Portable Hydroelectric Generator

Benjamin Kennedy, Joshua Kennedy and

Steven Benetatos

Supervisor: Dr. Wilson Wang

Department of Mechanical Engineering

Date Submitted: April 7, 2017

Abstract:

This degree project explores the power output of a portable hydroelectric system, the materials necessary to manufacture the unit and its feasibility. The design can be used when camping or at any location that has access to flowing water. It was determined that the system, can operate in river conditions ranging in velocity from 1.5 m/s to 4 m/s but can handle forces up to 5 m/s. The design can operate in rivers 8 inches or deeper, weighs only 44 lbs and is 1.3 m long, allowing the system to be easily transportable. The design can generate enough power to charge small electrical devices and is equipped with a portable battery making charging convenient.

Acknowledgements:

We would like to thank Dr.Wang for being our supervisor and providing guidance for our degree project. We would also like to thank Bob Borst of “Borst, Engineering and Construction LLC” for being so helpful in the design calculations of the turbine and shaft dimensions. As well as offering his own opinion on the design of the system.

Table of Contents:

Figures:

Tables:

Nomenclature:

$$H = Head\ (ft)$$

$$V = Velocity\ (ft/s)$$

$$g = force\ of\ gravity\ (ft/s^2)$$

$$D = Diameter\ of\ turbine\ (ft)$$

$$W_d = Working\ diameter\ (ft)$$

$$W_c = Working\ circumference\ (ft)$$

$$Oprts = Optimal\ rim\ tangential\ speed\ (ft/s)$$

$$e = efficiency\ (\%)$$

$$Oprs = Optimal\ rotational\ speed\ (RPM)$$

$$W_a = Working\ cross\ sectional\ area\ (ft^2)$$

$$E_f = Effective\ flow\ rate\ of\ the\ Turbine\ (ft^3/s)$$

$$P = Theoretical\ Max\ Power\ (KW)$$

$$T = Torque\ (ft - lb)$$

$$B_w = Blade\ width\ (in)$$

$$B_s = Blade\ spacing\ (in)$$

$$F_b = Max\ force\ on\ the\ blades\ (lb)$$

$$M_b = Max\ blade\ bending\ moment\ (in - lb)$$

$$t = Minimum\ blade\ thickness\ (in)$$

$$t_f = Flange\ Thickness\ (mm)$$

$$B_L = Blade\ length\ between\ supports\ (in)$$

$$Ww = Weight\ of\ the\ wheel\ (lb)$$

$$F_s = Max\ force\ on\ the\ shaft\ (lb)$$

$$M_s = Max\ shaft\ bending\ moment\ (in - lb)$$

$$d = Minimum\ recommended\ shaft\ diameter\ (in)$$

$$f_s = Factor\ of\ Safety$$

$$\tau = shear\ stress\ (Mpa)$$

$$\sigma = Normal\ stress\ (Mpa)$$

1.0 Introduction

Many people today are using portable electronic devices in all parts of the world. The two most common are a cellphones and laptops. All the devices are powered by electricity, which means they often depend on access to electrical outlets to charge. However, most electrical outlets are placed somewhere stationary and must be connected to the electrical grid. Options are limited for those who seek to charge their devices but do not have access to an electrical outlet. External battery packs and power banks a popular options, but these themselves much be charged. The proposed solution for this problem is to have a portable generator at a given secluded location. This can be achieved a number of ways, such as the use of portable gasoline/diesel generators or by utilizing renewable energy, including solar, wind and water.

The purpose of this project is to determine the best way to obtain enough power to charge small electrical devices in secluded areas with no access to the electrical grid. The following is a description of the advantageous and disadvantageous of each design option to harnessing electricity. It is from this comparison that a system for producing electricity will be chosen in order to solve for the current design problem.

Wind Turbine: a device that converts the wind's kinetic energy into electrical power.

Advantages:

1. Green – Wind energy is a green energy source. Harnessing wind energy does not pollute the environment, where fossil fuels, coal and nuclear power do.
2. Renewable – Wind energy is renewable. Wind is naturally occurring and is virtually limitless.
3. Space Efficient – Wind turbines require a limited amount of land to be installed.
4. Low Operational Costs – Operational costs are very low once a turbine has been installed.

Disadvantages

1. Unpredictable – Wind is unpredictable and the availability of wind energy is not constant.

2. Costs – The competitive cost of wind power is highly debatable. Both utility-scale wind farms and small residential wind turbines typically rely heavily on financial incentives. This is to give wind power a fair chance in the fierce competition against already well-established energy sources such as fossil fuels and coal.
3. Threat to Wildlife – Birds, bats and other flying creatures have slim chances of surviving when coming into contact with rotating turbine blades.
4. Noise – **It can become unbearable for some people living in the proximity of wind turbines. Building wind turbines in urban environments should be avoided.**

Gas Generators: a device that uses the theory of the internal combustion engine to produce electricity.

Advantages

1. Cheap – They are relatively cheap to purchase.
2. Fuel – The fuel is readily available, making it a very attractive option for many.
3. Multiple Options – They come in different sizes and kW outputs.
4. Portable – They're mostly portable, so that they can be used for various purposes.

Disadvantages

1. Environmental – Gasoline generators produce green house gases.
2. Limited fuel storage – Generators cannot hold much fuel in the tanks. This means that the generators cannot run for long.
3. Noise – They're usually loud, especially the cheaper ones.

Hydroelectricity: power is the harnessing of flowing water into electricity.

Advantages

1. Renewable – Hydroelectric energy is renewable
2. Green – Generating electricity with hydro energy is not polluting itself.
3. Reliable – Hydroelectricity is very reliable. There is little fluctuation in terms of the electric power produced by hydro plants, unless a different output is desired.

Countries that have large resources of flowing water use hydroelectricity as a base load energy source.

4. Flexible – Adjusting water flow and output of electricity is relatively simple. At times where power consumption is low, water flow is reduced and the magazine levels are being conserved for times when the power consumption is high.
5. Safe – When compared to fossil fuels and nuclear energy, hydroelectricity is much safer.

Disadvantages

1. Environmental Consequences – The environmental consequences of hydropower are related to interventions in nature due to damming of water, changed water flow and the construction of roads and power lines.
2. Expensive – Building power plants in general is expensive. Hydroelectric power plants are not an exception to this. On the other hand, these plants do not require a lot of workers and maintenance costs are usually low.
3. Droughts – Electricity generation and energy prices are directly related to how much water is available. A drought could potentially affect this.

<u>Solar Energy</u>: radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies.

Advantages

1. Renewable – Solar energy is a renewable energy resource.
2. Sustainable – Energy source abundant and sustainable.
3. Environmentally Friendly – **Harnessing solar energy does not cause pollution.**
4. Good Availability – Solar energy is available all over the world. Germany, for example, has by far the highest capacity of solar power in the world.
5. Many Applications – Solar energy can be used for many different purposes. It can be used to generate electricity in places that lack a grid connection, for distilling water in Africa, or even to power satellites in space.

6. Silent – There are no moving parts involved in most applications of solar power. There is no noise associated with photovoltaics.
7. Low Maintenance – The majority of today`s solar power systems do not require a lot of maintenance.

Disadvantages

1. Expensive – Solar panels are expensive to purchase. Normally government subsidies are needed to lower the cost of solar panels so that they can become more affordable.
2. Intermittent – **Solar energy is an intermittent energy source.** Access to sunlight is limited at certain times (i.e. morning and night).
3. Energy Storage is Expensive – Energy storage systems such as batteries will help smoothen out demand and load, making solar power more stable, but these technologies are also expensive.
4. Associated with Pollution – While solar power certainly is less polluting than fossil fuels, some problems do exist. Some manufacturing processes are associated with greenhouse gas emissions. Nitrogen trifluroide and sulfur hexafluoride have been traced back to the production of solar panels. These are some of the most potent greenhouse gases and have many thousand times the impact on global warming compared to carbon dioxide. Transportation and installation of solar power systems can also indirectly cause pollution.
5. Exotic Materials – Certain solar cells require materials that are expensive and rare in nature. This is relevant for thin-film solar cells that are based on either cadmium telluride (CdTe) or copper indium gallium selenide (CIGS).
6. Requires Space – Solar panels require large amounts of space for installation.

Business Opportunity:

Currently in North America there are 46 million people annually who go camping. 83% (38.2 million) of these campers bring their cellular device with them as shown in Figure 1.A. Along with a cell phone, campers bring other electronic devices with them on trips, all that require electricity to charge. Only 10% of polled campers said they brought no electronic technology while camping. It can be assumed that the demand for electrical power is high even when out in the wilderness. 36% of campers stated that access to electricity was the greatest luxury amenity on a camping trip. This statistic allows for one to assume that gaining access to power can be difficult.

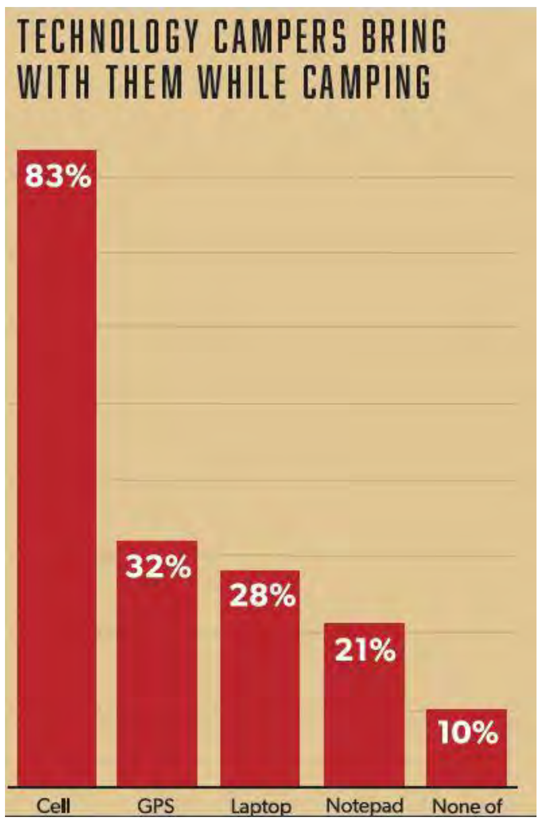


Figure 1.A: Electric devices campers brought with them while camping [7]

Figure 1.B allows for the assumption that 77% of the camping population will be located in forested areas (i.e. national parks, privately owned land, backcountry). Therefore, a generator that can produce enough power to charge small devices while remaining portable will be required.

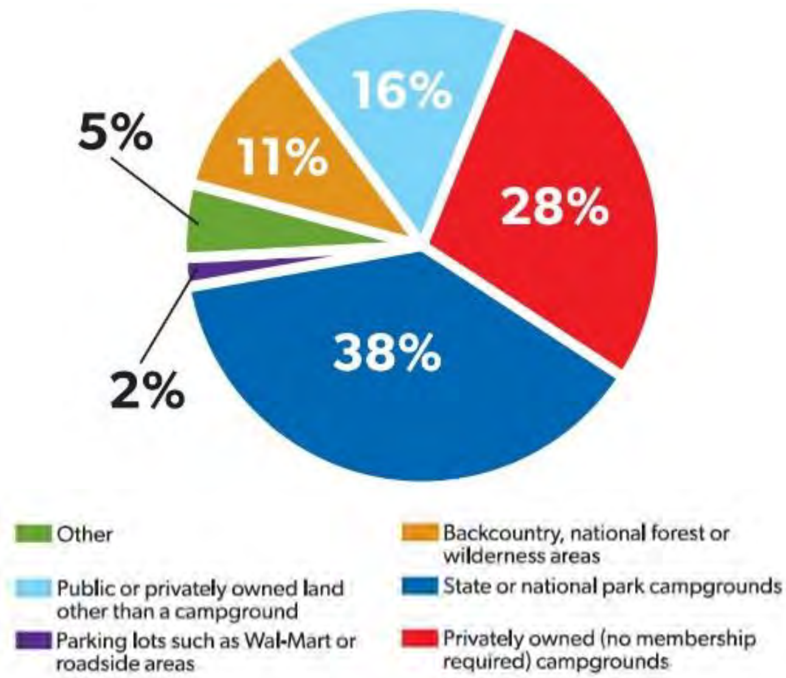


Figure 1.B: Graphical depiction of locations where people camp [7]

It is estimated that there are 1.2 billion people who do not have access to electricity. Majority of these people live in developing Asia or sub-Saharan Africa with 80% living in rural areas. Majority of these rural areas are forested with access to flowing water. Figure 1.C illustrates an accurate distribution of different populations around the world that either lack adequate electricity or have no access at all.

In Africa alone, roughly 58% of the population living rurally owns a cellular device. This means that the majority of the population owns a small electronic device but has no where to charge them. Africa also does not have the necessary infrastructure to transport the electricity to where it is needed. Only 34% of the population of sub-Saharan Africa have access to roads. The infrastructure inadequacy and the African government's solution of building large scale electrical plants but no ability to distribute the power leaves a big opportunity. Currently the United States in Africa has devoted its resources to large scale projects, like harnessing the winds that blow through Kenya's Lake Turkana plains to power hundreds of thousands of homes. Our solution to this problem is to design a small electrical generator that is light enough to be carried and easy to set up. To be able to generate enough power for small electrical devices and to be able to operate in a forested environment.

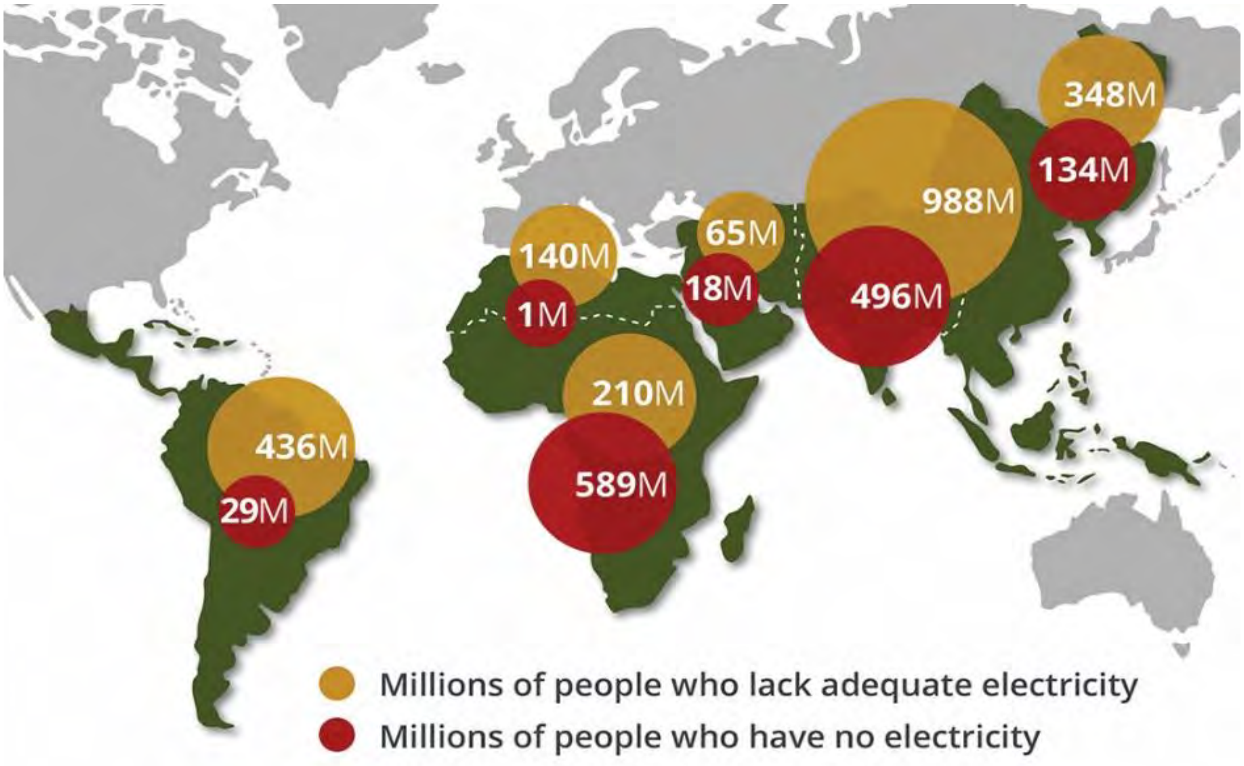


Figure 1.C: Third world populations lacking electricity [18]

Intellectual Property:

A great deal of resources has gone into the technological advancement of large scale infrastructure projects. However, it has not been until recently that any resources have been diverted to technological advancements of small scale energy production. With rising energy and environmental costs people are looking for cheaper and cleaner sources of energy. This gap in intellectual property provides a good opportunity to design and patent systems that produce electricity that is clean, renewable and if possible, portable.

2.0 Problem Definition

The problem definition of this design is providing electricity to people who are either travelling or live in rural forested areas. To be able to generate the necessary amount of power to charge essential electrical devices (i.e. phones, laptops, flashlights, etc.).

3.0 Constraints and Criteria

1. The system cannot weigh more than 50 lb. Alberta workplace Health and safety bulletin states that the average person can carry no more than 55 lb before it becomes uncomfortable.
2. The system cannot exceed 1.3 m to fit in the smallest of car trunks for transportation.
3. The system must be able to produce at least 9 volts to be able to charge to smallest acceptable battery for the system.
4. The system must be able to charge the storage unit in a sufficient amount of time.
5. The generator must be able to be installed in a location that is as common as possible in a forested area and can still generate the necessary amount of power. Must be simple to install with no pre-construction.
6. The system must be environmentally friendly

4.0 Concept Generation

In order to reach the optimal design for the generator, we initially met as a group and created a list of constraints/criteria to design a generator. Afterwards each group member individual conducted their own research so that the maximum number of possible ideas could be generated. This technique led to many different ideas utilizing gasoline, wind, water and solar energy. We met again and discussed all the possible options and filtered out any ideas that proved to be inadequate. The first item discussed was the generator location. It was determined that the primary location of the generators use would be in rural forested areas. As previously stated in the introduction the options for powering the generator are gasoline, wind, water or solar.

Next, power options where eliminated. For the circumstances of this design, a fuel source will not be close which makes a gasoline fueled design ineffective. Solar energy was dismissed because solar energy is intermittent and in a forested area the probability of this increases dramatically. Wind energy is found to be limited in a forested setting. Wind, like solar is intermittent and the goal of the project was to be able to generate power at a consistent rate.

The final design option we discussed was a hydroelectric generator. Hydro electricity is renewable, green, and the only intermittent factors that affect water are caused by fluctuations in water supply, due to droughts. These fluctuations in the water supply occur less often then the intermittent factors of wind and solar. Also, water flow rate is not affected by the forest which makes it the best option for a source of electricity. The drawbacks of using hydroelectricity are that floating debris can interfere with the unit and hydroelectric generators normally require large civil projects to mount the generator and create a reservoir to hold the needed water for energy production.

With a hydroelectric generator selected, individual design assessments where conducted to create design ideas. Each group member did their own research separately and created their own design and specifications that they thought would be the best for the generator design. We then met and discussed our findings. A design criterion was agreed upon and the preliminary design could begin.

5.0 Preliminary Design Layouts and Analyses

The first major design decision the group made was the blade design. There are numerous options to consider, each for different purposes:

Impulse Turbine – The impulse turbine uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. For the circumstances that the proposed design will be under low head and low flow applications, impulse turbines will not be suitable for the current design criteria.

Reaction Turbine – A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with low head, high flow and large amounts of pressure. For the application use that this current design will be under, reaction turbines are not suitable.

Kinetic Turbines – Kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway. This design concept works well for the conditions that the proposed generator would be under.

There are many different kinds of kinetic turbine designs. It was determined that the optimal turbine design for this generator would be an undershot poncelet water wheel (Figure 5.A).

Undershot Poncelet Water Wheel – A undershot poncelet water wheel uses the kinetic velocity of the flowing water to generate electricity. It does not require any large civil project to create a water reservoir or to increase the head value. The blades are angled by 30 degrees toincrease the efficiency of the system from 30% to 70%, generating more power.

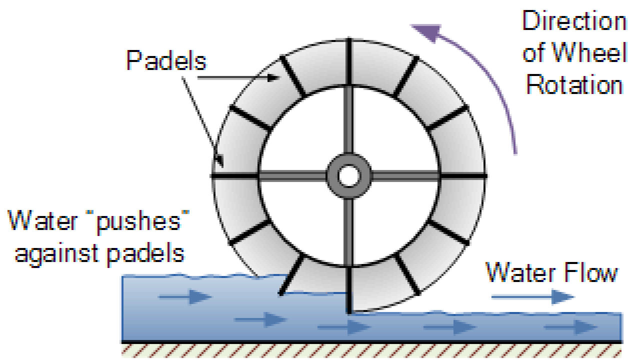


Figure 5.A: Undershot Poncelet Water Wheel Diagram [5]

With the design of the turbine selected, it was determined that the undershot turbine had to operate on the surface of the river. In order achieve this, the system would be fitted with pontoons. The pontoons would be designed so that the system will be able to be submerged to its necessary depth. The generator that is to be selected for the system determines the size of the turbine. Every generator has its own torque and RPM requirements to produce the optimal output. The turbine will be what generates the torque and RPM of this system. The power created from the system will be stored in an external battery that can be removed and transported anywhere a device needs to be charged. Figure 5.B shows the preliminary layout of the system. To determine the maximum size the system is based on the weight and length criteria. The system succeeded in determining the maximum size the generator and turbine can be without breaking the size restrictions. However, the system did fail to meet the necessary criteria.

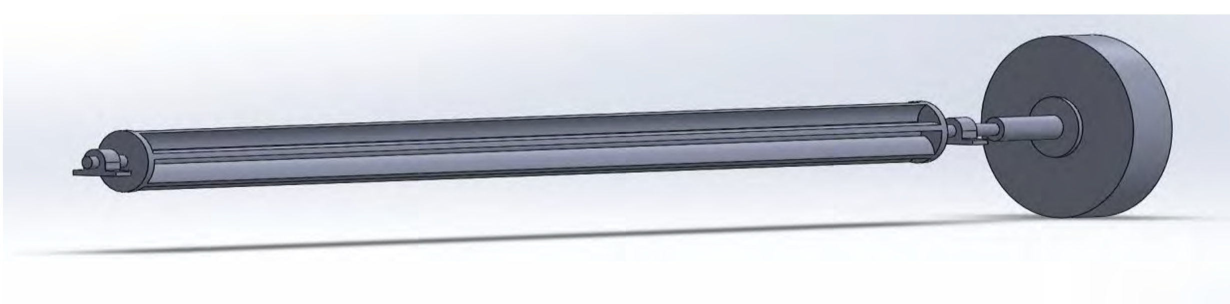


Figure 5.B: Preliminary design, drawn in SolidWorks.

6.0 Final Design and Analyses

Generator

The generator selected for this hydroelectric system is the *DC-520 High Wind Permanent Magnet Generator* by Wind Blue Power (Figure 6.A). The unit is made up of 303 Stainless steel which provides corrosion protection and increased power output. The permanent magnet generator transforms the mechanical energy from the rotating turbine shaft into electrical energy. The generator has an external connection output on the back to allow for easy access for an electrical cable to the power storage. Some of the features of the generator are:

1. Completely Brushless design eliminates the need for maintenance and reduces friction
2. The unit weighs a total of 12 lbs
3. Zero cogging
4. Built in rectifier
5. Weather proof

The generator is designed so that it can generate electricity at very low Torque and RPMs as well as being able to perform at high amounts of Torque and RPMs. The generator was not designed by the design group, but the manufacturer provided power output and efficiency data, as well as the minimum start up torque (Figure 6.B & 6.C).

Provided by Wind Blue Power, the start-up torque was determined to be less then 0.5 ft-lb. This value works well for our design, since the minimum torque this system will generate is 0.74 ft-lb.

In order to determine the efficiency of the system and the total power output we first have calculate the voltage and amperage output of the generator. The value of amperage is proportional to the amount of torque the system generates, while voltage is proportional to the RPMs of the system. Depending on the generator selected, the optimal torque and rpm ratio will differ.

Figure 6.B is an analysis of the generator of the output voltage of the system and the corresponding torque at different rpm values. Figure 6.C describes the output amperage generated by the system with the corresponding torque value.

Figure 6.A: DC-520 High Wind Permanent Magnet Generator [15]

values

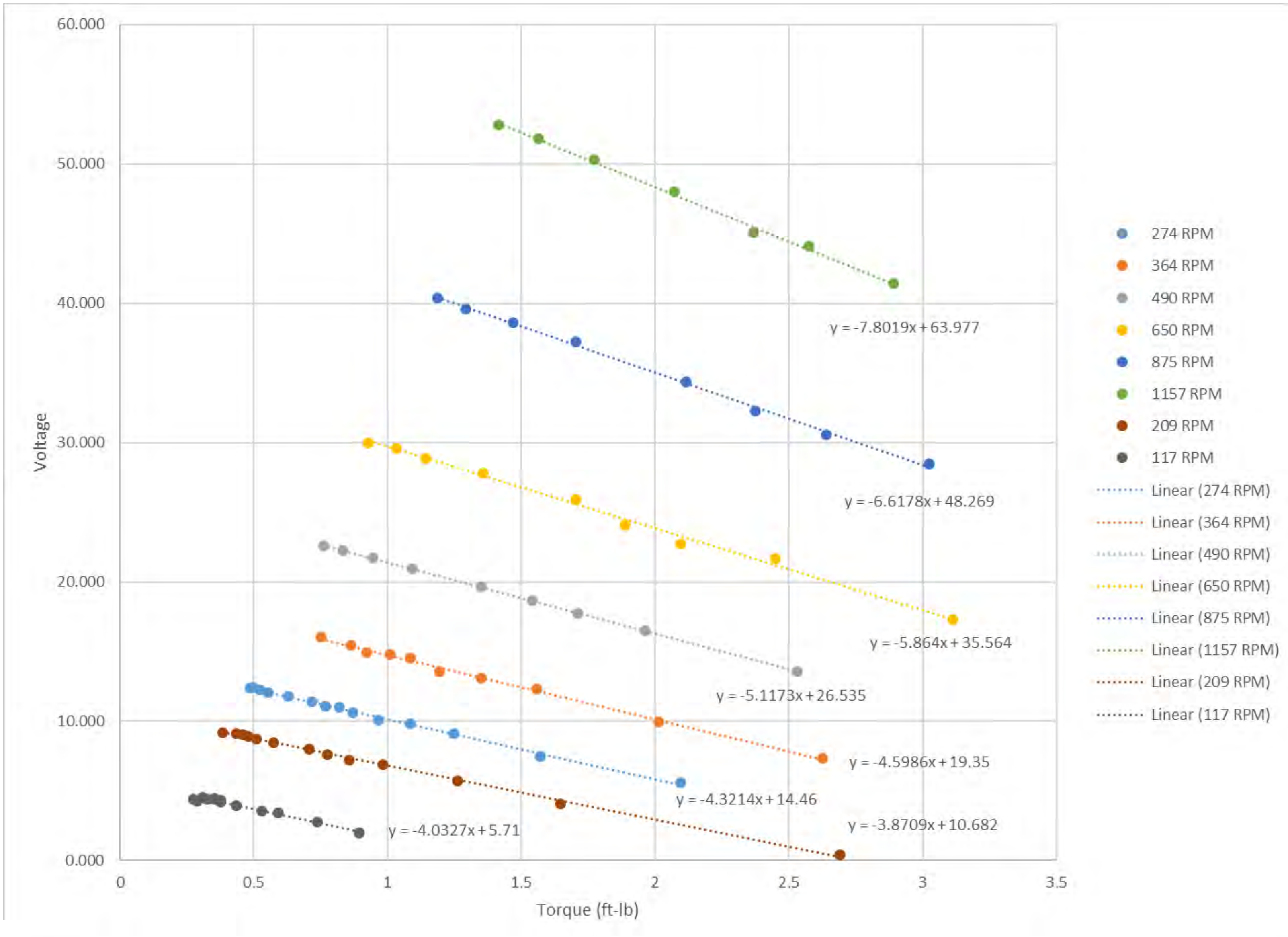


Figure 6.B: Output voltage of the generator vs Torque at varying RPM values [15]

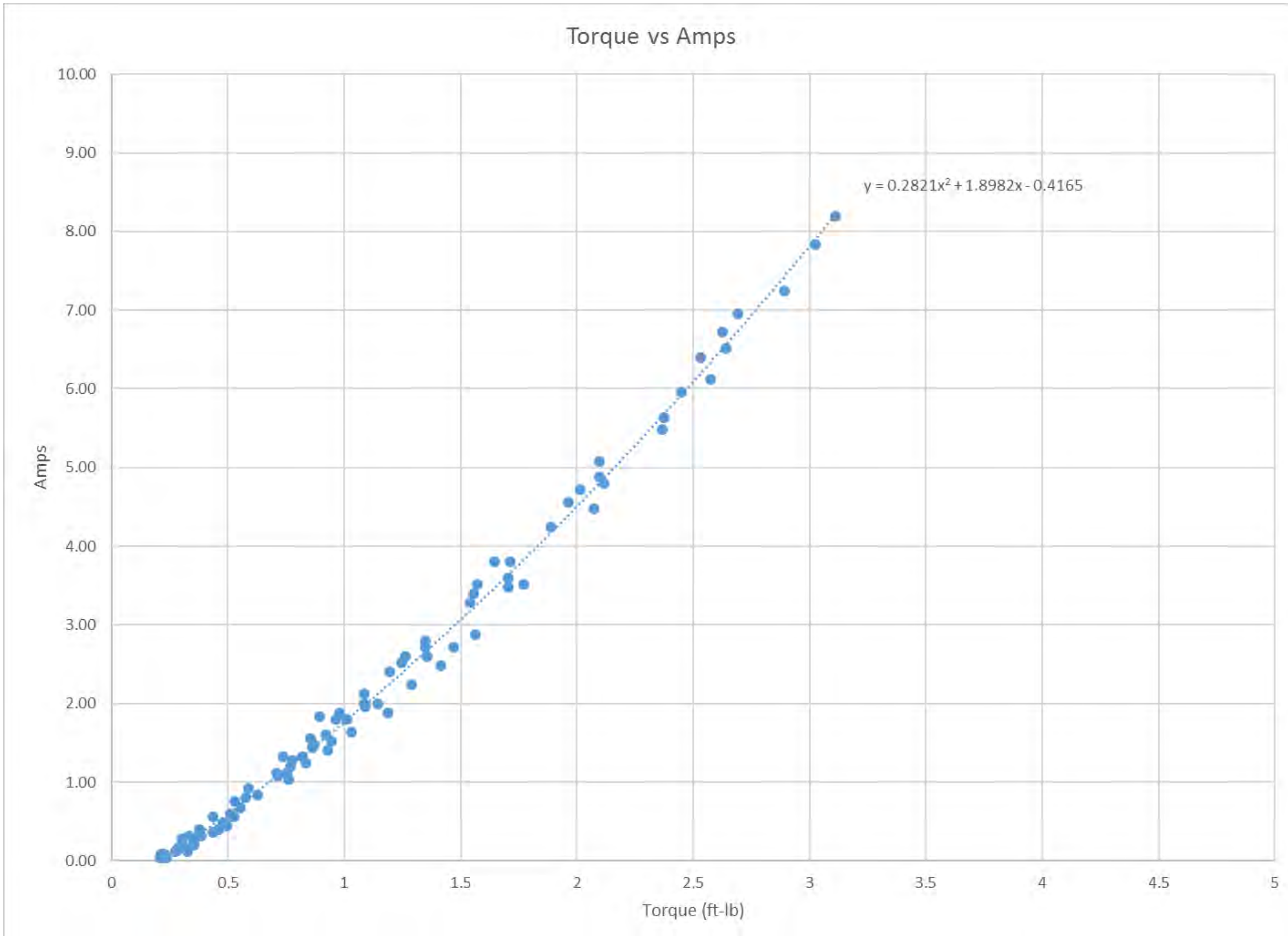


Figure 6.C: Output Amperage vs Torque [15]

Turbine

With the generator selected, the turbine size can be determined through trial and error to optimize the power output of the system. The turbine is a component of the system that captures the kinetic energy of the flowing water and transforms the energy into mechanical energy. The blades of the turbine are made of G-9 Fiberglass Melamine Laminate Sheet. The side cylinders are constructed from AK 304 Austenitic Stainless Steel. The reason for this is that the forces acting on the turbine are small, meaning is was unnecessary for the blades to be made from stainless steel, which is stronger then fiberglass. Fiberglass is much lighter then stainless steel, which by utilizing fiberglass for the blades reduces the weight.

To determine the optimal dimensions of the turbine, first the head value of the water needed to be determined. Head is the result of an elevation change between the penstock inlet and the water machine inlet. This value of head is then converted to a water velocity that strikes the water machine blades. With an undershot water wheel, the stream velocity is already directly striking the blades so there is no need to have a penstock to create this water velocity. Using the following spouting velocity formula, one can determine what the head value is in the river at any speed.

$$H = \frac{V^2}{2g}\ (ft)$$

When designing a undershot waterwheel it is important to know the value of head because a turbines diameter is a ratio of the head. Using trial and error we were able to determine the optimal diameter of the turbine. For the proposed design it turned out to be 2.311 times the Head value.

$$D = 2.311 * H\ (ft)$$

The next design aspect is to determine the working diameter. This value is given that a portion of the turbine is submerged below the river surface which we assume is equal to the head value.

$$W_d = D - H\ (ft)$$

The working circumference was then determined based on the working diameter.

$$W_c = W_d * \pi \ (ft)$$

Next the optimal rim tangential speed was calculated. Based on design research it was determined that the optimal rim velocity is 67% of stream velocity. This value cannot be confirmed since no experimentation was conducted by the group, leaving room for error.

$$Oprts = e * V \ (ft/s)$$

The optimal rotational speed of the wheel requires the calculated values of the working circumference and the rim speed. This value represents the number of revolutions per minute the turbine will be under. If RPMs need to be increased, reduce the wheel diameter.

$$Oprs = \frac{Oprts * 60}{W_c} \ (RPM)$$

The working cross sectional area, is the area of the blade that is submerged. This value represents the surface area of the blade that will have the forces of flowing water acting upon it.

$$W_a = L * H \ (ft^2)$$

Once the working cross sectional area has been calculated, the effective flow rate of the turbine can be determined. This value is proportional to both the stream velocity and the working cross sectional area.

$$E_f = W_a * V \ (\frac{ft^3}{s})$$

The theoretical maximum power is the maximum power that can be generated if the turbine and generator are 100% efficient. This value is needed to determine the actual efficiency of the system.

$$P = \frac{H * E_f}{11.8} \ (KW)$$

Next is to calculate the amount of torque that will be acting on the turbine. If necessary, the torque of a system can be increased by either lengthening the shaft or increasing its diameter.

Increasing the diameter of the turbine will reduce the RPM’s, however increasing the turbines length will increase the torque.

$$T = 5252 * e_t * P/0.746/Oprs\ (ft - lb)$$

The depth the blades in the water is equal to the head value. The spacing between the blades is equal to the 95% the blade width and the number of blades on the turbine is equal to the working circumference divided by the blade spacing. If the number of blades value has a decimal, always round to the nearest even value. This is because if there is an odd number of blades on the turbine, then the rotation will not be even.

$$B_w = 12 * H$$

$$B_s = B_w * 0.95$$

$$Number\ of\ blades = \frac{W_c}{B_s}$$

The maximum force acting on the blades was determined by multiplying the flow rate by velocity. In order to prevent the blade from breaking, it was determined that the maximum flow rate and velocity would correspond to 5m/s. This is because the maximum velocity the system intends to operate under is 4m/s. To make sure that the system would not break if fluctuations greatly exceeding the forces from the water travelling at 4m/s were to occur, the system was designed to withstand forces up to 5m/s. A design factor of safety of 2 was used. This value is sufficient for the limited forces acting on the blades and by the recommendation of water wheel manufacturers.

$$F_b = f_s * E_f * V$$

Using the calculated maximum force acting on the blades we then could calculate the maximum bending moment of the blades.

$$M_b = 12 * F_b * (\frac{L}{12})/12$$

Once the maximum blade bending moment was calculated, we were able to determine the minimum blade thickness using Euler-Bernoulli stress analysis. Using the same design factor of 2 and the material endurance limit for G-9 fiber glass, the minimum blade thickness recommended to handle the forces acting on the blades could be determined.

$$t = \left(\frac{6 * M_b * f_s}{B_w * endurance\ limit}\right)^{0.5}$$

Continuing to use Euler-Bernoulli stress analysis, the blade length between the supports was calculated. Since the blades are only supported at either end. It is important to determine if the could resist the maximum forces acting on the system.

$$B_L = \left(\frac{2 * t^2 * B_w * endurance\ limit}{F_b * f_s}\right)$$

The previously stated formulas can be viewed in Appendix A.1 where sample calculations can be reviewed.

With all of the previous calculations solved, it is then possible to determine whether the turbine dimensions will be optimal. Using trial and error the Figures 6.D & 6.E show the iterations that were conducted to determine the optimal dimensions of the turbine.

It was determined that the turbine length is 0.5 meters (19.685 in). This value was determined based on the fact that the generator requires 0.5 ft-lb of torque to begin rotating and any shorter of a turbine and the necessary amount of torque will not be able to be generated. Also the head value was determined to be equal to 0.1673 ft. This value was calculated by using the base velocity of 1m/s. This velocity value was used because any slower and the turbine will not have adequate surface area to rotate. Based on that criteria the diameter of the turbine was altered to determine the optimal dimensions.

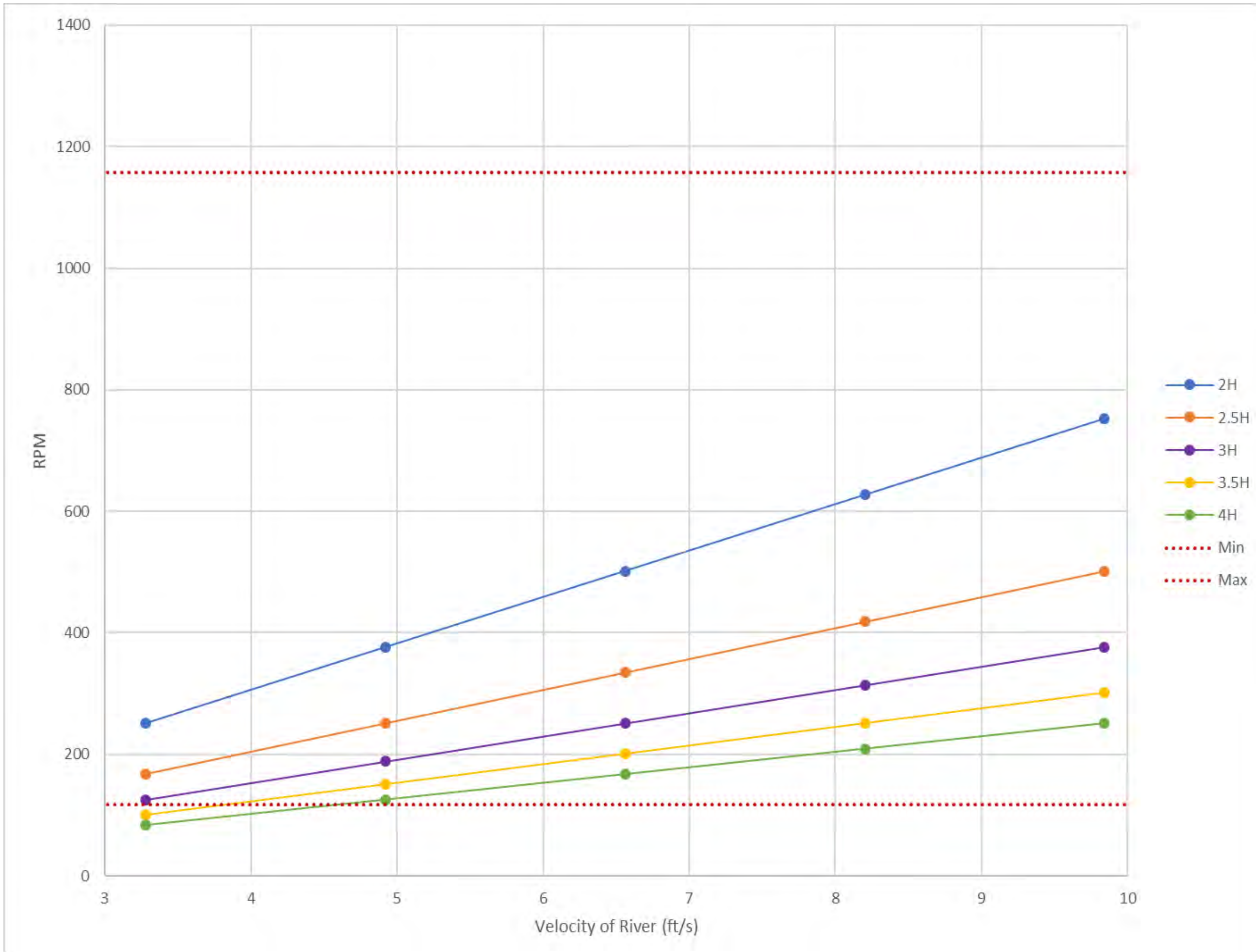


Figure 6.D: River speed vs Turbine RPM at varying diameters

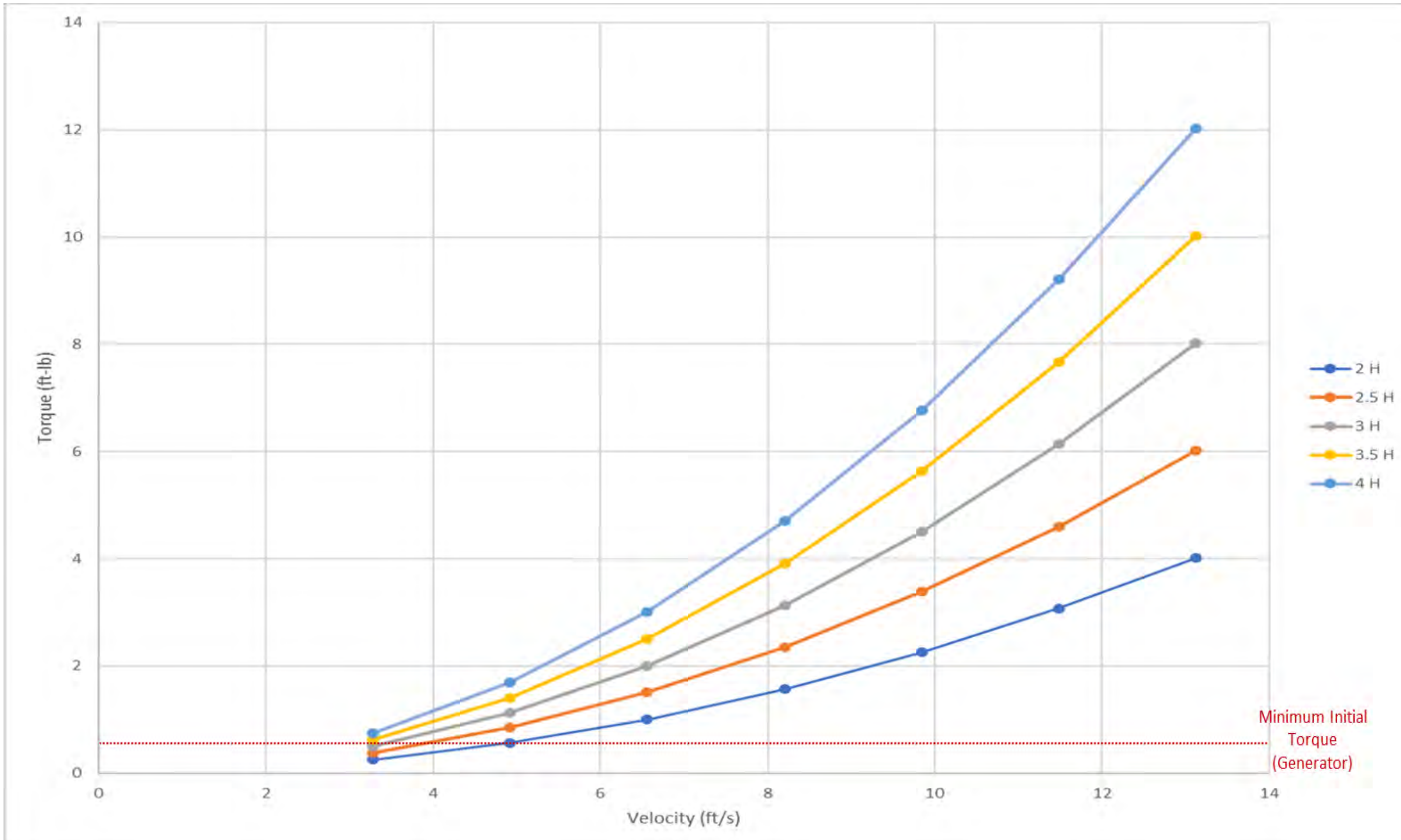


Figure 6.E: River speed vs Torque on shaft at varying diameters

The graphs above depict the iterations that were done to determine the optimal diameter of the turbine. By using the generator graphs in the previous section, it was determined that the smallest diameter of the turbine would be best for the system. This is due to the fact that the generator selected and the criteria outlined for the turbine dimensions, the largest RPM and smallest torque will be able to produce the maximum amount of power. In this case 2H is the best diameter for the turbine. However due to design specifications, the diameter of the turbine must be increased to allow the shaft to be inserted inside. The shaft must have enough space to fit inside the turbine to not only support it but also be able to transfer the mechanical energy from the turbine to the generator. This diameter is 0.625 inches, which will be outlined in the next section. Therefore the optimal diameter of the system is 4.639 inches or 2.311H.

Velocity (m/s)	Torque (ft-lb)	RPM
1.0	0.329	191
1.5	0.739	287
2.0	1.314	383
2.5	2.053	479
3.0	2.957	574
3.5	4.025	670
4.0	5.257	766
4.5	6.653	861
5.0	8.213	957

Table 6.F: Calculated results for turbine with 4.639 in diameter (2.311H) at varying river speeds.

Above is an analysis of the torque and RPM values that were calculated using a turbine with a diameter of 4.639 inches. These values were then inputted into the generator graphs in the previous section to determine the power that would be produced (Figure 6.B). Using the Figure 6.C, the output amperage the generator will produce at a specified Torque can be determined.

Battery

The battery that was selected for this system is the *Universal Lithium Ion Battery Pack* by Power Stream. The battery will be mounted on the top of the case in its own protective housing. This housing is designed for easy access and will allow the battery to be protected from the elements when charging. Once the battery is fully charged, it can then be removed and transported anywhere. The battery can also handle a range of input voltages and amperage. This is useful for the designed system, because the voltage and amperage the generator produces changes over a variety of speed inputs from the river.

The unit can handle input voltages ranging from 9 to 24 volts and various amperages depending on the cable selected. At the same time has an output voltage from 5-19 volts and 3 to 4 amps. This large range in voltage and amperage means that the battery can charge small electrical devices and be charged using a wide range of voltage and amperage inputs. The following is a list of the special features of the battery setup:

1. The battery has automatic overcharge protection built in.
2. Gas gauge tells how much power is remaining
3. Battery can store 104 watts
4. Highly regulated voltage sources.
5. Weight of the total unit is 3 lb
6. Total dimensions of the unit are 3.28 x 6.8 x 2 inches.
7. Detachable
8. Battery is weather proof

Figure 6.G: Universal Lithium Ion Battery Pack [23]

Cable

The electrical cable that is selected for this system is *Orange Type G Portable Power Cable* by Super-Trex. The military grade cable meets the necessary criteria for this system. The cable can handle outputs of current 1.14 A - 17.36 A and voltage 9V - 16V. This ability of the cable to handle the minimum and maximum loads of the generator is important because the system will be operating in rivers that differ in velocity and generate a variety of loads.

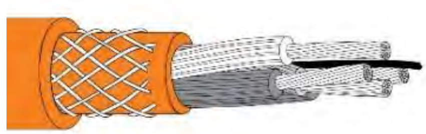


Figure 6.H: Orange Type G Portable Power Cable [26]

The cable will be attached to the generator inside the casing and will feed into the protective casing. This will allow for easy access to charge the battery.

Velocity (m/s)	Amps (A)	Watts (W)	Volts (V)	Amperage per hour (AH)	Time to charge Battery (Hours)	Efficiency of the System (%)
1.0	0.24	2.0	8.5	12.3	51.8	16
1.5	1.14	13.8	12.1	8.6	7.5	32
2.0	2.57	36.6	14.3	7.3	2.8	36
2.5	4.67	72.3	15.5	6.7	1.4	36
3.0	7.66	114.9	15.0	6.9	0.9	33
3.5	11.8	151.2	12.8	8.1	0.7	28
4.0	17.4	160.3	9.2	11.3	0.6	20
4.5	24.7	93.3	3.8	27.5	1.1	8

Table 6.I: Calculated results of the system

Table 6.I above represents the calculated values from the above graphs and calculations. The minimum voltage the battery can take is 9 volts. This means that the range of velocities this system can operate at is between 1.5m/s and 4m/s. Once the total volts and amps were calculated, the total watts the system can generate per hour can be determined and therefore the total time to charge the battery. The efficiency of the system is low. This is due to the fact that the generator is more efficient at a higher rpm value. A higher rpm value could be reached if the diameter of the turbine could be reduced. However due to design specifications, the turbine diameter could not be any smaller than the dimensions already specified.

Figure 6.J shows that as the velocity of the river increases the power output of the generator increases up to 4m/s before declining. Figure 6.K indicates that as the velocity of the river increases the total time to charge the battery decreases until 4m/s. Figure 6.L describes that as the velocity of the river increases, the efficiency of the system increases to 36% at 2.5m/s and then decreases.

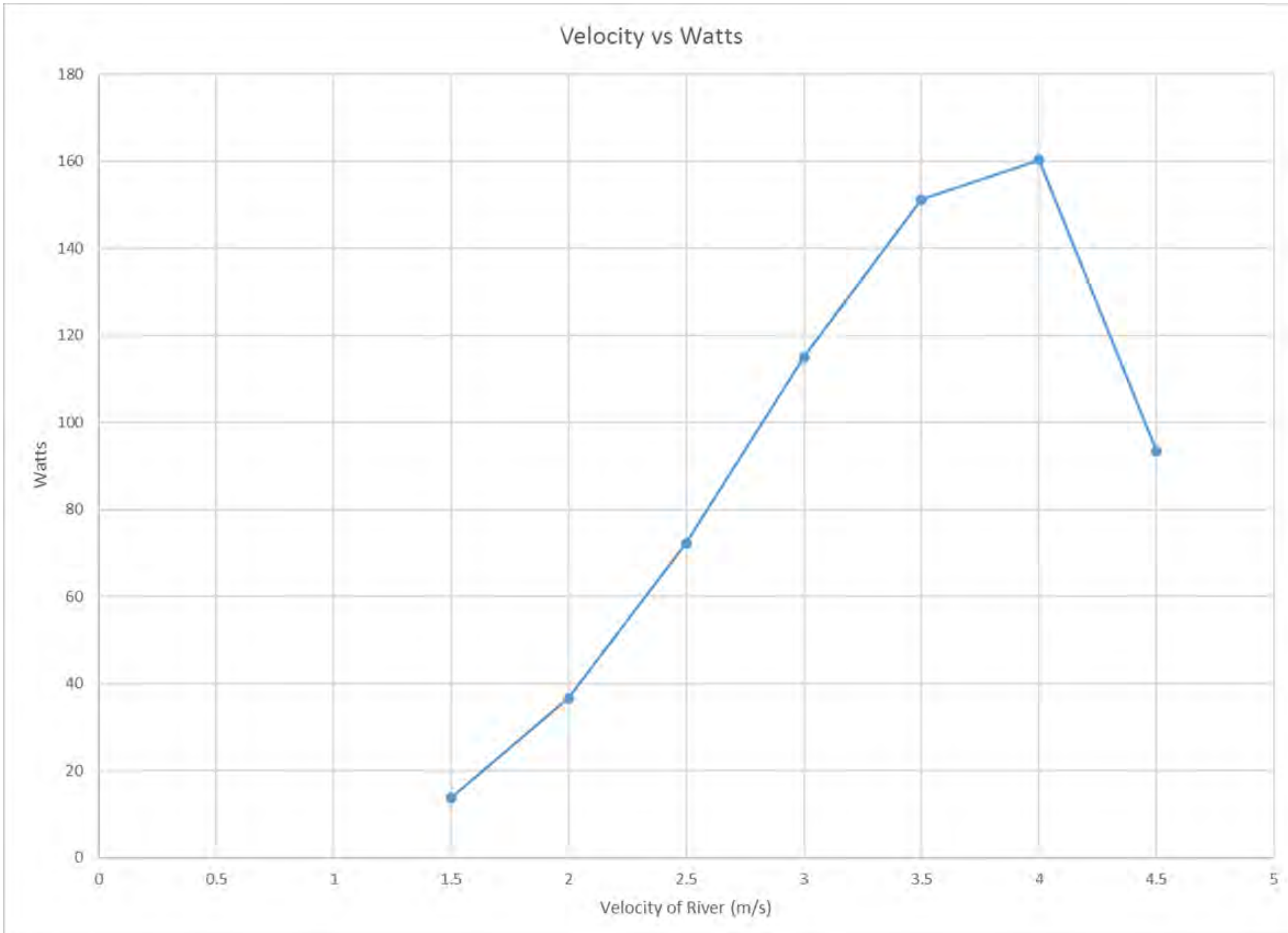


Figure 6.J: River speed vs Watts produced by the generator

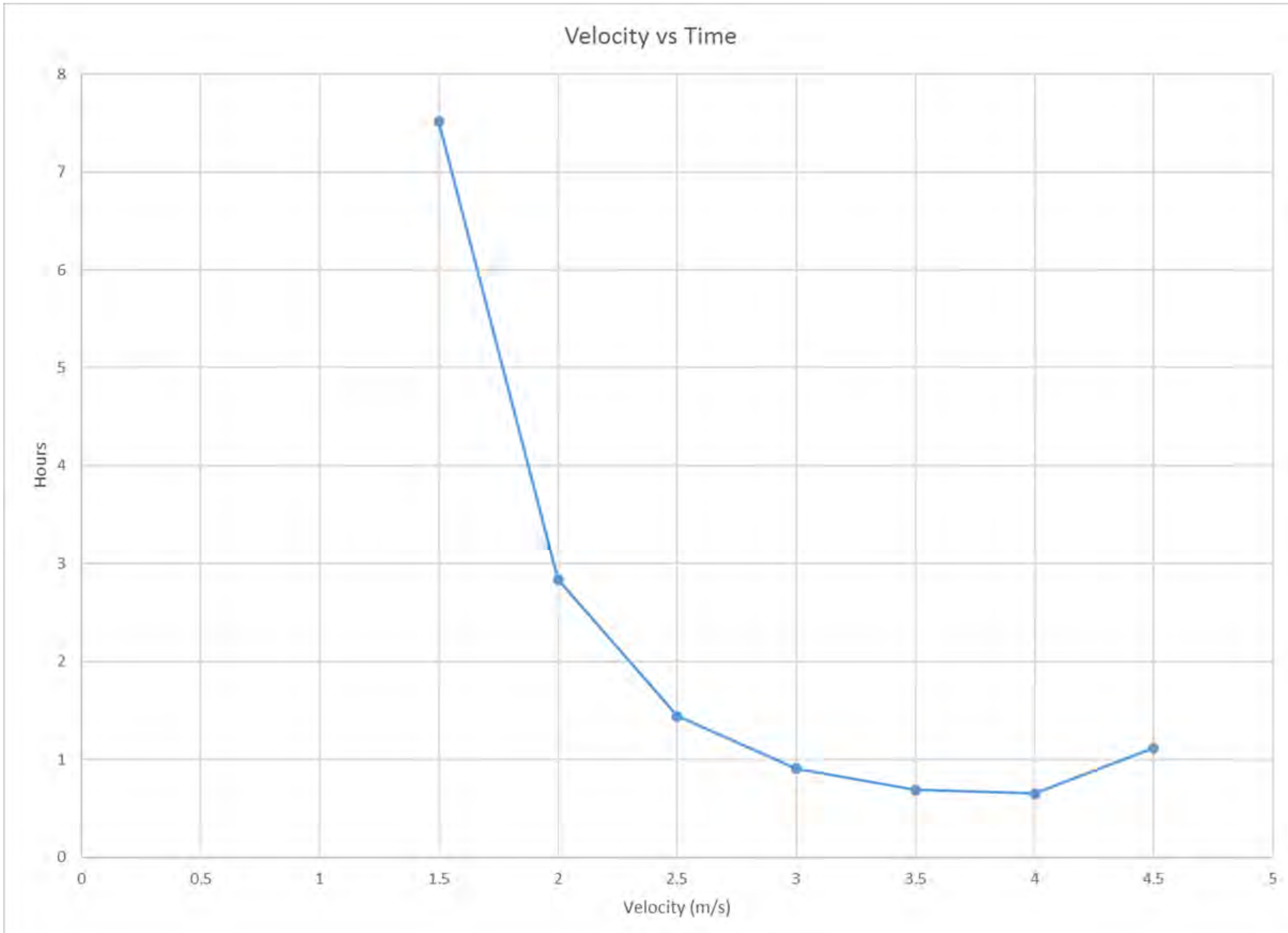


Figure 6.K: River speed vs Time to charge the battery

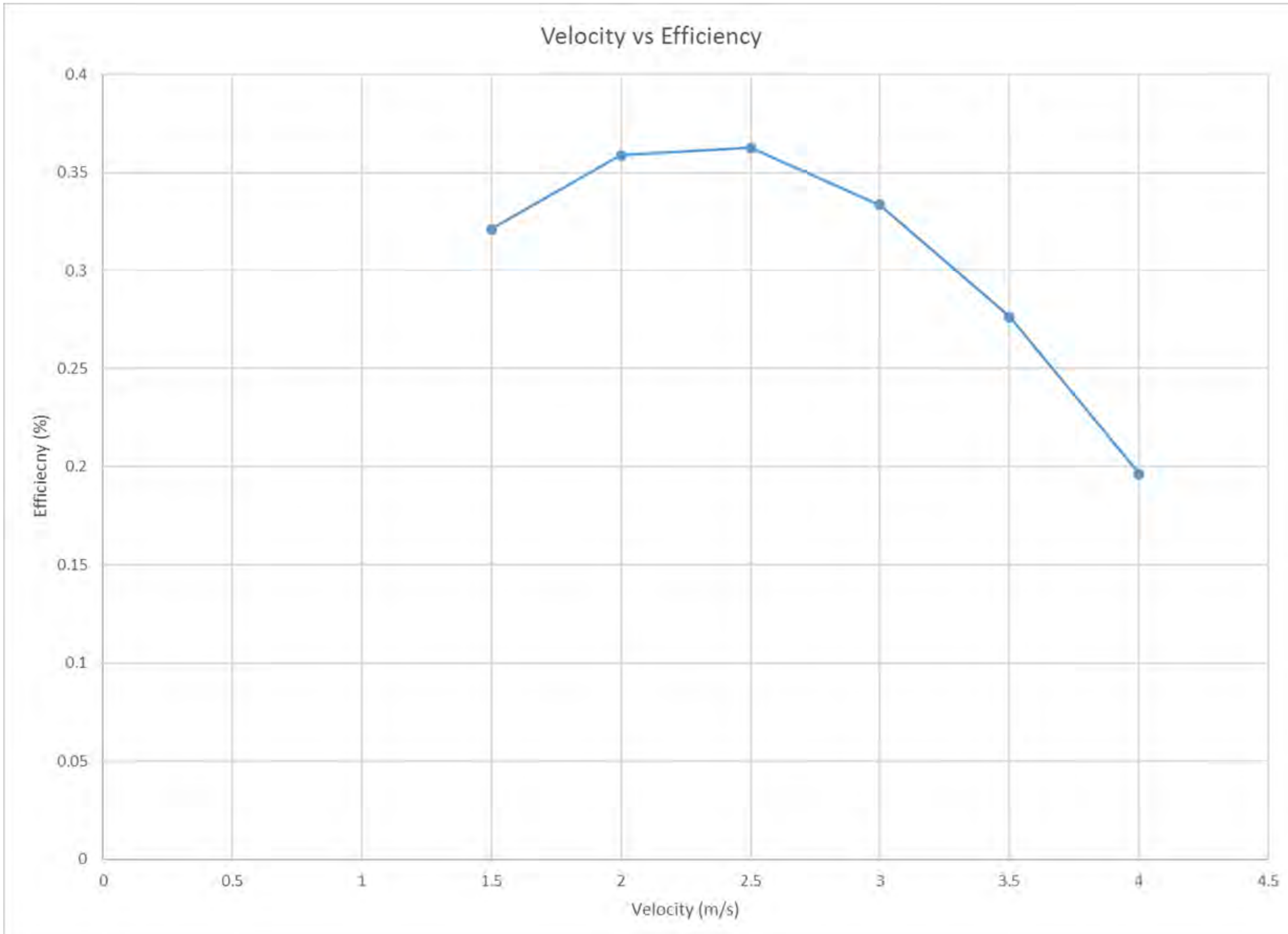


Figure 6.L: River speed vs Efficiency of the system

Shaft

The shaft of the turbine is made of AK 304 Austenitic Stainless Steel. This is because stainless steel is strong and will not rust from prolonged contact with water. The shaft is supported at either end by pillow blocks before being connected to the generator. The following formulas were used to determine the optimal diameter of the shaft.

The first step in order to determine the minimum recommended shaft diameter is to determine the amount of torque that will be acting on the shaft. If necessary, the torque of a system can be increased by either lengthening the turbine or increasing its diameter. Increasing the diameter of the turbine will reduce the RPMs, however increasing the turbines length will maintain the RPMs while increasing the torque. In order to do the following calculation, the efficiency of the turbine must be known. This value is impossible to know unless the turbine was constructed. This value must be estimated based on poncelet undershot water wheel research, which estimates the efficiency of its turbine designs to be 70%. This approximation leaves room for error in the dimensions of the shaft. The formula can be shown in the previous section.

The next calculation is to determine the weight of the turbine and shaft system. This system consists of the shaft, blades and side plates. With the shaft and side plates being made up of stainless steel and the blades made up of fiberglass. In order to determine the weight of the system you first have to estimate the shaft diameter in order to determine its weight. Only then can you determine if the shaft diameter you have selected is able to handle the forces acting on the blades and the weight of the system.

$$Ww = p_{fg} * (L * Bw * Bt * Number\ of\ blades) + p_{steel} * (2 * (\pi * (6 * D)^2 * Sp) + (Ls * \pi * Sr^2)$$

The maximum force on the shaft is the maximum total force experienced by the shaft, comprising of the weight of the wheel and the maximum force on the blades.

$$F_s = Ww + F_b$$

The maximum shaft bending moment of a fixed shaft will occur in the middle of the shaft. This equation was derived from Soderberg analysis.

$$M_s = F_s * \frac{L_s}{8}$$

Now that the max shaft bending moment has been determined the minimum recommended shaft diameter of the turbine can now be determined. The shaft diameter was estimated in order to determine the weight of the wheel. This calculation will determine whether our approximation of the shaft diameter was correct.

$$d = \left(32 * \frac{f_s}{\pi} * \left(\left(\frac{T}{material\ yield\ strength} \right)^2 + \left(\frac{M_s}{material\ enduarance\ limit} \right)^2 \right)^{1/2} \right)^{1/3}$$

The previously explained formulas can be seen in Appendix A.1 as sample calculations.

<u>Pillow Block:</u>

There are two pillow blocks in this generator system, each one is located exactly the same distance from the turbine. This was designed this way to concentrate the maximum force that will occur from the turbine in the middle of the shaft. The pillow blocks are made of stainless steel and the bearings have a single lip seal to make the entire unit water proof. Stainless steel is corrosive resistant and the single lip rubber sealing protects the bearings from water and dust particle. The pillow block sizing was selected from NSK motion and control but altered to fit our design specifications. The bearings are self-lubricating with grease. The pillow blocks are mounted to the inside of the stainless-steel case.

Flange

The flange of the system is designed to connect the shaft of the turbine to the shaft of the generator. The flange is made of stainless steel as well as the nuts and bolt holding the flange together. The following flange calculations were used to determine the dimensions of the flange. By determining the shear and normal stress of the different sections of the flange one can determine the maximum stress each section will be under. In order to make sure the dimensions of the flange would be able to handle the stress, the factor of safety was altered according to each pieces expected stress fluctuations.

i) Keyway and bolts

$$\tau = \frac{0.5 * Syt}{fs}$$

$$\sigma = \frac{1.5 * Syt}{fs}$$

ii) Flanges

$$\tau = \frac{0.5 * Sut}{fs}$$

The dimensions of the flange follow the following calculation dimensions. If the following shear stress value is less than the flange shear stress value above then the following dimensions will work for the flange.

$$diameter\ of\ shaft, d$$

$$hub\ diameter, d_h = 2 * d$$

$$hub\ length,\ l_h = 1.5 * d$$

$$Bolt\ circle\ diameter, D = 3 * d$$

$$Flange\ thickness, t_f = 0.5 * d$$

$$Outside\ diameter\ of\ flanges, Do = 4 * d$$

$$J = polar\ moment\ of\ inertia\ (mm^4)$$

$$J = \frac{\pi * (dh^4 - d^4)}{32}$$

$$T_d = design\ Torque$$

$$\tau = \frac{T_d * d}{J}$$

The following calculations are used to determine the necessary bolt diameter for the flange. The normal stress can then be determined and if the normal stress below is less than the normal stress outlined in (i) Keyways and bolts. This will prove that the bolt with the diameter selected will be able to handle the stresses acting on the flange.

$$db = bolt\ diameter\ (mm)$$

$$N = Number\ of\ bolts$$

$$db^2 = \frac{8 * T_d}{\pi * D * N * \tau}$$

$$\sigma = \frac{2 * T_d}{N * db * t * D}$$

The dimensions of the keyway can be determined with the formulas below. Using the attached data sheet, dimensions could be selected for the calculated shaft diameter and using the following formulas to determine the normal and shear stresses acting on the keyway. If the normal and shear stress values are lower than the values in Eq. (i) then the keyway dimensions are acceptable.

From data sheet [2]

$$H = 0.19685\ in$$

$$W = 0.19685$$

$$l_h = L = 0.9375\ in$$

$$\tau = \frac{2 * T_d}{d * W * L}$$

$$\sigma = \frac{4 * T_d}{d * L * H}$$

The sample calculations for the flange can be seen in Appendix A.1.

Protective Casing

The protective casing is made of 2000-Series Aluminum. Its purpose is to protect the generator from constant exposure to the elements as well as a fixed position to mount the pillow blocks, pontoons and battery pack.

Pontoons

The pontoons are made from 2000-Series Aluminum. The pontoons are designed to keep the system afloat, to stabilize the system from rocking back and forth due to the rotation of the turbine and to allow the system to sink to the operational depth in the water. The following calculations were used in order to determine the necessary size of the pontoons.

$$Buoyancy = Volume\ (ft^3) * 62$$

This formula is derived from the fact that 1 cubic foot of water weighs 62lbs. This means that a 1 cubic foot box will be able to hold up 62lbs before sinking. For the purposes of our system the pontoons have been designed to be submerged halfway. This will keep the system afloat but the system will be at the necessary depth for the turbine blades to enter the water. The full calculations for the pontoon dimensions can be seen in Appendix A.1.

The entire system and all its components in detail can be seen in Appendix A.2.

Finite Element Analysis

The following image is a FEA analysis of the turbine blades. The maximum force that will occur on a fixed beam will happen at the location where the beam the support are fixed, which can be visually seen on the FEA below. The FEA that the SolidWorks program conducted determined the maximum von Mises stress the system will be under and the maximum stress the system can endure based upon the selected materials. The maximum force acting on the blades was calculated from 5m/s river conditions. The reason for this was that the system may only be operating in rivers that travel at most 4m/s, however do to the possibility of damage to the blades, river debris, material processing error or misuse of the system, we wanted to make sure the system would not fail under any circumstance. Looking at the FEA below, we can see that the turbine blades will not break.

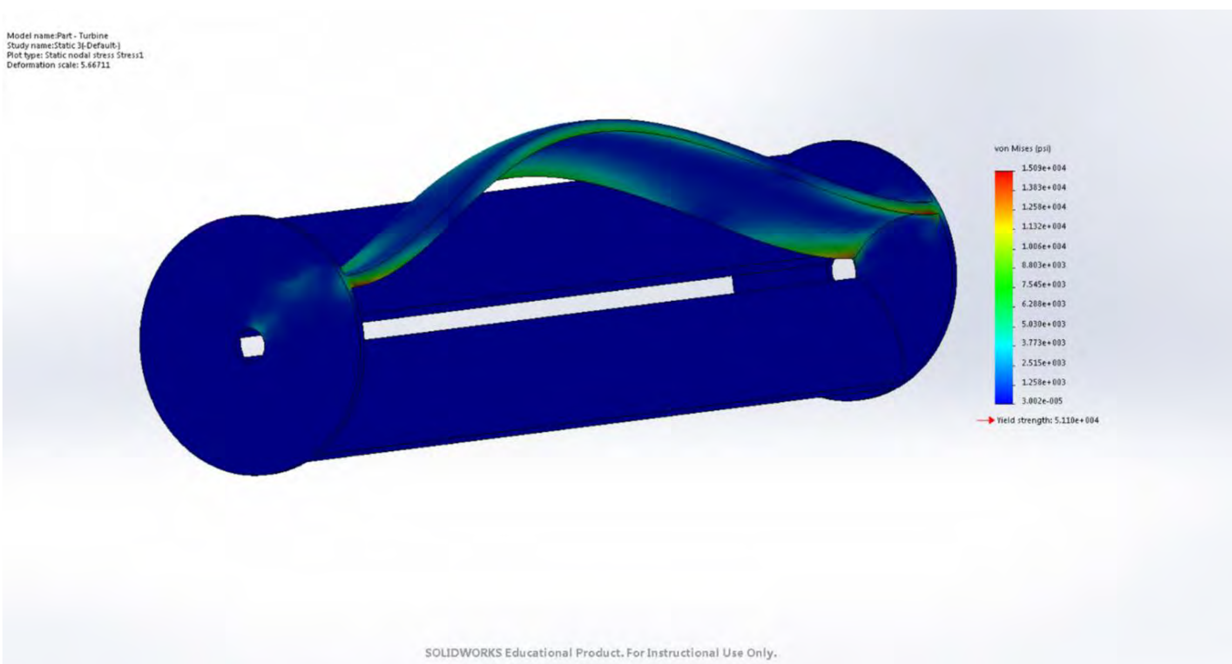


Figure 6.M: Finite element analysis of turbine blades. Constructed in SolidWorks.

The FEA analysis for the following image is stress analysis of the supporting side cylinders for the turbine. This stress analysis determines whether the dimensions selected will be able to handle the forces acting on the support plates. It can be seen that the forces acting on the cylinder while rotation occurs are not very large and does not exceed the max yield strength of the stainless-steel material. Therefore, the dimensions selected for the side cylinders will not be deformed or break.

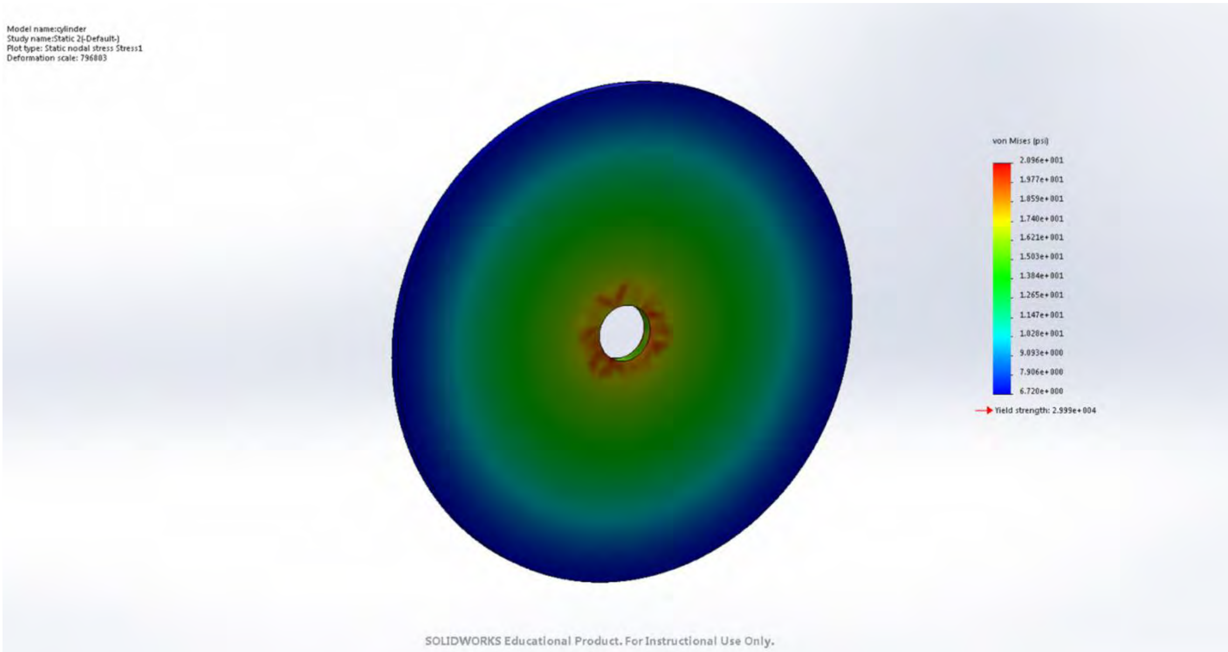


Figure 6.N: Finite element analysis of turbine end plates. Constructed in SolidWorks.

The following image is a detailed FEA analysis of the turbine shaft. It can be seen on the figure below that the torque and RPM the shaft will be under are not significant enough to cause the shaft to fail due to stress. This is confirmed by the fact that the von Mises stress the system is under is much less than the materials yield strength. This proves that the dimensions that were selected for the shaft are sufficient in keeping the shaft from failing due to stress.

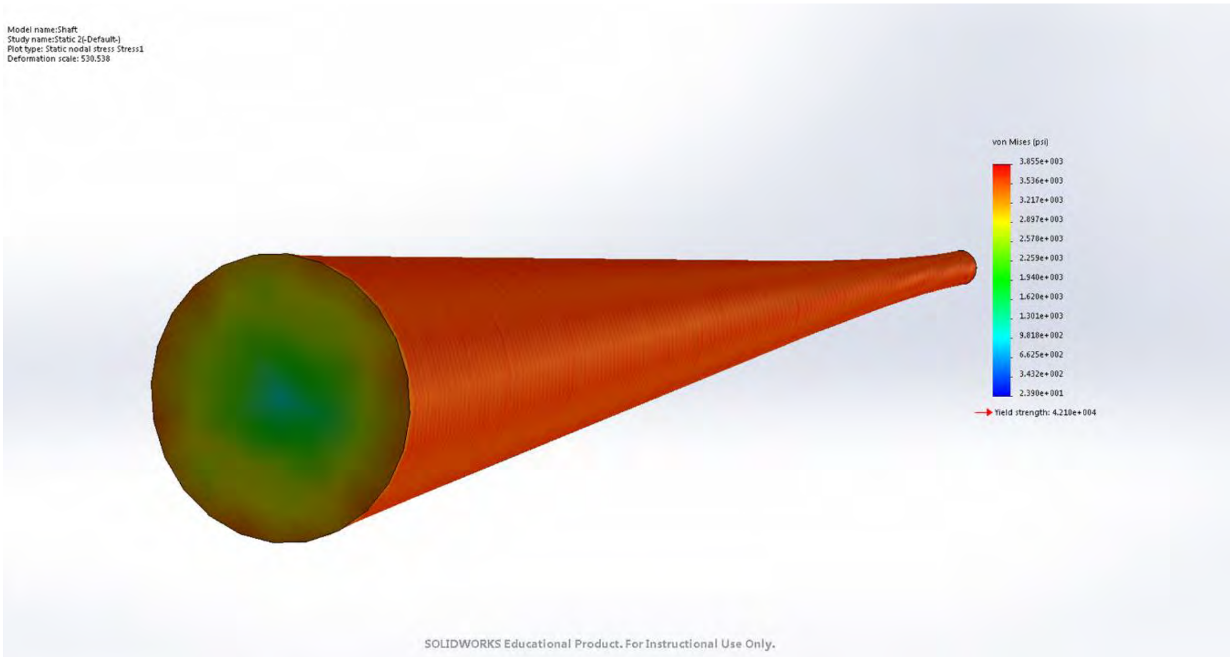


Figure 6.O: Finite element analysis of shaft. Constructed in SolidWorks.

The following FEA analysis depicts the forces of torque and RPM's acting on the pillow block. This analysis proves that the chosen pillow block from NSK with its dimensions will be able to support the rotating shaft since the max stress acting on the pillow block is lower then the yield strength of the pillow block.

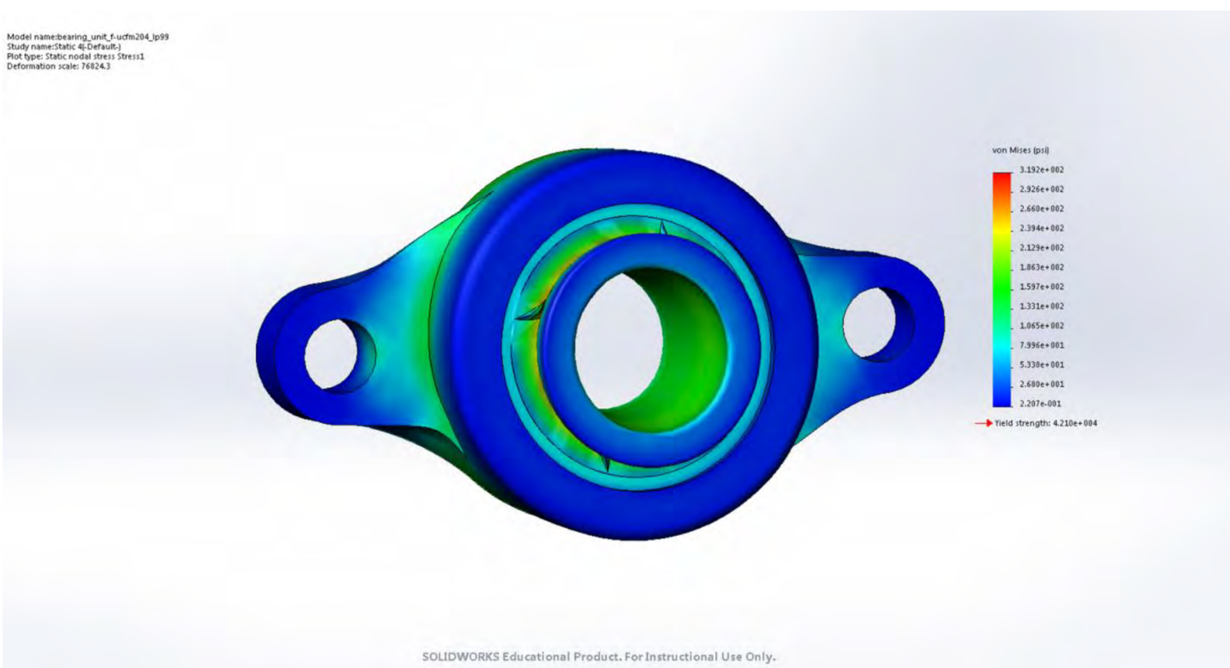


Figure 6.P: Finite element analysis of pillow block. Constructed in SolidWorks.

The following FEA of the Flange system shows that torque and the RPM's acting on the shaft will not cause the flange to fail. The shaft of the turbine and the generator is under much more stress then the forces acting on the flange.

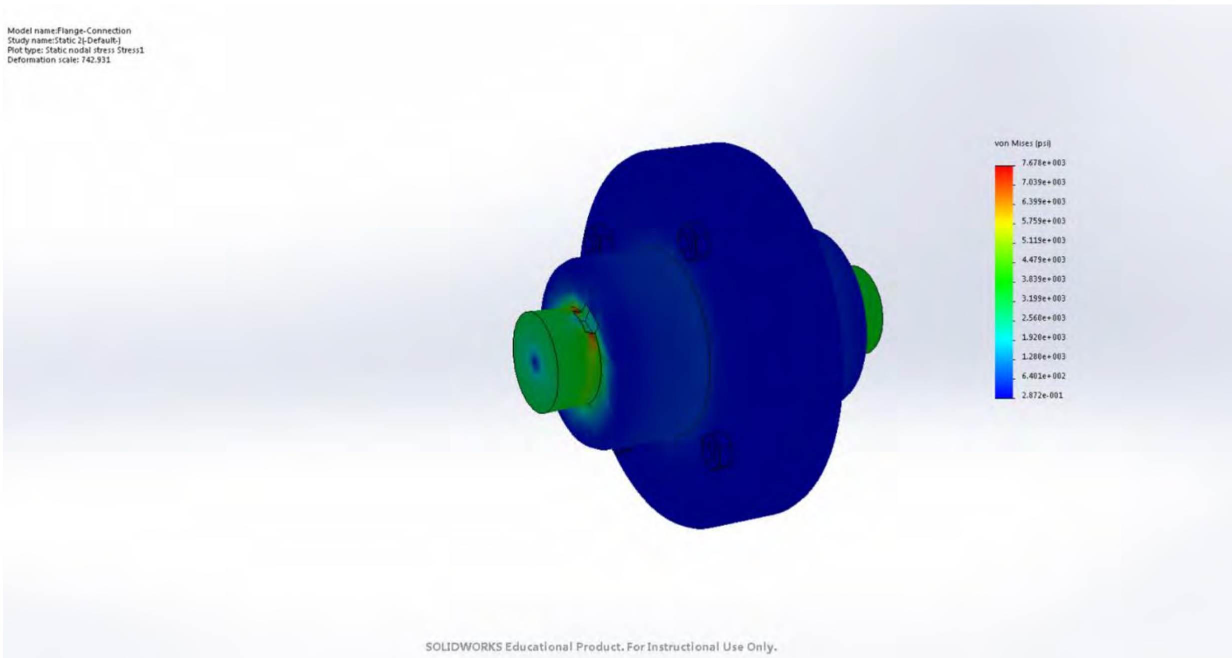


Figure 6.Q: Finite element analysis of the flange. Constructed in SolidWorks.

7.0 Operation, Maintenance, Service and Disposal

Operation

The system operates in rivers flowing between 1.5m/s and 4m/s, but has been built to withstand the forces of the water travelling up to 5m/s. The system can operate in flowing water with a depth of 8 inches or more. To determine the velocity of the river, one can use a range of measuring devices. For the purposes of this design and to avoid carrying excess gear the float method is appropriate.

You need:

- tape measure
- stop-watch
- at least three highly visible buoyant objects
- Waders

Float method – inexpensive and simple. This method measures surface velocity. Mean velocity is obtained using a correction factor. The basic idea is to measure the time that it takes the object to float a specified distance downstream.

$$V_{surface} = \text{travel distance/ travel time}$$

Step 1 – Choose a suitable straight reach with minimum turbulence

Step 2 – Mark the start and end point of your channel.

Step 3 – If possible, travel time should exceed 20 seconds.

Step 4 – Drop your object into the stream upstream of your upstream marker.

Step 5 – Start the watch when the object crosses the upstream marker and stop the watch when it crosses the downstream marker.

Step 6 – You should repeat the measurement at least 3 times and use the average in further calculations.

Using these steps, you can determine if the location of your selected site is suitable to place the hydroelectric generator. System cannot be placed in location where rapids or waves occur. The system cannot handle impact from large debris. The system must be secured while in the river. There are three different ways to accomplish this:

1. By attaching a rope or chain to the protective casing and an anchor. The unit can be placed on the river while the anchor keeps the unit stationary. The unit is not very heavy so, regular camping rope could be used. As for the anchor, a cinder block or a bag filled with a heavy substance, whatever is portable and feasible at the time.
2. If the river is narrow enough, ropes can be attached to the casing and secured on either side of the river. This system is ideal for it removes the finding of an anchor, like in the previous set-up.
3. Steel rods can be hammered into the river bed and then secured to the protective casing. This approach only can work if the river is shallow enough and the base of the river is comprised of material that will not hinder the steel rods being secured, like a bedrock river. This set-up requires additional tools, sledge-hammer and steel rods to accomplish and is not ideal if constantly travelling

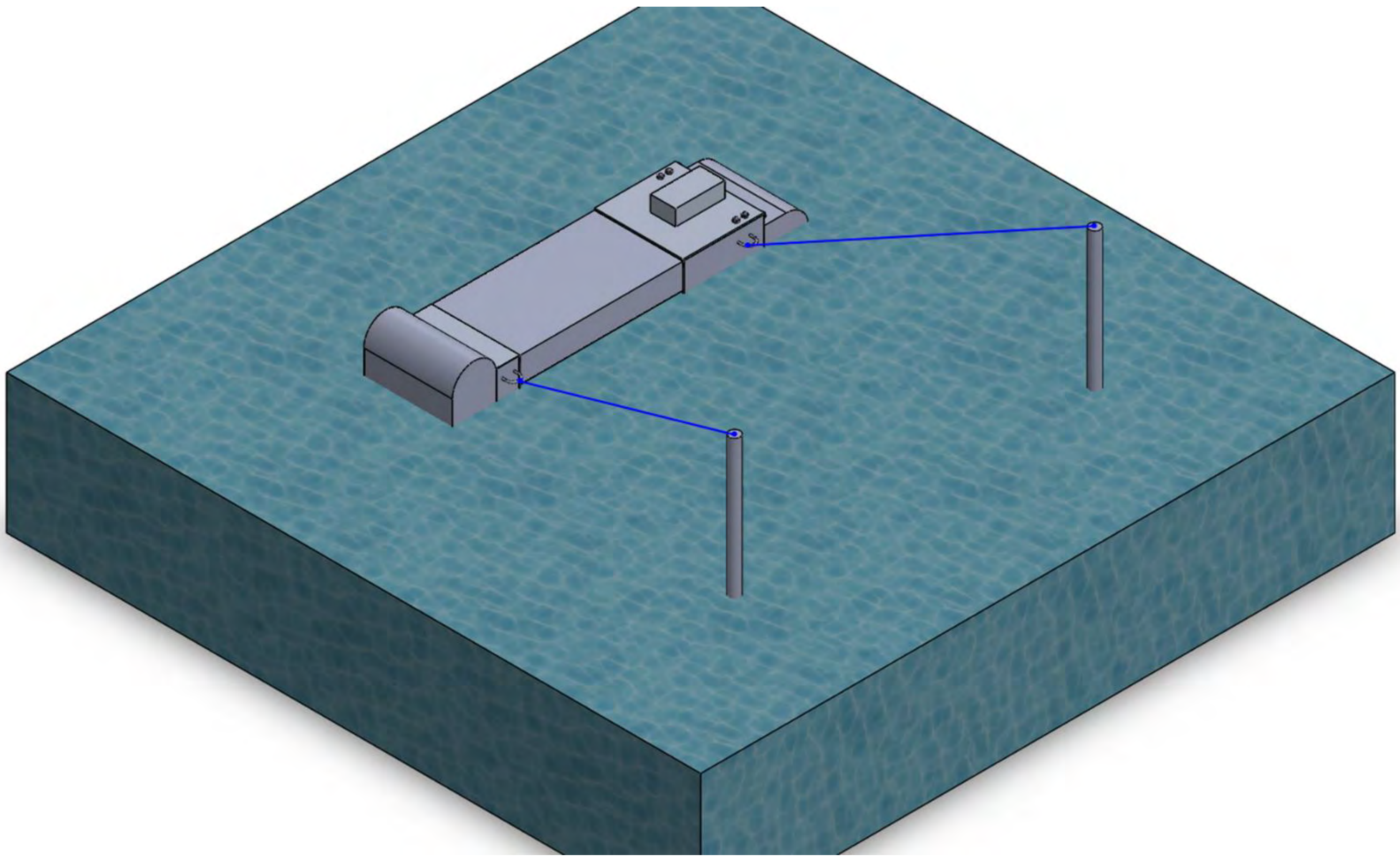


Figure 7.A: System in water, fixed to steel rods placed in river bed. Constructed in SolidWorks

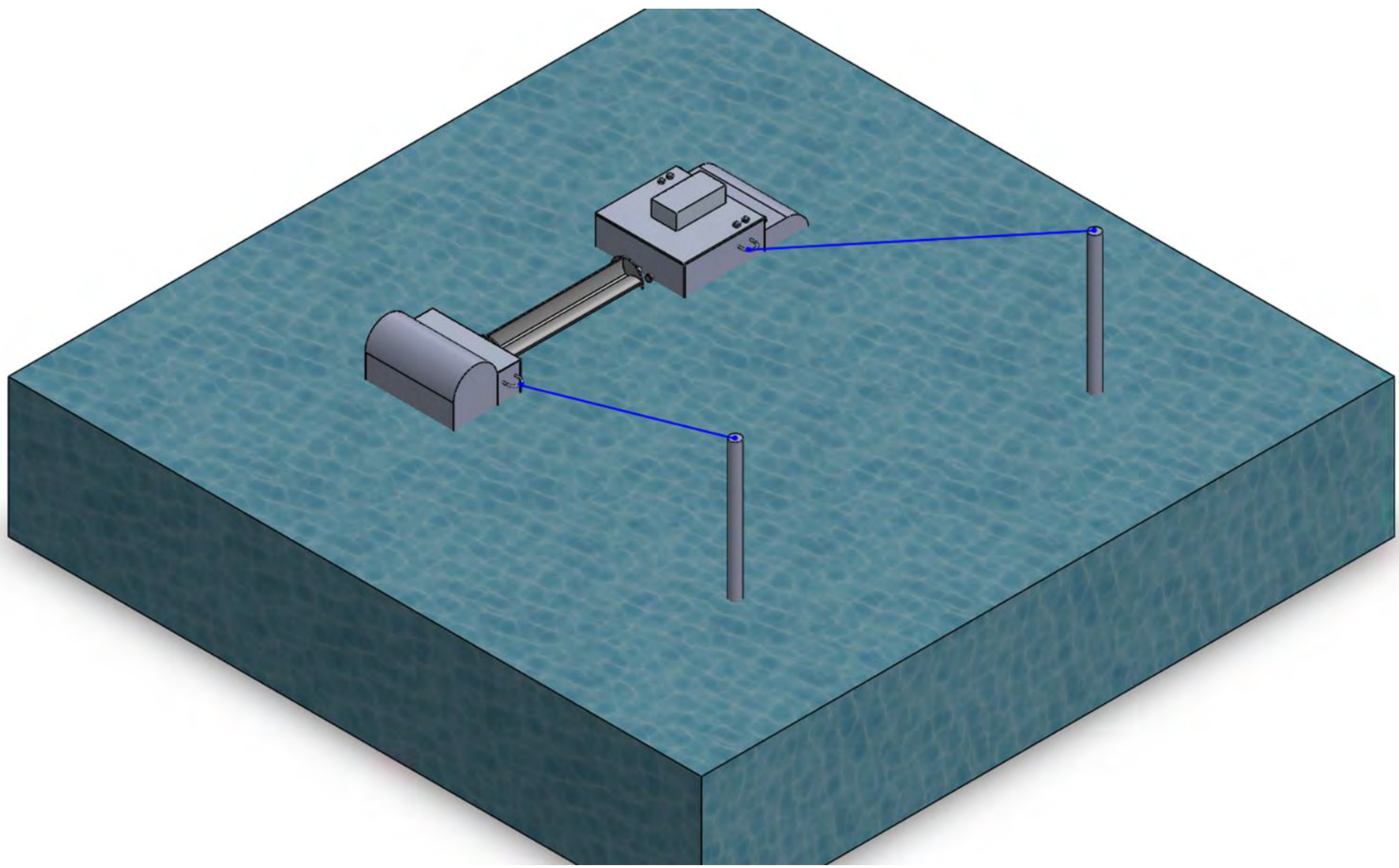


Figure 7.B: System in water, no turbine housing to show blade contact with water. Constructed in SolidWorks

Maintenance

A general inspection of the system should occur when general maintenance occurs. This will determine if the system requires any repairs that are not normal to the maintenance of the system.

Pillow block

There are two waterproof stainless steel pillow blocks in this assembly. To achieve maximum performance from them, the bearings must be lubricated appropriately. This can only done by loosening the shaft and opening the bearing housing unit. Once that has been achieved the bearings can be lubricated with any lubrication grease. Add grease until it shows at the seals. The bearing unit can then be closed and the shaft reattached. The pillow block should be lubricated at least once per year or more often if the use of the system is substantial. The grease used in the lubrication of the bearing can be any standard grease in a hardware store.

Flange

The flange that connects the generator shaft to the turbine shaft does not require any form of lubrication or anticorrosive spray. All that is required for maintenance is to check and retighten the bolts when necessary.

Shaft/Turbine

The turbine and shaft will be under the most amount of force when operating. In order to maintain optimal output, the shaft and turbine should be cleaned depending on the amount of usage. Cleaning the assembly will ensure that a build up of dust and particles does not occur. This will increase the performance of the turbine because there will be no residual debris built up causing the turbine and shaft to rotate at a slower rate and therefore generate less power. The turbine and shaft connection should be retightened during every maintenance inspection to ensure optimal performance.

System Casing

The system casing should be inspected to determine if any damage to the unit occurred from either floating debris or general handling of the unit.

Pontoons

The Pontoons should be inspected to determine if any punctures occurred. If the pontoons are punctured the system will be unable to maintain the correct depth in the water.

Disposal

The generator system is comprised of mostly fiberglass, stainless steel and aluminum. All materials can be easily recycled or reused in other products. The battery must be disposed of depending on your local municipality. It is legal in some locations to dispose of batteries in your trash, other locations require you bring the battery to your local recycling center to be safely disposed of.

8.0 Cost and Bill of Materials

All parts of the assembly are manufactured separately. The casing is welded together excluding end plates and caps. The turbine blades are welded to the side plates. The pillow blocks are then attached to the casing via bolts. The generator, flange, shaft and turbine are all installed at the same time. This is because in order for the internal assembly support itself, all of the pieces must be connected at the same time. The end plates of the casing are welded to the pontoons and then fixed to the case via bolt. The battery is then placed in its own separate casing.

Part	Material	Unit Cost	Retail	Wholesale
Turbine Blades	G-9 Fiberglass Melamine Laminate	$1.013/in^3$	$19.43	$9.72
Turbine Side Plates	Stainless Steel	$8.00/plate	$16.00	$8.00
Shaft	AK 304 Austentic Stainless Steel	$7.73/in^3$	$64.07	$32.04
Pillow Block	NSK	$40 each	$80.00	$40.00
Generator	DC-520	$219 each	$219.00	$109.50
Battery	ULIBP	$212 each	$212.00	$106.00
Cable	Orange Type G	$2.00/ft	$30.00	$15.00
Case	2000-Series Aluminum	$0.76/in^3$	$118.11	$59.06
Pontoons	2000-Series Aluminum	$0.76/in^3$	$42.41	$21.21
Bolt (3mm)	A2 Stainless Steel	$0.07 each	$0.28	$0.14
Bolt (0.4in) Long	A2 Stainless Steel	$0.56 each	$2.24	$1.12
Bolt (0.4in) Short	A2 Stainless Steel	$0.37 each	$2.96	$1.48
Nut (3mm)	A2 Stainless Steel	$0.05 each	$0.20	$0.10
Nut (0.4in)	A2 Stainless Steel	$0.24 each	$2.88	$1.44
	Total Cost of Components		**$809.58**	**$404.79**

Table 8.A: Bill of Materials

Table 8.A is the cost analysis of each piece of the assembly. The cost break down is split between two categories, retail and wholesale price. The wholesale is the cost to produce the unit. The retail price of any merchandise is normally a 40%-60% markup of the wholesale cost. If this system was built, the system pieces would be purchased at the wholesale price. We were unable to determine the labour cost to assemble the system. The manufacturers contacted would not give an estimate to produce this unit. This was the same situation for determining the transportation costs of the unit.

9.0 Validation and Compliance

The system can operate in common river conditions. Which greatly increases the units usability. Common river conditions range from 1.5 to 2.5 m/s. This system can operate in rivers ranging from 1.5 to 4 m/s and still produce the necessary voltage to charge the battery. The system is safe to use. It’s not made of any material that could cause harm to an individual. The design is light and making it easy to transport. The conditions that the system can operate in are not extreme, meaning that there is very little risk in being injured when setting up. The design is made of materials that are easy to access and manufacture. With the current design, manufacturing and assembling the system will be simple. This will keep costs down and allow a greater range of clients. There were no physical validations that occurred to test the design. This is due to the fact that we did not have the resources or time to manufacture this assembly.

The people who will be affected by this design are the customers and the manufactures. The design meets the needs of the customers, for the design is light enough to be carried. Simple to operate, easy to maintain and produces enough power to charge small electronic devices. For the manufacturers, the design meets the needs of being simple to manufacturer and to assemble. This factor is critical in keeping manufacturing costs down, because if the assembly used rare metals like solar panels, the cost and time to manufacturer would increase.

10.0 Conclusions and Recommendations

In conclusion, the total length of the system is 1.3 meters. This dimension meets the necessary length constraint for the system. The total weight of the design is 44.2 lbs, which is less then the weight limit. The minimum 9 volts necessary to charge the battery was met while the generator operated in average river conditions of 1.5 - 2.5 m/s. The time necessary to charge the battery ranged from 0.5 - 7.5 hours.

The design was innovative because it has the ability to harness hydroelectricity without any infrastructure cost. This is the primary cost when trying to harness hydroelectric electricity and the main deterrent. The floating design allows easy access and setup, with the added benefit of not impeding wildlife. The portable design allows you to take it where you want to go and the system is made of materials that will not oxidize do to water exposure and therefore cause harm to the environment.

The unit is relatively cheap for the amount of power that is produced. The time and cost to assemble the unit is low. The system is green, minus the environmental impacts in production and transportation. In todays markets, green technology is very popular, with individuals wanting to reduce their carbon footprint. This makes this system very popular. Also with energy costs rising today, the demand for renewable sustainable electricity is high.

Future research that can be conducted to improve on this system are that the unit can be designed so that it can be assembled by the consumer. Bringing down costs further. Investigating into reducing the costs of the materials or selecting different materials that will further reduce the cost. Designing a generator that’s torque and RPM requirements are closer to the outputs of the turbine. This will increase the amount of power produced. Designing a more sophisticated housing unit. When designing the housing, we did not take into account water resistance from flowing water and the unit is not visually appealing, making selling this product difficult.

In conclusion, this project allowed us to apply the different skills we have acquired in our engineering education. We feel that it accurately demonstrates our problem solving abilities along with showing our creativity.

11.0 References

[1] AboutGenerators.com, "Gas powered Generators are popular but is it for you?", www.aboutgenerators.com

[2] Armstrong Metalcrafts-Key Dimensions" www.armstrongmetalcrafts.com

[3] "Beam Calculator" by SkyCiv, Online Engineering Software, www.bendingmoment diagram.com

[4] Bolt Depot, www.BoltDepot.com

[5] "Borst Engineering and Consturction LLC", CEO Robert G. (Bob) Borst, 19000 E.Evans Creek Road, Rogue River, OR 097537

[6] B.Tech Students, Department of Mechanical Engiennering, NIT Durgapur, Durgapur, India "Design and Stress-Analysis of a Rigid Flange Coupling using FEM", International Journal of Innovative Research in Science Engineering and Technology, , Vol.4, issue 10, October 2015

[7] Cairn Consulting Group , "North American Camping Report, 2015"

[8] Coleman Company, Inc , "2014 American Camper Report"

[9] "Efficiency in Small Permanent Magnet DC Generators", www.windstreampower.com

[10] Energy Informative, "Wind Energy Pros and Cons", www.energyinformative.org

[11] "How and Why you Might SINK AND DIE", www.manitoupontoonboats.com

[12] "Instruction Manual for Pillow Blocks", www.SKF.com

[13] Jacob Poushter and Russ Oates , "Cell Phones in Africa: Communication Lifeline", Pew Research Center, April 15, 2015. www.pewresearch.org

[14] MatWeb: Online Materials Information Resource, www.matweb.com

[15] Wind Blue Power, DC-520 High wind, www.windbluepower.com

[16] Metals Depot, www.metalsdepot.com

[17] Microsoft Word, Excel and PowerPoint, 2016

[18] Mission 2014: Feeding the World, "Roads in Sub-Saharan Africa", www.12.000.scripts.mit.edu

[19] Mission 2014: Feeding the World, "Water Access in South Africa", www.12.000.scripts.mit.edu

[20] Motion and Control NSK, Stainless steel flange, www.nskamericas.com

[21] Operating Technical Electronics, Inc, "A Guide to Battery Charging", 1289 Hemphill St. Fort Worth, TX. 76104

[22] Physics Factbook-Speed of a River , www.hypertextbook.com

[23] "Power Stream", Universal Lithium Ion battery pack, www.powerstream.com

[24] "Solacity Inc", The Truth about Small Wind Turbines. www.solacity.com

[25] "SolidWorks Software", www.solidworks.com

[26] "TPC Wire and Cable Corp", Super Trex Type G Portable Power Cable, www.tpcwire.com

[27] "Workplace Health and Safety Bulletin-You Want Me To Lift How Much?", Government of Alberta, www.work.alberta.ca

12.0 Appendices

Appendix

A.1

All material specifications provided by matweb.

Materials:

AK Steel 304 Austenitic Stainless Steel

Density= 0.290 lb/in^3

Tensile Strength, Ultimate= 621 MPa or 90100 psi

Endurance Limit= 0.5*90100 = 45050 psi

Tensile Strength, Yield= 290 MPa or 42100 psi

Poissons Ratio= 0.24

G-9 Fiberglass Melamine Laminate Sheet

Density= 0.0668 lb/in^3

Tensile Strength, Ultimate= 51100 psi

Endurance Limit= 0.5*51100 = 25550 psi

Tensile Strength, Yield= 51100 psi

2000 Series Aluminum Alloy

Density= 0.0932 lb/in^3

Tensile Strength, Ultimate= 25000 psi

Endurance Limit= 0.5*90100 = 12500 psi

Tensile Strength, Yield= 10000 psi

AISI Type A2 Tool Stainless Steel

Density= 0.284 lb/in^3

Tensile Strength, Ultimate= 90100 psi

Endurance Limit=45050 psi

Tensile Strength, Yield= 42100 psi

Turbine:

Using velocity of the river at 1m/s or 3.281 ft/s to determine the Head value

$$H = \frac{V^2}{2g} = \frac{(3.281)^2}{2 * (32.174)} = 0.1673\, ft$$

Diameter of the turbine is determined from the head value. Optimal diameter for the system is 2.311H.

$$D = 2.311 * H = 2.311 * 0.1673 = 0.3866\, ft$$

Working Diameter of the turbine

$$W_d = D - H = 0.3866 - 0.1673 = 0.2193\, ft$$

Working Circumference

$$W_c = W_d * \pi = 0.2193 * \pi = 0.689\, ft$$

Optimal rim tangential speed is assumed to be 67% of the water speed. For these calculations velocity at 2.5m/s or 8.2021 ft/s

$$Oprts = e * V = 0.67 * 8.2021 = 5.495\, ft/s$$

Optimal rotational speed determines the RPM's on the system

$$Oprs = \frac{Oprts * 60}{W_c} = \frac{5.495 * 60}{0.689} = 478.59\, RPM$$

Working cross sectional area. The length of the system is 0.5 m or 19.685 in.

$$W_a = L * H = \left(\frac{19.685}{12}\right) * 0.1673 = 0.2744\, ft^2$$

Effective flow rate of the turbine

$$E_f = W_a * V = 0.2744 * 8.2021 = 2.251\, \left(\frac{ft^3}{s}\right)$$

Theoretical Max Power generated by the turbine. Using the Head value at 2.5m/s

$$P = \frac{H * E_f}{11.8} = \frac{1.045 * 2.251}{11.8} = 0.199\, KW$$

Torque of the system. Using a poncelet system assuming efficiency of the turbine in 70%. Calculated torque at 5m/s for maximum value.

$$T = 5252 * et * P/0.746/Oprs = 5252 * 0.7 * \ 1.595/0.746/957.181 = 8.213\ ft - lb$$

The width of the blades

$$B_w = 12 * H = 12 * 0.1672 = 2.007\ in$$

The Blade spacing

$$B_s = Bw * 0.95 = 2.007 * 0.95 = 1.9069\ in$$

The number of blades

$$Number\ of\ blades = \frac{W_c}{B_s} = \frac{0.689}{1.9069/12} = 4.34 = 4$$

The max force on the blades. The factor of safety used is 2. Used speed and flow rate 16.4042 ft/s

$$F_b = f_s * E_f * V = 2 * 4.501 * 16.4042 = 147.683\ lb$$

Max blade bending moment

$$M_b = 12 * F_b * (\frac{L}{12})/12$$

$$M_b = 12 * 147.683 * (\frac{19.685}{12})/12 = 242.261\ in - lb$$

Minimum blade thickness, using the endurance limit of fiber glass

$$t = \left(\frac{6 * M_b * f_s}{B_w * endurance\ limit}\right)^{0.5} = \left(\frac{6 * 242.261 * 2}{2.007 * 25550}\right)^{0.5} = 0.238\ in = 0.25\ in$$

The blade length between supports

$$B_L = \left(\frac{2 * t^2 * B_w * endurance\ limit}{F_b * f_s}\right)$$

$$B_L = \left(\frac{2 * 0.238^2 * 2.007 * 25550}{147.683 * 2}\right) = 19.685\ in$$

Shaft:

The following is the weight of the wheel. This includes the weight of the blades, side plates and shaft. Side plate thickness was determined to be 0.15 in. The length of the shaft was determined to be 27 inches. The Shaft diameter was estimated at 0.625 inches.

$$Ww = p_{fg} * (L * B_w * B_t * Number\ of\ blades) + p_{steel} * (2 * (\pi * (6 * D)^2 * Sp) + (Ls * \pi * Sr^2)$$

$$= 0.0668 * (19.685 * 2.007 * 0.25 * 4) + 0.29 * \left(2 * (\pi * (6 * 0.3866)^2 * 0.15) + (27 * \pi * \frac{0.625^2}{2}\right)$$

$$Ww = 6.386\ lb$$

Max force on the shaft

$$F_s\ = Ww + F_b = 6.386 + 147.683 = 154.194\ lb$$

Max shaft bending moment

$$M_s = F_s * \frac{L_s}{8} = 12 * 153.826 * \left(\frac{27}{12}/8\right) = 520.407\ in * lb$$

Minimum recommended Shaft diameter

$$d = \left(32 * \frac{f_s}{\pi} * \left(\left(\frac{T}{material\ yield\ strength}\right)^2 + \left(\frac{M_s}{material\ enduarance\ limit}\right)^2\right)^{1/2}\right)^{1/3}$$

$$Msd = \left(32 * \frac{2}{\pi} * \left(\left(\frac{12 * 8.213}{42100}\right)^2 + \left(\frac{520.407}{45050}\right)^2\right)^{1/2}\right)^{1/3}$$

$$Msd = 0.622\ in$$

Therefore shaft diameter of 0.625 in works

Generator Calculations:

At 766 RPM

At T= 5.2567 ft-lb

Using Formulas on Graph

At 650 RPM Formula

$$y = -5.864 * x + 35.564 = -5.864 * 5.2567 + 35.564 = 4.74\ Volts$$

At 875 RPM Formula

$$y = -6.6178 * x + 48.269 = -6.6178 * 5.2567 + 48.269 = 13.48\ Volts$$

Interpolating

$$y = \frac{(766 - 650)(13.48 - 4.74)}{875 - 650} + 4.74$$

$$y = 9.25\ Volts$$

Therefore at 766 RPM the system will be able to generate the necessary voltage to charge the battery

Flange Calculations:

Yield Strength=S_{yt}= 290 N/mm^2

Ultimate Tensile Strength=S_{ut}= 621 N/mm^2

Used a different factor of safety for different sections

i) Keyway and bolts

$$\tau = \frac{0.5 * S_{yt}}{f_s} = \frac{0.5 * 290}{2.5} = 58\ Mpa$$

$$\sigma = \frac{1.5 * S_{yt}}{f_s} = \frac{1.5 * 290}{2.5} = 174\ Mpa$$

ii) Flanges

$$\tau = \frac{0.5 * S_{ut}}{f_s} = \frac{0.5 * 621}{6} = 51.75\ Mpa$$

Dimensions of Flange:

$$diameter\ of\ shaft, d = 15.875\ mm = 0.625\ in$$

$$hub\ diameter, d_h = 2 * d = 31.75\ mm = 1.25\ in$$

$$hub\ length, l_h = 1.5 * d = 23.8125\ mm = 0.9375\ in$$

$$Bolt\ circle\ diameter, D = 3 * d = 47.625\ mm = 1.875\ in$$

$$Flange\ thickness, t_f = 0.5 * d = 7.9375\ mm = 0.3125\ in$$

$$Outside\ diameter\ of\ flanges, D_o = 4 * d = 63.5\ mm = 2.5\ in$$

$$J = polar\ moment\ of\ inertia\ (mm^4)$$

$$J = \frac{\pi * ({d_h}^4 - d^4)}{32} = \frac{\pi * ((31.75)^4 - (15.875)^4)}{32} = 93528.957\ mm^4$$

$$T_d = design\ Torque = 11136.6891\ N - mm$$

$$\tau = \frac{T_d * d}{J} = \frac{11136.6891 * 15.875}{93528.957} = 1.89\ Mpa$$

$$\therefore 1.89 < 51.75\ Mpa\ \therefore ok$$

Bolt Diameter:

$$db = \ bolt\ diameter\ (mm)$$

$$N = \ Number\ of\ bolts$$

$$db^2 = \frac{8 * T_d}{\pi * D * N * \tau} = \frac{8 * 11136.6891}{\pi * 47.625 * 4 * 58} = 2.57 = 3\ mm$$

$$\sigma = \frac{2 * T_d}{N * db * t_f * D} = \frac{2 * 11136.6891}{4 * 3 * 7.9375 * 47.625} = 4.91\ Mpa$$

$$\therefore 4.91\ Mpa < 174\ Mpa\ \ \therefore ok$$

Dimensions of Keys:

$$From\ data\ sheet\ H = 5mm\ W = 5mm\ l_h = L = \ 23.8125\ mm$$

$$\tau = \frac{2 * T_d}{d * W * L} = \frac{2 * 11136.6891}{15.875 * 5 * 23.8125} = 11.784\ Mpa$$

$$\therefore 11.784\ Mpa < 58\ Mpa\ \ \therefore ok$$

$$\sigma = \frac{4 * T_d}{d * L * H} = \frac{4 * 11136.6891}{15.875 * 5 * 23.8125} = 23.568\ Mpa$$

$$\therefore 23.568\ Mpa < 174\ Mpa\ \ \therefore ok$$

Pontoons:

$$Buoyancy = V\ (ft^3) * 62$$

Casing has a natural buoyancy. Must calculate that to determine the size of Pontoons

Short End:

$$V = 4.18 * 12.75 * 3.16 + 2.745 * \frac{9.58 + 12.75}{2} * 3.16 = 265.2596\ in^3 = 0.15351\ ft^3$$

$$Buoyancy = 0.15351 * 62 = 9.52\ lb$$

Generator End:

$$V = 12.75 * 4.18 * 11.47 + 2.745 * \frac{9.58 + 12.75}{2} * 11.47 = 962.826\ in^3 = 0.5572\ ft^3$$

$$Buoyancy = 0.5572 * 62 = 34.55\ lb$$

Pontoon short end:

System weighs 44 lbs. System center of gravity is closer to the generator end. Short end needs to be less Buoyant to make the system flat against the water.

$$V = 6.36 * 3.18 * 12.75 + \pi * 3.18^2 * 12.75 = 920.7877\ in^3 = 0.53286\ ft^3$$

$$Buoyancy = 0.53286 * 62 = 33.04\ lb$$

Pontoon Generator end:

Buoyancy of casing on generator end is greater then the short end. Therefore the pontoon can be smaller.

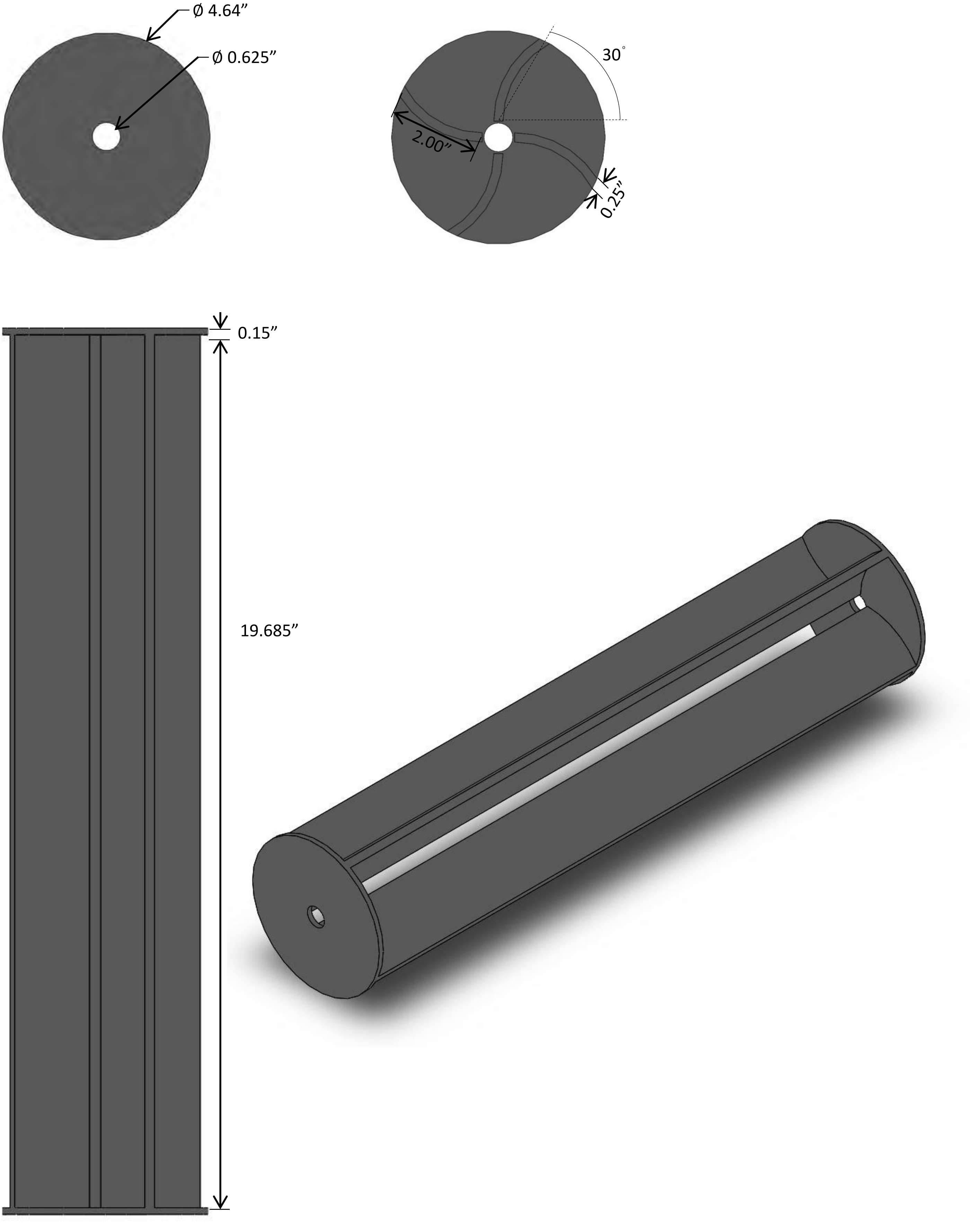
$$V = \pi * 3.18^2 * 12.75 + \frac{3.18^2}{2} * 12.75 = 469.525\ in^3 = 0.2171\ ft^3$$

$$Buoyancy = 0.2171 * 62 = 13.461\ lb$$

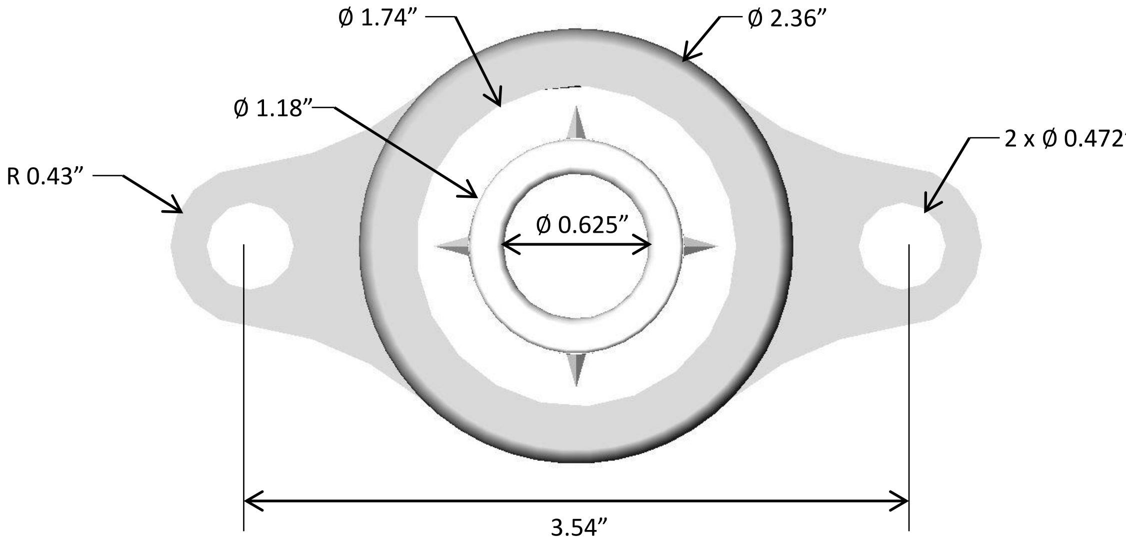
Appendix

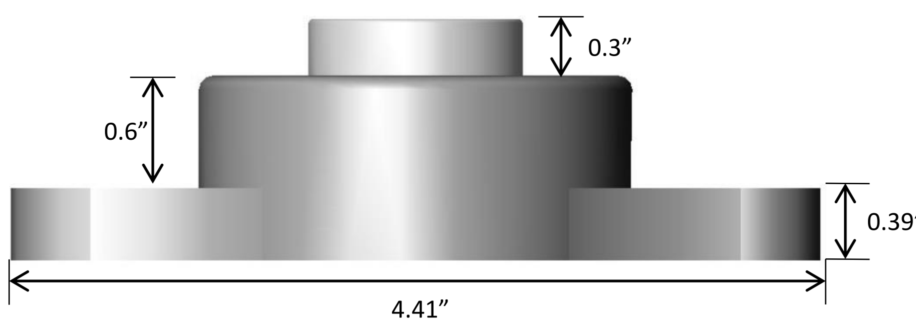
A.2

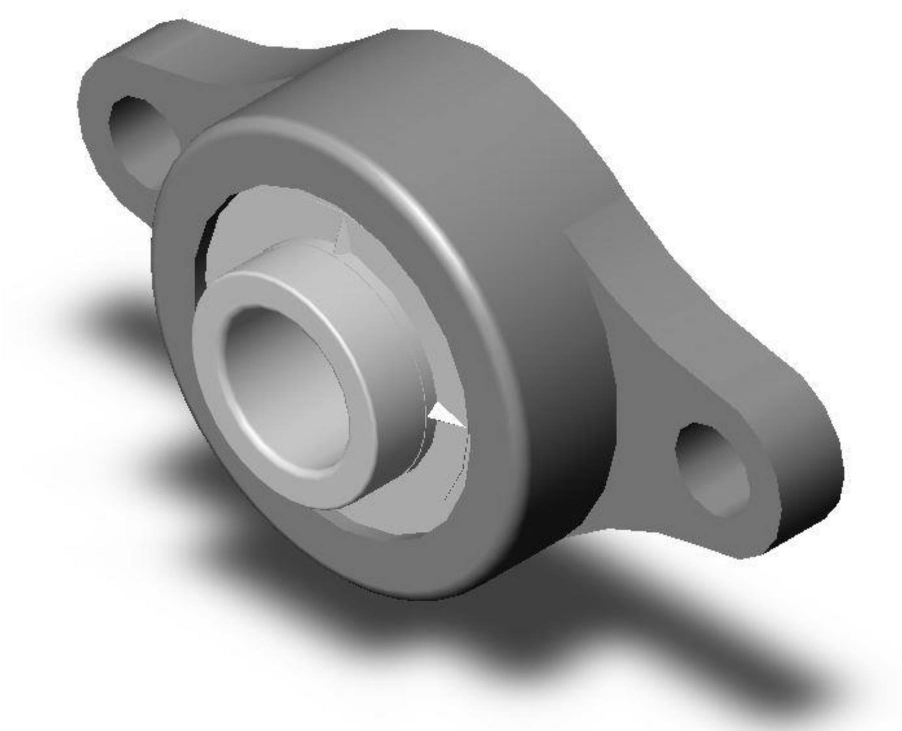
Turbine



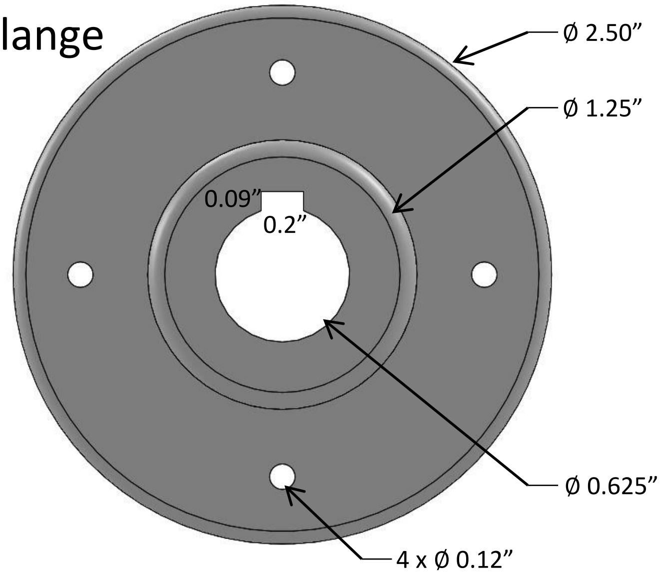
Pillow Block

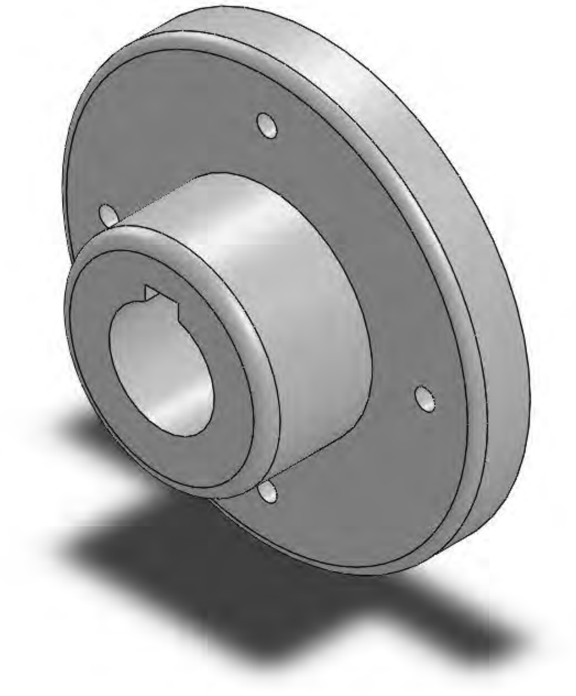


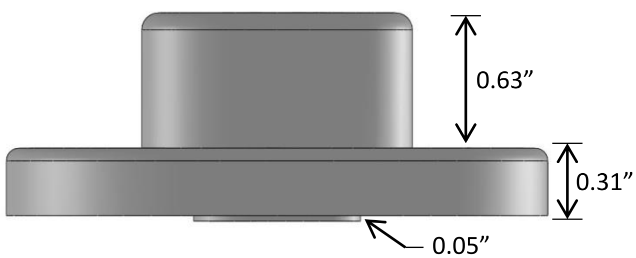


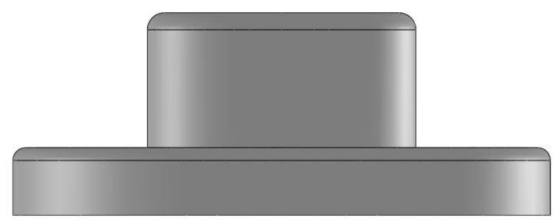


Flange

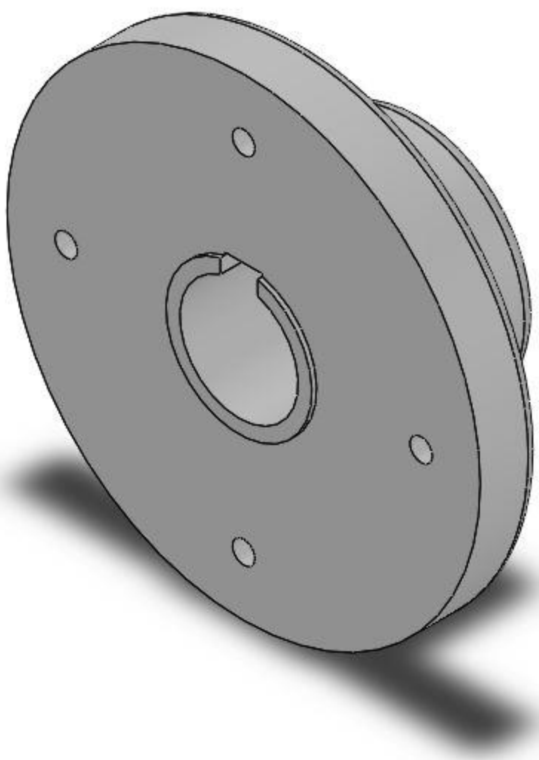




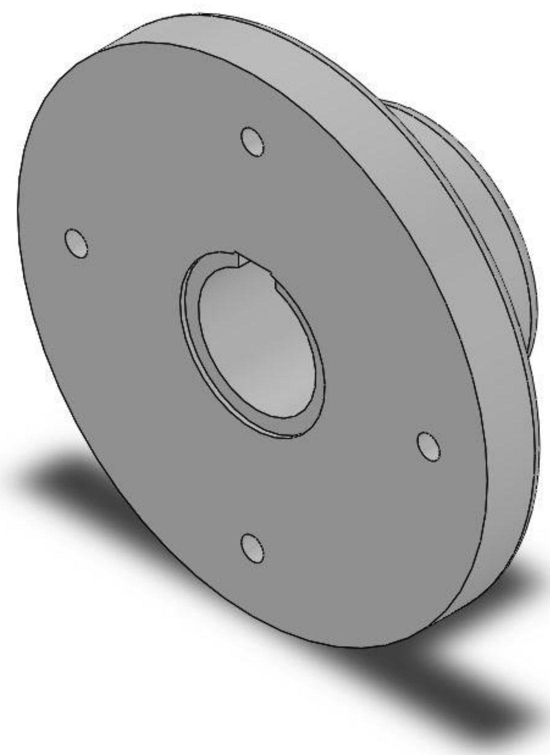


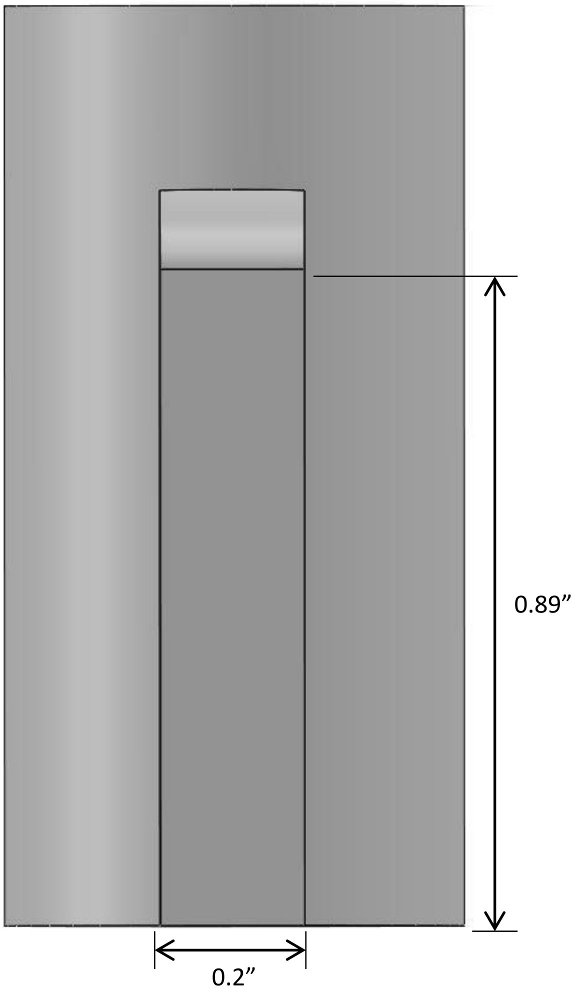


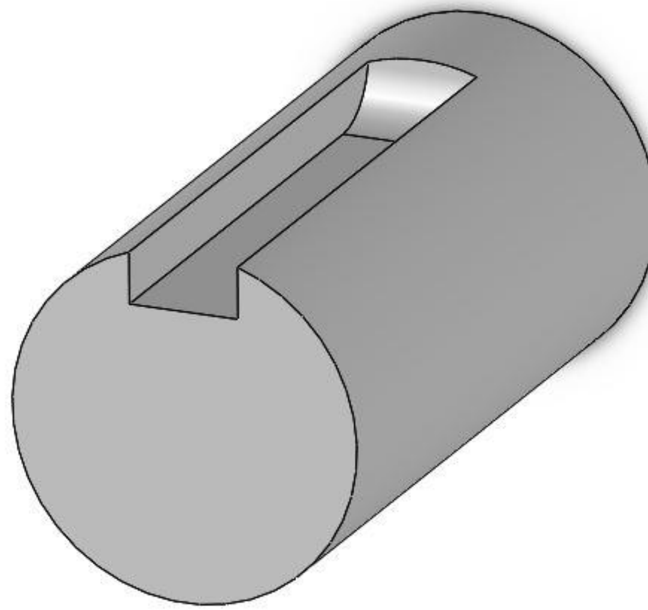
Front



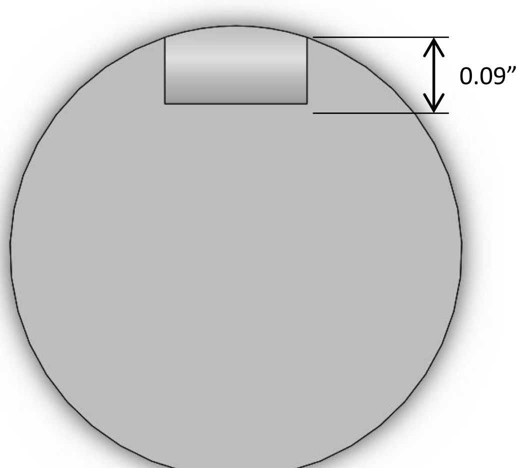
Back



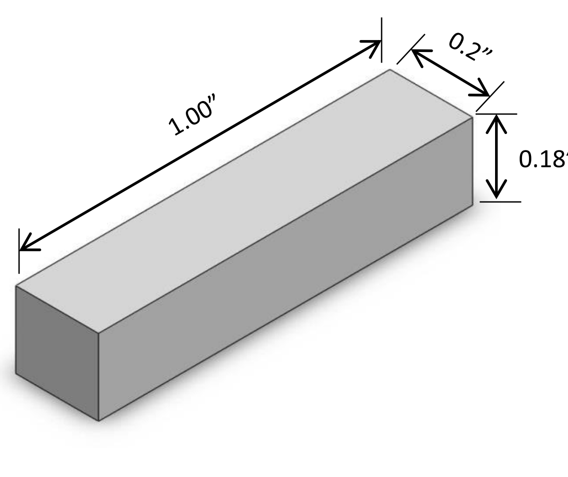




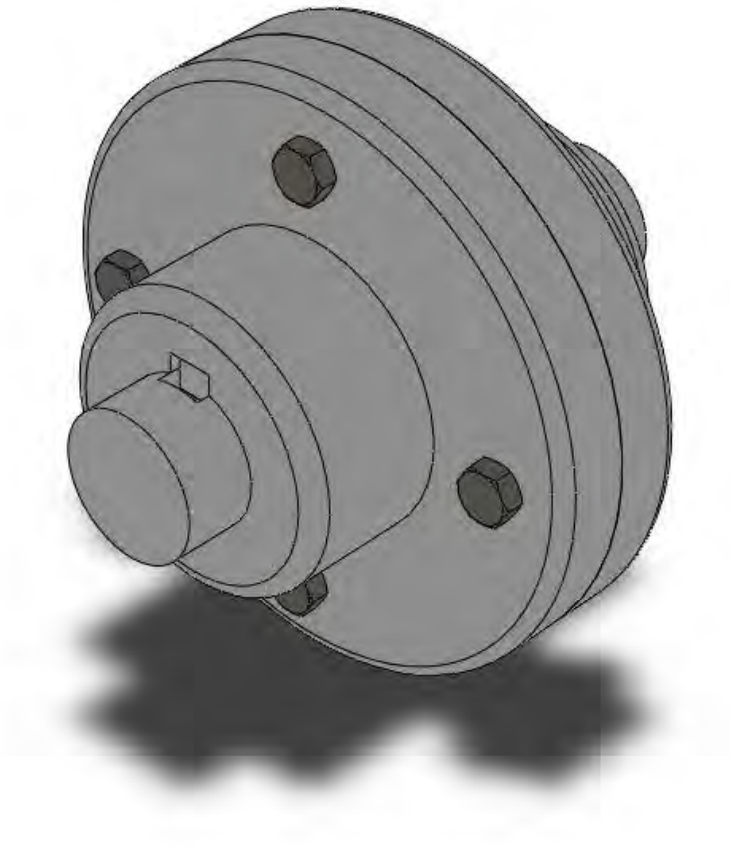
End of Shaft



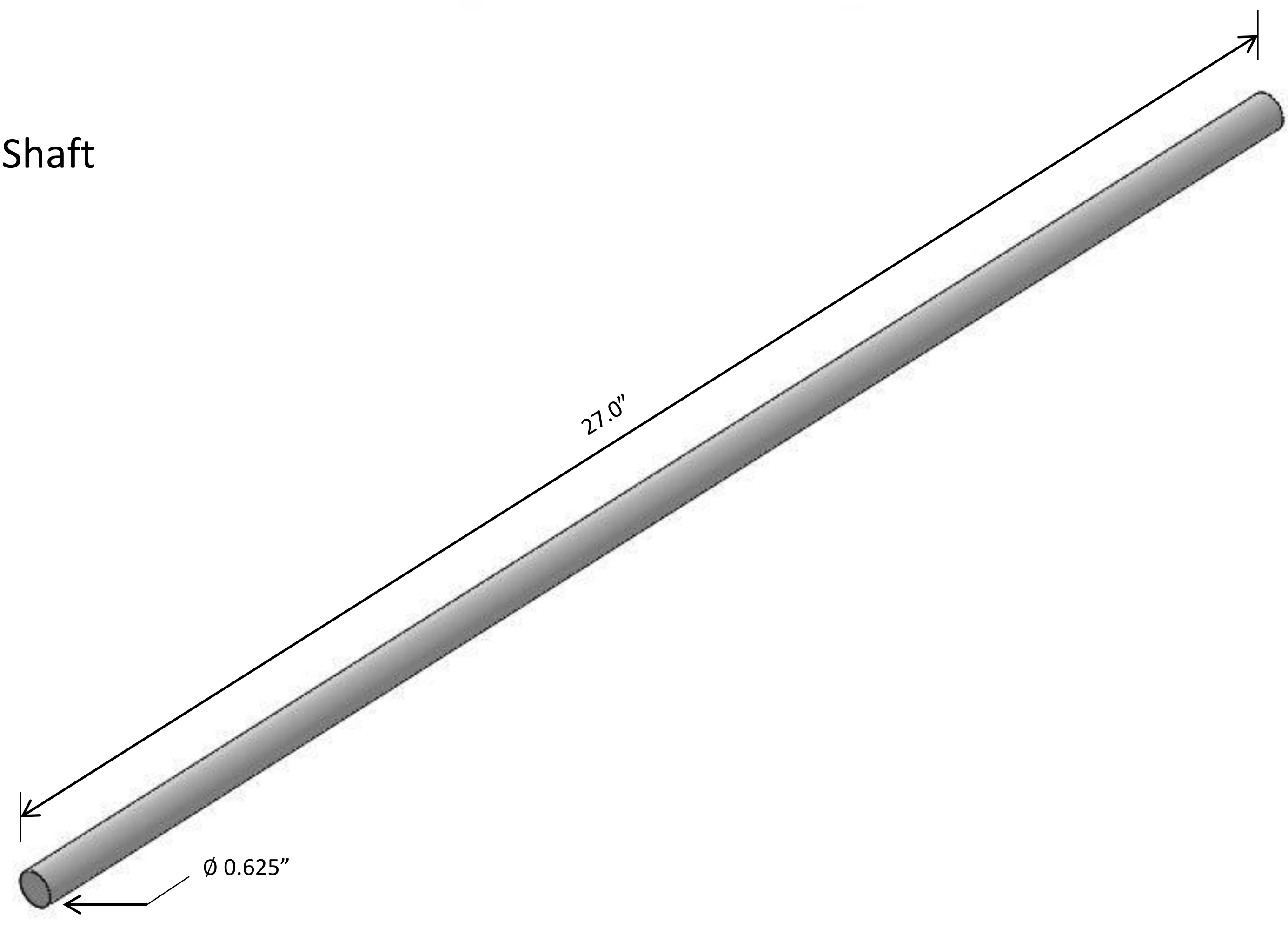
Tapper Pin



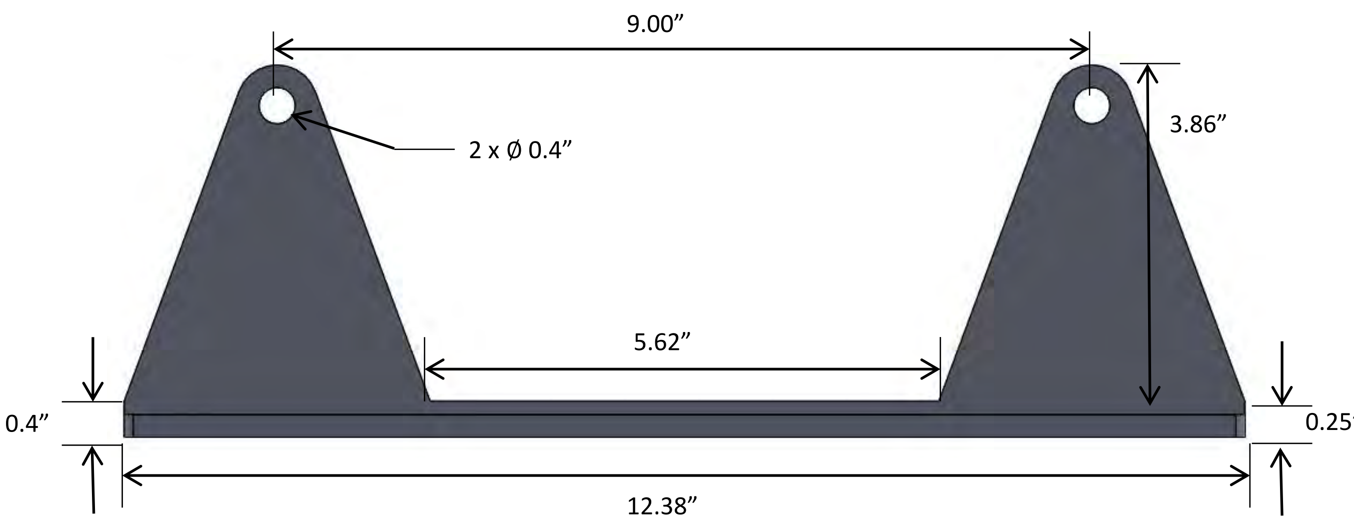
Flange Assembled

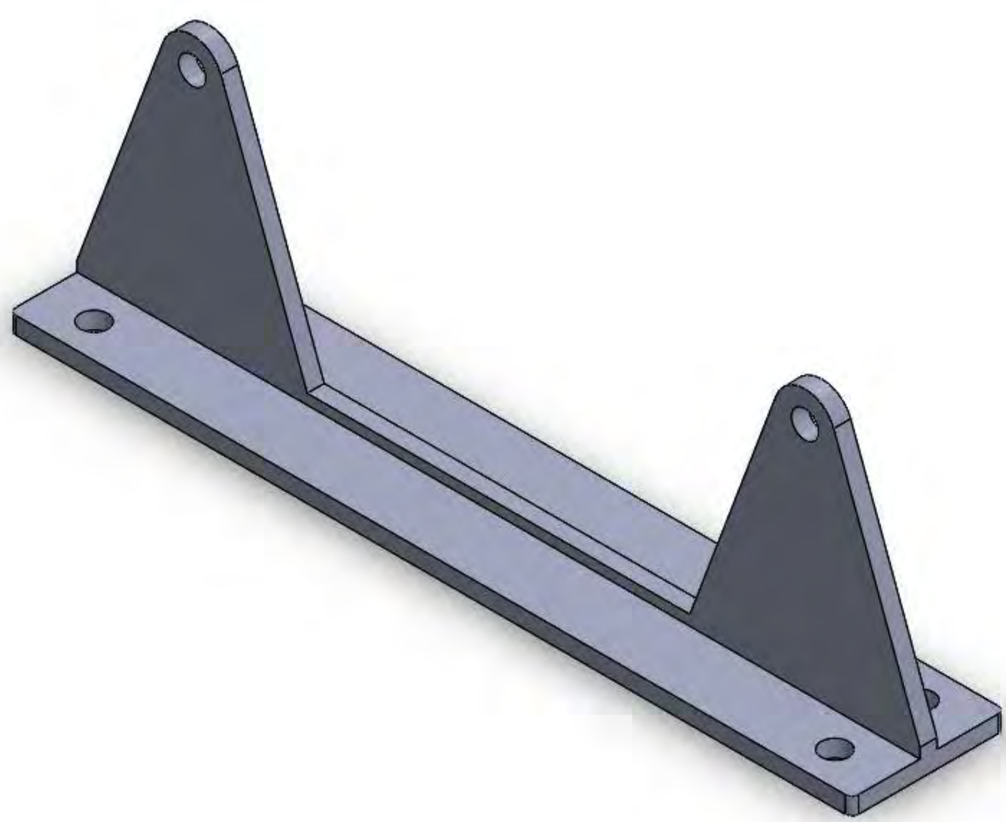


Shaft

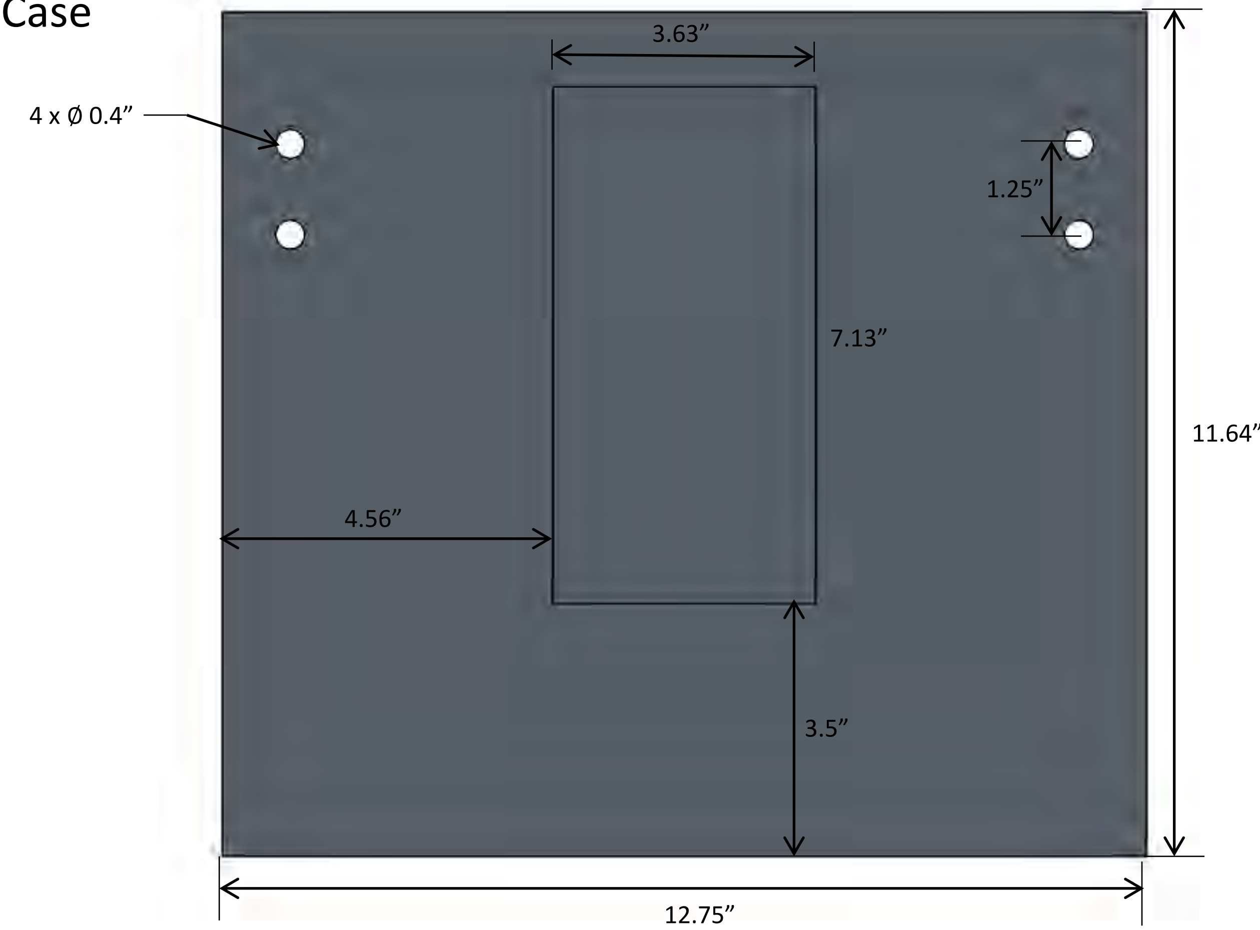


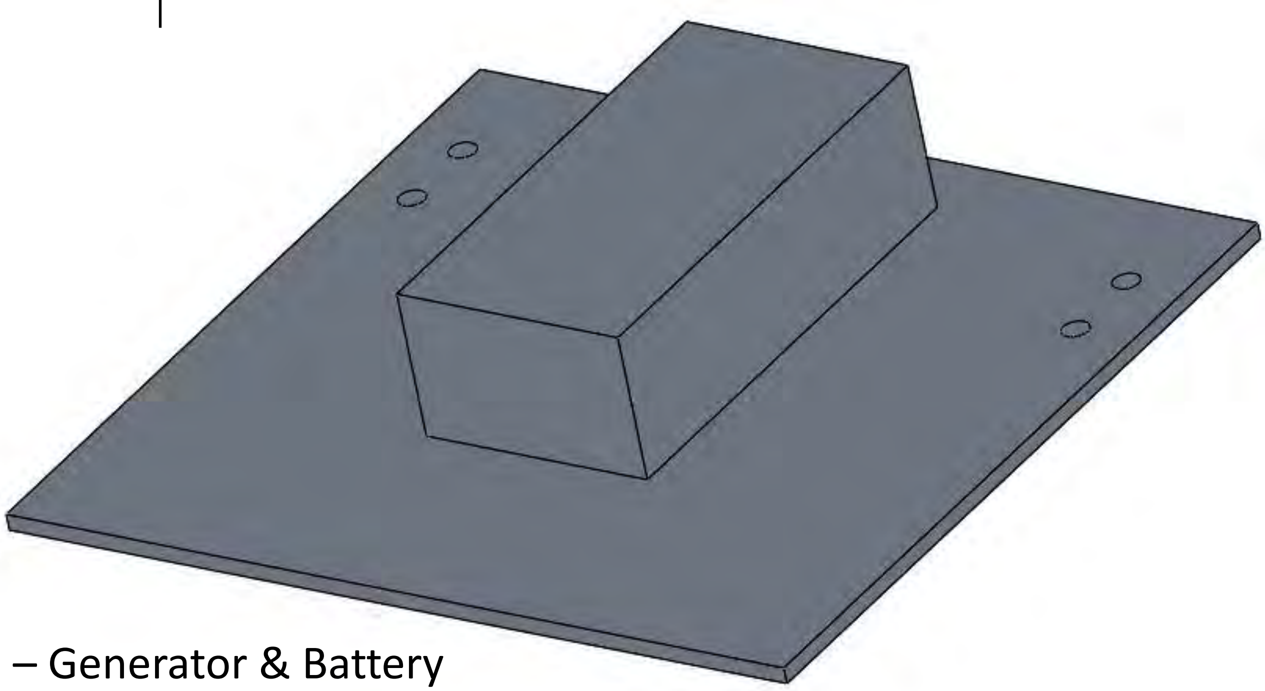
Generator Support





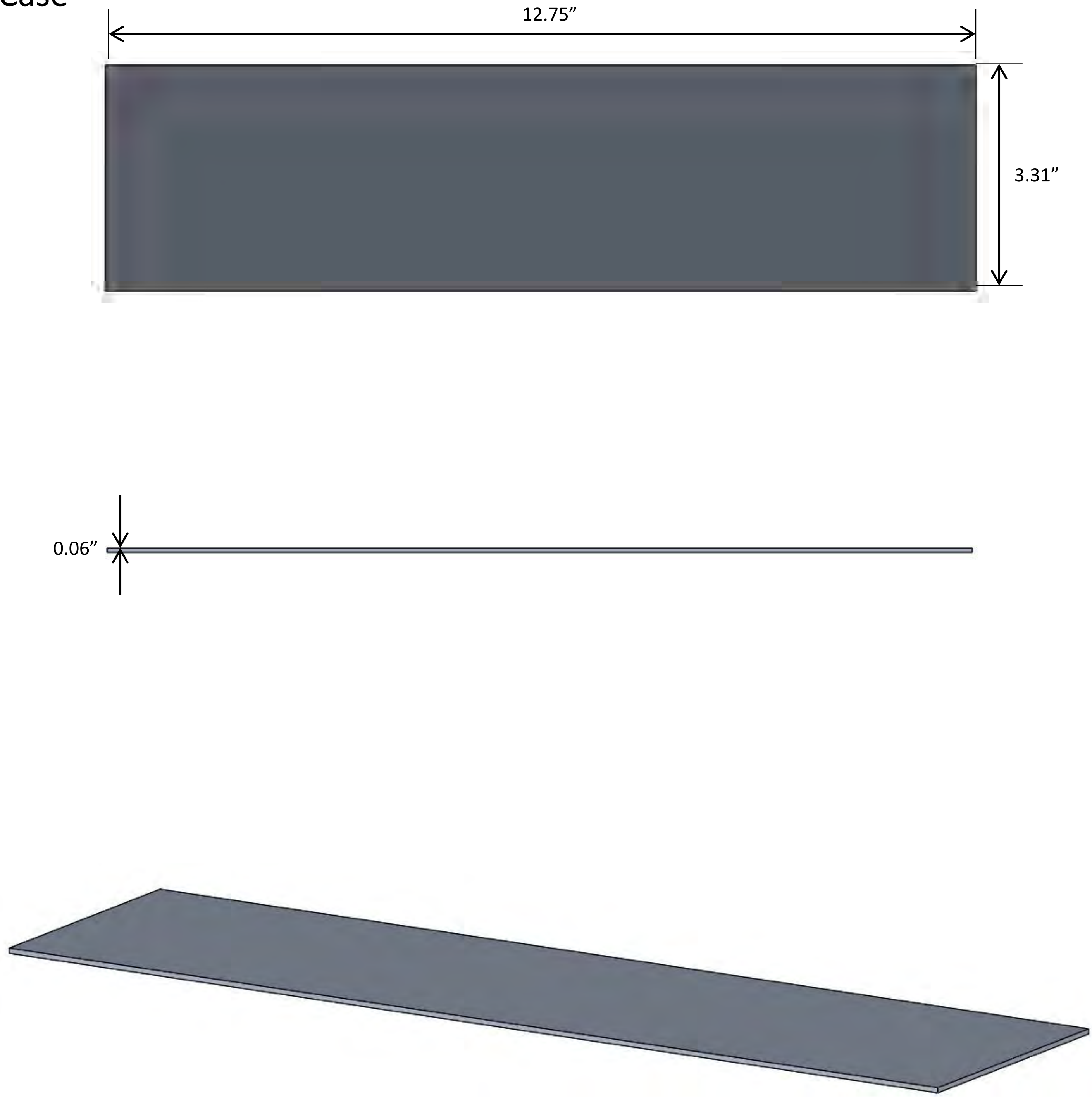
Case



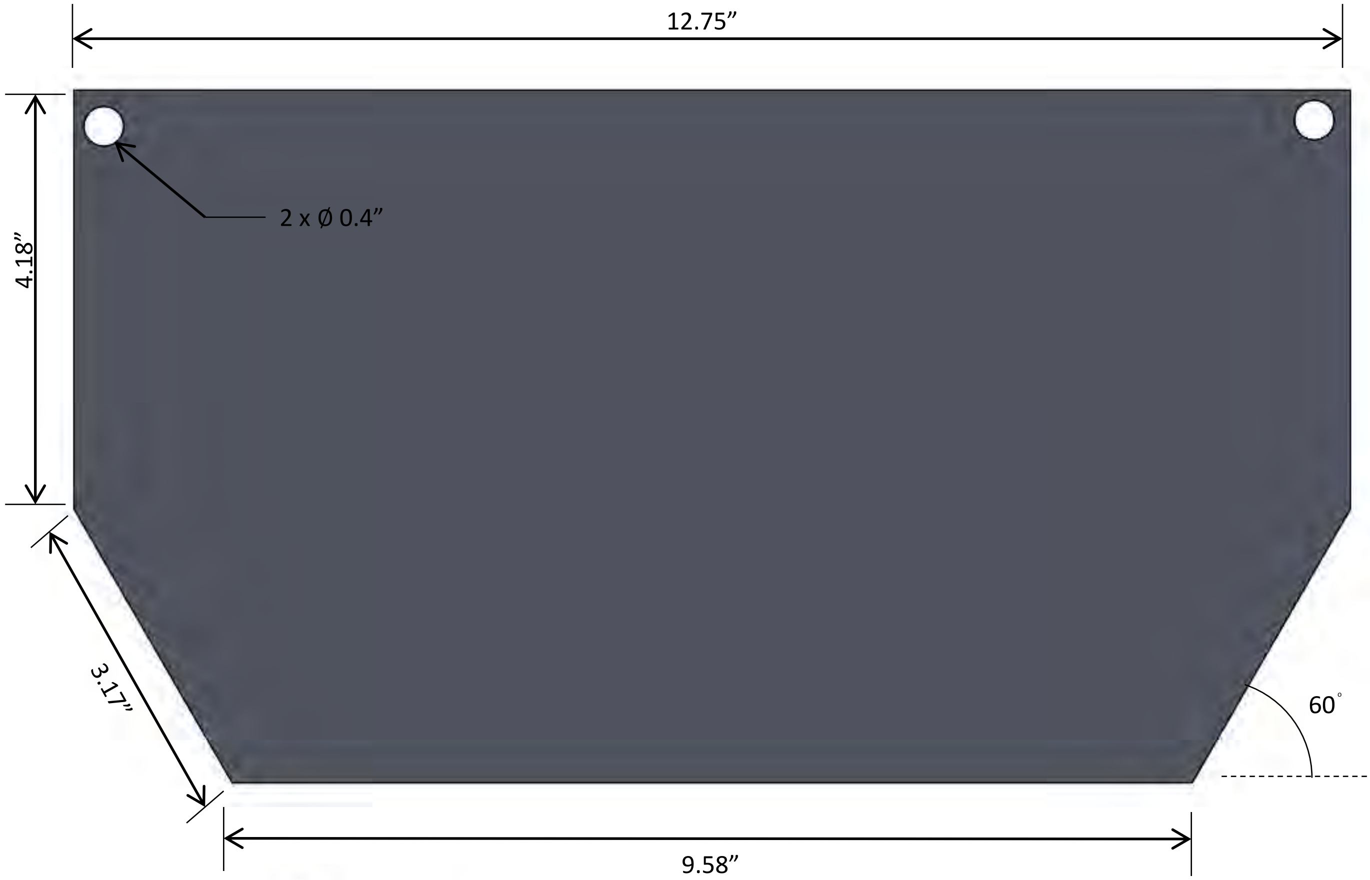


Cap – Generator & Battery

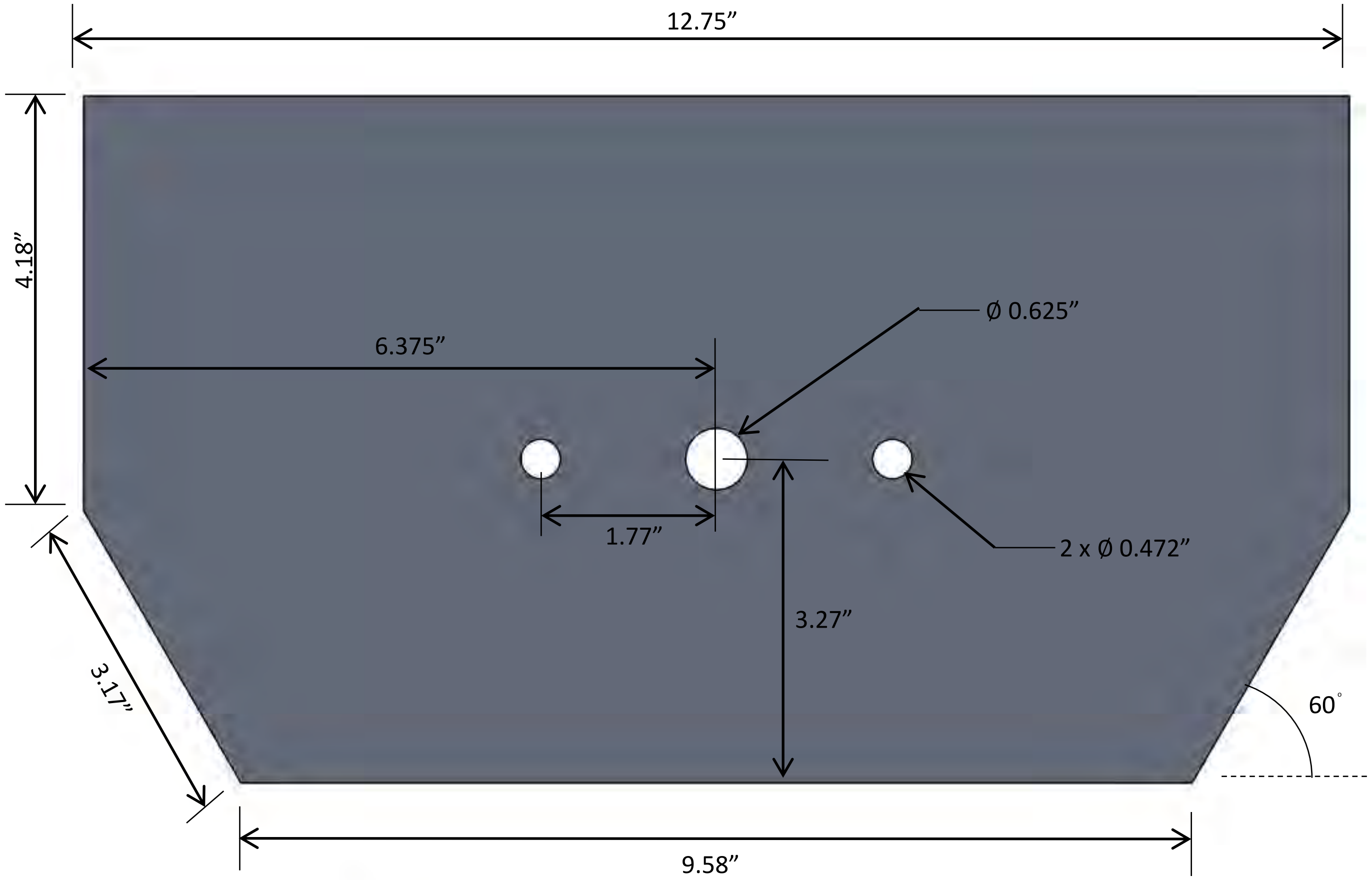
Case

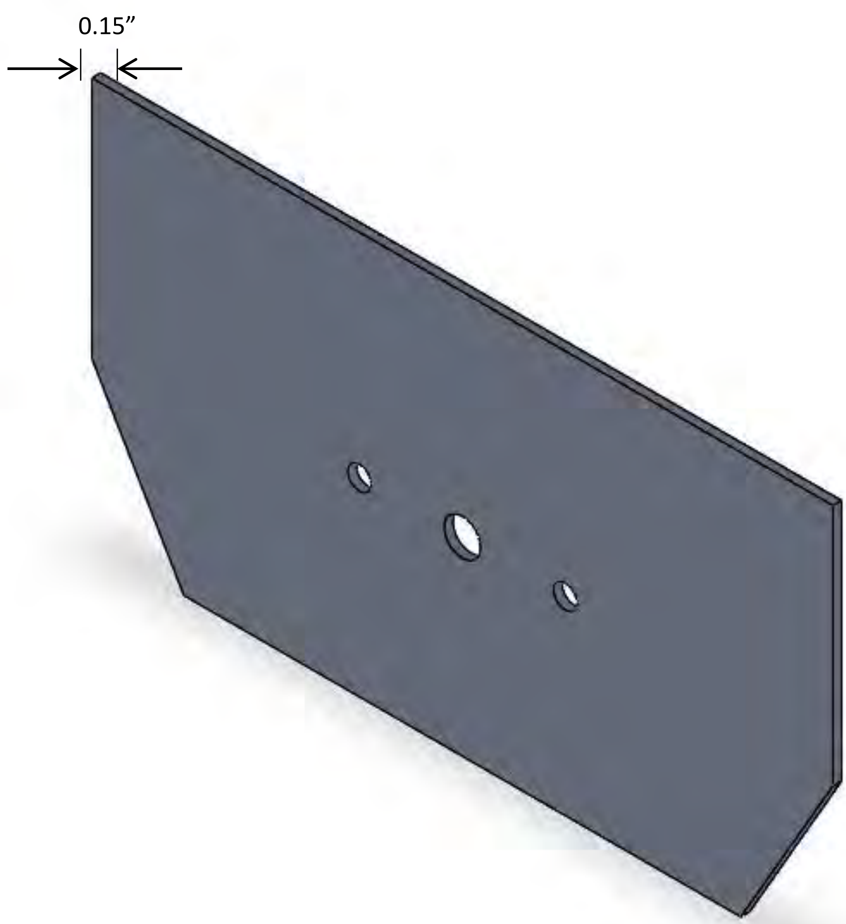


Cap – Short End



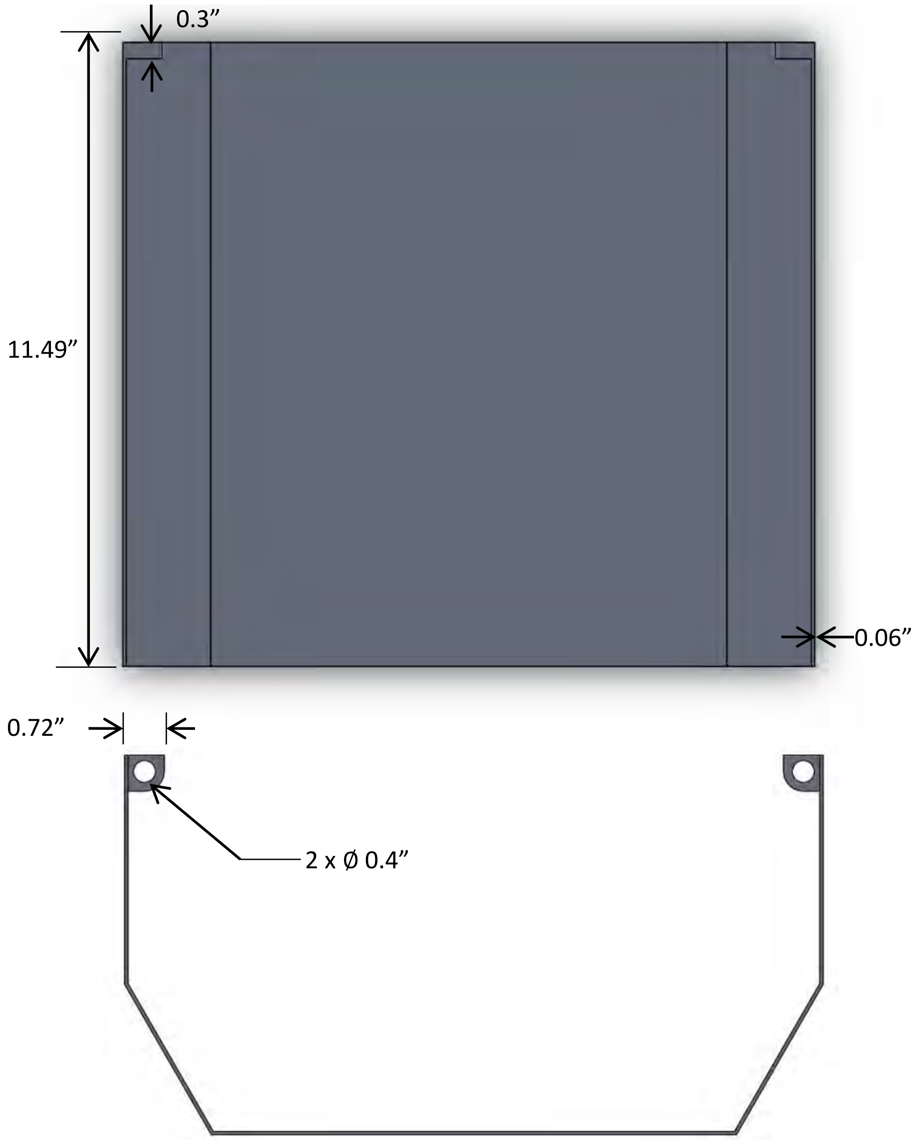
Case End

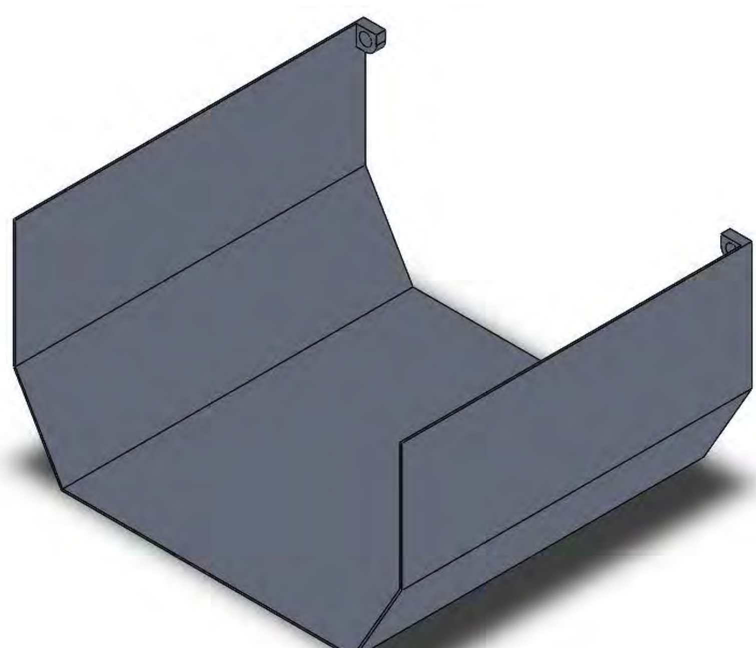




Case Mid Plate

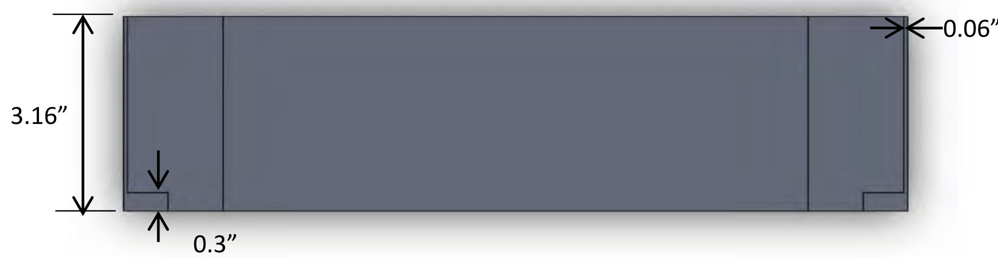
Case

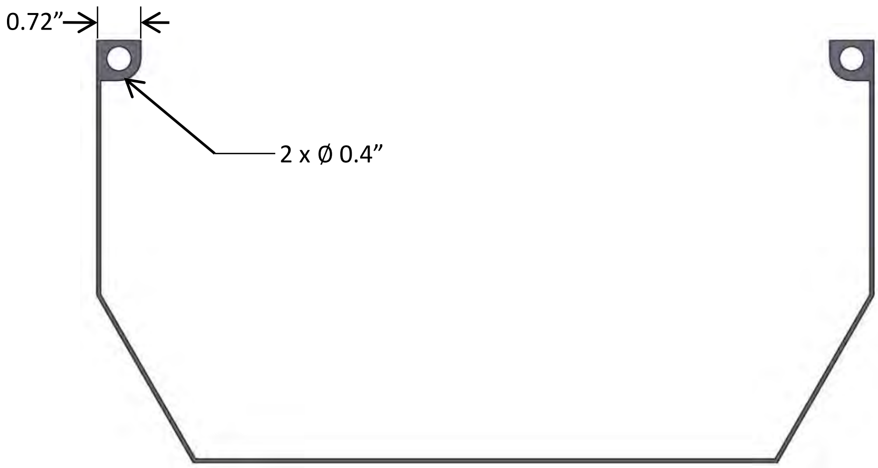


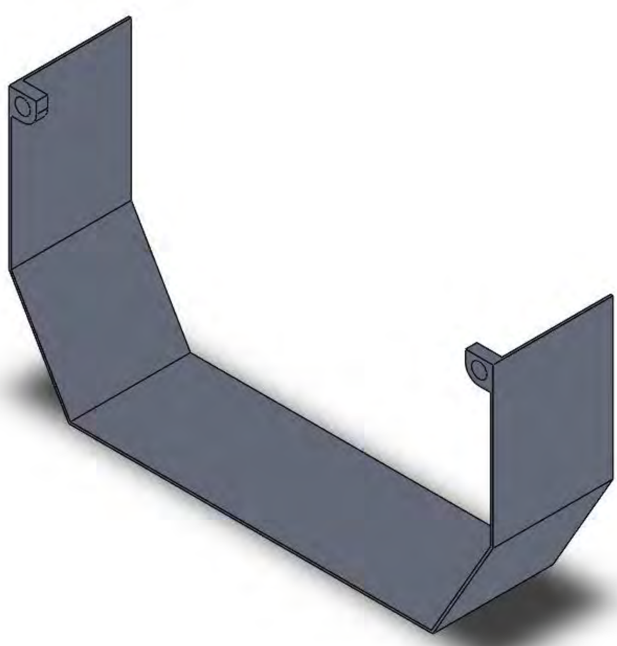


Generator Housing

Case

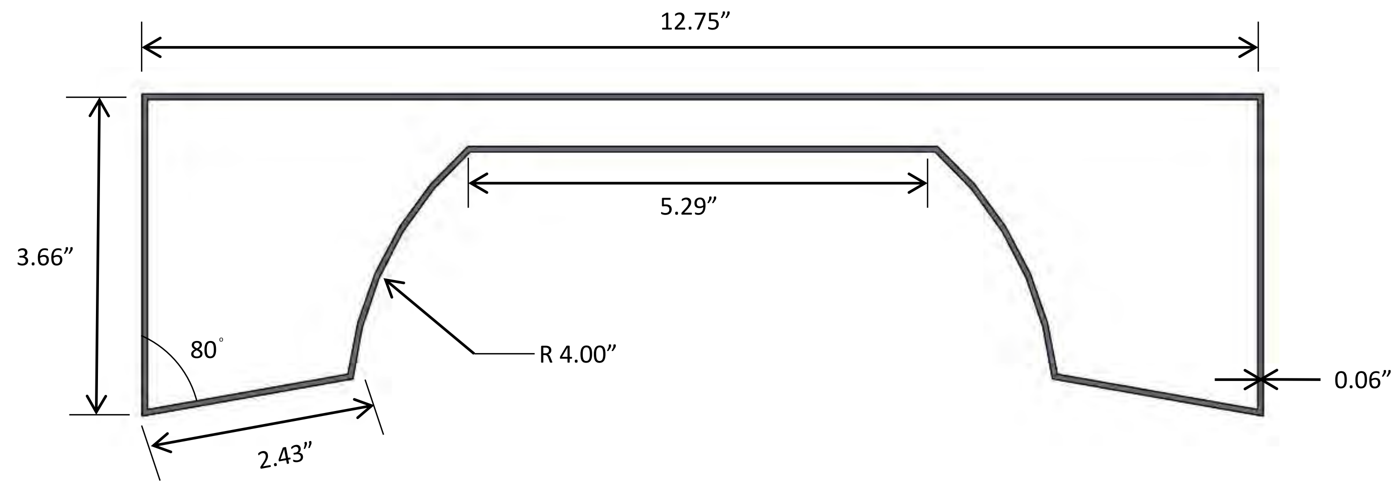


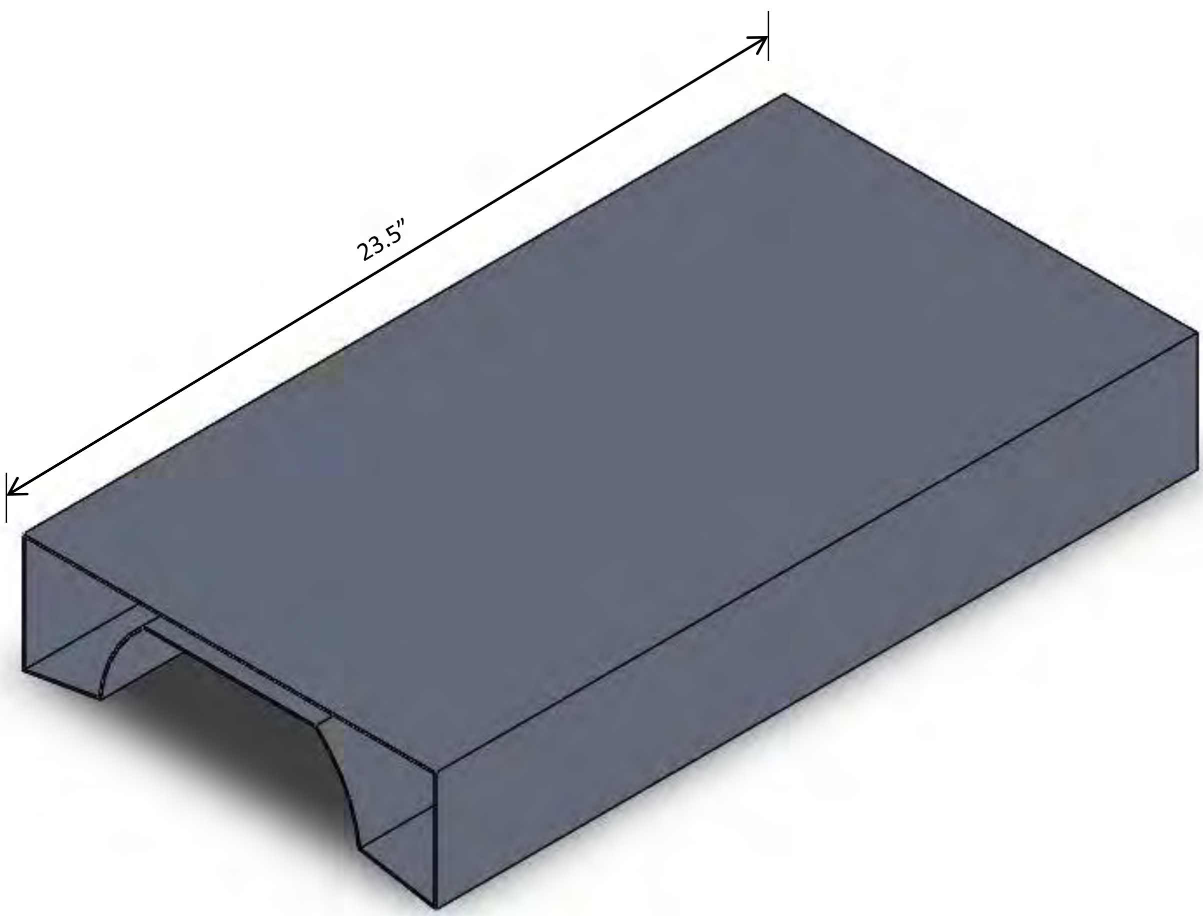




Short End Housing

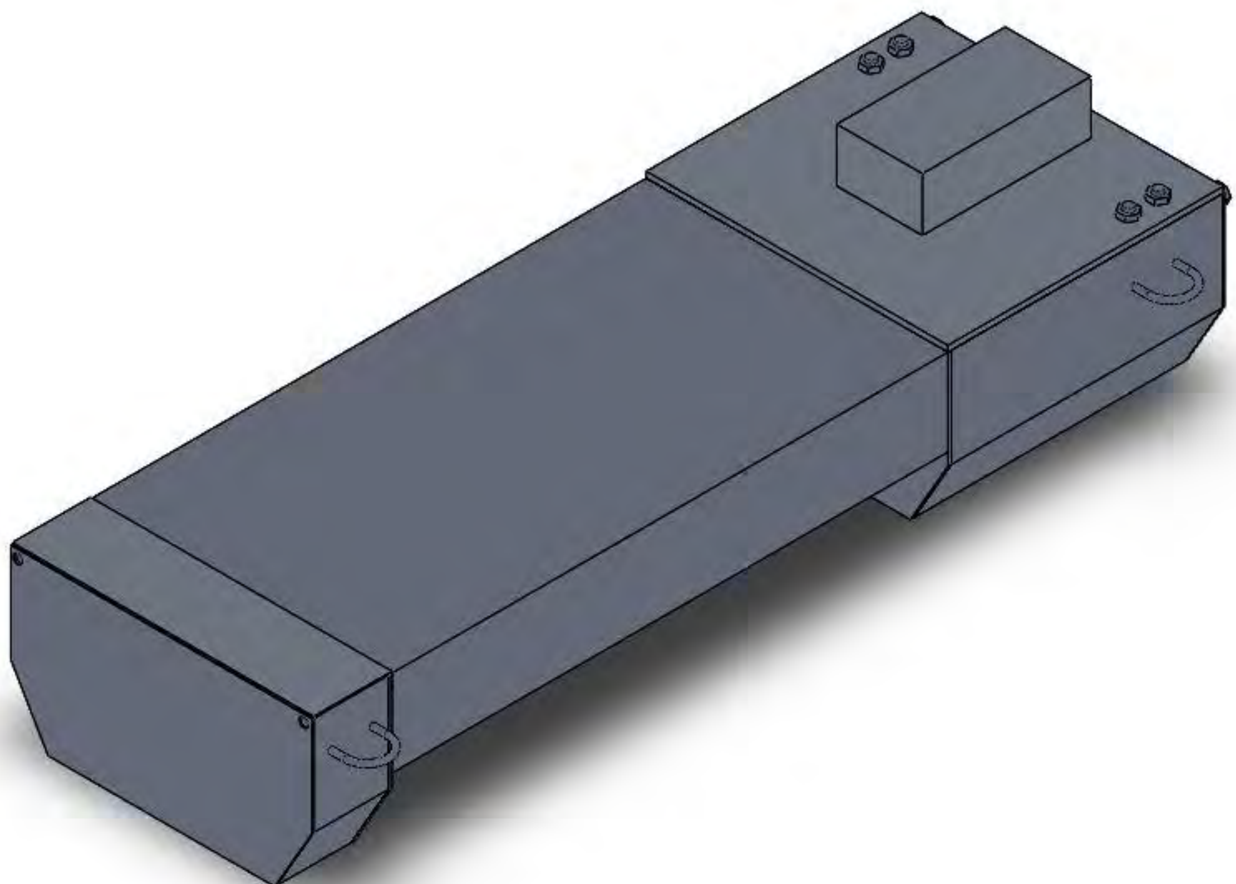
Case



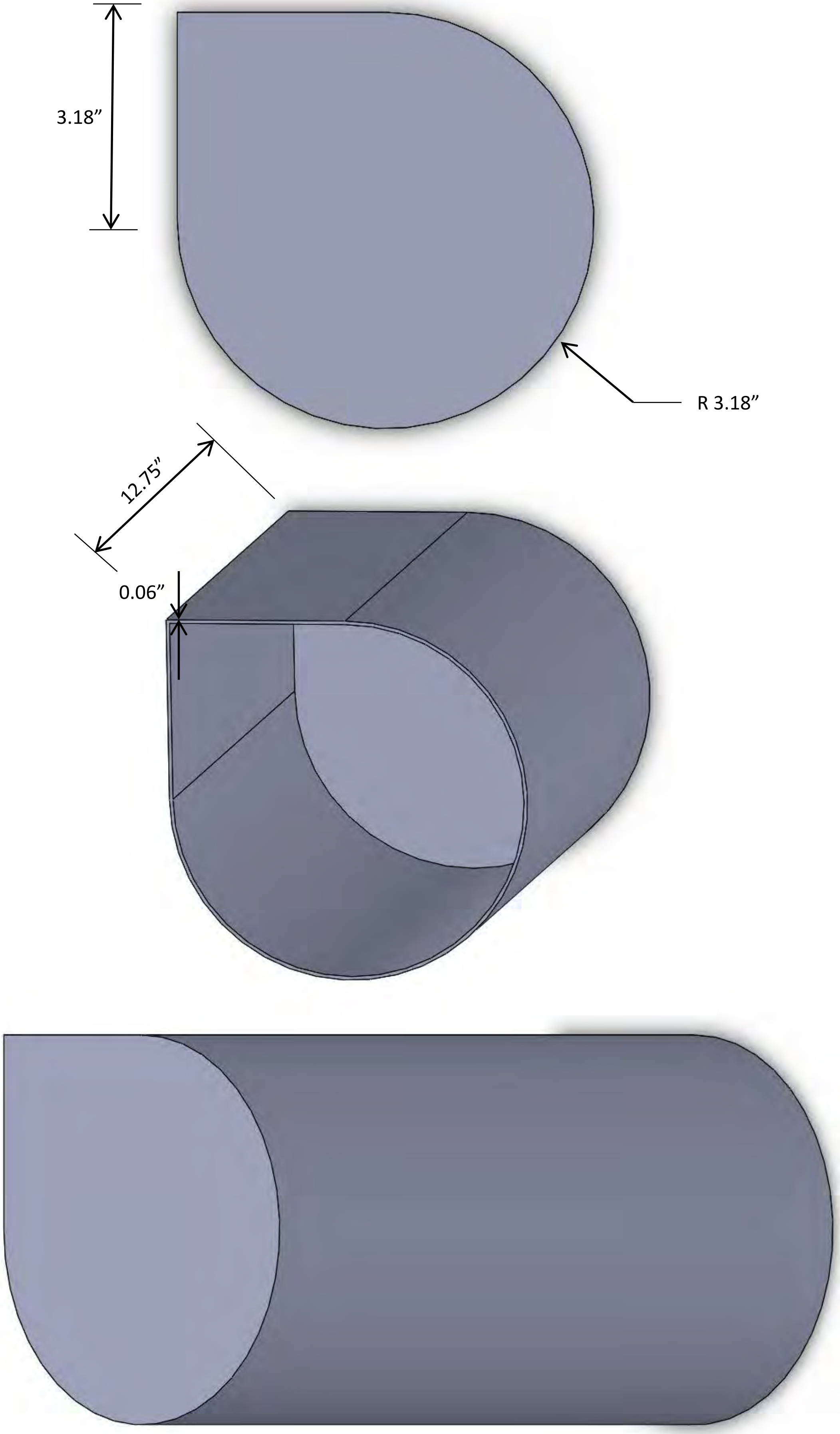


Turbine Housing

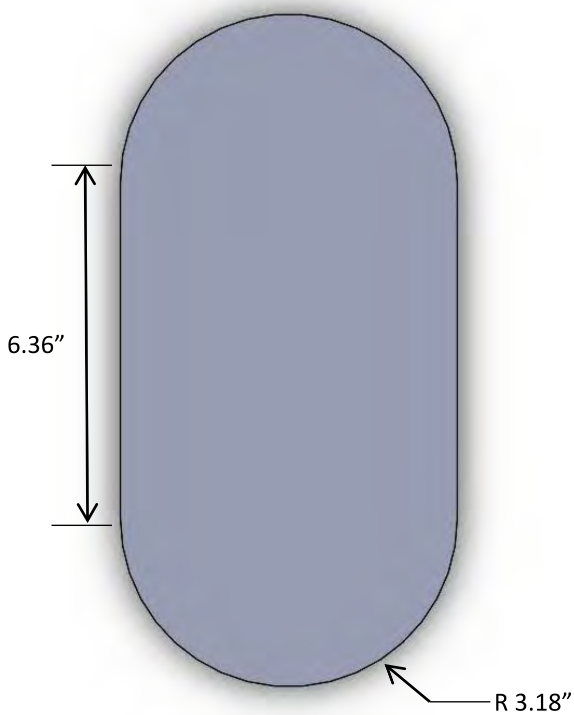
Case Assembled

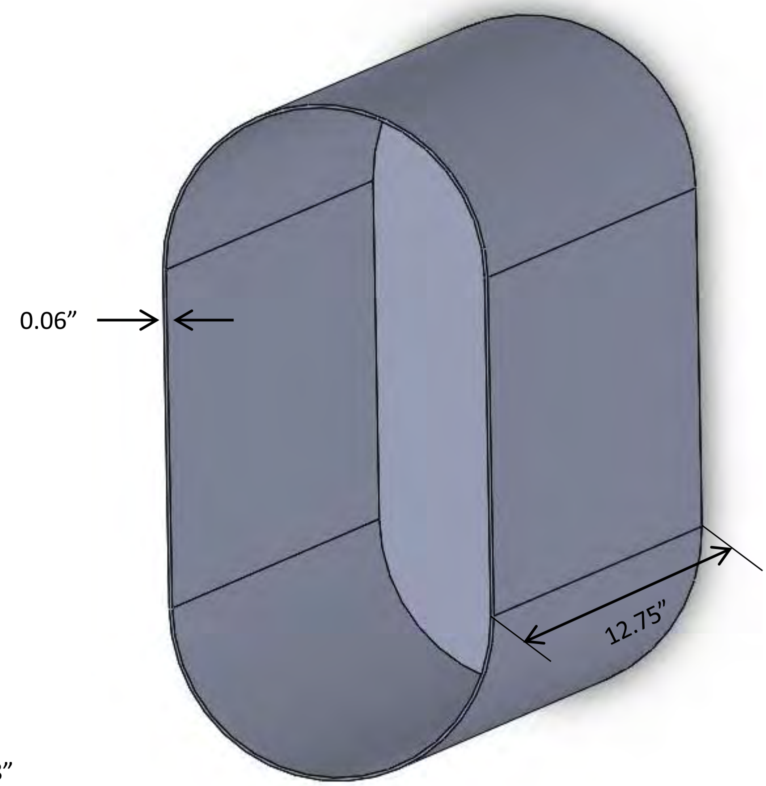


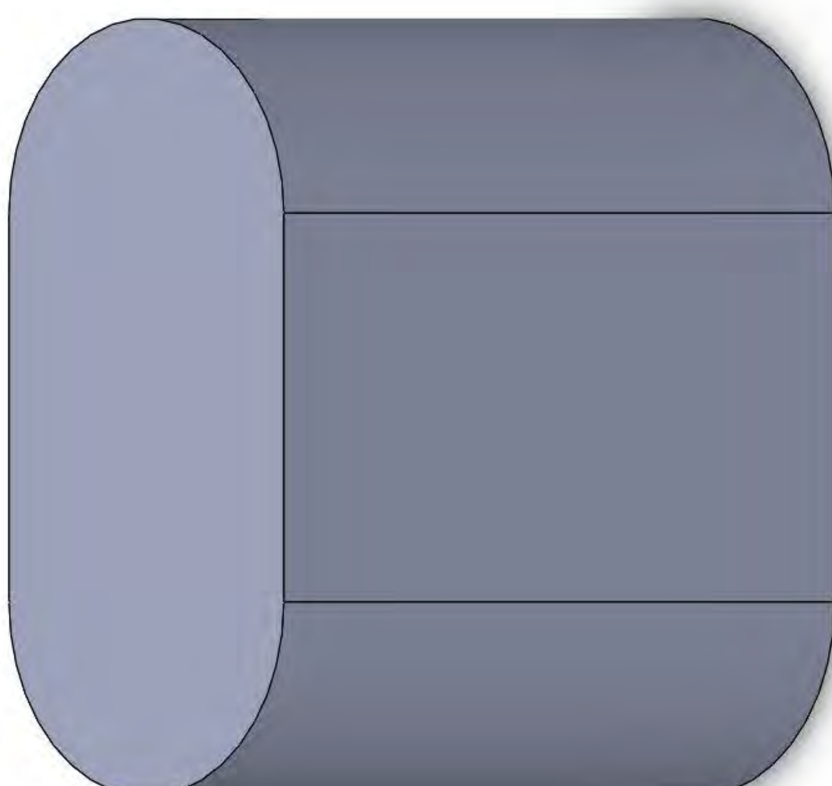
Pontoon : Generator



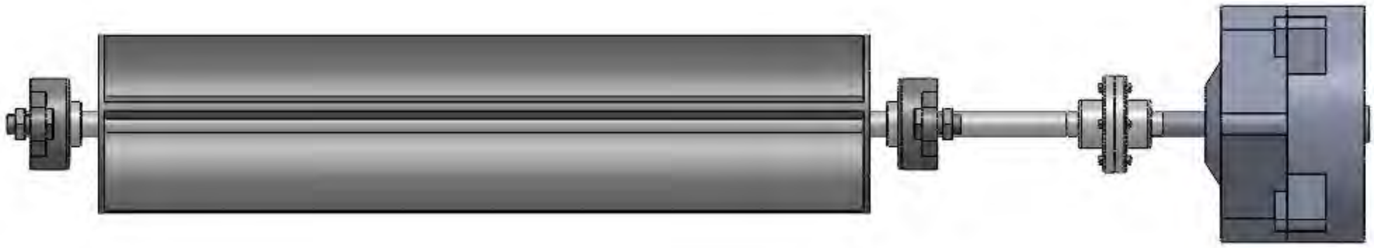
Pontoon : Short End

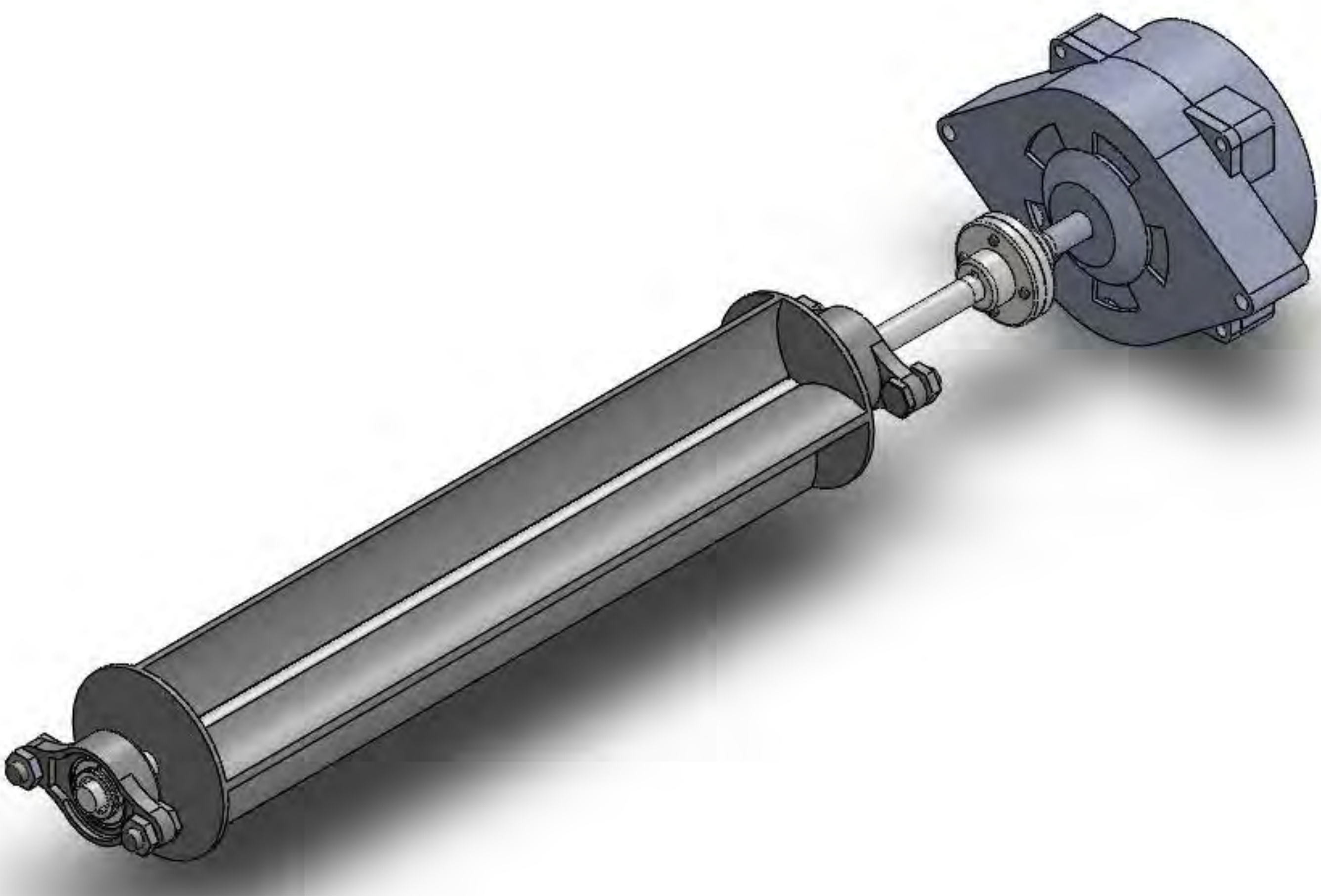




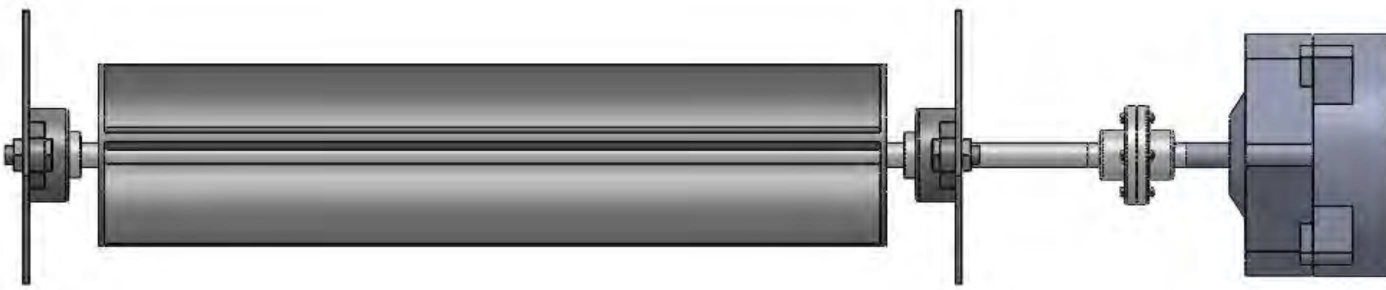


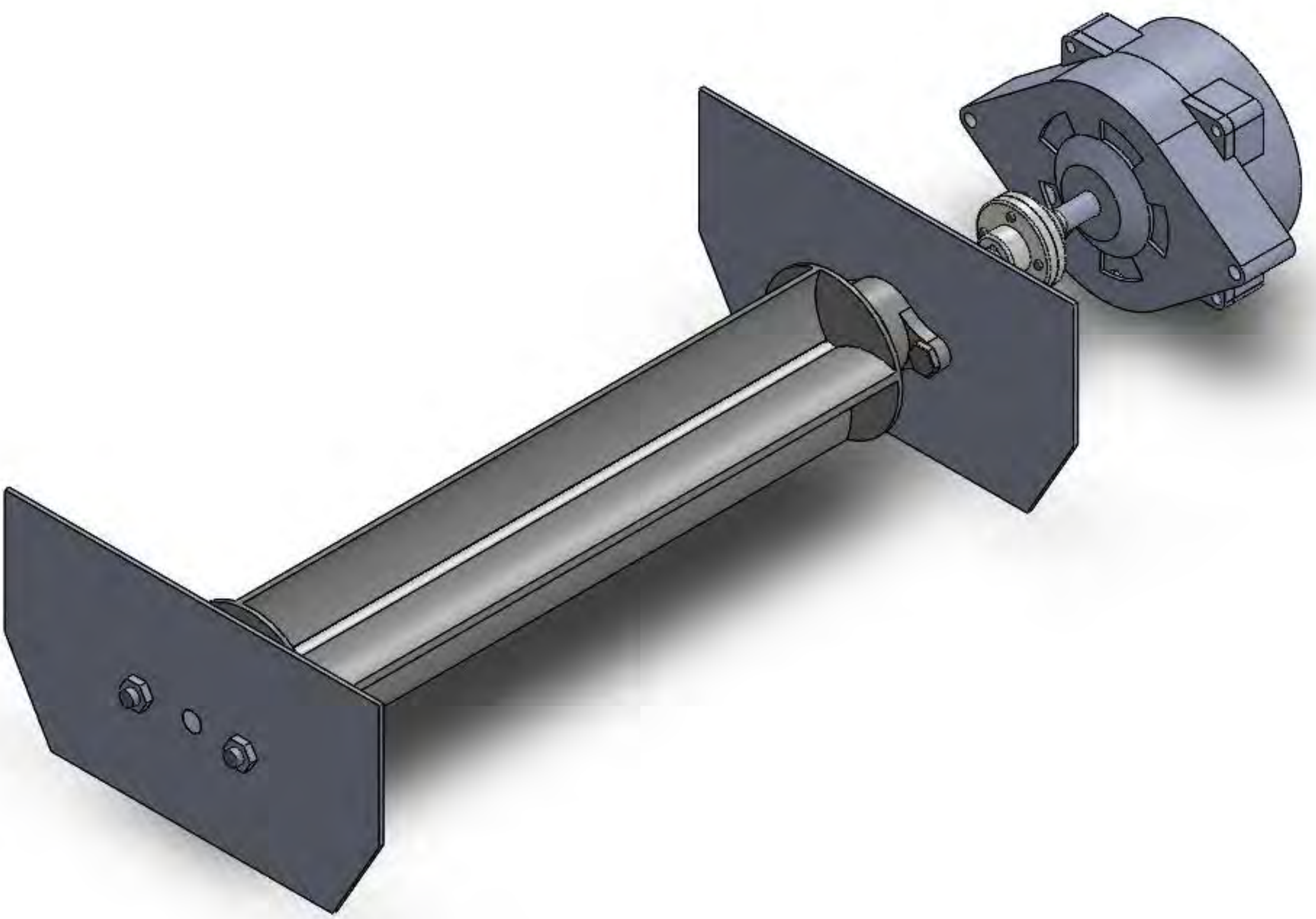
Assembly: Parts



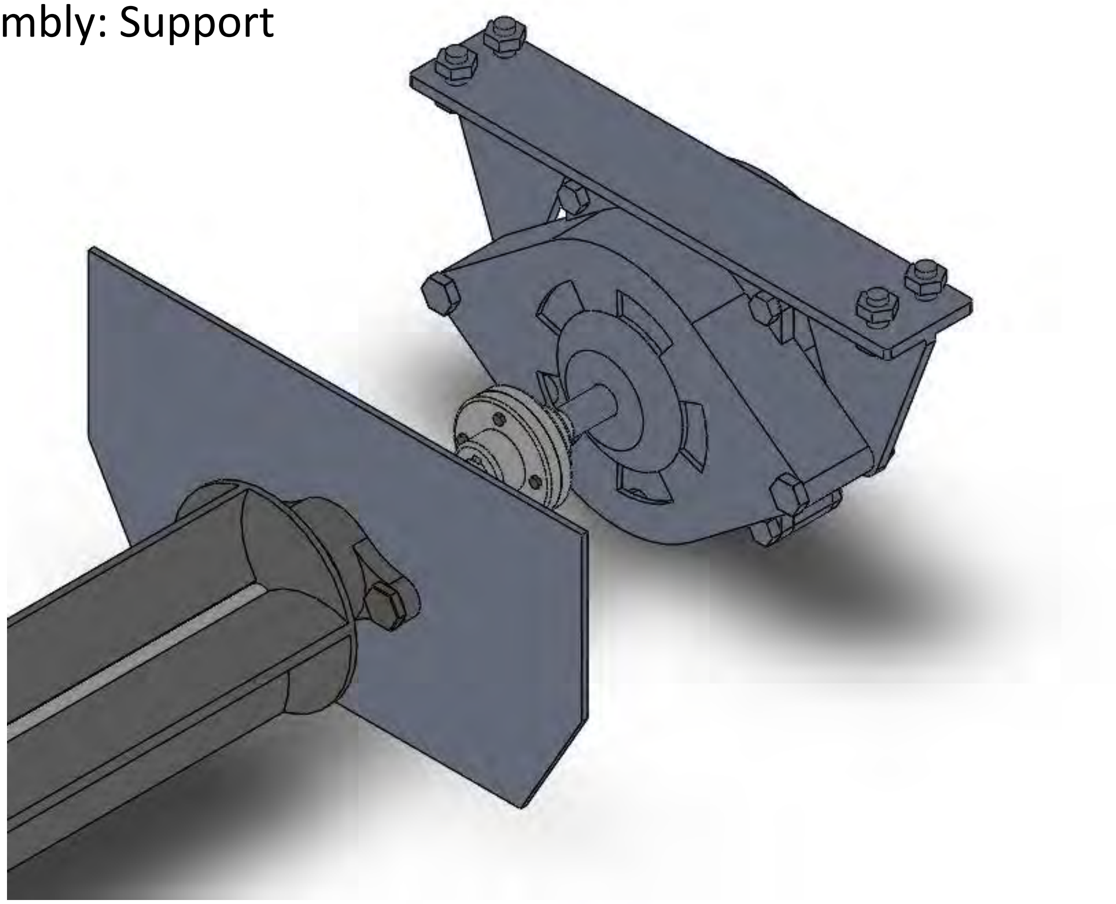


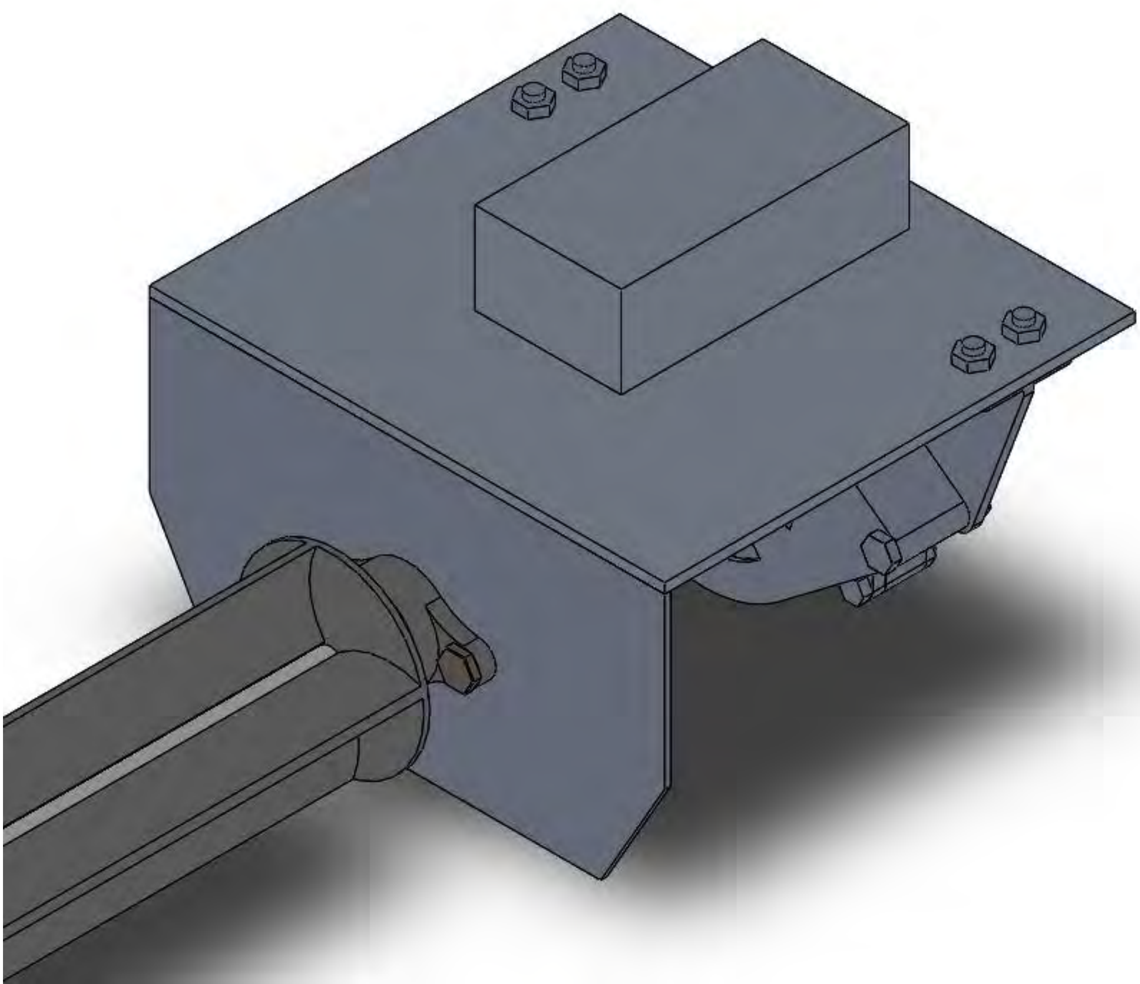
Assembly: Parts & Mid Plates



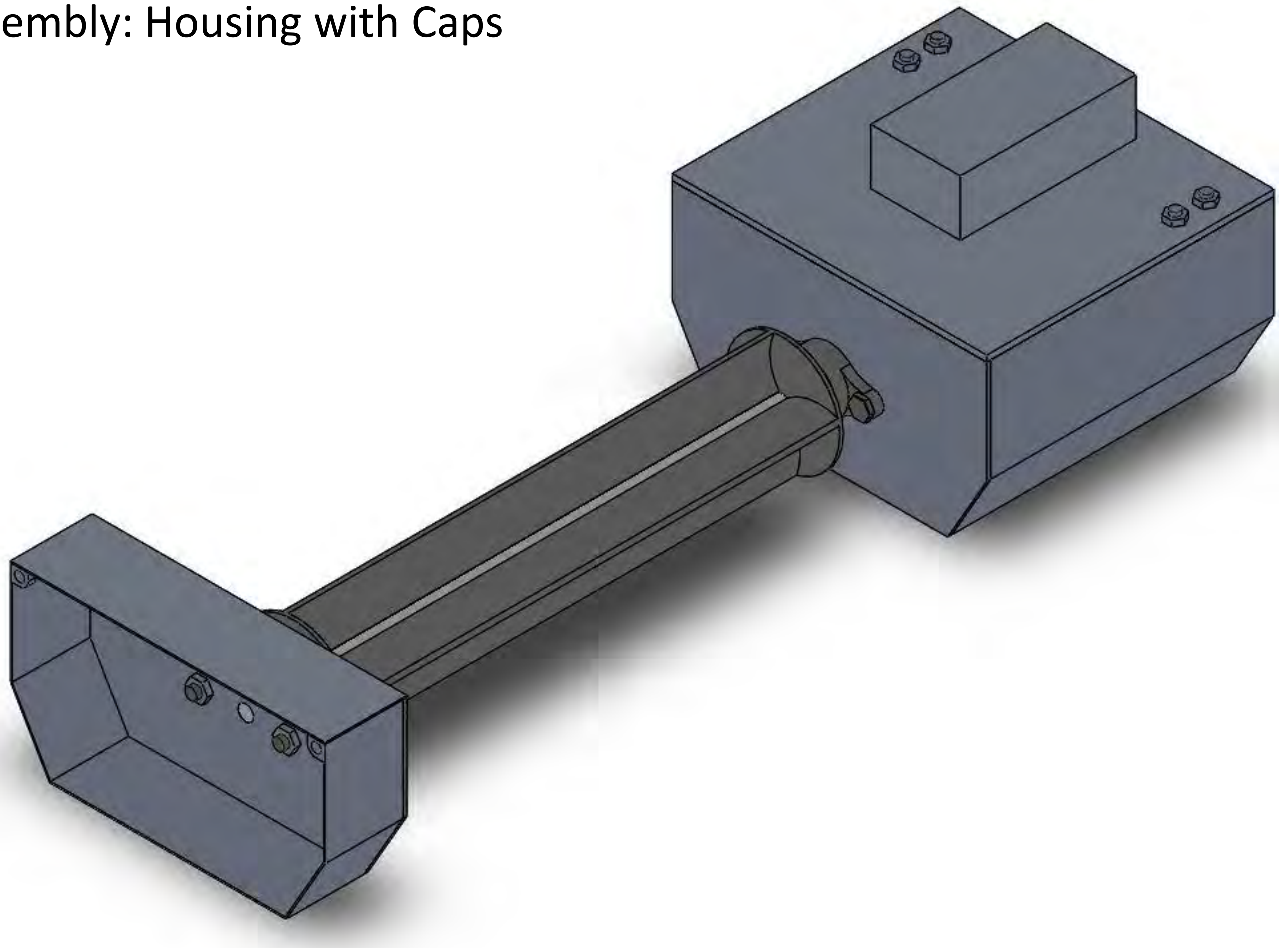


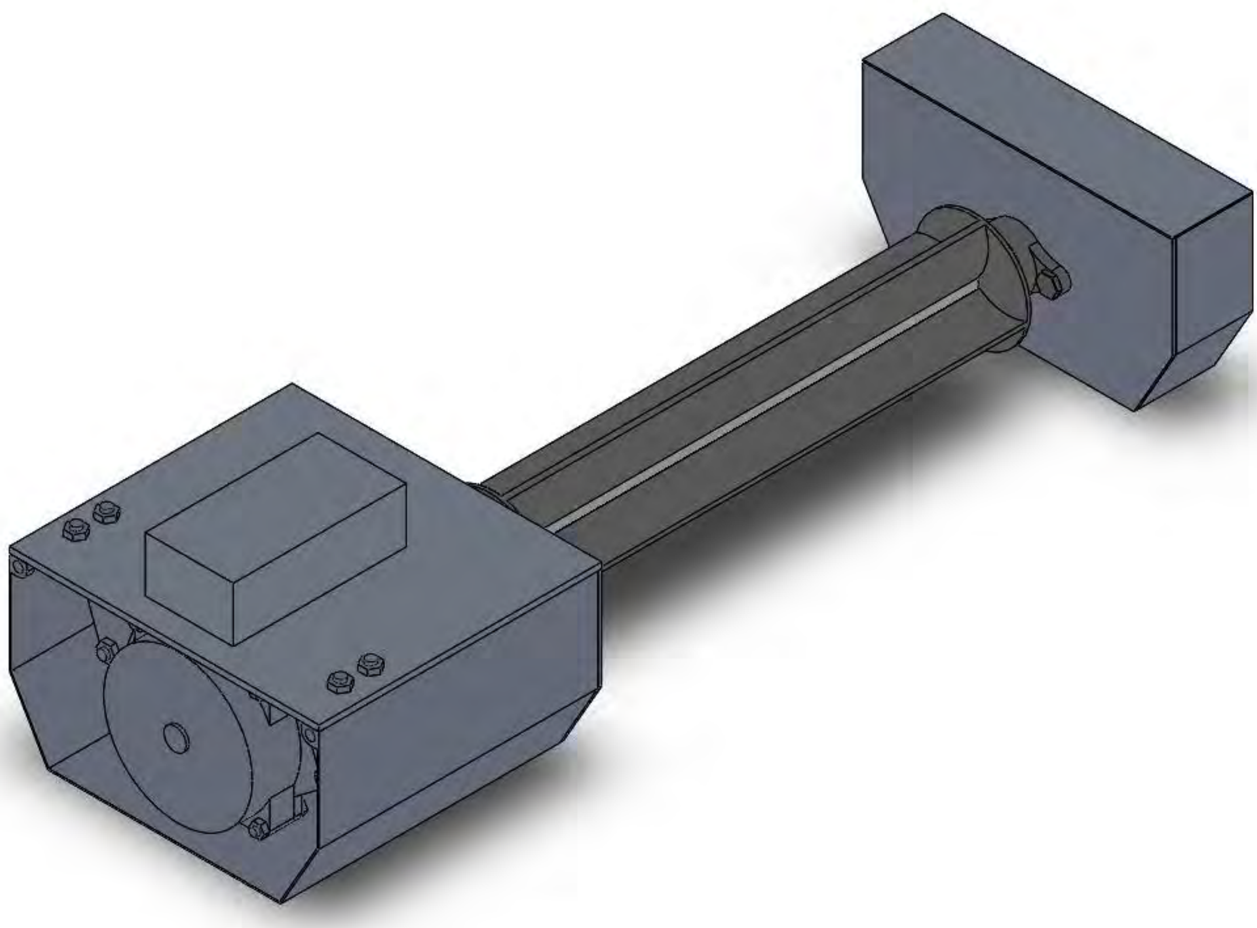
Assembly: Support



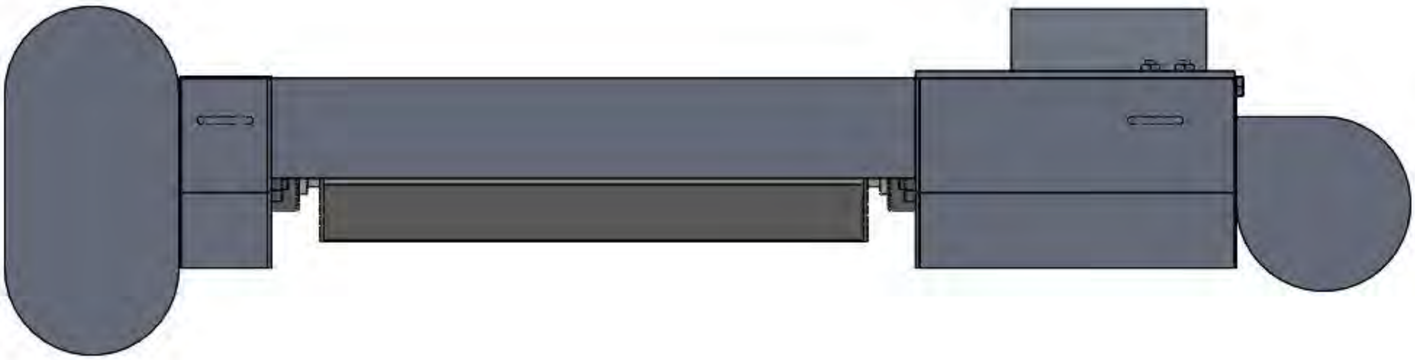


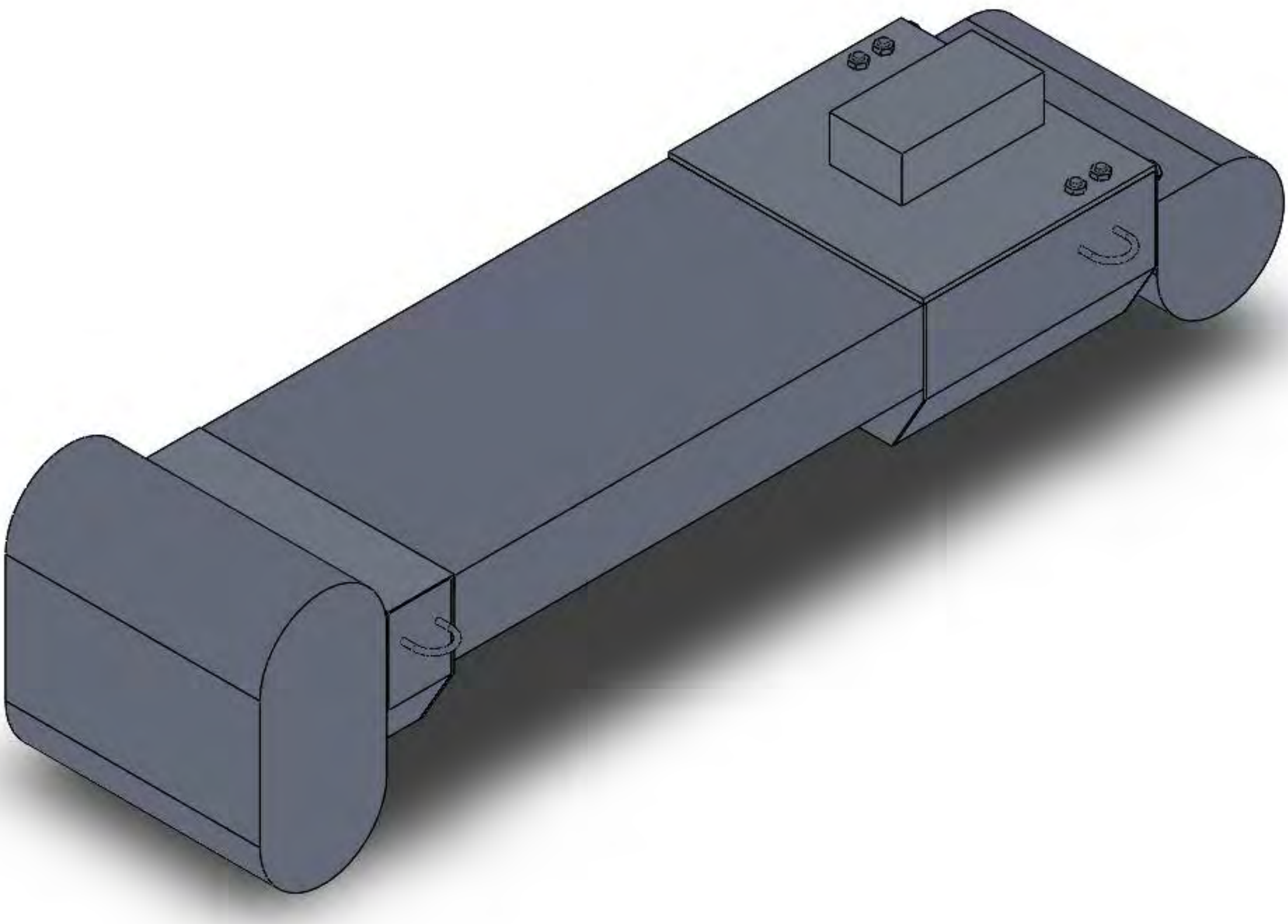
Assembly: Housing with Caps



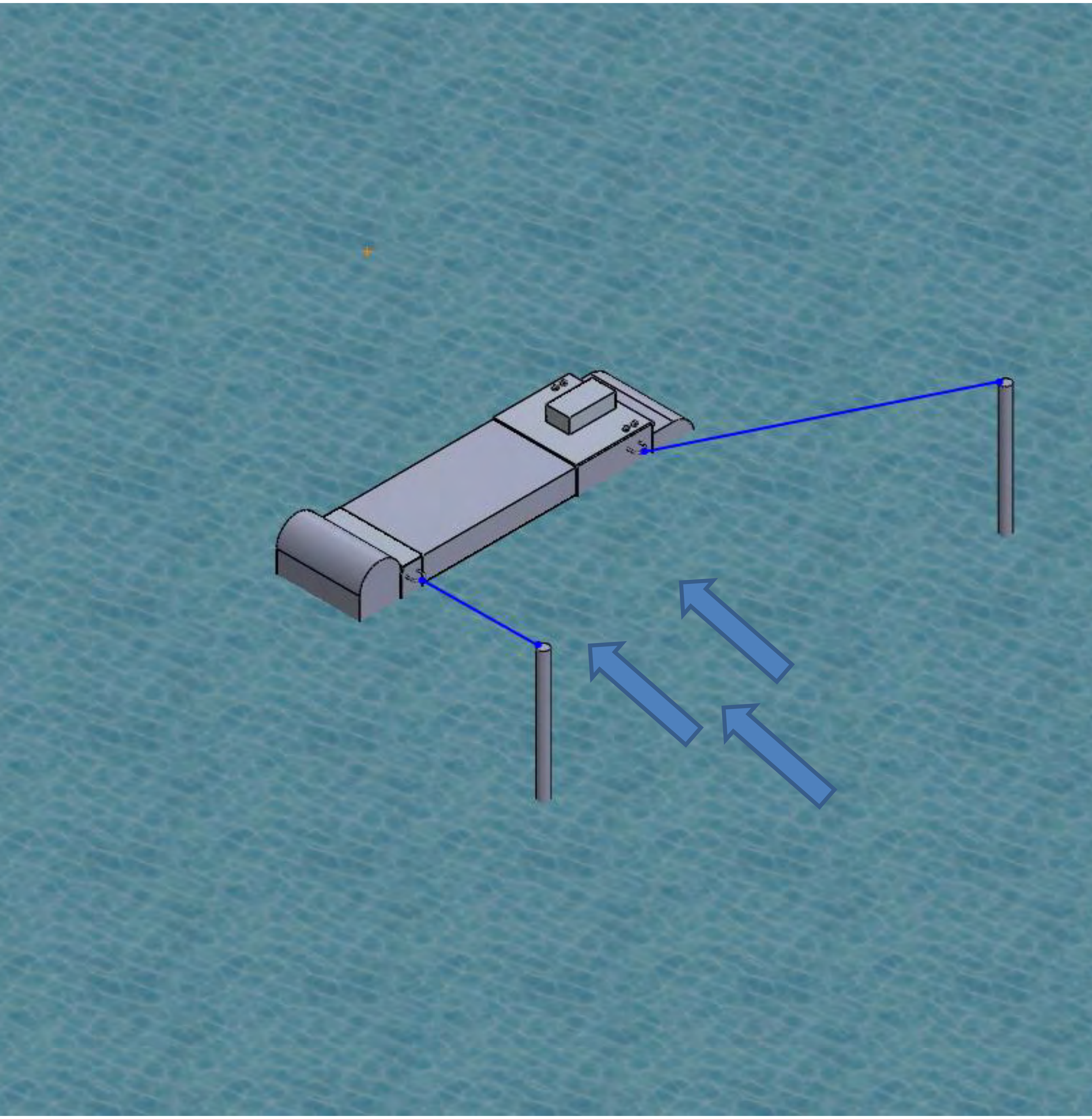


Assembly: Complete

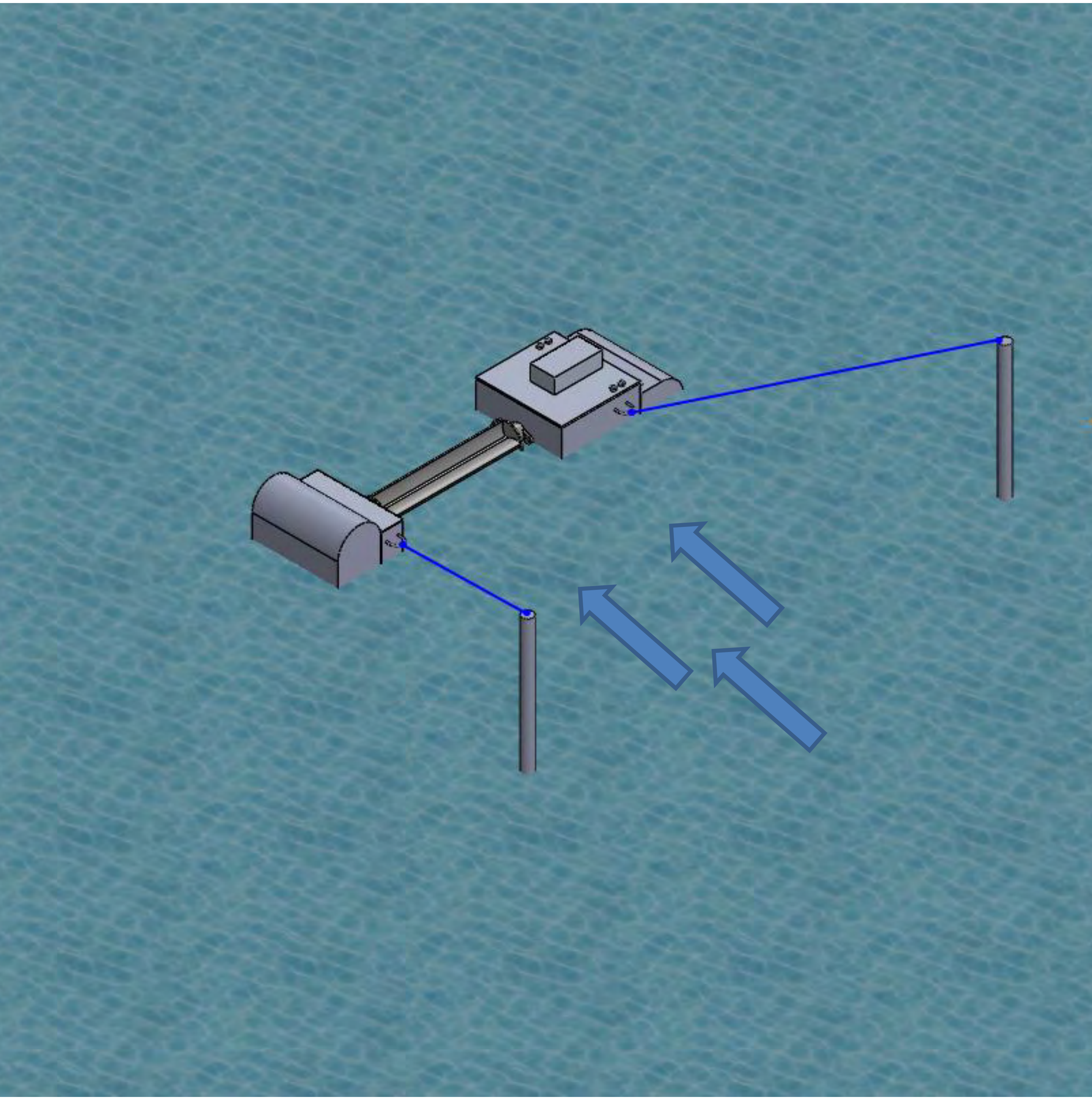




System Setup



System Setup: Turbine View



Appendix

A.3

DATE	**Josh Kennedy**	**Ben Kennedy**	**Steve Benetatos**
Oct. 7	First meeting, discuss idea		
Oct. 12	Preliminary research		
Oct. 21	Discuss details of proposal		
Oct. 23	Hand in proposal		
Oct. 25	Discussed proposal, made alterations to project		
Oct. 28	Discuss next step, final project requirements, presentation requirements		
Nov. 1-12	•Researched hydro dams turbines	•River and stream research, velocities, depth, environments	•Watch videos on •Research turbines and their uses
Nov. 14-27	Head flow, potential, kinetic energy		Turbine sizes, efficiencies, etc
Dec.	Worked independently over winter break to come up with a design as to how the design should look		
Jan. 2-6	Poncelet turbines	Underflow turbines	Turbine blade angles and how they effect efficiency
	Optimal diameter		
Jan 9-14	Blade width spacing, and number of blades	•Working circumference, working cross-sectional area •Calculated rpms, max power, HP	Researched materials
Jan. 16	Contacted water wheel companies for assistance		
Jan. 17	Received input on materials used, and their own analysis procedure for designing a turbine along with an appropriate generator/motor		
Jan. 18-21	•Researched generators, watched videos, learned how they function •Found appropriate generator. Decided on treadmill generator/motor	Calculated max force on blades, max bending moment, minimum blade thickness, weight of turbine	Unknown
Jan. 23-28	With all specs determined for generator and turbine, created AutoCAD drawing	Calculate max force on shaft, max shaft bending moment, minimum recommended shaft bending moment	Battery Research
Jan. 30	Emailed Dr. Wang to set up meeting to present current findings and discuss what else needs to be accomplished		
Feb. 1-4	Research on river environment (speed, flow, conditions. What effects velocity?)		
Feb. 6-10	Acquired SOLID WORKS, learning to use in-order to create working video of design in action	Graphical analysis of calculated data	Battery Research
Feb 13-18	Began Solidworks drawings of Design	Did Research and selected generator	Cable Research
Feb 20-25	Continued Solidworks drawings (All)	Selected turbine/shaft dimensions and materials	
Feb 27-Mar 4		Selected Battery for the system	
Mar 6-11		Research Flange and determined dimensions	
Mar 13-18		Researched pillow blocks and determined dimensions	
Mar 20-25		Determined dimensions of casing and pontoons	Selected Cable
Mar 27-31	Made Presentation	Made presentation	Unknown
Apr 3-7	Write up	Write up	