Solar-Powered Fountain
Final Design Review (FDR)

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Team Solar Fountain

Andy Kim
bkim43@calpoly.edu

Jun Kim
hkim89@calpoly.edu

Kota Ozawa
ozawa@calpoly.edu

Joseph Ciolino
jgciolin@calpoly.edu

<u>Sponsor</u>

Dr. Gary Epstein

<u>Advisor</u>

Dr. Peter Schuster

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo, CA

Statement of Disclaimer:

Abstract:

This Final Design Review (FDR) document outlines the senior design project started by four mechanical engineering students from California Polytechnic State University, San Luis Obispo for Dr. Gary Epstein, a retired Cal Poly mathematics professor and avid gardener. This project entails creating a solar-powered fountain for his backyard that has two buckets, a top bucket that will pour into a bottom bucket and then finally into a basin. The goal is to create a fountain that includes the tipping motion of the buckets powered fully by photovoltaic panels. In order to tackle the bucket tipping motion, formulas were derived to create a computer simulated model that could aid the team during the prototyping phase. The team agreed that rapid prototyping and testing while tweaking parameters would be the best design process for the project. A pump will be powered by the photovoltaic panels and will produce the desired flow rate without draining too much power. Through the initial research, the team found that there are existing solar-powered fountains, which ensures that the solar panels can generate enough power to activate the water pump. The team has since purchased a solar panel and pump, tested them both, and determined that the solar panel will supply the necessary power. The team first developed a bucket-testing apparatus to determine the effect on the rotation by changing the axis of rotation and adding weight. A second bucket was added to the device to experiment with the spacing of the buckets in the vertical and horizontal directions. A full-scale structural prototype was developed to determine real spacings of the two buckets by allowing the team to adjust the locations of them. The structural prototype was tested with the solar panel and pump, and the buckets filled at a good flow rate. A final fountain design was decided on, along with a manufacturing plan and design verification plan. The fountain was assembled with minor design changes and tested to determine if the confirmation prototype met the specifications. This document outlines the background information, main objectives, concept designs, final design, manufacturing, design verification, project management, results, and recommendations for future work.

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1.0 Introduction:

Team Solar Fountain is made up of Andy Kim, Jun Kim, Kota Ozawa, and Joseph (Joey) Ciolino, who are Mechanical Engineering students from California Polytechnic State University. We took on this project from our sponsor, Dr. Epstein, who saw a fountain with a particular bucket tipping motion that is no longer available. The purpose of this project was to recreate that fountain but include more features, such as the ability to be self-sufficient with the addition of photovoltaic panels and an extra bucket to add complexity to the water-pouring motion. This project will involve a close study of the motion of water in the buckets to ensure that when the top bucket is filled, it will pour into the bottom bucket, and the bottom bucket will pour its contents into the basin when filled at least twice by the top bucket. The two buckets can be different on the inside, but must be the same apparent size, even though they must tip at different intervals. This document includes a Background section with information and research that affects our final product, an Objective section that outlines what the team will be doing for the sponsor, a Concept Design section that explains our alternatives, chosen concept, and Structural Prototype, a Final Design section that explains our final design, analysis, and expected cost, a Manufacturing section that details how we built our confirmation prototype, with what materials, and a final budget status, a Design Verification section that explains the testing procedures conducted, a Project Management section that provides an overview of the design process the team performed, and a Conclusion section that summarizes the FDR and recommendations for future work.

2.0 Background:

The background section aims to provide the reader with all the information the team has gathered through extensive literary, product, and patent research. The initial steps of research require us to clearly understand what to research. The first step to understanding the problem was to interview the sponsor. The second step was the research of patents and existing products with similar ideas. Since our Critical Design Review (CDR), our sponsor has given us a few more recommendations on the design of our final product.

2.1 Interview with Sponsor

We met with Dr. Epstein in person to better understand his requirements for the solar-powered fountain. Dr. Epstein saw a fountain with just one self-tipping bucket and decided he wanted to add one more bucket. Thus, he made a senior design project requiring two buckets that are the same exact size, but tip at different rates. This will leave watchers wondering how buckets of the same size tip at different rates. He also emphasized that the speed of the tipping motion should be slow enough for people to really appreciate the contraption. Table 1 lists the needs and wants we determined for our sponsor.

Table 1. Sponsor Needs and Wants Table

Needs	Wants
Solar-Powered	Aesthetic
Durable	Clear Water
Cheap	Low Maintenance
Easy Assembly	Quiet
Leak-Proof	Slow Tipping of Buckets
Stable	

After our Preliminary Design Review (PDR), Dr. Epstein asked for the bottom bucket to be rotated perpendicularly to the top bucket, or rotated 90 degrees. This change enhanced the aesthetic design and prevented premature tipping of the bottom bucket, a problem caused by the force of the dropped water from the top bucket. He also suggested the use of an Archimedes' screw to lift the water from the basin to the top bucket, but this idea was set aside due to cost and feasibility issues. After our CDR, Dr. Epstein asked us to implement rectangular buckets instead of cylindrical ones, a false "V"-shaped bottom for them, and to put the axis of rotation of the buckets in the exact center of the bucket height and width. The rectangular design improved the aesthetics of the fountain, made simulation water level calculations easier, and made the bearings easier to mount on the side of the buckets. The false bottom was used in order to raise the center of mass of the bucket without changing the overall size of them. This allowed us to customize the tipping points instead of changing the location of the axis of rotation as was previously planned. Dr. Epstein also recommended we use disk dampers on the rods to create the slow tipping motion desired. Unfortunately, the disk dampers available for this application were all too small in diameter for the size of the supporting rods needed to support the weight of the buckets and water.

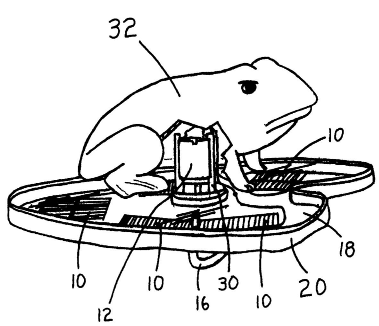
2.2 Existing Designs and Patent Research

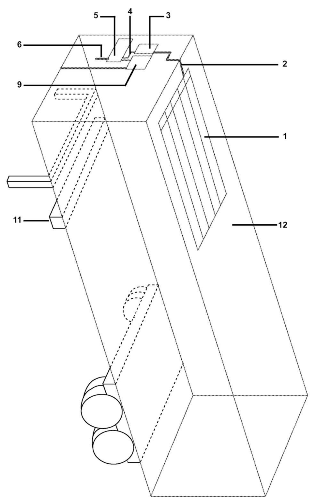
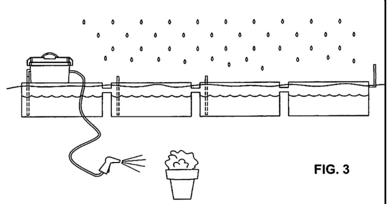
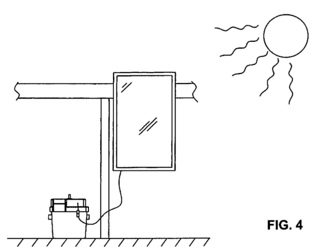
Our sponsor has already mentioned that fountains with the bucket-tipping motion already exist, but the fountain he initially saw is no longer available. Through patent and market research, we found that although there were designs with photovoltaic panels or buckets pouring, there has been no fountain that includes both the photovoltaic panels and two buckets. Case studies were looked into for relevant information on our solar-powered fountain.

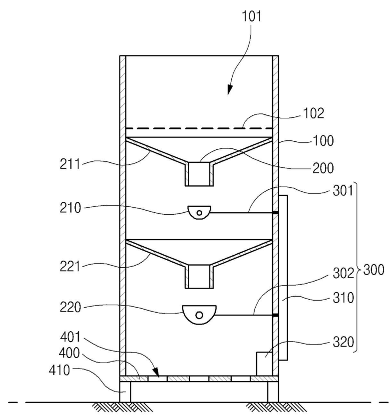
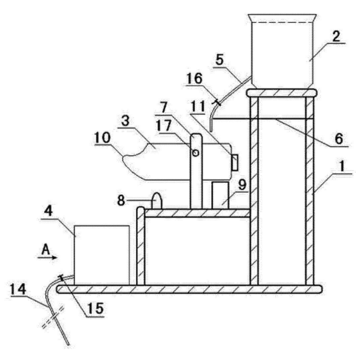
2.2.1 Patent Research

There are already multiple patents regarding self-sustaining systems powering small electrical applications. However, none of these designs, shown in Table 2, fulfill all of our sponsor's desires. The majority of the patent research focused on the technical functional components of our project.

Table 2. Patent Research

Patent	Picture	Description
Solar Powered Water Fountain (US6179218B1)		This fountain was patented to create a stand-alone fountain that can be placed in bird baths, pools, and ponds to serve as an aesthetic piece which does not need an external water or electricity source. It aims to be aesthetically-pleasing, cheap, and able to operate in wet environments. The main features of this fountain include: at least one solar cell, a direct-current motor, and a submersible sealless pump all contained on a float (Gates).

Patent	Picture	Description
Method for Generating Electricity from Solar Panels (US9315088B2)		This method was patented to create a standalone trailer that could power electrical systems, specifically those handling air, off of just photovoltaic panels. The main goal of this patent was to create an air conditioning system that could be powered by photovoltaic panels. Essentially, we are creating the same system where we run a motor off of electricity generated from the photovoltaic panels. The electrical diagrams from the patent could be implemented into our electrical system (Reichart).
Portable, Solar Rechargeable Water Pumping System (US20100303654A1)	 FIG. 3  FIG. 4	This is a design for a solar rechargeable water pump with a filter. The water pump is 12 Volts and run by a rechargeable 12 Volt battery. The 12 Volt battery is recharged with a 5 Watt or 15 Watt solar panel. This design could be how we run our pump, where the battery could act as a nighttime power source (Petersen).

Patent	Picture	Description
Multi-tipping Bucket Rain Recorder (KR101146330B1)		This rain recorder is built with two buckets that empty themselves at a certain water level. The top bucket pours out its water to the bottom bucket and through a tipping motion. From the tipping motion, an electronic signal is sent to the collection and the computer measures the signals over the span of time to measure the amount of rain. This design is very similar to our fountain set up, which will have two self-tipping buckets, one on top of the other (“KR101146330B1”).
Automatic Plant Watering System (CN203279604U)		This construction is unique because of the long bucket shape. The buckets center of mass is past the axis of rotation, yet the bucket manages to stay upright because of its counter weight. Also, the water is poured behind the axis of rotation making it harder for the bucket to tip. However, the range of motion does not match the requirements of the sponsor (“CN203279604U”).

2.2.2 Existing Designs

Of the researched existing designs shown below, none met all of the requirements of our sponsor, but each provided useful information in our design process.

Figure 1. The Bucket Fountain from New Zealand (Kaushik)

The Bucket Fountain in Wellington, New Zealand is an iconic sculpture that utilizes multiple buckets which fill and pour their contents into the buckets and pool below. However, this fountain seems to be designed such that the water pours onto walking pedestrians for an entertaining effect rather than into the buckets below. It is also not powered by solar panels and has a unique bucket shape with an elongated spout (Kaushik).

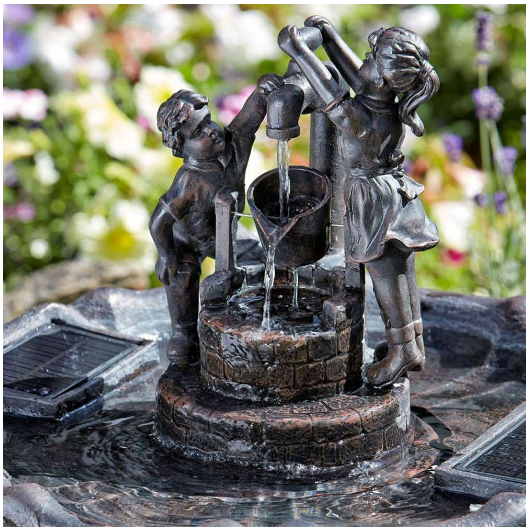


Figure 2. Powerbee Solar Fountain (Powerbee)

Powerbee is a retailer for all sorts of solar-powered appliances. One of their fountains has a girl pouring water into a pail, which tips after being filled. This design implements the same ideas as our solar fountain; however, it lacks complexity, and the tipping motion is so fast it is difficult to appreciate. It is currently being sold for $148.03 (Powerbee).

Figure 3. Solatec Solar Fountain (Solatec)

Solatec is a company that produces an affordable solar-powered water fountain that is placed in existing pools of water. It is essentially a floating fountain pump that is surrounded by a circular array of solar panels. This product is $10.94 on Amazon and requires one lithium-ion battery. Unlike our product, it is not a stand-alone piece and requires a birdbath, pool, or pond for it to be placed in (Solatec).

Figure 4. Florence Art Company Fountain

Florence Art Company does not have any solar-powered fountains, but the figure above was given to the team by the sponsor as an inspiration for the bucket-tipping motion. Our sponsor saw this fountain a few years ago at an Ace hardware store but this exact model is currently not available due to lack of parts from China. Our team contacted the manufacturing company but there is no available information such as cost or water flow.

Figure 5. Watering Can and Bucket-Tipping Feature ("waterfeaturesuk.com")

Kaemingk sells a fountain called the "Watering Can and Bucket Tipping Water Feature." This fountain sells for $103, is water resistant, and made from a durable resin. It also comes with a 100 liters per hour pump with a 10 meter cable. The dimensions of this fountain are 12.7" x 20.8" x 18.1" ("waterfeaturesuk.com").

2.2.3 Journal Article Research

There are multiple journal articles regarding solar-powered fountains and the motion of a tipping bucket. This section summarizes the research done on previously mentioned topics.

1. **Solar Powered Decorative Fountain**
   This journal article demonstrates the simplicity of working with solar panels, as the project was aimed towards non-engineering majors. The fact that these people with zero background knowledge were able to build a decorative solar powered fountain from scratch reassures the team that the solar panel will be enough to power a fountain (Camille G. and Karl M.).

2. **Solar Powered Floating Water Fountain**
   This journal article demonstrates the viability of solar panels to power demanding motors. The large scale building showcases the amount of energy a solar panel can provide. However this project was more of an electrical project and does not include the specific dynamics for our project (Chapman H.).

3. **Research on a syphon or funnel attachment and the effects of the syphon choice on the buckets ability to tip**
   This journal article researches the effect of having a syphon or funnel on the spout of the water. The students performed field tests with many different types of funnels, and performed statistical analysis in order to get significant meaning out of the data. The buckets would demonstrate different behaviors depending on the syphon used. This could

be used in order to compare our models, and decide on the method of delivering water to the buckets (Overgaard S.).

4. **Archimedes Screw Design**
   This journal article aims to clarify the advantages and disadvantages of an ancient method of displacing water in the Archimedes' screw design. This could potentially be a solution to the function of raising water (Waters S.).

5. **Optimum Solar Panel Angle**
   This journal article provides test data of solar panels set at different angles at different sun intensity. The data from this journal article could be implemented within our fountain design, to calculate the optimum angle for the residents of California (Ekadewi A.).

2.3 Technical Information

For this project we will focus on four main components: the photovoltaic panel, the pump, the bucket-tipping motion, and the overall aesthetics. Based on the desired flow rate of the system as well as the size of the buckets and fountain, we calculated the required power of the pump and the size of the photovoltaic panels.

Photovoltaic cells produce direct current electricity from sunlight. Most of the solar panels on the markets are made out of silicon but there are more developments with different types of materials. A single junction silicon cell can produce a maximum open circuit voltage of 0.6 volts. The solar panels can produce the most amount of energy when the sunlight is perpendicular with the solar panels. It is advantageous for the fountain to have the solar panel facing towards the sun at an angle according to the sun's location. The calculations of the optimal solar panel size, cost, and power output are included in Appendix C. The motor used as reference is a "Shysky Tech" pump with nearly 30 feet of head lift requiring 54 watts of power (Shysky). This far exceeds our lift requirement. There were multiple solar panels with 100 watt output capabilities at affordable prices around $100 each (Dawn). Through these calculations, the team is confident that this solar panel and motor combination will work in all moderately sunny states.

3.0 Objectives:

This section presents our problem and defines the scope of this design project. Engineering specifications were produced from the sponsor's needs and wants.

3.1 Problem Statement

Dr. Epstein is an avid outdoor gardener who wants a nice conversation piece to place in his backyard. He wants a solar-powered fountain with two buckets which fill and pour at different rates. Although solar-powered fountains already exist, none of them include a self-tipping bucket setup. The fountain should also include a pump that can produce the desired flow rate without draining too much power.

3.2 Boundary Diagram

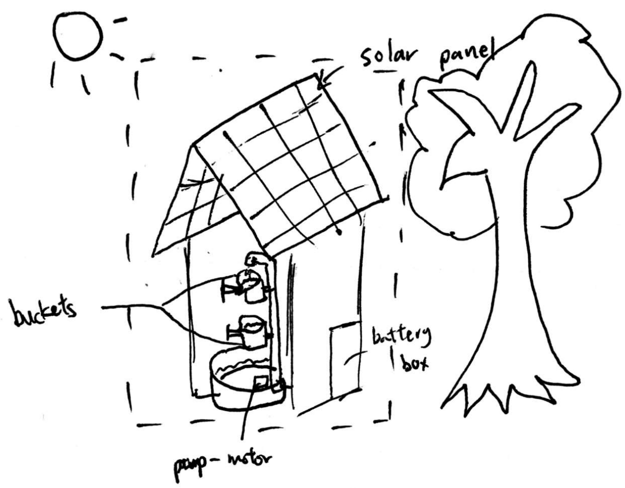


Figure 6. Boundary Diagram Illustrating Scope of Design

Figure 6 illustrates the scope of design of this project and the relationships between the subsystems and surroundings. The external references that affect our design decisions are the location of the sun and the ground condition for the fountain. The sun is directly related to the angle and position the solar panels are set up in because solar panels produce the most amount of energy when the sun rays are in contact with the panel perpendicularly. The condition of the ground also impacts our project because the fountain needs solid ground to stand firm and not tilt over when it is introduced to strong winds. As for evaporation or possible loss of water from the fountain, the sponsor had mentioned that a simple line on the inside wall of the basin would suffice to communicate with the owner that the water volume is low. Because a black pond liner has been used to line the basin, a line would not be visible. Instead, Dr. Epstein has been advised to always keep the basin at least half full of water, which ensures the pump is completely submerged.

3.3 Quality Function Deployment

Quality Function Deployment (QFD) is a process that helps transform the voice of the customer into detailed engineering specifications. It uses a table called a House of Quality to compare the different specifications to the expected customers and what is important to them. The House of Quality for our fountain can be seen in Appendix A. Listing out the needs and wants of our sponsor in the House of Quality allowed us to easily produce a list of how we could quantitatively measure the achieving of those needs and wants. This helped develop detailed engineering specifications which we will test to see if the measurements are satisfactory.

3.4 Engineering Specifications

The Engineering Specifications Table shown below documents the evaluation criteria for our project. Each specification has its own requirements and target value, and it displays the level of risk regarding the specification. It is derived from the QFD House of Quality in Appendix A.

The risk level for each specification is rated at low, medium, or high. The risk defines how likely it will be out of range of the tolerance. The compliance methods describe how we will be taking the measurements and are analysis (A), test (T), and inspection (I). We rated the number of parts and the cost as high risk because these specifications contain the most customer requirements. Cost depends on the solar-powered aspect, durability, and aesthetics of the fountain, all of which can easily drive up the overall cost. The number of parts depends on the durability, ease of maintenance, and ease of assembly. This was rated at high risk because it can not only increase the overall cost of the fountain, but also affect the build time and complexity of the fountain.

Table 3. Engineering Specifications

Spec. #	Specifications	Customer Requirements	Target Value	Tolerance	Risk	Compliance
1	Time to tip	Slow-tipping	3sec	±1sec	M	A, T
2	Flow Rate	Slow-tipping, quiet	1 gpm	±0.5gpm	M	A, T
3	Cost	Solar-powered, durable, cheap, aesthetics	<$1000	+$200	H	I
4	Number of Parts	Durable, cheap, ease of assembly, low maintenance	<15	+3	H	I
5	Force Required to Tip Over Fountain	Stable	1.6 lbf	+0.7lbf	M	A, T
6	Noise Level	Quiet	50db	+10db	L	T, I
7	Survey Results (out of 10)	Aesthetics, quiet	>6	-1	M	I
8	Rate of Water Lost	Durable, leakproof	<0.1gph	+0.05gph	L	A, T
9	Power Consumption	Solar powered	80Watt/m^2	±10Watt/m^2	M	A, T

While some of the engineering specifications were specifically provided by our sponsor, the others are common desirable features for backyard fountain owners. The following list will describe each engineering specification in Table 3 as well as how we will evaluate each:

1. The slow-tipping motion of the buckets will be measured by the time it takes for the bucket to pour out its contents as well as the flow rate of the water. This can be done with a stopwatch to time the amount of time it takes for each bucket to tip.
2. The flow rate of the fountain will be measured by timing how long it takes a 1 gallon container to fill with water using a stopwatch.
3. Cost is determined by the size of the photovoltaic panels and the amount and quality of materials that go into building the fountain. The cost will be calculated by adding up the cost of each component that goes into producing the fountain.
4. The number of parts will be counted.
5. Although we want to make the fountain as stable as possible, we are also looking to reduce the number of parts to manufacture the fountain to make it cheap, easy to assemble, and have it require very little maintenance. The stability of the fountain will be measured by the force required to knock over the fountain, which should mimic a strong gust of wind.
6. The noise level of the fountain will be measured by a decibel meter. Depending on how quiet our sponsor wants the fountain, we will attempt to adjust the flow rate of the pump.
7. The aesthetics of the fountain will be determined mostly by our sponsor's opinion and general survey results. The public has different opinions on what makes a fountain look interesting and aesthetic, so a simple survey will determine which design direction we will take.
8. The rate of water lost is measured to see if any areas are a source of potential leakage or excessive splashing. This can be evaluated by measuring the volume of water before and after a period of time.
9. The power consumption is fully dependent on the pump and solar panels we use. We will calculate the amount of power we need to produce the lift that the fountain will require to produce a flow rate at the maximum height of the fountain.

4.0 Concept Design:

This section outlines the concept development process and the design direction. We discuss how we developed and chose our top concept design as well as an explanation of how it will be manufactured, how it will function, and a description of tests and calculations that demonstrate that the design will satisfy the specifications. Current risks, challenges, and unknowns with our design are also outlined. Since our PDR, a Structural Prototype section has been added to detail the experiments completed with this device, and the challenges section was updated.

4.1 Development Process

To develop, evaluate, and select our alternative concept designs, the team had multiple brainwriting sessions to generate numerous ideas. Brainwriting sessions are rounds of a set time interval where team members write ideas on a paper, trade it with another member, and continue writing on it. This strategy aims to trigger creative ideas from each group members' ideas, creating a domino effect of ideas. Those ideas were then refined using decision matrix analysis. In a concept modeling session, each team member modeled their top five fountain concepts using cardboard, dixie cups, popsicle sticks, and other readily-available materials. This process allowed us to validate any ideas that the team had, and possibly generate new ones. We then generated a Pugh matrix for each function to filter concept ideas. Pugh matrices are design matrices that focus on one function, and scores each alternative of the function against a datum function feature. Three of the best function designs from each Pugh matrix were then put into a morphological matrix to generate randomized design concept ideas. A portion of our brainstorming session, the Pugh matrices and the morphological matrix are shown in Appendix B. These concepts were scored in a weighted decision matrix to give us a general idea for which design direction to take.

4.2 Concepts

The concept designs we generated from ideation sessions are presented in this section.

4.2.1 Concept 1

The design in Figure 7 utilizes clear material to showcase the motion of water through the pumps and buckets. The clear material also removes any structural distractions and allows the user to focus their attention on the water. This concept utilizes three small spouts instead of one large one to increase the streams of flow for a visual effect. The buckets are held in place by a "U" shaped hinge that reduces the number of stands that must be installed to hold each bucket.

Figure 7. Natural Design with Clear Pillars and Spouts

4.2.2 Concept 2

The design in Figure 8 contains the solar panel, buckets, and the basin in an easy assembly. The ease of assembly comes from the simple design and structural integrity of the fountain, as it can be found in many other competitor's fountains. The pump and spout will be hidden along the stands of the solar panel to improve the aesthetics of the fountain. The solar panel would be actuated so it rotates to stay perpendicular to the sun during the day for maximum absorption.

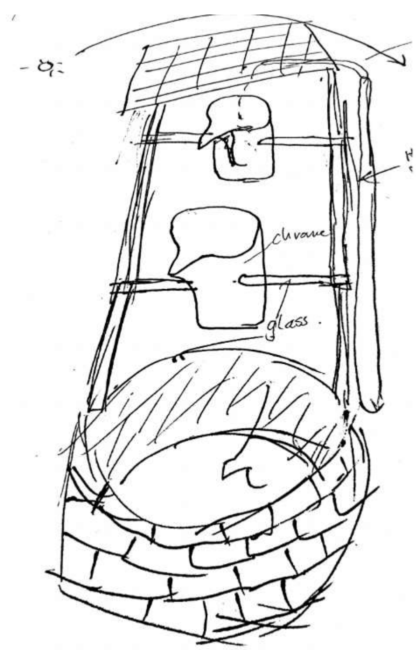


Figure 8. Simple Well Design

4.2.3 Concept 3

The design in Figure 9 is a design similar to the one in Figure 8, which has the basic structure and basin with a moving solar panel and the buckets on top of each other. Most of the structure is made of wood, which will reduce overall cost, and the stands are not connected to the basin. The water pours onto a flower-like feature that disperses the water into multiple streams for improved aesthetic value.

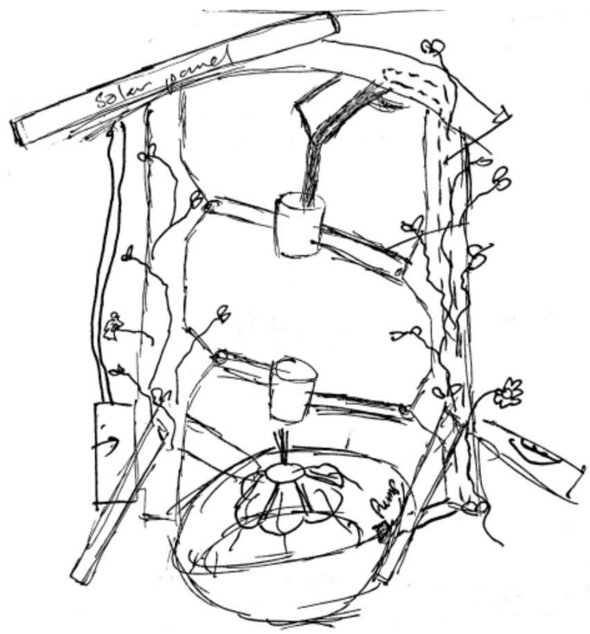


Figure 9. Wooden Frame Design

4.2.4 Concept 4

The design in Figure 10 is similar to the others, except that the spout has a horizontal opening to provide a waterfall-like look for the water leaving the spout. A waterfall look would be a unique, aesthetically-pleasing design. Because the water stream is already geometric, it would look better if all the other components were geometric shapes with sharp edges as well. This would be an extremely unique fountain that would attract a lot of attention.

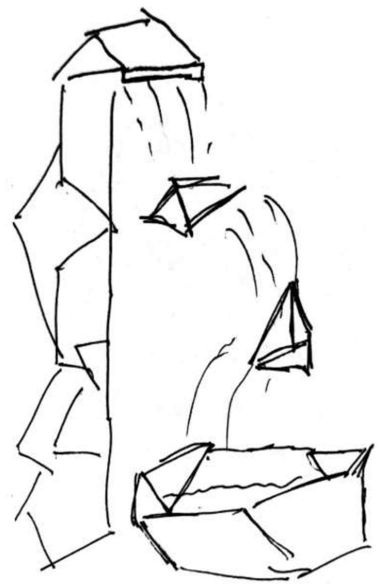


Figure 10. Modern Geometric Design

4.2.5 Concept 5

The design in Figure 11 has horizontal supports instead of vertical supports like the other designs. The pump is located at the base of the spout and pumps water to the top. The solar panel would be placed in the basin, hiding the fact that the fountain is solar. The buckets would be supported by arms connecting to the spout support.

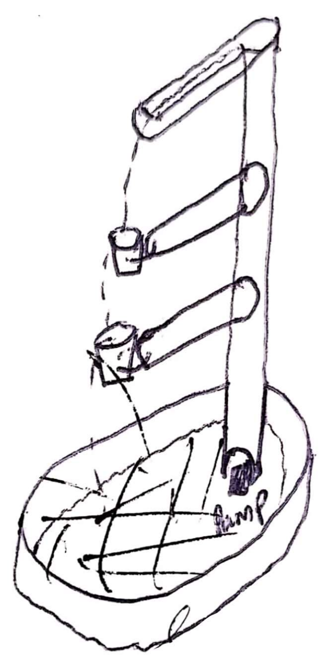


Figure 11. Tower-like Spout and Buckets Design

4.2.6 Concept Selection

Sketching these concepts allowed us to generate more ideas in the process and choose certain elements that we liked from each concept. Elements from each concept were chosen for each function and were put into Pugh matrices to select the top ideas. Pugh matrices for the functions “moving water”, “solar panels”, “holding buckets”, and “damping” are shown in Appendix B.

Using the top ideas from each Pugh matrix, a morphological matrix was created in order to develop possible combinations of all the functions. Appendix B also contains the morphological matrix, which aims to create multiple randomized conceptual fountains. These mixed combinations formulated several good, standalone fountain design alternatives which were put into the weighted decision matrix for analysis.

From the top five possible combinations determined from the morphological matrix, a weighted decision matrix was created to decide on the best combination. Each concept was judged on weighted criteria and the concept with the highest score would be the best design. The top five concepts are shown below in a list, and Table 4 shows our final weighted decision matrix.

1. Concept I: spout, actuation, poke rod, weight
2. Concept II: funnel, mirror, welded side, weight
3. Concept III: spout, actuation, poke rod, rubber bushing
4. Concept IV: funnel, actuation, welded side, weight
5. Concept V: funnel, tilt action, poke rod, weight

Table 4. Final Weighted Decision Matrix with 5 Concepts from Morphological Table

Criteria	Weight	I		II		III		IV		V	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Cost	5	5	25	3	15	5	25	4	20	2	10
Low Maintenance	4	4	16	2	8	4	16	3	12	3	12
Slow Tipping	3	3	9	3	9	3	6	3	9	5	15
Durability	3	4	12	4	12	4	12	3	9	4	12
Aesthetics	5	4	20	5	25	4	20	4	20	4	20
Ease of Assembly	2	4	8	3	6	3	6	2	4	4	8
Total			90		75		85		74		77

To select our design direction from these top concepts, we took the needs and wants from our Quality Function Development and scored the concepts against those same criteria. While most of them did score relatively well, Concept I with the normal spout for water flow, actuation method for the solar panel, a rod poked through the bucket, and weights as the damping method produced a total score of 90. This concept scored the highest because it is the cheapest and simplest to manufacture while maintaining durability and aesthetics.

4.3 Chosen Concept

This section presents our chosen concept design from our weighted decision matrix. A concept prototype was constructed and tested, and once specific parameters were analyzed, a CAD model of the fountain was created. The prototype is shown in Figure 12 and Appendix C.

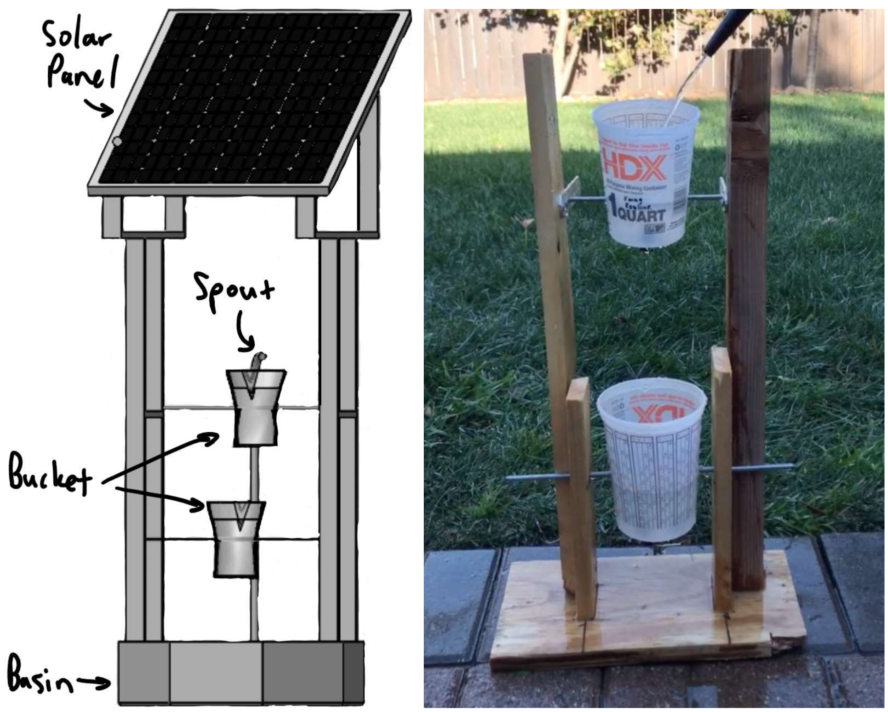


Figure 12. Chosen Concept CAD Model and Concept Prototype

Through different brainstorming sessions and the use of decision matrices, the team came up with a final concept model with basic functionality and slight aesthetic considerations. The fountain modelled in Figure 12 is around 70 inches tall and 36 inches wide. These dimensions are derived mainly from the solar panel and the basin. The solar panel must sit high enough to avoid obstructing the watcher's view and to avoid casting a shadow on the pouring water. This is because sunlit water glistens and is more aesthetically-pleasing to look at than water under shadows. The solar panel sits at a fixed angle calculated using latitude, so that the solar panel can absorb enough power to activate the motor. The pump is directly wired to the solar panel, so that at night, the fountain turns off, and on a cloudy day, the solar panel will absorb less energy and the pump will perform accordingly.

The pump will send the water to the bucket via a tube and as the top bucket fills up with water, it will tip forward to discard the water when the water level passes the calculated axis of rotation of the bucket. The bottom bucket works the same way, and it discards the water back to the base of the fountain, and the water continuously circulates. Currently, we have decided to use wood for the basin and structure of the second prototype, but expect to use material that is both aesthetically-pleasing and sturdy in the final product. The team has completed working on finding the axis of rotation of the two bucket system and the concept prototype proved that the calculations were accurate. The team also worked on the damping portion of the bucket system, solar panel testing, and the electrical system while continuing to build concept prototypes to further perfect the solar fountain.

4.4 Structural Prototype

The purpose of our Structural Prototype was to determine the ideal spacing of the two buckets in the vertical and horizontal directions, while also verifying that our bucket assembly would work in the way it was designed. The device, shown in Figure 13, would allow us to move the two buckets vertically with ease due to the holes drilled at multiple locations. The top bucket holder could also be moved horizontally closer to or further from the bottom bucket by moving the beams to the desired location. All beams were to be made with wood 2x4's.

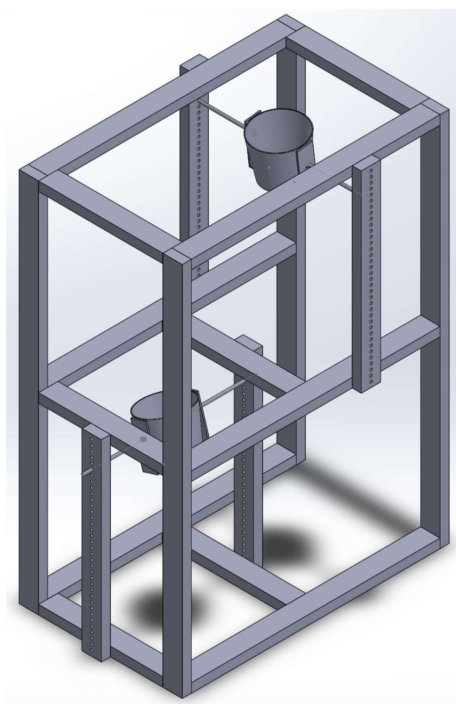


Figure 13. Structural Prototype CAD Model

In Figure 14, a close up of the bucket assembly is shown, where the bucket would be supported on both ends by securing the rods with snap rings. This assembly was designed to allow us to easily change the location of the rods, thereby changing the axis of rotation and the motion of the bucket.

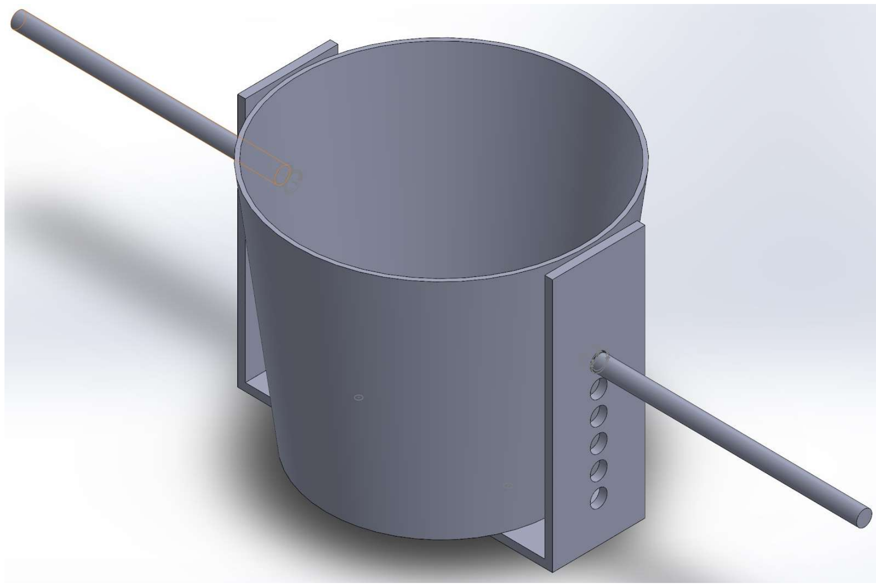


Figure 14. Structural Prototype Bucket Assembly CAD Model

While building the Structural Prototype, we decided that having the buckets supported on only one side would be much more aesthetically-pleasing, so we welded a rod to a square plate, drilled holes in the plate, and secured to the bucket with screws as shown in Figure 15.

Figure 15. Structural Prototype Bucket Assembly

Each rod was supported by two ball bearings press-fit into two 2x4's. The two pieces of wood were connected to each other and allowed the bucket to move vertically and horizontally by moving the bearings into different vertical holes or resecuring the wood pieces at different horizontal locations. A CAD model of the finished Structural Prototype after it was built is shown in Figure 16.

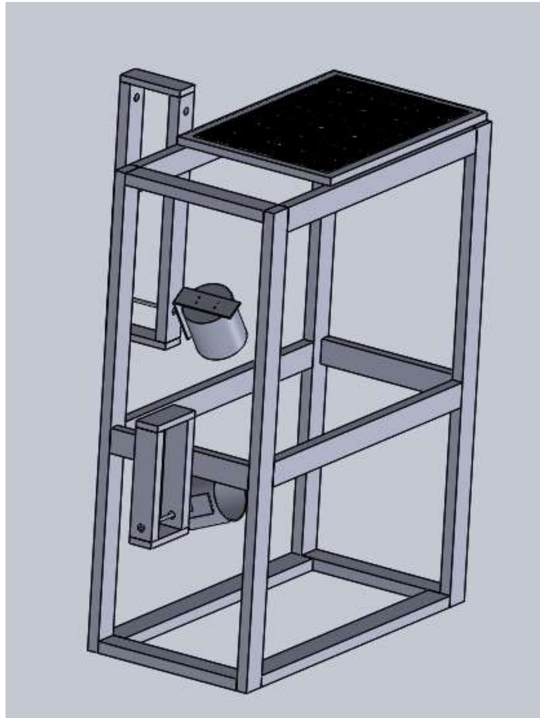


Figure 16. Structural Prototype Final CAD Model

4.5 Risks and Challenges

The chosen concept design fountain from Figure 12 had risks of electrical shock and design hazards because of the weight of the solar panels. The revolving buckets filled with water could cause possible pinch points at the location where the shaft comes into contact with the bearings in the stand. Mounting the solar panel on the roof would expose users to overhanging weights. Although we do not anticipate sharp edges being exposed on the structure, the solar panel itself might have sharp corners. Since the sponsor does not want a battery, there would be no stored energy in the system except for the pressurized water in the pump and pipes. The fountain is an outdoor feature so it will be exposed to all environmental conditions such as high/low temperatures, rain, humidity, and fog.

The team worked on devising a method to reduce the number of oscillations as the bucket completes its rotation after spilling its contents. We wanted the oscillation of the buckets to be as little as possible so that people can appreciate the motion of the water-filled buckets, and were faced with a challenge where the buckets were not tipping with too much damping. We looked into possible solutions of using magnets or modifying the buckets, but found that when the plastic buckets were replaced with metal they tipped much slower and nicer, but did not always discard all of the water inside.

One challenge we are facing right now is the fact that the buckets are at a constant, tilted angle, not at a perfect 90 degrees. Because of this, not all of the water leaves the bucket when it tips.

We need to figure out a way to have the buckets sit perfectly straight up when at rest, and a way to make sure all of the water leaves the buckets when they tip. Another challenge is designing a structure that can be both structurally sound and aesthetically-pleasing. We want to keep the structures to a minimum to showcase the motion of the buckets and fountain itself, but are challenged with creating a stand that can hold the weight of a solar panel (10 kg/m^2) and two buckets filled with water. Our final design is made of sheet metal, and there is a possibility that the material will bend or break when all the weight is added from the solar panel, buckets, and water. We need to make sure that the material selected will support the required weight, otherwise the material will be broken and wasted.

5.0 Final Design:

This section introduces our inspiration for our final fountain design and outlines how each major component has been designed to fit our application. Because the final product has to function properly and be manufacturable, we had to sacrifice some aesthetic features. This section also outlines the functionality of our fountain, and the analysis for each component that proves that our design will work successfully. A summary cost analysis of the final prototype can be found in the indented Bill of Materials in Appendix D.

5.1 Overall Design

After exploring many possible options for our final fountain design, we came across Strawberry Tree Black, which is a public solar mobile device charger in Belgrade, Serbia designed by architect Miloš Milivojević. Shown in Figure 17, this design looks sleek and seemed relatively easy to manufacture as it was made out of straight sections of steel.

Figure 17. Solar Charging Tree (Milivojević)

To make this design work for our application and budget, we reduced the number of branches to lower the cost and manufacturing time. A CAD model of our final design is shown in Figure 18. To go along with the sleek design, we decided to support the buckets from only one side by welding L-shaped rods onto the tree trunk and supporting the buckets by inserting through them. We added a basin to the bottom of the tree made of the same steel sheets to collect the water from the pouring buckets. To pump the water, we will be running tubing and all electric components within the hollow trunk. An exploded assembly view is shown in Appendix D.

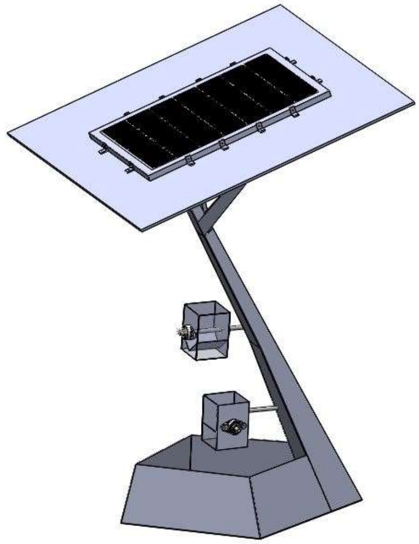


Figure 18. Final Design CAD Model

5.2 Top Assembly of the Fountain

Replacing the wooden solar panel sheet with metal allowed us to forgo the metal connecting plates required and just directly weld the branches to the solar panel sheet. The team used excess steel sheet from manufacturing of the buckets, which saved weight and cost for the fountain.

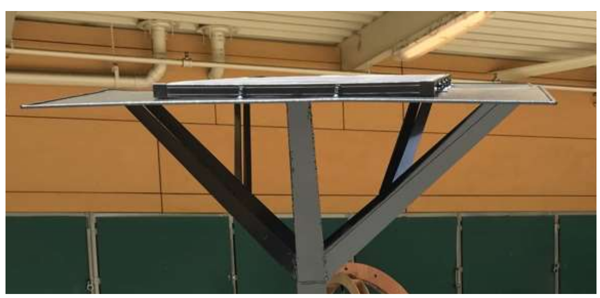


Figure 19. Updated Top Half of the Fountain

5.3 Basin

Figure 20 shows the basin of the structure after the team welded all four sides. The edges of the basin panels meet at one specific angle, but the team fully welded the left side of the basin first, without taking into consideration the right side of the basin. Due to the misalignment, the team was required to patch a gap in the front of the basin with an extra piece of metal. This patch was created by welding a spare piece into the gap, cutting the excess off, and sanding down the edges to a smooth finish. This could have been avoided if the team had tack-welded the basin in place before committing to the angles on the left side. The flat steel piece to patch the gap is marked in Figure 20.

Figure 20. Basin of the Fountain

5.4 Bucket Design

The design of the bucket is critical as it determines the size and design of all the other components. Although the bucket design was initially cylindrical, we found that the calculations for tracking the center of mass of the system was simpler if the buckets were square buckets as seen in Figure 18. Both buckets look identical in terms of outside appearance, with the rotation axis at the midpoint of the walls of the buckets for both. However, the top and bottom bucket exhibit different behavior. The top bucket flips three times, pouring its contents into the second bucket. The bottom bucket is placed such that the rotation axis is perpendicular to the top bucket to negate the momentum added by the water pouring from the top bucket. The buckets are supported by ultra-corrosion resistant plastic ball bearings on both sides. The updated bucket design is shown in Figure 21.

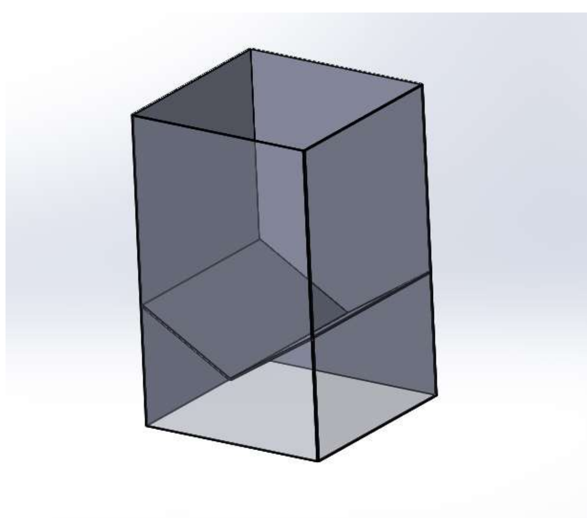


Figure 21. Bucket with “V”-Shaped Bottom

The buckets have a modified bottom plate, where it is not flush with the bottom, and also has a "V"-shaped cross section. If the base plate was flat, the water has a tendency to accumulate in the corner because of its nature to achieve steady state. The center of mass of the water creates a torque and prematurely tilts the bucket one way or another. By placing the "V"-shaped base plate, the water accumulates in the center every time, making the bucket right itself using the water. A sketch diagram of this phenomenon can be found in Figure 22.

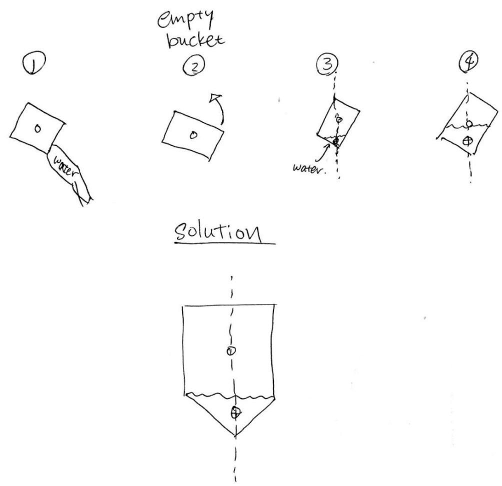


Figure 22. Bucket Motion Depiction

Since the rod holding the bucket will poke through the entire bucket, two bearings will be mounted at the outer walls of the bucket. Although this tampers with the sleekness of the overall design, we had to attach the bearings on the outside because we do not want to change the inside shape of the buckets as it would affect the simulations and the pouring feature.

5.5 Rod Design

The top and bottom buckets will be held by "L"-shaped steel rods and tubes. The diameter and length of these tubes and rods are determined by the weight and location of the buckets. Because the top bucket is welded near the top of the structure, the rod for supporting the bottom bucket must be longer to compensate for the overhang and for the two buckets to align properly. The rods will be welded such that the top bucket will pour perpendicularly to the direction that the trunk is tilting and the bottom bucket will pour parallel to the trunk.

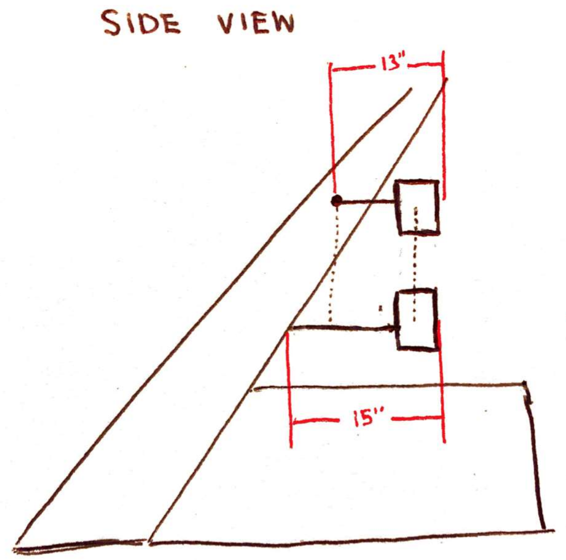


Figure 23. Tube and Rod Lengths from Side View

5.5.1 Top Tube

The top tube is a steel tube that not only holds the bucket assembly, but also transports water into the top bucket. In Figure 24, the top tube has a steel hose fitting on the left where it will connect with the tube pumping the water through the trunk of the tree. To allow the water to flow out of the tube, a hole is drilled underneath the rod between the two bearings where the bucket will be mounted. A tapered plug will be used to prevent any leaking or extra flow of water coming out of the tube's end. The green arrows shown in the figure depict where the rod is "fixed" in the SolidWorks Finite Element Analysis (FEA) simulation, showing that the rod will be welded to the trunk at this location.

After testing the bucket offset on the final structure, the lengths of the tube have been changed to 6.5" out from the side of the trunk and 13" towards the front of the basin. Since there was no available way to bend the top tube to a 90° angle, two pieces of the tube were cut at 45° angles and welded together. The hole on the bottom of the tube for water flow was changed to a ⅜" slot of 1" in length. This ensured that whatever water flowing into the tube was exiting at the same rate so that there is no excessive pressure built up. The welded hose fitting design was also changed to a threaded 90° elbow hose fitting. A ¼" NPT to ½" hose fitting was sufficient to thread onto the tube, which eliminated the dangers of toxic fumes released from welding zinc-plated steel. The 90° elbow also allowed easier access for installation and removal of the hose fitting inside the trunk of the structure. Finally, the end of the tube was Metal Inert Gas (MIG) welded to create a seal, which eliminated the need for a plug. Figure 24 shows the final top tube design.

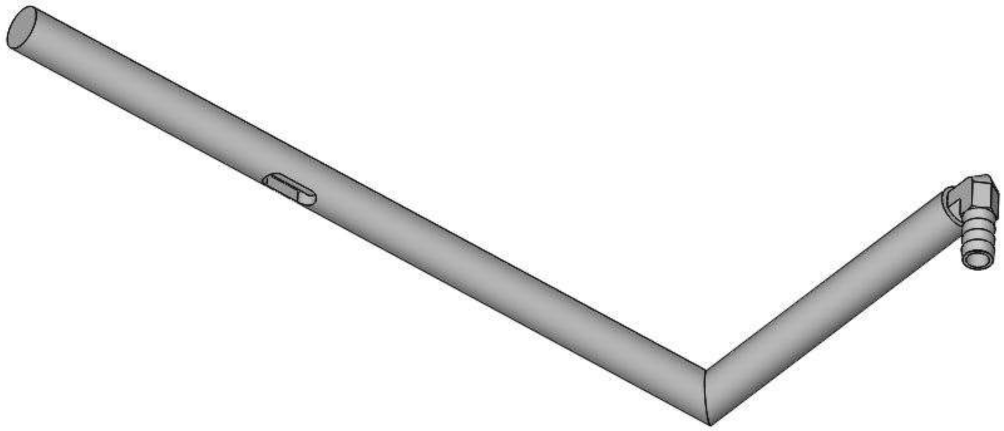


Figure 24. Top Tube Assembly

5.5.2 Bottom Rod

To simplify manufacturability and improve the simplicity of the structure, the bottom rod was reduced to an "L"-shaped rod similar to the top tube. This design change was feasible because the size of the buckets was reduced. With a smaller bucket, the weight that the rod had to bear was much lower, eliminating the need for an extra truss for support. After testing the bucket offset on the final structure, the lengths of the rod have been changed to 13" out from the trunk and 10.5" across the width of the basin. Furthermore, just like the top tube, since there was no available way to bend the bottom rod to a 90° angle, two pieces of the rod were cut at 45° angles and welded together. Figure 25 shows the final bottom rod design.

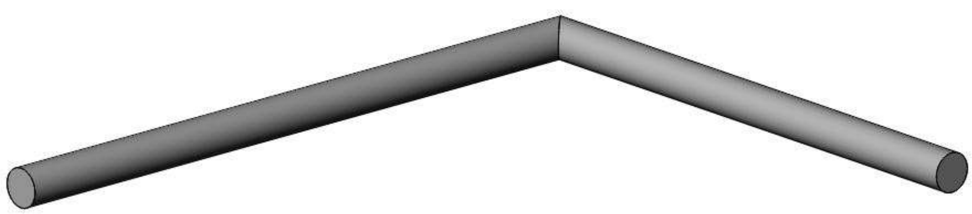


Figure 25. Bottom Rod

5.6 Functionality

The main function of our design is to obtain enough energy from the solar panel to power a pump that feeds the buckets with water. To obtain useable power from the sun, we are mounting a solar panel on top of our structure at an angle of 25°. While this angle is not the optimum angle to receive the most solar energy, we found through testing that at the peak hours of energy absorption, we have more than enough power to utilize the pump. The 25° angle was a compromise between aesthetics and energy absorption.

To power the pump, we will directly connect a 12V DC submersible water pump with a flowrate of 620 liters per hour. Connecting the pump directly to the solar panel will allow the pump to work according to the weather conditions. On cloudy days with less sunlight, the pump will feed less water to the buckets, and therefore, the bucket feature will not be as fast as it would be if it were clear and sunny. Between the pump and solar panel, we will also include an on/off switch so that the user can easily turn the fountain on and off. The on/off switch will come in handy when the user would like to perform maintenance on or clean the fountain. It also allows the user to prevent the fountain from running without water in it, saving the pump from running dry and damaging it. The Operator's Manual is shown in Appendix M.

Tubing that carries the water from the pump to the top bucket will run up along the inside of the trunk. The tubing will connect to the barbed steel hose fitting that will be welded onto the top rod. This will allow for water to be pumped into the rod. The water in the rod will come out of a hole located at the other end of the rod where the bucket is resting on the bearings. Delivering the water to the buckets through the rod will eliminate any disturbances to the motion of the pouring bucket like using a spout at the top would.

Finally, once the top bucket is filled with water above its center of mass, it will pour perpendicular to the tilt of the trunk into the bottom bucket. The bottom bucket will not pour its contents until it has had 3-4 fills of the top bucket, and then it will pour its contents perpendicular to rotation of the top bucket, with the tilt of the trunk. All the water will be poured into the basin, where the water will be reused and pumped back into the buckets by the submersible water pump. When the buckets are full of water, the basin water level goes down by a negligible amount, so there is no possibility of the pump running incorrectly.

5.7 Wiring Diagram

The wiring diagram shown in Appendix E includes a simple layout of how the 100W 12V solar panel, on/off switch, and 12V DC submersible water pump are connected.

5.8 Design Analysis

To analyze the design of our structure, we used programs such as SolidWorks to perform Finite Element Analysis studies to validate our hand calculations. To analyze the motion of our buckets, we performed basic hand calculations on the location of the centroid and simulated the more complicated behavior of water in MATLAB. For full analysis, refer to Appendix I.

5.8.1 Bucket Simulation

Our sponsor worked on calculating and simulating the behavior of water in multiple bucket shapes. He found that the cylindrical bucket was more difficult to predict the motion of water than a rectangular bucket, which was one of the reasons our fountain design was changed to use rectangular buckets. Since then, he has been creating code on TrueBasic to visually simulate the tipping motion of the bucket. We worked with our sponsor to translate the code into MATLAB, so that we can test different inputs and see the effects without physically experimenting with multiple buckets. The MATLAB code can be seen in Appendix F.

5.8.2 Hand Calculations

Hand calculations for deflection of the top tube, bottom rod, and the structure were completed and compared to the FEA results. Calculations concerning the center of mass of the buckets on the Structural Prototype and the loads on our final design are also shown in Appendix I.

5.8.3 Finite Element Analysis

Using SolidWorks, we were able to run studies of FEA to test the stresses and deflections of the rods that are supporting the buckets. Using FEA, we were able to test the rods and quickly alter the lengths and diameters of the rods to test the minimum amount of material and manufacturing needed to achieve desirable results.

Because the top rod is actually a tube, we had to make sure that it was able to support the weight of the bucket filled with water. Through trial and error, we found that a rod with a 0.75” outer diameter with a wall thickness of 0.188” was sufficient enough to carry its load. As shown in Figure 26, a total force of 60N acting on the purple arrows indicated shows that the stresses acting on the weld point are about 30 MPa. The end of the tube is expected to deflect a maximum of approximately 1.3 mm. These results gives us a factor of safety of about 20.

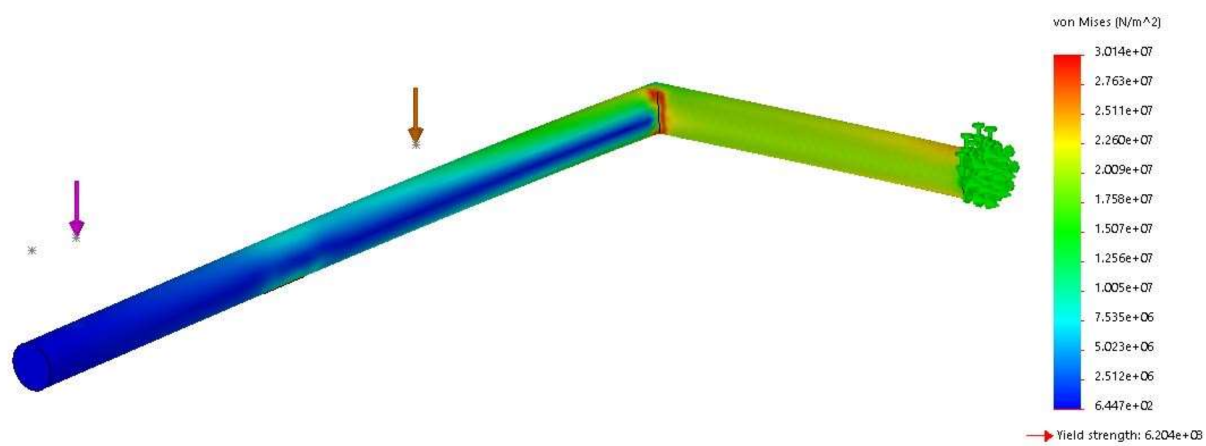


Figure 26. Stress Analysis on Top Tube

Since the bottom rod is not transporting any water, we designed it as a solid steel rod. We designed the bottom rod with a 0.75” diameter because we wanted to keep the rod and bearing sizes uniform with the top rod. However, since the bottom rod had to be longer to align with the top bucket, the moment arm was a lot bigger, causing extraneous stress at the weld point and a larger deflection at the tip where the bucket is mounted. Since the top tube is hollow and can still support the weight of the bucket and water, and the team concluded that a solid rod can easily withstand the weight of the bucket and water; thus, we skipped the stress analysis.

Using the shop technicians' advice of using at least ⅛" thick steel for the approximately 6 ft tall structure, we applied a total force of 482N which is equal to the weight of the roof assembly on the structure and the branches. A wind load acting on the roof assembly and the structure of 332N for the worst case scenario was also applied. The FEA shown in Figure 27 shows that with extra wind and anchor loads, the highest stress points exist at the base of the structure and the weld points of the branches. The stress in these areas are approximately 12 MPa. The structure is expected to deflect 0.6 mm at the top. This gives us a factor of safety of about 12.8.

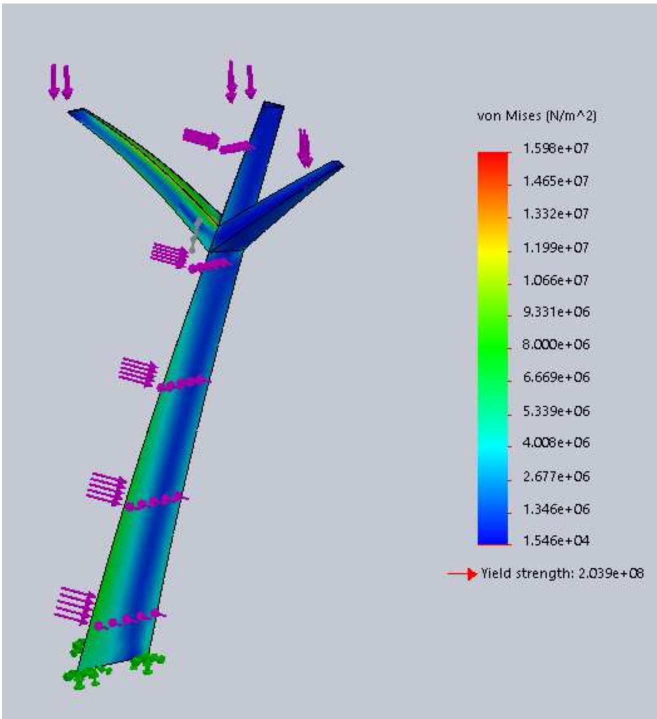


Figure 27. Trunk and Branches Stress Analysis

5.8.4 Prototype Test

From our initial prototype, we focused on the concept of the bucket tipping feature. We obtained multiple small plastic buckets where we could poke rods through and test different axes of rotation. We found that poking the rod through the center of mass with weights attached to the bottom allowed for the bucket to pour all its contents and return to the upright position. Because the bottom bucket has to tip less frequently than the top bucket, we simply raised the axis of rotation by not adding as many weights. Although the initial prototype was unstable and included a lot of disturbances to the bucket tipping motion, we were able to identify what modifications and improvements to the bucket and next prototype had to be made.

For our Structural Prototype, we decided to scale everything up to full size to get a better idea of how our final design will work. We wanted to test if the solar panel could provide the pump with enough power to lift the water and what distance the two buckets had to be offset in order to fill correctly. Using bigger and more rigid metal buckets allowed us to more accurately mimic the final product. We attached L-brackets to the sides of the buckets to verify our calculations that a certain diameter rod was strong enough to hold the bucket when fixed only on one end. The L-brackets also had holes so that the rod can be mounted to different heights without having to drill directly into the buckets. The Structural Prototype also allowed adjustments to be made in the x-,y-, and z-directions so that we could determine the offset of the buckets as shown in Figure 28.

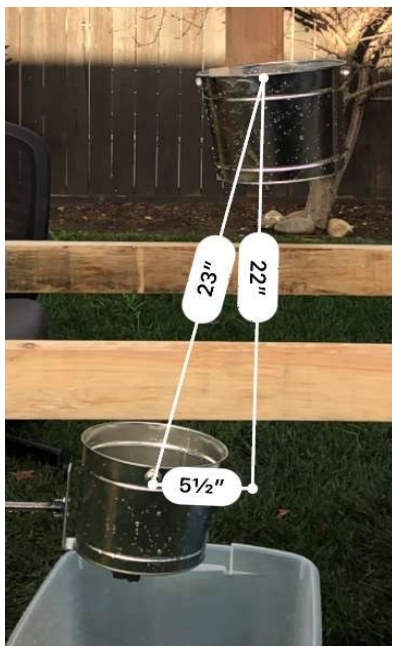


Figure 28. Structural Prototype Bucket Offset

5.9 Safety, Maintenance, and Repair

The full Bill of Materials with all pre-purchased and manufactured parts is shown in Appendix D. The full project budget for the Bill of Materials can be seen in Appendix H. Failure Modes and Effects Analysis (FMEA) is a method of analyzing a product to determine possible points of failure, the causes of the failure, and the impact of those failures. Failures, in this case, are situations in which the product does not meet design specifications, not necessarily that the product breaks. For full FMEA analysis and a Risk Assessment from the Designsafe software, see Appendices J and L, respectively. A Design Hazard Checklist for our fountain is shown in Appendix K.

A safety concern of ours is the large mass of steel and the solar panel “roof” that it is holding. Although we accounted for the weight being held by a perfectly fixed trunk in our FEA analysis, we failed to consider the high stress concentration points at the branches holding the solar panel, as well as the extra load that can be caused by strong winds. To account for this issue, we more accurately modeled the branches and the extra forces acting upon the entire structure.

For maintenance considerations, a potential issue was brought up where algae can build up in the tubes and clog up the water flow. Originally, our design had no easy access to the tube running from the pump to the barbed steel hose fitting. The upper portion of our trunk was welded and enclosed, which would have caused trouble in changing or cleaning the tubes for maintenance. To fix this issue, we designed an access panel, cut it out of the front panel in front of the tube connection, and added a latch. The on/off switch was secured in this area as well.

6.0 Manufacturing:

This section outlines how all the material used to manufacture the fountain was obtained and what manufacturing processes were performed to assemble the final product.

6.1 Procurement & Final Budget Status

Most of the electrical and off-the-shelf components were purchased from Amazon and McMaster-Carr as they provide fair prices and quick shipping. We also purchased miscellaneous items such as bolts, nuts, and adhesives from Home Depot as it is conveniently located in SLO. Both 10 gauge and 16 gauge steel sheets were purchased from Coast Pipe in Paso Robles for their affordable price. The team drove to Coast Pipe in order to save shipping fees. Table 5 displays the updated final budget status.

Table 5. Final Budget Status

Item	Cost
Structural Prototype	$179.98
AUDBIG 12v DC Water Pump	$25.51
Newpowa 100W 12V DC Solar Panel	$92.00
Wire	$3.01
Clear Hose	$17.61
4ft by 10ft Steel Sheet (⅛ in thickness)	$190.97
Top Tube	$47.84
Bottom Shaft	$27.94
Buckets: 4ft by 10ft Steel Sheet (1/16 in thickness)	$60.51
Loctite Power Grab	$11.00
L Brackets and Screws	$13.15
Resin	$18.66
Dampers ($37.35 Returned)	$27.16
Stainless Bearing ($229.92 Returned)	$0.00
Latch for Access Door	$3.21
Spray Paint	$27.46
Pond Liner	$37.68
Plastic Bearings	$135.80
Basin Edge Trim	$16.98
Loctite	$9.96
Hose Clamps	$1.06
Plastic Bearings	$106.14
Pump Filter	$7.63
Miscellaneous Items	$38.74
Total	**$1100.00**

The team's initial budget of $500 was extended to $750 to allow for the increased cost for a steel structure. The budget was further increased due to the unexpected high price of the bucket bearings. The website links for all purchases are shown in Appendix G.

6.2 Manufacturing

Many of the parts for our fountain could not simply have been bought; they needed to be manufactured. The detailed CAD drawings for the parts we manufactured can be seen in Appendix D. For most of the manufacturing the group was split up into two teams: Andy and Joey were tasked with welding the structure and Jun and Kota were tasked with finishing and implementing the bucket and damping design.

6.2.1 Structure

The structure of the fountain includes the tree trunk, branches, and basin. The entire structure was built from a ⅛" thick, 4' x 10' steel sheet purchased from Coast Pipe. We laid out all the pieces, including extra pieces that were cut out from the leftover steel, on the 4' by 5' sheets in Figure 29. These pieces were cut on the water jet in the Cal Poly IT Department.

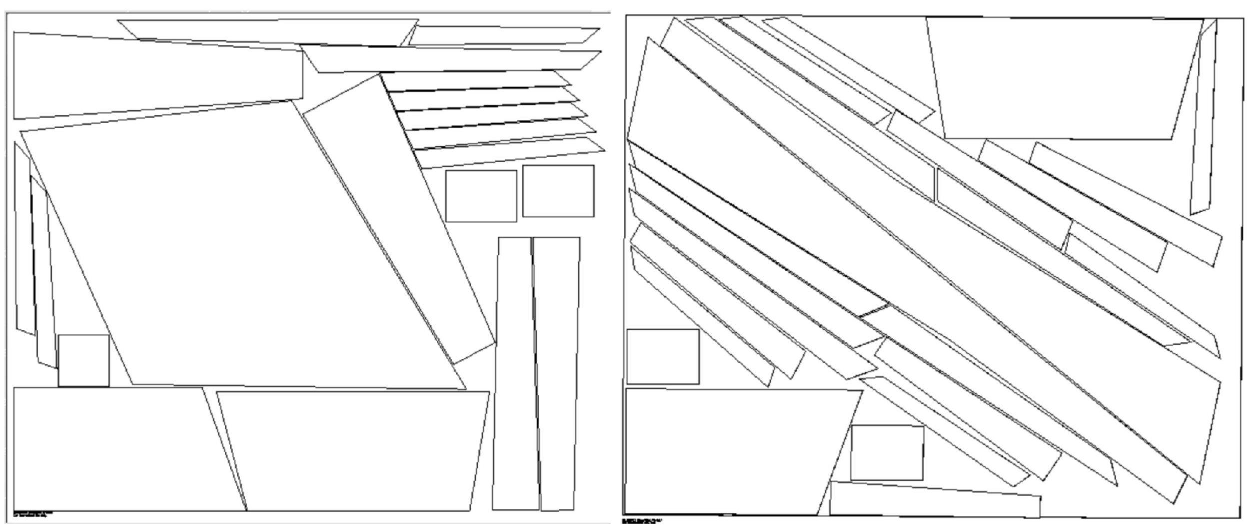


Figure 29. Layout of Pieces on Steel Sheets

After cutting the pieces, the welding team dried and sanded the edges as a preparation for welding. The structure has been MIG welded in three parts: branches, trunk, and basin. The four wider pieces of steel were welded to make up the walls of the basin. The three longer pieces were welded like an extruded triangular prism to form the trunk. The branches, however, needed more precision as they are designed to be fixed at an angle and are much smaller pieces than the trunk and basin. To achieve the precision needed, the team was advised by Professor Kevin Williams of the Industrial Manufacturing Engineering department to tack-weld the pieces to make sure the angles were correct before fully welding the panels. Tack-welding is when the welder executes two or three small weld beads to hold the pieces at the correct angle, allowing minor adjustments if needed. All of the welding was done in machine shops on campus.

Prof. Williams helped the team with welding the fountain using tack-welding techniques. In order to weld the trunk pieces with 3 sides, Prof. Williams tack-welded 2 sides at a time and bent the panels to form a triangle. The misalignment of the basin panels previously mentioned caused the trunk panels to misalign as well. Prof. Williams and the team used multiple trigger clamps to warp the basin walls to line up with the trunks, then Prof. Williams proceeded to tack-weld the panels. The team finished welding by using MIG welds along the seams of the panels to secure the trunk and basin's position. The finished lower half of the fountain is shown in Figure 30.

Figure 30. Lower Half of Fountain Welded

The team used the tack-welding method to assemble the branches tentatively to ensure the angles were correct, and then again to attach them to the metal top sheet as shown in Figure 31. Attaching the branches to the top sheet required that all the ends of the branches lie on the same plane, otherwise there would be another misalignment. Therefore, the tack-welding was essential. The design change to make the top sheet metal instead of wood made this process much easier. Before, the five points of connection would have required five small rectangles of metal to be welded to the end of each branch and then screwed into the wood. By changing the sheet to metal, the branches are just welded directly to the top sheet.

Figure 31. Top Half of Fountain with Welded Branches

Figure 32 shows the solar panel with L-Brackets attached to it that were used to secure it to the metal top sheet. The team decided to use twelve L-Brackets total to increase the sturdiness of the panel and sheet, while also trying to account for possible deflections due to wind load. The team used ¼-20 bolts with nylock nuts to prevent the bolts from disassembling due to vibrations. While trying to disassemble the aluminum frame from the solar panel, the team broke the glass protection of the solar panel. To secure the glass and minimize cracking, the team applied multiple layers of polyurethane resin on the surface of the solar panel.

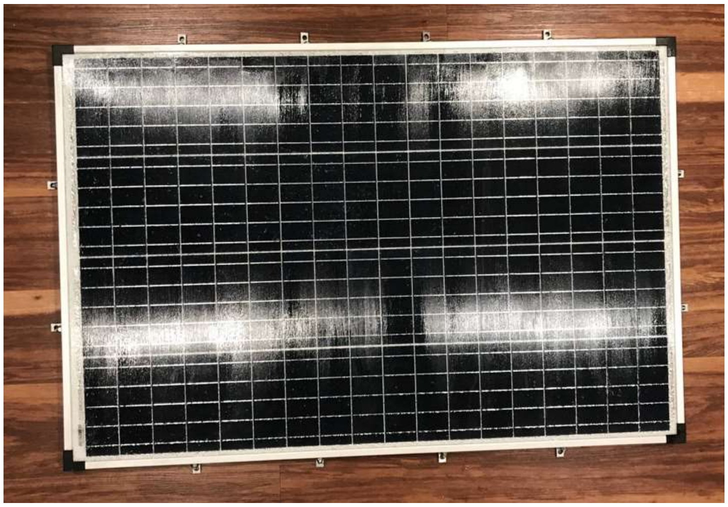


Figure 32. Solar Panel with L-Brackets

The next step was to finish off the trunk welds where there were only tack-welds. Once all the incomplete edges on the trunk were fully welded and finished off, the branches were finished off as well. Finally, the top half of the fountain was welded to the trunk, completing the fountain structure. After finishing construction of the fountain, the team cleaned the surface of the structure with a wire angle grinder to remove weld slags and impurities then wiped the surface with white vinegar solution. This step was taken to prep the surfaces of the fountain before painting. The team used black Rust-oleum Paint and Primer in one to coat the surface of the fountain, and a black high heat resistant Rust-oleum paint for the 4 ft by 4 ft steel solar panel surface facing the sun. Four coats total were used on the structure, except on the bearings. The team was worried about painting the inner workings of the bearings and causing them to malfunction, so the bearing was covered for the first three coats and only painted on the last finishing coat. The basin of the fountain was waterproofed by applying a pond liner with a Loctite silicone-based adhesive. The team purchased edge trim and applied it to the edges of the basin and the steel plate holding the solar panel for safety reasons and a cleaner finish. Figure 33 shows the fountain structure completely painted.

Figure 33. Painted Structure

6.2.2 Buckets

The bucket was fabricated completely out of 0.0625” steel sheets welded at the seams to create a water-tight container. The bucket used for the final product is 6.5” in width, and 9” in height.

However, the bucket used for the prototype, and also pictured in the following figure, Figure 34, is 7.5” in width, and 12” in height. We deemed that this bucket was too large to fit with the fountain, and decided to scale down. All of these bucket dimensions were input into a custom MATLAB code that tracked the center of mass of the system, and monitored when the tipping motion will occur. The key point of this study was to determine what mass of water-to-bucket ratio will force the bucket to empty all of its water after tipping.

Figure 34. Confirmation Prototype Bucket

The base plate is displaced from the bottom of the bucket a certain amount to move the system center of mass. This is best demonstrated in the diagram in Figure 22. After testing the confirmation prototype, we saw that the contents of the bucket spills completely, so we know that at 180% mass ratio, the water completely spills. This helps with future design decisions whether it be scaling up or down.

To test whether the buckets were watertight, the buckets were submerged, and the team looked for bubbles, and tried to weld that area. However, there were leakages, which were patched by caulk.

The bearing housing was attached to the bucket with ¼”-20 zinc dipped screws to avoid corrosion. However, a substantial amount of water leaked through the space between the bearing housing and the bucket walls, so this seam was sealed with caulk. The screw holes of the bearing housing was also sealed with caulk. The remaining leakage comes from the bearings itself, however caulking this component would make the bearings unusable.

At first, the top bucket tipped too far, causing water to hit the side of the bottom bucket and splash everywhere, including outside the basin. To mitigate this, an “L”-shaped hard stop was attached to hit the bearing and prevent it from rotating more than approximately 90°. This helps the bucket pour all of its contents into the bottom bucket instead of into the basin. We put the basin edge trim on the metal stop to prevent the paint on the bearing from being scratched off. Figure 35 shows the hard stop marked with red circle.

Figure 35. Top Bucket Hard Stop

6.2.3 Top Tube

The top tube was manufactured out of a low carbon steel tube from McMaster-Carr. The tube has an outer diameter of 0.75" with a wall thickness of 0.188". Due to stress and deflection, we wanted to keep the length of the tube as short as possible, so we used a 16" tube. To achieve the bend in the tube, we cut two pieces from the 16" tube at a 45° angle and welded the pieces together. Once the L-shaped tube was formed, we welded a 3/8" inner diameter 90° elbow barbed steel hose fitting from McMaster-Carr to the left end of the tube as shown in Figure 24 to allow the tube from the pump to connect to the top tube. A ⅜" slot of 1" was drilled underneath the top tube, halfway between the bucket walls to allow water to flow out of the top tube. The end of the tube was MIG welded to stop any leakage and water flow to that end. Finally, the top tube was welded onto the structure, exposing the barbed hose fitting on the inner wall of the trunk. The top tube was welded 4 feet from the bottom of the structure to the rear of the trunk as shown in Figure 18.

6.2.4 Bottom Rod

The bottom rod, shown in Figure 25, was manufactured out of a 0.75" low carbon solid steel rod from McMaster-Carr. With our setup, we found that a 22" rod was sufficient enough to align the bottom bucket with the top bucket. To achieve the bend in the rod, we cut the rod into two pieces at a 45° angle and welded them together. The bottom rod was welded to the front of the trunk at 23 inches below the top tube as shown in Figure 18.

6.2.5 Final Assembly

All the structural components such as the basin, trunk, rods, and branches were welded together. The solar panel is connected to the top of the trunk with L-brackets and the branches were welded to the sheet of steel in Figure 31. The bucket assemblies with the bearings are press-fit onto the top tube and bottom rod. Once the final assembly was complete, the team started the painting process. First, all surfaces were cleaned with a white vinegar solution to remove any dirt or rust. Once all surfaces were clean, we rubbed the surfaces with a scuffing pad to prep for primer and paint. We used Rust-oleum primer and acrylic enamel spray cans to apply multiple coats.

6.3 Challenges

Throughout the design and manufacturing process, our team faced many challenges. One very critical design challenge that we had to constantly face was the design of the buckets. Although through our sponsor's calculations and our MATLAB simulations, we were able to obtain ideal bucket shapes and sizes, there were too many factors that were neglected for the simplicity of the calculations. To make matters worse, the tipping motion of the buckets relied heavily on so many different factors that it seemed impossible to narrow down our solutions to one specific bucket design. Factors such as flow rate into the bucket, bucket offsets, and disturbances such as extra friction/stiction, weather conditions, and water hitting the outside bucket walls all affected our testing in a negative way. Through some of our initial prototype testing we found that the results from our simulations did not translate well into the real world.

To overcome this obstacle, we used rapid prototyping. Using the simulation results as guidance, we used our extra 1/16" steel plate to create a bucket and test the pouring behavior. Initially, we observed that a flat bottom design did not upright itself when the bucket was empty like the simulations suggested, so we created a "V"-shaped bottom that proved to work successfully. Once a favorable bucket design was achieved, we were able to downsize or upsize the buckets to the amount of water we wanted it to pour.

Another challenge that we faced was welding everything from the structure to the buckets. First, we found it extremely critical to hold all the steel pieces in place before welding to ensure that all the edges and corners line up. Since all the pieces were water-jet cut extremely accurately according to our SolidWorks model, it was important to have all the pieces at the right place and angle.

MIG welding was also a struggle since no one on the team was experienced in welding. Therefore, to gain confidence in welding, the team practiced welding on extra steel plates and parts before moving onto the final pieces. For the main structure of the fountain including the basin and the trunk, we were able to weld with little difficulty and later angle-grind the welds to make it look better. For the more intricate and thinner-walled buckets, we got assistance from Prof. Williams to weld the buckets and make it watertight. Through the manufacturing process, we learned that it is important to plan ahead and manufacture the structure in chunks so that it is finished in a timely manner.

6.4 Future Production

For the future production of our design, we highly recommend making a larger basin. A larger basin will greatly reduce the volume of water lost due to splashing and dripping. During our design and testing period, we sized the buckets according to the size of the basin to minimize water loss, but if we had a large enough basin to begin with, water loss would not be such a big issue. Currently, if the top bucket were to fill with more than ideal water, it would cause a violent pour which creates a lot of splashing. Some of the water leaking through the bearings also drips out of the basin during windy weather.

During future production, all the cut outs and holes on the truck structure should be planned and placed ahead of time so that it can all be cut on the waterjet. Due to design changes and waterjet availability, our team had to drill the holes for the shafts and angle-grind the access door after the structure has been welded together. This took more time and created a sloppier job.

Another problem that would be beneficial to fix in the future would be the leaking bearings. At the moment, the bearings leak water through their inner workings, something that could not be caulked closed without compromising the performance of the bearing. We were expecting to purchase watertight bearings, but were not able to find any of the correct size that fit our budget. Poking the tube and rod through the buckets was a problem that could have been solved with a different bucket-holding solution, such as the “coffee cup sleeve” design.

Lastly, a small detail that cost us a lot of time and trouble was the size of the ¾” rod and tube. Due to the tolerance of the rods and the plastic bearings, we struggled with taking on and off the bearings. Once the bearings were press fit using the hydraulic press, the rod and bucket assembly was welded onto the structure. After it was welded, it was extremely difficult to take off the bucket and bearings for adjustment. If we had reduced the diameter of the rods, we would have been able to easily make minute adjustments.

7.0 Design Verification:

This section explains how the team confirmed that our final product met all of the design specifications. It will discuss each of the specifications and describe all tests and their facility and equipment needs. Appendix N shows the full Design Verification Plan.

7.1 Specification #1: Bucket Tip Time

For Specification #1, the time for the buckets to tip and empty water slowly was tested by the entire team. The acceptance criteria for the bucket to empty its contents is 3 seconds since our sponsor has mentioned that he wants to slow down the motion of the bucket pouring motion. This specification was tested on our final design with the manufactured steel buckets and plastic ball bearings. To test the acceptance criteria, we used a stopwatch to time the point right before it tips and the point when the bucket returns to its original upright position. The team performed 3 tests to get an accurate estimate of the tipping time.

Our testing proved that our acceptance criteria of a 3 second tipping time was not met. While the simulations showed that having the center of mass of the bucket and the water slightly above the rotation axis will create a slow tipping motion, it was very difficult to recreate on the physical buckets. Factors such as stiction of the bearings and even extra weld slags affected the motion of the bucket and created a less than perfect tipping motion. The only way to slightly improve the tipping time was to add weights to raise the center of mass. This caused the bucket to tip sooner, and the smaller volume of water created less momentum, thus slowing the tip time slightly.

7.2 Specification #2: Flow Rate

For Specification #2, the flow rate of the water from the pump was tested by Andy. The acceptable flow rate is 2.5 gallons per minute, which is slightly less than the rated flow rate of the chosen pump. This acceptance criteria was chosen to ensure that the bucket will fill up in a controlled and timely manner. This specification was tested by measuring the mass of water pumped in a minute using a stopwatch, scale, and a bucket. One gallon of water is roughly about 8.34 lbs, so after a minute, the goal for the pump is to output 25 lbs of water. Andy performed 3 tests and the results are shown in Table 6.

From testing, the pump consistently output 3.3 gallons per minute and passed the required criteria. Currently, it takes 30 seconds to fill and tip the top bucket, which is faster than our specified time in the problem statement. However, the testing was done on a sunny day with maximum power output from the solar panel. No testing was done with varying weather, since our sponsor specified that he wants the fountain to operate reflecting the weather. This test was done to verify that the pump can operate at its full potential on a sunny day.

Table 6. Flow Rate Test Results

Trial	Flow Rate (gpm)
1	3.42
2	3.375
3	3.315

7.3 Specification #5: Force Required to Knock Over Fountain

For Specification #5, the force required to tip over the fountain was tested by Joey. This specification is important because the fountain can be subjected to severe weather conditions. The fountain will be placed in the backyard of our sponsor and the goal is for the fountain to withstand 100 lbf of force against the structure. The test was separated into two components: physical and computer analyses. The physical test was conducted on the final product when it was fully assembled by having Joey mimic natural disturbances by pushing against the structure. The computer analysis consisted of FEA studies mimicking wind and anchor loads in correspondence with the highest wind speeds in the area. These studies show how much force the structure can withstand in the worst case scenarios. We expected the fountain to pass the acceptance criteria because the fountain is very sturdy and weighed down well with the basin full of water.

7.4 Specification #6: Noise Level

For Specification #6, the noise level from the fountain was tested by Jun. The acceptable level of noise is 80 dB; this test was conducted 5 times using a decibel meter while standing at different distances away from the fountain. Jun performed the test while the fountain was fully functioning. This test is important because our sponsor does not want a loud obstruction in his backyard. A normal quiet living room is around 65 db, so it is reasonable to set the acceptable level at 80 db.

We expected to meet this acceptance criteria because the only source of noise is the water dumping. However, because the water is being dumped so violently, we were concerned there would be an issue with the noise level closer to the basin. The average noise level never exceeded the surroundings at 1 meter away. The test results are shown in Table 7.

Table 7. Decibel Test Results

Trial	Distance From Fountain (m)	Decibel (db)
1	0.5	60
2	1	55
3	2	55
4	3	55
5	4	55

7.5 Specification #8: Rate of Lost Water

For Specification #8, the rate of water lost from splashing and evaporation was tested by Kota. The acceptable rate of water loss is 0.1 gallons per hour. It is important that the final product does not lose water because running the pump dry will destroy the pump and constantly having to refill the fountain with water is troublesome.

This test will be performed on the fountain for an hour with 11 gallons of water. The group will input a gallon at a time, until the water level is sufficient to run the pump. After running the system in the sun for an hour, Kota checked how much water was remaining by pouring the basin water into measuring cups. We expected to find that the water loss was less than the specified amount, passing the test. However, the fountain is losing water, and has leaks through the bearing as well as the splashing of the water. The bottom bucket loses a significant amount of water after getting poured into because of the turbulent, abrupt flow. This amounted to a loss of 3 gallons of water per hour. Because the bearings are revolving, it is difficult to cover the bearings without tampering with the bucket motion. In order to get a smooth laminar flow out of the top bucket it would require a redesign of the bucket shape, possibly adding a funnel. Table 8 logged the results throughout the one-hour test.

Table 8. Rate of Water Loss Results

Date of observation	Observed By	Observation
6/1/19	Kota Ozawa	3 gallons per hour

7.6 Specification #9: Power Consumption

For Specification #9, the power consumption of the solar panels was tested by Andy. The pump purchased for the final product requires 12 Volts DC and maximum current of 1.2 Amps to operate, so this is the acceptance criteria for this specification. It is important for the pump to operate within 12V and 1.2A because it is the optimum voltage and current for the pump. The voltage and current were tested using a multimeter. The results of the test are displayed in Table 9.

Table 9. Current and Voltage Test Results

Trial	Current (A)	Voltage (V)
1	0.61	20.6
2	0.57	20.3
3	0.56	20.5
4	0.56	20.3

The pump is currently operating around 0.58 Amps and 20.4 Volts. Although the voltage is higher than the recommended 12 Volts, it is beneficial for pumps to run at higher voltage, because then the pump operates at lower current, producing less heat. Figure 36 shows the generic current versus voltage of a 100W solar panel with the operating point marked with a red circle.

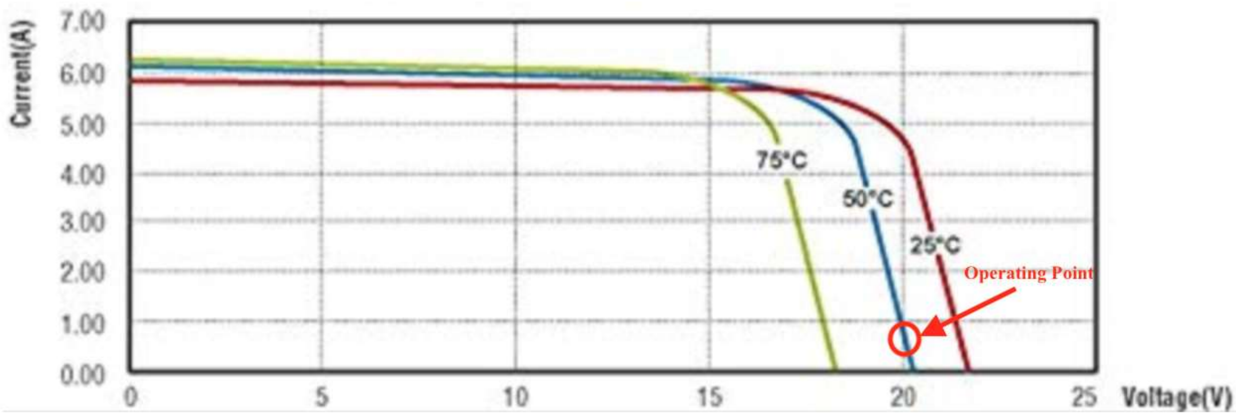


Figure 36. Current vs. Voltage of a 100W Solar Panel

8.0 Project Management:

This section outlines the management process of the project, including what worked well and what can be done differently on our next design project. It also includes our project Gantt chart and the next steps to be taken.

8.1 Overall Design Process

After ordering and acquiring components for the fountain, the team started manufacturing the fountain as described in the Manufacturing chapter. The fountain was built from bottom to top and subsystems such as rods and buckets were attached to the main portion for the fountain after. After painting the fountain and applying a pond liner to the basin, the team performed the tests described in the Design Verification Plan in Appendix N. Because the team completed the fountain behind schedule, the team was allowed three more days to finish testing. The details of the team's schedule can be seen in Appendix O - Gantt Chart.

Overall, the design manufacturing process went well because of all the help from the Mustang '60 tech assistants and the water jet cutting technology from the Industrial Manufacturing Engineering department. We utilized the resources at our disposal well and had professional help from many individuals along the way.

If the team was allowed to change the design of the fountain, there would be changes in the bucket design, as well as the size of the basin. The bucket design was what caused the leaking through the bearings which contributed to the high amount of water lost. This could have been avoided if this issue was discussed early in the design phase. We would have also prepared the shafts by sanding them down in order to not affect the bearing behavior when press-fitted on.

8.2 Overall Timeline

The overall timeline is included in Appendix O in a Gantt chart. The Gantt chart presents the day to day tasks of each member from the start of the project until the final presentation at the Project Expo.

8.3 Next Steps

The next steps for the team are to deliver the final product to our sponsor and install the fountain in Dr. Epstein's backyard. Along with the delivery, the team will go over how to operate and maintain the fountain with Dr. Epstein in person, but the same information regarding the operation of the fountain is available in Appendix M - Operator's Manual.

9.0 Conclusions & Recommendations:

Throughout the project, the team has made major discoveries regarding the motion of the bucket, alternative solutions for mitigating overshoot, and some flaws in our design. Our sponsor worked with the team to be able to accurately describe the physics behind the bucket motion.

First off, the buckets needed to look identical, so the rotation axis was placed at the midpoint of the bucket walls. With this, the bucket wall center of mass and the rotation axis coincide, preventing the bucket motion. When water is added, it shifts the center of mass of the bucket water system. When this center of mass reaches the rotation axis it becomes unstable, and forces the bucket to tip. Water is also denser and heavier than the bucket itself, so it plays a big role in shifting the center of mass. The base of the bucket lowers the center of mass of the bucket, providing torque to erect the bucket to its upright position. We created a prototype out of wood, with the base flush with the bottom of the bucket walls. When filled with water, the bucket never tipped and water began to overflow. This is because the center of mass of the bucket water system never reaches the rotation axis. Attaching a base to the bucket lowers the center of mass, in turn lowering the system center of mass when filled with water. The solution to this was to raise the base of the bucket, until the water added would cause the system center of mass to rise above the rotation axis. This discovery was crucial in proceeding with the bucket design. We found that with a raised base that the heavier water eventually raised the system center of mass to instability.

The second discovery we made was that the bucket would react differently depending on the relative mass of water to mass of the bucket. If a lot of water is stored, there is more momentum built up when the bucket tips. This causes a violent tipping motion, and carries water outside of the basin. On the contrary, if the mass of the water is relatively low to the mass of the bucket, there is not enough momentum for the bucket to empty all of its contents, and the buckets will be left with some water. Our sponsor requested that the buckets empty all of its contents on each tip. The team made multiple buckets, and created MATLAB code which would track the amount of water in the bucket when the tipping occurs. We found that 140% water mass to bucket mass would cause the bucket to empty its contents, while keeping the tipping motion relatively peaceful. The bucket used for the final product had a mass of 2.36 kg while the mass of water was 3.68kg. The team would like to have done more testing to see what % water mass to bucket mass would have been the optimal number for the most peaceful tipping motion while emptying its contents. However, due to budget and time, the team only had the chance to test three bucket dimensions. All the buckets tipped and held no water. The first two buckets had a bottom base angle of 60 degrees, and the first one 50 from the vertical walls. The bottom base offsets are measured from the axis of rotation, or the midpoint of the bucket walls to the top edge of the base plates. All of these tests were performed for the top bucket, and the bottom bucket was adjusted accordingly to only hold twice the volume of the top bucket. These numbers are listed in Table 10.

Table 10. Bucket Dimensions, Water Mass, Bucket Mass, and Percentage of Water to Bucket

Bucket #	Dimension (WxLxH)(in)	Base offset (in)	Water mass(kg)	Bucket mass(kg)	Percentage(%)
1	7.5 x 7.5 x12	1.28	5.62	3.52	160.05
2	6 x 6 x 8	1.02	2.67	1.92	139.33
3	6.5 x 6.5 x 9	1.94	3.68	2.36	156.24

The third discovery the team made was an issue with the stiction of the bearings. As the bucket gets filled up, the load placed on the bearings increases, and creates enough friction within the bearings to prevent the bucket from flipping. In order to solve this issue, the team had to add mass to one side of the bucket to provide extra torque and promote the tipping motion. This was done by adding magnets above the rotation axis to raise the system center of mass as well as bias the tipping direction. However, in the future we would like to invest in stainless steel bearings or bearings which don't have a problem with stiction. Another solution would be to use weights other than magnets that could be concealed better within the bucket walls.

Finally, here are some notes about ways to slow down the return motion of the bucket. Our sponsor had an aesthetic request for the buckets to return to its upright position as slowly as possible. This would make the fountain much more peaceful. The buckets tends to overshoot its upright position, and continue oscillating for several seconds after dumping its contents. We believe that dampers or torsional springs could be a solution to this. Currently, the team has welded on a hard stop in the form of a "L" shaped plate, which the bearing housing would hit. However, the team has also experimented with torsional dampers in the place of bearings. The team purchased a pair of dampers from Bansbach with a torsional friction of 3 N-m. These required precisely machined shafts which would be press-fit into clutch bearings. The team was unable to manufacture a shaft of this precision. Also, the 3 N-m dampers were much stronger than anticipated. We had done calculations of the bucket torque caused by the base of the bucket, but found that there were calculation errors. After correcting these errors, we found the returning torque of an empty bucket to be 0.23 N-m. For future teams, it would be advised to purchase a friction damper instead of a fluid damper as these are much weaker.

References:

Aggarwal, Vikram. “How Much Energy Can a Solar Panel Produce in 2018? | EnergySage.” *Solar News*, EnergySage, 23 Oct. 2018, news.energysage.com/what-is-the-power-output-of-a-solar-panel/.

Chapman, Hans. “Design, Operation, and Analysis of a Floating Water Fountain System Using Renewable Energy Technology.” *Scholar.lib*, The Journal of Technology Studies, 2012, scholar.lib.vt.edu/ejournals/JOTS/v37/v37n2/pdf/chapman.pdf.

“CN203279604U - Automatic Plant Watering Device.” *Google Patents*, Google, 13 Nov. 2013, patents.google.com/patent/CN203279604U/en?oq=CN203279604U.

Dawn, et al. “Grape Solar 100-Watt Polycrystalline Solar Panel for RV's, Boats and 12-Volt Systems-GS-Star-100W.” *The Home Depot*, The Home Depot, 6 Nov. 2018, www.homedepot.com/p/Grape-Solar-100-Watt-Polycrystalline-Solar-Panel-for-RV-s-Boats-and-12-Volt-Systems-GS-Star-100W

Ekadewi A.Handoyo. “The Optimal Tilt Angle of a Solar Collector.” *NeuroImage*, Academic Press, 17 May 2013, www.sciencedirect.com/science/article/pii/S1876610213000246.

Gates, Christopher. “US6179218B1 - Solar Powered Water Fountain.” *Google Patents*, Google, 30 Jan. 2001, patents.google.com/patent/US6179218B1.

Kaushik. “The Bucket Fountain in Wellington, New Zealand.” *Amusing Planet*, Amusing Planet, 12 Dec. 2013, www.amusingplanet.com/2013/12/the-bucket-fountain-in-wellington-new.html.

“KR101146330B1 - Multi-Tipping Bucket Rain Recorder.” *Google Patents*, Google, 21 May 2012, patents.google.com/patent/KR101146330B1/en?q=tipping bucket&oq=tipping bucket.

Milivojevic, Milos. “BLACK TREE – A SOLAR CHARGING STATION / Milos Milivojevic.” *FORMAKERS - One Bucket at a Time / Factor Eficiencia + 5468796 Architecture*, FORMAKERS, 23 Mar. 2013, www.formakers.eu/project-705-milos-milivojevic-black-tree-a-solar-charging-station.

Overgaard, S. “Calibration of Tipping Bucket Rain Gauges.” *Watermark.silverchair.com*, Elsevier Science, 1998, https://www.scribd.com/document/331616481/Calibration-of-tipping-bucket-rain-gauge-pdf

Petersen, Matthew, and William Petersen. “US20100303654A1 - Portable,Solar Rechargeable Water Pumping System.” *Google Patents*, Google, 2 Dec. 2010, patents.google.com/patent/US20100303654A1.

References Continued:

PowerBee. “Solar Fountain Water Feature Tipping Pail.” *PowerBee - Solar Fountain Water Feature Tipping Pail*, PowerBee, www.powerbee.co.uk/solar-fountain-water-feature-tipping-pail.html.

Reichart, Chris John, and Gerald Gilbert Glass. “US9315088B2 - Method for Generating Electricity from Solar Panels.” *Google Patents*, Google, 19 Apr. 2016, patents.google.com/patent/US9315088

shysky tech. “Shysky Tech High Pressure Pumps, 1500LPH 10M High Lift, 5-12V DC Submersible Small Water Pump, Brushless DC Motor Driven Hot Water.” *Amazon*, Amazon, www.amazon.com/Shysky-Tech-Pressure-Submersible-Brushless/dp/B06X9XCH6V/ref=sr_1_17?m=AA8QYD006QBTB&s=merchant-items&ie=UTF8&qid=1541972246&sr=1-17.

“Solar Electric System Sizing Step 4 - Determine the Sun Hours Available Per Day.” *Solar Water Heating Systems: Solar Hot Water, Solar Water Heaters*, www.solardirect.com/pv/systems/gts/gts-sizing-sun-hours.html.

Solatec. “Solatec Solar Fountain, Black.” *Amazon*, Amazon, www.amazon.com/Solatec-Solar-Fountain-Black/dp/B077215M1R.

“Watering Can and Bucket Tipping Water Feature.” *Watering Can and Bucket Water Feature*, UK Water Features, www.ukwaterfeatures.com/products/watering-can-and-bucket-tipping-water-feature.html.

Waters, Shaun. “Over 2000 Years in Review: Revival of the Archimedes Screw from Pump to Turbine.” NeuroImage, Academic Press, 2 July 2015, www.sciencedirect.com/science/article/pii/S1364032115005985?via%3Dihub.

Appendices:

Appendix A - QFD House of Quality

Appendix B - Ideation, Pugh Matrices, and Morphological Matrix

Appendix C - Initial Testing Apparatus/Preliminary Analysis

Appendix D - Bill of Materials and Drawing Package

Appendix E - Wiring Diagram

Appendix F - Code

Appendix G - Purchased Parts Links

Appendix H - Project Budget

Appendix I - Design Analysis

Appendix J - Failure Modes & Effects Analysis and Risk Assessment

Appendix K - Design Hazard Checklist

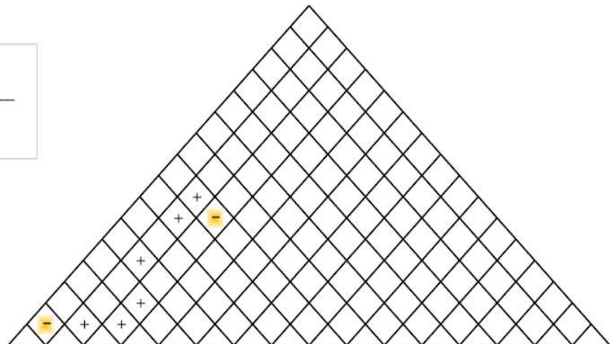
Appendix L - Risk Assessment

Appendix M - Operator's Manual

Appendix N - Design Verification Plan

Appendix O - Gantt Chart

Appendix A - QFD House of Quality



Correlations	
Positive	+
Negative	–
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: SOLAR FOUNTAIN

Revision Date: 10/15/18

Andy Kim
Jun Kim
Kota Ozawa
Joseph Ciolino

Row #	Weight Chart	Relative Weight	Gardeners	Outdoor Designer	Homeowners	Gary Epstein	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Time to tip	Flow rate	Cost	# of parts	Force req'd to knock over	Noise level	Survey results	Volume of water lost	Power Consumption	10	11	12	13	14	15	16	Our Current Product	Power Bee	Florence	solatec		Row #
	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products					
								Direction of Improvement	▲	▼	▼	▼	▲	▼	◇	▼	▼													
1		8%	5	6	9	10	9	Solar Powered	○	▽	●	○	○	▽	○	▽	●								?	8	0	10		1
2		9%	8	7	9	8	9	Durable	○	○	●	●	○	▽	○	●	▽								?	7	9	7		2
3		8%	7	7	9	4	9	Cheap	▽	▽	●	●	▽	▽	○	▽	○								?	5	4	9		3
4		9%	9	7	9	8	9	Ease of assembly	○	▽	○	●	▽	▽	○	▽	▽								?	7	7	9		4
5		9%	9	8	10	3	9	Leakproof	▽	○	○	▽	○	▽	▽	●	▽								?	8	8	3		5
6		9%	8	8	10	7	9	Stable	▽	▽	▽	○	●	▽	▽	▽	▽								?	8	8	4		6
7		10%	8	10	9	8	3	Clear water	▽	▽	○	▽	▽	▽	▽	▽	▽								?	8	9	8		7
8		9%	9	5	10	9	9	Low maintenance	▽	▽	○	●	▽	▽	▽	▽	▽								?	9	7	8		8
9		11%	8	10	10	10	9	Aesthetics	▽	▽	●	○	▽	▽	●	▽	▽								?	7	9	4		9
10		10%	8	8	10	10	9	Quiet	▽	●	▽	▽	○	●	●	▽	▽								?	5	6	3		10
11		7%	5	5	5	10	9	Slow tipping	●	●	▽	▽	○	○	▽	○	▽								?	3	8	0		11
12		0%																												12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

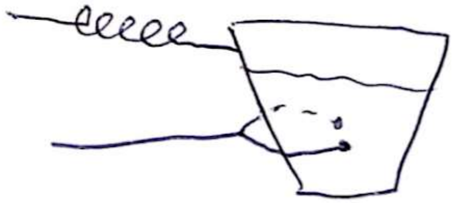
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	more than 3 seconds	100 gallons per hour	less than $500	less than 6	less than 50N	less than 40 db	greater than 10	less than 2 gallons	less than 5 W							
	Max Relationship	9	9	9	9	9	9	9	9	9							
	Technical Importance Rating	211.1	274.2	462.7	440.8	261.8	196.1	337.7	255.1	183							
	Relative Weight	8%	10%	18%	17%	10%	7%	13%	10%	7%							
Curr. Products	Our Current Product	?	?	?	?	?	?	?	?	?							
	Power Bee	2	3	10	1	7	7	?	8	8							
	Florence	?	10	4	5	10	8	?	10	3							
	solatec	0	6	10	10	7	7	?	6	8							
	0																
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B - Ideation, Pugh Matrices, and Morphological Matrix

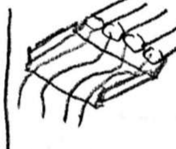
Brainstorming 10/23/18

hold buckets:

- coffee cup sleeve
- rope and pulley system
- magnet
- spring/dampeners
- weld side
- glue side
- glue/weld coffee cup sleeve
- poke through
- by hand
- hold from top
- velcro
- human hair
- rubber bands
- spider webs
- electromagnetic levitation
- invisible rod
- waterstreams float a bucket

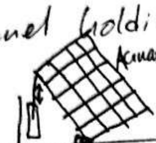
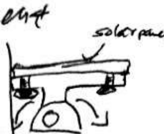
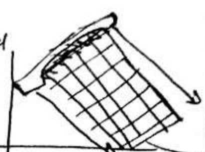


Pugh Matrix: Moving Water

	spout	spout w/ funnel	waterfall	end cap
				
Cheap	S	—	—	S
Durable	S	S	—	S
Ease of Assembly	S	—	—	S
Low Maintenance	S	+	S	—
Aesthetics	S	+	+	S
Slow Tipping	S	+	S	+

Pugh matrix

function: solar panel holding/Attachment

				
Does this idea have a competitive Advantage	S	S	S	—
Is there a clear need?	S	—	S	S
How big is the impact of idea	S	+	+	S
How much effort will it take to install	S	—	+	+
Aesthetic damage	S	—	+	+

Pugh Matrix: Holding Buckets – 11/5/18

	Coffee Cup Sleeve	Spring down middle	Welded side	Poke rod through	Welded side with spring
					
Leak Proof	S	S	S	—	+
Easy Assembly	S	—	—	S	—
Looks nice	S	—	S	+	S
Low maintenance	S	—	S	—	—
Slow tipping	S	S	S	S	+
Quiet	S	—	S	S	—
Stable	S	—	S	S	+
Net Score	Ø	-5	-1	-1	Ø

PUGH CHART FOR DAMPING

Features	weight	#1	#2	#3	#4
		 only mouth	spring	rubber band	weight
cost	7	0	—	—	—
easy set up	5	0	—	—	+
damping	9	0	+	+	+
durability	8	0	+	—	+
aesthetics	8	0	—	—	0
accuracy	9	0	—	—	0
+		0	2	1	3
0		6	0	0	0
—		0	4	5	1
net score		0	-21	-28	15

Morphological Matrix - 11/6/18

	Sub-Function	Concept I	II	III
1	Move water	Spout	Spout with funnel	Spout with cap
2	Solar Panels	Actuation	Mirrors	Tilt action
3	Hold bucket	Coffee cup sleeve	Poke rod through	welded side with spring
4	~~B~~ Damping	Spring	rubber band	weight

1) Spout with funnel, tilt action, Poke rod through, weight

2) Spout, Mirrors, Coffee cup sleeve, rubber band

3) Spout with cap, Actuation, Poke rod through, Spring

Appendix C - Initial Testing Apparatus/Preliminary Analysis

Figure C-1. Initial Testing Apparatus

Figure C-2. Two-Bucket Testing Apparatus

Solar Panel and Motor Power Calculations

11/11/2018

solar panel power calculations

30 inches — bottom basin radius.

we have approximately a $(30in)^2 \pi$ Area for the solar panel to cover.

Area = 2827.43 in²

Average solar panels for residential use

5ft x 3ft.

so the Area of a solar panel is.

$Areas_{SP}$ = 2160 in²

with a research of solar panels on Amazon, the average wattage for $100 was 100 watts with a average size of 1000 in²,

So we can afford to place 2 solar panels.

If this fountain were to be used in california, The lowest amount of peak daylight is in La Jolla, at 4.77 hours. (Solar Direct).

The basic calculation of a solar panel output is: (energy sage)

4.77 hours × 200 watts = 954 watts-hours

21

There is a motor off of amazon for $60, "shysky Tech High pressure Pump, 1500LPH 10m high lift, 5-12V DC submersible small water pump, Brushless DC Motor driven".

It takes 12V DC input, and provides nearly 30ft of life and takes 54 watts to power.

from previous calculations

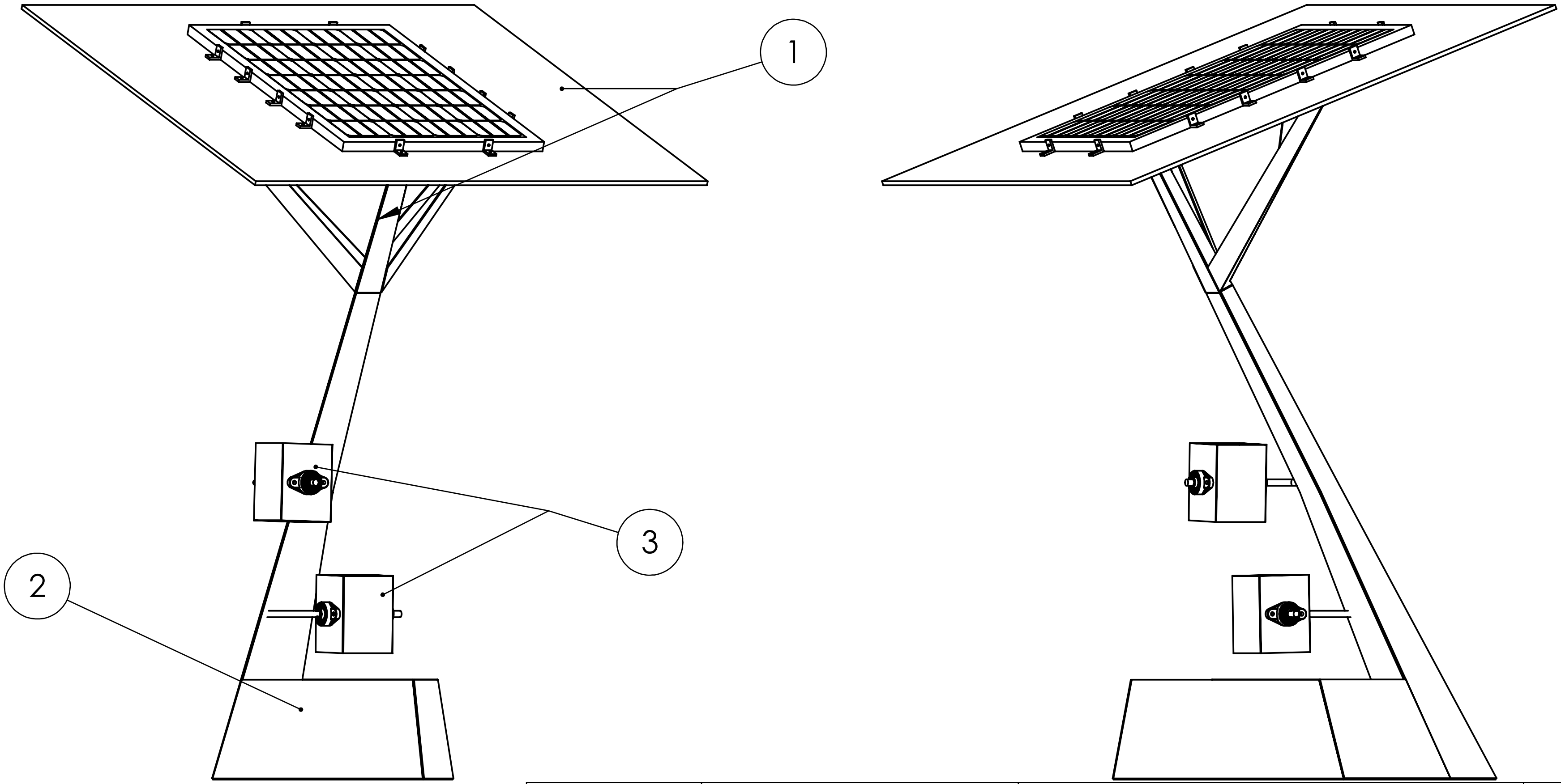
54 watts • 4.77 hours = 257.58 watts-hour.

The solar panel provides nearly 4 times the power required by the motor.

Appendix D - Bill of Materials and Drawing Package

Indented Bill of Materials (BOM)
Solar Fountain

Assembly Level	Part Number	Lvl0	Lvl1	Lvl2	Lvl3	Lvl4	Vendor	Qty	Cost	Ttl Cost
0	A	Final Assy					------------------			
1	A001		Solar Panel Assembly				------------------			
2	A001-1			Newpowa 100W 12V DC Solar Panel			Amazon	1	92.00	92.00
2	A001-4			Top Assembly: Upper Middle Planel			Coast Pipe	1	30.25	30.25
2	A001-5			Upper Side Panel			Coast Pipe	2	10.61	21.22
2	A001-6			Branch 1			Coast Pipe	4	10.61	42.44
2	A001-7			Branch 2			Coast Pipe	4	10.61	42.44
2	N/A			L - Bracket			Home Depot	12	1.10	13.15
1	A002		Bottom Structure				------------------			
2	A002-1			Basin Wall 1			Coast Pipe	2	10.61	21.22
2	A002-2			Basin Wall 2			Coast Pipe	2	10.61	21.22
2	A002-3			Basin Plate			Coast Pipe	1	10.61	10.61
2	A002-4			Structure Side Panel (shaft side)			Coast Pipe	2	10.61	21.22
2	A002-5			Structure Middle Panel			Coast Pipe	1	10.61	10.61
2	A002-6			Structure Upper-Middle Panel			Coast Pipe	1	10.61	10.61
2	A002-7			AUDBIG 12v DC Water Pump			Amazon	1	25.51	25.51
					Pump Filter Bag		Petco	1	7.53	7.53
2	A002-8			Structure Side Panel (switch panel)			Coast Pipe	1	10.61	10.61
3	A002-9				Pond Liner		Amazon	1	37.68	37.68
3	A002-11				Spray Paint		Amazon	5	6.00	30.00
3	N/A				Edge Trim		Amazon	1	17.00	17.00
1	A003		Bucket Assy				------------------			
2	A003-1			Top Shaft			McMaster	1	47.84	47.84
3	N/A				Hose Fitting		Home Depot	1	5.00	5.00
2	A003-2			Bucket			Coast Pipe	2	30.25	60.50
2	A003-4			Plastic Bearing			McMaster	4	96.74	386.96
2	A003-5			Bottom Shaft			McMaster	1	27.94	27.94
1	A004		Clear Hose				Amazon	1	17.61	17.61
1	A005		Wire				Amazon	1	8.80	8.80
1	A006		Switch				Amazon	1	0.00	0.00
1	N/A		Hose Clamp				Home Depot	2	1.06	2.12
1	N/A		Adhesive				Home Depot	6	12.99	77.92
	Total Parts							**63**		**1100.00**



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A001	Top Assembly: Solar Panel	1
2	A002	Bottom Assembly: Basin	1
3	A003	Bucket Assembly	1

	NAME	DATE
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Solar Fountain

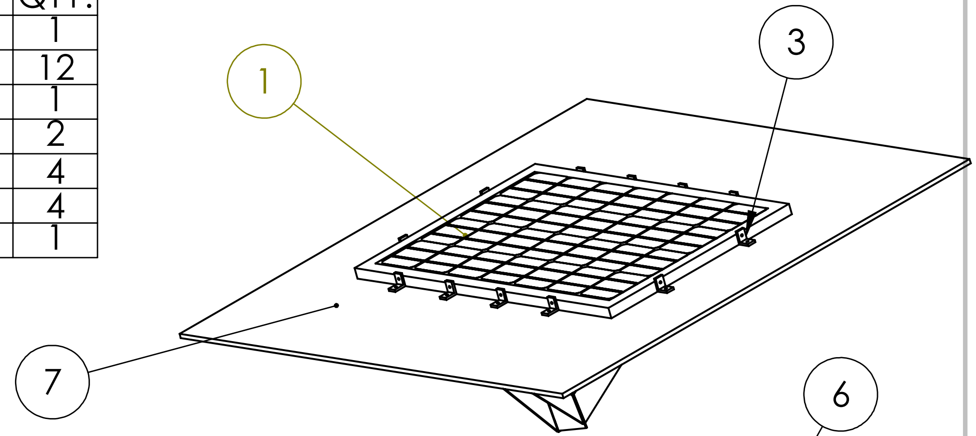
TITLE:
FINAL TREE ASSEMBLY

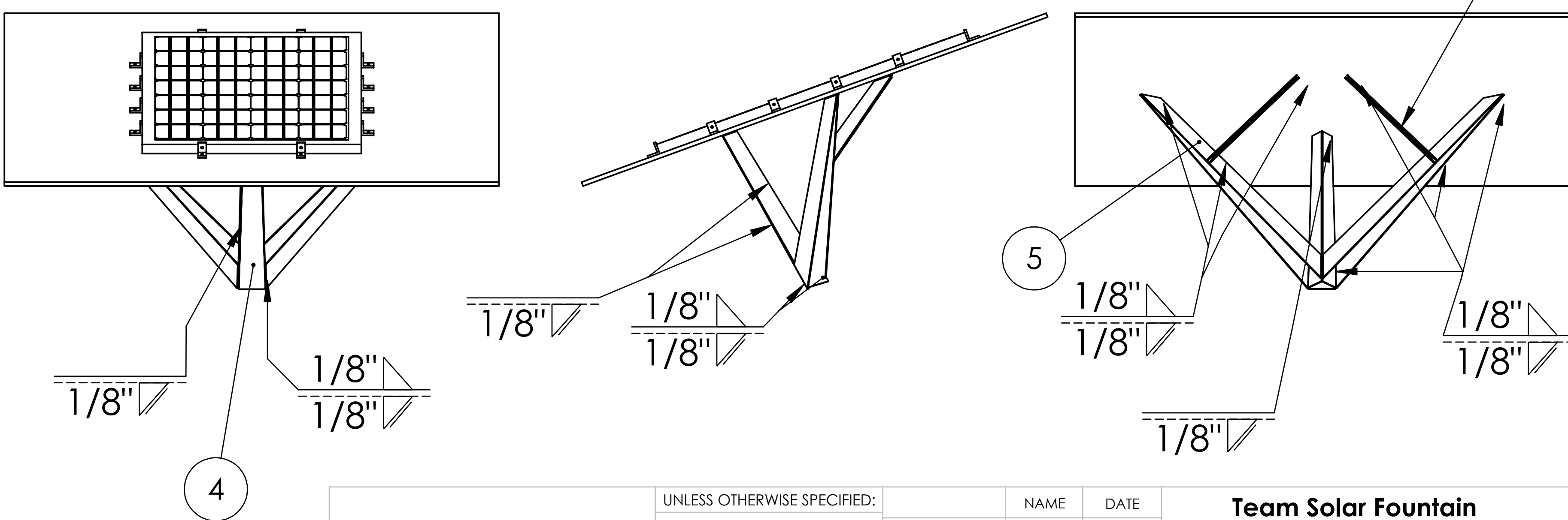
SIZE A | DWG. NO. A | REV A

SCALE1:20 | SHEET 1 OF 1

FINISH
PAINT PRIMER COATING

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A001-1	PV panel	1
2	A001-3	L - Bracket	12
3	A001-4	Upper middle panel	1
4	A001-5	Upper side panel	2
5	A001-6	Branch 1	4
6	A001-7	Branch 2	4
7	A001-8	Steel panel base	1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
MILD STEEL

FINISH
GROUNDED WELD BEADS
ANTI CORROSION COAT

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	KOTA O.	2/11/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

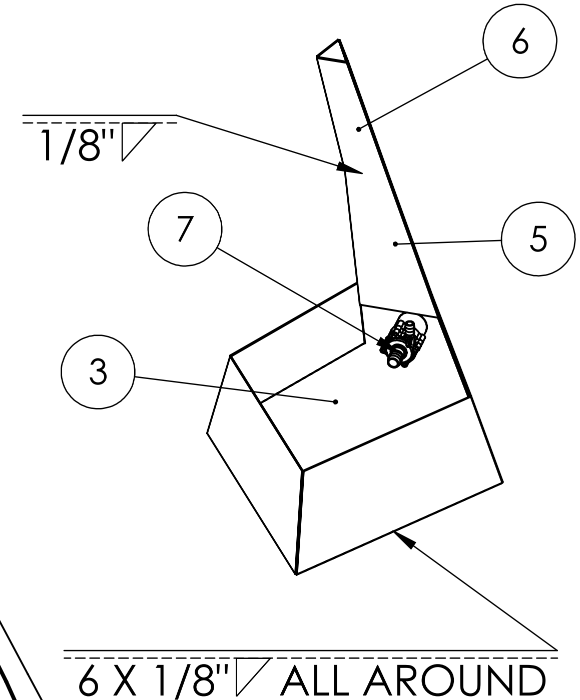
Team Solar Fountain

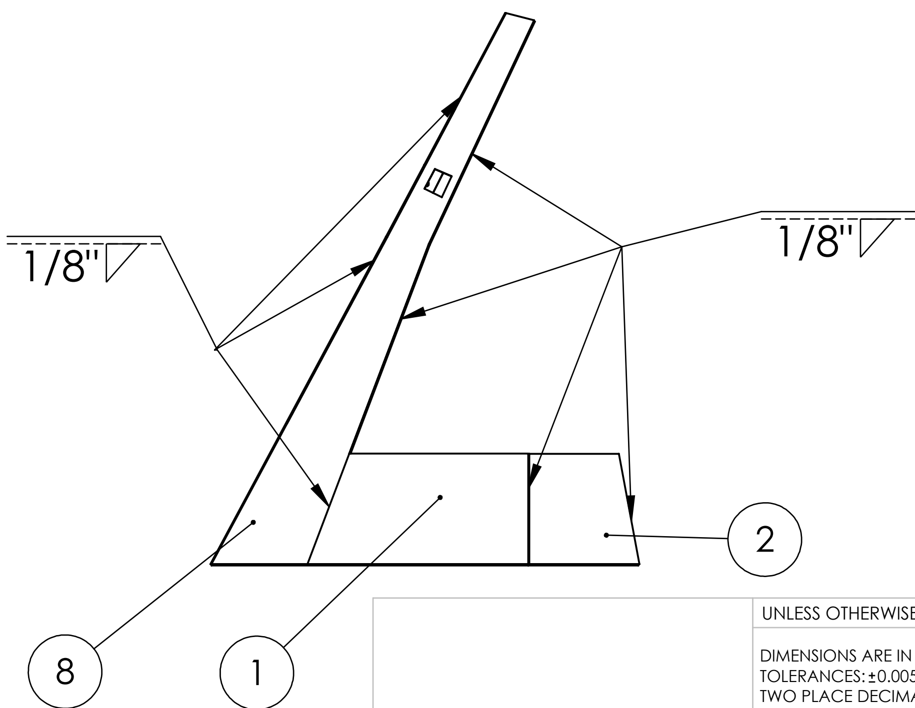
TITLE: Top Tree Assembly

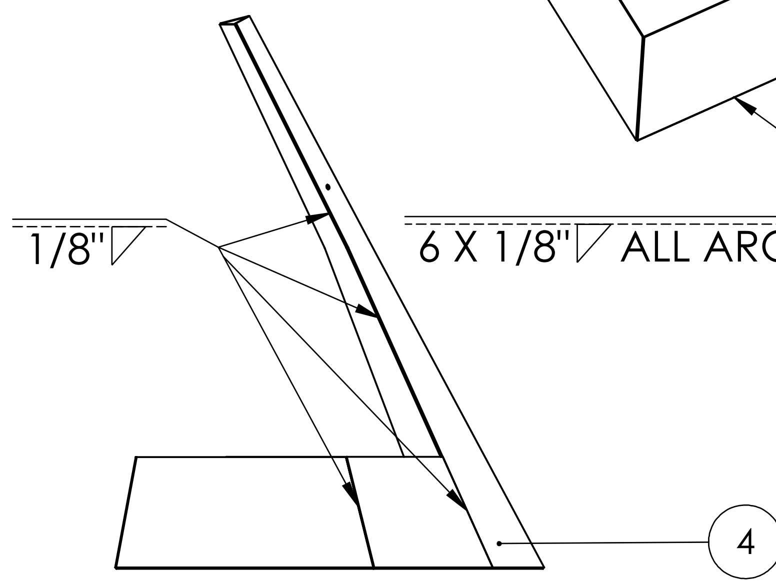
SIZE A | DWG. NO. A-001 | REV A

SCALE: 1:50 | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	A002-1	Basin wall 1	2
4	A002-2	Basin wall 2	2
8	A002-3	Basin plate	1
6	A002-4	Structure side panel(shaft)	2
5	A002-5	Structure middle panel	1
6	A002-6	Structure upper-middle panel	1
7	A002-7	AUDBIG 12v DC water pump	1
8	A002-8	Structure side panel(switch panel)	1

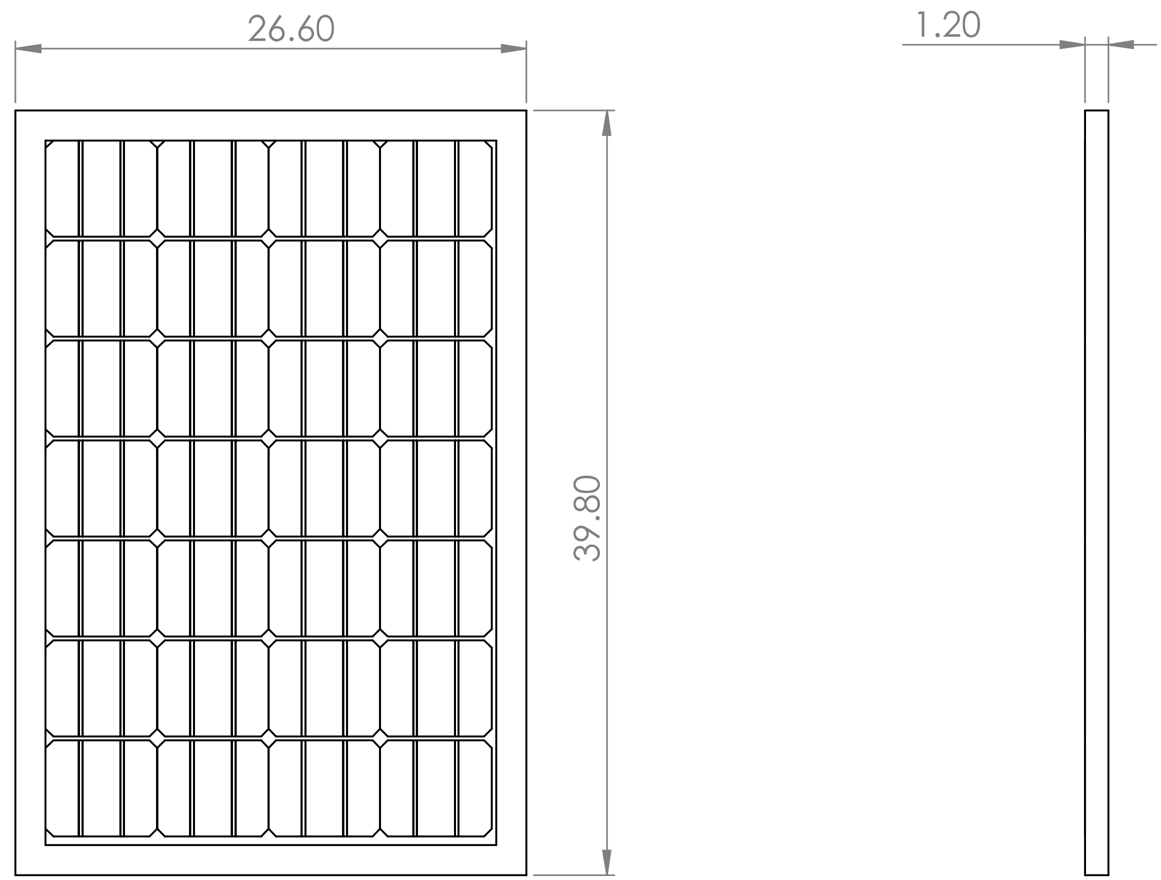






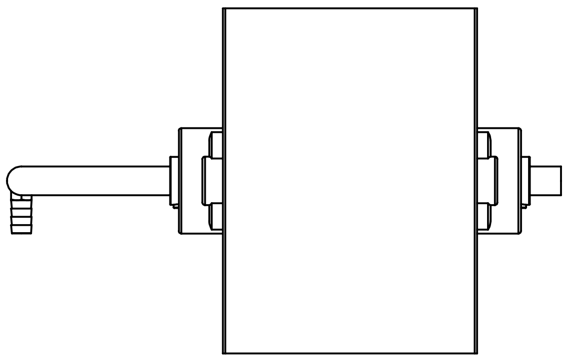
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team Solar Fountain
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19	TITLE: BOTTOM ASSEMBLY: BASIN STRUCTURE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL STEEL	COMMENTS:			SIZE **A** DWG. NO. A002 REV A
FINISH GROUNDED ALONG WELD BEADS				
DO NOT SCALE DRAWING				SCALE: 1:20 SHEET 1 OF 1

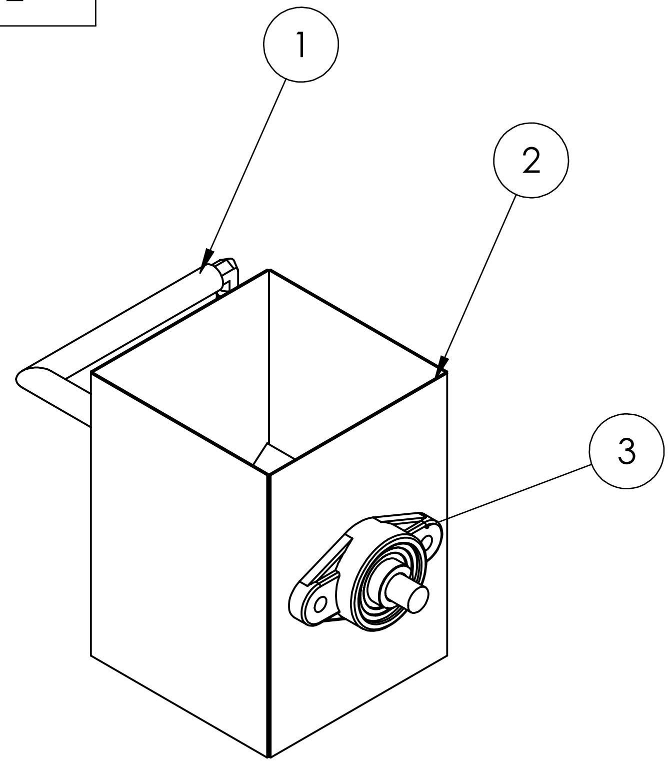
Purchased part with no modifications.



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	NewPowa
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE: NEWPOWA 100W 12V DC SOLAR PANEL
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A / DWG. NO. A001-1 / REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:10 / SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A003-1	Top shaft	1
2	A003-2	Bucket	1
3	A003-3	6357K46_ULTRA CORROSIVE RESISTANT BEARING	2





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DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL

FINISH
GROUND SHARP EDGES AND WELD BEADS

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	KOTA O	6/3/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

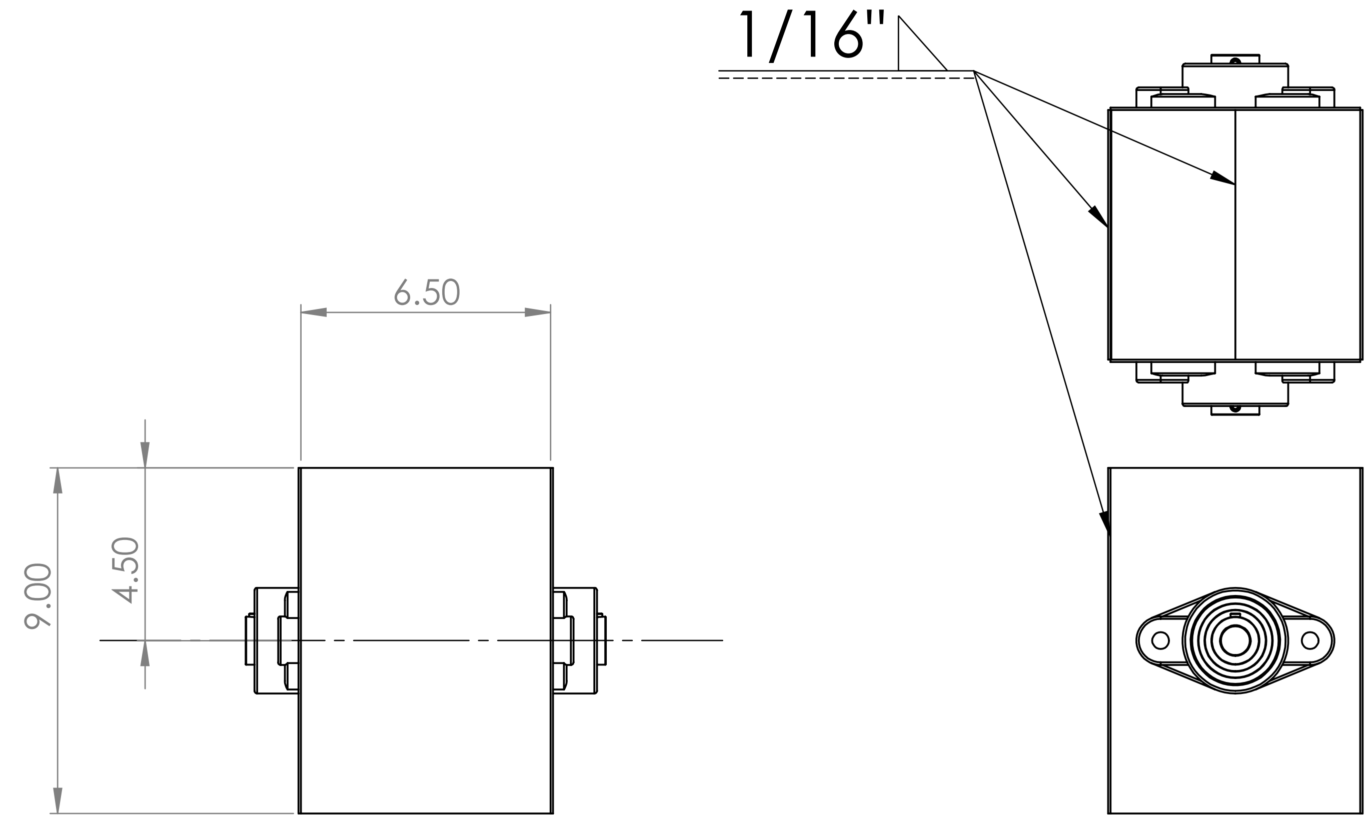
COMMENTS:

Team Solar Fountain

TITLE:
BUCKET ASSEMBLY

SIZE	DWG. NO.	REV
A	A003	A

SCALE: 1:5 SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Kota O	6/3/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Team Solar Fountain

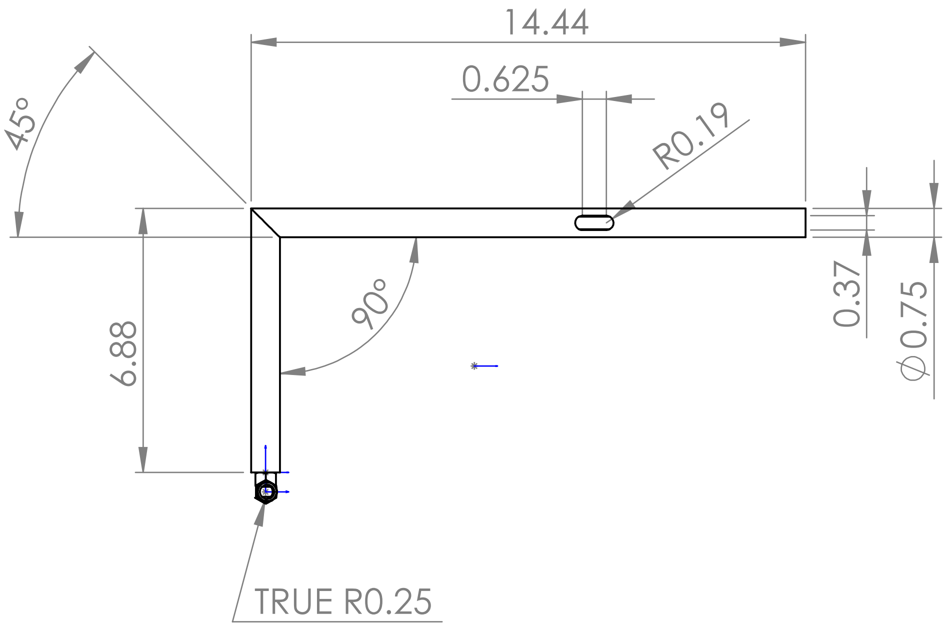
TITLE:
A003 - 2

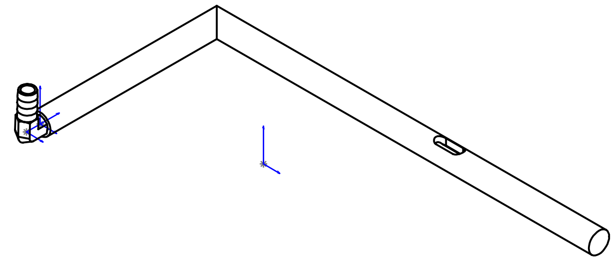
SIZE	DWG. NO.	REV
A	TOP BUCKET	

SCALE: 1:5 SHEET 1 OF 1

2 1

B B





A A

UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL STEEL		
FINISH GROUND SHARP EDGES		
DO NOT SCALE DRAWING		

	NAME	DATE
DRAWN	JUN K	6/3/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TEAM SOLAR FOUNTAIN

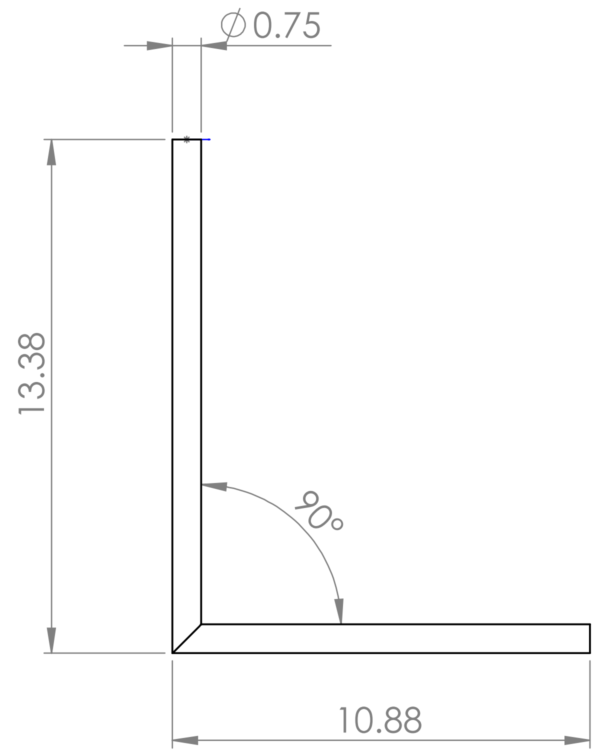
TITLE: Top Tube

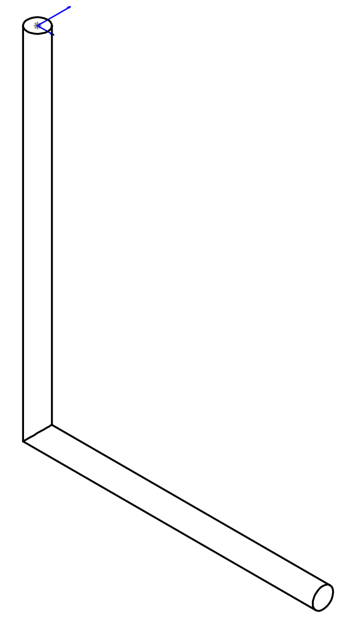
SIZE	DWG. NO.	REV
A	A003-1	B
SCALE: 1:5		SHEET 1 OF 1

2 1

2 1

B B





A A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL

FINISH
GROUND SHARP EDGES

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JUN K	6/2/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

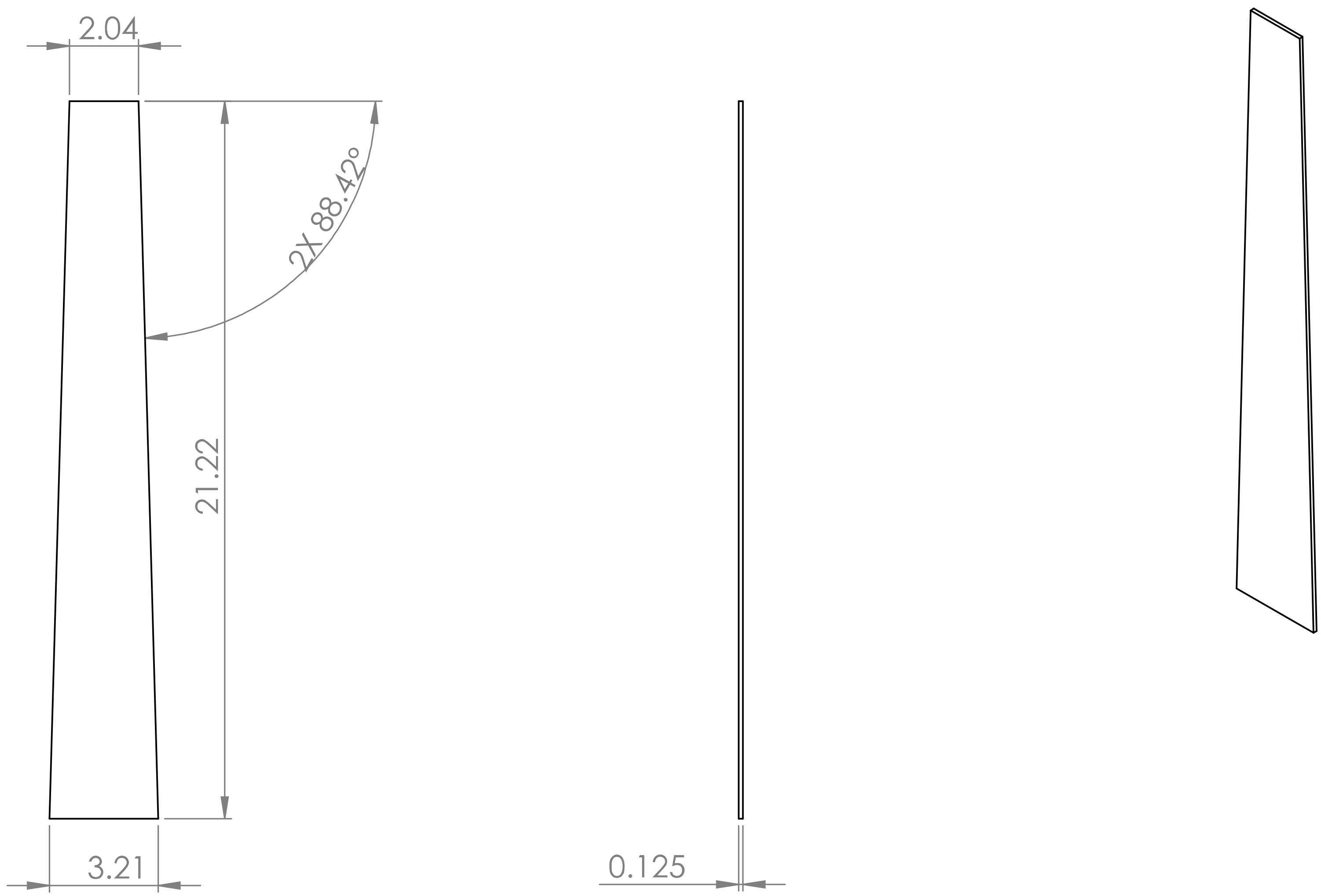
TEAM SOLAR FOUNTAIN

TITLE: BOTTOM SHAFT

SIZE	DWG. NO.	REV
A	B003-1	B

SCALE: 1:5 SHEET 1 OF 1

2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

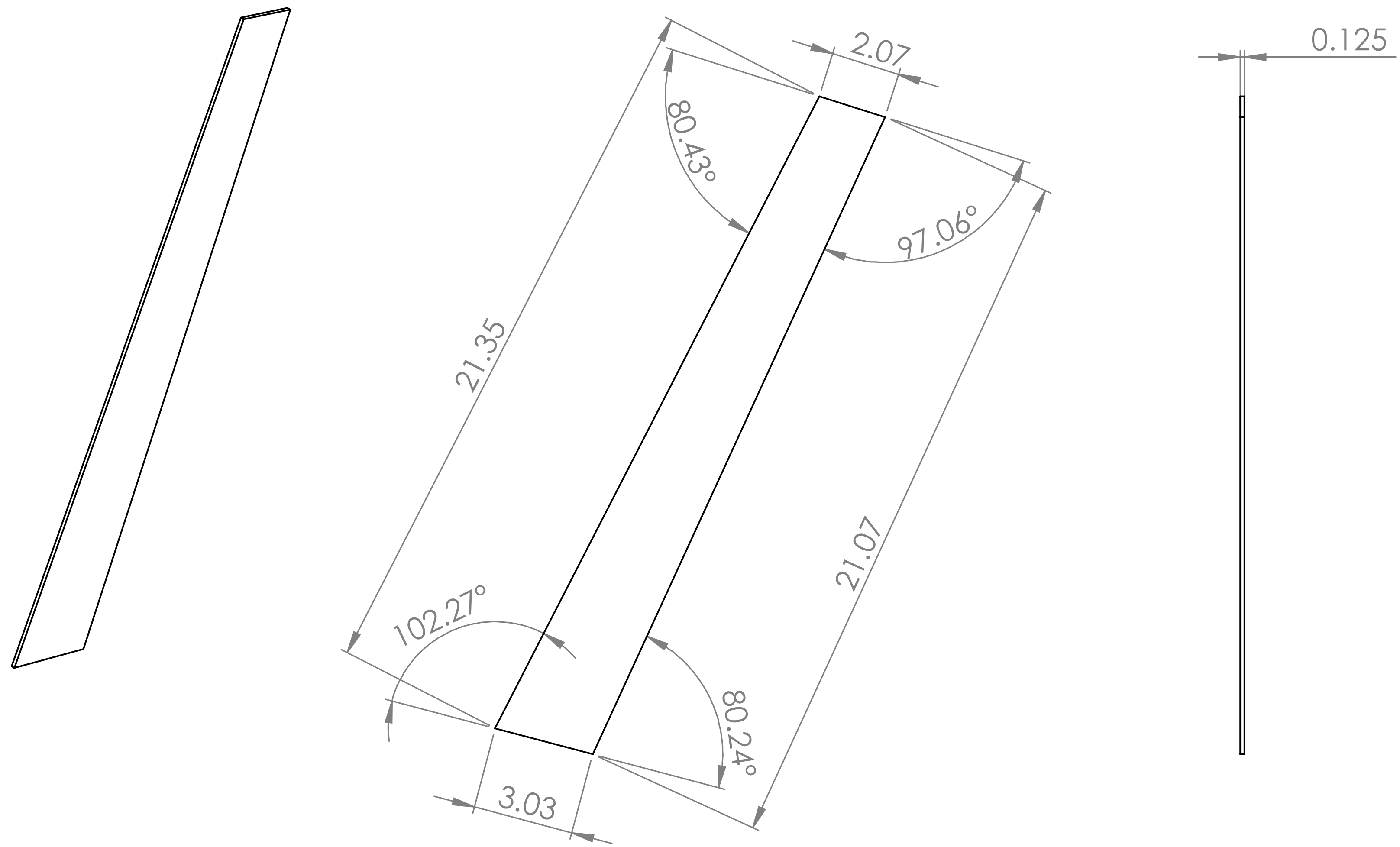
COMMENTS:

Team Solar Fountain

TITLE:
TOP ASSEMBLY: UPPER MIDDLE PANEL

SIZE A | DWG. NO. A001-4 | REV A

SCALE: 1:5 | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:	NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005		
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		
MATERIAL STEEL		
FINISH		

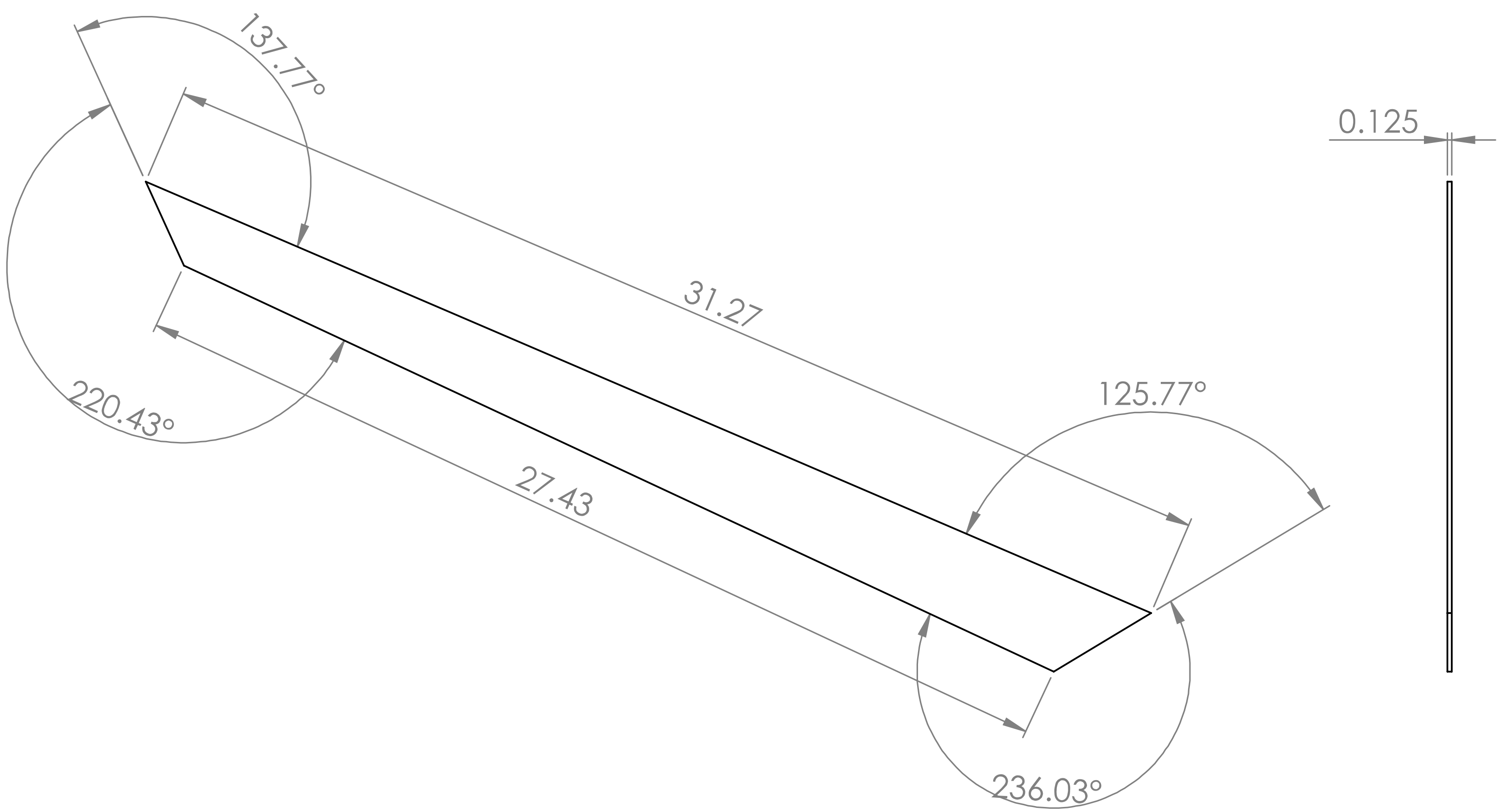
DO NOT SCALE DRAWING

Team Solar Fountain

TITLE:
UPPER SIDE PANEL

SIZE A | DWG. NO. A001-5 | REV A

SCALE: 1:5 | SHEET 1 OF 1



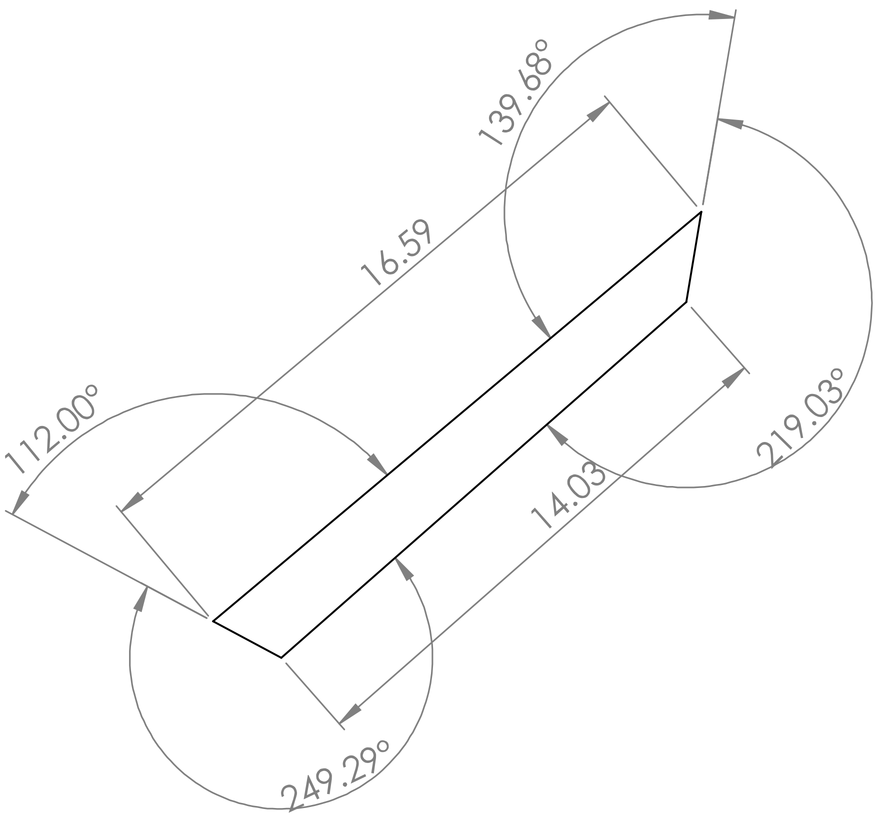
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH GROUND SHARP EDGES			
DO NOT SCALE DRAWING			

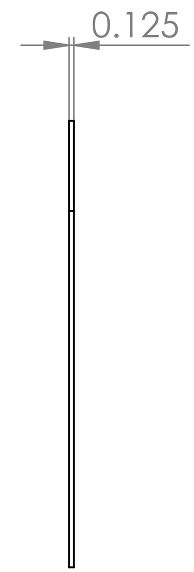
Team Solar Fountain

TITLE:
BRANCH 1

SIZE A | DWG. NO. A001-6 | REV A

SCALE: 1:5 | SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL

FINISH
GROUND SHARP EDGES

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

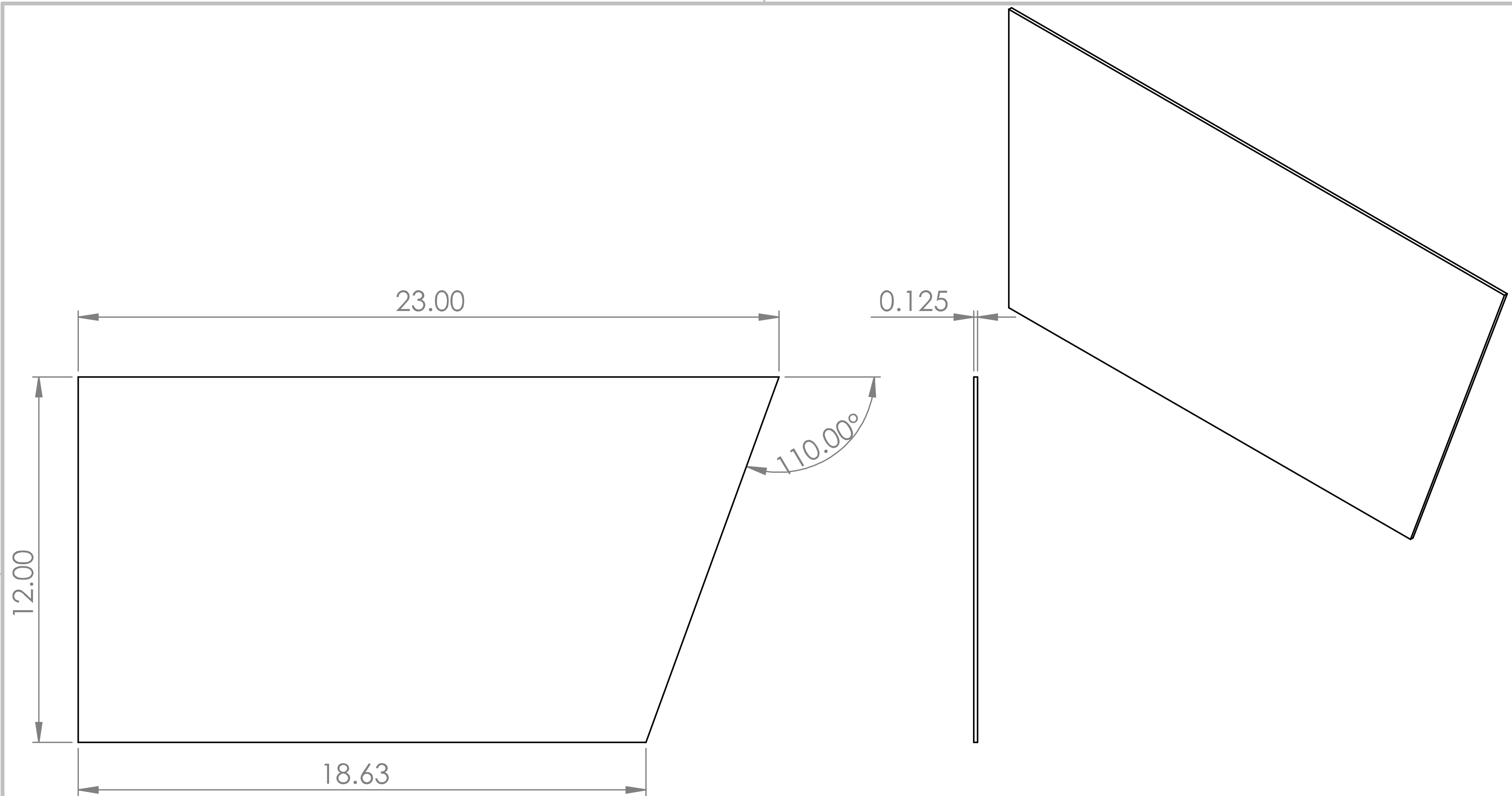
COMMENTS:

Team Solar Fountain

TITLE:
BRANCH 2

SIZE A | DWG. NO. A001-7 | REV A

SCALE: 1:5 | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL

FINISH
GROUND SHARP EDGES

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

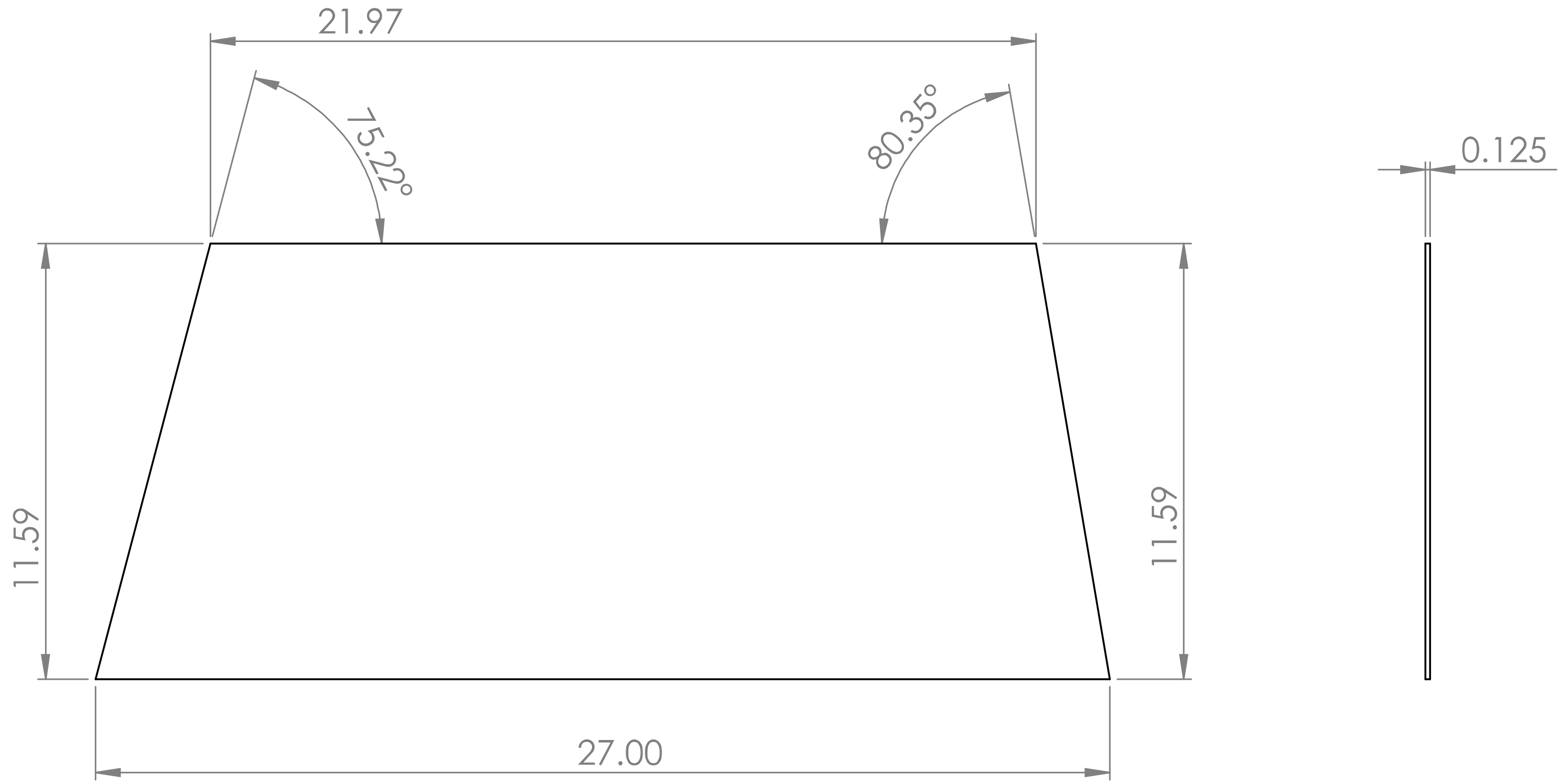
COMMENTS:

Team Solar Fountain

TITLE:
BASIN WALL 1

SIZE	DWG. NO.	REV
A	A002-1	A

SCALE: 1:5
SHEET 1 OF 1



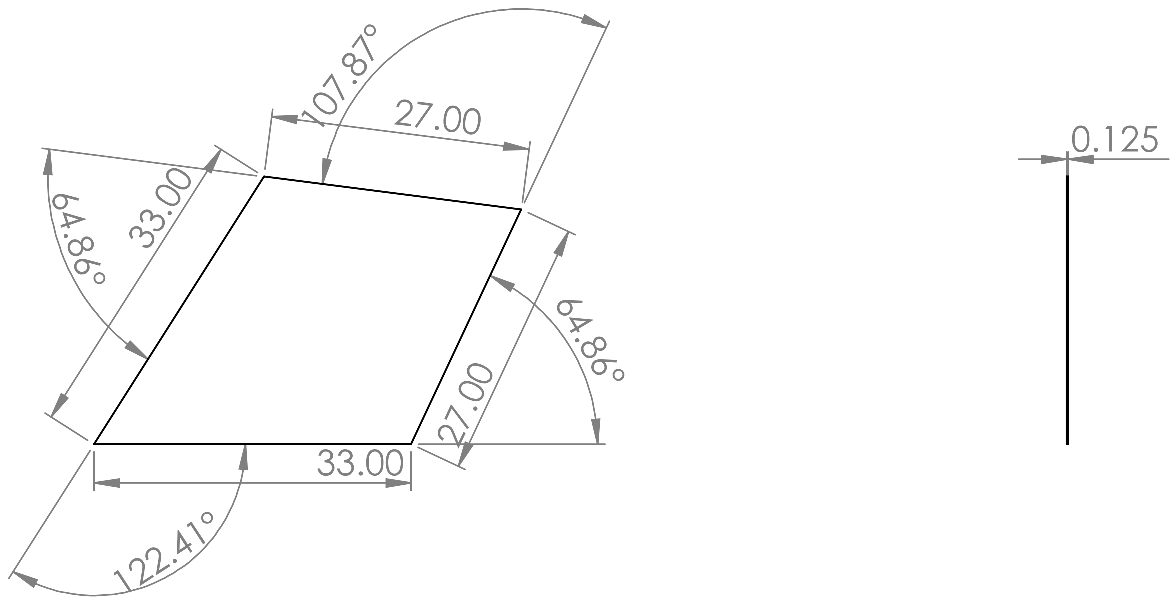
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH GROUND ANY SHARP EDGES			
DO NOT SCALE DRAWING			

Team Solar Fountain

TITLE:
BASIN WALL 2

SIZE **A** | DWG. NO. A002-2 | REV A

SCALE: 1:5 | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH GROUND SHARP EDGES			
DO NOT SCALE DRAWING			

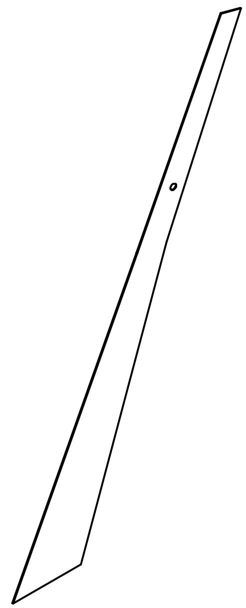
PROPRIETARY AND CONFIDENTIAL

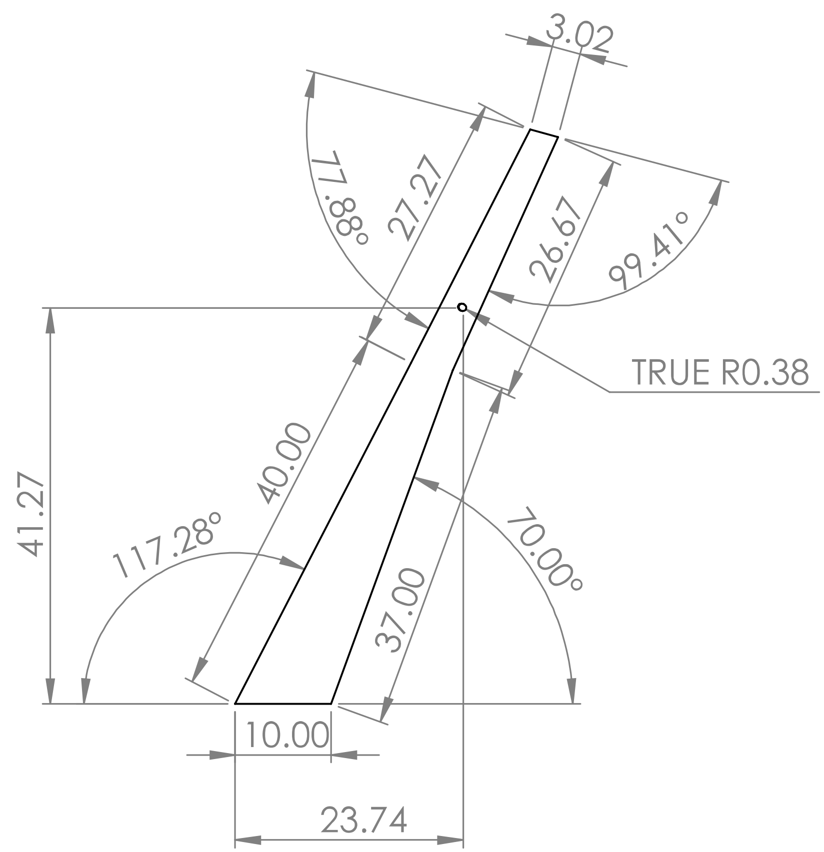
Team Solar Fountain

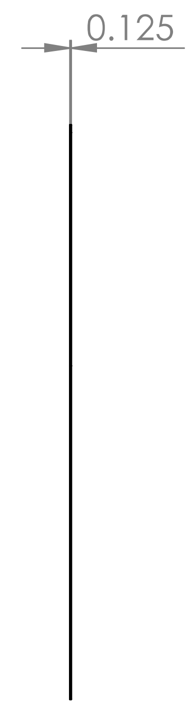
TITLE:
BASIN PLATE

SIZE	DWG. NO.	REV
A	A002-3	A

SCALE: 1:20 | SHEET 1 OF 1





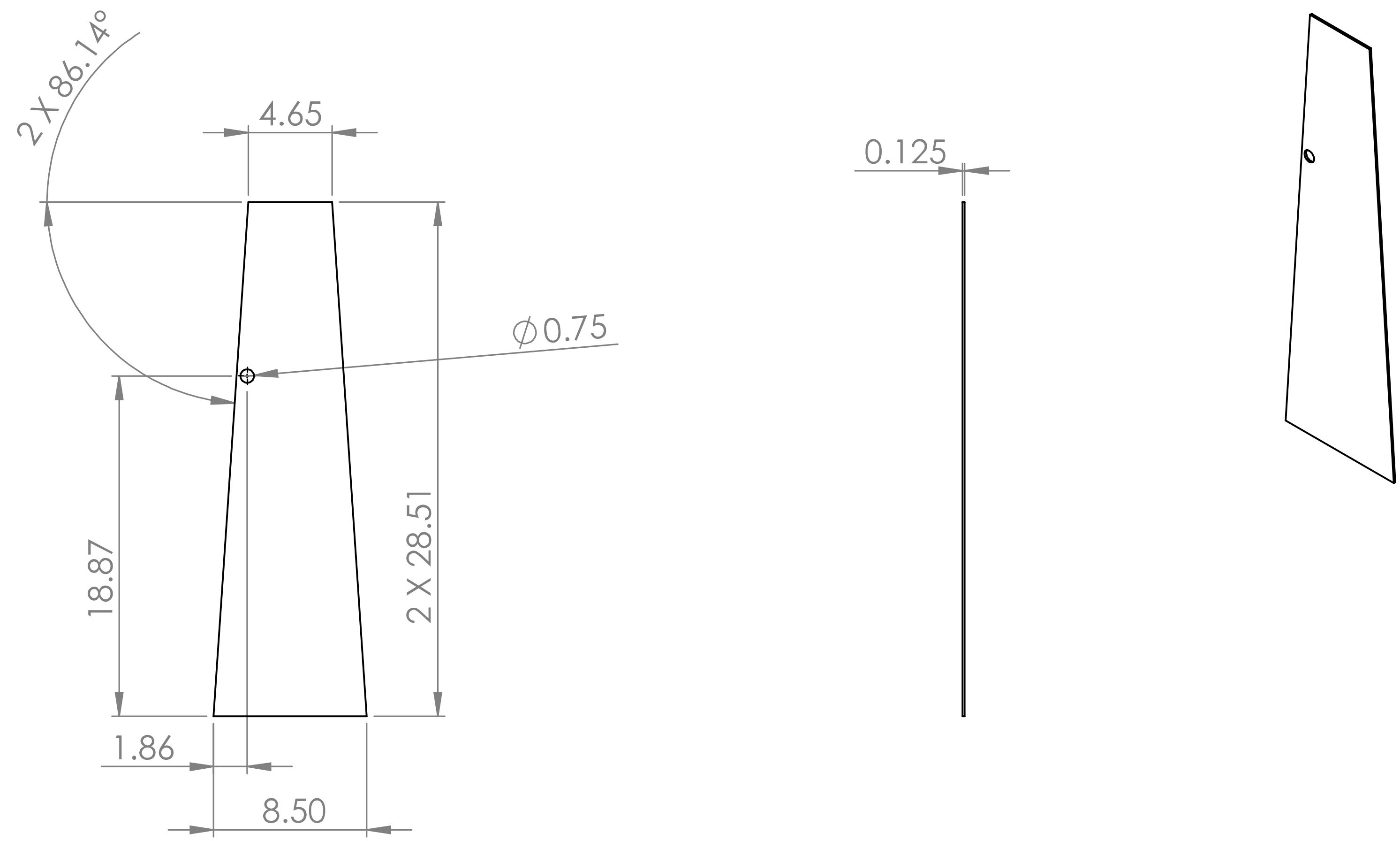


PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005 INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL STEEL FINISH GROUND SHARP EDGES DO NOT SCALE DRAWING		NAME	DATE
		DRAWN	KOTA O	2/13/19
		CHECKED		
		ENG APPR.		
		MFG APPR.		
		Q.A.		
		COMMENTS:		

Team Solar Fountain

TITLE:
STRUCTURAL SIDE PANEL(SHAFT SIDE)

SIZE	DWG. NO.	REV
A	A002-4	A
SCALE: 1:20		SHEET 1 OF 1



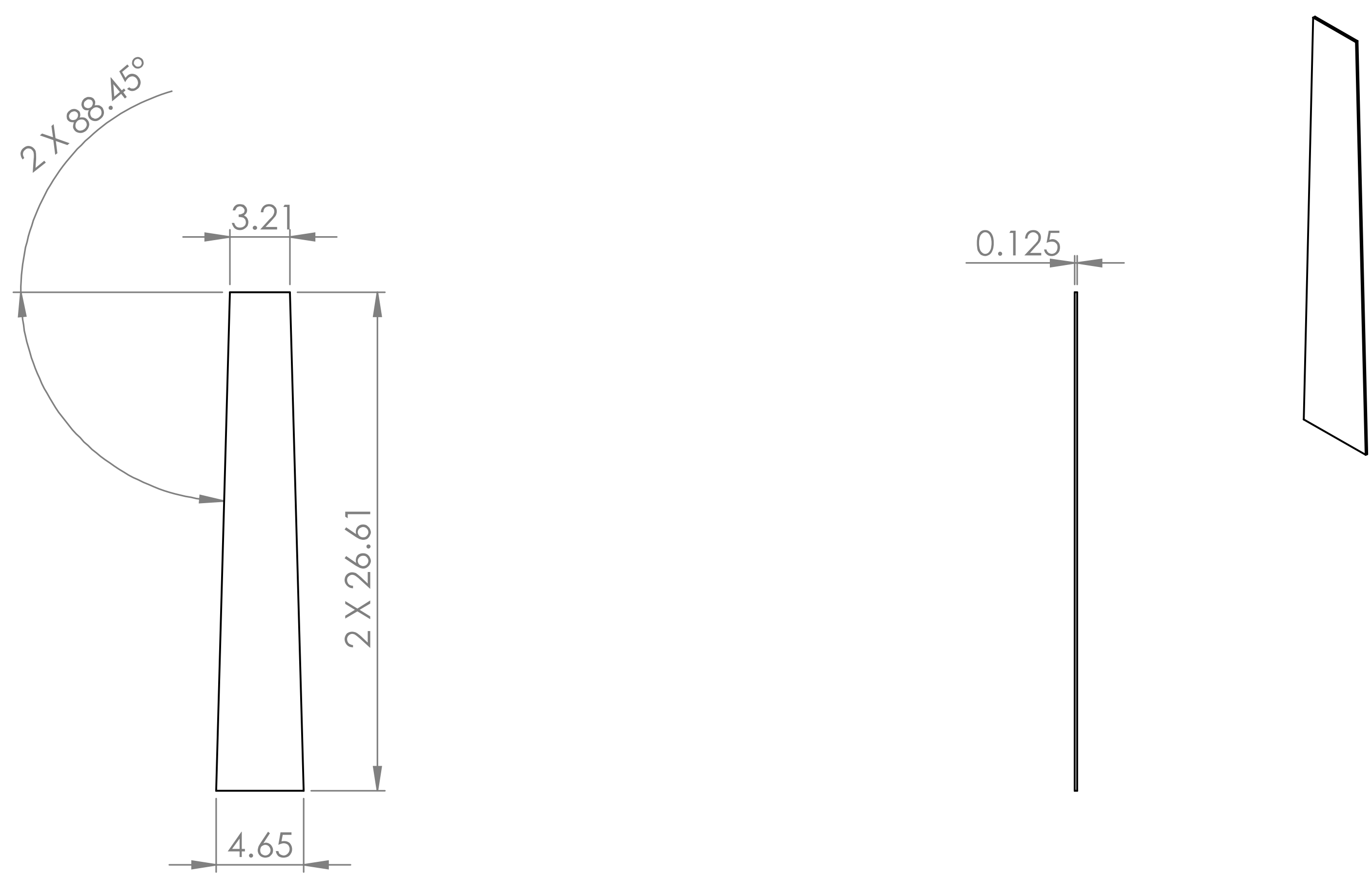
UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL STEEL		
FINISH GROUND SHARP EDGES		
DO NOT SCALE DRAWING		

	NAME	DATE
DRAWN	KOTA O	2/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Team Solar Fountain

TITLE:
STRUCTURAL MIDDLE PANEL

SIZE	DWG. NO.	REV
A	A002-5	A
SCALE: 1:10		SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH GROUND SHARP EDGES			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

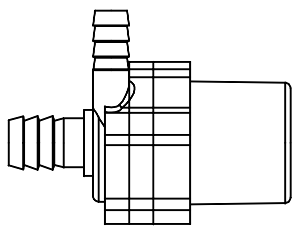
Team Solar Fountain

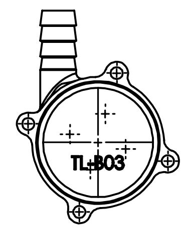
TITLE:
STRUCTURAL UPPER-MIDDLE PANEL

SIZE	DWG. NO.	REV
A	A002-6	A

SCALE: 1:10 | SHEET 1 OF 1

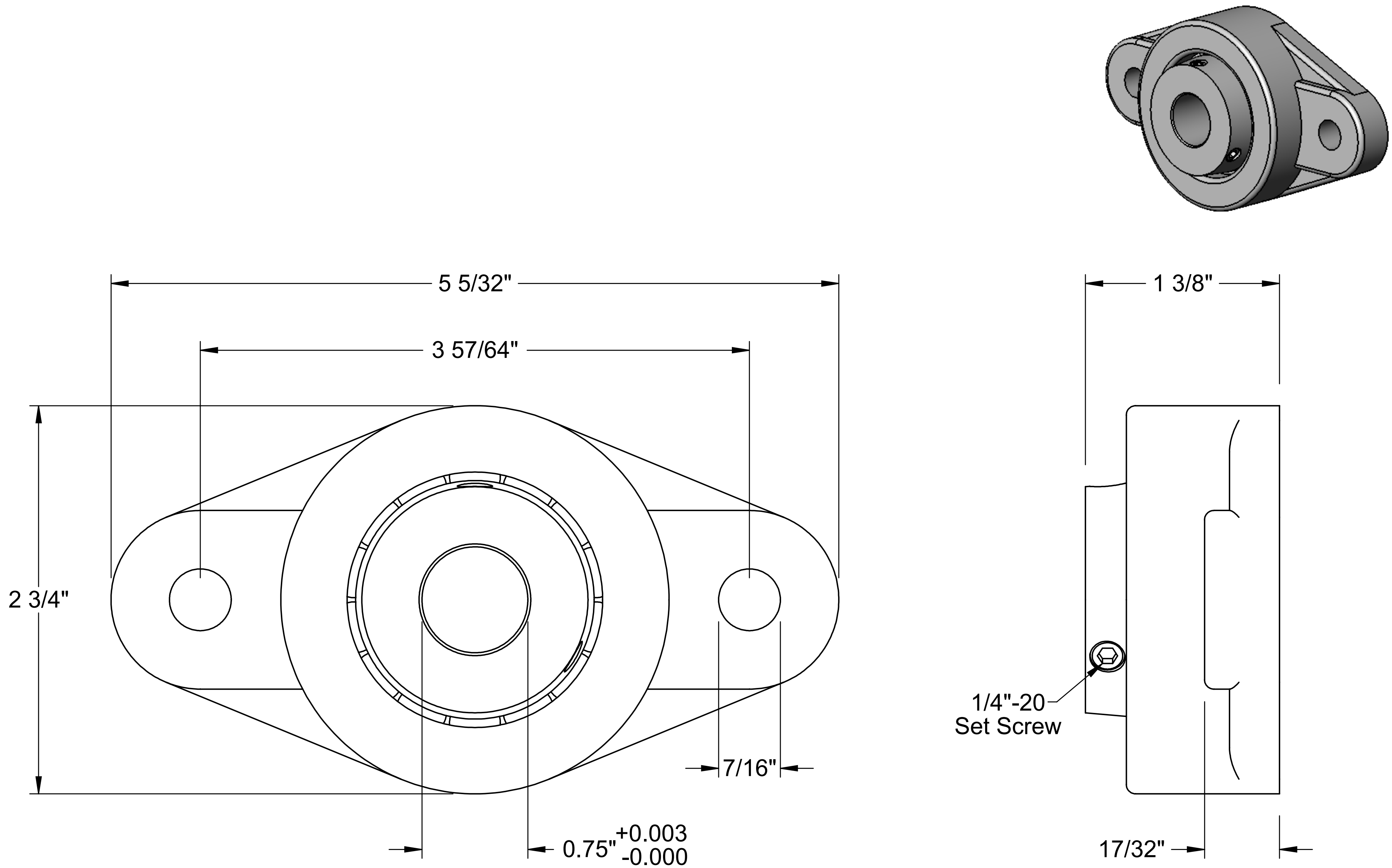
Purchased part with no modifications.





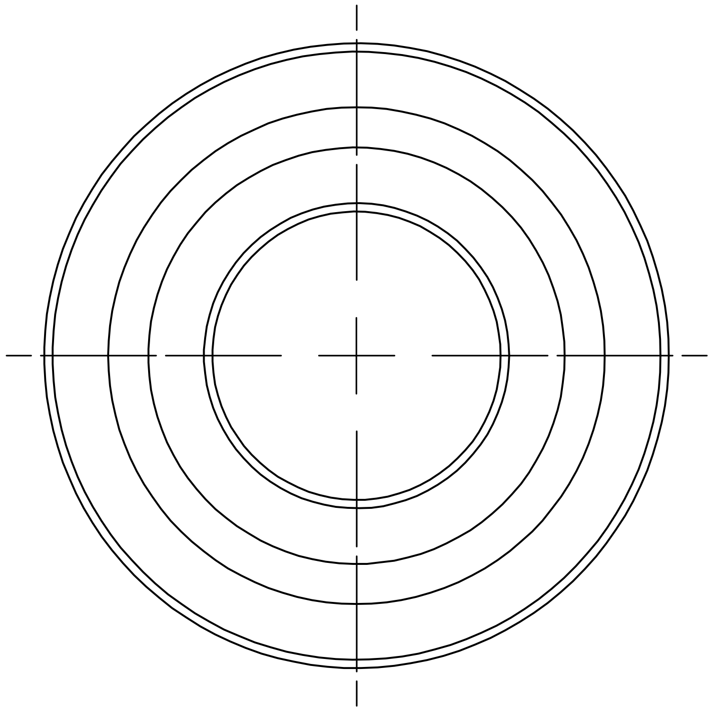
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AUBIG	
DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19	TITLE: AUBIG 12V DC FOUNTAIN PUMP DC40-1250	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL	COMMENTS:			SIZE A	DWG. NO. A002-7 / REV A
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:5	SHEET 1 OF 1

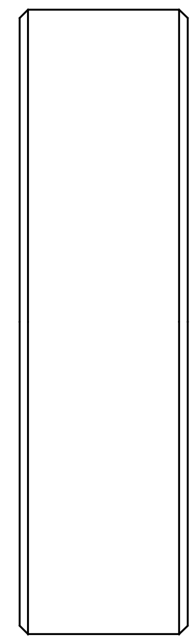
NEXT ASSY	USED ON
APPLICATION	



McMASTER-CARR® CAD	PART NUMBER	7192K55
http://www.mcmaster.com © 2017 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Ultra-Corrosion-Resistant Mounted Ball Bearing with Two-Bolt Flange	

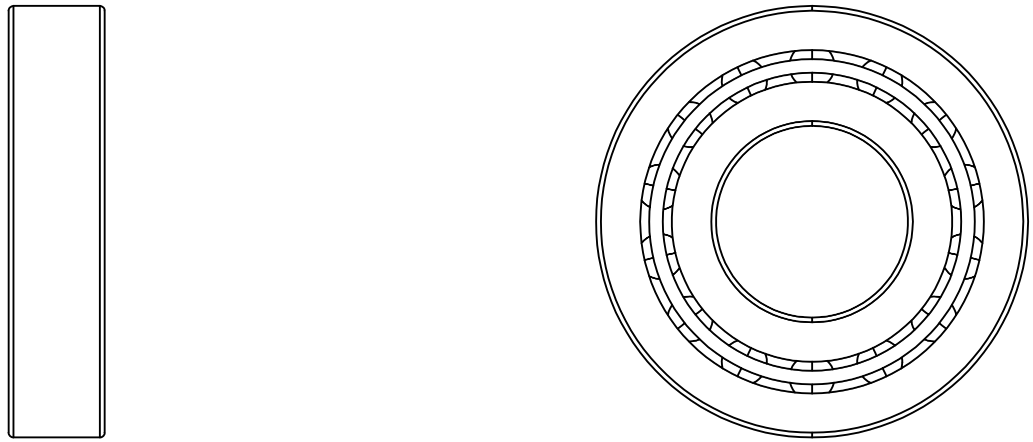
Part purchased as is, no modifications made.





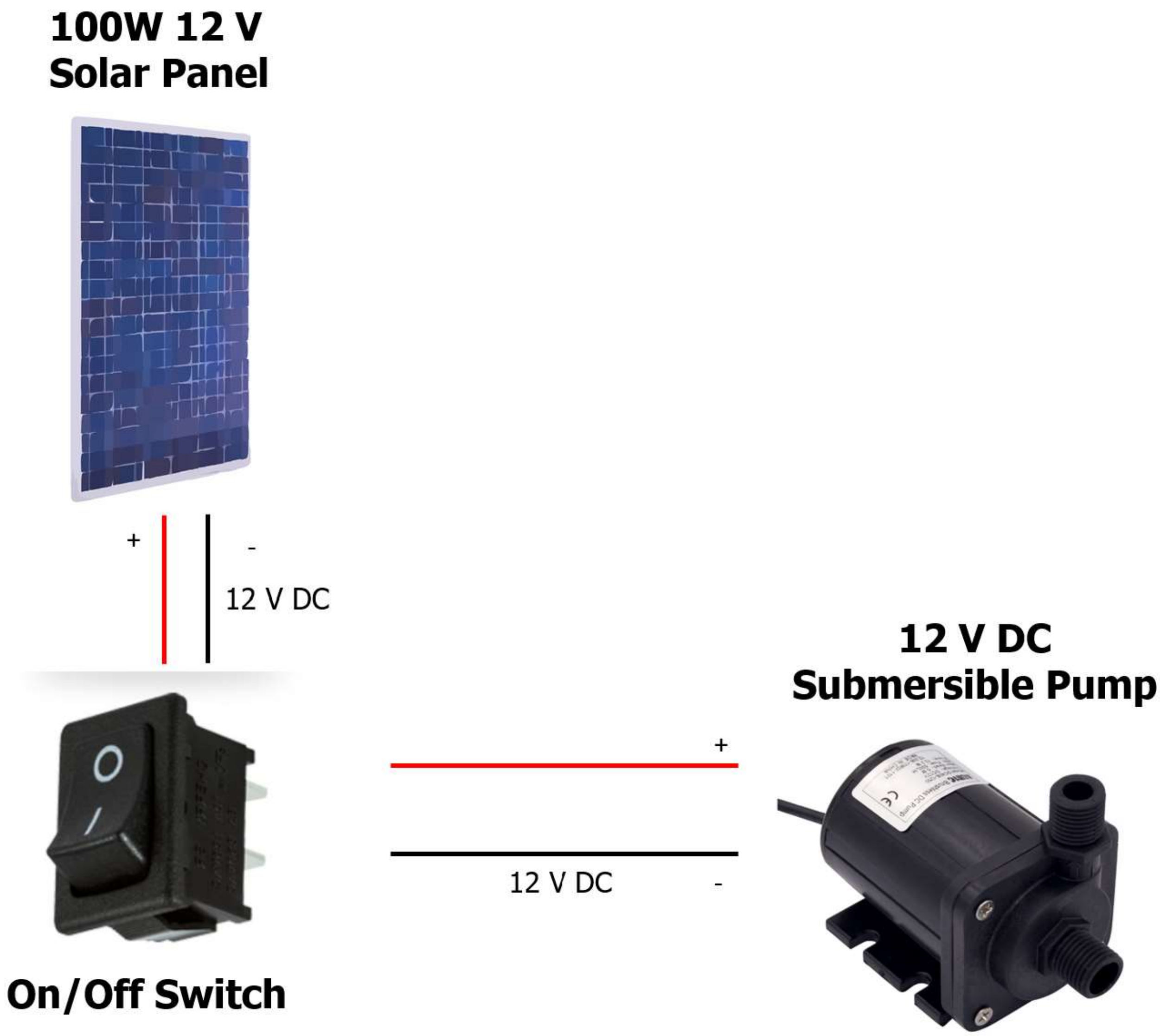
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MCMASTERCARR
		DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19	TITLE: 3/4" BALL BEARINGS
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. A003-4 · REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1 · SHEET 1 OF 1

Part purchased as is, no modifications made.



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MCMASTERCARR
		DIMENSIONS ARE IN INCHES TOLERANCES: ±0.005 TWO PLACE DECIMAL ±0.05 THREE PLACE DECIMAL ±0.005	DRAWN	KOTA O	2/13/19	TITLE: 1/2" BALL BEARINGS
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A
NEXT ASSY	USED ON	FINISH				DWG. NO. A003-4
APPLICATION		DO NOT SCALE DRAWING				REV A
						SCALE: 2:1
						SHEET 1 OF 1

Appendix E - Wiring Diagram



Appendix F - MATLAB Code

Table of Contents

initialization

```
t = 0;
theta = -17*pi/18;     % ! Equivalent to #170 degrees; bucket almost
 upside down.  (radians)
omega = 0 ;
H = 0.2286; %height of the bucket walls  (m)
%H_water = H-;%height of the bucket above the fake bottom. the part
 that carries water.
W = 0.1651;  %width of the bucket
L = 0.1651; %length of the bucket
V = H*W*L; %volume of inside the bucket
%Mc = 20;%      ! Total mass of the four walls of the rectangular
 bucket  (kgm)
%Mb = 0.05;%  ! Mass of bottom of rectangular bucket  (kgm)
%M = Mc + Mb;%
g = 9.81;%        ! Acceleration of gravity   (m/s^2)
```

Mass of the bucket

```
WLR = L;     %! Width of left and right walls  (m)
Thickness = 0.0015875;  %! Thickness of steel sheets (m)
WFR = (0.0015875 + 2*Thickness);%  ! Width of front and rear walls (m)
AFW = H*WFR;%  ! Area of front wall  (m^2)
ALW = H*WLR;%  ! Area of left wall (m^2)
VFW = AFW*Thickness;%  ! Volume of front wall (m^3)
VLW = ALW*Thickness;%  ! Volume of left wall (m^3)
V4W = 2*VFW+2*VLW;%  ! Total volume of all four walls (m^3)
denSteel = 7850;%   ! Density of steel  (kgm/m^3)
denH2O = 1000;%(kgm/m^3)
m1 = V4W*denSteel;%  !  Total mass of all 4 bucket walls  (kgm)
Abot = ((W/2)/sind(50))*L*2;%   ! Area of bucket bottom  (m^2)
Vbot_water = (0.5*L*cosd(50)*((L/2)/sind(50)))*L;
Vbot = Abot*Thickness;%   ! Volume of bucket bottom  (m^3)
m2 = Vbot*denSteel+Vbot_water*denH2O;%    !  Mass of bucket bottom
 (kgm) + the magnets added(8g each)
Abot2 = W*L;%! Area of #new bottom# of bucket  (m^2)
Vbot2 = Abot2*Thickness;%    ! Volume of #new bottom# of bucket
 (m^3)
denFakeBottom = 1180; %Density of the "new bottom" of bucket(kg/m^3)
%m3 = Vbot2*1180;%    ! Mass of #new bottom# of bucket  (kgm)
m3=0;
```

```
z_rotation = 0;% The height of the rotation of the bucket from middle.
z = 0; %This is the center of mass of the bucket, the shaft location,
 and center of rotation.
z_1 = -0.215*H; %This is the center of mass of the fake bottom of the
 bucket.
z_2 = -0.5*H; %This is the center of mass of the  bottom of the
 bucket.
z_initial = (m1*z+m2*z_1+m3*z_2)/(m1+m2+m3);%This is the center of
 mass from the middle of the bucket
H_water = 0.5*H-z_1;
V_water_inside = H_water*W*L;
```

This is some geometry stuff

zcm = (Mc*0 + Mb*(-H/2))/(Mc+Mb); % D = zcm ; Ic = (1/8)*Mc*H^2 + (1/6)*Mc*W^2;% ! Total moment of inertia of the 4 walls of the bucket about the shaft Ib = (1/12)*Mb*W^2 + Mb*(-H/2)^2 ;% Itot = Ic + Ib ; %! Total moment of inertia about shaft

```
%rs = sqrt(4*M*g*Itot*(abs(D)));%    !  Critical damping resistance
 (kilogram meter^2/sec^2)
%rs = 0.5;    %!  Any other resistance you#d like to try out.
% %% Bucket tipping
% figure()
% while t < 60
% z_t = -0.4*H+0.0015
% %Provide initial Conditions:
%              %    ! Angular velocity zero means starting from rest.
                  (radians/sec)
% %REM  Solving Newton#s 2nd Law for rotary motion of physical
 pendulum (using a simple numerical method)
% dt = 0.2;    %! Time step for numerical integration
% %t = 0 to 45 step dt;
%
% alpha = M*g*D*sin(theta)/Itot - rs*omega/Itot;  %  !  Computing
 angular acceleration from differential equation
% omega = omega + alpha*dt ;    %! Updating angular velocity
% theta = theta + omega*dt;     %  ! Updating angular displacement
% figure(1)
% hold on
% plot  (t, theta,'.');
% %  !  Plot of angular displacement vs. time
% %! plot theta,omega;    !  Plot of angular velocity vs. angular
 displacement.  (so-called #phase portrait#)
%
% t=t+0.2
% end
```

Bucket tipping time graph

```
t = 0;
%figure()
 i = 1;
% Zcm = [];
```

```
% M = [];
t_array = [];
z_water_change_rate = (1E-5)/(W*L);%m/s
while t<700
    dt = 1;%      ! Time step  (second)
z_top_of_water = (z_1)+(z_water_change_rate)*t;%The coordinates of the
 top of the water column.
z_bottom_of_water = z_1;%The coordinates of the bottom of the water
 column.
z_t = (z_top_of_water + z_bottom_of_water)/2;%Center of mass of the
 water.
m4 =(z_top_of_water-z_bottom_of_water)*W*L*denH2O;
Zcm = (m1*z + m2*z_1 + m3*z_2 + m4*z_t)/(m1 + m2+ m3 + m4);
M = m1 + m2 + m3 + m4;
%plot(t,Zcm,'+');
% plot(t,M,'+');
%hold on
if Zcm < z_rotation
    z_top_final = z_top_of_water;
    z_tip_final = Zcm;
    t_flip = t;
    M_max = M;
    water_mass_tip = m4;
    V_water = (z_top_of_water - z_bottom_of_water)*W*L;
    V_ratio = (V_water/V_water_inside)*100;
end
if z_top_of_water < H
    t_spill = t;

end

t_array(i) = t;
t=t+1;
i = i+1;

end
m_ratio = (water_mass_tip/(m1+m2))*100;
disp("V of water:    "+V_water);
disp("V_ratio:   "+V_ratio);
disp("m_ratio:   "+m_ratio);
 disp("Top of water:   " +z_top_final);
 disp("Height of COM:   "+z_tip_final);
% figure()
% plot(t,Zcm);
% figure()
% plot(t,M);
%  disp(t_flip);
%  disp(t_spill);
 disp(M_max);
 disp("Mass of the water:    "+water_mass_tip);
% disp(m3);
% disp(m2);
 disp("Mass of the bucket:    "+m1);
 disp("initial center of mass:    "+z_initial);
```

```
V of water:    0.00368
V_ratio:   82.5984
m_ratio:   156.2446
Top of water:   0.085857
Height of COM:   -0.00010771
    6.0353

Mass of the water:    3.68
Mass of the bucket:    0.9678
initial center of mass:    -0.028953
```

BOTTOM BUCKET CALCULATIONS

This bucket will be the exact same dimensions, but we will attach weights to the bottom of the bucket to get it to tip later. This requires the bottom bucket to be able to accept two twips before it tips once. This means that the COM has to be sufficiently pushed down, in order for it to be able to take twice the amount of water, then tip. input of the function should be the mass of water accepted, and a go no-go check for tipping to occur. same dimensions will be used.

```
 %bottom_weight = 0.5;%The extra weight added on the bottom to move
 the center of mass down.
%  z_1_bottom = -0.39*H;
%  m2_bottom = m2+1;
%  water_mass_bottom = 2*water_mass_tip;
%  total_bottom_bucket_mass = m1+m2+m3+water_mass_bottom;
%  %z_top_bottom = ((z_top_final - z_1)*2)+z_1_bottom;
%  z_bottom_water_cm =(z_top_final-z_1)+z_1_bottom;
%  Zcm_bottom = m1*z+m2_bottom*z_1_bottom
+m3*z_2+water_mass_bottom*z_bottom_water_cm;
%  disp("This is the Zcm of the bottom:    "+Zcm_bottom);
  z_1_bottom = -0.265*H;
  H_water_bottom = 0.5*H - z_1_bottom;

V_water_inside = H_water_bottom*W*L;

 m2_bottom = m2;
 water_mass_bottom = 2*water_mass_tip;

 total_bottom_bucket_mass = m1+m2+m3+water_mass_bottom;
 %z_top_bottom = ((z_top_final - z_1)*2)+z_1_bottom;
 z_bottom_water_cm =((z_top_final)+z_1_bottom)/2;
 Zcm_bottom = m1*z+m2_bottom*z_1_bottom
+m3*z_2+water_mass_bottom*z_bottom_water_cm;
 disp("This is the Zcm of the bottom:    "+Zcm_bottom);
disp("This is the top height of bottom bucket water column:
 "+z_bottom_water_cm*2);
```

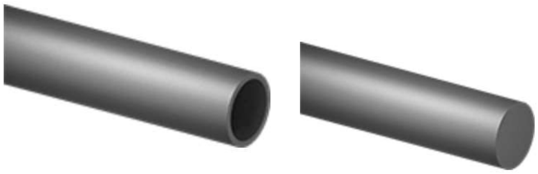
```
This is the Zcm of the bottom:    0.0089717
This is the top height of bottom bucket water column:    0.025278
```

Published with MATLAB® R2018b

Appendix G - Purchased Parts Links

Part	Link
 4ft by 10ft ⅛ in/ 4 ft by 8 ft 16 gauge steel plate	http://www.coastpipeca.com
 Pond Liner	https://www.amazon.com/gp/product/B004DL0Y4Y/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1
 Rust-Oleum Painter's Touch 2X Ultra Cover Gloss Black and Specialty High Heat Black Spray Paint 12oz	https://www.acehardware.com/departments/paint-and-supplies/spray-paint/hobby/1396001 https://www.acehardware.com/departments/paint-and-supplies/spray-paint/general-purpose/11901

 Newpowa 100 Watts 12 Volts Polycrystalline Solar Panel	https://www.amazon.com/Newpowa-Polycrystalline-Efficiency-Module-Marine/dp/B00L6LZRXM/ref=sr_1_2?s=hi&ie=UTF8&qid=1548909299&sr=8-2&keywords=newpowa+100+watt
 AUBIG DC40A-1245	https://www.amazon.com/dp/B076DWJR4Z/ref=pe_385040_30332210_TE_dp_2
 Electrical Wire 16 AWG 16 Gauge Silicone Wire	https://www.amazon.com/gp/product/B0746HRVZP/ref=ppx_yo_dt_b_asin_title_o02__o00_s00?ie=UTF8&psc=1
 Duda Energy LPpvc056-010ft 10' x 9/16" ID	https://www.amazon.com/gp/product/B00LX6M6OI/ref=ppx_yo_dt_b_asin_title_o00__o00_s00?ie=UTF8&psc=1

 Top Tube/ Bottom Shaft	https://www.mcmaster.com/metal-rods
 Edge trim	https://www.amazon.com/MATCC-Guards-Rubber-Protector-Protection/dp/B07CG41NXD/ref=sr_1_9?keywords=edge+trim&qid=1557986445&refinements=p_85%3A2470955011%2Cp_72%3A1248861011&rnid=1248859011&rps=1&s=automotive&sr=1-9
 Pump Filter Bag	https://www.petco.com/shop/en/petcostore/product/imagitarium-media-filter-bag
 Hose Clamp	https://www.homedepot.com/p/Everbilt-1-2-1-1-4-in-Hose-Repair-Clamp-6712595/202309385

 Plastic Bearings	https://www.mcmaster.com/standard-mounted-bearings
 Hose Fitting	https://www.mcmaster.com/hose-fittings
 Access Panel Latch	https://www.homedepot.com/p/Everbilt-2-3-4-in-x-1-1-2-in-Oil-Rubbed-Bronze-Chest-Latches-19866/301015022

Appendix H - Project Budget

Item	Vendor	Vendor Part	Part Numbers	How Purchased	When Purchased	When Received	Cost
Structural Prototype	Various	N/A	N/A	By Team & Reimbursed	1/28/19	1/28/19	$179.98
AUDBIG 12v DC Water Pump	Amazon	DC40A -1245	A002-7		1/29/19	2/1/19	$25.51
Newpowa 100W 12V DC Solar Panel	Amazon	B07JX61QJ 5	A001-1		1/29/19	2/2/19	$92.00
Wire	Amazon	Haerkn	A005		2/7/19	2/9/19	$3.01
Clear Hose	Amazon	LPpvc056-0 10ft	A004		2/10/19	2/12/19	$17.61
Glue Gun	Home Depot	N/A	N/A		3/3/19	3/3/19	$14.00
4ft by 10ft Steel Sheet (⅛ in thickness)	Coast Pipe	N/A	A001-3:7, A002-1:6, A002-8, A003-2:3, A003-6		2/28/19	3/5/19	$190.97
Top Tube	Home Depot	N/A	A003-1		3/16/19	4/22/19	$47.84
Bottom Shaft	Home Depot	N/A	A003-5		3/16/19	4/22/19	$27.94
Buckets	Coast Pipe	N/A			4/22/19	4/22/19	$30.26
4ft by 5ft Steel Sheet (1/16 in thickness)	Coast Pipe	N/A	N/A		4/23/19	4/23/19	$30.25
Locktite Power Grab	Home Depot	N/A	N/A		4/23/19	4/23/19	$11.00
L bracket and screws	Home Depot	N/A	N/A		4/26/19	4/26/19	$13.15
Resin	N/A	N/A	N/A		4/25/19	4/25/19	$18.66
Dampers	damppot	N/A	N/A		5/2/19	N/A	$27.16
Stainless Bearing	McMaster-Carr	2431K72	N/A (returned)		5/7/19	N/A	$0.00

Item	Vendor	Vendor Part	Part Numbers	How Purchased	When Purchased	When Received	Net Cost
Latch for door	Home Depot	N/A	N/A	By Team & Reimbursed	5/9/19	5/9/19	$3.21
Spray Paint	Amazon	N/A	A002-11		N/A	N/A	$19.92
Spray Paint	Amazon	249331	A002-10		5/20/19	5/20/19	$7.54
Switch	Amazon	248647	A002-11		N/A	N/A	$0.00
Pond Liner	Amazon	11-0190	A006		5/14/19	5/14/19	$37.68
Plastic Bearings	Amazon	KINGSOkijop6550	A002-9		4/20/19	N/A	$135.80
Basin Edge Trim	Amazon	N/A	N/A		5/15/19	5/17/19	$16.98
Loctite	Home Depot	N/A	N/A		5/14/19	5/14/19	$9.96
Hose Clamp	Home Depot	N/A	N/A		5/2/19	5/2/19	$1.06
Plastic Bearings	McMaster-Carr	N/A	N/A		5/1/19	5/1/19	$106.14
Pump Filter	Petco	N/A	N/A		5/30/19	5/30/19	$7.63
Glue	Home Depot	N/A	N/A		5/29/19	5/29/19	$24.74
						Total	**$1100.00**

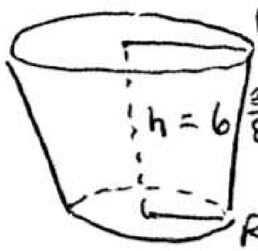
Appendix I - Design Analysis

The hand calculations shown in this Appendix are:

- Bucket center of mass
- Roof weight
- Wind load on structure
- Top rod stress analysis

Geometric Centroid of Conical Frustum

Structural Prototype Dimensions:



$$\bar{z} = \frac{h(R_1^2 + 2R_1R_2 + 3R_2^2)}{4(R_1^2 + R_1R_2 + R_2^2)}$$

$$= \frac{6.375(8.375^2 + 2(8.375)(7.375) + 3(7.375)^2)}{4(8.375^2 + 8.375(7.375) + 7.375^2)}$$

$= 3.05$ in from bottom

With weight of L-bracket, fasteners, bucket

$$\bar{z}_{new} = \frac{\frac{0.377}{2}\text{ lb}(0) + 0.487\text{ lb}(0) + 0.646\text{ lb}(3.05\text{ in})}{\frac{0.377}{2} + 0.487\text{ lb} + 0.646\text{ lb}}$$

$= \underline{1.49 \text{ in}}$

Hand Calcs 2-14-19

- Bucket center of mass
- Wind load on structure
- Wind load on roof
- Roof weight

Roof Weight

- Solar Panel ≈ 20 lbs (40" × 26.6")
- Wood (5' × 5' × 0.5")

- Wood (5' × 5' × 1.5") w/ cut out

- Douglas Fir Density
  $\rho = 530 \frac{kg}{m^3}$

$$V_{wood} = (5\,ft)(5\,ft)\left(\frac{0.5}{12}\,ft\right)\left(\frac{0.3048\,m}{1\,ft}\right)^3 + \left[(5ft)(5ft)\left(\frac{1.5}{12}ft\right) - \left(\frac{40}{12}\right)\left(\frac{26.6}{12}\right)ft^2\left(\frac{1.5}{12}ft\right)\right]\left(\frac{0.3048\,m}{1\,ft}\right)^3$$

$$= 0.092\ m^3$$

$$m = \rho V$$
$$= 530\frac{kg}{m^3}\left(0.092\,m^3\right)$$
$$= 48.67\ kg$$

$$F = 48.67\,kg\left(\frac{9.81\,N}{1\,kg}\right)$$
$$= 477.5\ N$$

$$F_{Total} = 477.5\,N + 4.5\,N$$
$$= 481.97\ N$$
$$\approx \underline{482\ N}$$

Wind Load on Structure

$$F_w = \frac{1}{2} \rho v^2 A$$

ρ = density of air (kg/m^3)

v = wind speed (m/s)

A = surface area

Strongest wind in SLO: 25.3 mph = 11.31 m/s

$\rho = 1.2\ kg/m^3$

$A_{roof} = 25\ ft^2$
$= 2.32\ m^2$

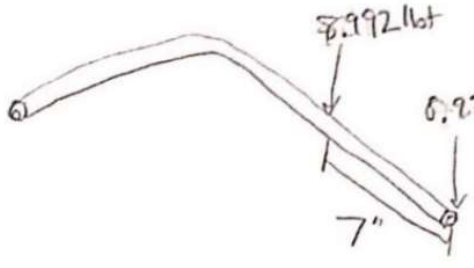
$A_{structure} \approx (7\ ft)(3\ ft)$
$= 21\ ft^2$
$\approx 2\ m^2$

$$\Rightarrow F_w = \frac{1}{2}(1.2\ kg/m^3)(11.31\ m/s)^2(2.32 + 2\ m^2)$$

$= \underline{331.56\ N}$ ⇒ most severe case

Stress analysis of Top rod, and a branch in order to confirm results of FEA.

Top rod schematics



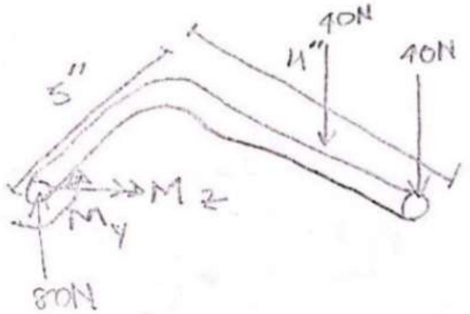
given

- 0.75" OD
- 0.188" wall thickness
- 17.984 lbf load along two contacts = 7" diameter bucket.

find

- max deflection
- maximum stress
- failure?

FBD



$\Sigma M_y = F \cdot r$

$M_y = F \cdot r$

$M_y = 8.992 \text{ lbf} \cdot 4'' + 8.992 \cdot 11''$

$\boxed{M_y = 134.88 \text{ lbf-in}}$

This will cause a shear stress along plane attached to wall.

Find stress at this location.

$\tau = \frac{Tr}{J}$

$J = \frac{\pi}{32}(0.75^4 - 0.374^4)$

$J = 0.029 \text{ in}^4$

$\tau = \frac{Tr}{J}$

$\tau = \frac{134.88 \text{ lbf-in} \cdot 0.75 \text{ in}}{0.029 \text{ in}^4}$

$\boxed{\tau = 3471.24 \text{ lbf/in}^2}$

getting angular displacement from this

$\theta = \frac{TL}{JG}$

$\theta = 20300 \text{ ksi}$

yield stress $= 50800$ psi

$$\theta = \frac{134.88\,\text{lbf-in} \cdot 11''}{0.029\,\text{in}^4 \cdot 20300\,\text{ksi}}$$

$\theta = 0.0026$

now get bending of cantilever beam

$I = J \cdot 2$

$I = 0.058$

$l = 5''$

$E = 29000\,\text{ksi}$

$$\max \Delta y = \frac{P l^3}{3EI}$$

$$\Delta y = \frac{17.984\,\text{lbf} \cdot 5^3}{3 \cdot 29000\,\text{ksi} \cdot 0.058}$$

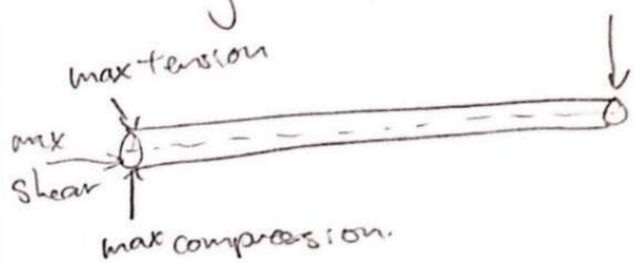
$\Delta y = 4.46 \times 10^{-4}$ inches.

rod end displacement $= \theta \cdot 11'' + 4.46 \times 10^{-4}$ inches

rod end displacement = 0.03 inches

= 0.762 mm

finding max shear stress along cantilever beam.



will most likely fail along torsion or mid plain shear stress.

$$\tau = \frac{VQ}{It}$$

$V = 17.984 lbf$

$Q = A\bar{y}$

$Q = \pi \cdot (0.75^2 - 0.374^2) \cdot \frac{0.75}{2}$

$Q = 0.4979 in^3$

$I = 0.058 in^4$

$t = 0.188 in$

$$\tau = \frac{17.984 lbf \cdot 0.498 in^3}{0.058 in^4 \cdot 0.188 in}$$

$\tau = 821.35$ psi

both stresses below yield stress so FEA is correct

Appendix J - Design Failure Mode & Effects Analysis

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Basin/ hold water	leakage	lose water	7	1) material wears down 2) holes aren't sealed properly	1) seal all holes 2) mind thickness of material	4	Fill with water and check for leakage	2	56	1) Apply protective coating 2) Check strength of material	Jun 1/23	Pond Liner	4	1	1
	corners of wall might break	1) sharp edges exposed 2) water is completely lost	8	1) structure flexes 2) basin walls too thin 3) basin not stable	1) smooth sharp edges 2) support weak points 3) stress analysis	5	Analysis, check thickness of walls	3	120	1) Check strength of material	Jun 1/23	Welded all wall seams	8	1	1
Pump/ move water	water flows too slow	buckets take too long to tip	8	1) cloudy day 2) solar panel not powerful enough 3) pump not powerful enough	get a strong solar panel	4	Observe time for buckets to tip and the resulting motion	1	32	1) increase pump power	Joey 1/23	Not needed	3	1	1
	water flows too fast	buckets tip too fast	8	1) solar panel too powerful 2) cannot control pump speed	be able to control pump speed	7	Observe time for buckets to tip and the resulting motion	1	56	1) add funnel to spout	Joey 1/23	Not needed	3	1	1
	water does not flow	fountain does not work	8	1) wiring incorrect 2) solar panel not strong enough	1) get a strong solar panel 2) wire panel and pump correctly	2	Observe if water is flowing	1	16	1) Purchase solar panels and pumps that will work together	Joey 1/23	Secured hose connections with clamps	5	1	1
Pump/ clean water	water not cleaned	dirty water, unappealing look	5	1) filter does not work 2) no filter	1) hook up filter correctly 2) make sure there is a filter	1	Look at clarity of water	1	5	1) Install a secure filter that will last awhile	Joey 1/23	Pump filter	5	3	1
Pump/ secure pump	water pumps incorrectly	fountain does not work	7	pump has shifted and is not pumping correctly	1) secure pump in place	3	Observe force of flow for water, if gettling slower, could be out of alignment	3	63	1) secure the pump in place	Joey 1/23	Secured hose connections with clamps	5	1	1
Buckets/ move water	buckets leak	lose water	8	1) buckets too thin 2) hole with rod not sealed 3) crack in bucket	1) stress analysis 2) mind thickness of material	3	Load bucket with force to find maximum	2	48	1) seal up all connection points 2) apply protective coating	Jun 1/23	Welded all seams and caulked leak points	3	9	1
	bucket misses	lose water	7	1) buckets too small 2) buckets not positioned properly 3) buckets not tipping at correct speed	1) reduce oscillations 2) slow tipping as much as possible 3) large buckets	7	Test relationship with offset and height of buckets	5	245	1) simulate bucket tipping motion 2) test different heights and offsets with different volumes of buckets	Jun 1/23	Shifted buckets along rod	4	7	1
Solar panel/ get energy	does not absorb energy	not power the motor	8	1) solar panel gets dirty 2) cloudy weather	1) clean solar panel	7	customer review	1	56	1) clean solar panel when necessary	Andy 1/15/19	Not needed	4	1	1
solar panel/ holds its postion	not hold its position	collapse on the fountain	8	1) wind bends the mount 2) panel too heavy	1) mind thickness of material	2	final testing	2	32	1) use stronger material for support	Andy 1/23/19	Secured with L-brackets and screws	9	1	1
Pillars/ provide support	members bend, members break, members get dirty/attract debri, members look unaesthetic	1) Members start to bend 2) Members start to break	9	1) Members cross section too small 2) Cross members are too long 3) Fasteners start to undo.	1)Perform stress analysis 2)fastener shear analysis	4	Observing the straightness of pillars. Observing for slants in the structure. Push on the pillars and test for yielding	2	72	1) Change material or dimensions of support material.	Kota 1/23/19	Have made a model and selected solar panels that will be mounted. Also have the height it will be mounted at.	3	1	1
Pillars/look aesthethic	members get dirty/attract debri, members look unaesthetic	1) members start to look unaesthetic	4	1) Weather affects the color and condition of pillar. 2) Water from fountain causes discoloring or attracting debri on the pillar.	1) Use strong adhesive paint or coating to protect pillar from weather	3	Observing the color fade of the pillar or collection of debri.	2	24	1) Clean the pillars 2) Reapply protective coating	Kota 1/23/19	spray painted the pillars, so its easy to clean	4	8	1
Pillars/holding bucket	Bearings fall out	1) bucket starts to not spin 2) bucket begins to not catch all the water	4	1) the bearings fall out of hole in pillar. 2) holes in pillar get too large 3) Shaft falls out of bearing.	1) pressfit the shaft into the bearing. 2) Secure shaft with interference 3) cancel moments of bearing within pillar by using two bearings.	4	Observing the allignment of buckets. Making sure the water from one bucket lands in the other bucket. Make sure the buckets are rotating with relative ease.	3	48	1) choose different bearings 2) Make bearing to pillar pressfit more exact by adding material	Kota 1/23/19	press fitted the bearing to the shaft	1	1	1

Appendix K - Design Hazard Checklist

DESIGN HAZARD CHECKLIST

Team: Solar Fountain Advisor: Peter Schuster Date: 2/14/19

Y	N	
☑	☐	1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐	☑	2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
☐	☑	3. Will any part of the design undergo high accelerations/decelerations?
☐	☑	4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐	☑	5. Could the system produce a projectile?
☑	☐	6. Could the system fall (due to gravity), creating injury?
☑	☐	7. Will a user be exposed to overhanging weights as part of the design?
☐	☑	8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐	☑	9. Will any part of the electrical systems not be grounded?
☐	☑	10. Will there be any large batteries (over 30 V)?
☐	☑	11. Will there be any exposed electrical connections in the system (over 40 V)?
☐	☑	12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐	☑	13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☐	☑	14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☑	☐	15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐	☑	16. Could the system generate high levels (>90 dBA) of noise?
☐	☑	17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☐	☑	18. Is it possible for the system to be used in an unsafe manner?
☐	☑	19. For powered systems, is there an emergency stop button?
☐	☑	20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Pinch points on the shaft when the buckets are revolving	Make the shaft clearances as small as possible	3/13/19	5/5/19
Solar panels are considered overhanging weights that might fall	We will secure the solar panel with brackets that attaches to the whole structure.	3/13/19	5/5/19
Solar panels might have sharp edges when delivered	Attach a rubber corner bracket to cover sharp edges	3/13/19	5/25/19
The device will be exposed to all forms of weather	Use durable materials and waterproof electrical parts	3/13/19	3/23/19

FDR Appendix L - Risk Assessment

designsafe Report

Application:	Solar Fountain	Analyst Name(s):	Joey Ciolino, Andy Kim, Jun Kim, Kota Ozawa
Description:		Company:	Cal Poly
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	operator normal operation	mechanical : crushing Assembly tips over	Moderate Unlikely	Low	prevent energy release	Moderate Remote	Negligible	Action Item [2/28/2019] Jun, Joey
1-1-2	operator normal operation	mechanical : head bump on overhead objects Solar panel overhangs	Minor Very Likely	Medium	safety mats / contact strip	Minor Unlikely	Negligible	Action Item [3/31/2019] Andy, Kota
1-1-3	operator normal operation	mechanical : machine instability Basin not secured	Moderate Unlikely	Low	prevent energy release	Moderate Remote	Negligible	Action Item [2/28/2019] Jun, Joey
1-1-4	operator normal operation	electrical / electronic : energized equipment / live parts Solar panel and pump	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
1-2-1	operator load / unload materials	electrical / electronic : energized equipment / live parts Adding water	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
1-2-2	operator load / unload materials	electrical / electronic : water / wet locations Adding water	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item [4/14/2019] All
1-3-1	operator clear jams	mechanical : pinch point Trying to work inside main trunk	Minor Likely	Low	gloves	Minor Unlikely	Negligible	Action Item [4/14/2019] All

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-3-2	operator clear jams	mechanical : head bump on overhead objects Hit solar panel while working	Moderate Likely	Medium	safety mats / contact strip	Moderate Unlikely	Low	Action Item [3/31/2019] Andy, Kota
1-3-3	operator clear jams	electrical / electronic : energized equipment / live parts Pump is energized	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
1-3-4	operator clear jams	electrical / electronic : water / wet locations Pump is submerged	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
1-4-1	operator basic troubleshooting	electrical / electronic : energized equipment / live parts Working with pump and panels in wet environment	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item [4/14/2019] All
1-5-1	operator clean machine	mechanical : pinch point Working with tubing	Minor Likely	Low	gloves	Minor Unlikely	Negligible	Action Item [4/14/2019] All
1-5-2	operator clean machine	electrical / electronic : energized equipment / live parts Working with pump	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
1-5-3	operator clean machine	electrical / electronic : water / wet locations Basin	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
2-1-1	engineer modify parts / components	mechanical : cutting / severing Working with cut sheet metal	Moderate Likely	Medium	gloves	Moderate Unlikely	Low	Action Item [4/14/2019] All
2-1-2	engineer modify parts / components	mechanical : pinch point Assembling fountain	Moderate Very Likely	High	gloves	Moderate Unlikely	Low	Action Item [4/14/2019] All

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-3	engineer modify parts / components	mechanical : stabbing / puncture Pointed metal ends	Serious Unlikely	Medium	gloves	Serious Remote	Low	Action Item [4/14/2019] All
2-1-4	engineer modify parts / components	mechanical : head bump on overhead objects Solar panel	Moderate Likely	Medium	safety mats / contact strip	Moderate Unlikely	Low	Action Item [3/31/2019] Andy, Kota
2-1-5	engineer modify parts / components	mechanical : machine instability Fountain not secured till end	Moderate Unlikely	Low	prevent energy release	Moderate Remote	Negligible	Action Item [2/28/2019] Jun, Joey
2-1-6	engineer modify parts / components	electrical / electronic : energized equipment / live parts Panel and pump	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
2-1-7	engineer modify parts / components	electrical / electronic : water / wet locations Panel might get wet from hands	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
2-2-1	engineer conduct tests	electrical / electronic : water / wet locations Water splashing	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
2-3-1	engineer trouble shooting	mechanical : pinch point Working with tubing	Minor Likely	Low	gloves	Minor Unlikely	Negligible	Action Item [4/14/2019] All
2-3-2	engineer trouble shooting	electrical / electronic : energized equipment / live parts Panel and pump	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item [4/14/2019] All
2-3-3	engineer trouble shooting	electrical / electronic : water / wet locations Pump is submerged	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item [4/14/2019] All

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-4-1	engineer inspect machinery	mechanical : head bump on overhead objects Solar panel	Moderate Likely	Medium	safety mats / contact strip	Moderate Unlikely	Low	Action Item [3/31/2019] Andy, Kota
3-1-1	passer-by / non-user walk near machinery	electrical / electronic : water / wet locations Wet ground from splashing	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item [4/14/2019] All
3-2-1	passer-by / non-user work next to / near machinery	mechanical : head bump on overhead objects Solar panel	Moderate Likely	Medium	safety mats / contact strip	Moderate Unlikely	Low	Action Item [3/31/2019] Andy, Kota
3-2-2	passer-by / non-user work next to / near machinery	electrical / electronic : water / wet locations Wet around fountain	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item [4/14/2019] All

Appendix M - Operator’s Manual

This user’s manual includes instructions for product use and important safety information. Read this manual entirely including all safety warnings and cautions before using the product.

Getting Started with the Solar Fountain

Warning: Do not move or reposition the fountain alone, it is very heavy and can tip over.

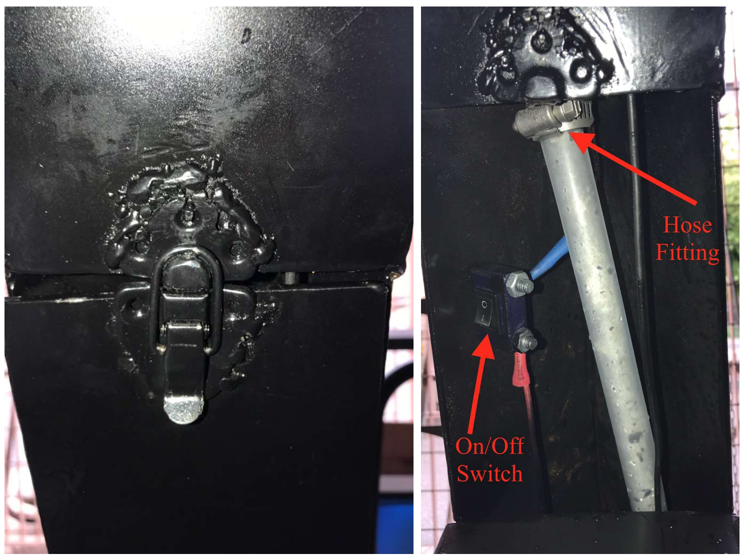


Figure 1. Control Panel of Solar Fountain

Setting Up / Turning On and Off

1. To get started with the Solar Fountain, ensure both the inlet and outlet of the pump is fully submerged under water.

Figure 2. Pump Inlet/Outlet Diagram

2. With a few other people, place the fountain in a sunny area on level ground and turn it on with the switch inside the enclosed panel. The “I” mark on the switch is the “On” position.

Figure 3. On/Off Switch

3. To turn it off, turn the switch off. The “O” mark on the switch is the “Off” position.

Maintaining the Solar Fountain

Warning: Do not allow the water level in the basin to get too low to prevent pump damage.

Adding Water

1. The water pump in the base of the fountain lasts longer when it runs with water.
2. If the water level gets below ¼ of the height of the basin, or if the pump makes a whirring sound, add more water until the basin is three-quarters full or turn the fountain off with the switch. If there are visible bubbles being pumped up into the hose, the water level is too low.

Cleaning the Pump

1. Turn off the fountain with the switch.
2. Without moving the pump, reach into the basin, unzip the pump filter, and disconnect the tubing from the pump.
3. Once removed, take a toothbrush or some other type of brush that will get in the small holes of the pump to clean out any debris.
4. Reconnect the tubing to the pump and place it back to its original position.

Cleaning the Solar Panel

If the solar panel becomes dirty, has debris on top of it, or if the fountain's performance seems lower than usual, it may be necessary to clean the solar panel.

Warning: When cleaning the panel, do not put weight on the panel sheet to prevent tipping.

1. Turn off the fountain with the switch.
2. Use a soft cloth or sponge to clean the solar panel. Hosing down the solar panel with water also works.
3. Warm water and soap can be used if needed.
4. Wipe the solar panel dry.
5. Make sure there is nothing obstructing the solar cells, as this will affect performance.

Cleaning the Fountain Walls

1. Turn off the fountain with the switch.
2. If there are stones in your fountain, take them out and clean them as well.
3. Once you have access to your pump and water, remove the pump from the fountain.
4. Empty all water from the fountain.
5. Take a bucket of water and a non-abrasive sponge to clean the inside of the basin.
6. Wipe and scrub until you have gotten rid of any algae and/or white scale buildup your fountain may have.
7. Once the basin is clean try to rinse out any soap or cleaning product by wiping with clean rags or cloths.

Replacing the Pump Filter

Figure 6. Pump with Pump Filter

1. Turn off the fountain with the switch.
2. Without moving the pump, unzip the filter and remove the pump from the filter.
3. Put a new filter around the pump and zip it up.

Replacing Solar Fountain Parts

Steps to replace certain fountain parts are detailed below.

Replacing Hose System

1. Turn off the fountain with the switch.
2. Open the front latch to expose the hose carrying the water.

Figure 4. Latch System for Control Panel

3. Loosen the hose clamp with a flathead screwdriver.

Figure 5. Hose Fitting Connection to Top Tube

4. Disconnect the hose from the outlet attachment.
5. Disconnect the hose from the submersible pump.
6. Connect new hose to the pump and outlet attachment and relatch the access panel.

Replacing Solar Panel

1. Make sure the fountain is off.
2. Unscrew all 12 screws attaching the solar panel and the brackets to the surface. Make sure to have someone help hold the solar panel so that it does not slide off the surface.
3. Gently remove the old solar panel off the surface.
4. Remove the brackets from the old surface panel and attach them to the new solar panel.
5. Place the new solar panel on the surface and while someone holds it in place, screw in the 12 screws to secure it.

Replacing the Pump

1. Turn off the fountain with the switch.
2. Without moving the pump, reach into the basin, remove the pump from the pump filter, and disconnect the tubing from the pump.
3. Connect the tubing to the new pump and place it back to its original position inside the pump filter.

Replacing the Pond Liner

Replacing the pond liner is a very difficult and extensive process that should only be completed if there is significant damage to the existing pond liner.

1. Turn off the fountain with the switch.
2. Without moving the pump, reach into the basin and remove the tubing from the pump.
3. Take out the pump, pump filter, and any decorations from the inside of the fountain.
4. Drain the water from the basin completely and wipe dry the pond liner.
5. Remove the edge trim from the basin edges.
6. Remove the pond liner from the basin.
7. Place new pond liner in the basin, keeping the bottom edges tight to provide a smooth surface.
8. Apply glue/caulking to all surfaces and apply the pond liner.
9. Trim excess edges of the liner and apply the same or new edge trim to the edges.
10. Replace fountain parts inside the basin.

Parts List

Below is a detailed list of the replaceable parts of the Solar Fountain with links to stores to purchase them from.

Solar Panel -
https://www.amazon.com/Newpowa-Polycrystalline-Efficiency-Module-Marine/dp/B00L6LZRXM/ref=sr_1_2?s=hi&ie=UTF8&qid=1548909299&sr=8-2&keywords=newpowa+100+watt

Pump -
https://www.amazon.com/dp/B076DWJR4Z/ref=pe_385040_30332210_TE_dp_2

Pump Filter -
https://www.amazon.com/Sumind-Aquarium-Pelletized-Ammonia-Remover/dp/B075XMXV2Q/ref=sr_1_fkmrnull_1?keywords=sumind+5+pack+aquarium&qid=1558629204&s=gateway&sr=8-1-fkmrnull

Pump Tubing -
https://www.amazon.com/gp/product/B00LX6M6OI/ref=ppx_yo_dt_b_asin_title_o00__o00_s00?ie=UTF8&psc=1

Pump Wiring -
https://www.amazon.com/gp/product/B0746HRVZP/ref=ppx_yo_dt_b_asin_title_o02__o00_s00?ie=UTF8&psc=1

On/Off Switch -
https://www.alliedelec.com/product/zf-electronics/cre22f2fbbne/70207347/?gclid=EAIaIQobChMIlrvtpJGy4gIV4SCtBh2JUgLvEAQYBiABEgLEOfD_BwE&gclsrc=aw.ds

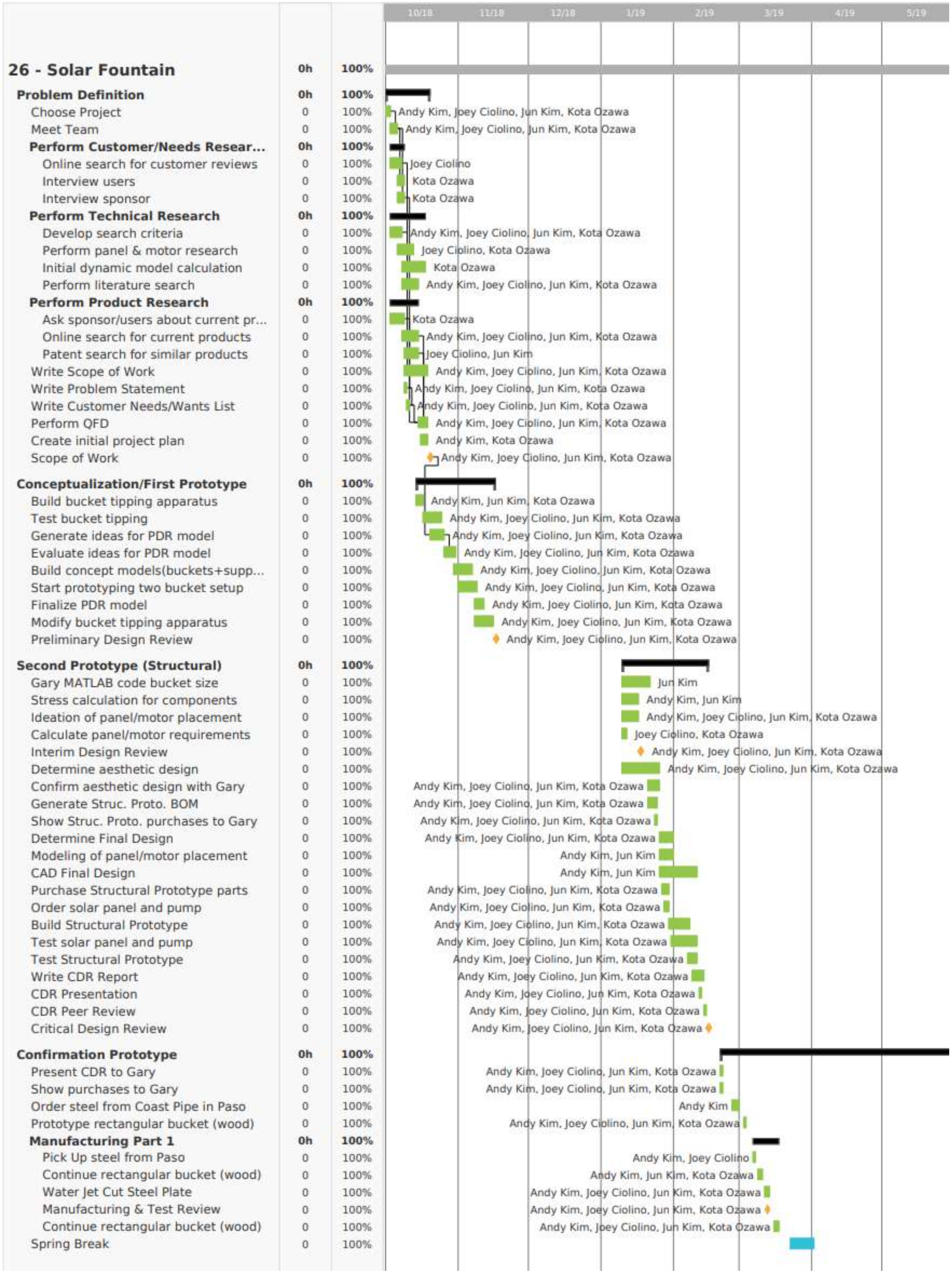
Pond Liner -
https://www.amazon.com/gp/product/B004DL0Y4Y/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1

Edge Trim -
https://www.amazon.com/gp/product/B07CG41NXD/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1

Appendix N - Design Verification Plan

Senior Project DVP&R													
Date: 2/13/19		Team: Team Solar Fountain	Sponsor: Gary Epstien			Description of System: Solar Fountain						DVP&R Engineer: Andy Kim, Jun Kim, Kota Ozawa, Joseph Ciollino	
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Time for both buckets to tip and empty water in a slow manner	3 secs for tipping	Everyone	SP	3	sub	4/13/19	6/1/19	N/A	0	3	Bearings and weld slags provided affected the motion of the bucket, the team tried to improved the tipping time with added weights to the top.
2	2	Flow rate of the water from the pump	2.5 gpm	Andy	SP	4	sub	4/2/19	5/27/19	3 pgm	4	0	
3	5	Force required to tip over the fountain	100 lbf	Joey	FP	1	sys	4/27/19	N/A	N/A	N/A	N/A	Due to the outstanding weight of the final product, tip test was not necessary
4	6	Noise Level from the water splashing	80 db	Jun	FP	5	sub	4/27/19	5/29/19	55 db	4	0	
5	8	Rate of Water Lost from splashing and evaportion	less than 0.5 gallon	Kota	FP	2	sub	4/27/19	6/1/19	3 gph	0	1	Water splashes off the bottom bucket from the top bucket, resulting in a high water loss voulme
6	9	Power consumption of the solar panels to ensure that the pump gets required amount of energy	minimum 12 V, 1.2 A	Andy	SP	4	sub	2/17/19	5/26/19	20V, 0.6 A	4	0	Although it is not operating at 1.2 A, the pump operates well with lower current.

Appendix O - Gantt Chart



Manufacturing Part 2	**0h**	**100%**
Develop Test Procedures	0	100%
Email Professor Kevin about welding	0	100%
Develop 3D Printed Molds for Weld,...	0	100%
Print 3D Molds	0	100%
Make Testing Bucket	0	100%
Develop Operator's Manual	0	100%
Test: Bucket Tipping	0	100%
Practice Welding	0	100%
Weld Basin Plates (Shops)	0	100%
Weld Trunk	0	100%
Purchase Bucket Materials	0	100%
Purchase Top Tube and Bottom Rod	0	100%
Pick up Bucket Materials	0	100%
Weld Branches	0	100%
Assemble Solar Panel Fixture	0	100%
Weld Buckets	0	100%
Weld Top to Bottom Structure	0	100%
Design and Build Access Panel	0	100%
Attach Top and Bottom Rod	0	100%
Purchase Pond Liner	0	100%
Angle Grind Fountain for Finish	0	100%
Purchase Paint, Primer, etc.	0	100%
Confirmation Prototype	0	100%
Apply Paint to the structure	0	100%
Apply Pond Liner after paint	0	100%
Apply Edge Trim to the basin	0	100%
Testing/Iterating	**0h**	**100%**
Fix any problems with Final Protot...	0	100%
Test: Voltage and Amps of Solar Pa...	0	100%
Test: Water Loss	0	100%
Test: Flow Rate	0	100%
Test: Noise	0	100%
Project Expo	0	100%