97	$5.97	https://www.homedepo	Yes
34	Red Wires	14AWG 17' Red Primary Wire	Purchased	Home Depot	1	$5.97	$5.97	https://www.homedepo	Yes
35	Circuit Terminal Block	22-10 AWG 6-Circuit Terminal Block (1-Pack)	Purchased	Home Depot	1	$5.99	$5.99	https://www.homedepo	Yes
36	Iron Tip Cleaner	Hakko 599B Tip Cleaner	Purchased	Frys	1	$9.99	$9.99	https://www.frys.com/p	Yes
37	Soldering Iron	40-Watt LED Soldering Iron Kit	Purchased	Home Depot	1	$24.97	$24.97	https://www.homedepo	Yes
38	Solder	8 oz. Lead-Free Rosin Core Solder	Purchased	Home Depot	1	$15.47	$15.47	https://www.homedepo	Yes
39	FPVC White Boxes	Komatex FPVC White Sheets	Purchased	Home Depot	2	$7.99	$15.98	https://www.homedepo	Yes
40	Velcro	VELCRO® Brand Industrial Strength Tape, 4 Feet x 2 Inch, Black	Purchased	Orchard Supply Hardware	1	$9.99	$9.99	http://www.osh.com/O	Yes
41	Caulk Gun	Dripless Contractor Open Frame Caulk Gun, 10 Ounce	Purchased	Orchard Supply Hardware	1	$3.79	$3.79	http://www.osh.com/O	Yes
42	Retractable Knife	Stanley 10-099 Knife Classic Retractable	Purchased	Orchard Supply Hardware	1	$6.99	$6.99	http://www.osh.com/O	Yes
43	Latex Sealant	DAP Dynaflex 230 10.1 oz White Paintable Latex Window and Door Caulk	Purchased	Orchard Supply Hardware	1	$4.29	$4.29	http://www.osh.com/O	Yes
44	Socket Wrench Set, Hex Bit	Craftsman Socket Wrench Set, Hex Bit, Metric, 3/8 Inch Drive, 6 Piece	Purchased	Orchard Supply Hardware	1	$29.99	$29.99	http://www.osh.com/O	Yes
45	Sanding Paper	Sand Belt 220G 9"X11"	Purchased	Orchard Supply Hardware	1	$5.99	$5.99	https://www.osh.com/p	Yes
46	Spray Paint	Painters Touch Ptouch 2X Plus Sspr Gloss Brilliant Blue	Purchased	Orchard Supply Hardware	2	$4.39	$8.78	http://www.osh.com/O	Yes
47	Hex Bolt	Grade 5 Steel Hex Bolt Zinc	Purchased	Orchard Supply Hardware	3	$0.33	$0.99		Yes
48	Hex Bolt	Grade 5 Steel Hex Bolt Zinc	Purchased	Orchard Supply Hardware	3	$0.36	$1.08		Yes
49	Socket Cap Screw	Midwest Fastener 7/16-14 x 1 Socket Cap Screws	Purchased	Orchard Supply Hardware	6	$1.65	$9.90	http://www.osh.com/c/	Yes
50	Button Head Socket Cap Screws	Midwest Fastener 5/16-18 x 3/4 Button Head Socket Cap Screws	Purchased	Orchard Supply Hardware	8	$1.29	$10.32	http://www.osh.com/c/	Yes

51	Lock Washers	Midwest Fastener 16mm Lock Washers - Class 10	Purchased	Orchard Supply Hardware	3	$1.55	$4.65	http://www.osh.com/c/f	Yes
52	Socket Adapter	Craftsman Socket Adapter, 1/2 Inch Drive, 1/2 Inch Female x 3/8 Inch Male	Purchased	Orchard Supply Hardware	1	$5.99	$5.99	http://www.osh.com/O	Yes
53	Two-Sided Tape	Scotch 0.5-in x 6.25 Two-Sided Tape	Purchased	Orchard Supply Hardware	1	$3.98	$3.98	https://www.lowes.com	Yes
54	Resistors	10k resisrors	Purchased	HSC	4	$0.95	$3.80	Electronic Store	Yes
55	Solid Electric Wire	18 AWG Red Solid Electric Wire	Purchased	HSC	1	$11.69	$11.69	Electronic Store	Yes
56	Solid Electric Wire	18 AWG White Solid Electric Wire	Purchased	HSC	1	$11.69	$11.69	Electronic Store	Yes
57	Solid Electric Wire	20 AWG Red Solid Electric Wire	Purchased	HSC	1	$9.59	$9.59	Electronic Store	Yes
58	Solid Electric Wire	20 AWG Green Solid Electric Wire	Purchased	HSC	1	$9.59	$9.59	Electronic Store	Yes
59	Solid Electric Wire	20 AWG Black Solid Electric Wire	Purchased	HSC	1	$9.59	$9.59	Electronic Store	Yes
60	Solid Electric Wire	20 AWG Blue Solid Electric Wire	Purchased	HSC	1	$9.59	$9.59	Electronic Store	Yes
61	Screw	1/2" for stand offs	Purchased	HSC	1	$0.13	$0.13	Electronic Store	Yes
62	Diode	Diode for Arduino protection	Purchased	HSC	6	$0.40	$2.40	Electronic Store	Yes
63	Zenor Diode	Zenor Diode for protection of Motor Drive	Purchased	HSC	8	$0.14	$1.12	Electronic Store	Yes
64	Nuts	1/2" Nuts for stand offs	Purchased	HSC	2	$0.50	$1.00	Electronic Store	Yes
65	Electronic Screw	1" for securing electronic circuit platform on to wooden frame	Purchased	HSC	2	$0.50	$1.00	Electronic Store	Yes
66	Nuts	Nuts for 1" long electronic screw	Purchased	HSC	2	$0.60	$1.20	Electronic Store	Yes
67	Resistors	10k Resistor	Purchased	HSC	5	$1.08	$5.40	Electronic Store	Yes
68	1" Stand Offs	Electronic Board Stand Off	Purchased	HSC	8	$1.79	$14.32	Electronic Store	Yes
69	Solder Remover/Wires	Color Solid Electric Wires/Electronic components	Purchased	HSC	3	$11.01	$33.03	Electronic Store	Yes
70	Washer	#10 Zinc Washers	Purchased	Home Depot	1	$1.73	$1.73	Electronic Store	Yes
71	Screw	Machined Screw FL HD PH ZINK #10-24X1-1/4"	Purchased	Home Depot	4	$1.18	$4.72	Electronic Store	Yes
72	Battery	Duralast power sports Battery ETX9	Purchased	AutoZone	1	$98.07	$98.07	Auto Store	Yes
73	Battery Charger	Duralast 15amp Battery charger/maintainer DL-15D	Purchased	AutoZone	1	$79.99	$79.99	Auto Store	Yes
74	Electric Tape	Electric Tape	Purchased	O'Reilly Auto Parts	1	$2.50	$2.50	Auto Store	Yes
75	Masking Tape	Masking Tape	Purchased	O'Reilly Auto Parts	1	$6.54	$6.54	Auto Store	Yes
76	Scotch Tape	Scotch lg Mounting	Purchased	Staples	1	$10.70	$10.70	Office Store	Yes
						Total:	$817.88		
						Overall Total	$1,248.20		

Figure 26. Bill of materials for SAVAWT project

Section XI. References

1. Langer, E., Fogelquist, J., Gutierrez, I., Quinn, M., & Sura, A. (2017). Hybrid Solar-Wind System. Retrieved November 21, 2017.
2. Dry friction: There is no lubrication. Retrieved November 13, 2017. From http://ffden-2.phys.uaf.edu/212_spring2011.web.dir/Justin_Cannon/Body1.html
3. (n.d.). Retrieved November 21, 2017, from http://www.wind-power-program.com/popups/powercurve.htm
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5. Reza, A., Tolentino, G., & Toledo, M. (2015). Construction of a helical vertical axis wind turbine for electricity supply. *Computer-Aided Design and Applications*, *12*(sup1), 9-12.
6. Kavade, R. K., & Ghanegaonkar, P. M. (2017). Design and Analysis of Vertical Axis Wind Turbine for Household Application. *Journal of Clean Energy Technologies*, *5*(5).
7. Rashidi, M., Kadambi, J. R., Ebiana, A., Ameri, A., & Reeher, J. (2012, November). The effect of number of blades on the performance of helical-savonius Vertical-Axis wind turbines. In *ASME 2012 international mechanical engineering congress and exposition* (pp. 3199-3202). American Society of Mechanical Engineers.
8. Srinivasan, C., Ajithkumar, G. Arul, S., Arulprasath, G., Dharunbabu, T.M. (2017, April). Design of Combined Savonius-Darrieus Wind Turbine. *IOSR Journal of Mechanical and Civil Engineering, 14*(2), pp.60-70.
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11. https://forum.farmbot.org/t/why-use-expensive-t-slot-extrusion/1026/3
12. The Royal Academy of Engineering: Wind Turbine Power Calculations. Retrieved October 15, 2017 from, http://www.raeng.org.uk/publications/other/23-wind-turbine
13. https://www.adafruit.com/product/1733?gclid=Cj0KCQiA3dTQBRDnARIsAGKSflnYxnCUteYwLyj9b1d_rbA2hO-2XDk4HtZ0tSrkgJCrWwdnAuBJbpUaAjMUEALw_wcB
14. https://www.tomtop.com/p-h18439-400.html?currency=USD&Warehouse=CN&aid=gplausyly&mid=10000016597&utm_source=SEM&utm_medium=Google+PLA&utm_campaign=TT_PLA_US_YLY&utm_content=2945&gclid=CjwKCAiAvf3RBRBBEiwAH5XYqP7miG5XZcHQfkcJI6R21NkROK4g2U_AZC5FQ4La7UZjZu_6lXPRzhoCADMQAvD_BwE
15. https://8020.net/45-4545-lite.html#product_tabs_additional_tabbed

Section XII. Appendices

***Appendix A* -** Three Phase Permanent Magnet Vertical AC Wind Generator Turbine Datasheet

Model	300W	400W
Generator power	300w	400w
Wheel diameter	1.4m	1.4m
turbine height	1m	1m
Blades material	Casting aluminum alloy	Casting aluminum alloy
Number of blades	6	6
Rated wind speed	11.5m/s	11.5m/s
Start-up wind turbine	2m/s	2m/s
Survival wind turbine	45m/s	45m/s
Output voltage	12/24V	12/24V
Net Weight	27kg	28kg
Generator type	Three phase permanent magnet ac synchronous generator	
Control system	Electromagnet	
Speed regulation	Automatically adjust windward direction	
Lubrication way	Lubrication grease	
Working temperature	From -40□ to 80□	

Figure 27. *Turbine technical performance and geometric specifications*

FEATURES:

- Beautiful 3-phase Vertical Wind Generator
- Easy to install, use, and maintain
- Low vibration
- Automatically adjusts windward; good for areas with frequent changes in wind direction

TECHNICAL SPECS:

- Rated Power: 300 watts
- Output Voltage: 12 volts
- Min wind speed: 6.5 feet per second (2 meters per second)
- Max wind speed: 150 feet per second (11.5 meters per second)
- Weight: 61 pounds (28 kilograms)
- Wheel Diameter: 4.5 feet (1.4 meters)
- Min wind speed: 6.5 feet per second (2 meters per second)
- Rated wind speed: 38 feet per second (11.5 meters per second)
- Max wind Speed: 150 feet per second (45 meters per second)
- Number of blades: 7
- Blades Material: cast aluminum alloy
- Generator type: 3 phase
- Generator Case: casting aluminum alloy
- Control System: electromagnet
- Working temperature: -40Â°C - 80Â°C

Figure 28. *Suppliers detailed Turbine wind power and weight data sheet*

Appendix B - Polycrystalline Solar Panels Datasheet

Newpowa

NPA20-12 SLIM

Multi-Purpose Module

ELECTRICAL CHARACTERISTICS

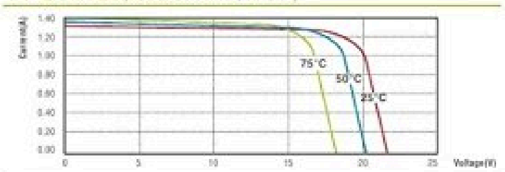
Type	NPA20-12 SLIM
Power Output(W)	20W
Voltage MPP Vmpp(V)	17.2V
Current MPP Impp(A)	1.16A
Voltage Open Circuit Voc(V)	21.6V
Short Circuit Current Isc(A)	1.31A
Temperature Coefficient Of Voc	-(80±10)mV/°C
Temperature Coefficient Of Isc	(0.065±0.015)%/°C
Temperature Coefficient Of Power	-(0.5±0.05)%/°C
NOCT (Air 20°C; Sun 0.8kW/m² wind 1m/s)	47±2°C

STC: 1000W/m² Irradiance, 25°C module temperature, AM1.5g spectrum according to EN 60904-3

MECHANICAL CHARACTERISTICS

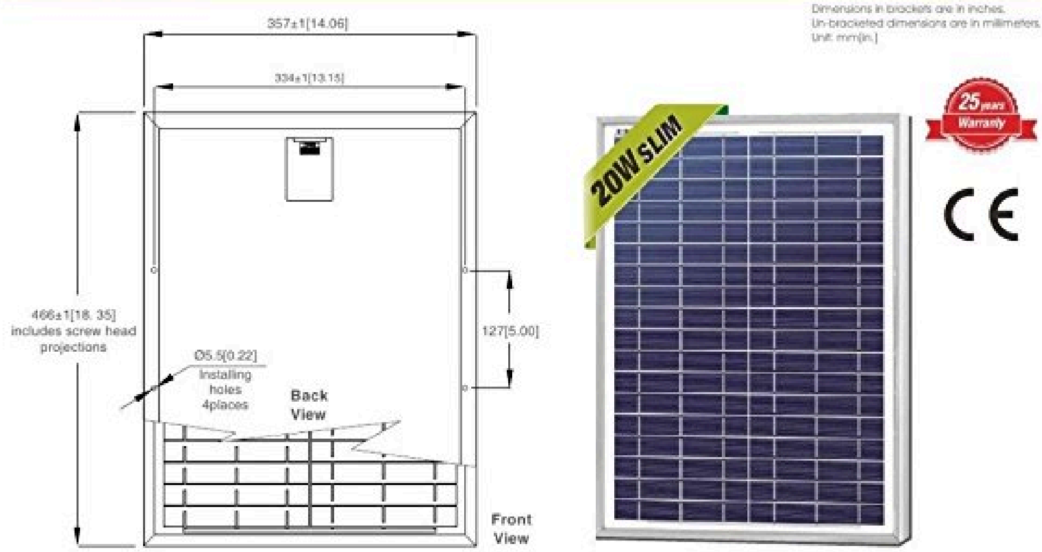
Cells	Polycrystalline Silicon
No. Of Cells And Connections	36(2X18)
Module Dimension(mm/in.)	466[18.35]x357[14.06]x23[0.91]
Weight(kg/lbs)	1.92[4.23]
Packing Information(mm/in.)	490[19.29]x190[7.48]x385[15.16]/(5pcs/ctn)

I-V CURVES (Irradiance: AM1.5, 1km/m²)



MODULE DIAGRAM

Dimensions in brackets are in inches.
Un-bracketed dimensions are in millimeters.
Unit: mm[in.]



**Specications subject to technical changes and tests. NEWPOWA reserves the right of nal interpretation.*

support@newpowa.com I www.newpowa.com

Figure 29. *Newpowa 20W Polycrystalline Solar Panel Technical Specifications*

Appendix C - Arduino Mega 2560 Datasheet and Diagram

Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Power

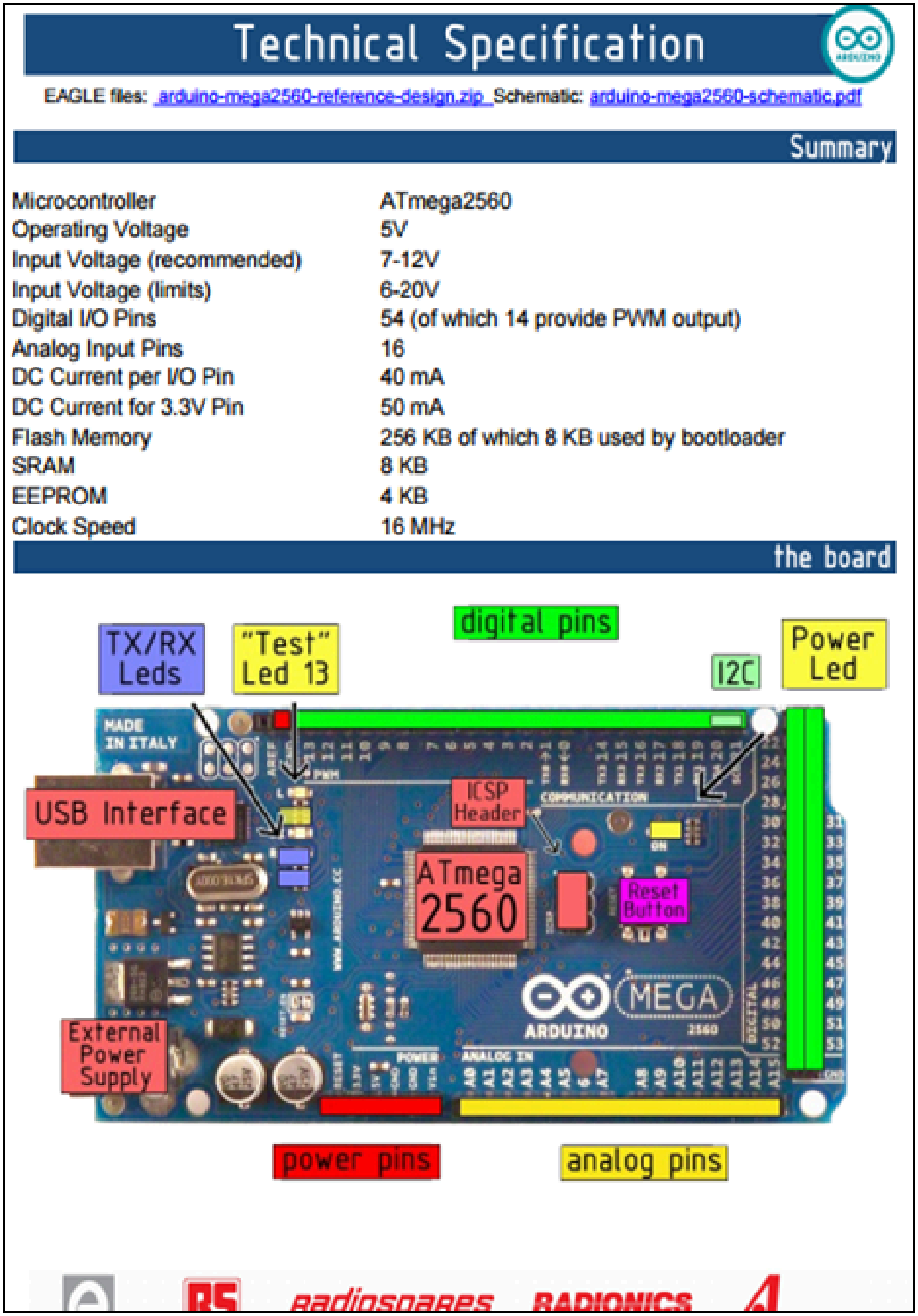
The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

Figure 30. *Technical specifications for the Arduino ATmega2560*



Technical Specification

EAGLE files: arduino-mega2560-reference-design.zip Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

the board

Figure 31. *Pins and ports available with Arduino ATmega2560*

Appendix D - Anemometer Datasheet

DESCRIPTION

An anemometer is a device used for measuring wind speed, and is a common weather station instrument. This well made anemometer is designed to sit outside and measure wind speed with ease.

To use, connect the black wire to power and signal ground, the brown wire to 7-24VDC (we used 9V with success) and measure the analog voltage on the blue wire. The voltage will range from 0.4V (0 m/s wind) up to 2.0V (for 32.4m/s wind speed). That's it! The sensor is rugged, and easy to mount. The cable can easily disconnect with a few twists and has a weatherproof connector.

Note: As of 11/06/2014, shipping weight has been changed on this product to match UPS' new dimensional weight regulations.

Figure 32. *Anemometer intended to measure wind speed*

TECHNICAL DETAILS -

Dimensions:

- Height (base to center): 105mm / 4.1"
- Center out to Cup: 102mm / 4"
- Arm Length: 70mm / 2.8"
- Weight: 111.8g

Wire Dimensions:

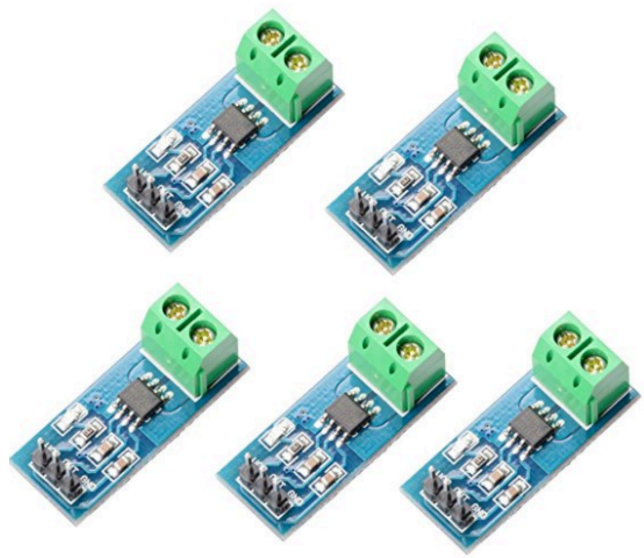
- Wire Length: 99cm / 39"
- Plug Length: 30mm / 1.2"
- Diameter (thickness): 4.8mm / 0.2"

Specifications

- Output: 0.4V to 2V
- Testing Range: 0.5m/s to 50m/s
- Start wind speed: 0.2 m/s
- Resolution: 0.1m/s
- Accuracy: Worst case 1 meter/s
- Max Wind Speed: 70m/s
- Connector details: Pin 1 - Power (brown wire), Pin 2 - Ground (black wire), Pin 3 - Signal (blue wire), Pin 4 not connected

Figure 33. *Technical specifications provided by Anemometer supplier*

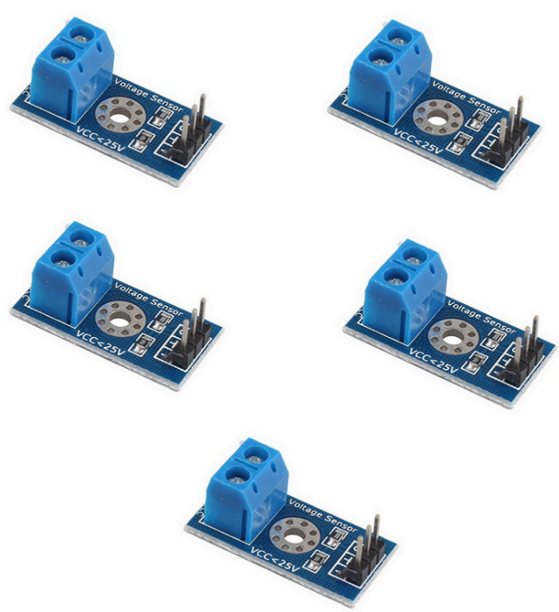
Appendix E - Current and Voltage Sensors Datasheets



Product description

Specification:
Model : ACS712
Range Current : 20A;Size : 31 x 12mm/ 1.2" x 0.47" (L*W)
Material : Plastic, Electronic Part
Net Weight : 5g

Figure 34. *Current sensors specifications*



Product description

100% brand new and high quality
Quantity:5pcs
Size: 28mm¡Á14mm(approx)
This module is based on principle of resistive voltage divider design, can make the red terminal connector input voltage to 5 times smaller.
Arduino analog input voltages up to 5 v, the voltage detection module input voltage not greater than 5Vx5=25V (if using 3.3V systems, input voltage not greater than 3.3Vx5=16.5V).
Arduino AVR chips have 10-bit AD, so this module simulates a resolution of 0.00489V (5V/1023), so the minimum voltage of input voltage detection module is 0.00489Vx5=0.02445V.
Voltage input range : DC0-25 V
Voltage detection range : DC0.02445 V-25 V
Voltage analog resolution : 0.00489 V
Output Interface :"+ " connected 5/3.3V, "-" connected GND, "s" connected Arduino AD pins
DC input interface : red terminal positive with VCC, negative with GND
By 3P connector, connect this module with the expansion of board Arduino, not only makes it easier for you to detect voltage battery, can also use the IICLCD1602 LCD to display voltage.

Packing List:
5PCS Max 25V Voltage Detector Range 3 Terminal Sensor Module for Arduino

Figure 35. *Voltage sensors specifications*

Appendix F - *Duralast Gold Power Sports Battery ETX9 Specifications and Datasheet*

Product Details

Part Number:	ETX9
Weight:	7.73lbs
	AGM
	12 Volt
	8 Ah
	.8 Amp
Amp-hour:	8
Application:	Power Sports
Battery Height:	107 mm - 4 3/16 in
Battery Length:	150 mm - 5 7/8 in
Battery Standard Group:	Battery Council International (BCI)
Battery Voltage:	12
Battery Width:	87 mm - 3 7/16 in
Cold Cranking Amps (CCA):	120
Core Charge Applicable:	Yes
Positive Terminal Side:	Left
Power Sport Battery Type:	BTX9-BS
Shipping Information:	Overnight and Two Day shipping are not available for PO Box, APO/FPO/DPO or US Territory addresses.

Figure 36. *Battery specifications*

Appendix G - Frictionless Flanged Ball Bearing

F6907ZZ Flanged Ball Bearing
35mm x 55mm x 10mm
One Bearing

F6907ZZ Flanged Ball Bearing, Bearing is made of Chrome Steel, bearing is metal shielded from both sides, inner diameter is 35mm, outer diameter is 55mm and width is 10mm

- Item: F6907ZZ Flanged Ball Bearing
- Type: Deep Groove Ball Bearing
- Closures: Metal Shielded
- Size: 35mm x 55mm x 10mm
- Inner Diameter: 35mm
- Outer Diameter: 55mm
- Width: 10mm
- Quantity: One Bearing

F6907ZZ Flanged Bearing 35x55x10 Shielded Bearings

F6907ZZ

Figure 37. *Flanged ball bearing specifications*

Appendix H - T-Slotted Framing

T-Slotted Framing

Single Rail, Silver, 1-1/2" High x 1-1/2" Wide, Hollow

Length, ft.
✓ 3

Each

ADD TO ORDER

In stock
$19.60 Each
47065T102

Rail	
Height	1 1/2"
Width	1 1/2"
Rail Construction	Hollow
Color	Silver
Finish	Anodized
Material	6360 Aluminum
Temper	T6
T-Slot Width	0.32"
Center Hole Diameter	0.26"
Rail Type	Standard
Rail Style	Single
Framing Type	T Slot
T-Slot Framing Component	Rail
Length	3 ft.

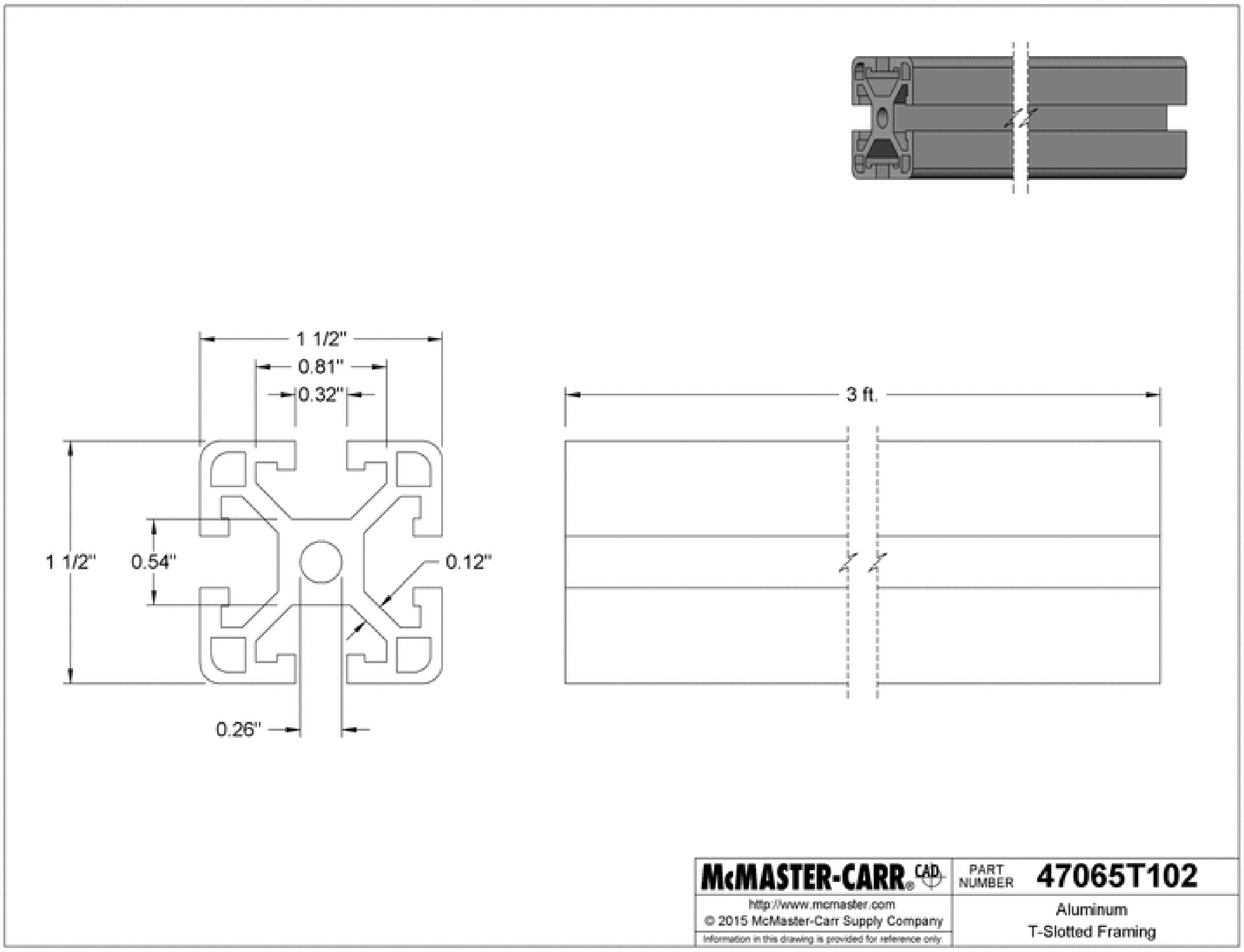


Figure 38. *T-Slot Aluminum Frame Technical Specifications*

Appendix I - CAD Models

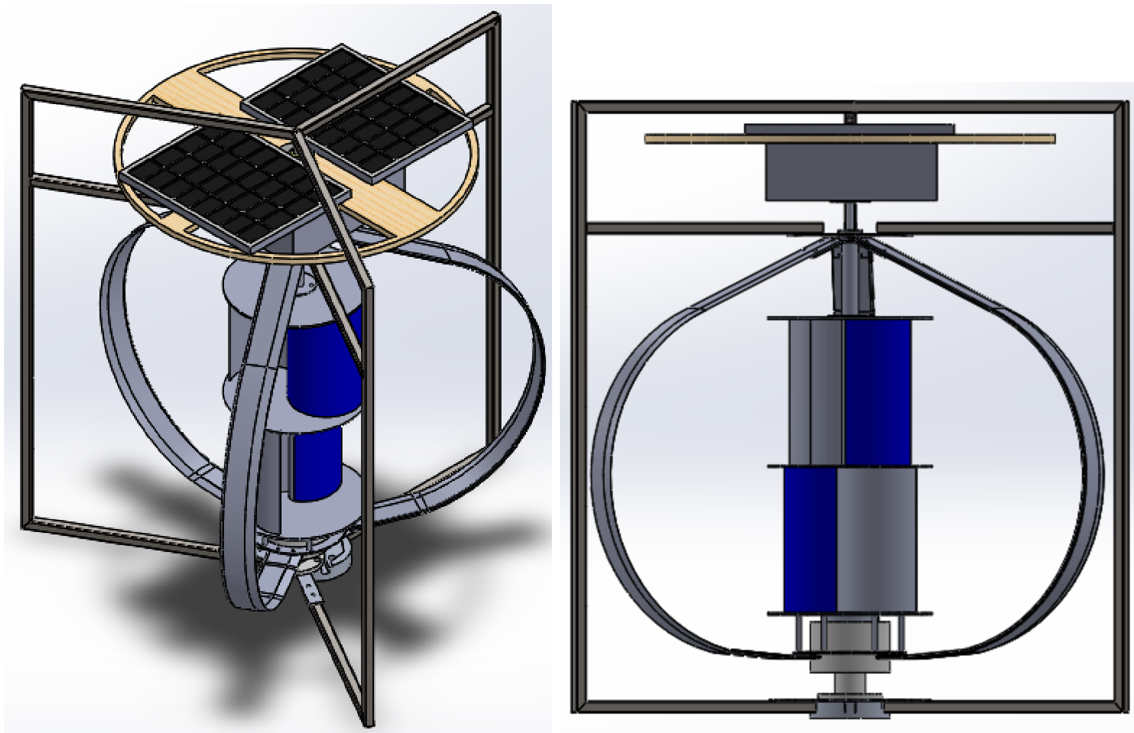


Figure 39. *Final CAD Design — **left:** Isometric View, **right:** Front View*

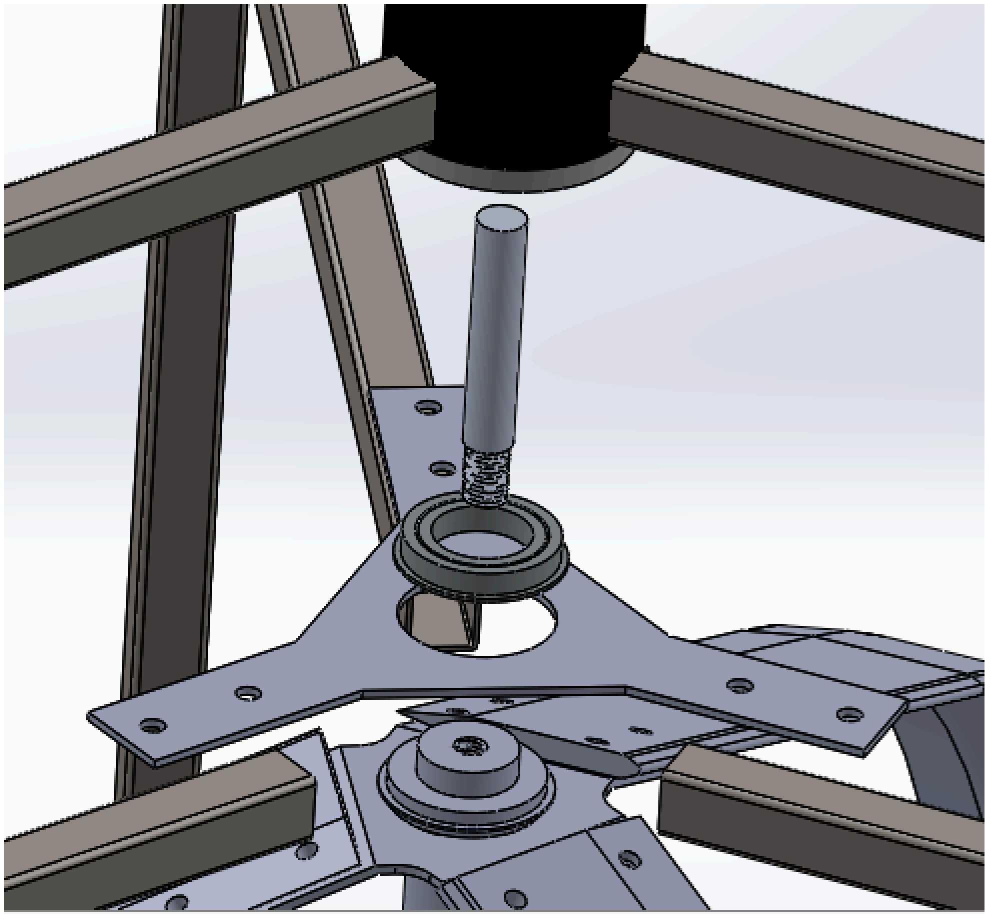


Figure 40. *Frame-Turbine-Motor Connection Exploded View*

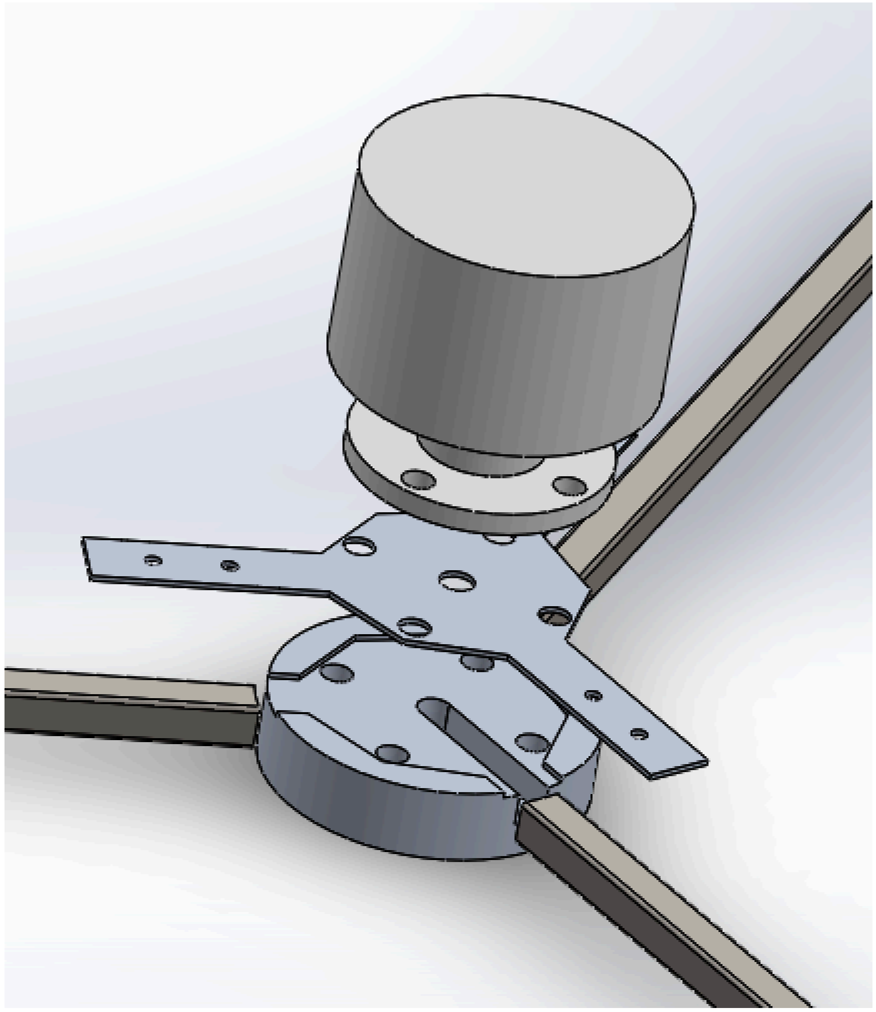


Figure 41. *Block-Frame-Turbine Connection Exploded View*

Appendix J - Fabricated Part Drawings

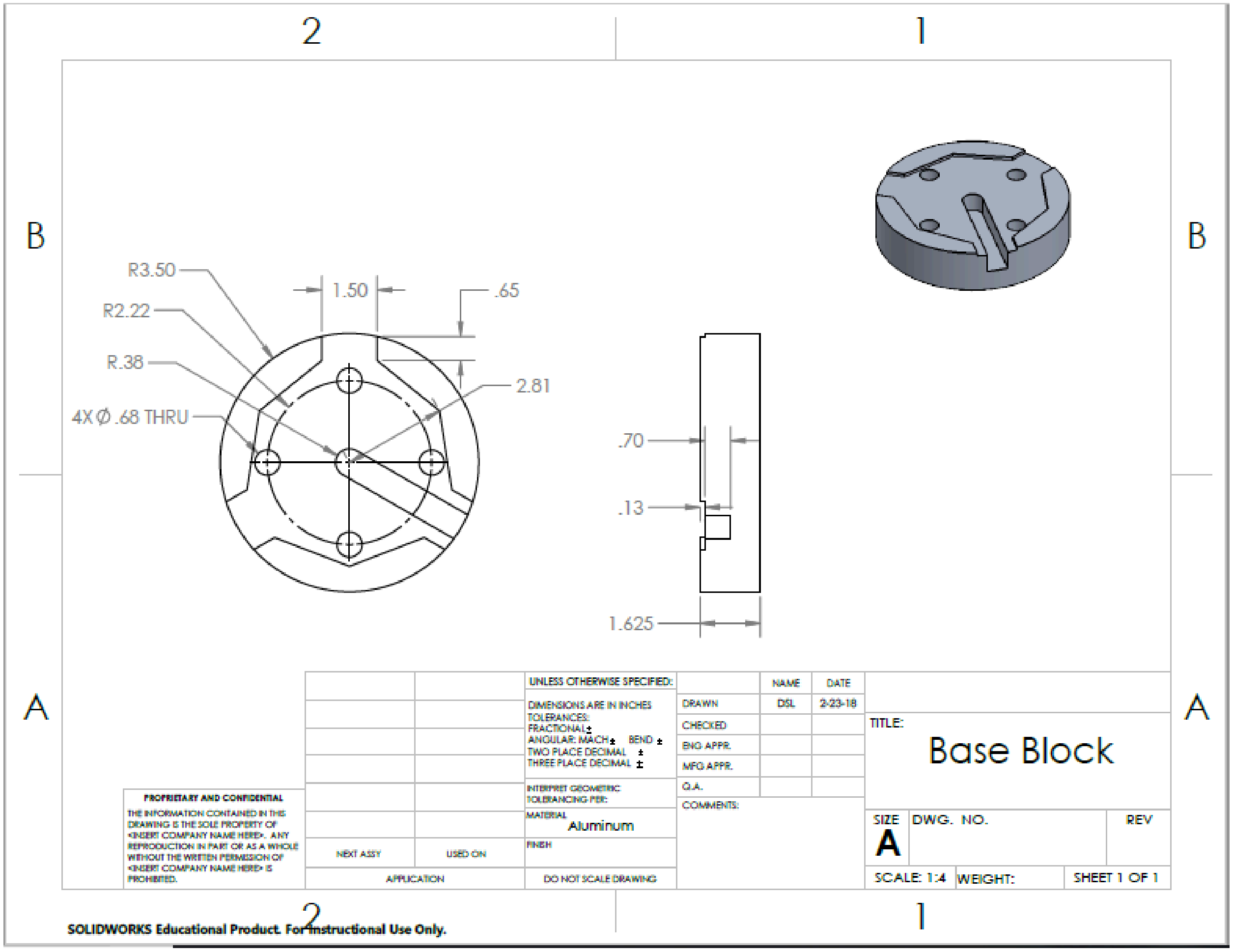


Figure 42. *Base Block Drawing*

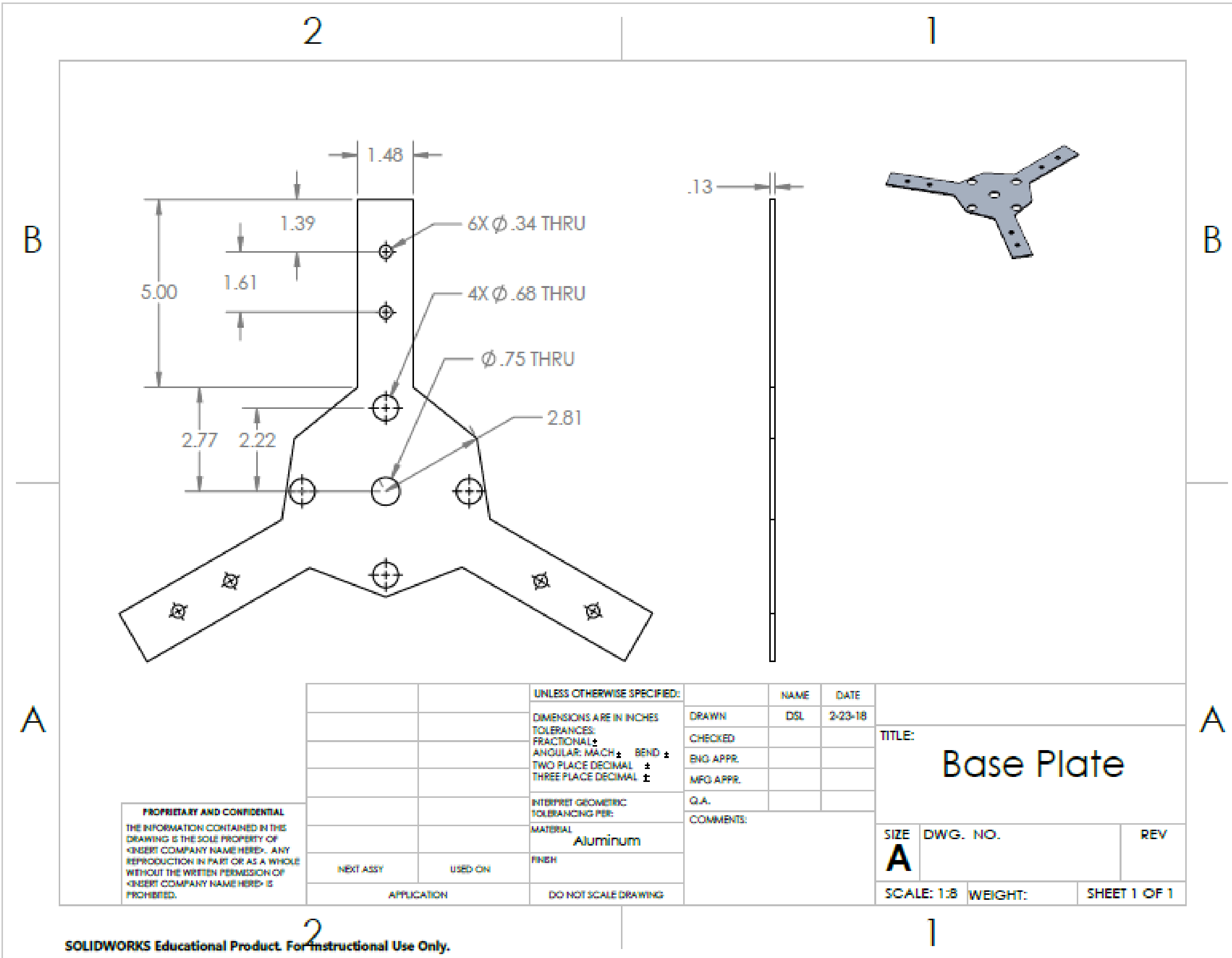


Figure 43. *Base Plate Drawing*

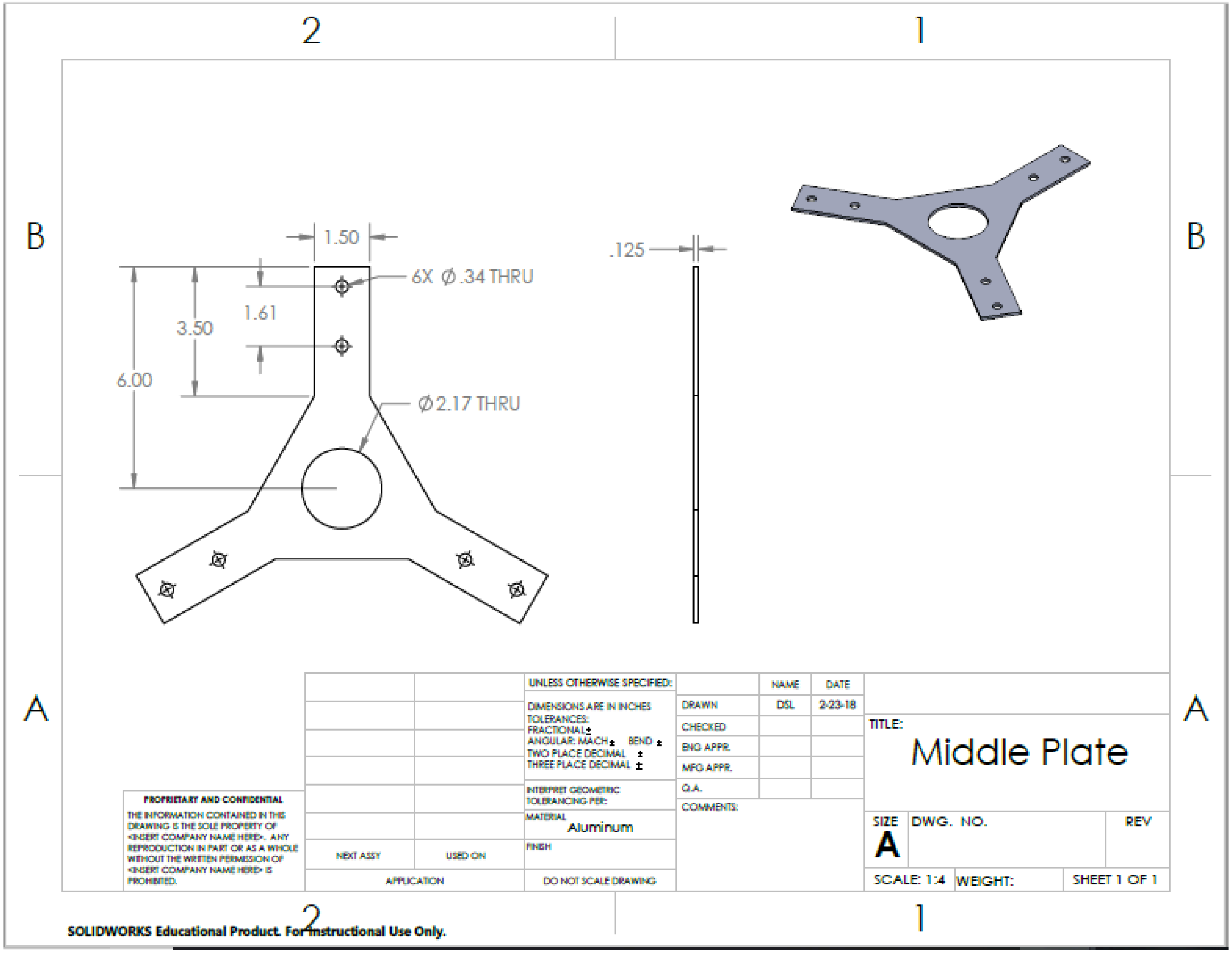


Figure 44. *Middle Plate Drawing*

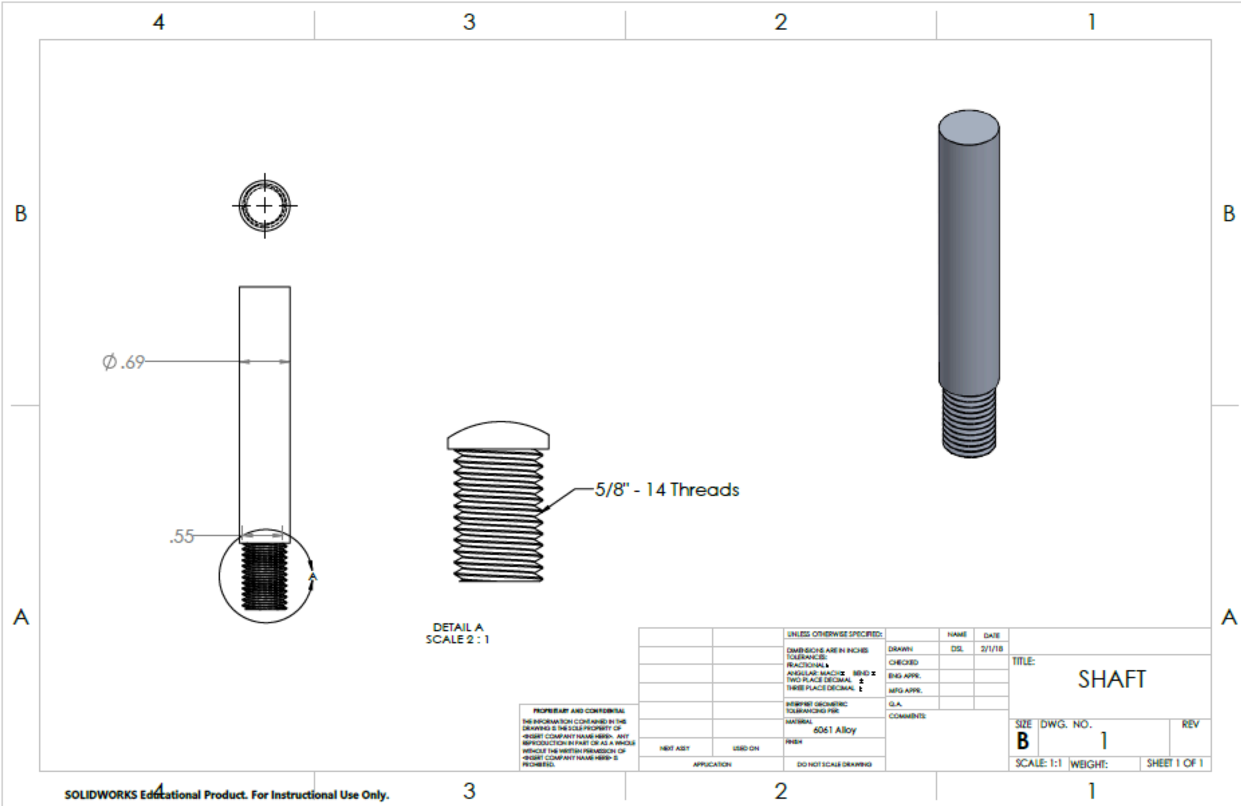


Figure 45. *Shaft Drawing*

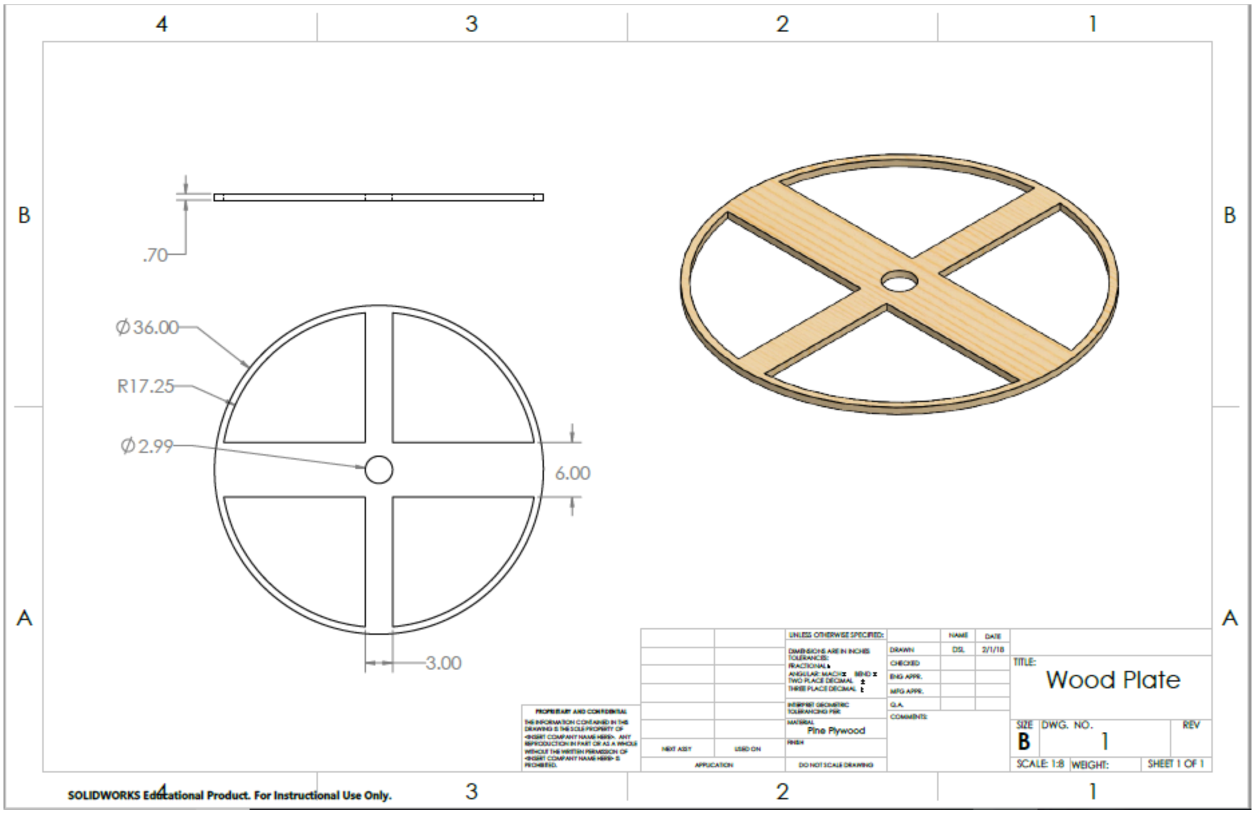


Figure 46. *Wood Plate Drawing*

Appendix K - Stress Analysis for Shaft

San Jose State University
1 Washington Sq
San Jose, CA 95192

Simulation of New Shaft

Date: Friday, May 4, 2018
Designer: Diana Lee
Study name: Static 2
Analysis type: Static

Table of Contents

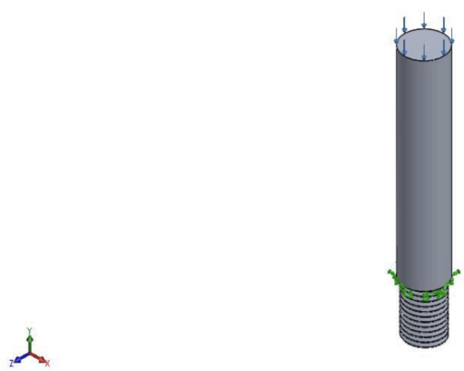
Description

Shaft connecting turbine top nut and bearing to motor bearing

Assumptions

Comments:
Weight of top assembly = 20 lbs

Model Information



Model name: New Shaft
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	**Mass:0.0674324 kg** **Volume:2.49751e-005 m^3** **Density:2699.99 kg/m^3** **Weight:0.660837 N**	**C:\Users\krngi\Documents\Turbine SolidWORKS\New Shaft.SLDPRT** May 04 11:47:01 2018

Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (c:\users\krngi\documents\dianalee_hw2_4-15\ch 4\solution database files)

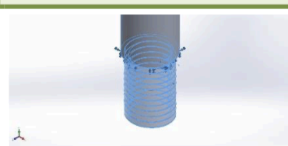
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/mm^2 (MPa)

Material Properties

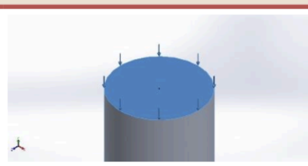
Model Reference	Properties		Components
	**Name:**	6061 Alloy	SolidBody 1(Cut-Extrude1)(New Shaft)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Unknown	
	Yield strength:	55.1485 N/mm^2	
	Tensile strength:	124.084 N/mm^2	
	Elastic modulus:	69000 N/mm^2	
	Poisson's ratio:	0.33	
	Mass density:	2.7 g/cm^3	
	Shear modulus:	26000 N/mm^2	
	Thermal expansion coefficient:	2.4e-005 /Kelvin	
Curve Data:N/A			

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.00141713	88.002	-8.687e-005	88.002
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 88 N

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	2.92404 mm
Minimum element size	2.92404 mm
Mesh Quality Plot	High

Mesh information - Details

Total Nodes	19097
Total Elements	12023
Maximum Aspect Ratio	32.431
% of elements with Aspect Ratio < 3	84
% of elements with Aspect Ratio > 10	5.03
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:05
Computer name:	

Resultant Forces

Reaction forces

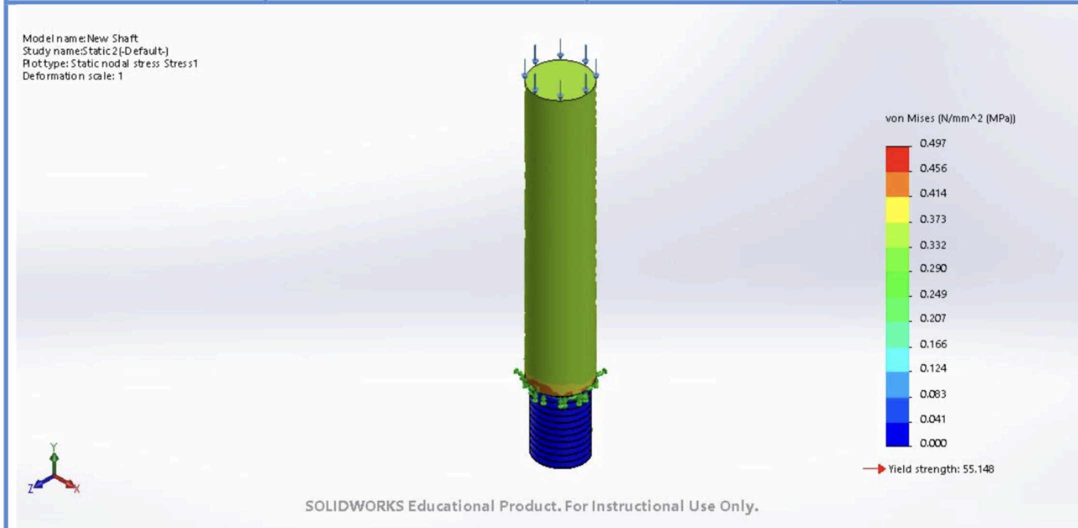
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00141713	88.002	-8.687e-005	88.002

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

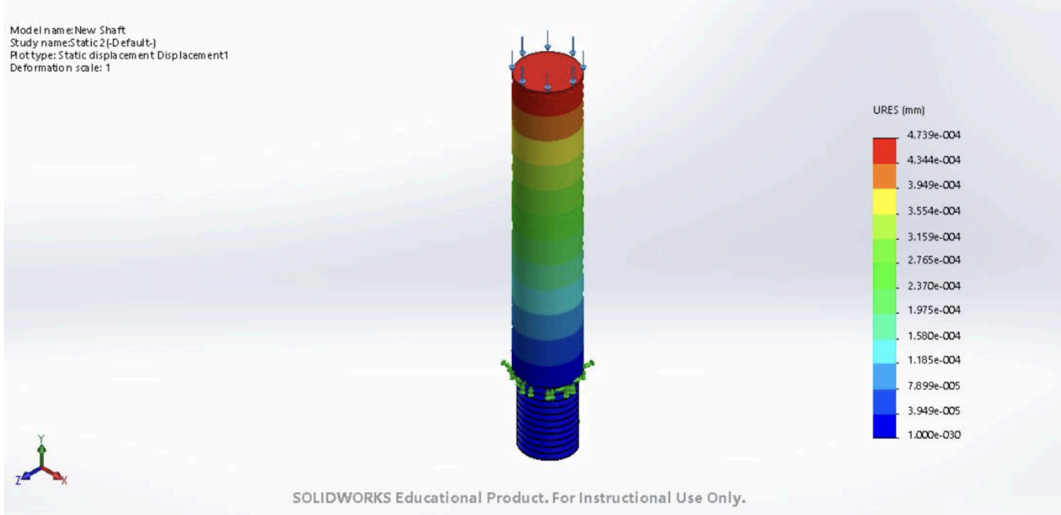
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000 N/mm^2 (MPa) Node: 677	0.497 N/mm^2 (MPa) Node: 2823



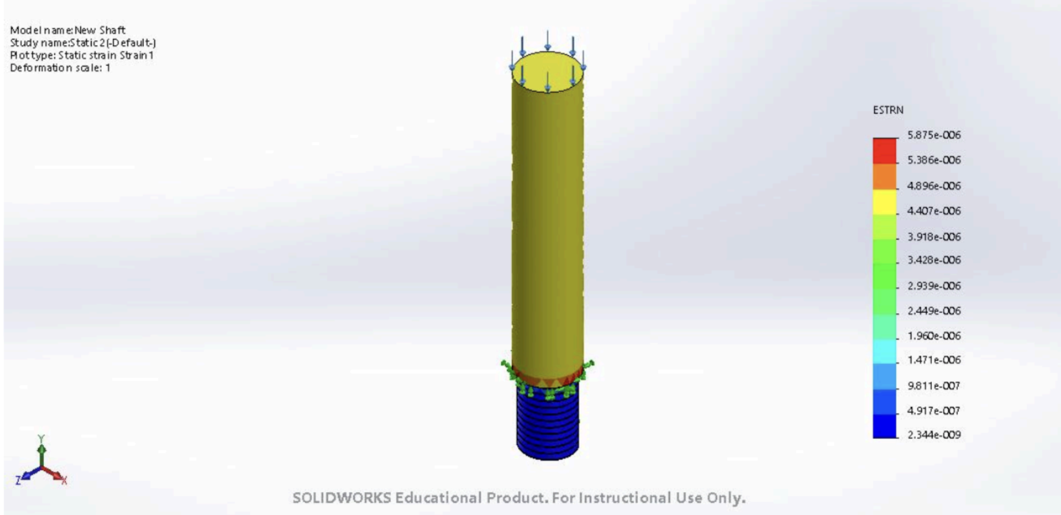
New Shaft-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+000mm Node: 1	4.739e-004mm Node: 2802



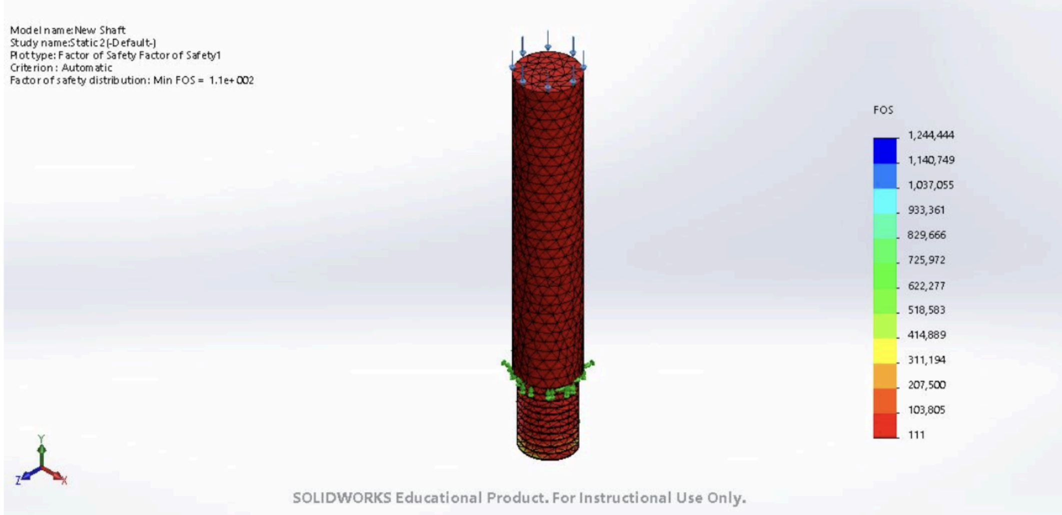
New Shaft-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.344e-009 Element: 6529	5.875e-006 Element: 9198



New Shaft-Static 2-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	111 Node: 2823	1,244,444 Node: 677



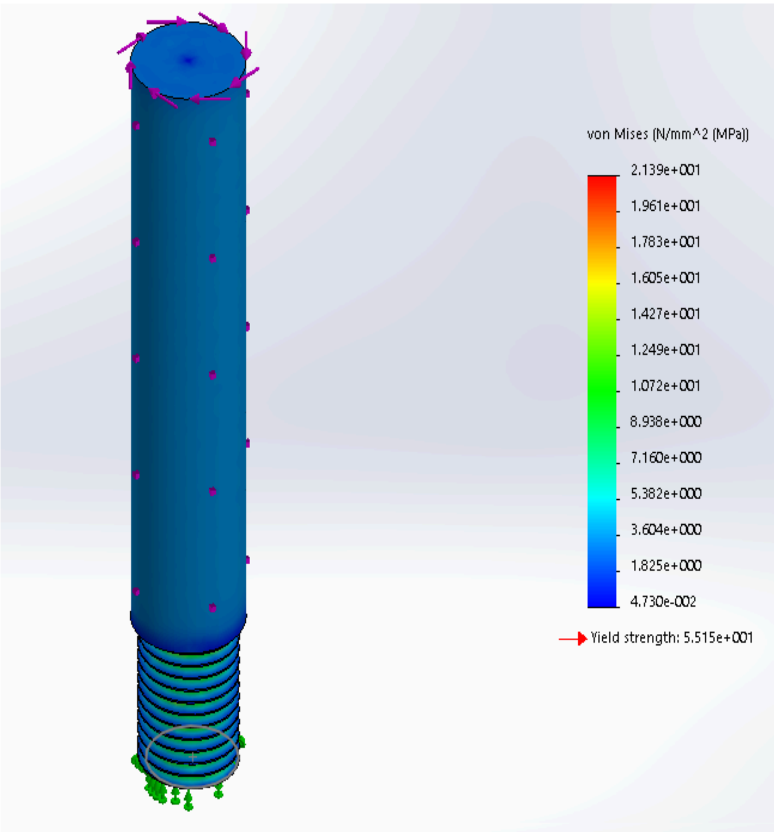
New Shaft-Static 2-Factor of Safety-Factor of Safety1

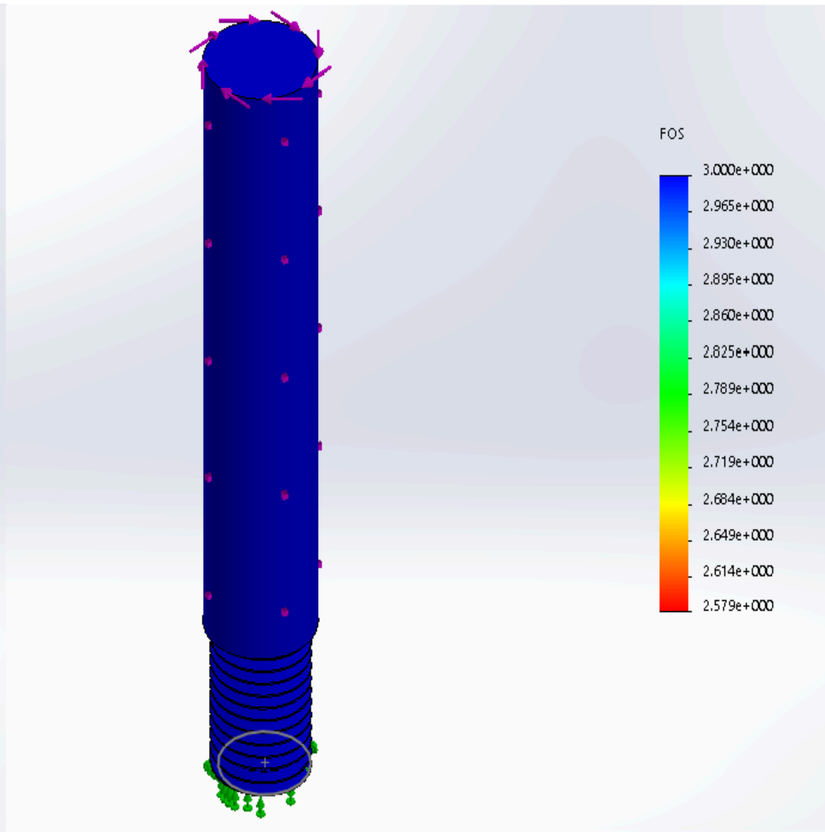
Conclusion

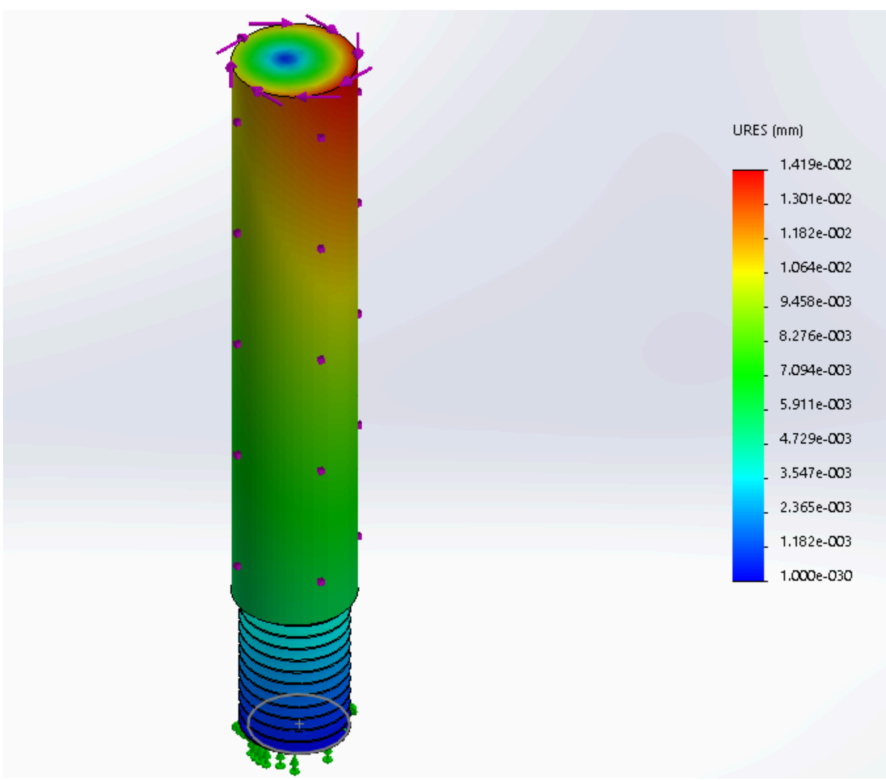
Comments:

The shaft has a high safety factor and will not fail

Appendix L - Torsional Analysis for Shaft (Von Mises Stress, Safety Factor, and Displacement)







Appendix M - Manta 12V Motor Specifications

Specifications:

- *Motor length 3.5" diameter / 6" long.*
- *7.5" over all length including shaft*
- *66 peak amps at full load for this 12 volt model (800W peak)*
- *12mm shaft with 1.75 pitch threads with flat slot at shaft tip.*
- *Shaft is 1.5" long with 3/4" threaded end (12mm/1.75 pitch)*
- *Torque 1.55 Ft. lb. or 2.1 Nm*
- *Two 5/16" extra large mounting holes on the front of the motor.*
- *5/16" NCT mounting holes are 2.874" from center to center (74mm)*
- *2999 rpm @ 12V / continuous duty at 75% of peak wattage.*
- *Heavy 10 AWG wire to handle the amps with water resistant rubber boot.*
- *A put-up and forget design! Expect decades of dependable service life.*
- *Rain, ice and weather resistant electronics in sealed case (not for under water)*
- *Long life graphite brushes. We sell replacement brushes and bearings.*
- *Works for both CW or CCW rotations. (over heat senor not active on this model)*
- *Epoxy/Lam rotor efficiency = 94.6% (Brushed motors convert more electricity into usable horsepower)*
- *Weighs ONLY 8.5 lbs. (Almost 100 Watts Per Pound !)*
- *Can be used as a generator, makes power when turned (Requires 100 amp blocking diode)*

Appendix N **-** Arduino Code for Top Circuit

```
/*
voltage measurement _with voltage sensor
*/
#include <SPI.h>
#include <SD.h>

// voltage
// motor //
int analogInputv = A1;// voltage sensor analog input m2
float voutv1 = 0.0;// voltage output var
float vinv1 = 0.0; // voltage measure var
float R1 = 30000.0; //  resistor 1
float R2 = 7500.0; // resistor 2
int valuev1 = 0;// converted voltage var

int analogInputm1 = A2;// voltage sensor analog input m1
float voutv2 = 0.0;// voltage output var
float vinv2 = 0.0; // voltage measure var
int valuev2 = 0;// converted voltage var

// current

int analogInput = A0;
float value5=0;
```

```
//SD
const int chipSelect = 4;
// motor control via BT
int motor_contpin3 = 3; // pin S1 on SyRen 10A Regenerative Motor Drive
int state;
int flag=0;

// solar panel//
//voltage//
int analogInputsv = A3; // voltage sensor analog input m1
float voutsv = 0.0;// voltage output var
float vinsv= 0.0; // voltage measure var
int valuesv = 0.0;// converted voltage var

//curent//
int analogInputsc = A4;
float values=0;

void setup(){
   // motor//
  // voltage
   pinMode(analogInputv, INPUT);
   pinMode(analogInputm1, INPUT);
  // curent
     pinMode(analogInput, INPUT);
  // motor cont
    pinMode(motor_contpin3, OUTPUT);
   Serial.begin(9600);

   //solar panel//
     // voltage
   pinMode(analogInputsv, INPUT);
  // curent
     pinMode(analogInputsc, INPUT);

// SD initialization
while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port only
 }
Serial.print("Initializing SD card...");

  // see if the card is present and can be initialized:

  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    while (1);
  }
  Serial.println("card initialized.");
  File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);

if(dataFile){

Serial.println("Writing to testLog.txt...");
```

```
Serial.print("Current motor (amp)=");
Serial.print("\t");
Serial.print("Voltage motor(V) =");
Serial.print("\t ");
Serial.print(" Power input (watt)=");
Serial.print("\t ");
Serial.print("Voltage solar panel(V) =");
Serial.print("\t");
Serial.print("Current solar panel (amp) =");
Serial.print("\t ");
Serial.println("motor status ");
Serial.println("\t ");

dataFile.println("Initializing data log for wind speed");
dataFile.println("card initialized.");
dataFile.print("Current motor (amp)=");
dataFile.print("\t Voltage motor(V)=");
dataFile.print("\t Power input(watt)=");
dataFile.print("\t Voltage solar panel(V)=");
dataFile.print("\t Current solar panel(amp)=");
dataFile.println("\t motor status ");
dataFile.println("\t ");
//close the file writer
dataFile.close();
}else{
Serial.println("error opening text file");
}}



void loop(){
   // motor control
 if(Serial.available() > 0){
state = Serial.read();
flag=0;
}
// if the state is '0' the DC motor will turn off
if (state == '0') {
digitalWrite(motor_contpin3, LOW); // set pin 2 on L293D low
if(flag == 0){
 Serial.print("\t\t\t\t" );
Serial.println("Motor: off");
// Status update about motor speed to file
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){
dataFile.print("\t\t\t\t");
dataFile.println("Motor: off");
dataFile.println("\r\n");
//close the file writer
dataFile.close();
}
flag=1;
}
}
```

```
// if the state is '1' the motor will turn left
else if (state == '1')
{
analogWrite(motor_contpin3, 64);
if(flag == 0){
Serial.print("\t\t\t\t" );
Serial.println("Motor: 25% of max speed-Right");
// Status update about motor speed to file
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){
dataFile.print("\t\t\t\t");
dataFile.println("Motor: 25% of max speed-Right");
dataFile.println("\r\n");
//close the file writer
dataFile.close();
}
flag=1;
}
}

// if the state is '2' the motor will turn left
else if (state == '2')
{
analogWrite(motor_contpin3, 127);
if(flag == 0){
Serial.print("\t\t\t\t" );
Serial.println("Motor: 50% of max speed-Right");
// Status update about motor speed to file
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){
dataFile.print("\t\t\t\t");
dataFile.println("Motor: 50% of max speed-Right");
dataFile.println("\r\n");
//close the file writer
dataFile.close();
}
flag=1;

}
}
// if the state is '3' the motor will turn right
else if (state == '3')
{
analogWrite(motor_contpin3, 191);
if(flag == 0){
Serial.print("\t\t\t\t" );
Serial.println("Motor: 75% of max speed-Right");
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){
dataFile.print("\t\t\t\t");
dataFile.println("Motor: 75% of max speed-Right");
dataFile.println("\r\n");
//close the file writer
```

```
dataFile.close();
}
flag=1;
}
}
// if the state is '4' the motor will turn left
else if (state == '4') {
digitalWrite(motor_contpin3, HIGH); // set pin 2 on L293D high
if(flag == 0){
Serial.print("\t\t\t\t" );
Serial.println("Motor: 100% of max speed-Right");
// Status update about motor speed to file
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){
dataFile.print("\t\t\t\t");
dataFile.println("Motor: 100% of max speed-Right");
dataFile.println("\r\n");
//close the file writer
dataFile.close();
}
flag=1;
}
}
                    // motor//
   // voltage
   valuev1 = analogRead(analogInputv);// read analog in m2
   voutv1 = (valuev1 * 5.0) / 1024.0; // convert to 0-5 voltage of reading of m2
   vinv1 = voutv1 / (R2/(R1+R2)); // convert to actual voltage of reading of m2
   valuev2 = analogRead(analogInputm1);// read analog in m1
   voutv2 = (valuev2 * 5.0) / 1024.0; // convert to o-5 voltage of reading of
   vinv2 = voutv2 / (R2/(R1+R2)); //convert to actual voltage of reading of m1
   float voltage_sup_mo =vinv1-vinv2; // voltage difference between m2 and m1 supply to motor

   // current
  float value = analogRead(analogInput);// analog current input
  float value1 = (101-value);// calibrating to zero
  if(value1<=-1)
  {value1=0;}
  //Serial.print( value1,4);
   // Serial.print("\t");
  float value2= value1*5;
  //Serial.print(value2);
   //Serial.print("\t");
  float value3= value2/1023; // converting analog input to 1023
 // Serial.print(value3);
  // Serial.print("\t");
  float value4= value3;
  // Serial.print(value4);
   // Serial.print("\t");
   float value5= (value4/0.135 );// measured current input to motor

                     // Solar panel//
  // voltage
   valuesv = analogRead(analogInputsv);// read analog in m2
```

```
  voutsv = (valuesv * 5.0) / (1023.0); // convert to 0-5 voltage of reading of m2
  vinsv= (voutsv / (R2/(R1+R2))); // convert to actual voltage of reading of
   // current
 float valuesc = analogRead(analogInputsc);// analog current input
 float valuesc1 = (101-valuesc);// calibrated to zero
 if(valuesc1<=-1)
 {valuesc1=0;}
 //Serial.print( value1,4);
  // Serial.print("\t");
 float valuesc2= analogInputsc*5;
 //Serial.print(value2);
  //Serial.print("\t");
 float valuesc3= valuesc2/1023; // converting analog input to 1023
// Serial.print(value3);
 // Serial.print("\t");
 float valuesc4= valuesc3;
 // Serial.print(value4);
  // Serial.print("\t");
  float valuesc5= (valuesc4/0.293 );// measured current input to motor

                //value sirial prints //
Serial.print(value5,5);// print to serial monitor of measured current
Serial.print("\t\t\t\t");
Serial.print(voltage_sup_mo,2);// print to serial monitor of measured voltage
float P = voltage_sup_mo*value5;// power delivered to motor
Serial.print("\t\t\t");
Serial.print(P);
Serial.print("\t\t\t");
Serial.print( vinsv,5);
Serial.print("\t\t\t");
Serial.println(valuesc5,5);
            //Print measured values to SD card//

// SD card
File dataFile = SD.open("POWERLOG.txt", FILE_WRITE);
if(dataFile){

dataFile.print(value5, 3); //Print current value to file
dataFile.print("\t\t\t\t ");
dataFile.print(voltage_sup_mo); //Print voltage value to file
dataFile.print("\t\t\t ");
dataFile.print(P, 3); // Print Power value to file
dataFile.print("\t\t\t ");
dataFile.print(vinsv,5);
dataFile.print("\t\t\t");
dataFile.print(valuesc5,5);
dataFile.println("\r\n");
//close the file writer
dataFile.close();


delay(1000);}
}
```

Appendix O **-** Arduino Code for Bottom Circuit

```
int analogInputv = A1;// voltage sensor analog input
float voutv1 = 0.0;// voltage output var
float vinv1 = 0.0; // voltage measure var
float R1 = 30000.0; //  resistor 1
float R2 = 7500.0; // resistor 2
int valuev1 = 0;// converted voltage var
// current
int analogInput = A0;
float value5=0;
// wind speed
const int sensorPin = A2; //Defines the pin that the anemometer output is connected to
float sensorValue_wind = 0; //Variable stores the value direct from the analog pin
float sensorVoltage = 0; //Variable that stores the voltage (in Volts) from the anemometer
float windSpeed = 0; // Wind speed in meters per second (m/s)
double x = 0;
double y = 0;
float voltageConversionConstant = .004882814; //constant maps the value provided from the analog pin, which
ranges from 0 to
//1023, corresponding to 0V to 5V
//Anemometer Technical Variables
//The following variables correspond to the anemometer sold by Adafruit,
float voltageMin = .05; // Minimum output voltage from anemometer in mV.
float windSpeedMin = 0; // Wind speed in meters/sec corresponding to minimum voltage
float voltageMax = 2.0; // Maximum output voltage from anemometer in mV.
float windSpeedMax = 32; // Wind speed in meters/sec corresponding to maximum voltage
void setup() {
  // put your setup code here, to run once:
pinMode(analogInputv, INPUT);
     pinMode(analogInput, INPUT);
       pinMode(sensorPin, INPUT);
   Serial.begin(9600);
   Serial.println("Writing to testLog.txt...");
Serial.print("Current (amp)=");
Serial.print("\t");
Serial.print("Voltage(V) =");
Serial.print("\t windspeed (m/s)=");
Serial.println("\t ");
}

void loop() {
  // put your main code here, to run repeatedly:
   // voltage
   valuev1 = analogRead(analogInputv);// read the value at analog input
   voutv1 = (valuev1 * 5.0) / 1024.0; // see text
   vinv1 = voutv1 / (R2/(R1+R2));
   // current
  float value = analogRead(analogInput);// analog current input
  float value1 = (99-value);// calibrating to zero
  if(value1<=1)
  {value1=0;}
```

```
  //Serial.print( value1,4);
   // Serial.print("\t");
  float value2= value1*5;
  //Serial.print(value2);
   //Serial.print("\t");
  float value3= value2/1023; // converting analog input to 1023
 // Serial.print(value3);
  // Serial.print("\t");
  float value4= value3;
  // Serial.print(value4);
   // Serial.print("\t");
   float value5= ((value4/0.135 ));// measured current //

 sensorValue_wind = analogRead(sensorPin); //Get a value between 0 and 1023 from the analog pin connected to the anemometer
sensorVoltage = sensorValue_wind * voltageConversionConstant; //Convert sensor value to actual voltage
//Convert voltage value to wind speed using range of max and min voltages and wind speed for the anemometer
if (sensorVoltage <= voltageMin){
windSpeed = 0; //Check if voltage is below minimum value. If so, set wind speed to zero.
}else {
windSpeed = ((sensorVoltage - voltageMin)*windSpeedMax/(voltageMax - voltageMin)-3.39); //For voltages above minimum value,use the linear relationship to calculate wind speed.
}
//Max wind speed calculation
x = windSpeed;
if (x >= y){
y = x;
}else {
y = y;
}
Serial.print(value5,5);// print to serial monitor of measured current
Serial.print("\t\t");
Serial.print(vinv1,2);// print to serial monitor of measured voltage

Serial.print("\t\t\t");
Serial.println(windSpeed);
delay(1000);

}
```

Appendix P - **Part of data collected during testing**

Table 9. *Input to motor at 25% duty cycle*

Input to Motor: 25%		
Current (A)	**Voltage (V)**	**Power (W)**
0	21.57869	0
0	21.33431	0.514
0	21.50538	1.983
0	21.33431	2.339
0	21.62757	2.649
0	21.40763	2.229
0	21.52982	2.36
0	21.43206	2.025
0	21.43206	1.909
0	21.40763	1.836
0	21.52982	1.411
0	21.60313	1.708
0	21.48094	1.856
0	21.4565	1.609
0	21.43206	1.494
0	21.48094	1.846
0	21.48094	1.647
0	21.48094	1.769

Table 10. *Input to motor at 50% duty cycle*

Input to Motor: 50%		
Current (A)	**Voltage (V)**	**Power (W)**
0.109	0	0
0.398	3	1.196
0.688	3.54	2.435
0.796	3.27	2.606
0.869	2.91	2.524
0.941	2.71	2.551
1.014	2.61	2.648
1.014	2.37	2.401
1.014	2.29	2.326
1.014	2.12	2.153
1.05	1.81	1.897
1.014	1.86	1.881
1.05	1.76	1.846
1.122	1.88	2.11
1.122	1.76	1.973
0.941	1.37	1.287
0.905	0.61	0.552
0.724	0.78	0.566

0	21.4565	1.538
0	21.28544	1.75
0	21.43206	1.443
0	21.40763	1.974
0	21.48094	1.757
0	21.50538	1.794
0	21.43206	1.79
0	21.60313	1.891
0	21.52982	2.121
0	21.50538	1.766
0	21.43206	1.717
0	21.62757	1.909
0	21.50538	1.782
0	21.48094	1.768
0	21.43206	1.732
0	21.48094	1.747
0	21.48094	2.015
0	21.52982	2.051
0	21.40763	1.883
0	21.50538	1.794
0	21.40763	1.962
0	21.52982	1.948

0.941	1.27	1.195
0.833	1.64	1.362
0.905	1.86	1.679
0.978	2.08	2.029
0.796	2.2	1.75
0.869	2.15	1.867
0.833	2.44	2.033
0.833	2.47	2.053
0.833	2.54	2.114
0.833	2.59	2.155
0.869	2.49	2.164
0.869	2.59	2.249
0.905	2.64	2.387
0.905	2.49	2.254
0.941	2.56	2.413
0.905	2.54	2.298
0.905	2.64	2.387
0.869	2.59	2.249
0.905	2.54	2.298
0.905	2.47	2.232
0.869	2.59	2.249
0.941	2.61	2.459

Table 11. *Input to motor at 75% duty cycle*

Input to Motor: 75%			
Current (A)	**Voltage (V)**	**Power (W)**	**Solar (V)**
0	0	0	20.08798
0.434	3.08	1.336	19.99023
0.579	3.78	2.192	19.94135
0.724	3.59	2.599	20.13685
0.833	3.2	2.663	20.0391
0.796	2.51	2.003	20.13685
1.014	2.12	2.153	20.06354
0.905	0.85	0.773	20.0391
0.833	1	0.834	20.0391
0.941	1.42	1.333	20.25904
0.869	1.78	1.549	20.16129
0.905	2.1	1.9	20.01466
0.869	2.17	1.888	20.08798
0.796	2.29	1.828	20.11241
0.905	2.29	2.077	20.13685
0.869	2.29	1.994	20.2346
0.869	2.51	2.185	20.18573
0.978	2.49	2.434	20.25904
0.869	2.47	2.143	20.13685

1.014	2.51	2.549	20.08798
0.833	2.56	2.135	20.06354
0.905	2.51	2.276	20.06354
0.905	2.49	2.254	20.18573

Tabel 12. *Input to motor at 100% duty cycle*

Motor: 100% of Max Speed-Right Input					
Current (A)	**Voltage (V)**	**Power (W)**	**Solar Voltage (V)**	**Solar Current (A)**	**Solar Power (W)**
0.109	-0.07	-0.008	20.72336	0.22	4.5591392
0.434	3.3	1.432	20.62561	0.22	4.5376342
0.724	3.91	2.828	20.7478	0.22	4.564516
0.941	3.64	3.424	20.62561	0.22	4.5376342
0.833	3.27	2.724	20.50342	0.22	4.5107524
0.833	1.78	1.484	20.50342	0.22	4.5107524
0.869	1.17	1.018	20.47898	0.22	4.5053756
0.905	1.51	1.37	20.52786	0.22	4.5161292
0.905	1.73	1.569	20.38123	0.22	4.4838706
0.833	2.03	1.687	20.57674	0.22	4.5268828
0.869	2.15	1.867	20.45454	0.22	4.4999988
0.869	2.2	1.909	20.52786	0.22	4.5161292
0.869	2.44	2.121	20.47898	0.22	4.5053756

0.905	2.37	2.143	20.40567	0.22	4.4892474
0.796	2.47	1.964	20.57674	0.22	4.5268828
0.796	2.49	1.983	20.40567	0.22	4.4892474
0.688	2.59	1.78	20.50342	0.22	4.5107524
0.796	2.54	2.022	20.45454	0.22	4.4999988
0.905	2.54	2.298	20.43011	0.22	4.4946242
0.869	2.69	2.333	20.47898	0.22	4.5053756
1.05	2.61	2.743	20.43011	0.22	4.4946242
0.796	2.81	2.236	20.50342	0.22	4.5107524
0.833	2.59	2.155	20.43011	0.22	4.4946242

Table 13. *Turbine output at 25% duty cycle*

25% Turbine Output			
Current (A)	**Voltage (V)**	**Power (W)**	**Wind Speed (m/s)**
0	0.07	0	5.73
0.07241	0.12	0.0086892	5.73
0.10861	0.22	0.0238942	5.16
0.10861	0.2	0.021722	5.08
0.10861	0.17	0.0184637	5.08
0.14482	0.27	0.0391014	5.08
0.18102	0.32	0.0579264	5.89
0.18102	0.32	0.0579264	6.05

0.21723	0.39	0.0847197	5.65
0.25343	0.37	0.0937691	5.57
0.25343	0.37	0.0937691	5.89
0.28963	0.44	0.1274372	6.13
0.25343	0.39	0.0988377	5.49
0.28963	0.46	0.1332298	5.57
0.28963	0.49	0.1419187	5.08
0.28963	0.56	0.1621928	5.24
0.32584	0.63	0.2052792	5.89
0.28963	0.56	0.1621928	5.57
0.32584	0.61	0.1987624	4.92
0.32584	0.61	0.1987624	5.08
0.39825	0.68	0.27081	5.4
0.36204	0.63	0.2280852	5.97
0.36204	0.66	0.2389464	5.32

Table 14. *Turbine output at 50% duty cycle*

50% Turbine Output					
Current (A)	**Voltage (V)**	**Power (W)**	**Wind Speed (m/s)**	**Availability**	**Efficiency**
0	0	0	5.4	62.986	0
0	0.15	0	5.97	85.110	0

0.10861	0.22	0.0239	5.49	66.188	0.03610069
0.10861	0.24	0.0261	5.08	52.439	0.04970842
0.14482	0.37	0.0536	5.73	75.253	0.07120433
0.18102	0.39	0.0706	5.49	66.188	0.10666309
0.18102	0.37	0.0670	5.24	57.551	0.11637895
0.25343	0.39	0.0988	5.16	54.955	0.17985128
0.28963	0.42	0.1216	5.24	57.551	0.21136788
0.36204	0.46	0.1665	4.92	47.638	0.34959007
0.43445	0.56	0.2433	4.84	45.352	0.53645309
0.47066	0.56	0.2636	5.08	52.439	0.50262512
0.50686	0.56	0.2838	5	50.000	0.5676832
0.57927	0.61	0.3534	4.84	45.352	0.77913874
0.54307	0.59	0.3204	5.16	54.955	0.58304051
0.57927	0.59	0.3418	5.49	66.188	0.51636408
0.61547	0.63	0.3877	5.32	60.228	0.64380234

0.57927	0.61	0.3534	4.76	43.140	0.81908698
0.54307	0.59	0.3204	5.08	52.439	0.61102179
0.57927	0.66	0.3823	4.76	43.140	0.88622526
0.57927	0.63	0.3649	4.6	38.934	0.93732047
0.57927	0.66	0.3823	4.44	35.011	1.09198349
0.65168	0.71	0.4627	4.52	36.938	1.25261453

Table 15. *Turbine output at 75% duty cycle*

75% Turbine Output				
Voltage (V)	**Power (W)**	**Wind Speed (m/s)**	**Availability**	**Efficiency**
0	0	5	50	0
0.1	0	5	50	0
0.22	0	4.84	45.3519616	0
0.27	0	4.92	47.6381952	0
0.39	0	4.6	38.9344	0
0.37	0	4.68	41.0012928	0
0.44	0	5	50	0

0.44	0	4.76	43.1400704	0
0.46	0	4.6	38.9344	0
0.49	0	5.4	62.9856	0
0.56	0	6.29	99.5432756	0
0.51	0	5.32	60.2275072	0
0.61	0	4.68	41.0012928	0
1.59	0	4.68	41.0012928	0
1.93	0	4.68	41.0012928	0
2.05	0	5.57	69.1234772	0
2.39	0	5.89	81.7345876	0
2.73	0	5.57	69.1234772	0
2.91	0	5.73	75.2530068	0
3.05	0	5.4	62.9856	0
3.1	0	5.57	69.1234772	0
3.39	0	4.92	47.6381952	0

Table 16. *Turbine output at 100% duty cycle*

100% Turbine Output					
Current (A)	**Voltage (V)**	**Power (W)**	**Wind Speed (m/s)**	**Availability**	**Efficiency**
0.1448	0.24	0.035	3.96	24.8396544	0.13992465
0.2172	0.34	0.074	3.64	19.2914176	0.38285522

0.2534	0.42	0.106	3.72	20.5915392	0.51691425
0.362	0.49	0.177	3.64	19.2914176	0.91957783
0.362	0.56	0.203	3.8	21.9488	0.92370608
0.3983	0.54	0.215	3.72	20.5915392	1.04438526
0.3983	0.56	0.223	3.88	23.3644288	0.95452794
0.5069	0.68	0.345	3.8	21.9488	1.57031273
0.5069	0.63	0.319	4.76	43.1400704	0.74019768
0.5069	0.71	0.360	5.08	52.4386048	0.68627036
0.5069	0.63	0.319	4.6	38.9344	0.82015339
0.5431	0.66	0.358	4.6	38.9344	0.92059002
0.5431	0.71	0.386	4.12	27.9738112	1.37835956
0.5793	0.66	0.382	4.28	31.3611008	1.21908412
0.6155	0.81	0.499	4.84	45.3519616	1.09924837
0.362	1.76	0.637	4.52	36.9381632	1.72501918
0.3258	2.17	0.707	4.44	35.0113536	2.01955288
0.3258	2.37	0.772	4.52	36.9381632	2.0906313
0.362	2.64	0.956	5	50	1.9115712
0.3258	3	0.978	4.68	41.0012928	2.38411995
0.362	3.17	1.148	4.44	35.0113536	3.27798466
0.3983	3.13	1.247	4.44	35.0113536	3.56033792
0.2896	3.3	0.956	4.28	31.3611008	3.04765769