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# Gravity Charger

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ENTITLED

# Gravity Charger

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

**BACHELOR OF SCIENCE**
IN
**MECHANICAL ENGINEERING**

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# Gravity Charger

By

Luke Lindsay, Will Gonder, George Montgomery

**SENIOR DESIGN PROJECT REPORT**

Submitted to
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in Partial Fulfillment of the Requirements
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# Abstract

According to a 2014 World Health Organization research initiative based on data collected from 14 global developing countries, “Only 28% of health facilities and 34% of hospitals had what could be called “reliable” access to electricity (without prolonged interruptions in one week)” [1]. Healthcare quality suffers because of this lack of reliable electricity. We propose that a gravity powered generator would stand as a reliable power source for small medical devices under any conditions at any location at any time of day. Our research examines how a gravity powered electric generator could best empower medical facilities in developing countries to provide improved healthcare. Our research has shown that most often, the greatest needs at these facilities are dependent upon an inadequate power supply, including lighting for emergency night-time care, refrigeration for blood and vaccines, facilities for sterilization, and electricity for simple medical devices [1]. We have chosen to focus on providing power for small devices as well as lighting. A successful charger must be lightweight, durable, and reliably provides dc power congruent with USB charging specifications. Testing has revealed a proof of concept, in that we were able to produce USB power from a mockup of the intended design, and further iterations of the charger will improve charge time per use. Initially, those seeking medical attention will be the main beneficiaries of our device; however, we expect the gravity generator project to expand if visitors see that our device could replace fossil or other solid fuel consuming device, such as kerosene lanterns, in their homes.

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# Introduction

A lack of access to reliable electricity is, in part, what defines and differentiates developed countries from developing countries. This shortage is the main problem our senior design team aims to address. A number of solutions have been proposed for ways to locally capture renewable energy and convert it into electricity. These solutions generally rely on solar, hydroelectric, or wind power. Though all of these sources are renewable, none is as reliable or readily available as gravity. Every location on earth has equal access to gravity, day or night, rain or shine. Gravity is one of the few constants all people have access to regardless of their circumstances.

The lack of reliable electricity affects the performance of many medical clinics in underdeveloped areas. One negative effect of unreliable electricity is that many small devices cannot be powered without a ready supply of batteries. Batteries may not always be available, should be disposed of in specific ways to reduce environmental impact, and do not hold an optimal charge in certain, warm and humid climates. Clinic hours also suffer since the workers must either close when the sun sets or use methods like the kerosene lantern seen in figure 1.

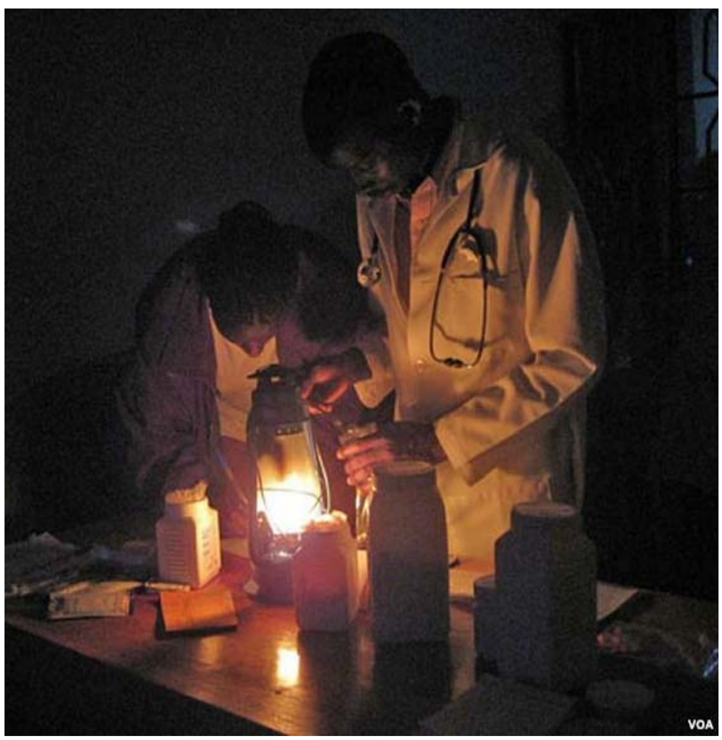



*Figure 1: Kerosene Lantern [7]*

Another issue, not directly related to electricity, our team will be addressing is the lack of STEM education tools in underdeveloped communities. Without the proper education tools, communities will remain "under" developed and will continue to struggle to catch up. William Kamkwamba of Malawian, pictured in figure 2, recently spoke at a TED conference and published a book about how he built a windmill generator for his family from spare parts and a plan from his local library [9]. His efforts show the effect that a single generator can have on a family and the impact one motivated inventor can have on a community. Inspired by Mr. Kamkwamba our team wants to empower local communities, not only with electricity, but with the knowledge of how to build their own generators and the pride of having completed one for themselves. Our team's gravity powered generator will address the need for reliable access to electricity and will potentially improve healthcare and empower the communities we seek to help.

*Figure 2: Kamkwamba's windmill generator [9]*

# System-Level

Overview

It is in this chapter that team Gravity Charger identifies specific customers and their personal needs to be met. After describing the needs of our customers the overview of the system at large and how it may be broken into subsystems follows. After this breakdown the requirements for the system to meet the required need are laid out along with a description of the expected general user interface. Having identified the constraints of the project a short portion thereafter explains a number of trade-offs which will be balanced.

Customer needs

*Global Medical Brigade*

The primary users of our device will be medical clinics, permanent or temporary, in areas with unreliable access to energy, and the local communities that surround them. Our team conducted an interview with Alex Young, the former president of Santa Clara University's Global Medical Brigade (GMB). He has organized and taken multiple trips with GMB. He believes the largest need for electricity was with regard to lighting. His personal expertise lies with the dental care group and he noticed flashlights would vastly improve the dentist's ability to perform even the most basic tasks. Alex also informed us that there is often a ministry of health which must issue permits for any group intending to provide healthcare, and their equipment undergoes light scrutiny at border customs. Furthermore he told us that their groups often performed other small public health projects while they are on location, such as erecting buildings or improving infrastructure. Inquiring further about these projects, we were able to determine that most areas that GMB serves have any non-power tool that may be required. As a means of transport, Alex told us they drive a van to wherever they will be setting up. With this information in mind, we have determined that our device will need to provide enough light to illuminate all parts of a mouth, be van portable, and maintenance must be completable with non-power tools.

The main need is for suitable light for the medical setting. This light needs to provide enough light to be able to properly perform medical tasks. This means, for dental needs, direct light into a patient's mouth and suitable room lighting. These lights will need to be powered in sync. Light is extremely important in being able to operate in a medical setting.

The second need is for charging USB devices. Portable electronics are nearly everywhere in the developing world. However, access to charging stations is difficult. Currently, if one wants to charge one's cell phone, one may have to travel into town and pay a person at a store to be able to get a charge. There are many medical devices that run on USB. For example, a pulse oximeter is a common device that runs on USB. This will provide information on blood pressure. There are also dental imaging devices that run on USB to capture x-ray images of teeth.

*International Medical Relief*

Our group also conducted an interview with Sarah MacGregor with International Medical Relief who gave us some interesting and encouraging information. Sarah explained that in Nepal and Haiti, the medical relief team often relied on battery-powered technologies. They had some access to solar panels if they brought their own. Otherwise, they were forced to wait till the end of the day to charge their devices in the hotel. Sarah also told us that whatever equipment they bring with them must be very durable. She explained that our Gravity Charger would need to be water – resistant, drop proof, small enough to be carried in a day pack, and that it would have to be allowed on planes. It was brought up that if medical professionals know they will have access to charging power, it would provide confidence in what tools they could bring along because of weight requirements. Sarah also told us that there would likely be structures on which to hang our device, but on several instances their group was forced to use tarps as temporary shelter.

We learned several great things from this interview. For example, it is important for a medical technician to be able to perform his tasks uninterrupted. This means that the fall time needs to be greater than 5 minutes. One cannot be constantly lifting the weight. The technician also should be able to lift the weight by himself. Also, we had not yet considered durability of our product to know that it will need to be durable enough to survive the rough and tumble environment of rural medical care.

*Baan Dada's Children's Home in Rural Western Thailand*

One of our Engineering World Health partners has a connection to the leader of a children's home in Thailand, and he was able to provide us with information pertaining to our project. For example, when asked what types of electrical devices they commonly used, he mentioned lights, computers, small electronic devices, and even motors. We also learned that in a more permanent location such as this, there are several things that cannot go without power. For example, lighting and the refrigerator both run on electricity, and they cannot afford to have any down time. We also learned that in response to power outages, the home uses candles and flashlights to illuminate the building and provide power to the essential parts of the home with an old generator. The man interviewed explained that he used AC current to charge their cell phones in all cases.

We were able to take several important lessons away from this interview. First, lighting is the most important thing that our device could reliably power in this situation, so we must ensure that we are fully capable of providing light. Second, many people use the ac to dc adapter provided by most mobile phone providers to convert AC current of wall power to DC power to charge a small battery. Our device may have a competitive advantage over some generators because it could provide acceptable DC current without having to use an adapter.

## System level requirements

It is important for the system to be able to supply sufficient power for USB devices, light sources and common portable electronics. The number of electronic devices to be powered in series would depend on the needs of the clinic, so the generator would need to be scaled to accommodate this. USB devices require 4.75-5.25V with a current of 0.5-1.5 A to operate. If multiple devices are to be used in series, the power generated would need to be increased to accommodate this need. The main device that would be powered by the Gravity Charger is a light. It is a common problem to not have enough light to be able to function well in a medical setting. Location also has an impact on the devices to power due to the differences in wall sockets. Wall sockets are different all around the world, as seen in table 1, but we avoid this issue by relying on the standard USB electrical layout.

Table 1: Locations where global medical brigade has done work and wall sockets used [4]

| Location | Wall socket types used |
|---|---|
| Thailand | A,B,C,O |
| Nicaragua | A,B |
| Ghana | G,D |

Table 2: Minimum requirements of USB 2.0 devices [2]

| PARAMETER | | REQUIREMENT |
|---|---|---|
| Voltage | Low-power device | 4.4 to 5.25 V |
| | High-power device | 4.75 to 5.25 V at upstream connector |
| Maximum quiescent current | Low-power device | 500 μA |
| Maximum low-power current | | 100 mA |
| Maximum high-power current | | 500 mA |
| Maximum power draw | | 2.25 W |
| Maximum input capacitor | | 10 μF |
| Maximum inrush | | 50 μC |

These considerations resulted in table 3 and our design specifications. The Gravity Charger needs to produce 2.5 Watts of energy to satisfy USB standards. We also cannot expect someone to lift more than 50 pounds repeatedly. On top of this the fall time needs to be 5 minutes or longer to provide a useful amount of time between resetting the device. Since the device will also be carried to its final location it should not exceed typical backpacking weights and must weigh less than 25 pounds.

Table 3: Design Specifications

| Specification | Value |
|---|---|
| Power Output | 2.5 watts |
| Lifted Weight | 50 lbs |
| Fall Time | 5 mins |
| Device Weight | 25 lbs |

System sketch with user scenario explanation

Our consumers are people who serve in underdeveloped nations with unreliable energy. It is intended for an individual to lift a weight, which will turn a generator as it drops in a controlled manner. There will be a device connected by a power socket or USB port that will need to be powered. After the weight has reached its lowest point, it will be lifted back up to generate more electricity.

An example of a use for our product would be light for medical examinations. It is important for a light to be sufficient to be able to see clearly at night: approximately 6 lumens [7]. The light would be connected with the Gravity Charger, and then the attendant would lift the attached weight.

Numerous small medical devices can be charged and run by the power supplied by a computer’s USB port. The gravity charging device would be able to power or charge such a device with universal USB plugs.

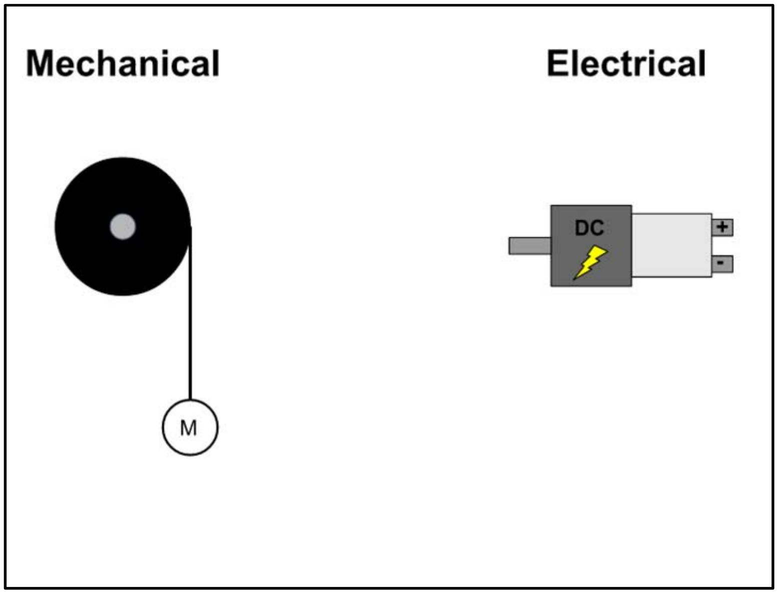



*Figure 3: Conceptual System Level Breakdown- Luke Lindsay*

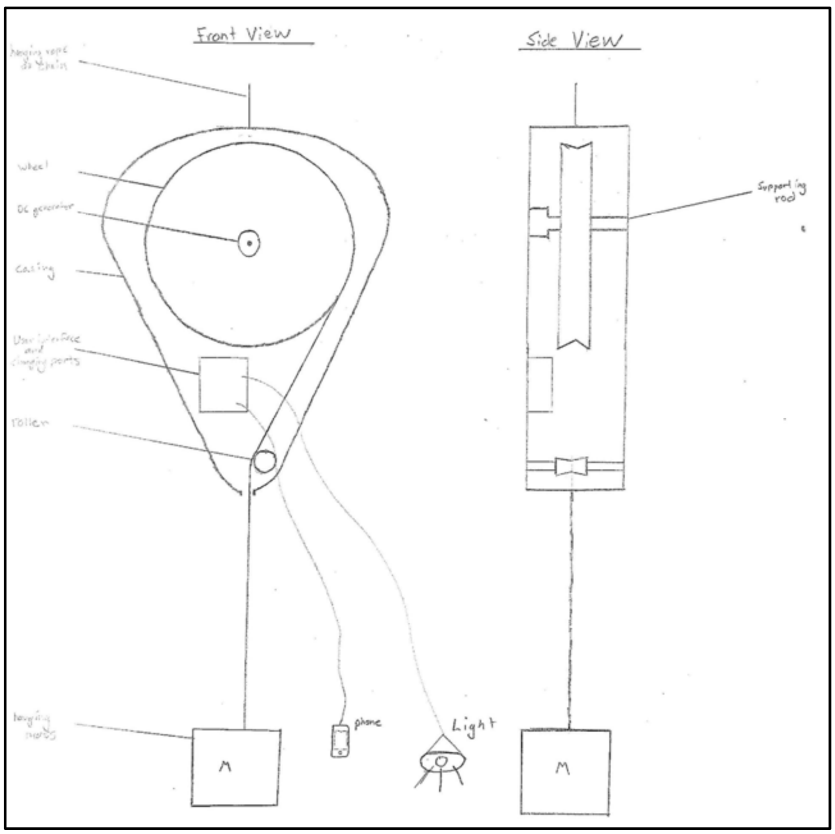



*Figure 4: Preliminary Conceptual Design- Will Gonder*

<u>Functional Analysis</u>

The ultimate function of our device is to generate electrical energy using the non-depletable resource of gravity. Lighting for nighttime treatment, small medical devices, and portable electronic devices are the main devices that would be powered. The subsystems of our project include the mass, the rope, the wheel, the shaft, the rope guide, the generator itself, two sprockets and a chain to convert rotation of the wheel to rotation of the generator, an electrical signal filter, a casing, the electrical connection point, the system support, and the devices which will be powered.

The mechanical subsystem is the storage of the gravitational energy. This part of the system has to hold the mass which is required for the electrical power output safely and securely. The rope attaches the mass to the wheel and transfers all of the gravitational power into a tensile force tangential to the wheel. The wheel converts the tensile force into a torque about the shaft. The wheel has two offset guide wheels next to it which function as a guide on the rope to keep it in place as it engages with the wheel while at the same time ensuring that the rope triple wraps the wheel without overlapping itself. The wheel is linked to the generator subsystem by means of two sprockets and a chain, which function as a means to transmit all of the torque generated by the previous subsystems into the generator. It is the generator's function to convert the torque and associated rotation into electrical power. The electrical signal produced by the generator will not be a perfectly usable signal right at generation. A signal filter subsystem ensures that the output signal is of the proper form to meet USB charging specifications. The casing encloses the signal filter, generator, and shaft to function as protection for both the device and the users. On the casing there is a connection point for USB electrical devices. This allows a variety of devices to interface with our Gravity Charger. A support subsystem will hold the casing, its contents, and the wheel above the ground at a predetermined minimum fall height. The final subsystem of our project, the devices which are powered, will have a broad range of functions from lighting an area to monitoring vital signs.

Benchmark results

The Gravity Light [5] pictured in figure 5 is a device that is strictly used for light with a small weight as its source for energy. From the videos of gravity light, it can be concluded that the light is not all that powerful. The main constraint that is holding back Gravity Light is cost. They are still prototyping, but want their final product to be only $5. Our device will cost more, but will provide more power and will be able to power more than just a light. The Gravity Light is now in its Third year of production and is still on its second prototype seeking funding. Other devices with similar functions are kerosene lanterns. However, they are not nearly as desirable due to kerosene being non-renewable and producing toxic emissions.


*Figure 5: Gravity Light*

Other devices which supply energy from a renewable resource include photovoltaic solar cells. These are convenient in terms of what a user needs to do to get energy, but not nearly as convenient due to sunlight not being available when light in a medical setting is needed most. Also, these systems generally involve the use of a lead acid battery. The locations where we foresee our device being used are not in the best climate for these batteries due to the warm humid environment that degrades such heavy batteries at an accelerated rate.

System level issues/tradeoffs/rational of choice

The approach for how the generator is rotated was chosen with a selection matrix. (Appendix 2) Power generation with a long fall time was emphasized as the key constraint to be designed around. The first finalist, for energy generation, was a design similar to a water wheel with discrete mass packages dropping into holders along a belt. The second finalist was a design that ran many weight drops in series or parallel so that once a weight reached the bottom of the fall the next one would be triggered to fall. This would allow one to go longer times without having to reset the generator by lifting the weight, so that a medical professional could focus on the needs of the patients. However the design we went with in the end was one of a sliding mass that could be slid up the main rope to allow for continuity of charge, and user simplicity.

Layout of System Level Design

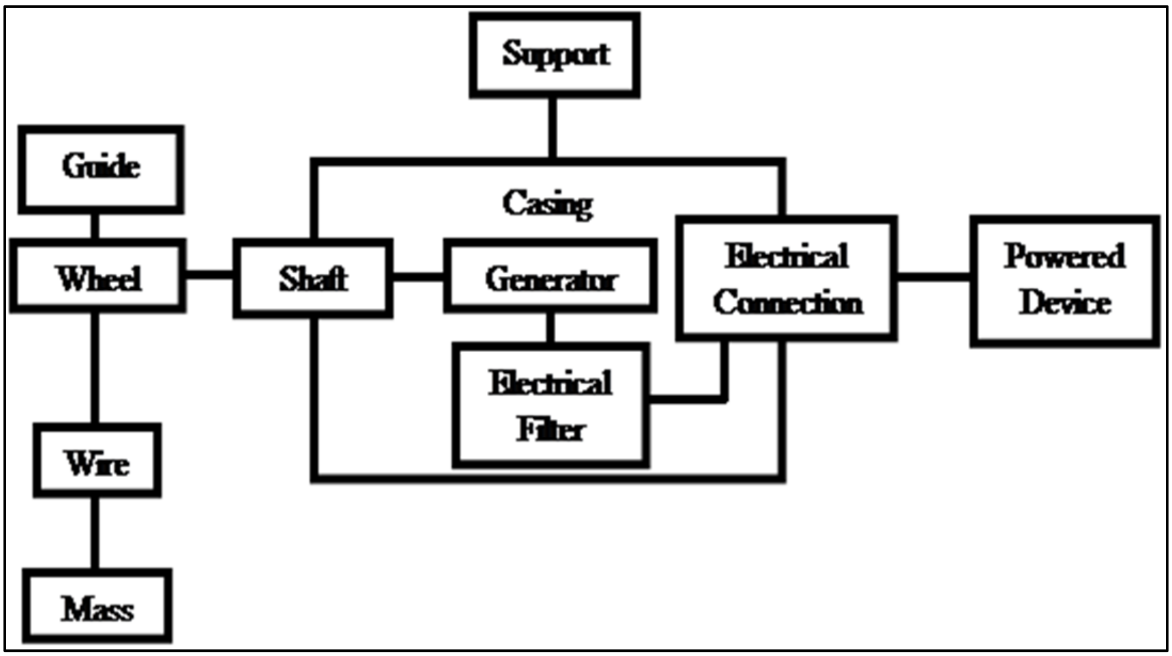



*Figure 6: Fine System Level Breakdown- Luke Lindsay*

User scenario

To use our device, it requires a hanging point which has multiple points where something can be hung. An eye bolt on a beam in a structure, or a branch of a tree that can withstand the hung weight would be suitable. Multiple hanging points would be beneficial as one can install a pulley system to provide mechanical advantage to the operator. A pulley system works by having multiple pulleys which a rope is threaded through. This rope is used purely for hoisting the weight up. For n pulleys, it is a n: 1 ratio. For example, four pulleys used to lift a 50 pound weight would only require 12.5 pounds of force for the operator. Pulleys have the disadvantage of taking up a lot of rope. If n pulleys are added, the rope needs to be n times the length which it is lifted over.

Our device uses a prusik knot, a knot that grips a line when tension is applied, to fix the weight to the rope that is threaded through the device. The Loop of rope wraps around the wheel. The requirement for the knot to work is that the rope acting as the prusik knot needs to be a smaller diameter than the rope which it is gripping. This was done in our testing iterations by using paracord wrapped around a ¼” diameter rope. A weight is attached by hanging a mass from this prusik with a carabiner. The mass is found on site, one would usually hang a bag filled with dense materials such as rocks. When the weight needs to be reset on the device, the mass is lifted by a separate line and cleated off once it gets into position. Then the prusik is slid up the line and attached to the mass with a carabiner. This procedure can be completed very quickly allowing one to have virtually continuous electrical output. If one were to split the mass into two bags and raise one and then the other, then they may be able to have truly continuous output. This would sacrifice power output during lifting by 50%, but would not stop electrical output at any point. If the user wishes to cut the power to their device they can flick the red kill switch located on the housing.

# Team and Project Management

Project challenges and constraints

From our customer analysis, it is important for our product to be reliable and provide sufficient energy to power portable medical equipment as well as lights. The Gravity Charger is necessarily portable so that a single person could carry it into an environment if need be. Transporting the Gravity Charger could also involve air travel, so it needs to fit in a carry on.

*Bike Wheel*

An early challenge in this project was attempting to repurpose bicycle parts for the structure and wheel of the Gravity Charger. The structure portion of the device was unable to be constructed from reused bicycle parts for a number of reasons, the most disruptive being that the tubular pieces are highly customized for a specific purpose. Complex geometry has been imparted to even the most straight-forward of sections to eke out efficiencies. The small bends in the tube and the circular nature of the tubing itself proved to be more of a challenge than the convenience of sourcing bike parts was worth.

*Figure 7: Child's Bike Wheel*

The wheel of the bicycle still seemed promising and was incorporated into one of the early iterations of the Gravity Charger. Since most bicycle wheels have a coast mode where the wheel may spin freely about the sprocket, we were forced to use a children's bike wheel.

Children’s bike wheels have a locking mechanism which engages when the wheel is spun in the wrong direction. Upon further investigation of this mechanism it was noted to be reliant upon two very small slits of metal which engage to provide the locking action. These tiny pieces of metal did not provide for much ease of mind when working with the bike wheel.

In order to ensure the brake mechanism did not break or disengage, the mechanism had to be bolted together in a manner that occasionally locked the wheel to the shaft itself. This process is pictured in figure 6 above. Locking onto the shaft removed all of the benefits of having bearings in place. The bolting of the wheel also caused its axial width to be larger than anticipated and cause a number of minor headaches with the spacing of the plates.

The final major problem with the wheel was attaching the no. 25 pitch sprocket to the sprocket already in place. In order to do this the wheel had to be disassembled. Once disassembled it was placed into a custom holding jig and onto a milling machine. After being carefully locked into position, four holes were drilled through the no. 25 sprocket, the bike sprocket, and three 0.75 inch washers. Those four holes were fitted with bolts and held the pieces together. Lining the no. 25 sprocket up so that it was concentric with the bike wheel axis was not an easy task.

*Initial Disaster*

The first mechanical failure occurred during initial testing of the first iteration. While lowering weight onto the machine a jerk was observed along the rope and the entire mechanism shuddered. After removing the weight and taking down the device, diagnostics were run. The most noticeable change was the ability of the previously resistant motor shaft to spin somewhat freely. To see why this was the team opened the gearbox on the front of the motor.

Inside of the gearbox many teeth were sheared off of their respective gears and scattered about the box. The teeth of the gears appeared to have shorn away under the torque conditions applied to the motor. The cause of this was the immense level of start-up torque which was required to spin the motor as a generator was actually higher than the torque the gears could bear.

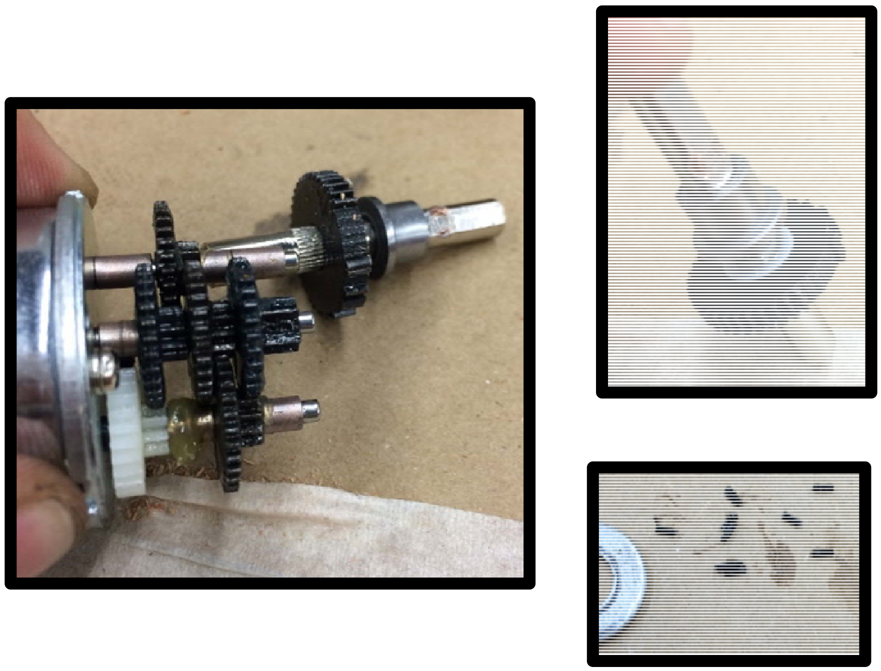


*Figure 8: Left: Gear Box, Right Top: Sheared initial gear, Right Bottom: Sheared gear teeth.*

<u>Budget</u>

Team Gravity Charger initially determined that the development costs of this project would amount to $700 USD. This money is broken out below into categories consisting of a Gravity Harness ($120), a Power Converter ($115), a Disinfection Chamber ($190), and Technical References ($180) seen in table 4. During the development process our budgeted money was reallocated (see table 5) to different portions of the project. Even with the reallocation the total estimation is still $700 USD.

The Gravity harness mentioned below is the portion of our device which will convert the translational energy of a falling mass into rotational energy and will constitute the majority of the mechanical portion of our project. The Power Converter is the portion which converts the rotational energy into electrical energy. It contains some mechanical parts but mostly electrical components such as the generator itself. The Disinfection Chamber was the reach goal portion of the budget and is where medical instruments would have been placed to undergo their disinfection irradiation. We anticipated needing UVGI lamps to test and multiple iterations of chamber geometry before finalizing the attachment. The final breakout, Technical References, refers to a textbook we located which clearly explains the ultraviolet germicidal irradiation process. This disinfection attachment no longer falls within the scope of our project and has been removed from the second budget estimation. The 15% contingency was included to cover any alterations to design or unanticipated expenses encountered.

The second budget was created to reflect the change in direction for the Gravity Charger project. The disinfection chamber was deemed beyond the scope of the project. As such the money allocated towards it and the technical references needed to form it was redistributed into two portions. The first new portion was for the test frame which was required in order to properly scale up the tests of the Gravity Charger. The second new portion added was allocated to provide funds for the iterative process inherent in the designing of the Gravity Charger. Even with the change of direction for the Gravity Charger, the total budget amount remained the same.

Table 4: First budget Iteration

| Section | Part | # of Units | Unit cost | Total cost |
|---|---|---|---|---|
| Gravity Harness | | | | |
| | Gear train | 1 | $100 | $100 |
| | Timing belts | 4 | $5 | $20 |
| | | | | **$120** |
| Power Converter | | | | |
| | Generator | 3 | $30 | $90 |
| | Electrical circuitry | 1 | $25 | $25 |
| | | | | **$115** |
| Disinfection Chamber | | | | |
| | UVGI Lamp | 5 | $10 | $50 |
| | Chamber fabrication | 6 | $15 | $90 |
| | Reflective coating | 1 | $50 | $50 |
| | | | | **$190** |
| Technical References | | | | |
| | UVGI Handbook | 1 | $100 | $100 |
| | UVGI alternatives | 1 | $80 | $80 |
| | | | | **$180** |
| | | | Subtotal | $605 |
| | | | 15% Contingency | $91 |
| | | | Adjusted Subtotal | $696 |
| | | | Funding Request | **$700** |

Table 5: Second budget Iteration

| Section | Part | # of Units | Unit cost | Total cost |
|---|---|---|---|---|
| Gravity Harness | | | | |
| | Gear train | 1 | $100 | $100 |
| | Timing belts | 5 | $10 | $50 |
| | | | | **$150** |
| Power Converter | | | | |
| | Generator | 3 | $30 | $90 |
| | Electrical circuitry | 3 | $25 | $75 |
| | | | | **$165** |
| Iterative Refinement | | | | |
| | Gravity Harness | 1 | $75 | $75 |
| | Power Converter | 2 | $50 | $100 |
| | Casing | 1 | $25 | $25 |
| | | | | **$200** |
| Testing Apparatus | | | | |
| | Lumber | 1 | $75 | $75 |
| | Hardware | 1 | $25 | $25 |
| | | | | **$100** |
| | | | Subtotal | $615 |
| | | | 15% Contingency | $92 |
| | | | Adjusted Subtotal | $707 |
| | | | Funding Request | **$700** |

## Timeline

Over the course of the design project many written submissions, oral presentations, and iterations were produced. In the fall quarter, proposals for grants to fund our project were due. This resulted in our team being awarded a Roelandt's grant to fund our project. The Roelandt's grant required a poster to be presented on Wednesday, 25 May 2016, in the Locatelli Center with results from our research.

The main written submission for the senior design course is the senior design thesis. A draft was due April 4th 2016 with the final draft due June 10th 2016. A rough draft of the Conceptual Design Report was due on the 19th of November 2015 and a final draft was due on the 9th of December 2015.

Oral presentations for the design project include the Conceptual Design Review on the 2nd of December 2015 and the Senior Design Conference on May 12th 2016. The Conceptual Design Review's purpose was to get outside responses to the designs proposed. Prototypes of our project were manufactured to demonstrate the main characteristics of our system. A Design Mockup was required for the Conceptual Design Review. For the Senior Design Conference a first and second iteration of our design occurred. The project timeline Gantt chart is located in appendix 3.

## Design Process

The Gravity Charger design has undergone many alterations throughout its design process. Initially the Gravity Charger was intended to be completed in conjunction with an ultraviolet germicidal irradiation chamber for the disinfection of medical instrumentation.

This attachment is no longer a team goal, it has been removed as the primary objective in favor of maximizing energy production. Our customer research revealed that though there is a need for disinfection of medical instrumentation it is not as vital, nor realistically feasible with our time constraints, as some other applications of reliable electricity.

With our focus shifted, we began investigating ways to maximize power output by characterizing the energy production capabilities of a DC motor. It became clear that power generation is linked to torque, rotational speed, and fall time. Knowing these variables to be crucial to our project, we began looking for ways to increase all three. With regards to torque, the diameter of the motor shaft and amount of mass can be increased without causing the device to fail. The wheel diameter and mass are both limited by portability constraints. As for the mass, we have decided on a design which allows the user to fill a container with a specified volume of a substance which sinks in water to ensure a minimum weight is reached. We also split the mass into multiple smaller, more easily lifted allotments. As for the rotational speed of the motor, we initially selected a generator with a 3000 to 1 gear ratio to allow for the longest fall time possible to increase the time of one fall for ease of use.

The design process is constant and iterative. Our team took a methodical approach to improving our base design by building and rebuilding the Gravity Charger. After our initial proof of concept a first iteration was constructed. When it failed testing, small improvements were made to the same base structure and we made iteration 1.2. After learning from that iteration we re-vamped the entire device in a large way and created our final, second iteration. We believe it is important to refine and develop an idea a number of times in order to create the best final product.

# Risks and Mitigations

Manufacturing

In the manufacturing, power cutting tools were used to make the exterior casing of the design. Proper training for the power tools occurred prior to operation. The general tools that were needed include a power drill, Dremel, laser cutter and other similar light fabrication equipment.

When using the power drill it is important to not place one's hand very close to the holes being drilled and keep the part firmly clamped. As with any tool with spinning parts, it is also important to not wear gloves and keep any snag-able clothing clear.

In our proof of concept, the laser cutter in the maker lab was used to create our wheel. To be able to use the laser cutter and any other tool inside the maker lab, training on how to use them was required. Power tools were used to fasten a motor to a piece of wood. Safety glasses were used at all times when fabricating.

Other heavy machining equipment was also used in the manufacturing of the Gravity Charger device iterations. Among that other equipment is included a mill and a lathe. The mill was used for drilling and forming operations. All proper safety procedures, including creating a jig for the first iteration support plates, were followed. Proper speeds and cutting tools were selected with help from the machine shop supervisors.

Assembly

During assembly it is important to keep all parts firmly affixed to a solid surface. Proper support for all components must be present at all times to avoid any precarious positions. All processes must also be completed with the proper tool for the job to maximize safety.

## Testing and Operation

The generator has moving parts as well as release of energy. The risk of pinch points from moving parts was eliminated from the main machine by enclosing the device. The machine should not run if there is too much load present so as to keep the counterweight mass from free-falling at a potentially dangerous speed. Ten years is the minimum age for operation.

There is the very real potential to deliver a painful and potentially damaging shock to a person. The generator could also produce a large amount of heat and pose a fire hazard should something go wrong. To reduce fire hazard no easily flammable parts will be connected to the generator and proper ventilation will be available for cooling. Even when functioning properly, if not properly enclosed the moving parts of the device create many pinch points. Since our final device relies on a mass with a height displacement, it is important to make sure the mass is secure and will not land on someone or something when falling.

## Storage

The device needs to be stored so that it will not be tampered with. The device was designed with the use environment in mind. The Gravity Charger is designed to use gravitational potential rather than batteries for energy storage, so it will not degrade with time. The construction materials also do not degrade over time if left unused. As for transportation storage, we made sure the device is able to be easily carried by one person. Airport guidelines for luggage were used as a benchmark for what an average human can be expected to carry.

## Disposal

The device would preferably never be destroyed, as it would be beneficial to fix it rather than dispose of it. Disposal would be hard in rural areas due to no communal land dump.

Planning for the worst case, we have made sure there are no materials in our product that would be hazardous if buried in the ground or thrown into a water source.

Team Management

In order to best organize our team, George Montgomery has taken on the role of Team Lead. Will Gonder is in charge of meeting notes and our Weekly Activity Reports. Our team is also working with three students from the Santa Clara University Engineering World Health group (EWH); Lucas Hill, Serena Chan, and Michelle Fat. Luke Lindsay is our main liaison with the EWH team.

# Engineering Standards and Realistic Constraints

Economic

Our final product is designed for areas with limited access to power. The initial implementation of our device will be through medical outreach programs with altruistic donors, however we have kept in mind the idea of leaving the device behind or ultimately marketing it to rural health care clinics. Those locations are not generally associated with disposable income. Therefor they are far more likely to be poverty ridden. As such, it is important to keep the cost of our final product as low as possible. Through contacting the International Medical Relief and the Global Medical Brigade we have learned that these groups have some sort of micro finance aspect associated with them which provides investment capital to people in the areas where they are operating. They also have their own budget for their trips which is far higher than the amount of disposable income in the underdeveloped areas being served. Knowing this, our team decided it would be more ethically responsible to create a product which is more effective at a little more expense and market them to the aid trip coordinators rather than the impoverished end users. Their trips will also provide an active distribution avenue which will reduce shipping costs.

Manufacturability

Our intention is to provide a small package product to deliver a big impact. We are still open to the possibility of building much of the kit on site, however if we are going to deliver this product as a kit, it must actually be buildable on the site. The directions would need to be clear to reduce any danger of improper assembly, and the tasks required to assemble the device must also be accomplishable on site. The tools necessary must be present, as it would not be ethical to ask a community with no welding capabilities to weld anything or mill parts etc.

Health & Safety

The first safety issue that involves our project are the potential dangers of working with an electric generator. There is the very real potential to deliver a painful and potentially damaging shock to a person. The generator could also produce a large amount of heat and pose a fire hazard should something go wrong. Even when functioning properly, if not properly enclosed the moving parts of the device create many pinch points. Due to these dangers, an appropriate age limit should be required to operate or work on the device.

Social

It is equally important to be aware of the cultural differences between Santa Clara University and our final end users. Our team has limited exposure to medical clinics in underdeveloped nations. We are, therefore, reliant on our Engineering World Health team members to make sure we do not cause unintended offence. Social differences could manifest themselves in aspects as simple as certain colors being associated with poor health. We would not like to have our medical device associated with any color which suggests anything negative. We will also have to make sure we are not asking anything of the locals which they would not accept. To aid us in this endeavor we consulted with the Global Medical Brigade in order to utilize their experience.

Political

Politically it is important to remember that our device will be primarily utilized in countries outside of the United States of America. Our device will have to cross international borders and clear customs. Proper documentation will be necessary and consideration of international regulations will be paramount. International Medical Relief and Global Medical Brigade both supplied copies of the paperwork they generally need to fill out before functioning in an area. Therefore, an accurate parts list will be crucial to avoid complications with travel. Most importantly, we must specify each material and include warnings for any hazardous materials.

# Subsystems

Mechanical Subsystem

*Summary of Options and Tradeoffs*

The Gravity Charger's mechanical subsystem consists of the support system on which all other systems will be mounted. There were several variations in design that our team has considered for our prototype development. First, the team considered the design of the support system used. With safety as our primary concern, we considered the strength of our support system to be paramount. We thought of three different ideas that would safely support all of our components and the tension forces that a weight would eventually provide on the system; a rectangular design, a triangular design and a teardrop shaped design pictured below.

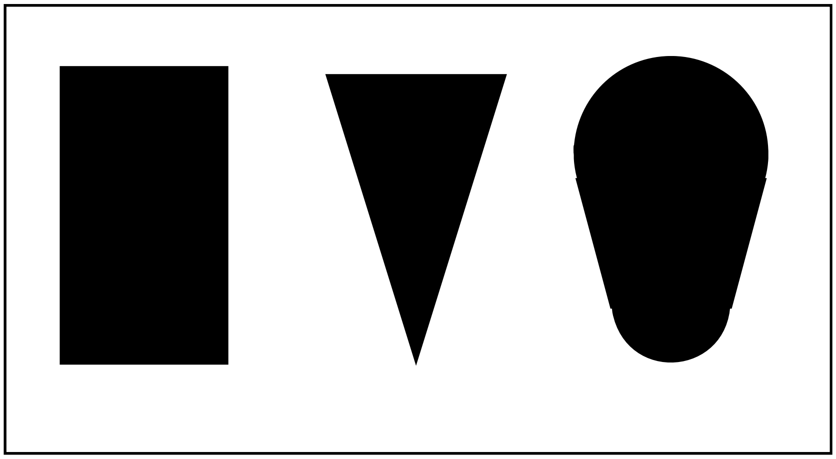


*Figure 9: Initial Support Plate designs*

For the rectangular design, ease of manufacturability would be high however the aesthetics of the design would suffer. Next we considered a triangular shaped design that would also be easy to manufacture and would fit into our aesthetic standards. When beginning production, the group came to a conclusion that aesthetics of our device is very important, and the teardrop shape would provide a great balance of aesthetics and functionality without sacrificing safety.

*Detailed Design Description*

-Proof of concept:

In order to prove to ourselves and our advisors that a DC motor could feasibly act as a power source able to replace other less reliable or non-environmentally friendly, we set out to develop our proof of concept. We were able to turn our initial motor with a fair amount of torque from our hands as seen in figure 10.

*Figure 10: Turning the proof of concept motor*

Next, the proof of concept iteration of our project was developed quickly and with very affordable materials. We started first with a DC motor, as we did in all iterations, and then we built everything around it. We designed this way because power output was identified as our most important objective. In order to maximize our output, we matched the lever arm of our proof of concept to the rated torque of our dc motor. The lever arm used was 10cm which added to the ease of calculations as well as providing ideal torque. Next we went to the design center to design our proof of concept.

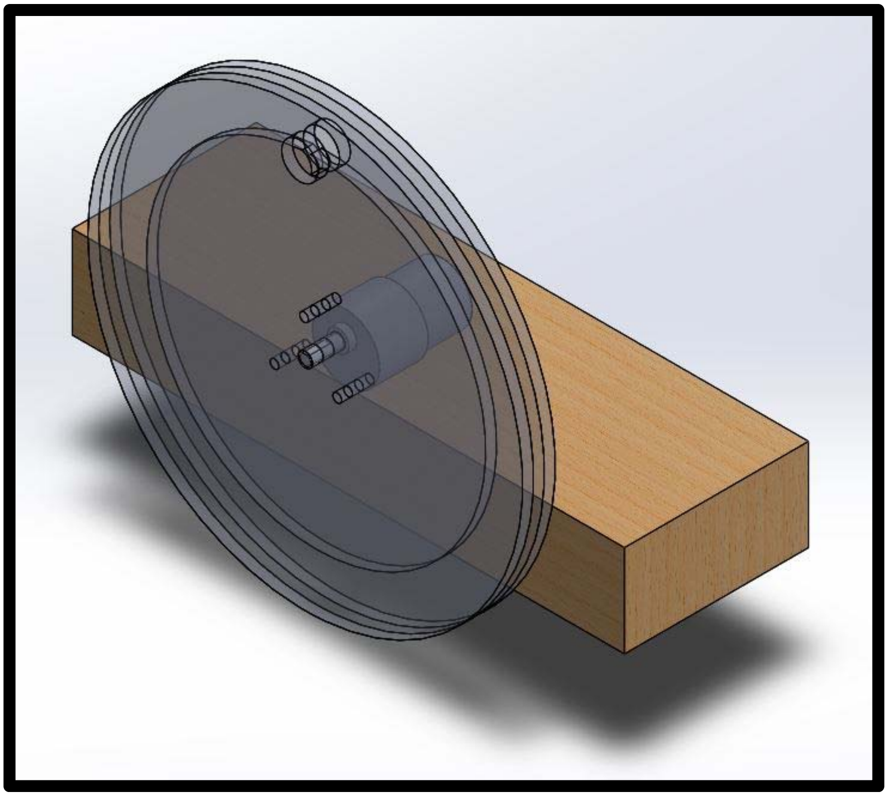


*Figure 10: Proof of Concept CAD*

We first designed a wheel to transfer torque to the motor with a 10cm radius. We opted for ease of fabrication and cost effectiveness over all, and therefore designed the wheel to be laser cut in the maker lab out of quarter inch acrylic. The wheel took a couple of hours to design because of its integrated rope hook and cost a grand total of three dollars for acrylic scrap. Next, we went to Home Depot to get ideas for how to attach our motor to the acrylic wheel and secure all of it to a bench. We found that conduit clamps closely approximated the size needed to fit around the motor and secure it to a small piece of two by four wood. We also found, and decided to integrate, rubber padding between the clamps, the motor, and the wood, to keep the motor from rotating in the proof of concept instead of turning the shaft. We also went to a hobby shop to find something to attach the motor to the wheel. We were pointed towards a shaft clamping device used to transfer the torque of a high rpm motor to a large propeller for RC planes. Like most things in our project, we were prepared to test if torque could be applied in reverse order of what was intended for this device. This meaning that the motor was designed to turn under load instead of having a load turn the motor.

Next we moved to production of the proof of concept. Production took one day once all of the materials were purchased and gathered. First, we cut the two by four wood to a two feet length and painted it black. Next, we soldered and hot glued leads onto the back of the motor, and wrapped it in the rubber. After that, we screwed the conduit clamps around the motor and secured it to the wood. We then secured the RC plane clamp to the laser cut wheel. Finally, we wrapped a rope around the wheel, and secured the wood to a bench using large clamps. A gallon milk jug was used to provide varying mass on the rope, which allowed for varying torque testing during that stage as seen in figure 11.

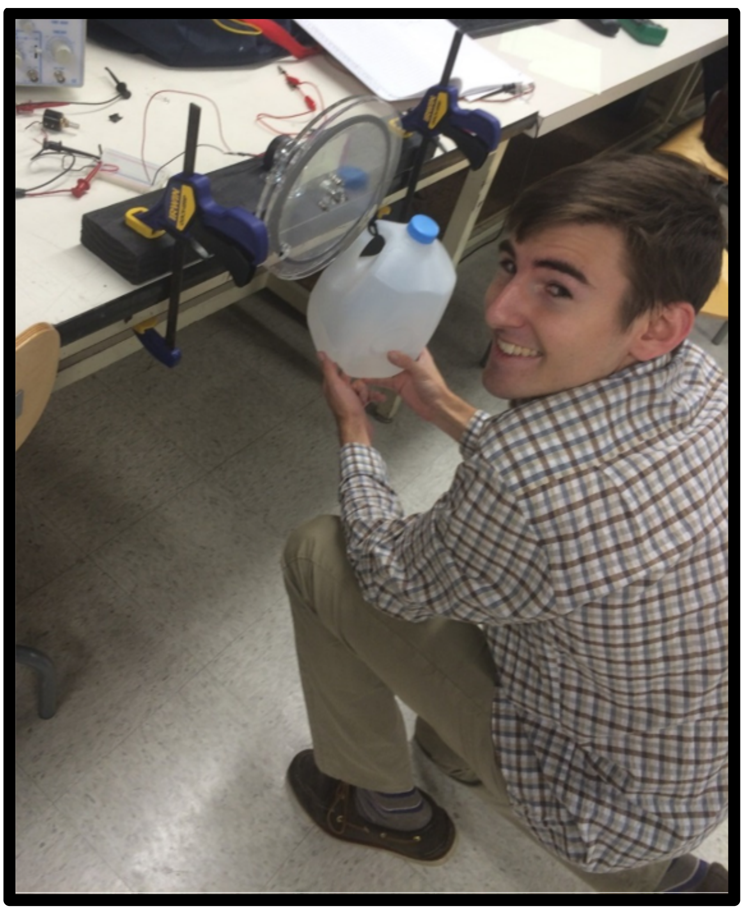


*Figure 11: Proof of concept testing*

The proof of concept iteration quickly and cheaply proved to us that the project was feasible. It showed that a motor could be turned to produce electricity. It showed us that a falling mass could provide the torque needed to turn the motor. Testing showed us that adding mass added to the power output. After the completion of the proof of concept, our team and advisor felt that we were ready to up the budget for the next iteration and up the mass.

-Test Frame:

With an increase in mass comes an increase in power output, but that’s not all. While we plan for our device to be hung from rafters or from a nearby tree, for testing purposes, we decided we must design our own test frame. To best simulate what we expect to be found in the field, we designed the frame to a height of 10 feet. With such a height, and with our designed mass on the frame at a maximum of 75 pounds, we knew we needed the frame to be safe.

We began in the computer lab designing the frame. This gave us all of the angles of cuts we would need to make in the manufacturing phase. In the design phase, we added supports to an A frame made of two by six lumber. During the design phase, we were able to visualize the frame, and we determined that the frame would be too large to fit through doors if the width was more than two and a half feet. For this reason, the frame is very slender.

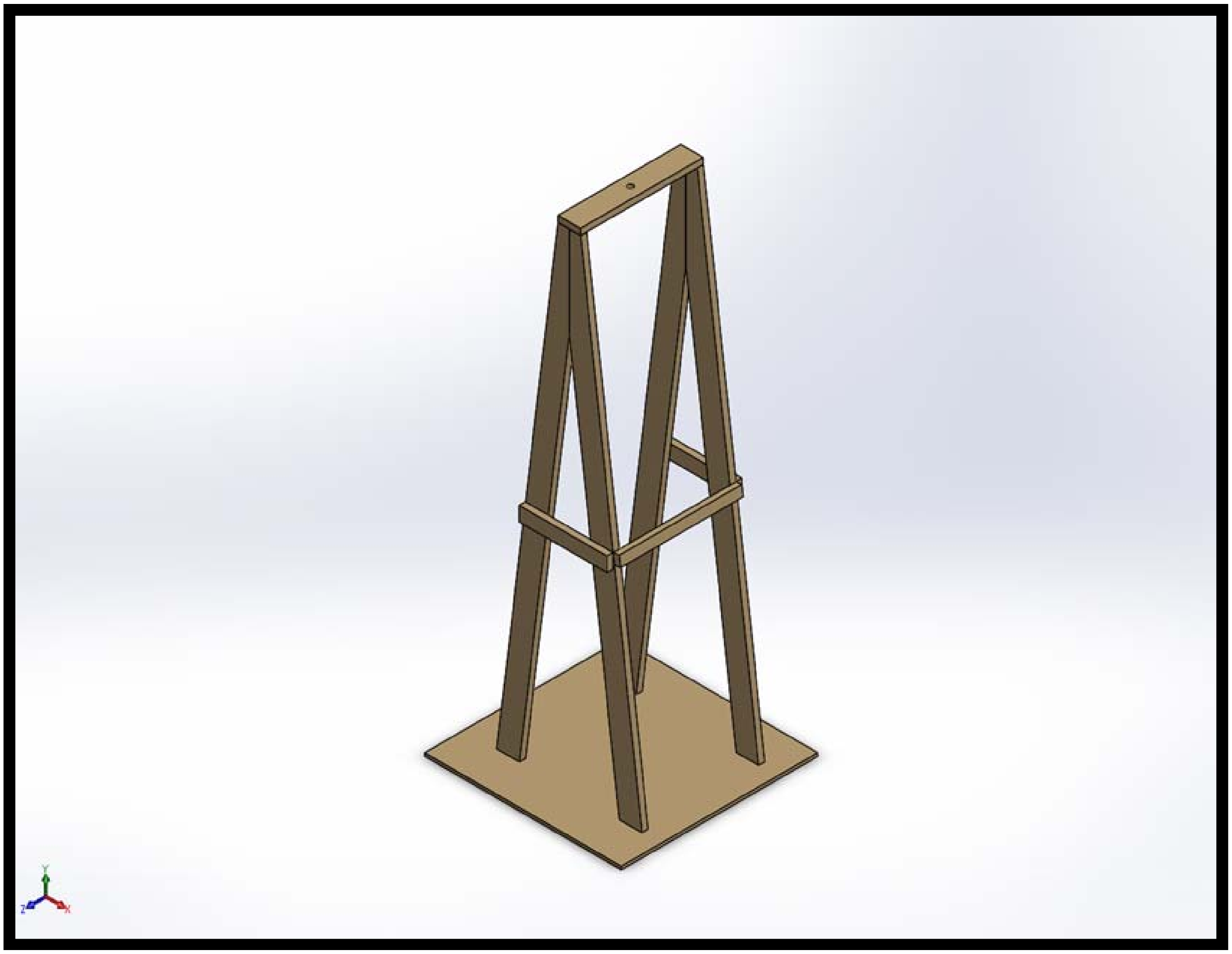


*Figure 11: Test Frame CAD*

During the fabrication process, we traveled to Home Depot with a bill of materials in hand. The rest of the day was spent in the backyard laying out the cuts, making them and securing the frame together. The frame came together well, however we recognized that we needed to go back to purchase and add more metal plates to the joints of the frame to make it stronger. After supports were added, and we were satisfied with the stability of our frame, we approached Don MacCubbin to apply for space in the machine shop. It was during this meeting that we realized we must follow all Engineering Health and Safety guidelines in order to keep ourselves and other safe.

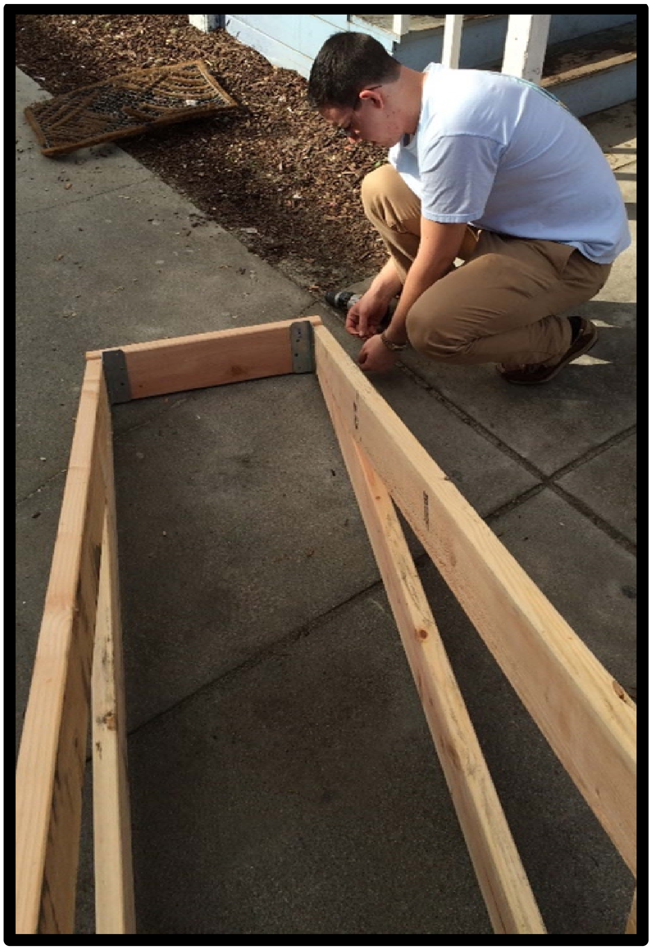


*Figure 12: Test Frame Fabrication*

We learned we needed to protect from tipping, pinch points, falling items, or flying materials. In order to counter the tipping risk with our frame, we added a plate on the bottom of our frame which secured the frame to a base where we added sand bags to prevent tipping. Then we moved to tackle the last three safety issues with the same solution. We aimed to fully enclose the frame. We looked into several options that might provide safety at an affordable cost. Corrugated plastic was far too expensive from a local store, however a thick fabric sheet provided adequate safety at a very low cost. We cut and stapled the fabric to the frame, and constructed a door complete with windows to the device so that we could see it during testing. Finally, we attached an eye bolt to the top of the frame and moved to the testing phase.

*Figure 13: Test Frame with safety features*

-Iteration 1:

For our first iteration we made a number of design choices to ensure the best device functionality. Two support plates form the backbone of the design housing all components internally and supporting the vertical loads. The support plates were cut into a teardrop shape for ease of transportation. The plates were placed four inches apart to accommodate the entire mechanism. Two dowel pins were placed to prevent the plates from twisting in relation to each other. There was also a bolt placed in the middle of the plates to prevent bowing. A support platform was fabricated to precisely hold the motor shaft in line with the flanged bearing to provide a doubly supported shaft instead of a cantilevered beam. A two to one gear ratio was applied to the chain in order to double the 3000:1 gear ration on the motor itself. A child's bike wheel was also used as the wheel in hopes of repurposing local materials.

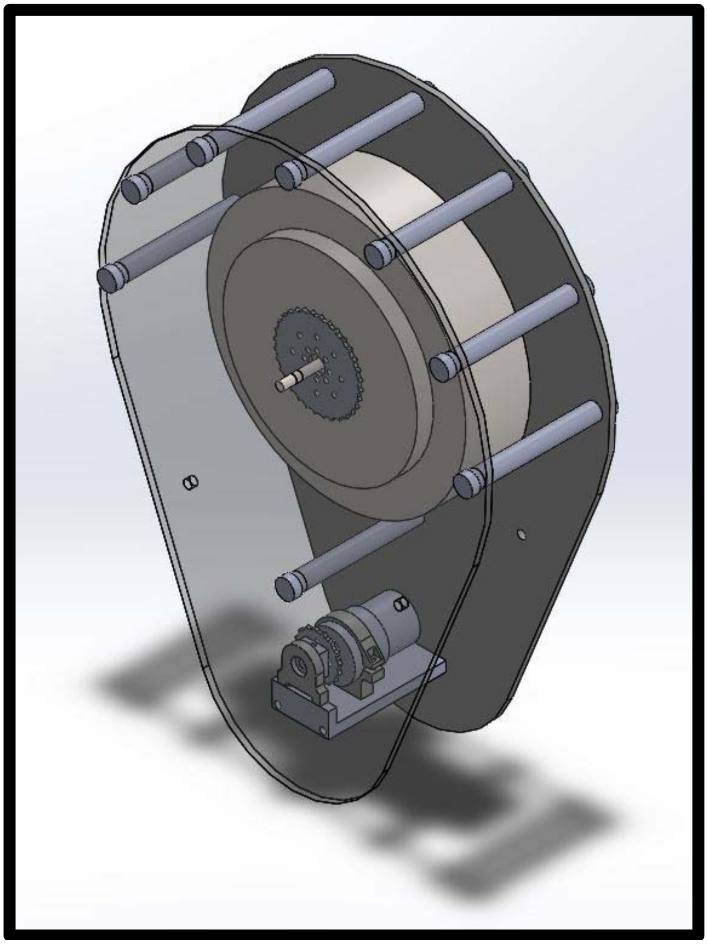


*Figure 14: Iteration 1 CAD Design with transparent front plate*

-Iteration 1.2:

The main alteration of the mechanical sub-system in iteration 1.2 was to the wheel. The bike wheel provided large time consuming delays during fabrication, so we opted for a rapid-prototyped laser cut custom wheel. The custom wheel was able to be the exact diameter we had designed for and had a number of other beneficial features. The most beneficial custom feature was the space we included for bearings to allow for free rotation around the shaft. The bike wheel had occasionally locked onto the shaft preventing it from rotating. The custom wheel was also able to have small teeth like protrusions cut onto the edge that bit into the rope and kept it from sliding around the wheel. As an added benefit the custom wheel was thinner than the bike wheel which allowed compacting of the plate to plate distance.

*Figure 15: Iteration 1.2 Wheel being fitted with custom sprocket*

In addition to swapping out the wheel, the 0.5 RPM motor was replaced with the 13 RPM motor from the proof of concept. This was done in order to reduce the amount of startup torque required to spin the motor as a generator. When iteration 1.2 began producing comparable amounts of energy to the proof of concept with similar amounts of weight the mechanical sub-system was verified and proceeded with.

-Iteration 2:

For our first iteration, we went with the teardrop design, however we found that we could make some improvements upon this. First, we noticed that the device was heavy and rather large, so we looked at a change in casing design and potentially material. In order to remedy this problem, we redesigned the support plates to only have material where we needed it.

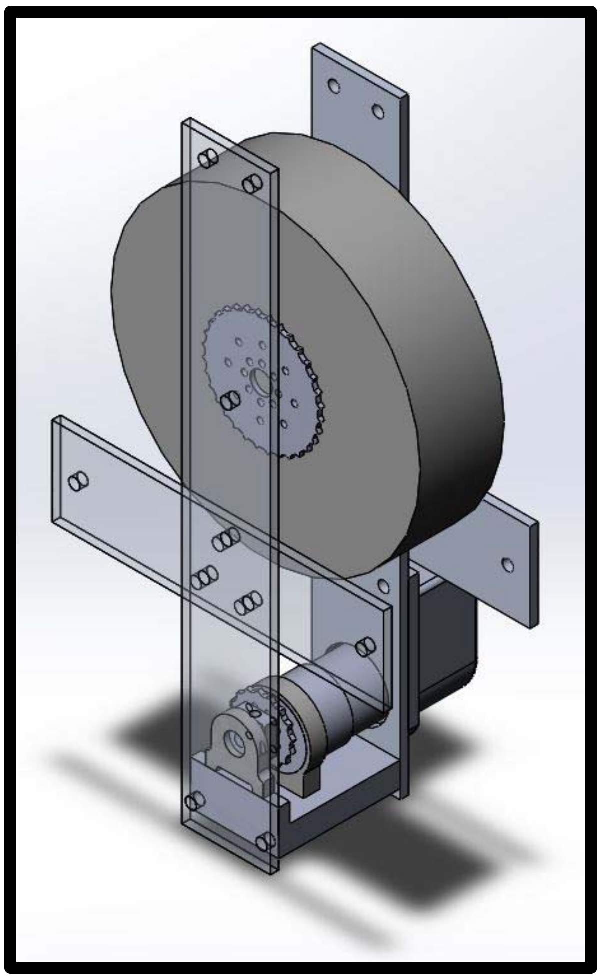


*Figure 16: Iteration 2 with transparent front plates*

We also considered replacing the material with 3/16" aluminum or ½ inch wood. For our material replacement considerations, we looked at cost, machinability, and maintenance. For the wood, we found that maintenance would be highest and cost would be the lowest with a potential trade off in durability due to the non-uniform tendencies for wood and its poor performance in tension. The 3/16" aluminum performed well and met all of our expectations for cost, machinability, weight, and maintenance. Additionally, we wanted to look at condensing the design. In order to do this, we milled out a hole for the motor, now the longest component, to stick out of the frame. This effectively separated the mechanical and electrical subsystems, and brought the overall thickness of our device under our original 4 inches. Also, we noticed that the chain in our first iteration had a bit of slack in the system which could potentially derail the chain from the sprockets. To improve upon this, we added two bolts with roller sleeves that acted as both supports holding the two plates together and rollers for the chains to take up slack and better keep them stuck to the sprockets.


*Figure 17: Fabrication of 2nd iteration*

The fabrication process of our second iteration took significantly less time than the first iteration had. Our laser cut wheel, and 3D printed electrical housing ran parallel to fabrication of the machined parts. This enabled our entire device's manufacturing time to be less than 24 man hours, while the first iteration took several weeks. Knowledge of the system gained from iteration one likely led to this decrease in production time.

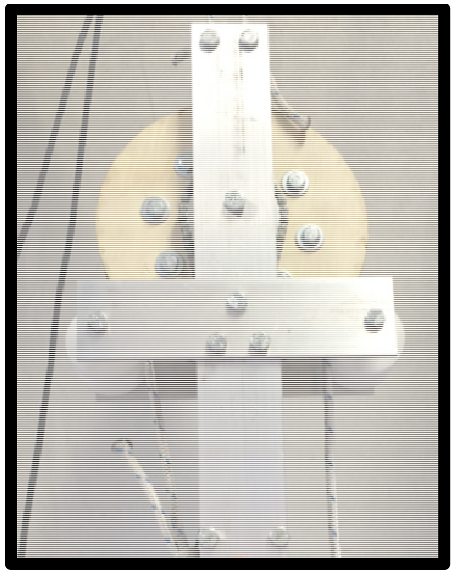


*Figure 17: Iteration 2 ready for testing*

*Supporting Analysis*

Finite Element Analysis was used to verify mechanical structural choices. A simulation was run on the first iteration side plates and the second iteration side plates as well as the test frame structure. The first iteration side plate analysis and the test frame analysis is analyzed below. The analysis of the second iteration side plates is found in appendix 4. All simulations resulted in a factor of safety of 9.6 or higher which is an acceptable amount. Figures detailing the stress and deflection can be found in the results section, and the detailed finite element analysis reports can be found in the appendix 4.

<u>How it was modeled</u>

The objects were computer modeled using the SolidWorks software in the Santa Clara University Design Center. Since the Side Plate Wall is a single sheet of metal with material removed, the computer model was created as a single extruded sketch. That way the properties of the materials are as similar to the physical product as possible. The Test Frame Assembly was created, as the physical assembly was created, by joining many parts together to form the final product. In the physical mock up the parts are held together by multiple screws at each joint and brackets in some locations. The computer model has perfect mates where the parts come together. For both models the material for the computer model was selected to match the material used in the physical model. For the Side Plate Wall 1023 Carbon Steel Sheet was used and for the Test Frame Assembly Douglas Fir wood was used. The material constants stored in SolidWorks were verified against online suppliers and appeared consistent.

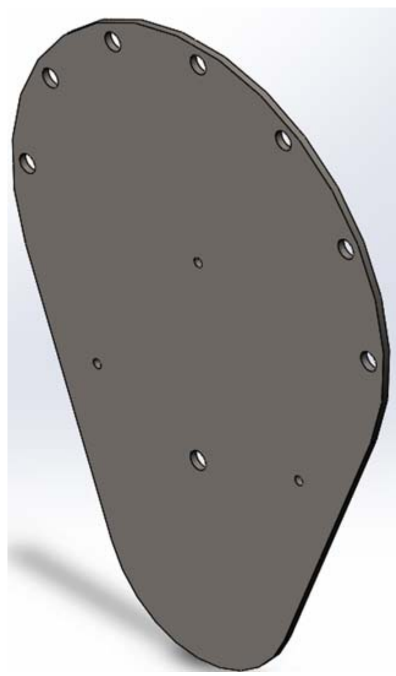


*Figure 18: Side Plate Wall*

The Side Plate Wall is expected to be hung from two of the holes near the top and have a weight hanging from the middle shaft hole. In a “worst case scenario” the Side Plate Wall would be hung from a single hole at the top and the weight would hang right below it from the middle shaft hole. To model this, the top hole was fixed in place and a force was applied downward at the middle shaft hole. Since two Side Plate Walls will be supporting the weight, a single Side Plate Wall was tested with half of the anticipated weight.

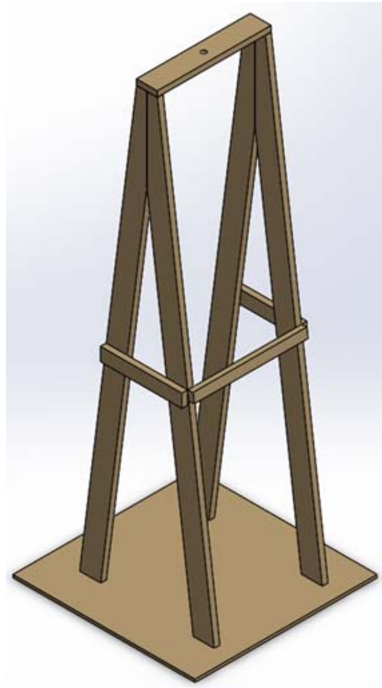


*Figure 19: Test Frame Assembly*

The Test Frame Assembly is expected to have the weight of the device and the weight of the falling mass hung from an I-bolt in the middle of the cross beam with an oversized washer to spread out the weight concentration. In a “worst case scenario” the washer would not be present and the weight would all apply itself directly at the hole, over a much smaller area. The worst case scenario was modeled by applying the anticipated weight of the device and the falling mass to the I-bolt hole.

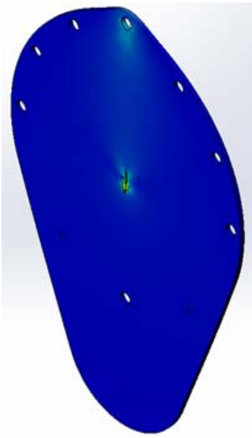
<u>Why it was modeled</u>

These computer models were chosen because they are critical to our design process. If the device and falling mass cannot be supported by our test frame, there can be no testing. If the Side Plate Walls cannot support the weight then the device would rip itself apart. These are also the two most likely points to fail in our project.

Goals

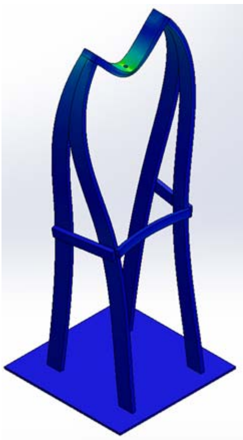
- Deflection of Side Plate Walls shall not exceed 1.5 mm.
- Deflection of Test Frame Assembly top piece shall not exceed 1 mm.
- Factors of Safety should not fall below 3.
- Stresses should not cause yielding.

Results



| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 94 Mpa | 5.483 Mpa | P |
| Max Deflection | 1.5 mm | 0.00044 mm | P |
| Factor of Safety | 3 | 17 | P |

*Figure 20: Side Plate Wall simulation and results table*



| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 41.4 Mpa | 3.251 Mpa | P |
| Max Deflection | 10.000 mm | 0.545 mm | P |
| Factor of Safety | 3 | 12.7 | P |

*Figure 21: Test Frame Assembly simulation and results table*

Test Frame

- Our test frame shall not buckle from loads applied by the device and the attached mass
- The deflection of the top piece was 0.545 mm
- Our test frame has a factor of safety of 3.08

Steel plates

- Our device will deflect a maximum of 0.00044 mm at the shaft hole
- Our steel plates will have a factor of safety rating of 51

What was learned from the modeling

From our FEA we ascertained that the thickness of our Side Plate Walls can be less than the original 1/4" design thickness and even the revised 3/8" is much stronger than necessary. We also learned that the Test Frame Assembly will not deflect more than a nominal amount.

Electrical Subsystem

*Summary of Options and Tradeoffs*

Our team has identified several design options for the electrical subsystem. There are two primary forms of delivering electricity, alternating current and direct current. Alternating current is the current typically provided by a wall outlet. Direct current, on the other hand, comes from either a battery source that gives a constant current or can be derived from alternating current by adding a bridge rectifier. A bridge rectifier allows current to only flow in one direction through the use of diodes. From experimentation, our team has concluded that a Direct Current motor turned with mechanical power will produce a Direct Current signal with periodic noise. Our proposed solution for this initial problem is to integrate a linear or switching regulator. A potentiometer could be implemented by future groups to aid in providing a more customizable range of output voltages. The potentiometer would help to provide impedance matching for the system which will maximize our power output. Further testing would reveal what electrical components are truly required to reach a desirable electrical output.

To regulate the voltage our team has identified two main options. The first, and simplest, option is to use a linear voltage regulator. Linear voltage regulators convert a voltage which is above a specified limit, down to a specified output voltage. These systems are sold as self-contained electrical components which may be coupled with other basic RLC components to reduce noise. The second, and more expensive, option is to use a switching regulator. These regulators intentionally switch between functioning as a step up and step down voltage regulator in order to function more efficiently. The downside to this process is a noisier signal.

*Supporting Analysis*

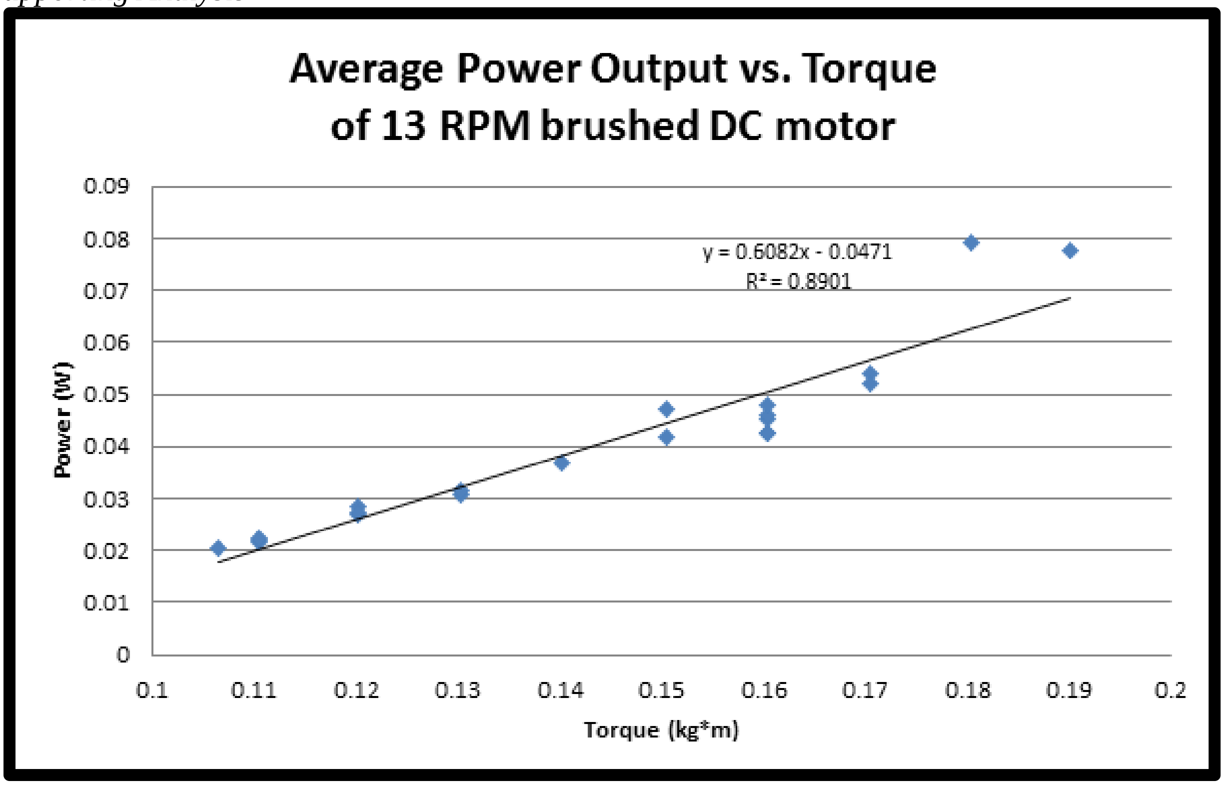



*Figure 22: Average Power Output Vs. torque for 7W geared DC motor*

From experimentation, we found that the DC motor could produce 0.08 W with a torque of roughly 0.2 kg*m. Extrapolating this linear fit to find the required torque for providing USB power yields that we would need to provide 4.2 kg*m of torque. This means that the weight at the current lever arm of 0.2 m would have to be 21 kg (46 pounds). While this data comes from a very specific motor under specific conditions, this test did prove the feasibility of our concept.

<u>Attachments Subsystem</u>

*Summary of Options and Tradeoffs*

Our group has considered several standard attachments for the Gravity Charger. Besides meeting the standard electrical output requirements of a USB port as detailed in Table 2, we plan to incorporate several attachments for the Gravity Charger. After extensive customer needs analysis, we have concluded that a source of light is one of the most important things to include as an attachment. Therefore, we incorporated an LED light fixture that will easily ran off of the power supplied by the Gravity Charger for the conference demonstrations.

# Testing and Results

After our proof of concept testing, we were able to construct and test several iterations of mechanical systems transferring torque to several generators. The results of those tests are discussed here. From figure 9, the power output of the 13 RPM generator we tested can be quantified. We calculated a power output of 0.34 watts with a fall time of 1.67 minutes. This amount of power output, when coupled with an LED, could provide 22 lumens of light, which is comparable to the light produced by a kerosene lantern.

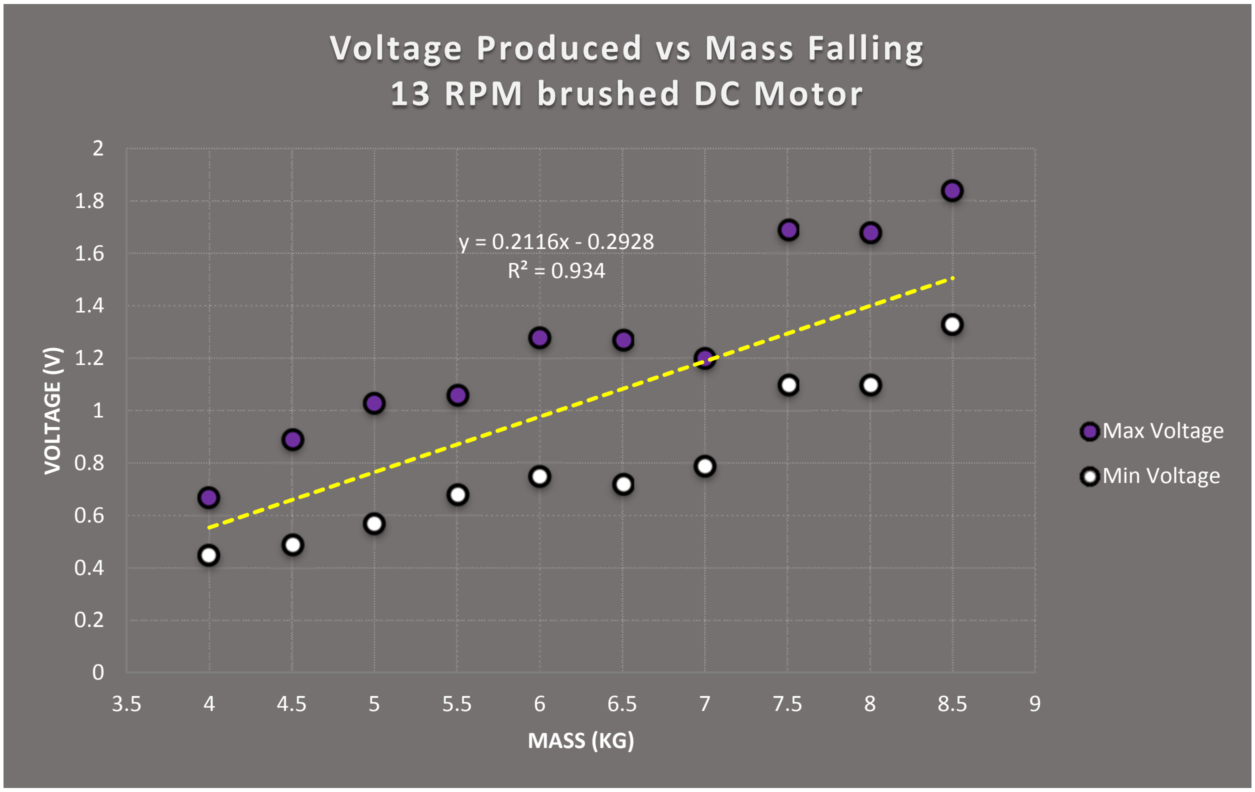



*Figure 23: Voltage vs Torque of 13 RPM motor on iteration 2*

Next we tested a 6 RPM motor which output 0.16 Watts for 6.3 minutes. This amount of power, when coupled with an LED light, could produce nearly 10 lumens, which is enough to light up a work station or be used to light a mouth during dentistry work.

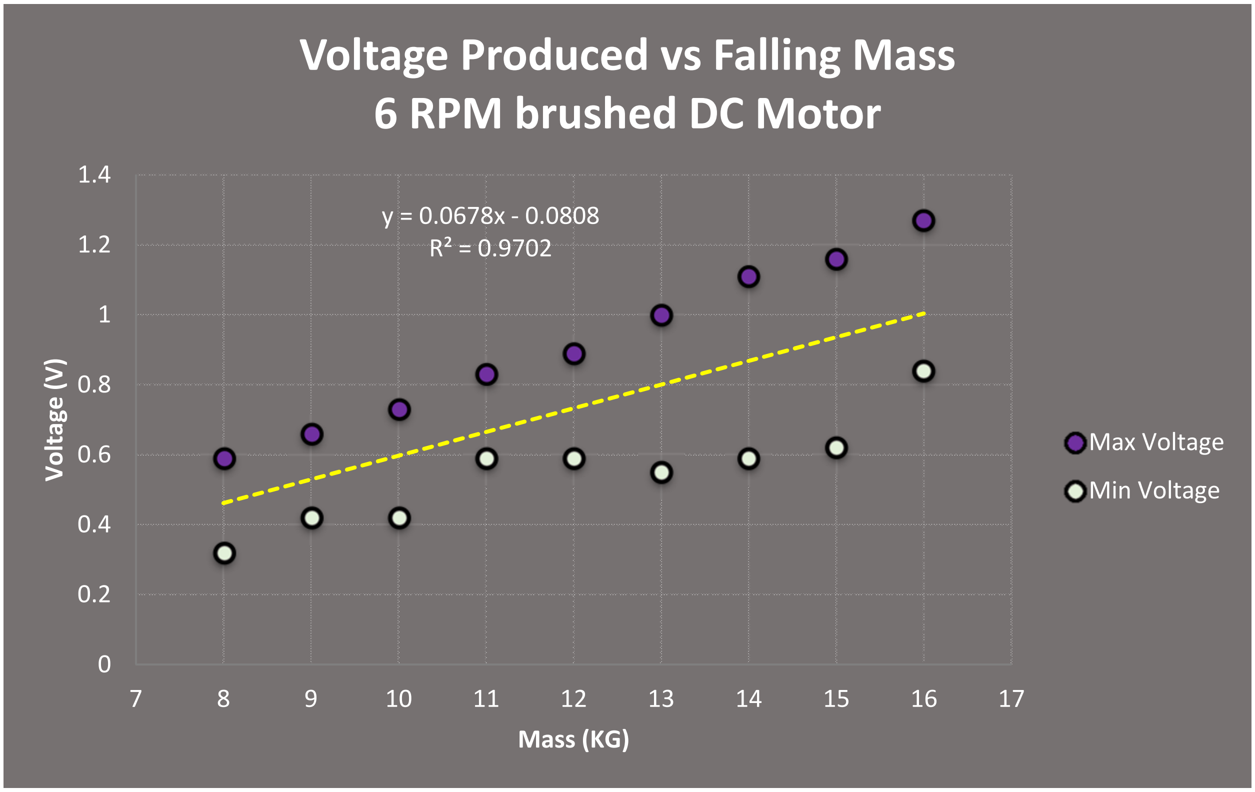



*Figure 24: Voltage vs Torque of 6 RPM motor on iteration 2*

# Future Work

To refine our design, a signal processing unit will need to be added to reduce noise coming from the voltage source. Currently there is a sinusoidal variation in power due to the cyclic nature of the device. A linear or switching voltage regulator would need to be used to process the signal. This would even out the signal to provide a constant power output.

To make it easier on the operator, multiple pulleys would be installed to provide mechanical advantage. This becomes more important as the weight gets heavier or is hung higher. Both of these actions increase the potential energy of the system. It is required to have a pulley system, as a normal person will have trouble lifting weights to 9 feet without assistance. Multiple pulleys can be used to vastly decrease the weight felt by the operator when lifting the weight.

In the system, we have encountered a 30% loss in efficiency in the mechanical subsystem. This is calculated based on the maximum power output of our device compared to the theoretical power output dictated by the equation for potential energy. Frictional losses need to be minimized. However, the loss is not large compared to other sources of electricity.

A customized generator is truly needed to make our device feasible for use. The off the shelf DC motors are not made to be run backwards. By designing the generator to withstand the loads applied, it would allow for more weight to be hung, increasing the power output. It would also ensure that the generator would survive for a much longer life cycle. A customized generator would be designed to produce sufficient power to charge a cellphone with USB and light up a work space. This is the next key step in the iterations of the Gravity Charger.

# Business Plan

## Business Plan Abstract

Gravity Charger provides a reliable replacement to fossil fuels burned for illumination in rural medical outreach, and has the additional capability of charging small electronic devices. Our 5 year plan shows that we will be debt free and making a profit after month 10. We have imposed a 30% markup to cover startup cost and warranty claims and servicing. Our marketing, sales, and distribution will be centered on a web site. After our 5 year plan has come to fruition, we plan to re-evaluate the possibility of expanding sales to a larger market than just medical outreach. Gravity Charger has the potential to tap into the multibillion dollar industry of rural lighting with fossil fuels.

Business Plan Introduction

The Gravity Charger is a device which harnesses the potential energy of a falling object and converts it into useable electrical energy. If one is located in a place with unreliable energy, this device offers a reliable way to light a workspace or charge USB devices. The device weighs 5 pounds making it extremely portable and able to be transported in a backpack and on airplanes.

The markets for this device are medical outreach programs and individuals without reliable access to power. There are many applications that one can use with USB devices. There are pulse oximeters and useful applications on cellphones that run on USB. In the developing world, people utilize cell phones without a reliable way of recharging the battery. Often times, one will have to travel some distance and pay someone for a charge. There is also a shortage for available power for light where we see our product being used. It supplies enough power to light up a work space.

The personnel involved in making the product are three mechanical engineers from Santa Clara University. With the advising of Dr. Hight, the product came to fruition after multiple iterations. The origin of the idea, as well as the product development, has been carried out by these individuals. Our goal is to empower the world by providing access to electricity to all mankind.

Current competition for electrical generation includes solar, wind and hydro power. All of these power sources use a battery as its electrical storage component. The Gravity Charger uses mechanical storage, so there is no need for a battery to be attached. One also has the option of charging batteries with the device. In the market where this is to be implemented, sometimes they are off the grid entirely. Kerosene lanterns are commonly used as a light source inside of homes because there is not a better alternative. This device eliminates the need for nonrenewable fuel as an energy source.

<u>Goals and Objectives of the Company</u>

As our interests are in helping the people of the world have access to electricity. It is a problem to not have reliable access to electricity in the developing world or in the event of natural disasters. We mean to provide reliable and sustainable products to empower individuals. All individuals should be able to take advantage of the technology of this day and age.

Another motive of our company is inspiring science, technology, engineering and mathematics, known as STEM, in the local youth. Our aim is to motivate individuals to be exposed to the rest of the world with applications of technology. Inspiring innovation in future generations is important to increase quality of life of mankind.

<u>Description of the Product</u>

Our Gravity Charger provides a portable and reliable means to power USB devices and light. It utilizes a falling mass to turn a generator creating energy. The weight falls at 1 cm/s. This a slow enough fall speed that it will not cause an inconvenience to the user. The user has to the lift the weight back up to reset the device which then continues generating electricity. Pulleys may be used to hoist the weight up to put less strain on the operator. This product provides a means of reliable power wherever there is a structure or tree to hang it from. The higher the Gravity Charger is hung, the longer the fall time will be. A 20 kg weight is hung from the device to generate the electricity.

The Gravity Charger consists of mechanical and electrical subsystems. For the mechanical subsystem, the device is housed in an aluminum frame to reduce weight and resist corrosion. Inside of the frame is a small laser cut wood wheel attached to a sprocket which connects to the motor with a chain. Standard fasteners are used throughout the device. Access to the mechanical and electrical subsystems is separate. The electrical subsystem includes two USB ports and a switching voltage regulator. The Gravity Charger weighs 2.3 kg.

## Potential Markets

### *What We Aim to Replace*

Wood, kerosene, and candles are common traditional energy sources used in households and community spaces. Each of these traditional energy sources contributes to increased indoor pollution (WHO). Burning wood and coal emits nitrogen dioxide; kerosene emits carbon monoxide; and candles emit particulate matter. All three of these combustion byproducts pose health and safety risks including: smoke, air poisoning, irritation of the eyes and lungs, and fire. Small children, the elderly, and the ill are particularly at risk. As well, traditional energy sources are not environmentally sustainable. These resources also add up in weekly costs and hours spent in collecting the resources. Many families in rural populations are left with no other choice but to burn wood, kerosene, and/or candles for lighting and to cook food on a daily basis. The health and safety risks associated with traditional energy sources make them an undesirable resource to use in a rural health clinic environment. Exposure to smoke and/or indoor pollutants may worsen a patient’s condition or create an environment not ideal for patient care and medical procedures. Smoke and open flames pose a great safety hazard for patients and medical personnel. Data collection on biomass sales in rural areas are hard to track since the recording method is primarily recall based, however, an article “Rural energy data sources estimations in India,” was able to provide an estimate of usage. Kerosene costs 22 cents per liter and 11.5 million tons of it is consumed in India each year. This means kerosene is a 1.8 billion dollar per year industry in

India. With 62% of that kerosene going to rural areas and 60% of rural people relying on kerosene for lighting, that makes the rural kerosene lighting industry in India a 670 million dollar per year industry.

The main need is for suitable light for the medical setting. This lamp needs to provide enough light to be able to properly perform medical tasks. This means, for dental needs, direct light into a patient’s mouth and suitable room lighting. These lights will need to be powered in sync. Light is extremely important in being able to operate in a medical setting.

The second need is for charging USB devices. Portable electronics are nearly everywhere in the developing world. However, access to charging stations is often not as available. Currently if one wants to charge his cell phone, he may have to travel into town and pay a person at a store to be able to get a charge. There are many medical devices that run on USB. Firstly, a pulse oximeter is a common device that runs on USB. This will provide information on blood pressure. There are also dental imaging devices that run on USB to take pictures of the teeth.

*Global Medical Brigade*

The primary users of our device will be medical clinics, permanent or temporary, in areas with unreliable access to energy, and also the local communities. Our team conducted an interview with Alex Young, the former president of Santa Clara University’s Global Medical Brigade (GMB). He has organized and taken multiple trips with GMB. He believed the largest need for electricity was with regard to lighting. His personal expertise lies with the dental care group and he noticed flashlights would vastly improve the dentist's ability to perform even the most basic tasks. Alex also informed us that there is often a ministry of health which must issue permits for any group intending to provide healthcare, and their equipment undergoes light scrutiny at border customs. Furthermore he told us that their groups often performed other small public health projects while they are on location, such as erecting buildings or improving infrastructure. Inquiring further about these projects, we were able to determine that most areas that GMB serves have any non-power tool that may be required. As a means of transport, Alex told us they drive a van to wherever they will be setting up. With this information in mind, we have determined that our device will need to provide enough light to illuminate all parts of a mouth, be van portable, and final assembly must be maintained with non-power tools. Currently, the Global Medical Brigade does not have a device to produce energy on site, and they told us they would consider adding our niche device.

*International Medical Relief*

Our group also conducted an interview with Sarah MacGregor with International Medical Relief who was interested in our device. Sarah explained that in Nepal and Haiti, the medical relief team often relied on battery-powered technologies. They had some access to solar panels if they brought their own. Otherwise, they were forced to wait till the end of the day to charge their devices in the hotel. Sarah also told us that whatever equipment they bring with them must be very durable. She explained that our Gravity Charger would need to be water - resistant and drop proof, small enough to be carried in a day pack, and that it would have to be allowed on planes. It was brought up that for medical professionals to know they would have access to charging power, it would provide confidence in what tools they could bring along because of weight requirements. Sarah also told us that there would likely be structures on which to hang our device.

*Baan Dada's Children's Home in Rural Western Thailand*

One of our Engineering World Health partners has a connection to a leader of a children's home in Thailand, and he was able to provide us with information pertaining to our project, and also served as another potential customer. For example, when asked what types of electrical devices they commonly used, he mentioned lights, computers, small electronic devices and even motors. We also learned that in a more permanent location such as this, there are several things that cannot go without power. For example lighting and the refrigerator both run on electricity, and they cannot afford to have any down time. We also learned that in response to power outages, the home uses candles and flashlights to illuminate the building and provide power to the essential parts of the home with an old generator. With the addition of a Gravity Charger, children would be able to make powering lights and charging devices into a game.

## Competition

One of the reasons we set out to develop Gravity Charger was that we fill a niche that others do not. We wanted to provide power where other devices could not in rural developing countries. During the initial phases of our project, we looked into devices with similar functions that had similar performance. In order to consider this business venture, we set out to prove that Gravity Charger could fill that niche and outperform any other devices in the same market at a reasonable price.

The main power generating competitors aimed at aid in developing countries are solar, wind, and water, while the main sources of light are the traditional nonrenewable sources such as; wood, kerosene, and candles. We aim to prove that we can replace these sources for environments where solar, wind, and hydro power are unavailable or not feasible. We also wish to reduce our market's reliance on nonrenewable sources. We looked at the current renewable energy sources such as solar, wind, and hydro power. We consider these to be competitors even though they rely on a different energy source.

*Solar Power*

Solar energy is one of the largest competitors for our product. There is a broad range of products from small, handheld lights at a very low cost to solar panel systems for entire buildings. Solar energy is also easily adaptable and fairly easy to learn to use. However, there are certain limitations to solar energy. Solar panels only produce energy when sunlight strikes them, so they do not work at night. Solar energy storage is developing, but batteries often have a limit in energy storage. In addition, various climate factors influence solar panel efficiency. Humidity reduces the lifespan of solar panels due to corrosion, and solar panels are less efficient in areas of heavy rain, overcast weather, and/or in times of hurricanes or monsoon season. Solar Panels are less effective the further away from the equator in latitude. In addition, solar panels deteriorate due to UV radiation damage, the elements, and temperature fluctuations no matter the climate. Solar panel efficiency drops with greater surrounding tree coverage, landscapes, and air pollution which reduce or block the intensity of sunlight hitting the solar panel. Solar panels also contribute to environmental pollution due to their photovoltaic cell components: silicon, mercury, lead, and cadmium. While solar energy is a popular and widely marketed renewable energy source, solar energy also has its limitations and may pose negative environmental effects in the long run.

The current top selling device that produces a comparable amount of energy as our design criteria goals is the Wakawaka Power Solar Charger. The device costs 80 dollars and can output

110 lumens from a built in LED. The device can charge a smart cell phone in about two hours. The device does not have corresponding sales information. We believe that its price and output represent the typical solar charger.

*Wind Power*

Wind power is another competitor to our device. However we found several pitfalls to its practical application in all environments and under all conditions. Wind power is poor in areas where wind is unreliable such as those along the equator where the effect of the sun's symmetrical North and South warming effect can cause Doldrums or stagnant air flow. According to the National Energy Education Development Project[4], windmills at homes and small business face troubles of their own. In order to effectively capture the power of the wind, one should ensure that the tips of their windmill are at least 9 meters or 30 feet above the highest wind obstacle in the area. This potentially limits a windmill's placement or mandates costly mounting supports. Additionally, one must take into consideration the possibility of extreme wind that may surpass a windmill's strength.

The top competition in the wind power sector is the WindMax at home power generator system which can provide 500W of power at optimal wind conditions for 650 dollars[1]. While the cost of the unit is high, at 1.3 dollars per watt, it is a good tradeoff.

Table 6: Competitor Breakdown

| Product | Manufacturer | Function | Price | Pros | Cons |
|---|---|---|---|---|---|
| Gravity Light | Not in production | Use gravity to provide light | $5 | 30 minute fall time | Very dim light |
| Pocket Socket 2 | K-Tor | Hand Crank power outlet | $65 | Standard outlet, 12 Watt output, 15 oz | Annoying crank motion |
| CydeKick | Spinetics | Hub Bicycle Dynamo | | USB standard output | Not released |
| Mini Sherpa LED Torch | Freeplay Energy | Hand crank flashlight | $30 | 60sec spin=20min light | Recommended external charge |
| WakaWaka Power | Bennu Solar | Solar charger with integrated lights | $80 | Small, Light, 75 lumens for 10 hours | 1 W solar charging limit, must have the sun |
| Kerosene Lantern | V & O | Emits Light from burning kerosene | $16 | Light anywhere with use of fuel | Costs over lifetime: Fuel & Wicks, not good for indoor use |
| WindMax H series | WindMax | Wind Power | $650 | Lots of power (500W) | 50 mph wind max, noise pollution, view obstruction, high cost |

Sales/Marketing Strategies

We considered several ways to successfully advertise our product to the potential markets we have identified. At first, we plan to release our product to medical outreach teams willing to take on the $149.99 cost per unit. After we have paid off our debt and developed rapport with the medical outreach community, we plan to broaden our marketing strategy to rural clinics, rural residents, and schools interested in the STEM aspect of Gravity Charger.

Our advertising plan is simple; we will purchase a domain and construct a website where medical outreach programs can take a look at our device. We hope that our device will be promoted by word of mouth; however we will also actively seek out medical outreach companies with emails. One will be able to purchase directly from our website with an approximately 2 week domestic order to delivery time.

## Manufacturing Plans

We have decided that we would like to be a nonprofit organization aimed at social entrepreneurship. We hope the Miller Center will help us out with the cost of opening shop because of our mission. We would be the ones who would build our device, and we would not employ the help of any outsider to manufacture. We would have a few initial costs such as a small space for material storage, manufacturing, and administration, as well as a drill press, 200 square feet of space, a hole saw, a band saw, and drill bits. It will take approximately one day to produce each Gravity Charger, and we plan to sell approximately two a month for the first several years. This would be considered a part time job with negligible pay for the first several years. We will purchase raw materials in bulk to receive wholesale prices and store what little materials we need in our space. Moving forward, we plan to expand our horizons and sell to people rather than organizations.

## Production Cost and Pricing

The Gravity Charger will be produced as frugally as possible in light of its non-profit status. As such, each step has been analyzed to reduce cost. The final production cost of each Gravity Charger is $106.25 per unit. The material price breakdown can be seen in table 7. In order to begin production, equipment must be purchased. The equipment required will include a Drill Press, a Band Saw, a 7” Hole Saw, and a set of drill bits. The prices for each are seen in table 9 totaling $315.00. The other overhead associated with running a business to sell the

Gravity Charger is the office space and the website for sales. These will cost a total of $23.83 per month if we relocate to Kansas City [10] as seen in table 8. To cover the costs of equipment and space the units will be given a 30% mark up and sold for $149.99 each. The pricing detail is in table 10. The production volume of the Gravity Charger will be at 2 per month. This will bring roughly $300 of revenue in to cover costs.

Table 7: Costs of Materials

| Material Costs | |
|---|---|
| 6 RPM motor | $35.00 |
| Aluminum | $14.00 |
| Fastenings | $11.00 |
| Wood Wheel | $4.00 |
| 16 tooth sprocket | $4.00 |
| 32 tooth sprocket | $5.00 |
| Set screw hub | $5.00 |
| Pillow block | $7.00 |
| Clamping mount | $7.00 |
| Wheel bearings | $8.00 |
| Flanged bearing | $3.00 |
| Electrical | $5.00 |
| Rope | $3.00 |
| r 16 tooth sprocket | $4.00 |
| r 32 tooth sprocket | $5.00 |
| r Electrical | $5.00 |
| MATERIAL SUBTOTAL | $125.00 |
| 15% Bulk savings | -$18.75 |
| TOTAL COST TO PRODUCE | $106.25 |

Table 8: Monthly Overhead Costs

| Monthly Overhead | |
|---|---|
| 200 sqft space per yr | $276.00 |
| website per year | $10.00 |
| MONTHLY TOTAL | $23.83 |

Table 9: Cost of Equipment

| Equipment Costs | |
|---|---|
| Drill Press | $130.00 |
| Band Saw | $125.00 |
| Hole Saw | $50.00 |
| Drill Bits | $10.00 |
| EQUIPMENT TOTAL | $315.00 |

Table 10: Pricing of Gravity Charger

| Pricing | |
|---|---|
| % markup | 30% |
| markup | $31.88 |
| Unit marked up price | $138.13 |
| Selling Price | $149.99 |
| NET PROFIT PER UNIT | $19.91 |

Service and Warranties

The Gravity Charger is designed and manufactured for last mile distribution and usage. As such it will be difficult to provide service. Since we will be unable to provide our own service we will provide a replacement part for all electronic components and the sensitive mechanical components as well as design drawings and assembly drawings for all other components. The only part that will not be cheaply replaceable is the motor itself. If the motor breaks, the entire assembly may be returned and a refurbished Gravity Charger will be shipped back. However, since we are not striving to make profit off of this venture, we will not have enough overhead to cover shipping free of charge.

*Example Warranty*

**Gravity Charger Warranty**

Should the customer not be satisfied with the Gravity Charger they have two weeks to return the Gravity Charger for a full refund. After the two week period all sales are final and returns will not be refunded.

The following parts will be provided with the Gravity Charger for in field replacement:

- USB connection port
- Toggle Switch
- Indicator LED
- Signal filtering circuitry
- 16 tooth sprocket
- 32 tooth sprocket

All design drawings included with the Gravity Charger may be used for in field fabrication purposes or educational purposes only.

In the event of motor failure the Gravity Charger may be returned in full and a refurbished Gravity Charger will be supplied. The owner needs only to pay shipping and handling.

Financial Plan and Investor's Return on Investment

As a non-profit, there will be low costs and low returns for the Gravity Charger. Though this is the case, there will still be profit. The $315.00 initial investment will be sought first from the Santa Clara University Miller Center for Social Entrepreneurship. Our product and business model match their mission and we hope they would be supportive of our endeavor with a grant. Though our case is strong for receiving a Miller Center grant, our financial plan is formulated with an assumed 3% loan interest rate in the unlikely event we have to turn to a bank.

Our plan is to sell two Gravity Chargers per month at a minimum. We believe this to be a reasonable number of Gravity Chargers to produce and sell each month since this will be a side endeavor which does not pay a salary. The $19.91 profit from the first unit sold will go towards paying off the debt of the loan and the second profit unit will be kept in company savings. By month 10 the debt will be paid off and both profit units will be kept in the company savings. As soon as the savings reaches $462.00 a laser cutter will be purchased at no debt to allow for more precise and swift manufacturing. With this plan in place, the Gravity Charger savings will be at $583.55 by the end of the fifth year. Having a company savings will allow us to cover any warranty replacement issues which may arise. This financial timeline is depicted in figure 11 below.

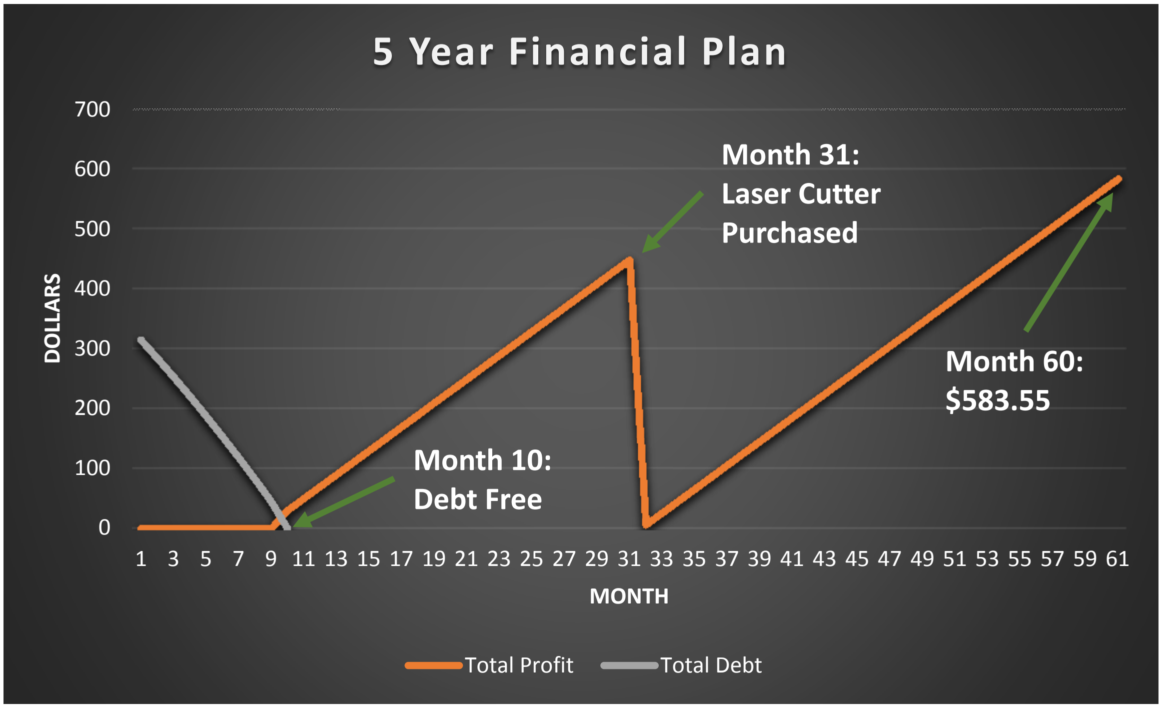



*Figure 25: 5 Year Financial Plan*

# STEM Education

Stem education is important to our team. It is important for the youth to be encouraged to be influenced by science, technology, engineering and mathematics. This leads to innovation in the field and helps countries become more developed. The quality of life is much higher with the influence of stem in society. Individuals with stem education are highly sought after in society. By engaging young individuals in stem, one hopes that they pursue careers within stem.

The Gravity Charger is the perfect classroom tool. It shows off a simple 2:1 gear ratio, uses electrical components students may not be familiar with. The technology is similar to other ways to generate electricity. It would be very easy to compare hydro power, steam turbines and other ways one turns a motor to generate electricity. There will also be provided other small electrical parts, which one could use to make a classroom lesson.

The first lesson that one could use our device for is explaining basic circuits. The gravity charger would be used as a power source and indicator LED that comes with the device is the resistor. Wiring would have to be provided. One could show what would happen when a short occurs; power is loss to the LED. If a multimeter is available, one could show the basics of Ohm's Law, V=IR.  Where voltage is measured and compared to the current and the resistance of the load. The voltage around a loop must add up to zero. If there are multiple loads on a circuit, the voltage drop on the loads will add up to the voltage gain of the power source.

The most common source of light from our device is an LED, a light emitting diode. LEDs only work with energy flowing one direction, they do not work going backwards. This can be shown in a circuit by trying to power it backwards. One could compare LEDs to conventional light bulbs and show the effectiveness of LEDs for how much power

Switches are also used in our device. A switch can be added to a circuit to allow current to flow. If a switch is turned off, there is no connection to the rest of the circuit, so there will not be power provided to the load. This can be seen with the LED not turning on. The key concept is that where there is a voltage differential, current will flow.

One can also look at understanding gearing of the motors. There is a simple 2:1 gear ratio, for every turn of the larger gear; the smaller gear will turn twice as much. Another place where they might see a gear ratio in their daily life is on bicycles.

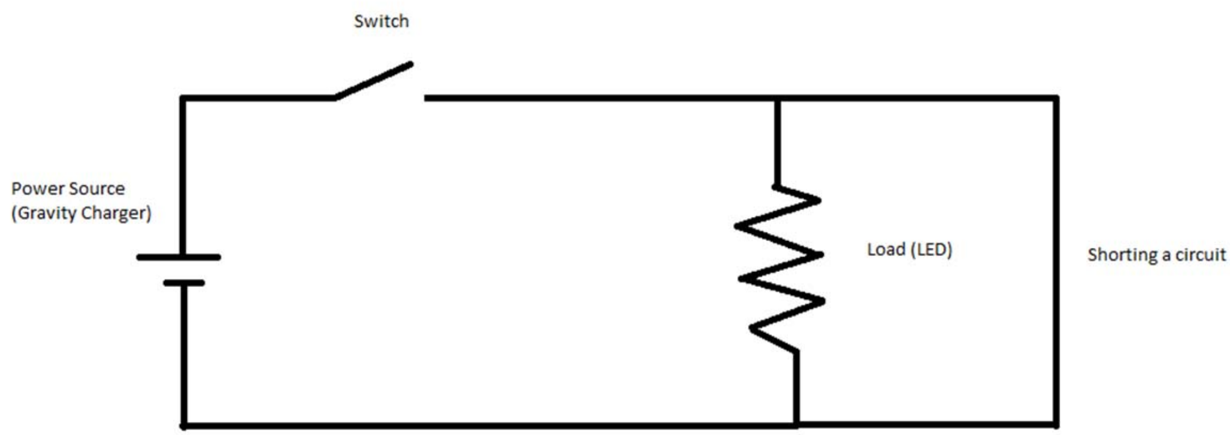



Figure 12: Sample circuit for STEM education plan

# Summary

Team Gravity Charger is addressing the need for electricity in underdeveloped areas. The two main needs for electricity are for lights and for small medical devices. With the ability to power these loads, a higher quality of life will be achieved through access to electricity and an increase in healthcare.

The target customers for our device are groups which travel to these areas to help out these communities. These are the individuals who would be purchasing our product to be used in underdeveloped communities. Testing was done on a simple mock-up with an acrylic wheel attached to a DC motor to prove the feasibility of the project. Later, a first iteration of the device design was created and revealed a number of mechanical issues which were resolved in iteration 1.2. A second iteration was created after iteration 1.2, was tested, and improved further upon the design. Though the gearing on the purchased motors is not strong enough to withstand the amount of torque required to meet all of the design requirements, the final iteration of the Gravity Charger was able to power a strand of LED lights.

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# Appendices

**Appendix 1:** Organized & detailed hand calculations
**Appendix 2:** Updated PDS with decision matrices
**Appendix 3:** Quarterly Timelines
**Appendix 4:** Finite Element Analysis Reports
**Appendix 5:** SCU Core Arts and Humanities Requirement
**Appendix 6:** Presentation Slides
**Appendix 7:** Design Drawings

Appendix 1: Organized & detailed hand calculations

100% Efficiency Energy Conversion

| variable | unit | symbol | value | |
|---|---|---|---|---|
| falling distance | m | Df | 2.5 | |
| gravity | m/s^2 | g | 9.8 | |
| falling time | sec | Tf | 0.714285714 | Tf=sqrt(2*Df/g) |
| Power needed | Watts | Pn | 7.5 | |
| mass needed | kg | Mn | 0.428571429 | Mn=Pn/(g*Df*Tf) |

UVGI Theoretical Calcualtions

| variable | unit | symbol | value (chosen value) | |
|---|---|---|---|---|
| Distance to lamp | cm | x | 5 | |
| | m | x | 0.05 | |
| Dia of lamp | cm | R | 0.5 | |
| | m | R | 0.005 | |
| Length of lamp | in | l | 2 | |
| | m | l | 0.0508 | |
| View Factor cyl to plate as per: http://www.aerobiologicalengine | | H | 10 | H=x/R |
| | | L | 10.16 | L=l/r |
| | | X | 224.2256 | X=(1+H)^2+L^2 |
| | | Y | 184.2256 | Y=(1-H)^2+L^2 |
| | | F1 | 0.0253326 | F1=(1/(PI()*H))*ATAN(L/SQRT(H^2-1)) |
| | | F21 | 1.00483 | F21=(X-2*H)/SQRT(X*Y) |
| | | F22 | 0.7843534 | F22=ATAN(SQRT((X*(H-1))/(Y(H+1)))) |
| | | F23 | 0.3234028 | F23=L/(PI()*H) |
| | | F2 | 2.1125862 | F2=F21+F22+F23 |
| | | F3 | 0.2378028 | F3=ATAN(SQRT((H-1)/(H+1)))*L/(PI()*H) |
| | | F | 1.900116 | F=F1+F2-F3 |
| midpoint multiplier | | MPM | 2 | |
| View Factor at midpoint | | Fm | 3.8002321 | Fm=F*MPM |
| Surface area of lamp | m^2 | SA | 0.0015959 | SA=2*PI()*R*l |
| | cm^2 | SA | 15.959291 | |
| Power of lamp | W | P | 2 | |
| | microW | P | 2000000 | |
| Intensity of Surface | microW/cm^2 | Is | 125318.85 | Is=P/SA |
| Intensity Effective | | Ie | 476240.72 | Ie=Is*Fm |
| coeff for E.coli | cm^2/microJ | k | 0.00093 | http://www.aerobiologicalengineering.com/mmuad.pdf |
| exposure time | s | t | 0.02 | |
| %Population remaining | % | %POPr | 0.0146351 | %POP=e^(-k*I*t)*100 |
| %Population killed | | %POPk | 99.985365 | %POPk=100-%POPr |

Appendix 2: Updated PDS with decision matrices and sketches

Problem Design Specifications

**Team name**: Gravity Charger Date: 12-9-2015

**Problem statement:** There are areas of the world that encounter problems with energy availability and sanitation. We seek to provide tools to empower local communities to solve these problems.

| **Specification** | **Reason** | **Units** | Sample value |
|---|---|---|---|
| Energy output | Sufficient for one USB device | Watts | 5 |
| Size of Device | Cannot be bulky; carry-on bag size | $cm^3$ | 23 x 36 x 56 |
| Weight | Must be able to be carried by an individual | kg | 11 |
| Portability | An average person must be able to carry | | See Weight and Size |
| Producing cost | Must be affordable | $ USD | 106.25 |
| Selling price | We need to make some money | $ USD | 149.99 |
| Customer | Grey area with unreliable power | N/A | |
| Maintenance | On site; spare parts will be provided | | |
| Quality and Reliability | Perform its function exquisitely and properly | Cost | Higher quality materials |
| Patents | Must not conflict with working patents | N/A | |
| Environment | Disposal of hazardous waste | | |
| Safety | No potential hazards | | Pinch, shock, fire |
| Product Life Span | Must be durable and lasting | Years | 10 |
| Materials | Local sources if possible, minimize travel weight | N/A | |
| Ergonomics | Easy to use when assembled. Can be used by a smaller medical examiner. | User Satisfaction | 7/10 |
| Fall Time | Time between lifting weights minimal | Minutes | 5 |

**Design Project =** Gravity Charger **Sub System =** Mechanical

| | | DESIGN IDEAS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **CRITERIA** | **WEIGHTING** | **1 = Baseline** | | **2 = Hanging Mass** | | **3 = Triggered Mass** | | **4 = Falling Balls** | | **5 = Water Wheel** | |
| Time – Design | | 12 | | 4 | | 24 | | 12 | | 24 | |
| Time – Build | | 12 | | 9 | | 24 | | 18 | | 18 | |
| Time – Test | | 48 | | 48 | | 60 | | 60 | | 60 | |
| **Time Score** | 10 | | 10 | | 6.94 | | 17.50 | | 12.50 | | 15.83 |
| Cost – Prototype | | $ 20 | | $ 80 | | $ 120 | | $ 140 | | $ 150 | |
| Cost – Production | | $ 100 | | $ 100 | | $ 175 | | $ 190 | | $ 200 | |
| **Cost Score** | 5 | | 5 | | 12.5 | | 2.03 | | 1.82 | | 1.71 |
| charging (fall) time | 4 | 2 | 8 | 2 | 8 | 5 | 20 | 5 | 20 | 5 | 20 |
| weight | 2 | 4 | 8 | 3 | 6 | 2 | 4 | 2 | 4 | 1 | 2 |
| aesthetics | 1 | 3 | 3 | 2 | 2 | 2 | 2 | 4 | 4 | 5 | 5 |
| amount of energy gen | 4 | 2 | 8 | 2 | 8 | 5 | 20 | 4 | 16 | 2 | 8 |
| safety | 3 | 4 | 12 | 2 | 6 | 3 | 9 | 3 | 9 | 2 | 6 |
| user simplicity | 2 | 4 | 8 | 5 | 10 | 2 | 4 | 5 | 10 | 4 | 8 |
| design life | 1 | 5 | 5 | 3 | 3 | 4 | 4 | 3 | 3 | 2 | 2 |
| | | | | | | | | | | | |
| | **TOTAL** | | **67.0** | | **62.4** | | **82.5** | | **80.3** | | **68.5** |
| | **RANK** | | **4** | | **5** | | **1** | | **2** | | **3** |
| | **% of MAX** | | 81.2% | | 75.7% | | 100.0% | | 97.3% | | 83.1% |
| | **MAX** | **82.5** | | | | | | | | | |

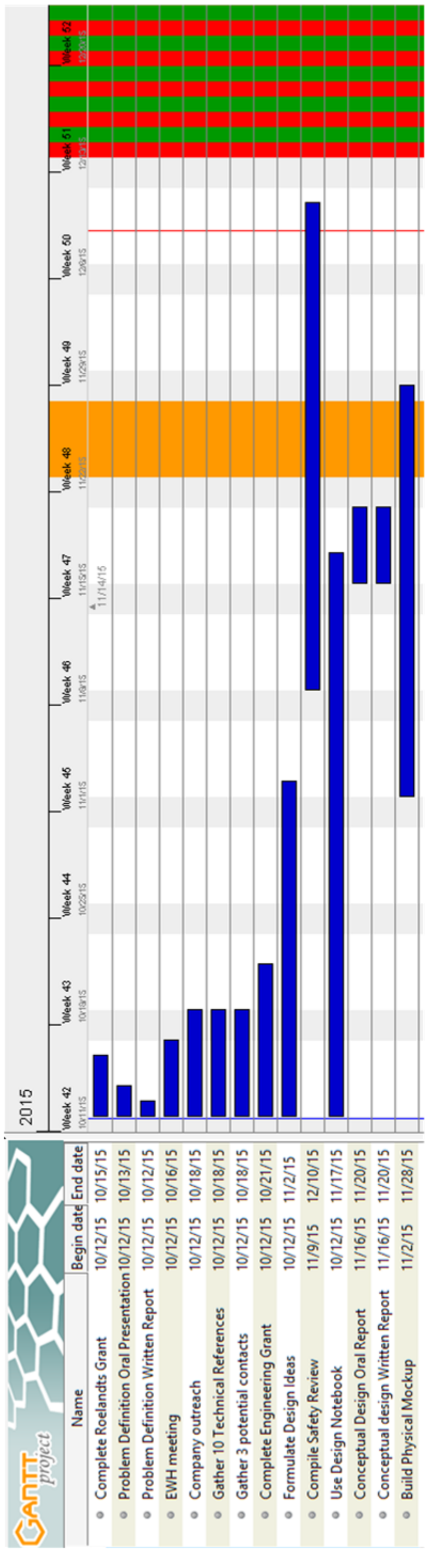
**BASELINE =** **Single Drop**

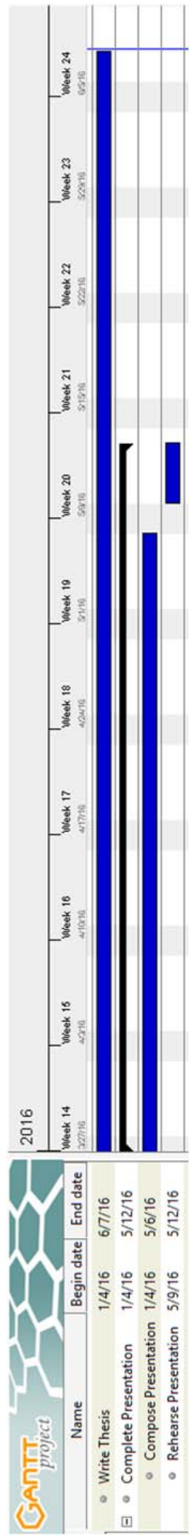
**Ideas**

1 Single Drop
2 Hanging Mass
3 Triggered Mass
4 Falling Balls
5 Water Wheel

| |
|---|
| calculated |
| user input |
| fixed |

# Appendix 3: Quarterly Timelines



| Week | 2 | | | | | | | 3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal Day | 3-Apr | 4-Apr | 5-Apr | 6-Apr | 7-Apr | 8-Apr | 9-Apr | 10-Apr | 11-Apr | 12-Apr | 13-Apr | 14-Apr | 15-Apr | 16-Apr |
| Iteration1 Assembly | | | | | | | | | | | | | | |
| Iteration1 Testing | | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | | |
| Iteration2 Design | | | | | | | | | | | | | | |
| Material Shipping | | | | | | | | | | | | | | |
| Iteration2 Fabrication | | | | | | | | | | | | | | |
| Iteration2 Assembly | | | | | | | | | | | | | | |
| Iteration2 Testing | | | | | | | | | | | | | | |
| Data Analysis2 | | | | | | | | | | | | | | |
| Regulator Tradeoff | | | | | | | | | | | | | | |
| Presentation Practice | | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | | |
| Thesis writing | | | | | | | | | | | | | | |
| Roelandts Grant | | | | | | | | | | | | | | |

| Week | 4 | | | | | | | 5 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal Day | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | 23-Apr | 24-Apr | 25-Apr | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr |
| Iteration1 Assembly | | | | | | | | | | | | | | |
| Iteration1 Testing | | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | | |
| Iteration2 Design | | | | | | | | | | | | | | |
| Material Shipping | | | | | | | | | | | | | | |
| Iteration2 Fabrication | | | | | | | | | | | | | | |
| Iteration2 Assembly | | | | | | | | | | | | | | |
| Iteration2 Testing | | | | | | | | | | | | | | |
| Data Analysis2 | | | | | | | | | | | | | | |
| Regulator Tradeoff | | | | | | | | | | | | | | |
| Presentation Practice | | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | | |
| Thesis writing | | | | | | | | | | | | | | |
| Roelandts Grant | | | | | | | | | | | | | | |

| Week | 6 | | | | | | | 7 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal Day | 1-May | 2-May | 3-May | 4-May | 5-May | 6-May | 7-May | 8-May | 9-May | 10-May | 11-May | 12-May | 13-May | 14-May |
| Iteration1 Assembly | | | | | | | | | | | | | | |
| Iteration1 Testing | | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | | |
| Iteration2 Design | | | | | | | | | | | | | | |
| Material Shipping | | | | | | | | | | | | | | |
| Iteration2 Fabrication | | | | | | | | | | | | | | |
| Iteration2 Assembly | | | | | | | | | | | | | | |
| Iteration2 Testing | | | | | | | | | | | | | | |
| Data Analysis2 | | | | | | | | | | | | | | |
| Regulator Tradeoff | | | | | | | | | | | | | | |
| Presentation Practice | | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | | |
| Thesis writing | | | | | | | | | | | | | | |
| Roelandts Grant | | | | | | | | | | | | | | |

| Week | 8 | | | | | | | 9 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal Day | 15-May | 16-May | 17-May | 18-May | 19-May | 20-May | 21-May | 22-May | 23-May | 24-May | 25-May | 26-May | 27-May | 28-May |
| Iteration1 Assembly | | | | | | | | | | | | | | |
| Iteration1 Testing | | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | | |
| Iteration2 Design | | | | | | | | | | | | | | |
| Material Shipping | | | | | | | | | | | | | | |
| Iteration2 Fabrication | | | | | | | | | | | | | | |
| Iteration2 Assembly | | | | | | | | | | | | | | |
| Iteration2 Testing | | | | | | | | | | | | | | |
| Data Analysis2 | | | | | | | | | | | | | | |
| Regulator Tradeoff | | | | | | | | | | | | | | |
| Presentation Practice | | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | | |
| Thesis writing | | | | | | | | | | | | | | |
| Roelandts Grant | | | | | | | | | | | | | | |

| Week | 10 | | | | | | | Finals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal Day | 29-May | 30-May | 31-May | 1-Jun | 2-Jun | 3-Jun | 4-Jun | 5-Jun | 6-Jun | 7-Jun | 8-Jun | 9-Jun | 10-Jun |
| Iteration1 Assembly | | | | | | | | | | | | | |
| Iteration1 Testing | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | |
| Iteration2 Design | | | | | | | | | | | | | |
| Material Shipping | | | | | | | | | | | | | |
| Iteration2 Fabrication | | | | | | | | | | | | | |
| Iteration2 Assembly | | | | | | | | | | | | | |
| Iteration2 Testing | | | | | | | | | | | | | |
| Data Analysis2 | | | | | | | | | | | | | |
| Regulator Tradeoff | | | | | | | | | | | | | |
| Presentation Practice | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | |
| Thesis writing | | | | | | | | | | | | | |
| Roelandts Grant | | | | | | | | | | | | | |

Appendix 4: Finite Element Analysis

Description
Support Bar modeled as wood.

# Simulation of Support bar

**Date: Monday, April 18, 2016**
**Designer: Luke Lindsay**
**Study name: Side Plate Bearing Load**
**Analysis type: Static**

## Table of Contents

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Sensor Details **Error! Bookmark not defined.**

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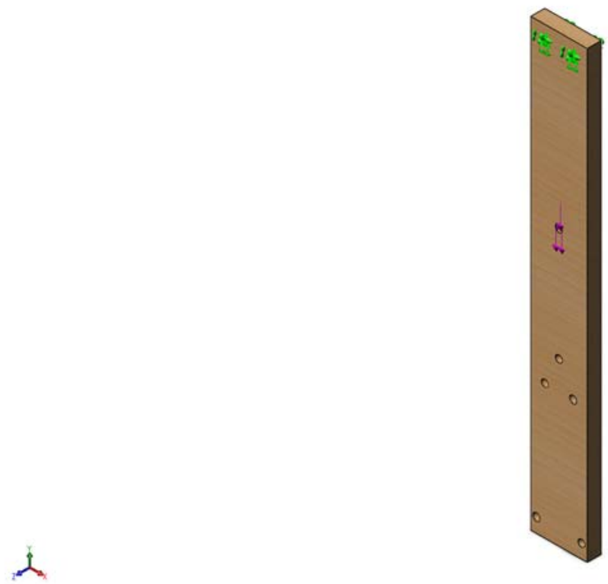
Model Information



Model name: Support bar
Current Configuration: Default

**Solid Bodies**

| Document Name and Reference | Treated As | Volumetric Properties | Document Path/Date Modified |
|---|---|---|---|
| Boss-Extrude1  | Solid Body | Mass:0.040778 kg<br>Volume:0.000254879 m^3<br>Density:159.99 kg/m^3<br>Weight:0.399625 N | Z:\Documents\Senior Design\device design\Support bar.SLDPRT<br>Apr 14 10:55:56 2016 |

Study Properties

| | |
|---|---|
| **Study name** | Side Plate Bearing Load |
| **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 (Z:\Documents\Senior Design\device design) |

Units

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

Material Properties

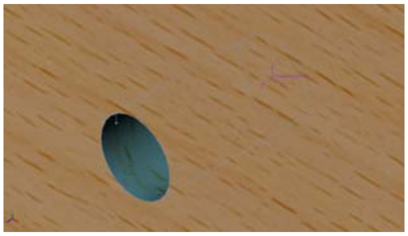
| Model Reference | Properties | Components |
|---|---|---|
|  | Name: **Balsa**<br>Model type: **Linear Elastic Isotropic**<br>Default failure criterion: **Unknown**<br>Yield strength: **20 N/mm^2**<br>Elastic modulus: **3000 N/mm^2**<br>Poisson's ratio: **0.29**<br>Mass density: **159.99 g/cm^3**<br>Shear modulus: **300 N/mm^2** | **SolidBody 2(Boss-Extrude1)(Support bar)** |
| Curve Data:N/A | | |

Loads and Fixtures

| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-3 |  | **Entities:** **2 face(s)**<br>**Type:** **Fixed Geometry** |

Resultant Forces

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Reaction force(N) | -0.00250569 | 140.025 | -0.0080232 | 140.025 |
| Reaction Moment(N.m) | 0 | 0 | 0 | 0 |

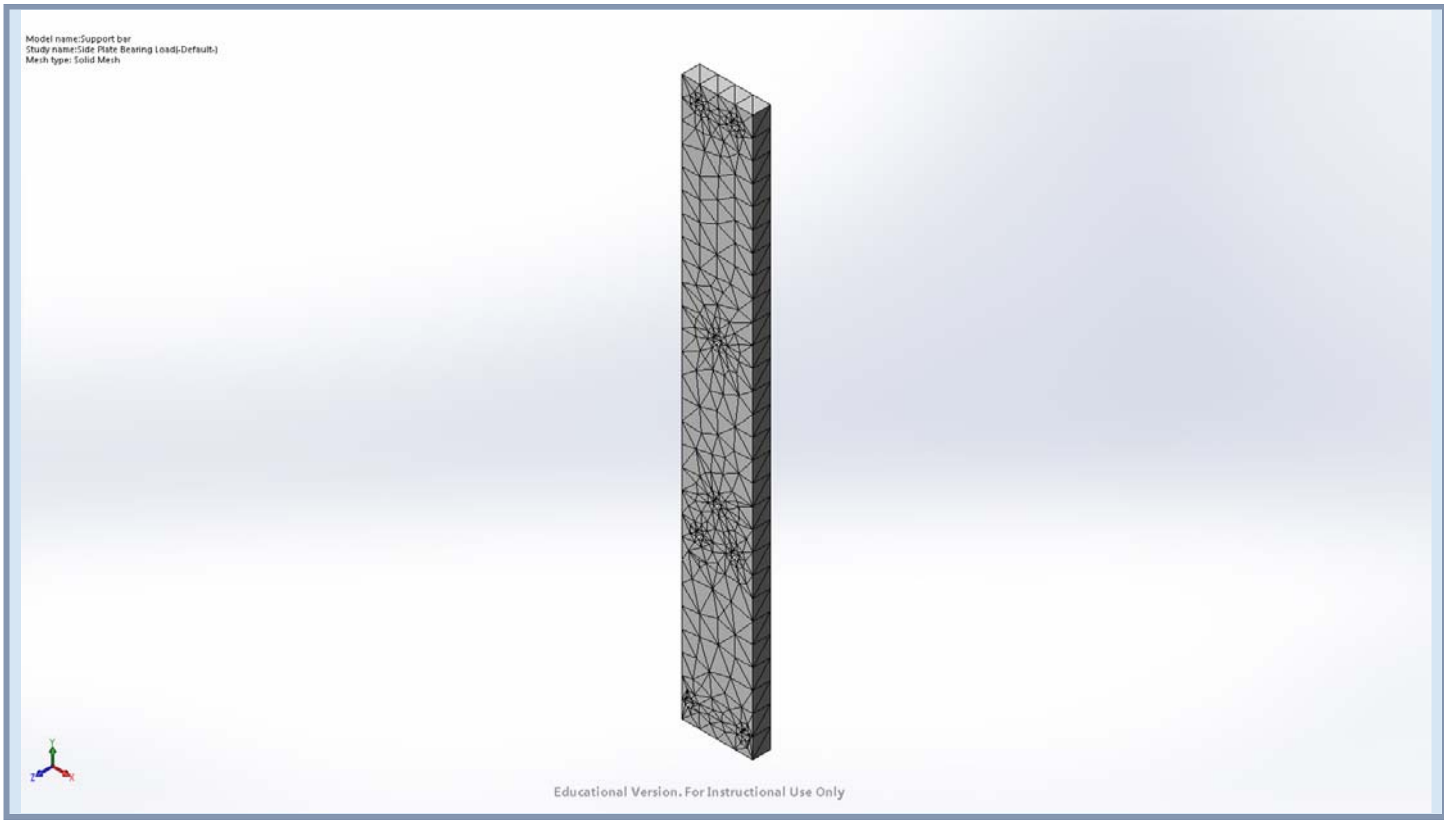
| Load name | Load Image | Load Details |
|---|---|---|
| BearingLoads-1 |  | **Entities:** 1 face(s)<br>**Coordinate System:** Coordinate System1<br>**Force Values:** 0 -140 0 N |

Mesh information

| | |
|---|---|
| **Mesh type** | Solid Mesh |
| **Mesher Used:** | Standard mesh |
| **Automatic Transition:** | Off |
| **Include Mesh Auto Loops:** | Off |
| **Jacobian points** | 4 Points |
| **Element Size** | 0.569695 in |
| **Tolerance** | 0.0284847 in |
| **Mesh Quality** | High |

Mesh information - Details

| | |
|---|---|
| **Total Nodes** | 5553 |
| **Total Elements** | 3032 |
| **Maximum Aspect Ratio** | 13.839 |
| **% of elements with Aspect Ratio < 3** | 82.6 |
| **% of elements with Aspect Ratio > 10** | 0.165 |
| **% of distorted elements(Jacobian)** | 0 |
| **Time to complete mesh(hh;mm;ss):** | 00:00:01 |
| **Computer name:** | DCPC61821 |




Resultant Forces

Reaction forces

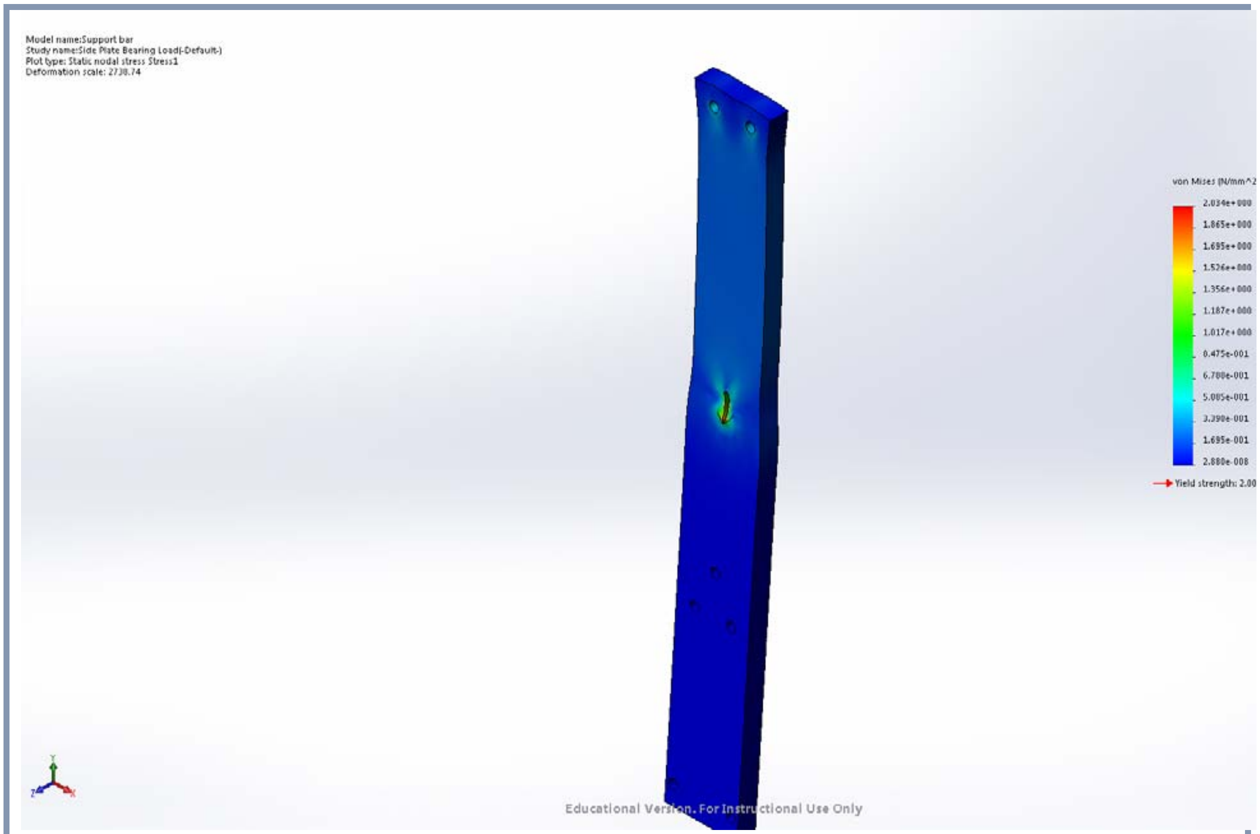
| Selection set | Units | Sum X | Sum Y | Sum Z | Resultant |
|---|---|---|---|---|---|
| Entire Model | N | -0.00250569 | 140.025 | -0.0080232 | 140.025 |

Reaction Moments

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

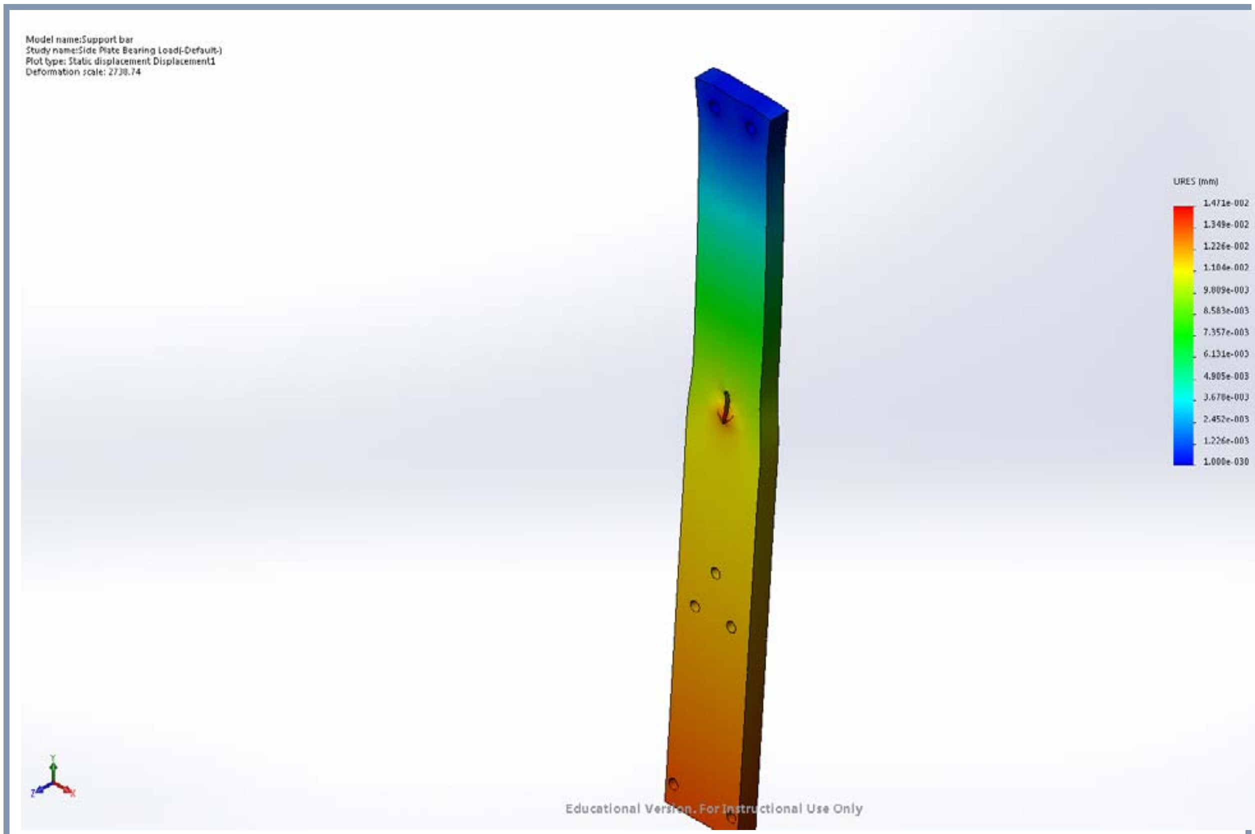
Study Results

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 2.88029e-008 N/mm^2 (MPa)<br>Node: 4289 | 2.034 N/mm^2 (MPa)<br>Node: 129 |



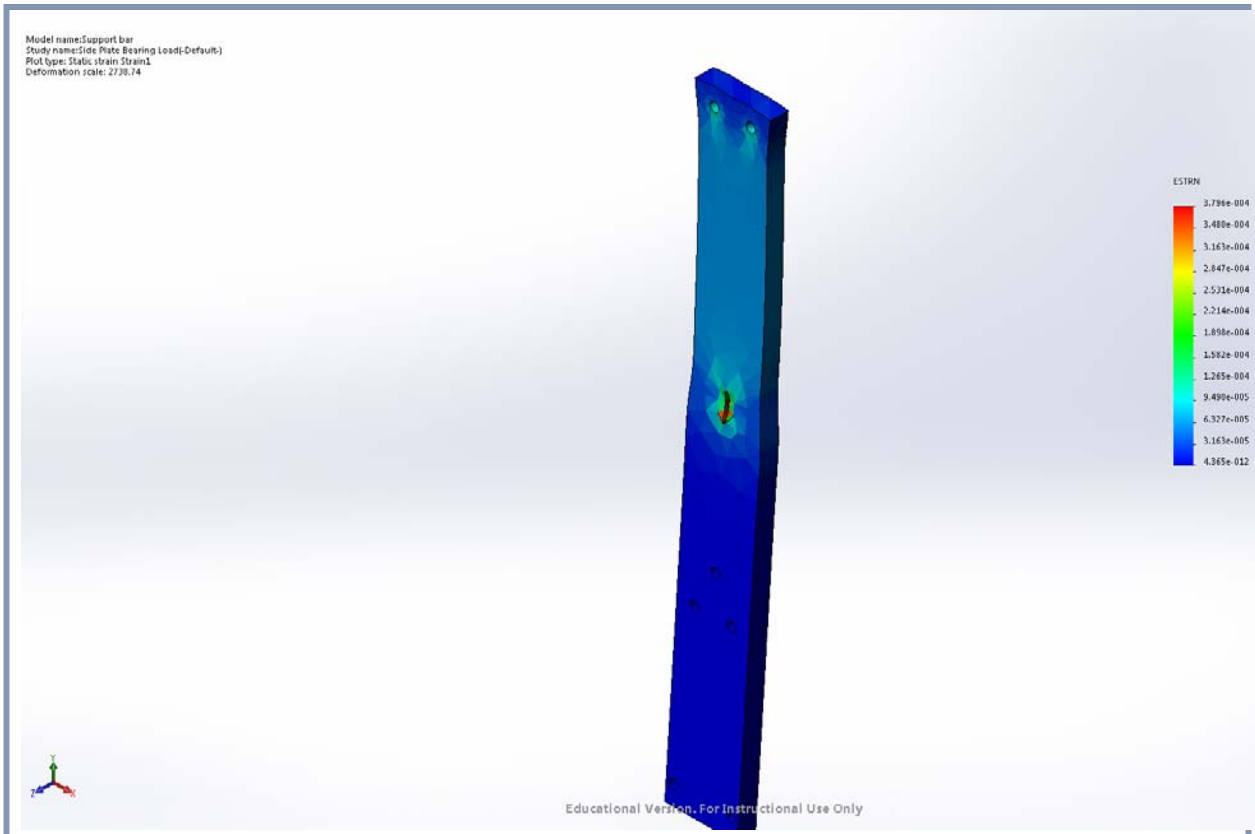

Support bar-Side Plate Bearing Load-Stress-Stress1

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm<br>Node: 1 | 0.0147137 mm<br>Node: 129 |



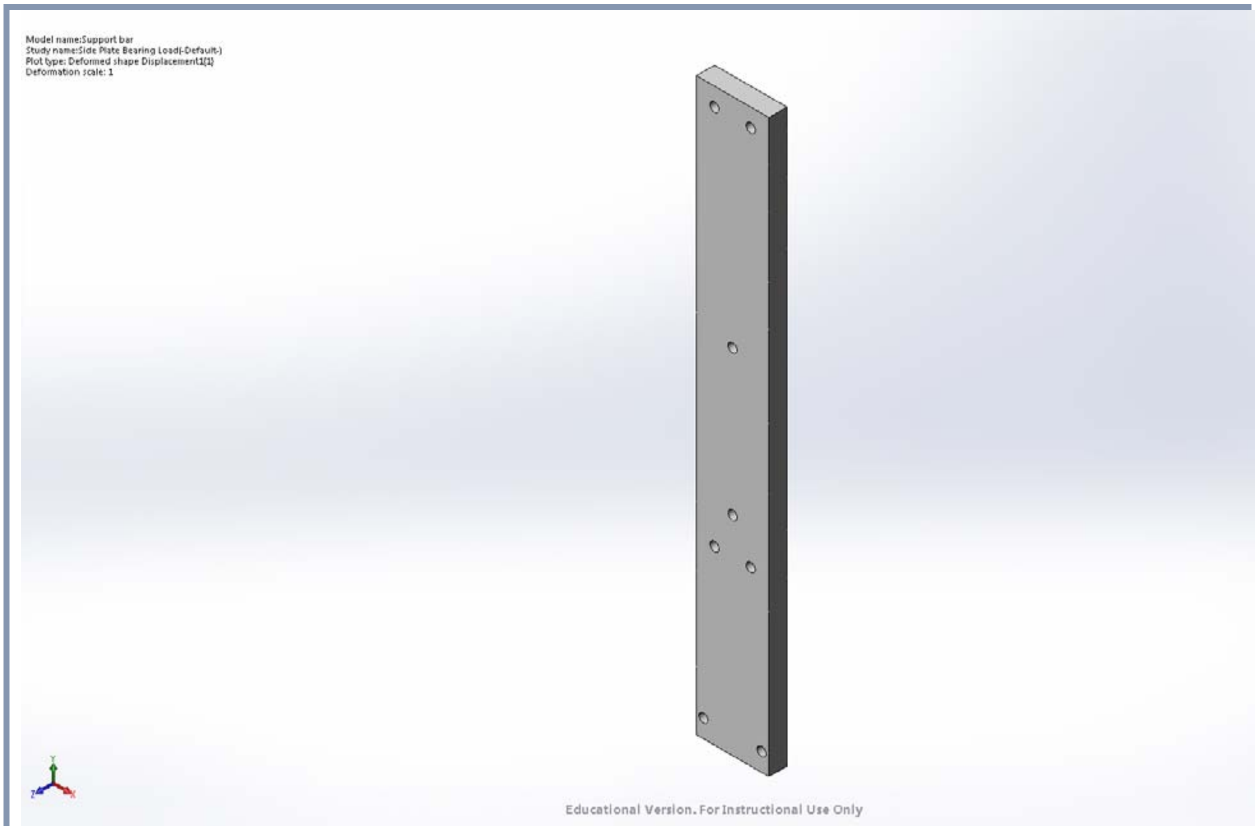

Support bar-Side Plate Bearing Load-Displacement-Displacement1

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 4.3649e-012<br>Element: 1574 | 0.000379605<br>Element: 2941 |




Support bar-Side Plate Bearing Load-Strain-Strain1

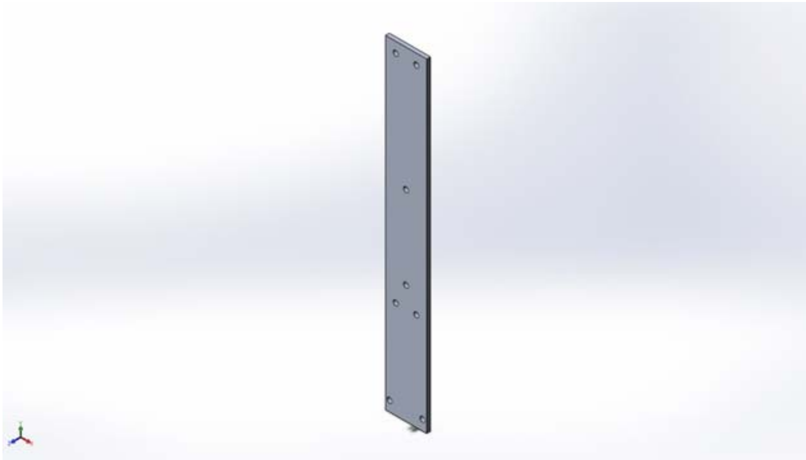
| Name | Type |
|---|---|
| Displacement1{1} | Deformed shape |



Support bar-Side Plate Bearing Load-Displacement-Displacement1{1}

Conclusion

Wood would be a satisfactory material.



Description
Support bar modeled as 6160 Aluminum.

# Simulation of Support bar

**Date: Monday, April 18, 2016**
**Designer: Luke Lindsay**
**Study name: Side Plate Bearing Load**
**Analysis type: Static**

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Sensor Details **Error! Bookmark not defined.**

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Beams **Error! Bookmark not defined.**

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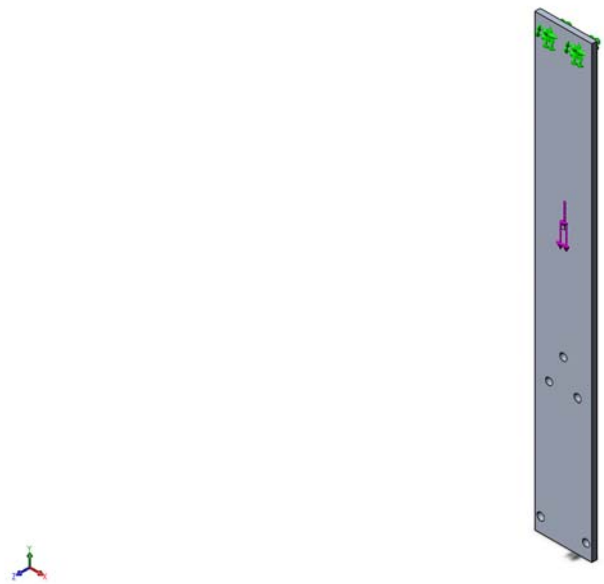
Model Information



Model name: Support bar
Current Configuration: Default

**Solid Bodies**

| Document Name and Reference | Treated As | Volumetric Properties | Document Path/Date Modified |
|---|---|---|---|
| Boss-Extrude1  | Solid Body | Mass:0.258065 kg<br>Volume:9.55795e-005 m^3<br>Density:2700 kg/m^3<br>Weight:2.52903 N | Z:\Documents\Senior Design\device design\Support bar.SLDPRT<br>Apr 14 10:55:56 2016 |

Study Properties

| | |
|---|---|
| **Study name** | Side Plate Bearing Load |
| **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 (Z:\Documents\Senior Design\device design) |

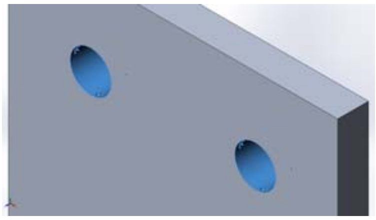
Units

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

Material Properties

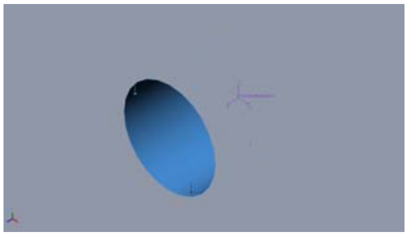
| Model Reference | Properties | Components |
|---|---|---|
|  | Name: **6061 Alloy**<br>Model type: **Linear Elastic Isotropic**<br>Default failure criterion: **Max von Mises Stress**<br>Yield strength: **55.1485 N/mm^2**<br>Tensile strength: **124.084 N/mm^2**<br>Elastic modulus: **69000 N/mm^2**<br>Poisson's ratio: **0.33**<br>Mass density: **2700 g/cm^3**<br>Shear modulus: **26000 N/mm^2**<br>Thermal expansion coefficient: **2.4e-005 /Kelvin** | **SolidBody 2(Boss-Extrude1)(Support bar)** |
| Curve Data:N/A | | |

Loads and Fixtures

| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-3 |  | **Entities:** **2 face(s)**<br>**Type:** **Fixed Geometry** |

Resultant Forces

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Reaction force(N) | -0.00118576 | 139.999 | 0.000862867 | 139.999 |
| Reaction Moment(N.m) | 0 | 0 | 0 | 0 |

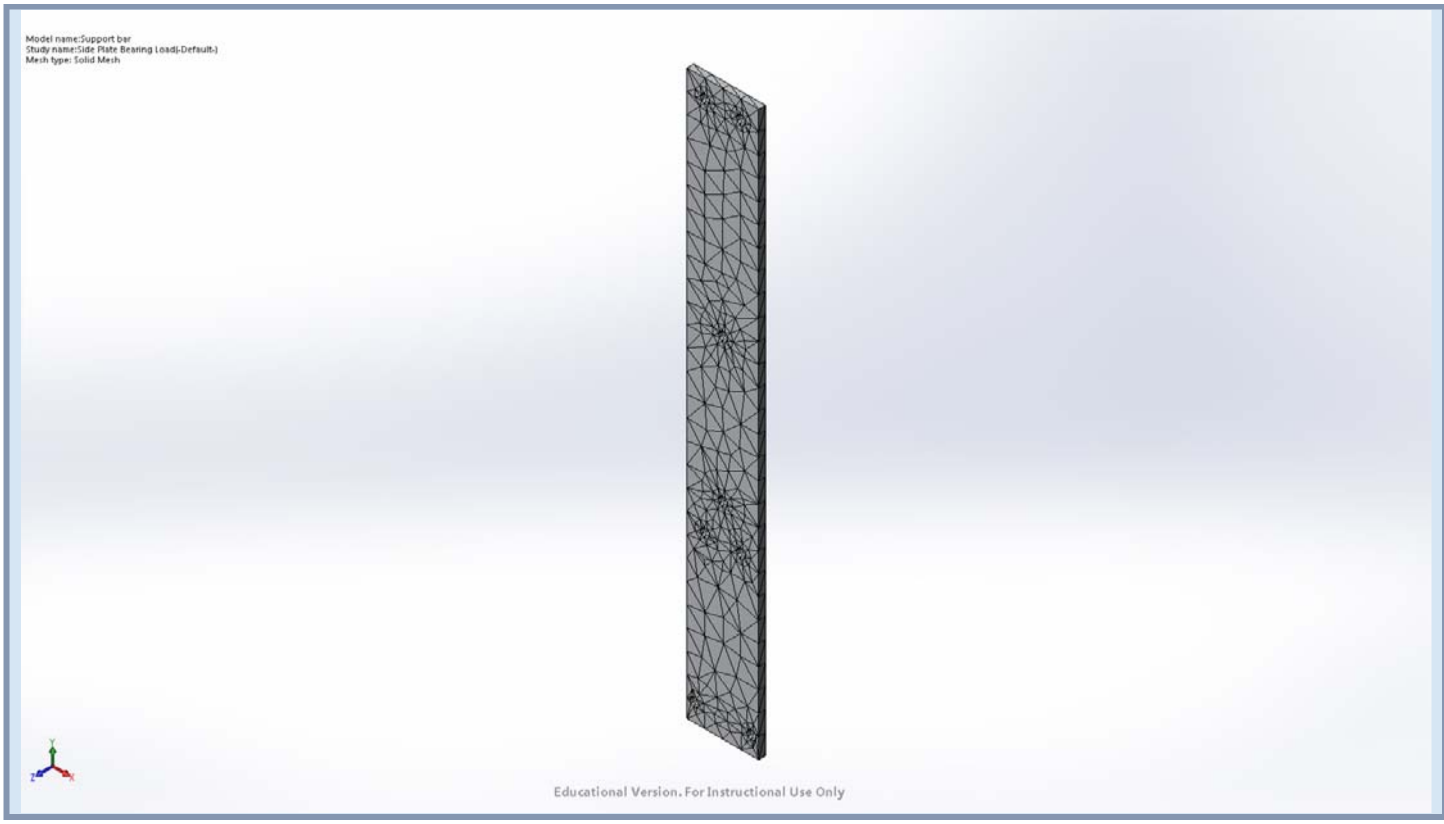
| Load name | Load Image | Load Details |
|---|---|---|
| BearingLoads-1 |  | **Entities:** 1 face(s)<br>**Coordinate System:** Coordinate System1<br>**Force Values:** 0 -140 0 N |

Mesh information

| | |
|---|---|
| **Mesh type** | Solid Mesh |
| **Mesher Used:** | Standard mesh |
| **Automatic Transition:** | Off |
| **Include Mesh Auto Loops:** | Off |
| **Jacobian points** | 4 Points |
| **Element Size** | 0.569695 in |
| **Tolerance** | 0.0284847 in |
| **Mesh Quality** | High |

Mesh information - Details

| | |
|---|---|
| **Total Nodes** | 3767 |
| **Total Elements** | 1752 |
| **Maximum Aspect Ratio** | 8.6866 |
| **% of elements with Aspect Ratio < 3** | 69.3 |
| **% of elements with Aspect Ratio > 10** | 0 |
| **% of distorted elements(Jacobian)** | 0 |
| **Time to complete mesh(hh;mm;ss):** | 00:00:01 |
| **Computer name:** | DCPC61821 |




Resultant Forces

Reaction forces

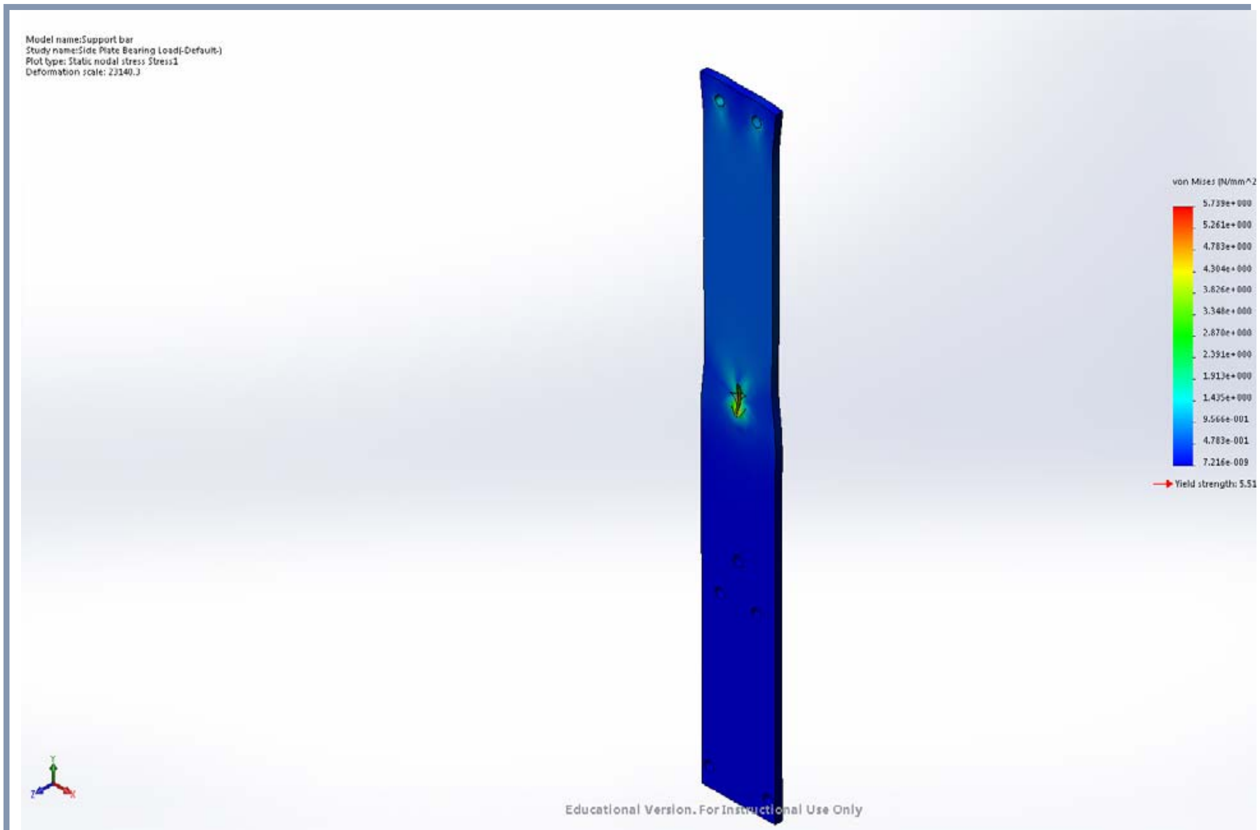
| Selection set | Units | Sum X | Sum Y | Sum Z | Resultant |
|---|---|---|---|---|---|
| Entire Model | N | -0.00118576 | 139.999 | 0.000862867 | 139.999 |

Reaction Moments

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

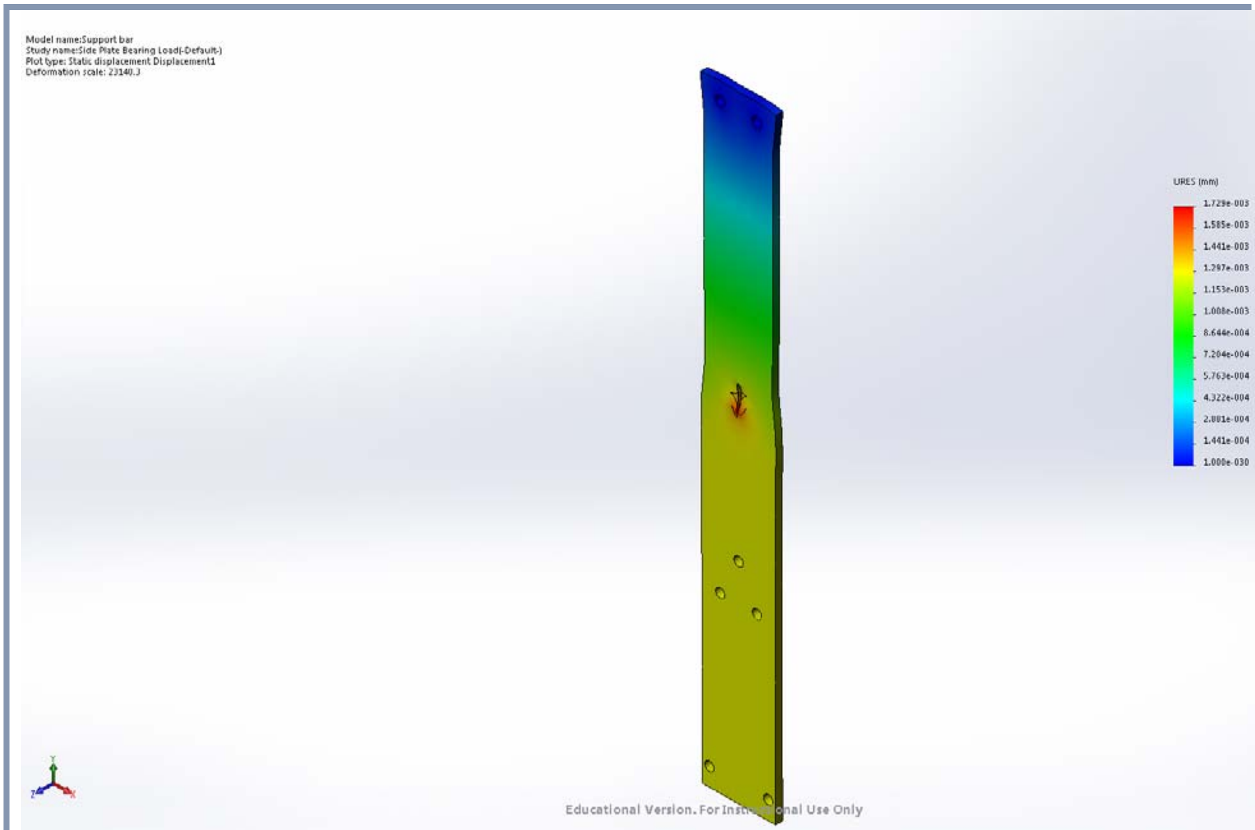
Study Results

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 7.21583e-009 N/mm^2 (MPa)<br>Node: 2917 | 5.73931 N/mm^2 (MPa)<br>Node: 104 |



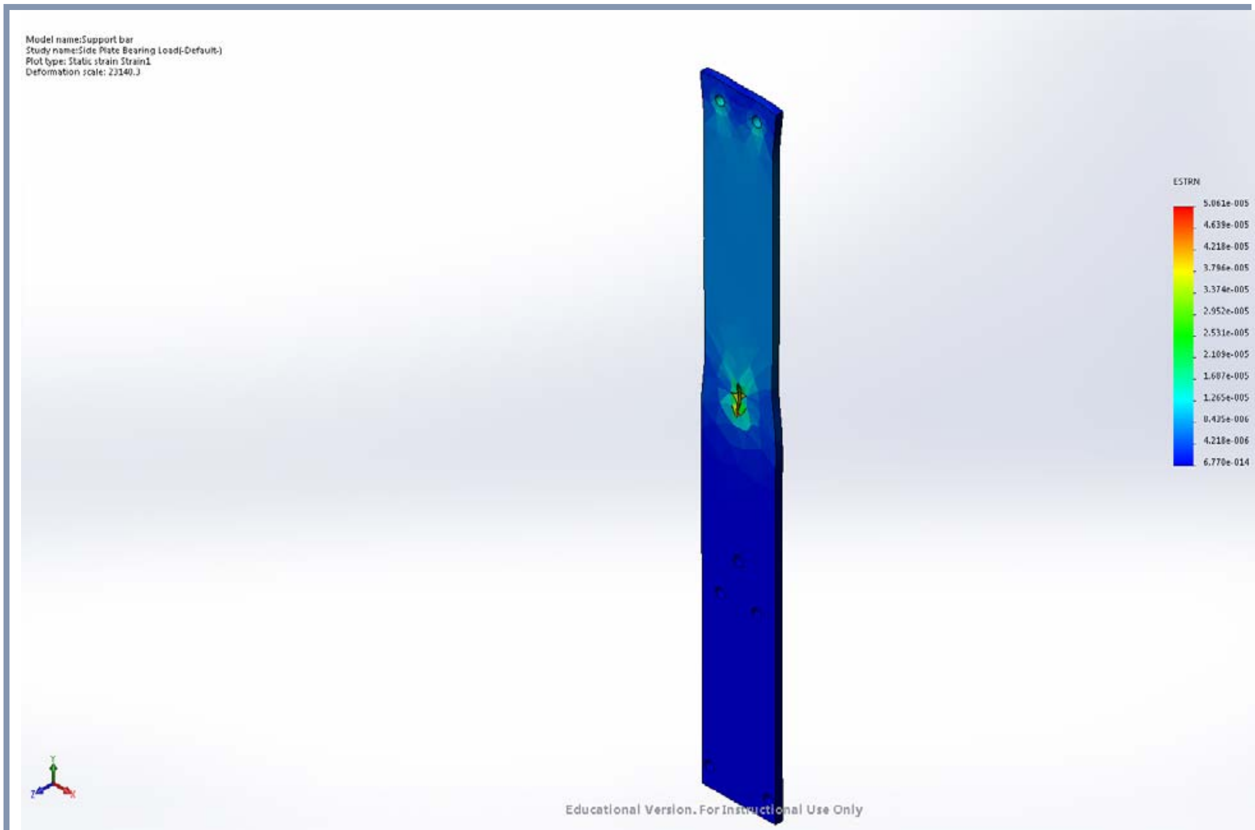

Support bar-Side Plate Bearing Load-Stress-Stress1

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm<br>Node: 1 | 0.00172884 mm<br>Node: 3233 |




Support bar-Side Plate Bearing Load-Displacement-Displacement1

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 6.76971e-014<br>Element: 1148 | 5.06126e-005<br>Element: 1336 |




Support bar-Side Plate Bearing Load-Strain-Strain1

| Name | Type |
|---|---|
| Displacement1{1} | Deformed shape |


Support bar-Side Plate Bearing Load-Displacement-Displacement1{1}

Conclusion

6160 Aluminum is a satisfactory material.

## Appendix 5: SCU Core Arts and Humanities Requirement

**Arts**

As part of satisfying the SCU Core Arts & Humanities requirements, members of this team have all contributed original drawings, sketches, and/or CAD models and drawings to this project. Below are listed a sampling of at least one such artifact, and a reference to it, for each of the team members.

| Team Member | Description | Location |
|---|---|---|
| Will Gonder | Preliminary Conceptual Design | Figure 4 |
| George Montgomery | Support Plate Solid works Part | Appendix 6 |
| Luke Lindsay | Conceptual System Level Breakdown | Figure 3 |
| Luke Lindsay | Fine System Level Breakdown | Figure 5 |

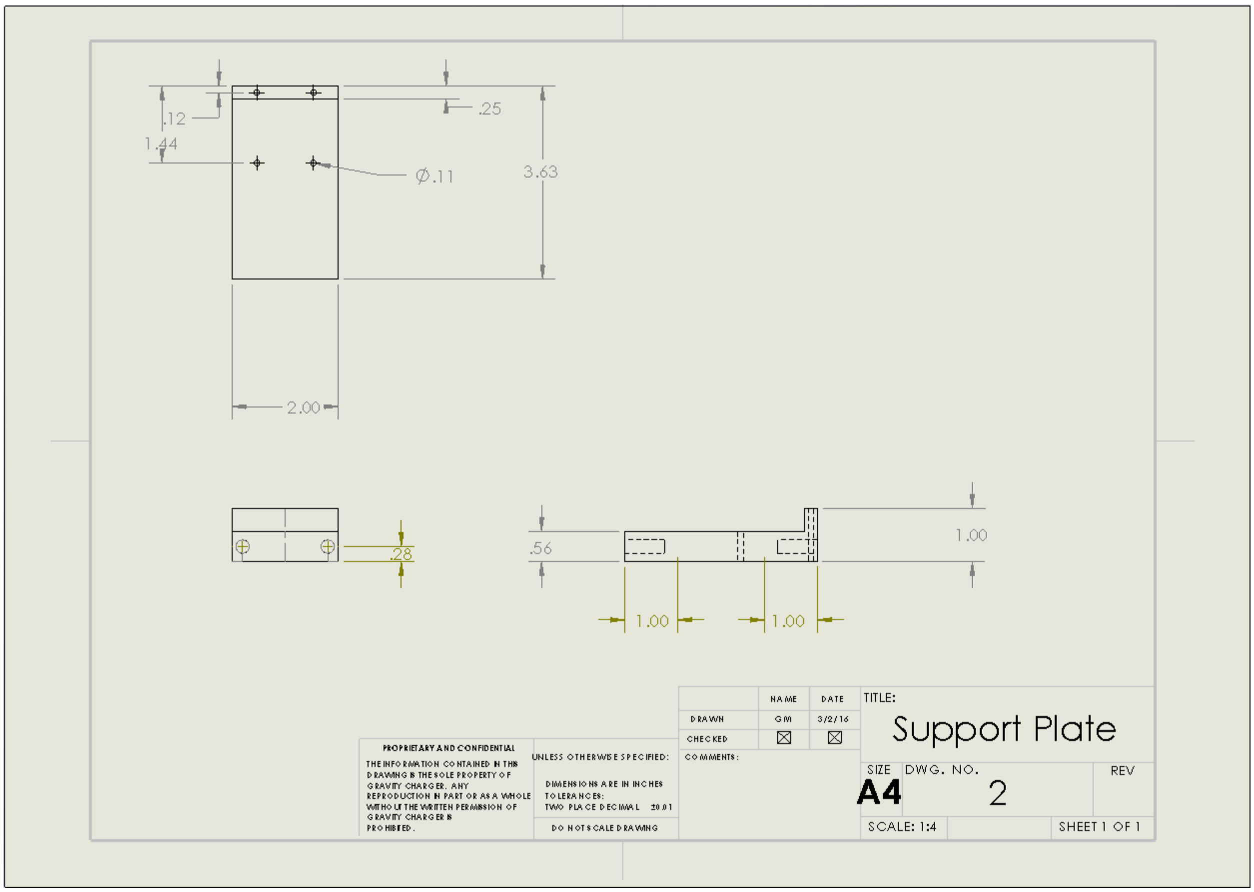



*Figure 25: George's Arts and Humanities Drawing*

Appendix 6: Presentation Slides

# Gravity Charger

George Montgomery

Will Gonder

Luke Lindsay

## Team Gravity Charger

George Montgomery

Luke Lindsay

Will Gonder

# Reliable Energy for Medical Outreach

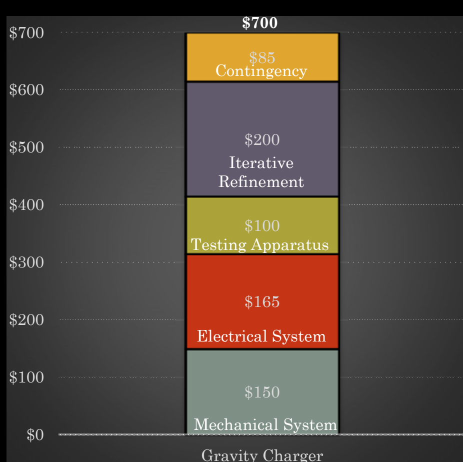
- Global Medical Brigade
- International Medical Relief
- Baan Dada's Children's Home
- Engineering World Health


# STEM education

# Project Overview

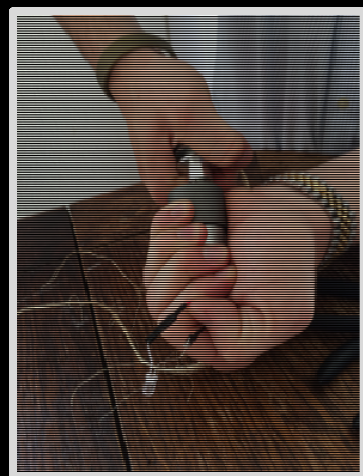
Gravity Charger harnesses the power of gravity to provide reliable, sustainable energy for medical outreach programs.

# Funding



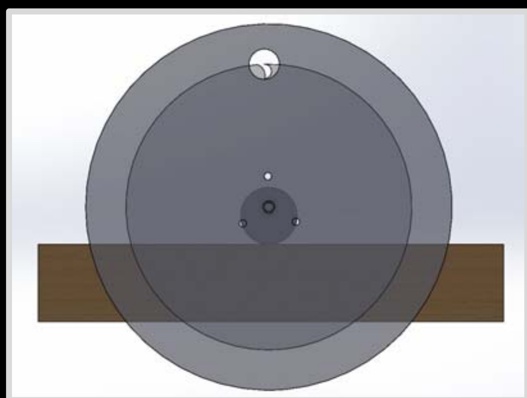

Miller Center for Social Entrepreneurship

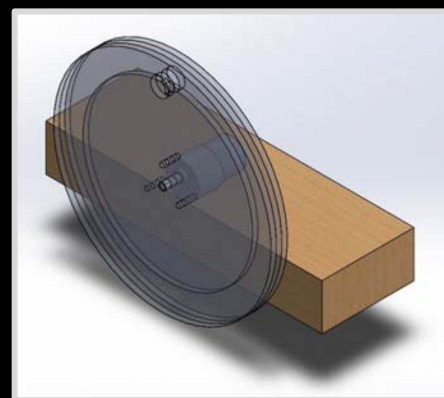
# Proof of Concept



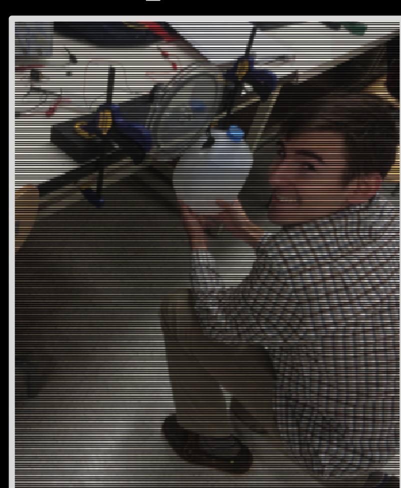
# Proof of Concept

## Proof of Concept

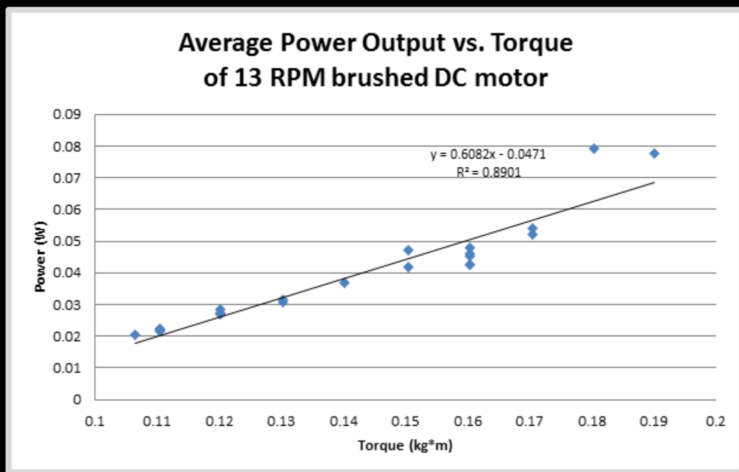




## Proof of Concept



# Initial Test Results

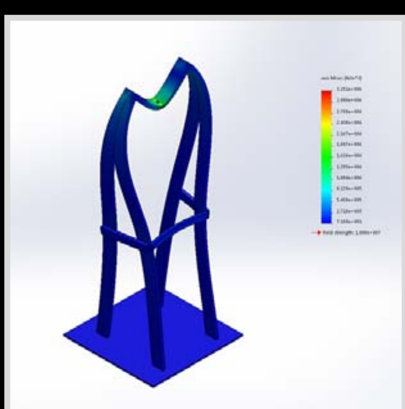



# Design Specifications

| Specification | Value |
|---|---|
| Power Output | 2.5 watts |
| Lifted Weight | 50 lbs |
| Fall Time | 5 mins |
| Device Weight | 25 lbs |

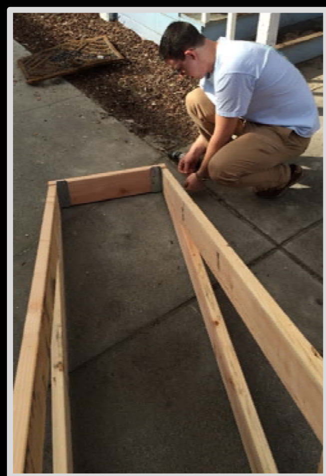
# Test Frame

# Finite Element Analysis



| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 41.4 Mpa | 3.251 Mpa | P |
| Max Deflection | 10.000 mm | 0.545 mm | P |
| Factor of Safety | 3 | 12.7 | P |

# Construction

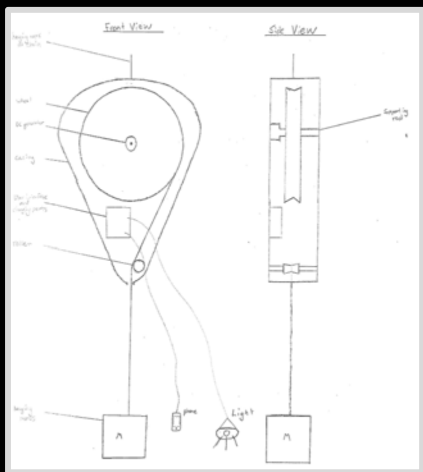


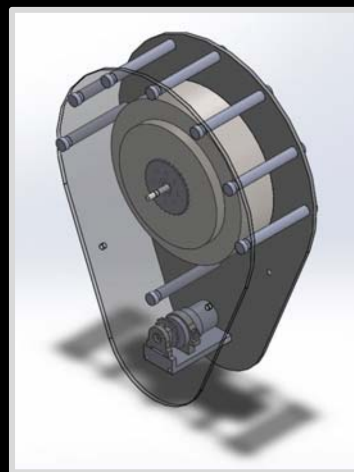
# Moving into the Lab

Safety First

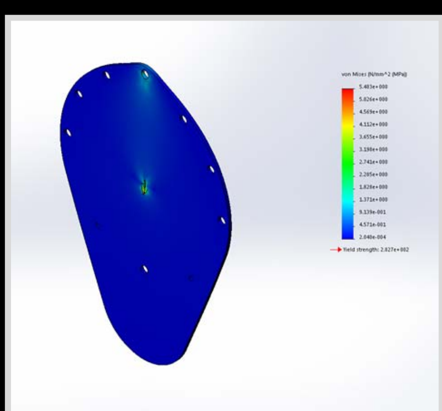
- Weighted Base
- Complete Enclosure
- Emergency Halt


# First Iteration



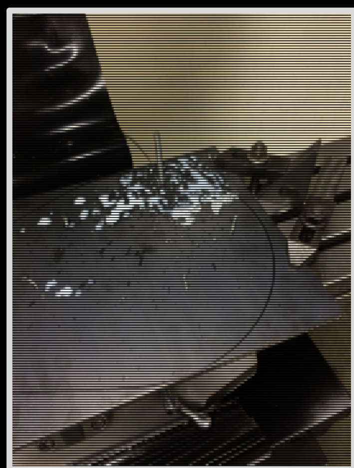



# Finite Element Analysis



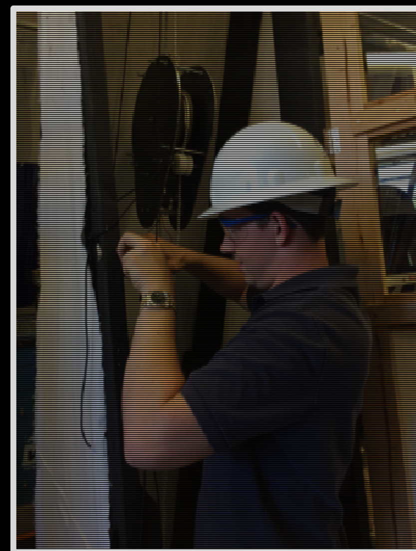
| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 94 Mpa | 5.483 Mpa | P |
| Max Deflection | 1.5 mm | 0.00044 mm | P |
| Factor of Safety | 3 | 17 | P |

# Fabrication



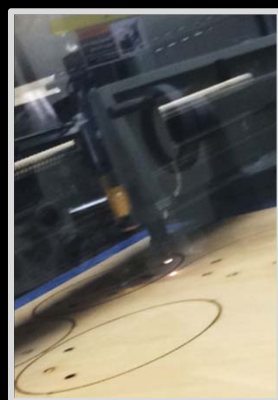
# Bike Wheel

## Testing Procedure

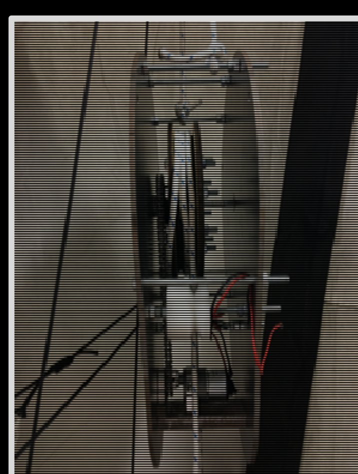


## DISASTER

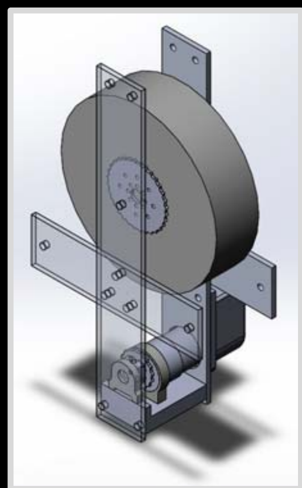
# Iteration 1.2

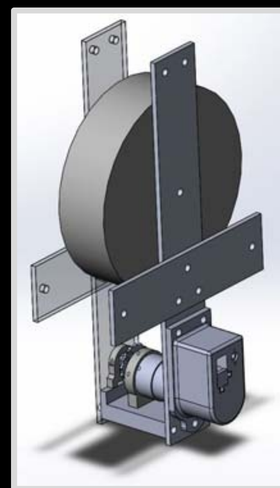


# Iteration 1.2 Testing

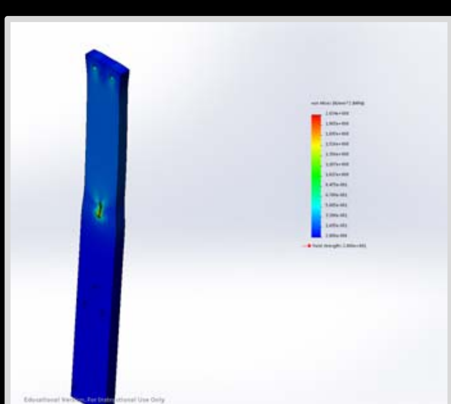


# Second Iteration





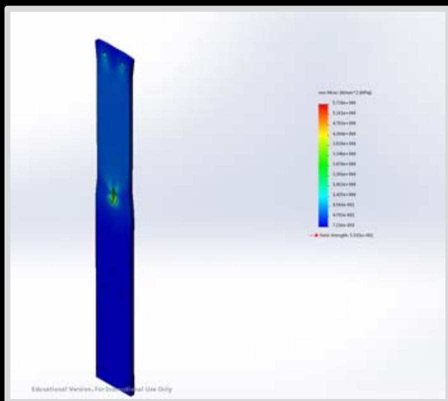
# Finite Element Analysis



1/2" Wood

| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 20 Mpa | 2.034 Mpa | P |
| Max Deflection | 1.5 mm | 0.015 mm | P |
| Factor of Safety | 3 | 9.83 | P |

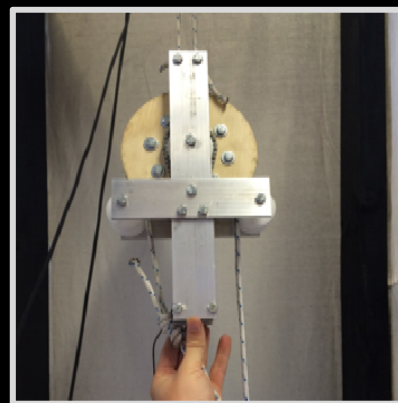
# Finite Element Analysis


3/16" 6160 Aluminum

| | Design Criteria | Simulation Results | PASS /FAIL |
|---|---|---|---|
| Max Stress | 55.15 Mpa | 5.74 Mpa | P |
| Max Deflection | 1.5 mm | 0.0017 mm | P |
| Factor of Safety | 3 | 9.6 | P |

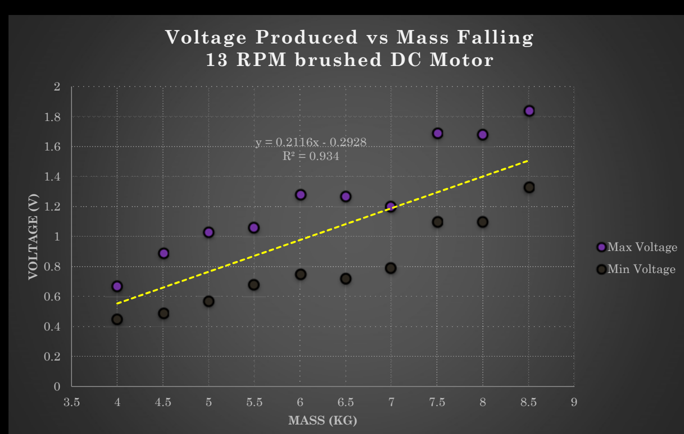
# Fabrication


# Second Iteration Testing



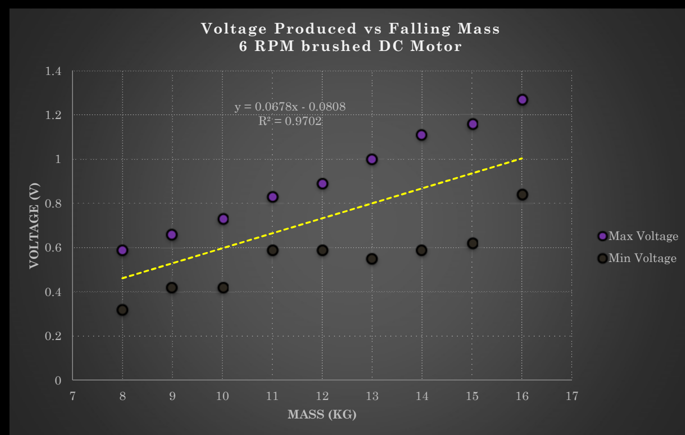
# Results

- 0.34 Watts
- 1.67 Minutes
- 22 lumens



# Results

- 0.16 Watts
- 6.3 Minutes
- 9.6 lumens




# Design Specifications vs Results

| Specification | Design | 13 RPM | 6 RPM |
|---|---|---|---|
| Power Output | 2.5 watts | 0.34 watts | 0.16 watts |
| Lifted Weight | 50 lbs | 19 lbs | 35 lbs |
| Fall Time | 5 mins | 1.67 mins | 6.3 mins |
| Device Weight | 25 lbs | 5 lbs | 5 lbs |

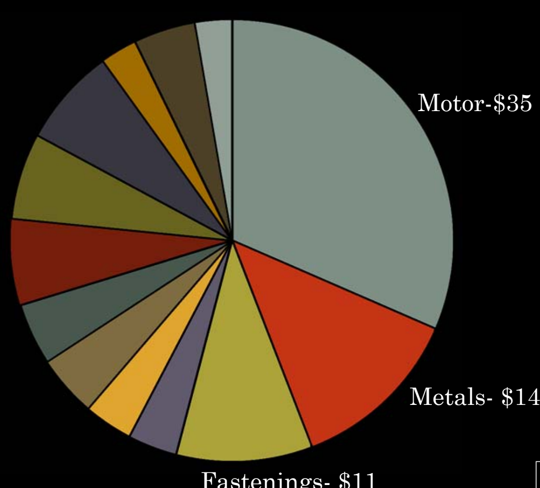
# Future Refinements

- Electrical signal processing
- Parallel mechanical sub-systems
- Add mechanical advantage for weight lifting
- Heighten efficiency

# Summary

Created a gravity powered generator to be used for medical outreach.

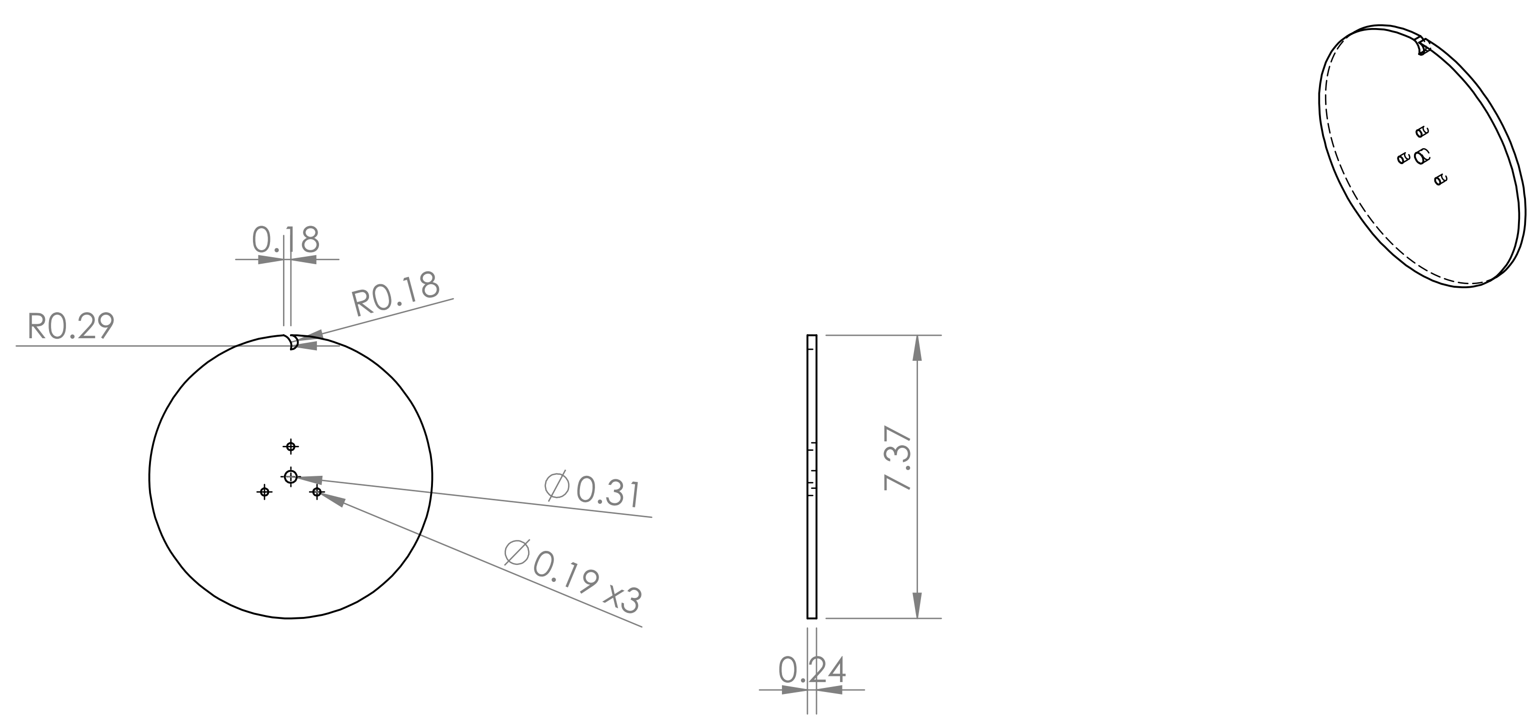
# Cost Breakdown




Total- $111

Gravity Charger

Appendix 7: Detailed Drawings




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/28/16 |
| CHECKED | | |

COMMENTS: This is the inner plate that provides a hook for the hanging mass to supply torque to the proof of concept.

TITLE: Wheel

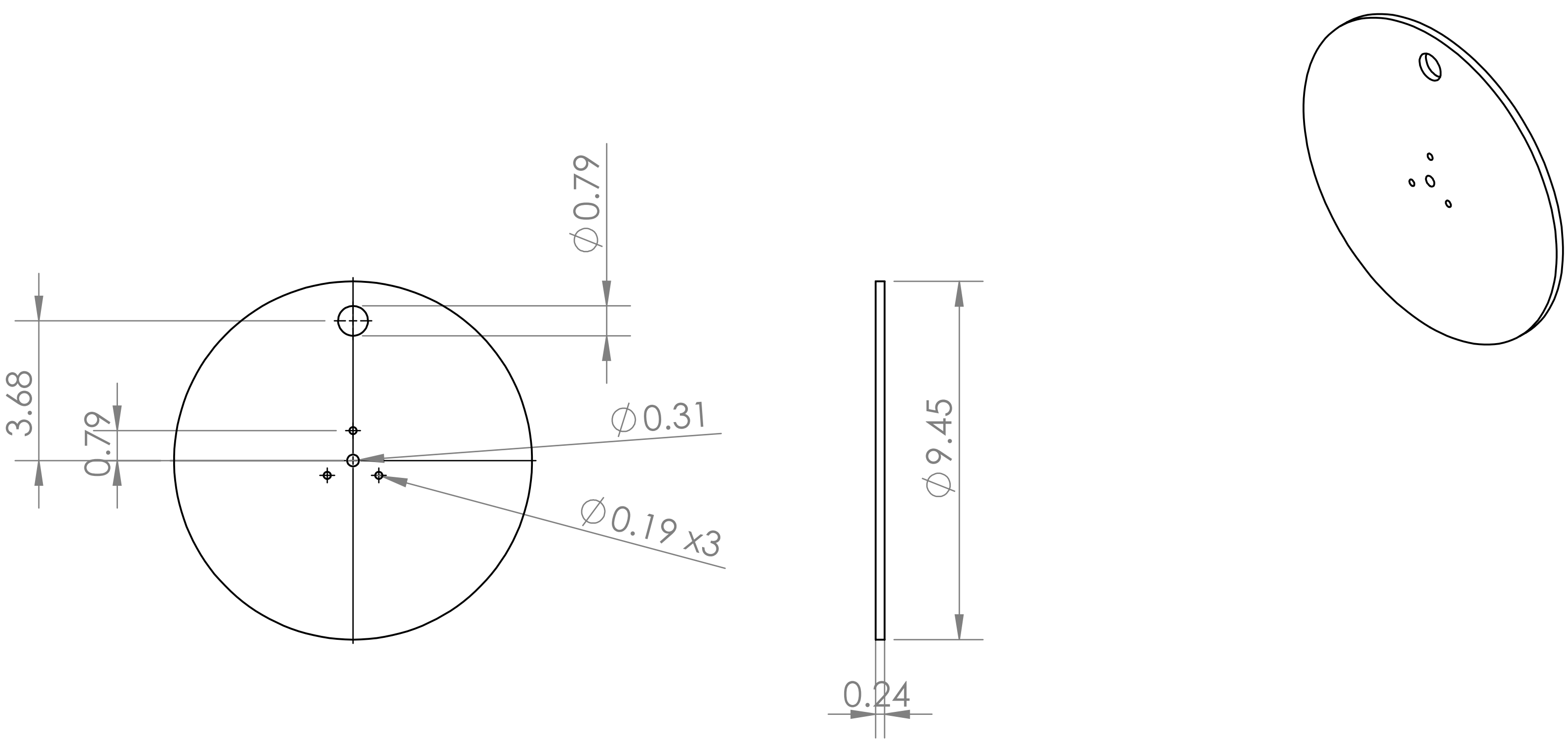
SIZE A | DWG. NO. 1.1 | REV

SCALE: 1:4 | SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/28/16 |
| CHECKED | | |

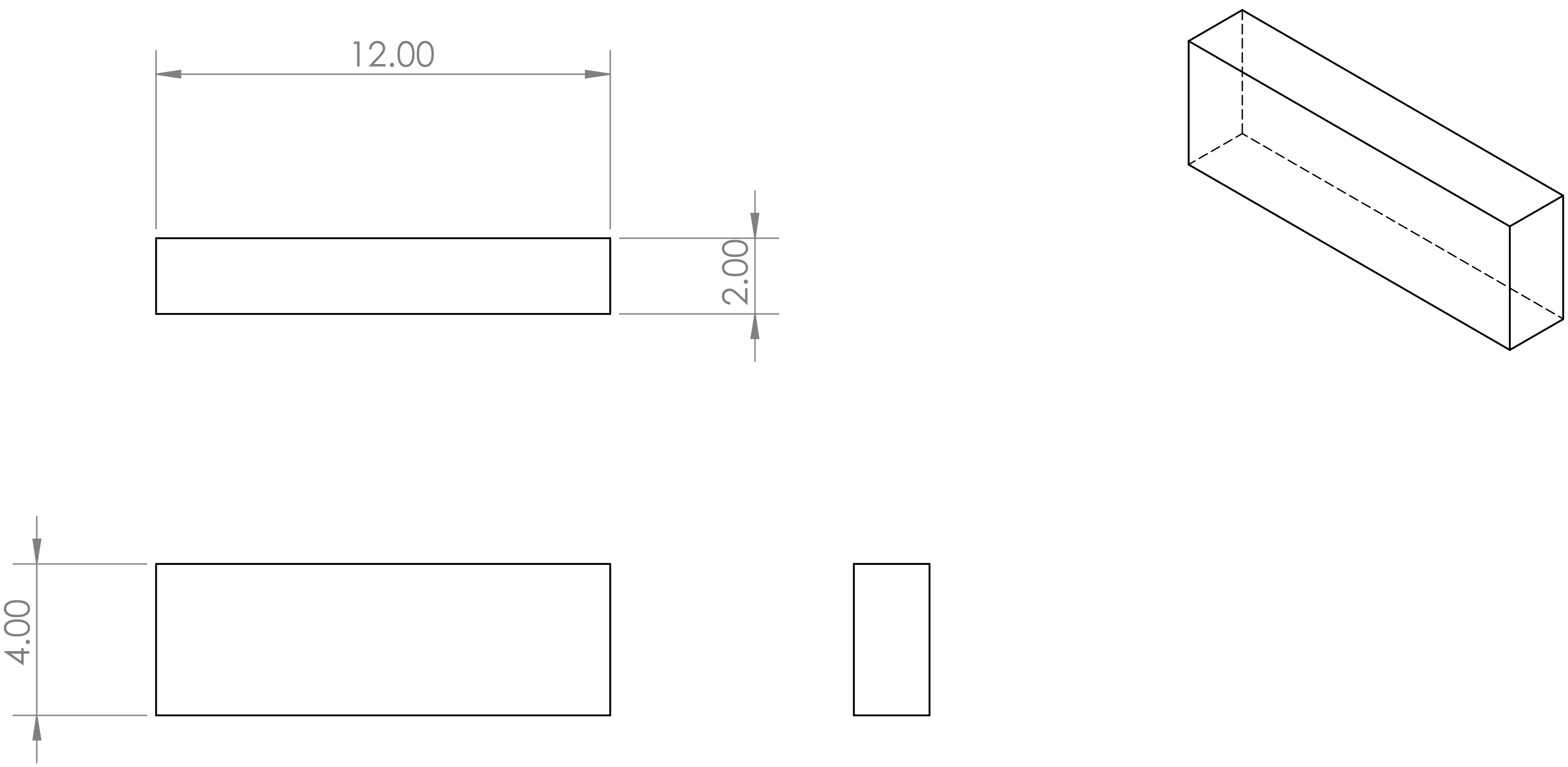
COMMENTS:This is the outer housing for our wheel. It has a hole in it to provide room for a rope to tie around the hook in drawing 1.1.

TITLE:

# Wheel Gaurds

SIZE A | DWG. NO. 1.2 | REV

SCALE: 1:4 | SHEET 1 OF 1




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/28/16 |
| CHECKED | | |

COMMENTS: standard lumber 2x4 cut to 12 inches.

TITLE: Support

| SIZE | DWG. NO. | REV |
|---|---|---|
| A | 1.3 | |

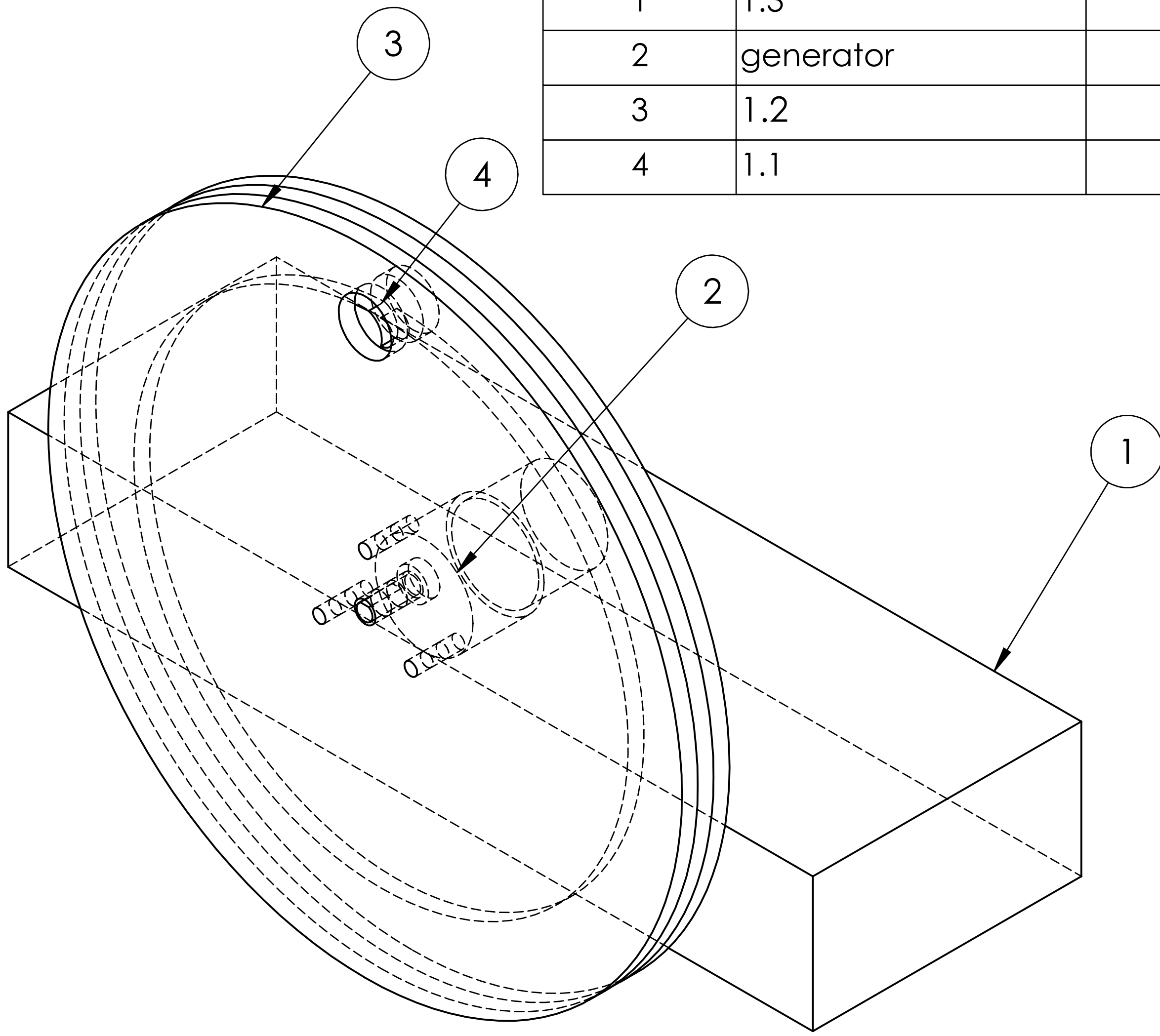
SCALE: 1:4 | SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 1.3 | 2X4 wood support | 1 |
| 2 | generator | 13 rpm DC motor | 1 |
| 3 | 1.2 | Outer wheel acrylic | 2 |
| 4 | 1.1 | Inner wheel acrylic | 1 |




SCALE 1 : 2

| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/28/16 |
| CHECKED | | |

COMMENTS: This is an assemble of parts 1.1-1.3.

TITLE: Proof of Concept Assembly

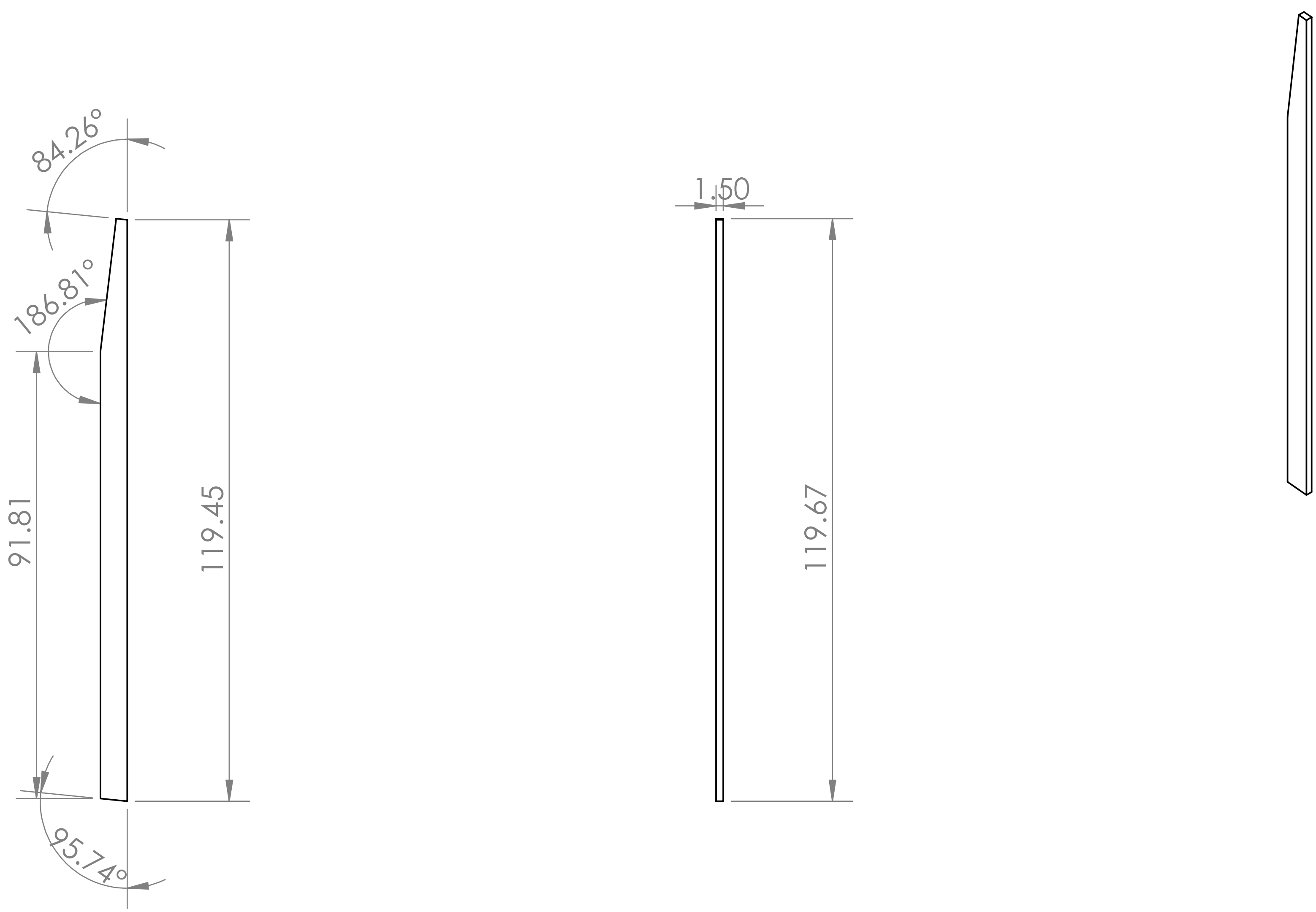
SIZE: A | DWG. NO. 1.4 | REV

SCALE: 1:2 | SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE: **10' Upright**

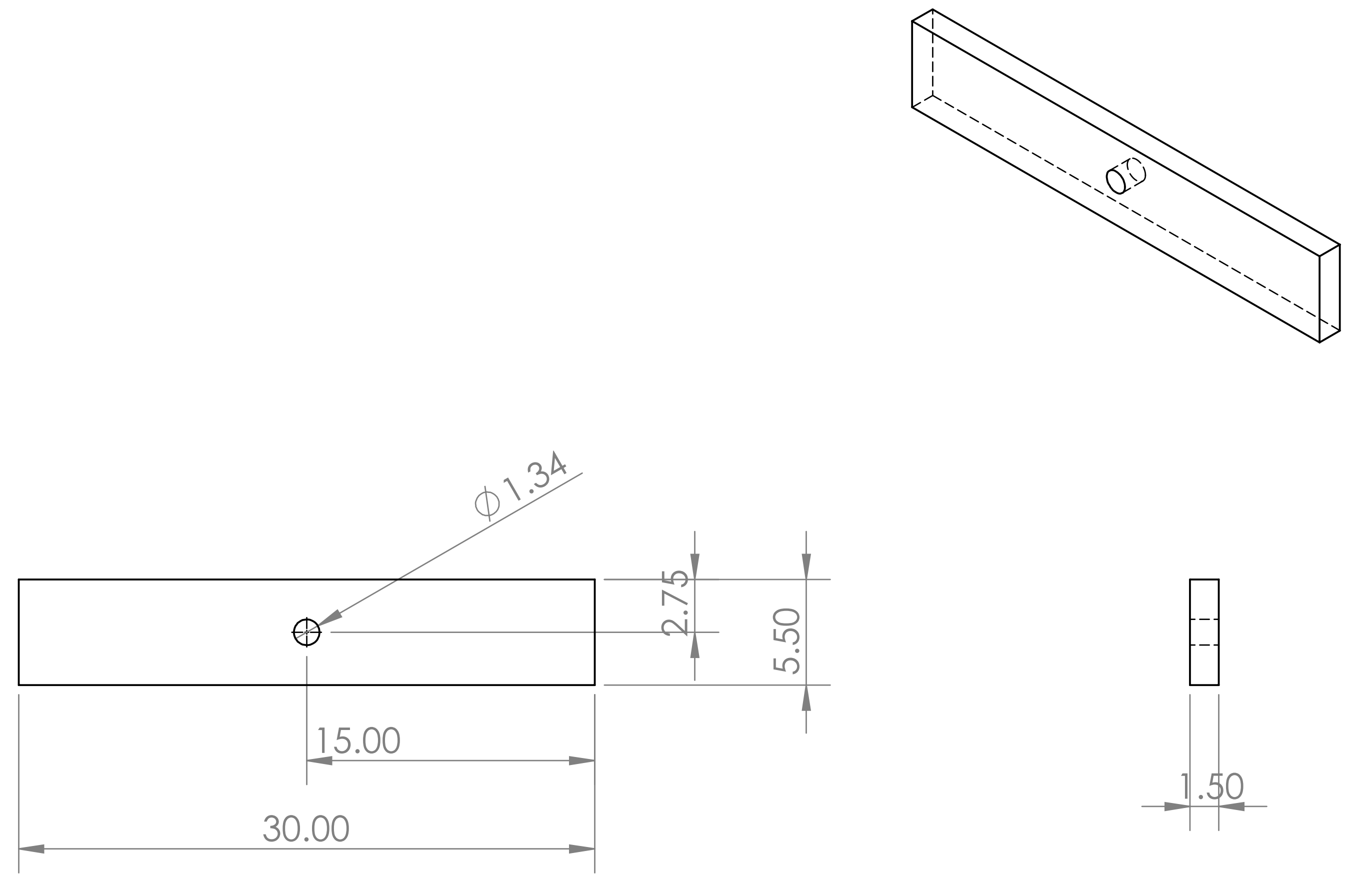
SIZE: **A** | DWG. NO. 2.1 | REV 2

SCALE: 1:33.3

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# Top

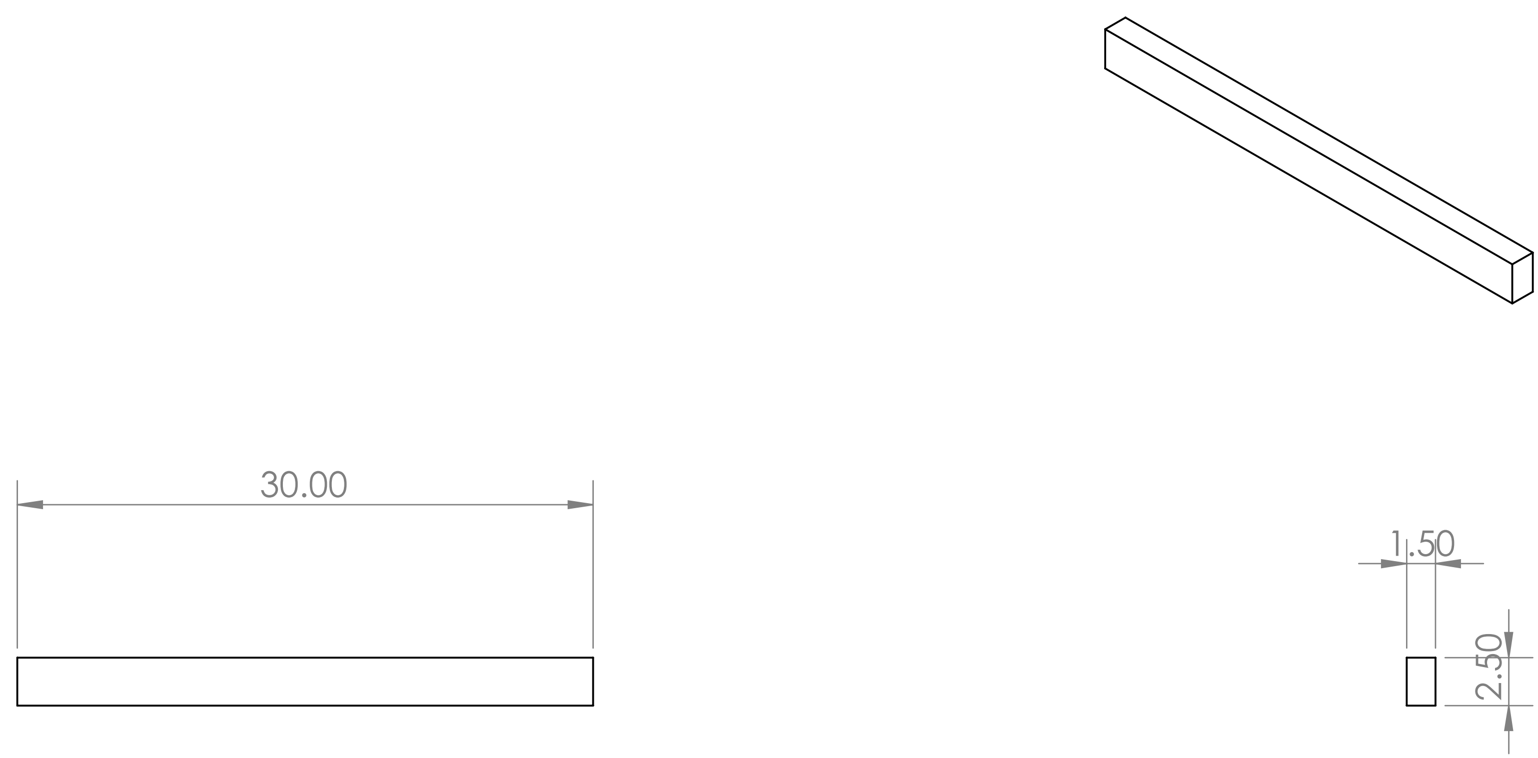
SIZE A | DWG. NO. 2.2 | REV 2

SCALE: 1:10

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# Cross Support

SIZE A

DWG. NO. 2.3

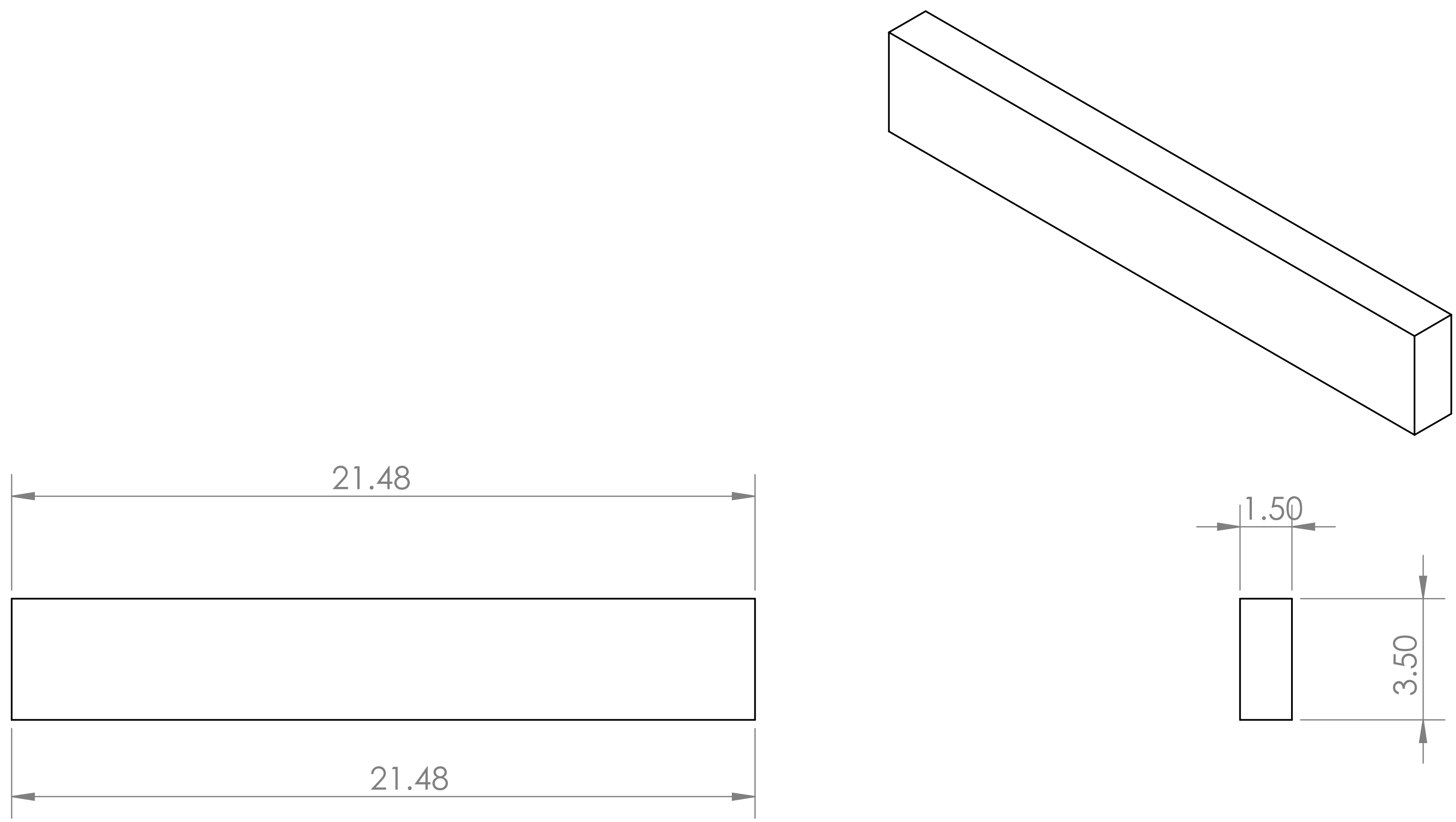
REV 2

SCALE: 1:10

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# Side Support

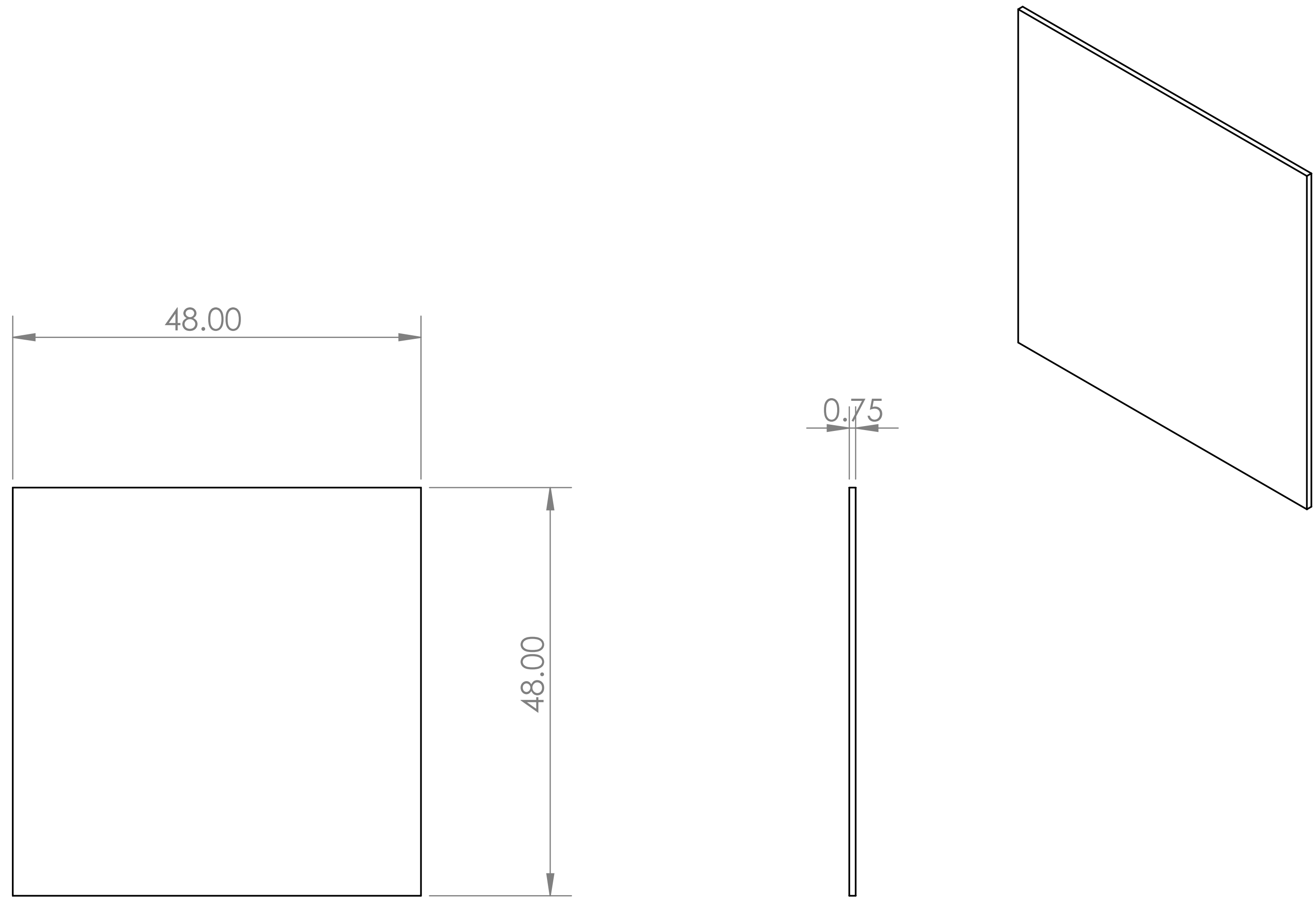
| SIZE | DWG. NO. | REV |
|---|---|---|
| A | 2.4 | 2 |

SCALE: 1:5

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE: 4ft X 4ft Base

SIZE: A | DWG. NO. 2.5 | REV 2

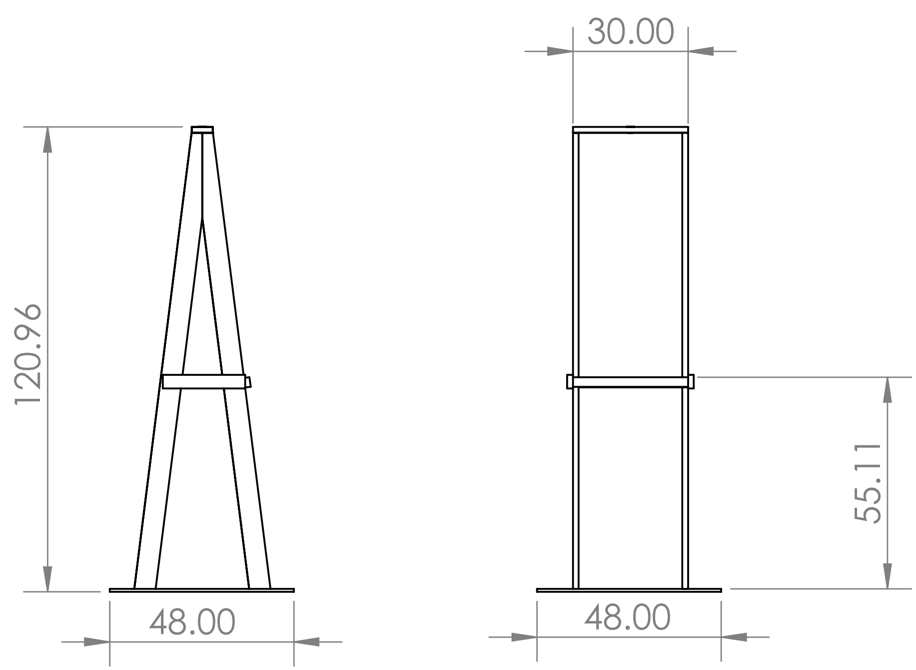
SCALE: 1:20

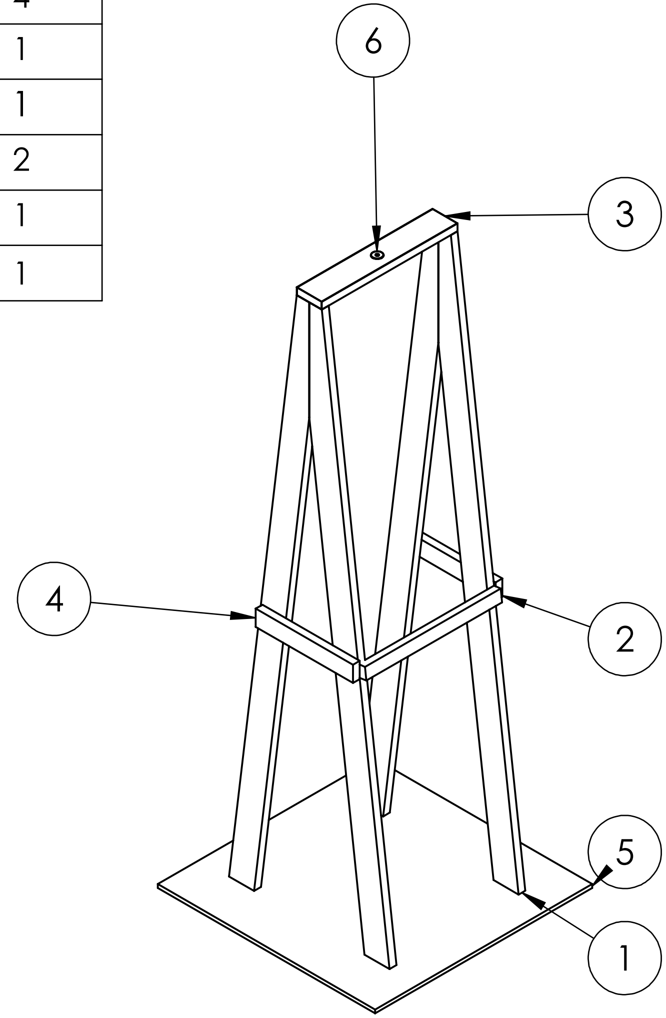
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 2.1 | 10 foot 2X6 | 4 |
| 2 | 2.3 | back support 2X4 | 1 |
| 3 | 2.2 | Top 2X6 | 1 |
| 4 | 2.4 | Side support 2X4 | 2 |
| 5 | 2.5 | Bottom 4foot by 4 foot plywood | 1 |
| 6 | washer | 1/2" diameter hole | 1 |

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TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

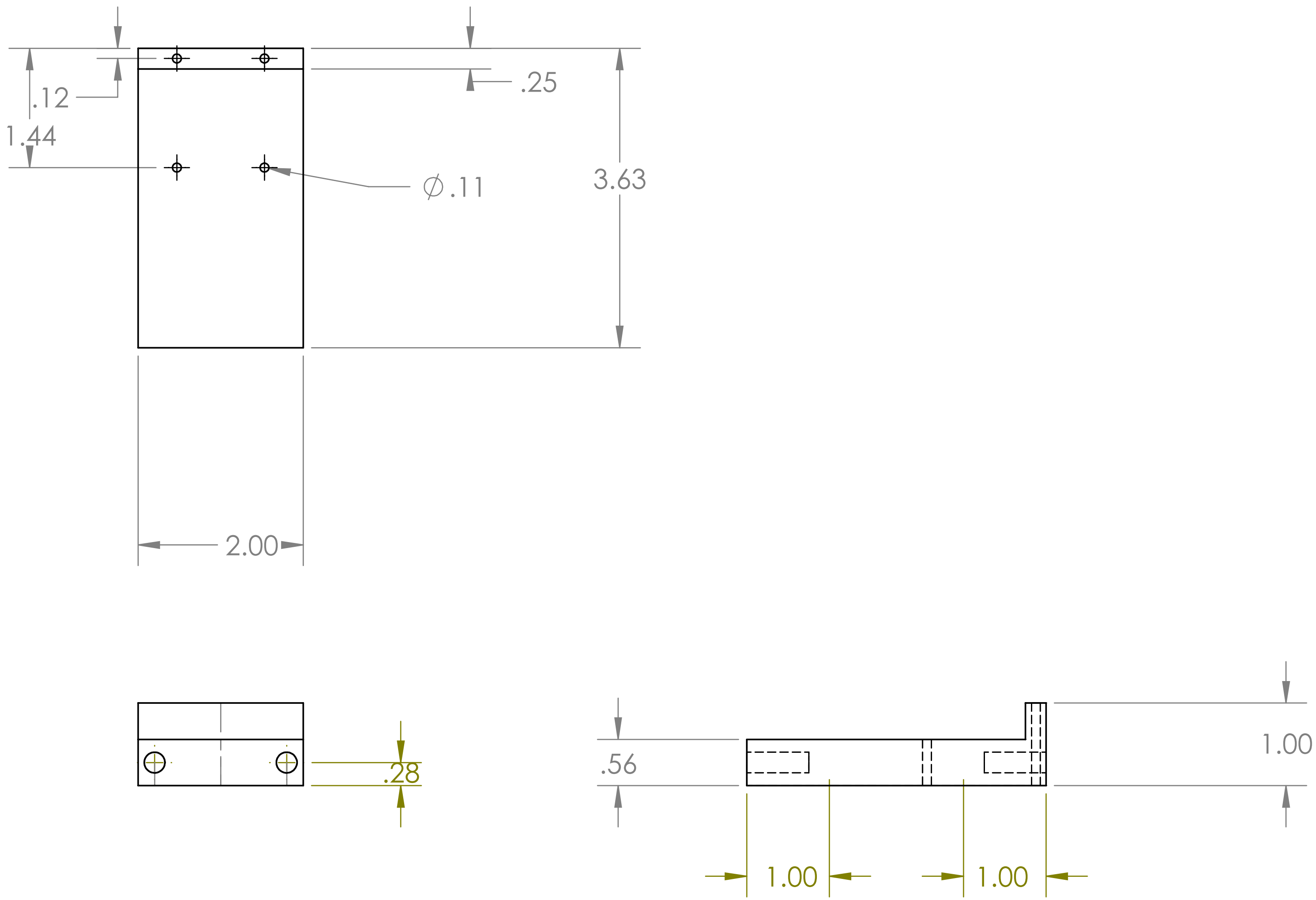
COMMENTS:

The test frame supports a device that in turn supports approximately 60 pounds hung from an eye bolt. The frame is made of common fir spray painted black. Wood screws hold the frame together, and metal brackets hold the frame to the base.

TITLE: Test Frame Assembly

SIZE A | DWG. NO. 2.6 | REV 2

SCALE: 1:50




| | NAME | DATE |
|---|---|---|
| DRAWN | GM | 3/2/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# Support Plate

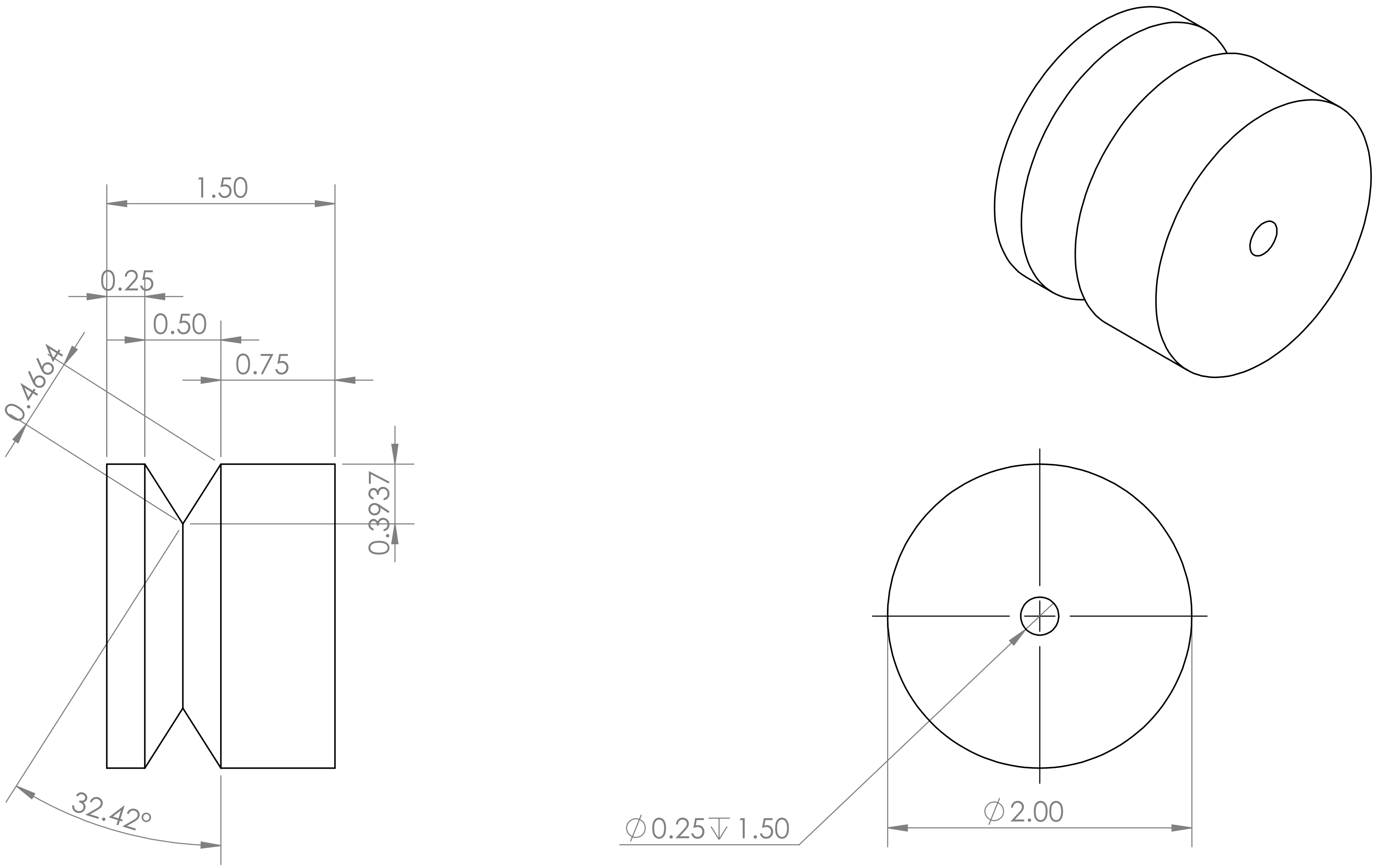
SIZE **A4** DWG. NO. 3.1 REV

SCALE: 1:4 SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/9/16 |
| CHECKED | | |

COMMENTS:

TITLE: Roller

SIZE: A

DWG. NO. 3.2

REV

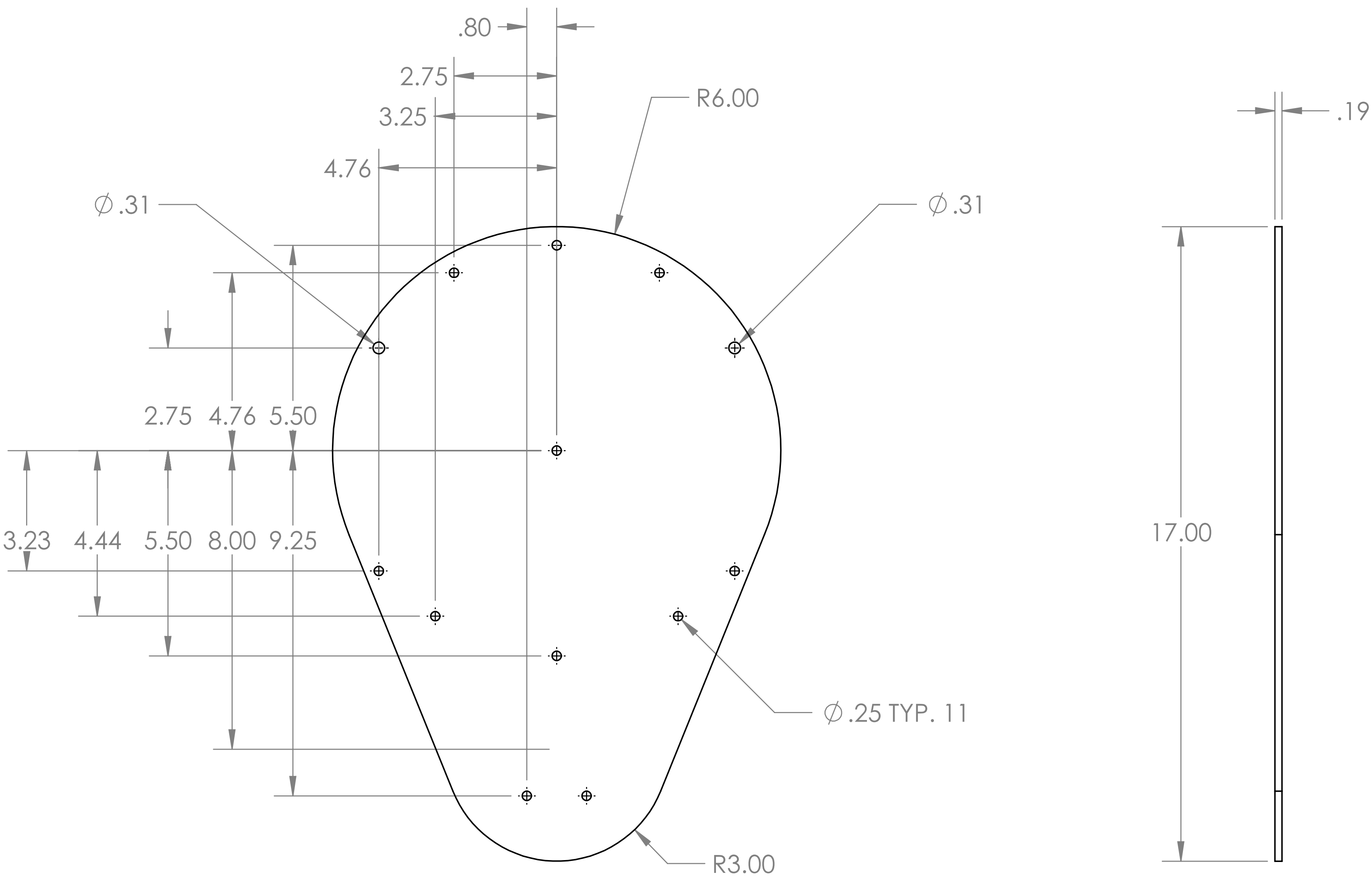
SCALE: 1:4

SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




**PROPRIETARY AND CONFIDENTIAL**



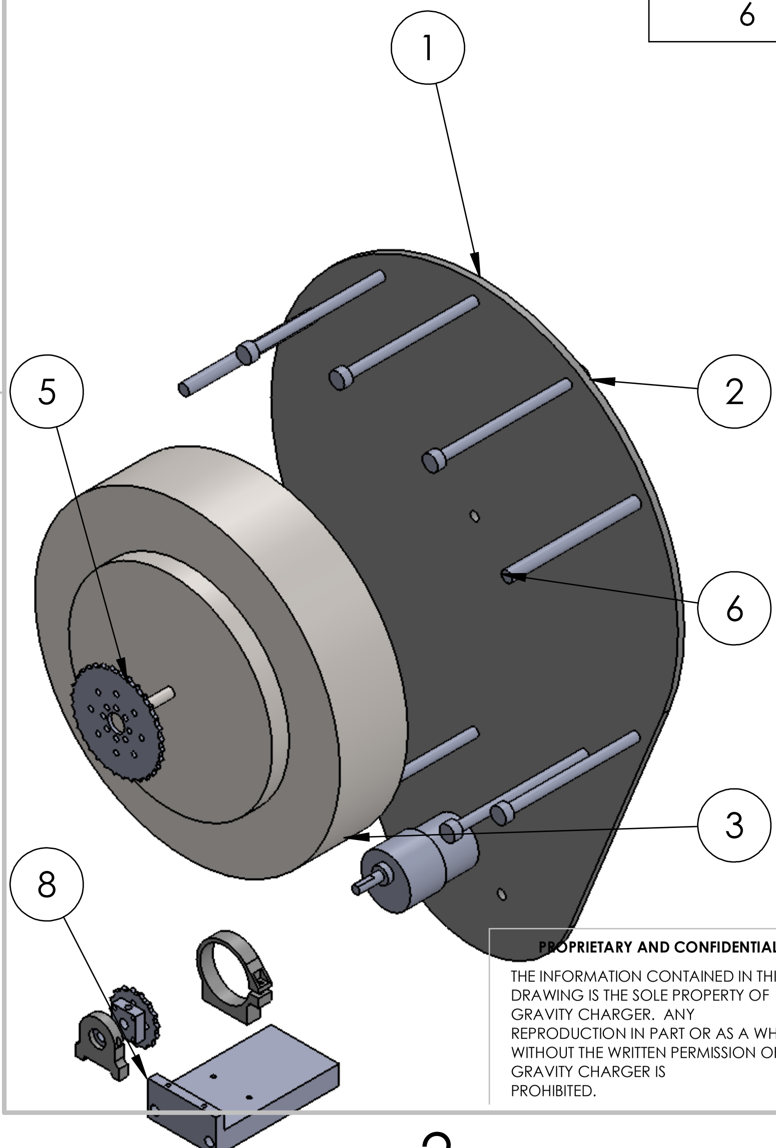
| UNLESS OTHERWISE SPECIFIED: | | NAME | DATE |
|---|---|---|---|
| | DRAWN | LL | 3/2/16 |
| DIMENSIONS ARE IN INCHES<br>TOLERANCES:<br>TWO PLACE DECIMAL ±0.01 | CHECKED | | |
| MATERIAL | COMMENTS: | | |
| DO NOT SCALE DRAWING | | | |

TITLE:

# Side Plate

| SIZE | DWG. NO. | REV |
|---|---|---|
| A | 3.3 | |
| SCALE: 1:4 | | SHEET 1 OF 1 |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 3.3 | Steel Side Plate | 2 |
| 2 | | 1/4" diam 4.5" lenght bolts | 8 |
| 3 | | Bike wheel | 1 |
| 8 | 3.1 | Motor mount | 1 |
| 5 | | 32 T sprocket | 1 |
| 6 | | dowel | 2 |






UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

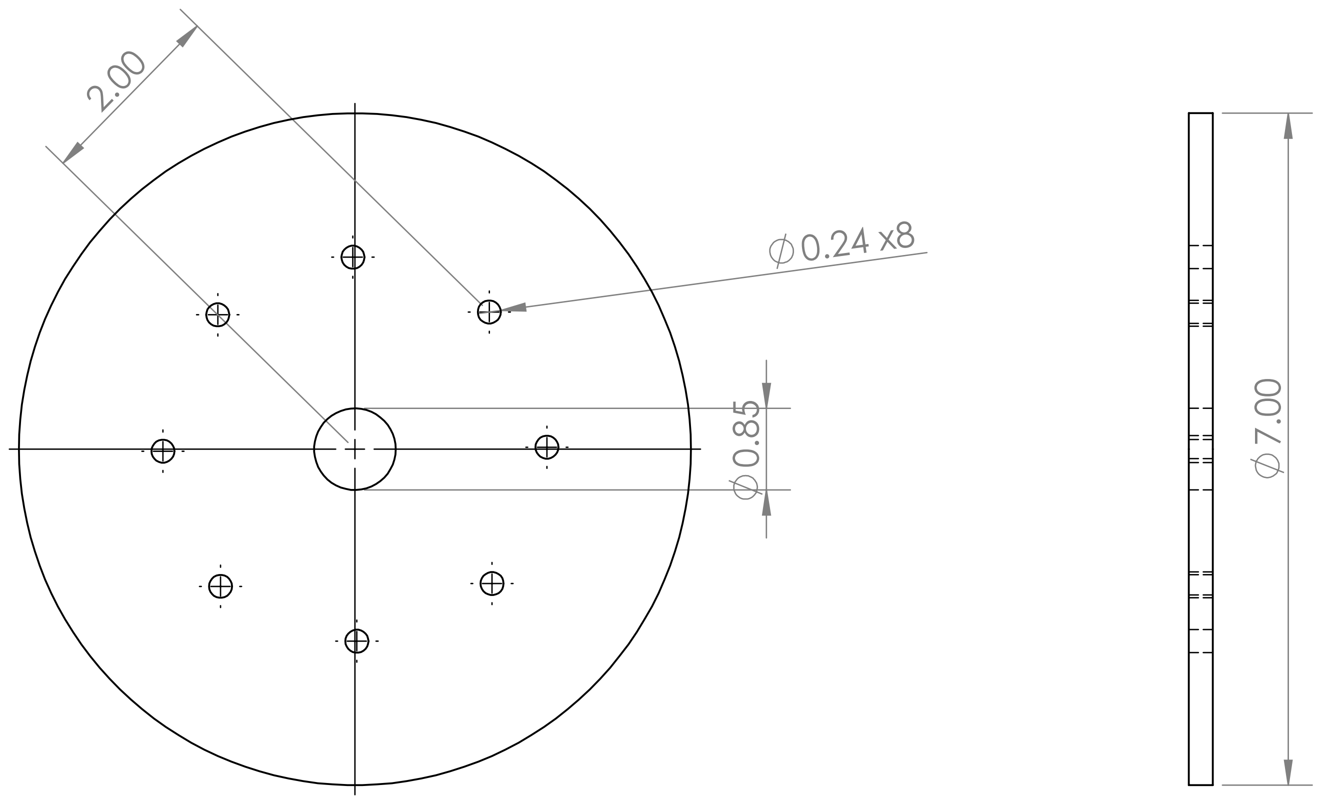
| | NAME | DATE |
|---|---|---|
| DRAWN | LL | 3/9/16 |
| CHECKED | | |

COMMENTS: The front plate has been removed in this exploded view for ease of inspection.

TITLE: 1st Iteration Assembly

SIZE A | DWG. NO. 3.4 | REV 2

SCALE: 1:33.3




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/15/16 |
| CHECKED | | |

COMMENTS:

TITLE: **Wheel Gaurd**

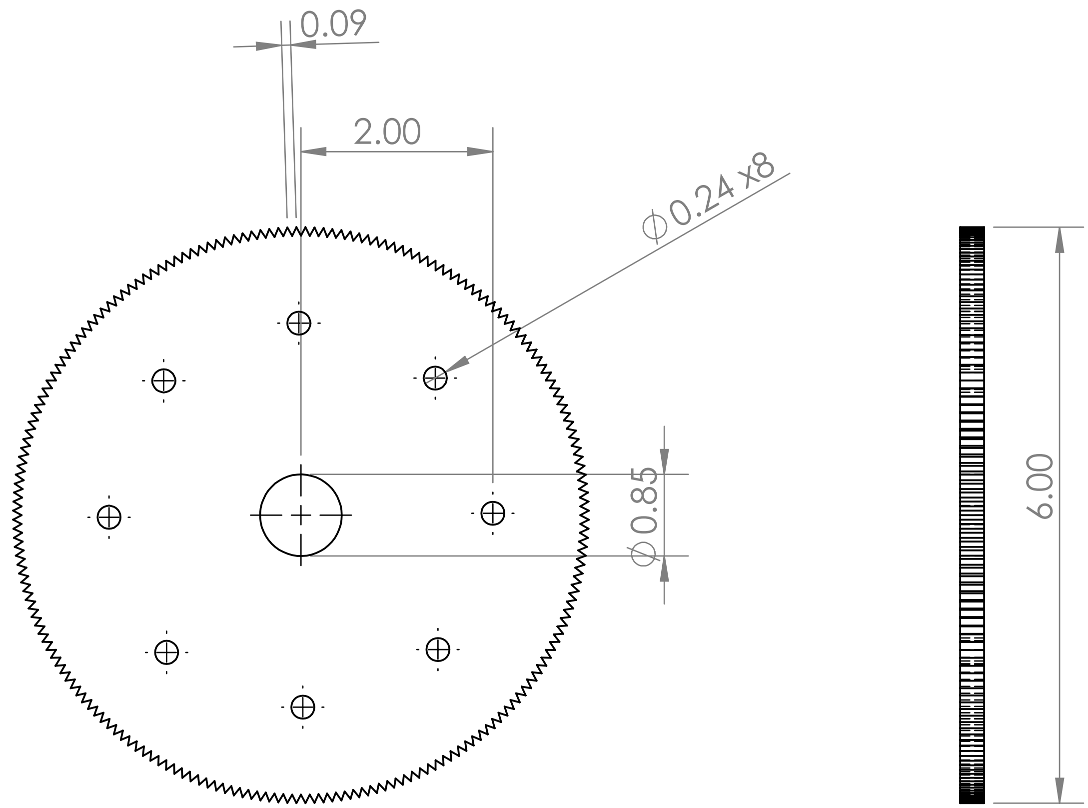
SIZE: **A** | DWG. NO. 4.1 | REV 2

SCALE: 1:33.3

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 3/15/16 |
| CHECKED | | |
| COMMENTS: | | |

TITLE:

# Wheel Grip

SIZE A | DWG. NO. 4.2 | REV 3

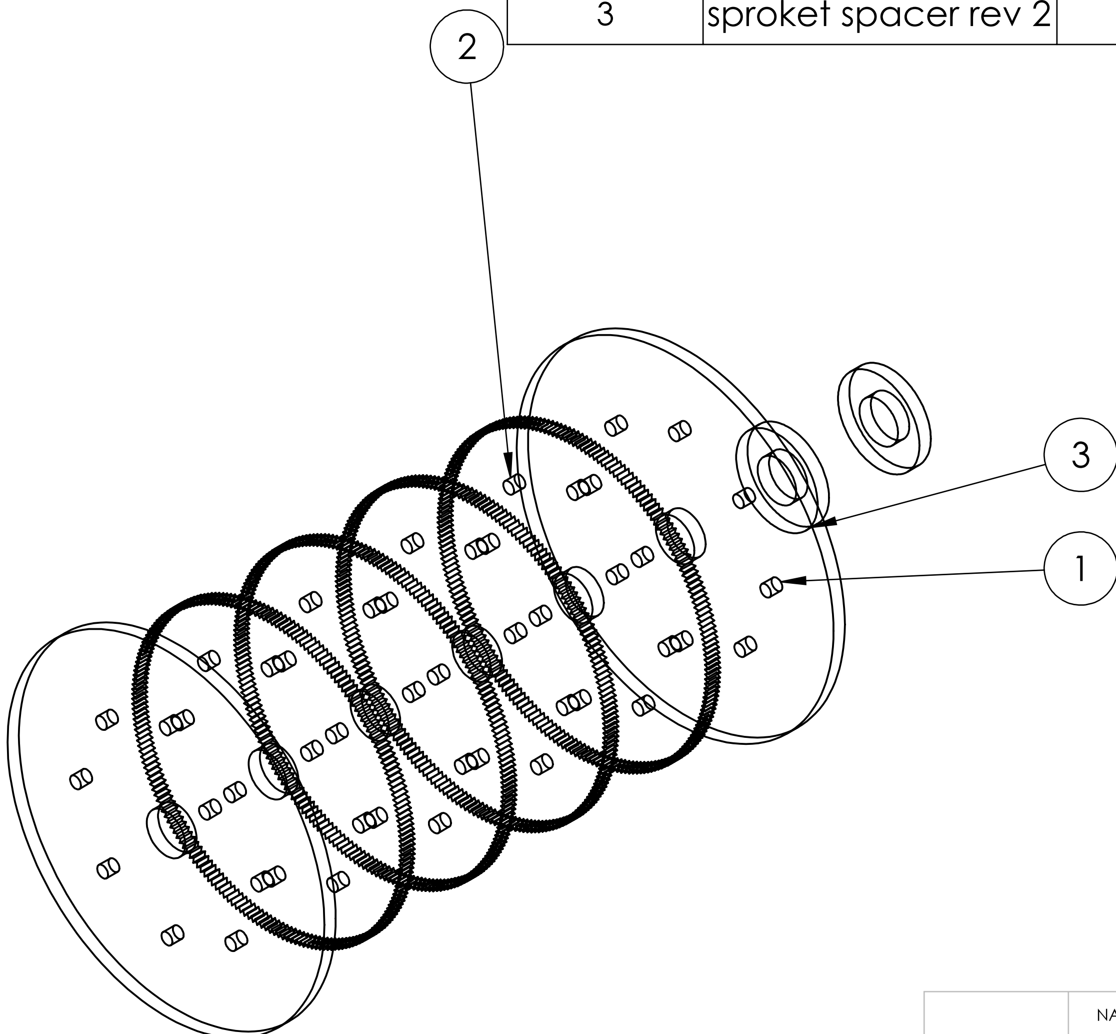
SCALE: 1:33.3

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 4.1 | Wheel gaurd | 2 |
| 2 | 4.2 | Wheel with grip | 4 |
| 3 | sproket spacer rev 2 | Sproket spacer | 2 |




PROPRIETARY AND CONFIDENTIAL

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DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

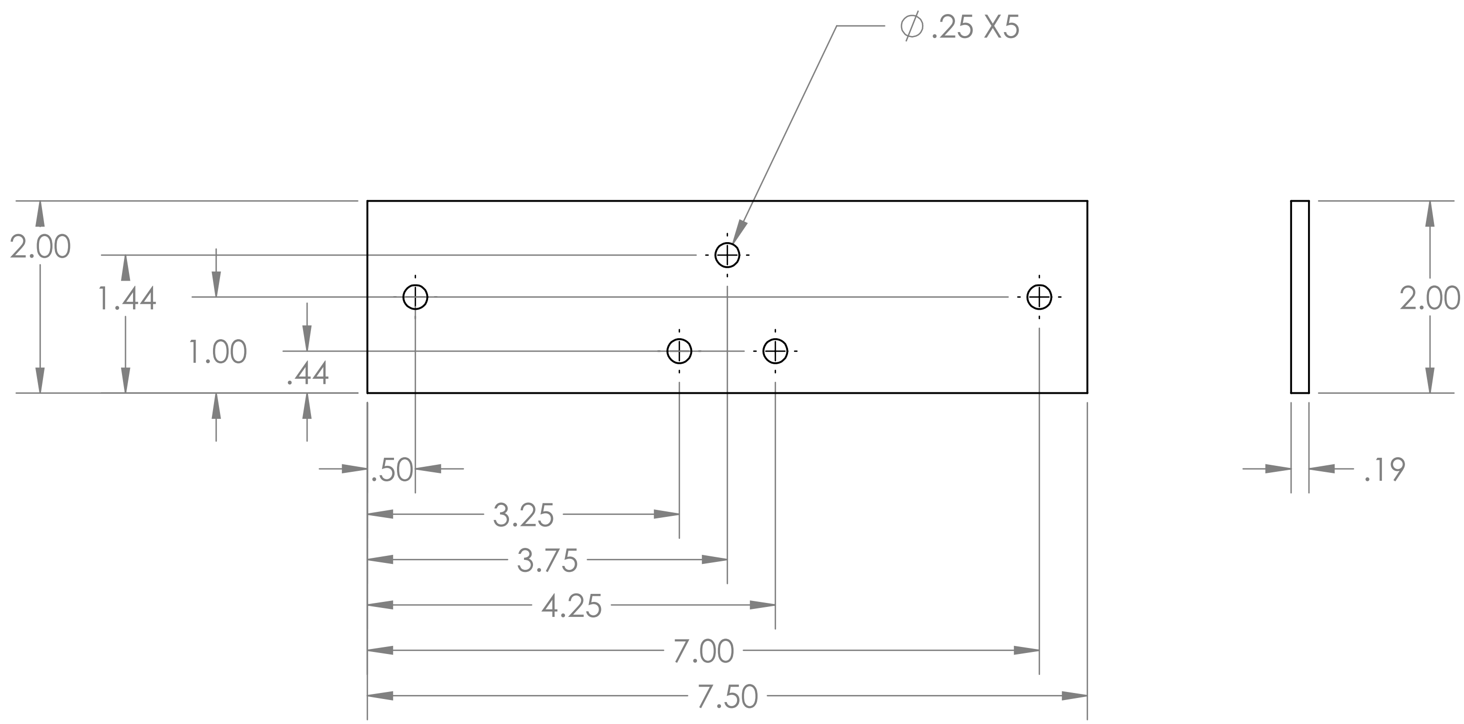
| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/15/16 |
| CHECKED | | |

COMMENTS:

TITLE: Lazer Cut Wheel Assembly

SIZE A | DWG. NO. 4.3 | REV 2

SCALE: 1:33.3




| | NAME | DATE |
|---|---|---|
| DRAWN | LL | 4/27/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# Cross Bar

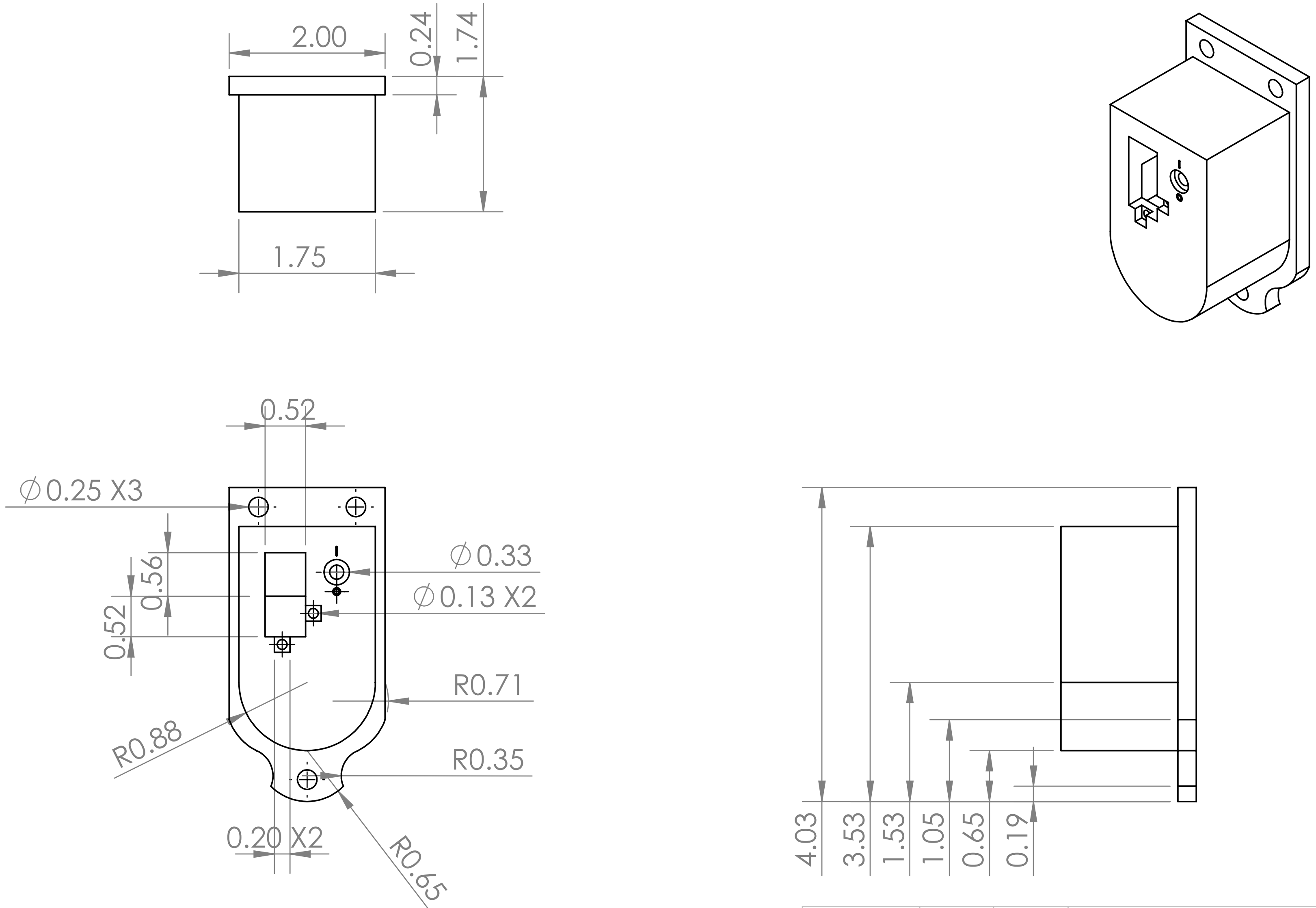
SIZE **A** DWG. NO. 5.1 REV

SCALE: 1:4 SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | WG | 4/28/16 |
| CHECKED | | |

COMMENTS: This is the inner plate that provides a hook for the hanging mass to supply torque to the proof of concept.

TITLE:

# Electronics Housing

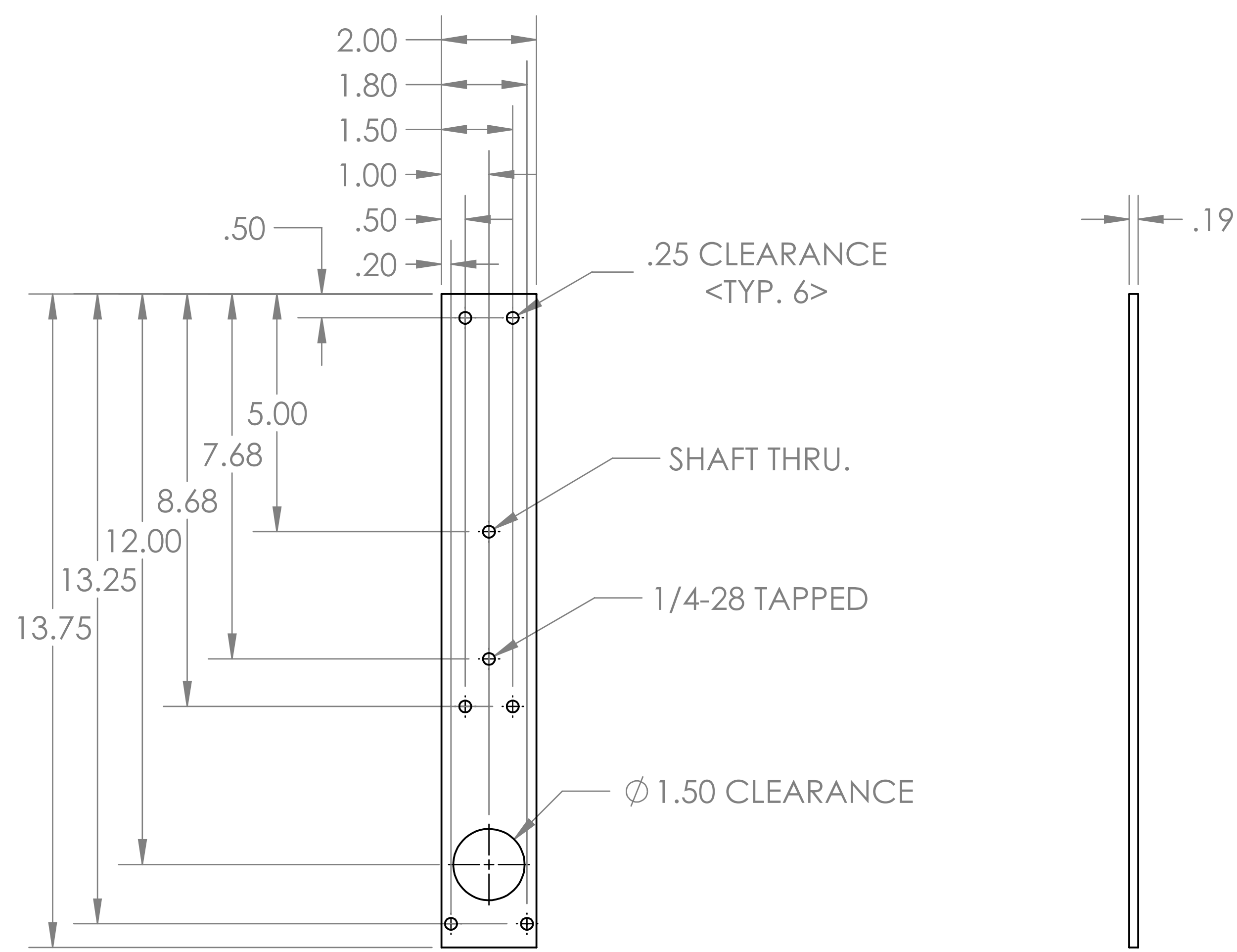
SIZE **A** | DWG. NO. 5.2 | REV

SCALE: 1:4 | SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




| | NAME | DATE |
|---|---|---|
| DRAWN | LL | 4/28/16 |
| CHECKED | | |

COMMENTS:

TITLE: Support Bar Motor Hole

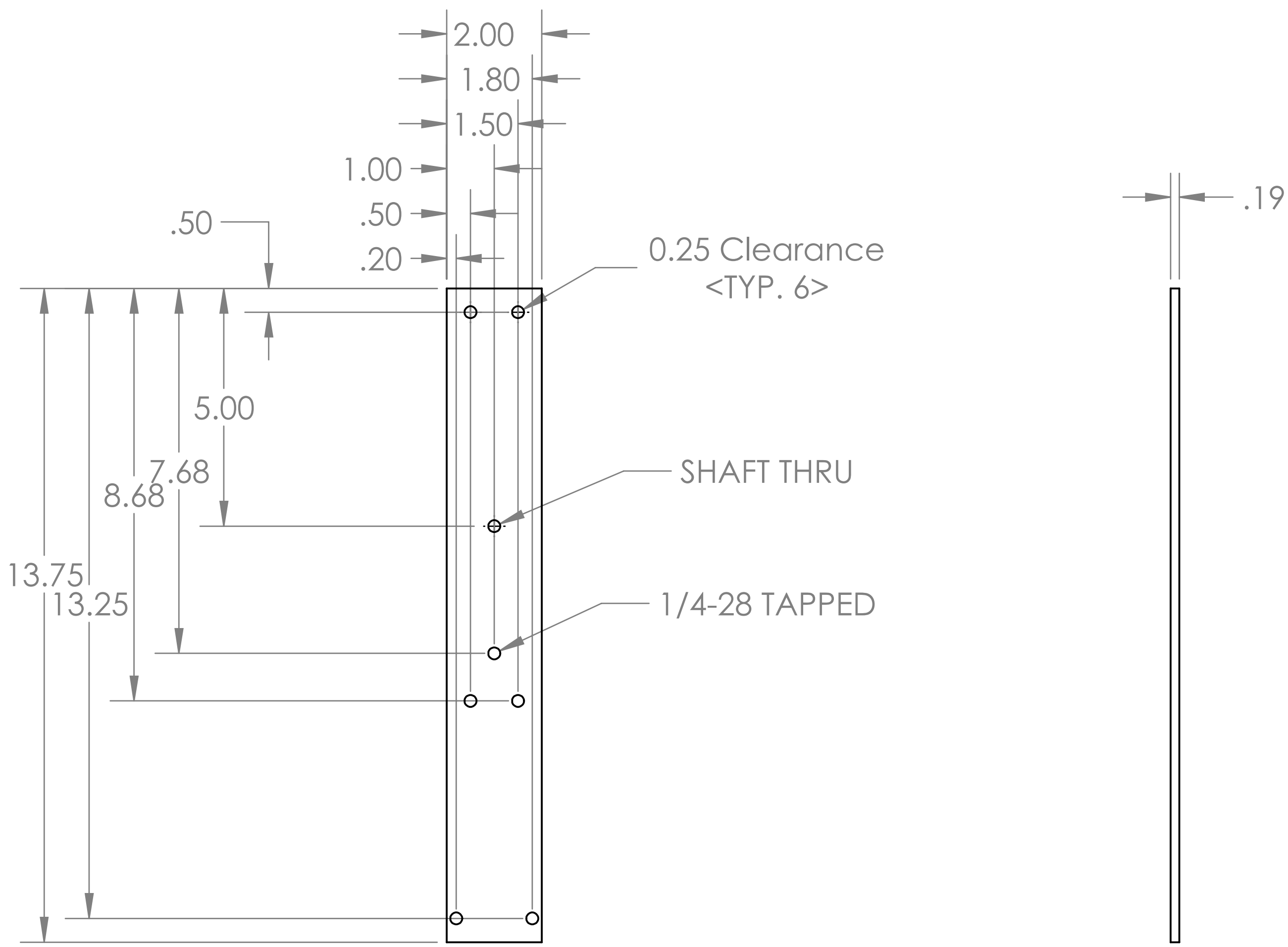
SIZE: A | DWG. NO. 5.3 | REV

SCALE: 1:4 | SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING




**PROPRIETARY AND CONFIDENTIAL**



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | LL | 4/28/16 |
| CHECKED | | |

COMMENTS:

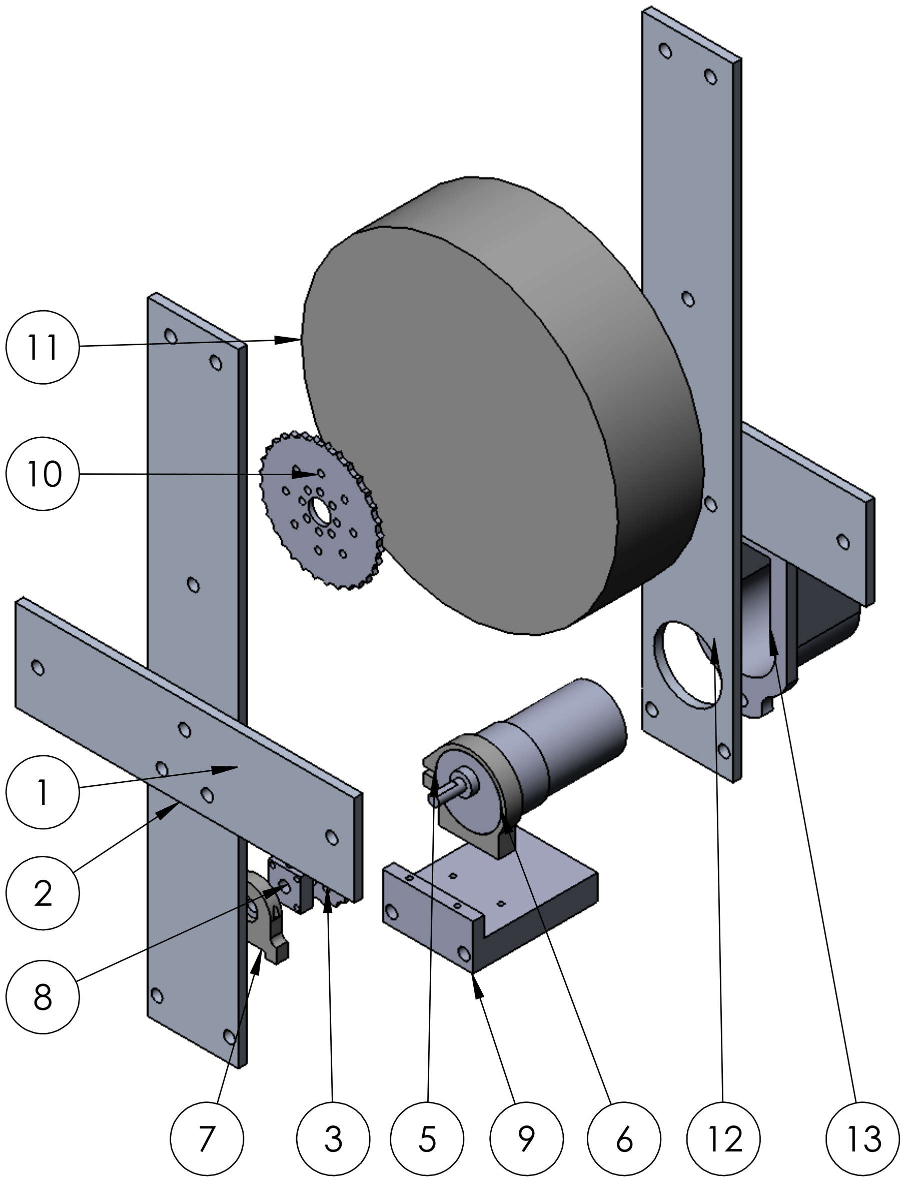
TITLE:

# Support Bar

| SIZE | DWG. NO. | REV |
|---|---|---|
| **A** | 5.4 | |

SCALE: 1:4

SHEET 1 OF 1




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 5.1 | Aluminum cross bar | 1 |
| 2 | 5.2 | Aluminum support | 2 |
| 3 | | 16T sprocket | 1 |
| 4 | | 6mm flanged bearing | 1 |
| 5 | | generator | 1 |
| 6 | | Motor Clamp | 1 |
| 7 | | Pillow Block | 1 |
| 8 | | set screw hub | 1 |
| 9 | | Support plate | 1 |
| 10 | | 32 T sprocket | 1 |
| 11 | | wheel sizer | 1 |
| 12 | | Support bar motor hole | 1 |
| 13 | | Electronics housing | 1 |
| 14 | | cover plate | 1 |



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | LL | 4/28/16 |
| CHECKED | | |

COMMENTS:

TITLE:

# 2nd Iteration

SIZE **A** | DWG. NO. 5.5 | REV

SCALE: 1:4 | SHEET 1 OF 1