Quiet Rushing Fountain

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Abstract

David Noble, the president of the Noble Foundation, has commissioned our team to design and build a quiet rushing fountain to be displayed at the University of Michigan Depression Center. This fountain is to move the water by the force of the water itself. An initial design was created and the individual components and mechanisms were then fully optimized, fabricated, tested, and evaluated. The outcome, from all processes listed above, is a design for a quiet rushing fountain that fascinates its observers.

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Executive Summary

The newly dedicated Richard Scott Noble Plaza, located outside of the University of Michigan Depression Center, is in need of a centerpiece. David Noble, the president of the Noble Foundation, has commissioned our team to design and build a quiet rushing fountain, which fascinates, captivates, and calms observers. To determine the direction of the design, we have developed various customer requirements and engineering specifications that the final design is driven to meet.

To create a design that best satisfies the customer requirements, dozens of concepts were generated in an attempt to fully capture all possible features or benefits. These concepts were evaluated in terms of feasibility, technological readiness, and customer satisfaction. After a thorough selection process an Alpha Design was generated by combing various concepts. Based on feedback from the project sponsor, the Alpha Design was altered to focus more on reservoirs and the water flow between these reservoirs. With this focus in mind, a final design was generated as shown in Figure E.1 below. To capture the important components of the final design, we have created a prototype design, shown in Figure E.2, which highlights the various water transfer mechanisms and structural attachments from the final design. A fabrication plan for this prototype design was also developed.

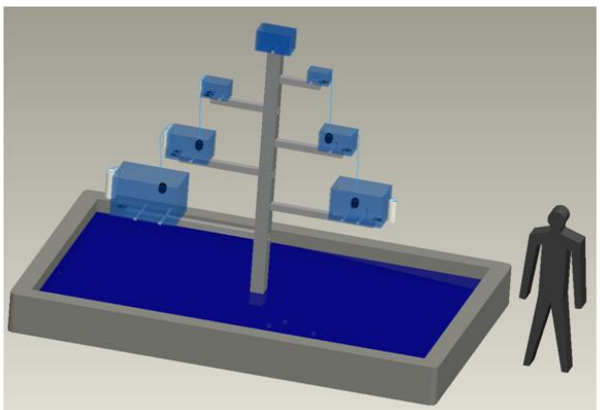

Figure E.1: Final Design

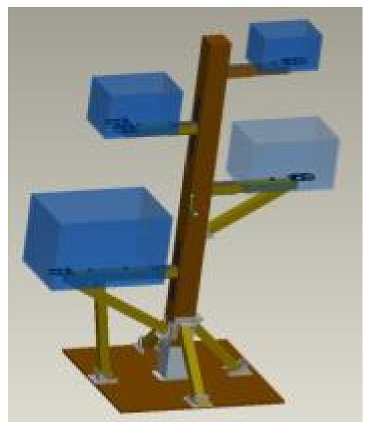

Figure E.2: Prototype Design

This prototype demonstrates the final design's functionality, and was tested to ensure that the final design will function safely and effectively. The effectiveness of the prototype was validated by comparing the prototype performance to the engineering specifications determined for the final design.

Beyond creating a prototype design, engineering analysis was performed for the final design to optimize the components, attachments, mechanisms, and water flow through the system. From mechanical analysis and functional requirements, we selected the best materials for the various parts of the fountain from the reservoirs to the ground support. This mechanical analysis helped ensure that no structural components were susceptible to possible failure.

Based on the initial fabrications plans, a prototype was successfully manufactured. This prototype and its components were tested, and evaluated to ensure they met the necessary prototype validation requirements. This validation process allowed us to prove the final design concept. At this stage it is possible to recommend the final design as the best solution to the design problem, with the validated prototype as evidence of its complete functionality. With critical changes in the appearance of the various fountain sections, including the use of aesthetically appealing reservoir mechanism components, the proposed quiet rushing fountain will meet all the design requirements.

Problem Description

In memory of his brother, Richard Noble, who suffered from depression his entire life, David Noble has dedicated a plaza at the University of Michigan Depression Center in his name. As a centerpiece to this plaza he wants to add a "quiet rushing fountain". The goal of this project will be to develop a physical prototype of the "quiet rushing fountain". Noble's vision for the fountain is that it will have a captivating flow of water created by the force of water itself and to "fascinate" its' observers.

One of the purposes that this fountain will serve is that along with the rest of the plaza it will create a relaxing environment for patients as well as guests at the Upjon Center. Having a fountain at this center will not only serve as a visual but also send a comforting feeling to its observers.

Literature Review

In order to gain a deeper understanding of existing research and technology, a literature review was performed. The goal of this task was to unearth information relating to principles associated with fountains and fountain design. Topics of study included water pumps, variable flow valves, the psychological benefits of fountains, and water turbulence amongst others. After considering various journal articles, product patents, and store catalogues, it was possible to determine the possible of uses of these objects and principles with our design, the theoretical information that can be applied, and also whether pre-existing items would be available for different aspects of prototype design.

Pumps/Screw/Wheel

Every fountain requires a mechanism to move water from a point of low potential to one of high potential as to allow gravity to take over and naturally generate the flow of water. In most fountains, this task is accomplished using a pump, specifically submersible pumps. Submersible pumps are essentially a motor driven apparatus that draws in fluid at an inlet and releases the fluid at an outlet, frequently, at a higher potential. Pumps are an existing technology and have been optimized for multiple uses. Some submersible pumps are able to move fluid/solid mixtures, dual liquid mixtures, etc.

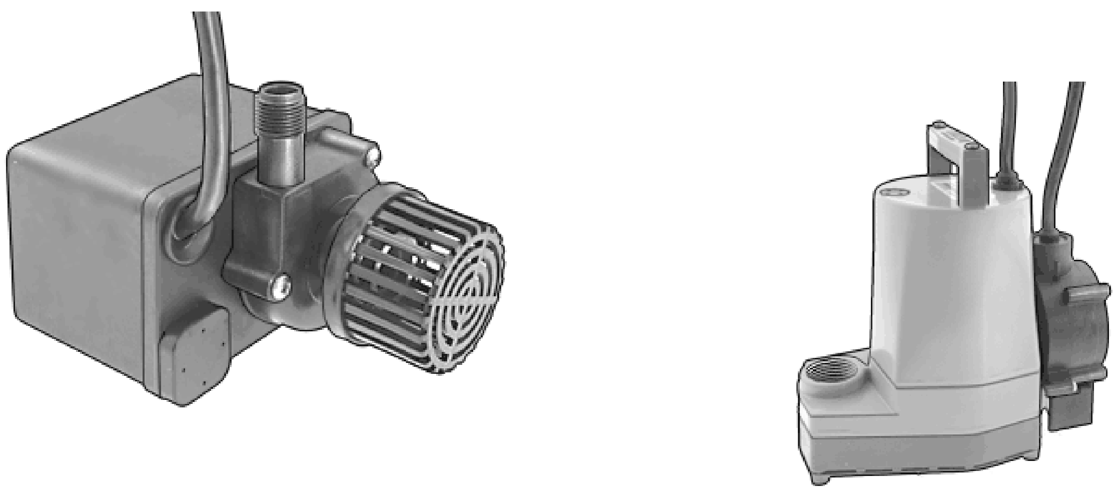

Figure 2: Pumps used for water alone and water with mixed solids
(mcmaster.com)

Pumps are available in a variety of sizes with variable flow rates. Figure 2 shows examples of pumps that can be used in submersible environments to pump various liquids of varying densities. Depending on a specific requirement, a pump with a certain set of characteristics will be required. Fortunately, for the scope of this design prototype, small-sized, electrical pumps are available for very low prices ($30-50). Heavy-duty, long –lasting pumps are also available at slightly higher prices ($100-200) [1,2]. There are also other methods available, other than pumps, for moving water in a vertical direction. Two common mechanisms include the Archimedes screw mechanism and a water wheel. Figure 3, below, shows the basic concept of an Archimedes screw mechanism. Both of these mechanisms require motors for completely autonomous operation. These devices are not the most efficient methods in moving fluids, but can be used and designed in a very aesthetically pleasing manner.

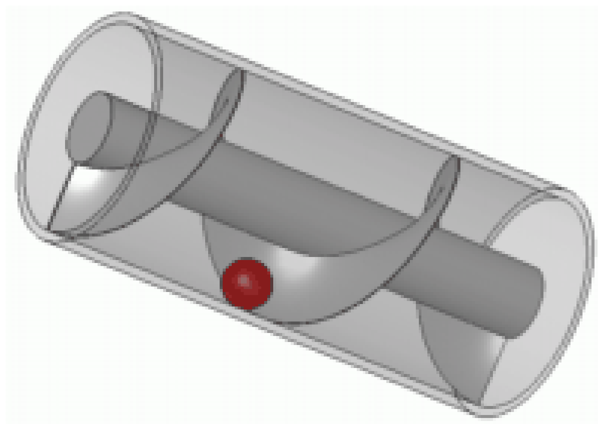

Figure 3: Archimedes Screw (*Wikimedia.org)*

Water Turbulence

Water turbulence is a motivating factor in the design of a quiet rushing fountain. Water turbulence can be linked to the level of noise generated. The larger the amount of turbulence, the louder the fountain. Thus, when designing a fountain that must be quiet at various stages, it is important to consider the level of water turbulence present.

There has been significant research done on the reduction of turbulence in fountains, specifically the design of fountains with low Reynolds numbers, essentially low levels of turbulence [3]. A theoretical design for a laminar fountain has been proposed but is not very practical because, a design of this type requires the elimination of every irregularity that can cause turbulence [4]. However, there are various methods for designing fountains with low Reynolds numbers, thereby reducing most of the noise generated by water turbulence. Figure 4 shows the behavior of a low Reynolds number fountain; it shows what can be considered relatively laminar flow at a small scale.

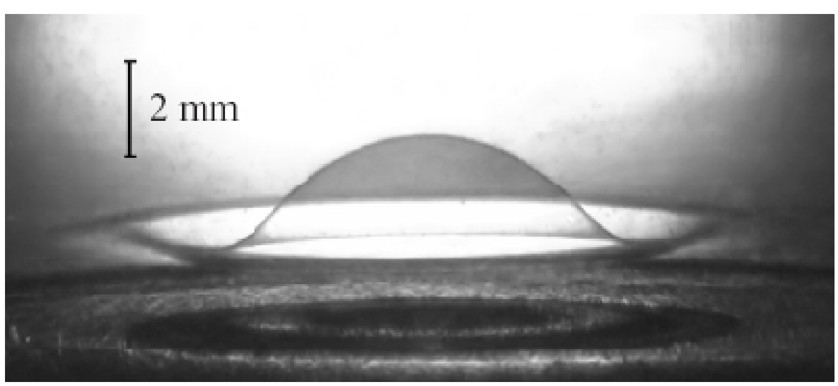

Figure 4: Low Reynolds Number Fountain Behavior (N. Williamson)

Another subject worth considering when looking at water turbulence is the flow of a jet of water into a pool of stationary water. This phenomenon can be observed at almost every prototypical fountain. The mixture of water at this stage and the creation of bubbles, and thus sounds, is a phenomenon that can have a great effect on the design of a quiet fountain [5]. Due to the impact that water turbulence has on various customer requirements, it is very important to incorporate various fundamentals of water turbulence and apply them to fountain design.

Immiscible Fluids

Immiscible fluids are another subject that can prove useful when designing an aesthetically pleasing fountain. Immiscible fluids are essentially fluids, specifically liquids in this case, that do not mix. Oil and water are a good example of this phenomenon. A possible use of immiscible fluids is to have regions where the fluids are separate and other regions where the fluids are emulsified [6]. Essentially, immiscible fluids can be used to intrigue the viewer through variable encapsulated bubble shapes and turbulent mixing of these fluids [7].

Drawbacks of the use of immiscible fluids include pumping requirements, filter requirements, and contamination. Since both fluids have to be pumped, possibly together, the design cost increases as more than one pump may be required. External contaminants, such as rain water, can also create mixing issues within the fluids. Thus, immiscible fluids provide an excellent aesthetic element but this also comes with a set of usage issues that must be addressed prior to prototype deployment.

Psychological Effects

There are several reasons for why fountains have naturally calming and relaxing effects on individuals within their proximity. One of the more proven reasons is due to the increase in negative ions that fountains produce due to the Lenard effect [8]. When water collides with another object or fluid, this impact causes the water to become positively charged and the surrounding air to become negatively charged, creating negative ions. Figure 5 provides a visualization of the Lenard Effect.

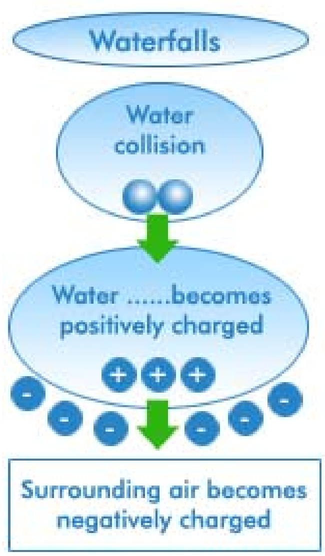

Figure 5: The Lenard Effect

Negative ions have several positive effects, such as increasing oxygen flow to the brain, which results in higher alertness, protection against airborne germs, and the reduction of serotonin, decreasing aggressiveness [8, 9]. Studies conducted at the University of Columbia have actually shown that negative ions are just as effective as antidepressants in relieving seasonal and chronic depression, without the side effects [9]. It has also been proven that high concentrations of negative ions, usually around waterfalls or mountain ranges, are essential for high energy and a positive mood [10].

An average home contains 100 negative ions per cubic centimeter whereas the average mountain range or beach contains several thousand negative ions per cubic centimeter [9]. This explains why most individuals find the beach or open mountain ranges relaxing and calming.

Project Requirements and Engineering Specifications

Accurately addressing what the customer's wants truly are, is a critical design phase. Without properly acquiring the customer's true wants, the chances of satisfying that particular customer are almost zero. Creating engineering specifications that relate directly to customer requirements is almost as critical as the previous phase. Engineering specifications are needed in order to translate what the customer wants into quantifiable values that can be measured and analyzed.

Customer's Wants

The main project requirement consisted of creating a prototype fountain for the Richard Scott Noble Plaza, which would have acoustic attributes of both quiet and loud. The second requirement, given to us by David Noble, was to incorporate multiple reservoirs into the prototype design. Having multiple reservoirs channeling water flow into one another would fascinate an observer, thus achieving Mr. Noble's last requirement.

Two additional requirements were added to our list after visiting the U of M depression center. Karen Crawford, the director of gifts at the center, informed us that children were often at the center and that liability concerns would require the fountain to be child safe. Mrs. Crawford also stated that currently there was limited funding for the fountain's operational and maintenance costs. Therefore, the designed fountain's upkeep costs needed to also be considered. Some other customer requirements are for the fountain to match the style of the plaza, and the fountain be resistant to damage or tampering .Table 1 below shows the top five customer wants.

Top 5 Customer Wants
Child Safe
Outdoor Functionality
"Fascinates"
Quiet/Loud - Time Dependent
Minimal Maintenance/Operational Costs

Table 1: Top 5 Customer Wants

After discussing the current customer requirements, our team believed there was a need to append the following requirements: child resistant (child damages fountain), aesthetically appealing, consistent style with proposed plaza, and low prototype cost.

Each customer want was given an importance weighting to determine its importance relative to other requirements.

Engineering Targets

The process for creating engineering specifications was a basic discussion evaluating what specifications could actually have an influence on any of the customer requirements. Basically, each requirement was discussed and various engineering specifications that could affect that particular customer requirement were recorded. See Table 2 for a complete list of our engineering specifications.

Technical Requirements	Weight
Max Water Depth (-)	5%
Edge Radius (-)	4%
Max Base Height (+)	4%
Material Yield Strength (+)	5%
Material Fracture Toughness (+)	5%
Grid Mesh Size (-)	4%
Total Material Cost (-)	4%
Reservoir Transparency (+)	7%
Reservoir Surface Roughness (-)	3%
# of Chambers	10%
Particle Concentration	2%
Corrosion Resistance	6%
Volumetric Flow Rate	12%
Visibility of Unsightly Components	6%
Power Consumption	2%
Mechanism Variety	10%

Table 2: Engineering Specifications

Each engineering specification was given a target value, a value that would be used to assist in assessing progress on fountain design and fabrication throughout the project. Actual target values were determined through personal knowledge and research. The assigned values and their corresponding units can be seen on the quality function deployment chart in Appendix I.

To achieve the customer requirement of "fascination" it was determined that the number of chambers carrying water and mechanism variety were essential. By approaching the conceptual fountain from an observers viewpoint, it was determined that the number of chambers that would hold water, should be around six. This particular number was chosen because it is not too many chambers as to which would result in confusion and possibly reduced "fascination" nor is it too little where the chambers have no resemblance to the central theme. It was also determined that the viewers' fascination would be increased by observing multiple mechanisms at work, instead of a single path, as observed in most fountains. It was determined that around three mechanisms would be sufficient in achieving a high level of fascination.

It was determined that the volumetric flow rate was a major contributor to achieving quiet/loud acoustics. The volumetric flow rate is the amount of water [gallons per minute] that is pumped into the system. It was determined that flow rate should be optimized such that the fountain maintains two stages of flow. A typical home water faucet was analyzed and it was determined that the average faucet uses around 2.5 gallons per minute. Relating the faucet flow rate to filling up a bucket it was determined that an optimal volumetric flow rate would be around 5 gal/min. At this rate, the fountain would be able have separate times for quiet and rushing flow.

In order to consider the safety of children in the area, many safety precautions were put into the design. To prevent children from reaching to the main fountain in the first place, a base with a height of about one foot is needed. A one foot base was considered because a wall one foot high would prevent most children, over the age of one, from falling into the fountain or from causing other injuries [11].

Competition

Fountains have been around for several hundred years, therefore the number and variety of fountains is abundant and most designs have been modified several times over, edging towards perfection. For these reasons, the fountain industry is a competitive market. Figure 6, below, shows a traditional fountain.

Figure 6: Traditional Outdoor Fountain (Photo by Amol Mody)

Current competitors offer fountains that either perform well in the majority of normal customer requirements. Mr. Noble has presented quite different desires for fountain performance, such as varying between quiet and loud over time and using multiple mechanisms to move water through the system by passing water through valves or cascading over the side. We chose two fountains to compare against the customer requirements. A traditional fountain was chosen similar to the fountain in Figure 6. This fountain functions well outdoors and is child resistant, but does not exhibit any quiet rushing aspect as desired. The other competitor that was chosen is a cascading fountain pictured Appendix I. This fountain design incorporates a cascading water flow, but despite this aspect, is still quite boring, lacking anything distinguishingly special that will captivate viewers.

Quality Function Deployment

In order to determine which engineering specifications should take higher priority, due to their influence on accomplishing more customer requirements than others, our team completed a quality function deployment chart (QFD). The QFD chart analyzes the level of correlation between each engineering specification and the customer's requirements and ranks each engineering specification based on this analysis. The higher the rank given, the more influence that particular engineering specification has in regards to accomplishing the customer's wants.

The level of correlation between each engineering specification and the customer's wants was decided within our team using each individual's best judgment to determine the level of correlation. The importance rating given to each customer requirement was also taken into account when determining the final ranking. Our completed QFD chart can be seen in Appendix I.

Concept Generation

The entire concept generation process was primarily driven by the motivating factor for this design project, the basic customer requirements. It was imperative to keep in mind the main requirements of this fountain; primarily the ability for the fountain to be quiet and loud at various times; thus, creating a quiet, rushing effect.

Based on these primary customer requirements, it was possible to decompose the various functionalities of possible fountain designs. This functional decomposition is a method to break down various design aspects into small design sections and help study their various aspects on the potential design environment. The functional decomposition is also useful in studying the input vs. output of a possible fountain design. The main functional concepts used were the transportation, distribution, reception (or collection), and the filtration of water. The major inputs of the system were power, possibly electrical, to move water to a high potential and water to be used during the cycles of the fountain. A detailed diagram describing the functional decomposition along with more details can be seen in Appendix II.

After generating a functional decomposition, the next step involved brainstorming various design concepts. This stage included brainstorming individually to develop concepts that were as unique as possible. The second part of brainstorming was to gather all the individual ideas and develop ideas as a team while possibly using individual ideas as inspiration. Although the customer requirement was kept in mind while brainstorming, the ideas generated did not all meet the customer requirement as visualized. After going through both the brainstorming steps, approximately 20 unique designs were generated. Of these 20, five were judged to be important precursors to the alpha design and will be discussed in detail. The rest of the brainstormed designs are presented in Appendix III with an explanation of each.

Golden Ratio Reservoirs

The brainstormed design shown in Figure 7 is one of the most important designs to come out of the brainstorming sessions, as it is one of the only designs that take into account the golden ratio. The golden ratio, approximately 1.618, is an irrational mathematic constant used in design by many artists and architects. Through our talks with an aesthetics expert, it became evident that incorporating the golden ratio into our designs would yield more aesthetically pleasing results. In Figure 7 we can see a basic fountain with four secondary reservoirs which allow for a cascading effect. The majority of the water along with the pump would be stored in the base of the fountain, and water would be pumped to the top reservoir. From this point various floating valves would open based on the water level in one reservoir and release water to the next reservoir. The incorporation of the golden ratio occurs in the secondary reservoirs and generates a more aesthetically pleasing feel.

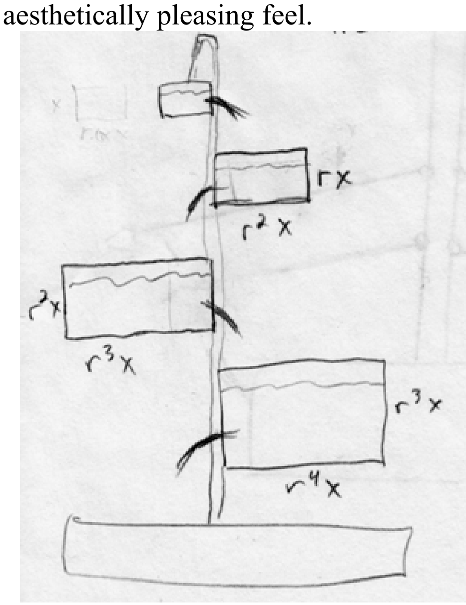

Figure 7: Brainstormed Design – Golden Ratio Reservoirs

Plinko

Another design with important future ramifications was the plinko design. Plinko is a mini-game on the popular game show, The Price is Right. This game uses a vertically-placed game board with many small slats. The contestant slides in a token at the top of the board, the token takes a random path, sliding and bouncing off the slats, to a final position. This concept of water moving through a random path is the allure of this design. The design shown in Figure 8 involves a pump that moves water to a reservoir on the top of the plinko board. The exit hole of this reservoir is controlled by a floating valve which rereleases water in small amounts when a certain water level is reached. Water then flows into the plinko board where it hits various bi-stable slats which rotate and randomize the water flow through the system.

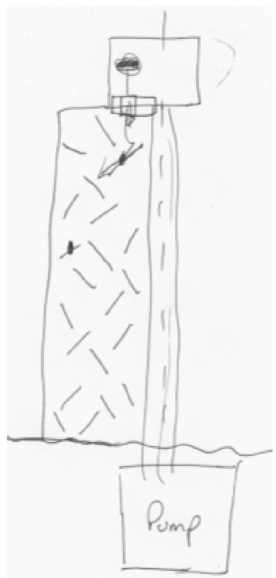

Figure 8: Brainstormed Design – Plinko

Volcano

It is also important to consider that the UM Depression Center is often visited by children. Thus, it is important to have a design that could possibly entertain children while also providing a safe environment for them. The volcano design shown in Figure 9 is a depiction of a design that serves both those purposes. In this design water is contained in a hidden reservoir on the interior of the volcano. Water is pumped up to the top of the volcano where it flows into secondary reservoirs on the side of the volcano mountain. Water moves down to other reservoirs and eventually makes it down to the base. There is also the potential to have the volcano *explode* occasionally by releasing a large amount of water at once.

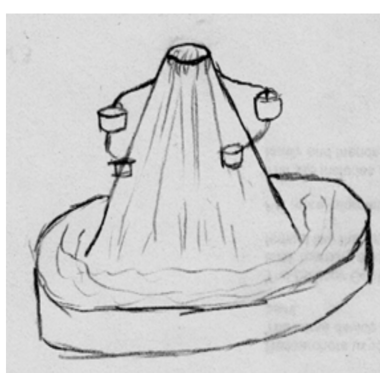

Figure 9: Brainstormed Design – Volcano

Balance Tree

The concept in Figure 10 below is a good example of a mechanically advanced design to meet the customer requirements. Essentially, water would first be pumped to the main reservoir. From this main reservoir, water would flow into the secondary reservoirs. The stability of these reservoirs would cause them to tip-over once they reach a certain water level. This is a good example of a design that is driven completely mechanically but also provides segments in the fountains cycles with quiet and loud periods.

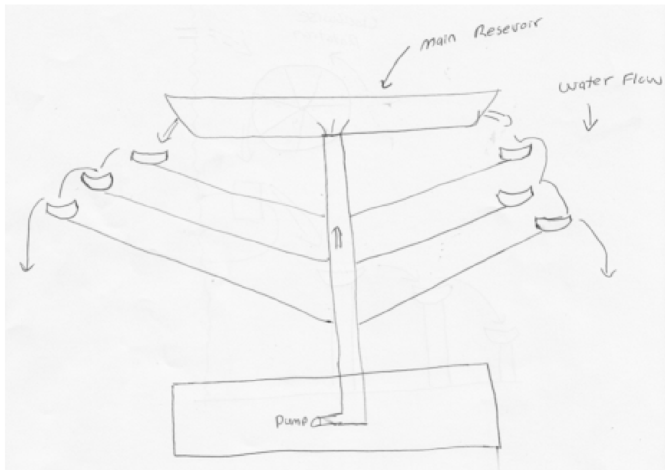

Figure 10: Brainstormed Design – Balance Tree

Rube Goldberg

Mechanical complexity is a big factor for this fountain. It is important to have a design that fascinates people, and one way to do this is to generate a design that is complex enough to leave people wondering how everything works. Figure 11 shows a design generated in the style of Rube Goldberg, an engineer with overly complex inventions that performed simple actions. The design below shows a mechanical process of water moving from the top of the fountain to the bottom using an immensely complex mechanism. The water initially moves to a secondary reservoir which then empties and moves water through a panel to another location where it arrives in a container that balances a valve on another container. This disturbance of balance causes water to flow into another section of the fountain, and so on.

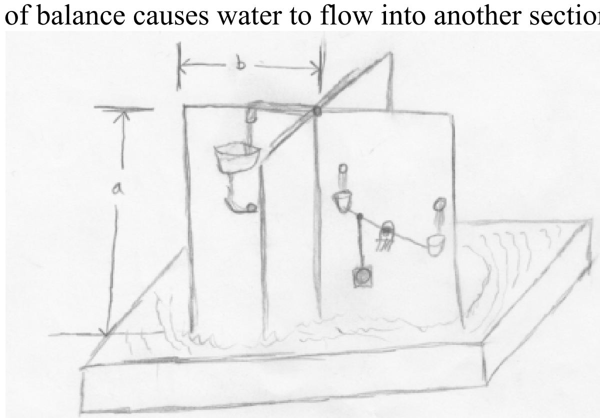

Figure 11: Brainstormed Design – Rube Goldberg

All other concepts generated can be seen in Appendix III.

Concept Selection

To select a feasible concept that could be conceived into a final prototype, various analysis methods were used to narrow down the initial 20 concepts that were generated. Initially the concepts were benchmarked based on technological availability, customer requirements, and manufacturing feasibility. Extensive research was done into the availability and need of certain technologies for each design. Designs that required technologies currently unavailable or defied laws of physics were rendered infeasible. After benchmarking our original 20 designs based on these requirements, it was determined that 12 designs would be feasible.

To further distinguish the concepts, a Pugh chart, as shown in Table 3, was used to weigh the 12 designs based on the customer requirements. Each customer requirement was given a weight from one to ten, ten being the most important. From that, each design was given a score of either, -1, 0, or 1, with 1 being the highest, on how well it met the customer requirements. The scores were multiplied by the weight and ranked from highest to lowest. From the rankings, five designs were selected with the highest score. These designs were determined to best meet the customer requirements.

	Weight	Design 1 (Golden Ratio)	Design 2 (Plinko)	Design 3 (Volcano)	Design 4 (Balance Tree)	Design 5 (Rube Goldberg)
Child Safe	7	0	0	1	0	0
Child Resistant	6	0	0	0	0	0
Outdoor Functionality	10	0	0	0	0	0
"Fascinates"	8	0	1	0	0	1
Quiet/Loud - Time Dependent	10	0	1	1	1	0
Cascading Water Flow	6	0	1	0	0	-1
Asthetically Appealing	5	1	0	0	0	1
Minimal Maintenance/Operational Costs	8	0	0	0	0	0
Same Style As Plaza	5	0	0	0	1	0
Sum		5	24	17	15	7
Rank		5	1	2	3	4

Table 3: Pugh Chart with Top 5 Designs

After reviewing each concept it was determined that no single concept would satisfy every customer requirement. In order to incorporate as many customer requirements as possible, we determined that it would be essential to take parts of each design and incorporate them into one final Alpha Design.

Analysis of Top Five Designs

To begin we looked at our first design which incorporated the Golden Ratio with four main reservoirs. This design is very aesthetically appealing because of the natural appeal of the Golden Ratio as well as the cascading flow of water from top to bottom. Also, it is very simple and elegant because of a limited number mechanisms and rectangular shape of the reservoirs. However this design does have its limitations, such as the simplicity of the design lacking mechanism variety.

Next we looked into the Plinko design. This design is fascinating and intriguing due to the variety of mechanisms that are incorporated. It would also create a varying flow of water because the slats would be rotational, which increases the viewers' fascination. Even though this design is very aesthetically appealing it does have its limitations. The concept does not incorporate any way to create a rushing of water, nor does it allow for a period of quiet, which is an important customer requirement. Child safety would also be a big concern, mainly due to the slats being an attractive feature for young children to play with. Furthermore, it might be difficult to maintain due to the possible failure of the rotating joints of the slats.

The Volcano design was determined to be very child safe, the only design out of the top five to be so. This was mainly due to the limited number of mechanisms used and the height at which mechanisms are placed at. Also, the timing of the quiet and loud phases would be very apparent. Even though this design is very safe, it does not have a very fascinating effect mainly because of the limited number of reservoirs and the difficulty of achieving a cascading flow of water.

The Balance Tree design was viewed to have incorporated the quiet and loud theme in a very elegant manner. Also, the flow of water is purely mechanical and the observer is fully aware of its flow direction. This design is limited by its durability to withstand heavy wind gusts or other forces of nature. It is also somewhat top-heavy, putting extra force on the main pipe that is holding it in place.

Finally, the Rube Goldberg concept has many mechanisms that contribute to changing the flow of water. As we have determined previously, increasing the number of mechanisms would increase the fascination effect for the viewer. Since this design has a different mechanism for each side, it allows for a changing visual experience that is spatially dependent.

Concept Design

In choosing our final design all five designs were considered and the benefits and disadvantages were analyzed of each. To conceive a concept from the top five designs, the objective was to have a design that would satisfy most if not all the customer requirements. Since none of the designs satisfied all the requirements, but each of them separately covered most of them, it was only plausible to combine certain aspects of each into a single design.

In order to have a fountain that would have the quiet and loud affect, we implemented the Balance Tree. Also, the observer would be able to predict the flow of water during any given time. To achieve a cascading flow of water, the Plinko design was also incorporated into the concept. The Plinko design fascinates the viewer by allowing for varying flow patterns which would be aesthetically as well as audibly pleasing. The changing flow patterns of the Plinko would especially be pleasing for the younger visitors at this plaza. To add an extra layer of excitement, it was determined that adding reservoirs on the sides of the concept, based on the Golden Ratio, would enhance the aesthetic appeal of the fountain.

After piecing together the top five concepts into one, we feel that this is the best design that satisfies all the customer requirements and engineering specifications. This design lends itself to achieving all the engineering specification targets, and possibly exceeding targets such as number of chambers and mechanism variety.

Alpha Design Description

Following concept generation and selection, the chosen concepts must be woven together to create a cohesive design which takes advantages of the good parts of each concept, but limits the effect of negative aspects of each idea. This alpha design is depicted in Figure 15.

Plinko-Wall

By placing the "Plinko" concept on a wall at the base, we were able to establish a good base for the fountain that increases the ability to create a transition zone and one that visually creates a sense of stability and helps the eye move up the fountain. The base of this concept can be seen below in Figure 12.

Figure 12: Plinko-Wall Detailed View

Volcano

Incorporating a volcano was a difficult task since both the plinko and the volcano concept do not fit visually anywhere other than the base of the fountain. To incorporate the volcano concept we found it necessary to make some minor changes to the appearance of the concept. By creating a reservoir in the top of the plinko-wall base, we have created a reservoir that can suddenly and unexpected overflow when water rushes into it. This is similar to the concept behind the volcano, without the strange aesthetics of a giant rock mountain. This added concept can be seen below in Figure 13.

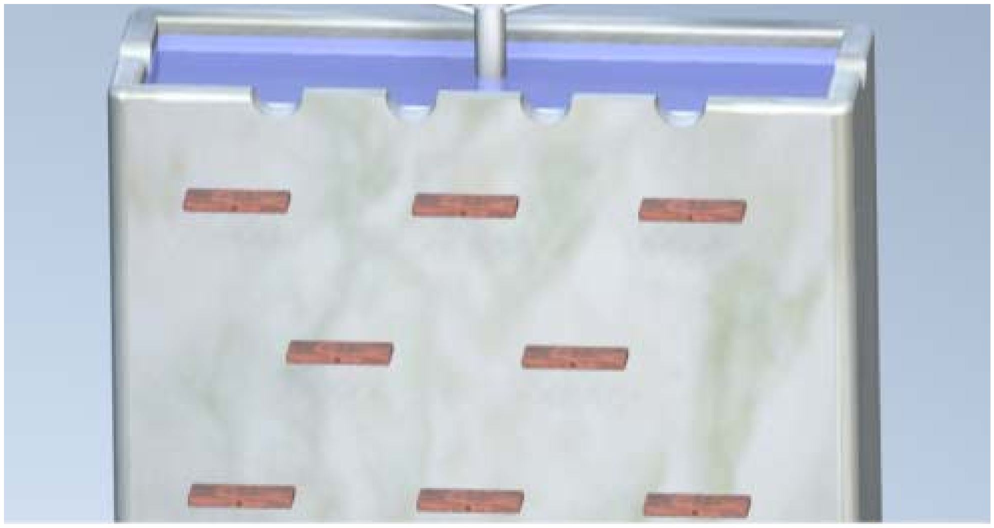

Figure 13: Plinko-Wall with Volcano Concept

Balance

By positioning the balance concept into the top of the fountain, we desired to create a method of distributing water in a predictable, but constantly changing manner. This is done by choosing various reservoir sizes, allowing each to fill and empty at different rates. The top reservoirs will fill and dump into the lower ones. This will happen multiple times until the large reservoirs fill and dump into the top of the Plinko-wall, creating an overflowing volcano-like effect as shown in Figure 14.

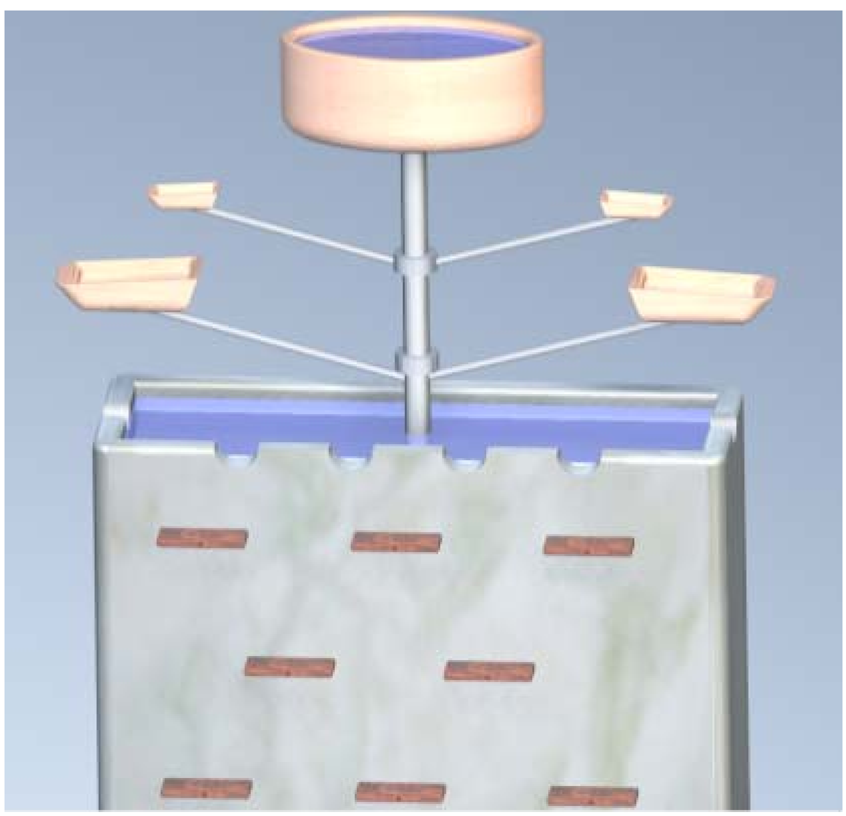

Figure 14: Plinko-Wall with Volcano and Balance Tree

Rube Goldberg

The final addition to the fountain increases the mechanical complexity and creates a fascinating viewing experience for any onlooker. By adding the transparent side reservoirs that can slide up and down the side of the wall, we can control each of the holes at the top of the Plinko wall, creating an almost random array of possible orientations. The combination of all of these designs is shown in Figure 15.

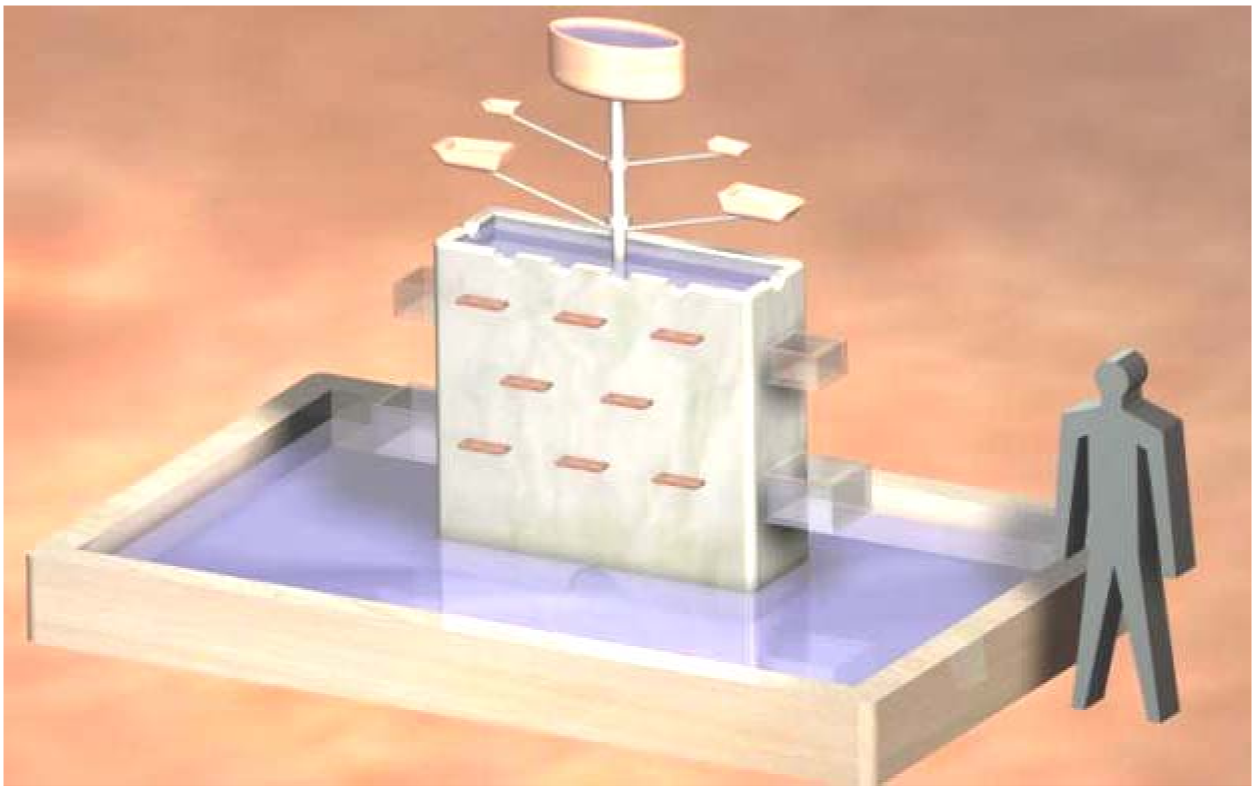

Figure 15: Alpha Design

In this Alpha Design, the water is pumped up the central pipe and flows from the central reservoir into the upper side buckets. These buckets slowly fill with water and tip over when full. All of the water then falls into the buckets below. Once these lower buckets fill there will be a large rush of water into the reservoir above the Plinko-wall. With this sudden increase in water volume in this chamber, the water will overflow over the Plinko-wall and into the side reservoirs. These side reservoirs, beyond containing the transparent aspect, also control which holes at the top of the Plinko-wall are open and which are closed. When water level is high in these transparent reservoirs, the corresponding hole is opened and water is allowed to flow through it. Water will be continually leaking out of these reservoirs to ensure that the holes open and close over time.

The Plinko-wall is special in that it truly captures Mr. Noble's desire to have the water change how the water flows through the system. The slats will be attached to the wall and will cause the water to fall in directed ways, however when the large rush of water comes down the wall, the slats will rotate to new positions, thus creating a new flow pattern down the wall. Overall the flow of water through the system exhibits both patterned and random qualities, which captures a viewer's attention, but also hold their attention for a long period of time and even surprise them with unexpected flow down the Plinko-wall.

This design incorporates all of the concepts discussed above and also relies heavily on the golden ratio in sizing almost all of the components. This allows for an aesthetically pleasing design that meets the customer requirements presented, and matches or exceeds the desired engineering specifications.

Final Design Concept Description

After receiving feedback from David Noble on our proposed Alpha design, several design changes were made in order accommodate his recommendations. The central focus of the final design is centered more around reservoirs and simple mechanisms that transfer flow between these reservoirs instead of the more complex flow transfer mechanisms found within the Alpha design. The proposed final design is shown in Figure 16 below. The designs and functionality of these components are discussed later within this section.

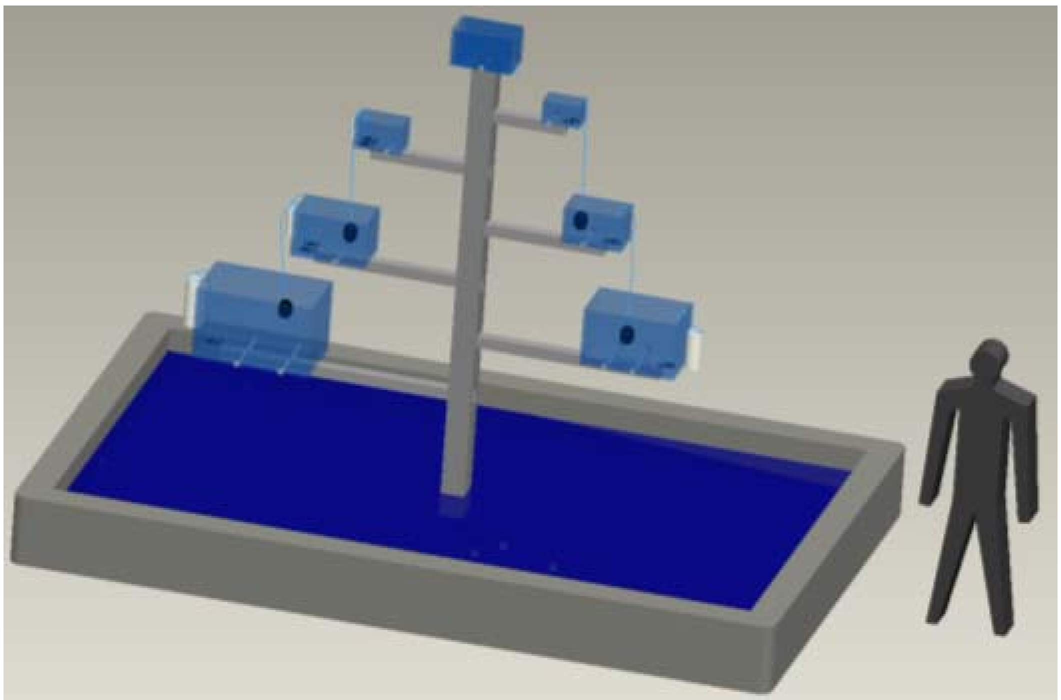

Figure 16: Quiet Rushing Fountain Final Design

The created fountain is a simple yet elegant design that will use simple mechanisms along with variable water flow to fascinate its observers. This final design was also created to resemble a tree like structure in order to ensure an appropriate transition zone for the Richard Scott Noble plaza. In order to guarantee that our fountain will fit well within its surroundings, a landscape artist could be contracted to incorporate foliage, branches, and vines within the fountain's design. A bill of materials for our final design is attached in Appendix V. Beyond this list of functional materials, any materials needed by the contracted artist would also need to be included.

Engineering Drawings
Dimensioned drawings for all components of the final design are shown in Figures 16.1 to 16.26 below. These drawings include the fountain's reservoirs, arms, center post, support bars, and subsidiary reservoirs.

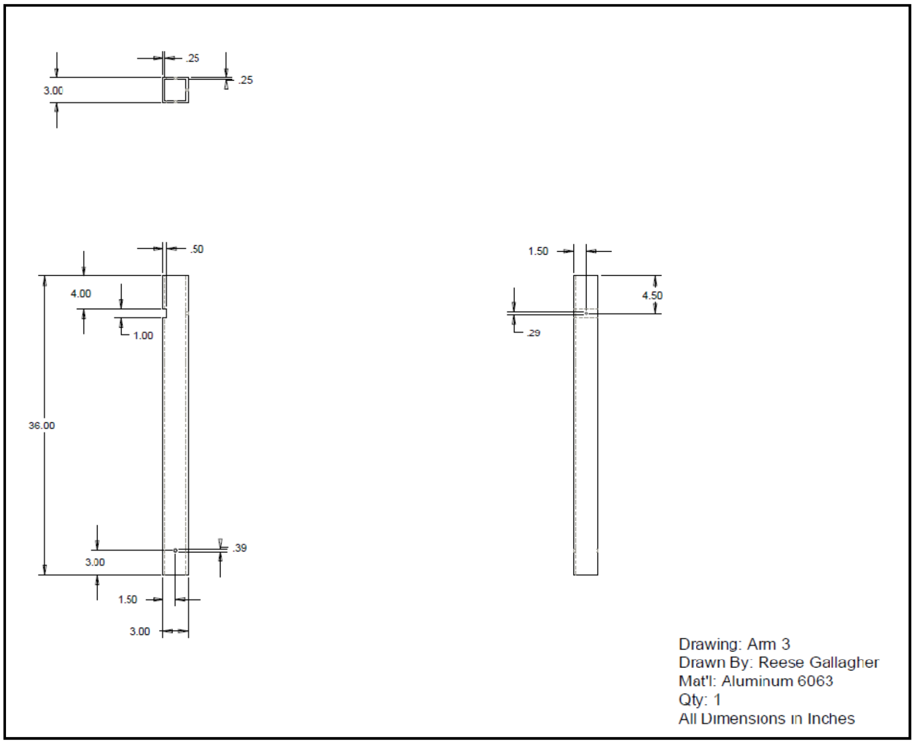

Figure 16.1: Arm 3 Dimensional Drawing

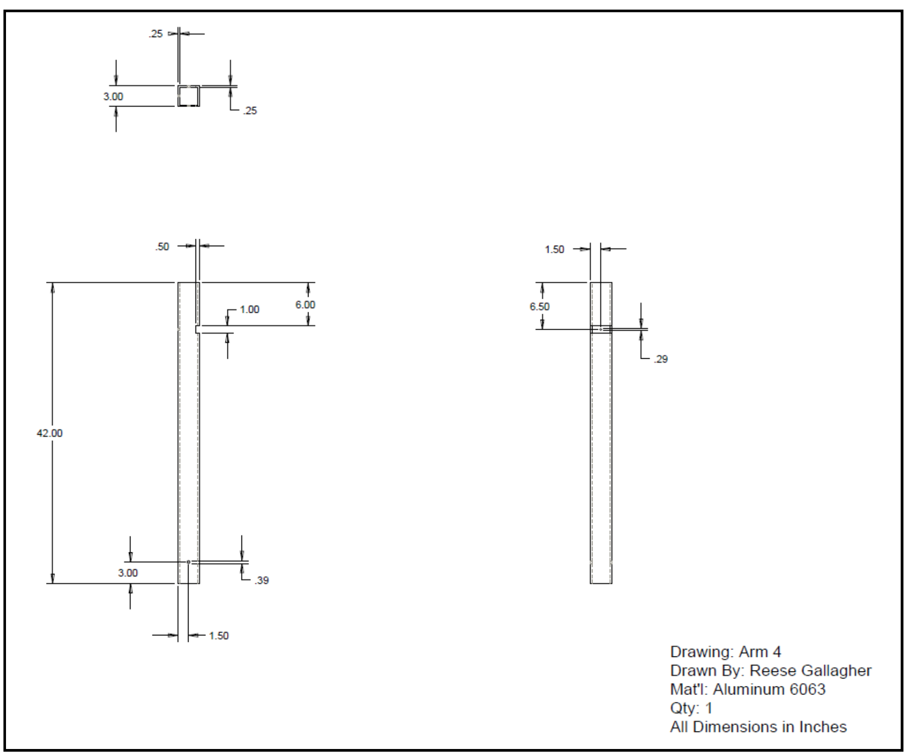

Figure 16.2: Arm 4 Dimensional Drawing

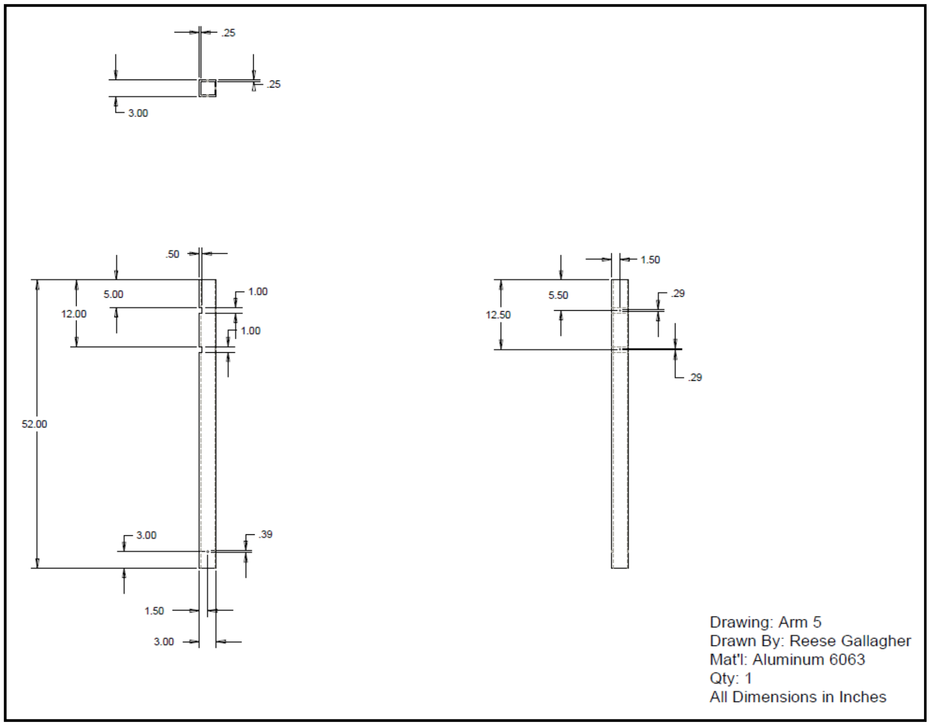

Figure 16.3: Arm 5 Dimensional Drawing

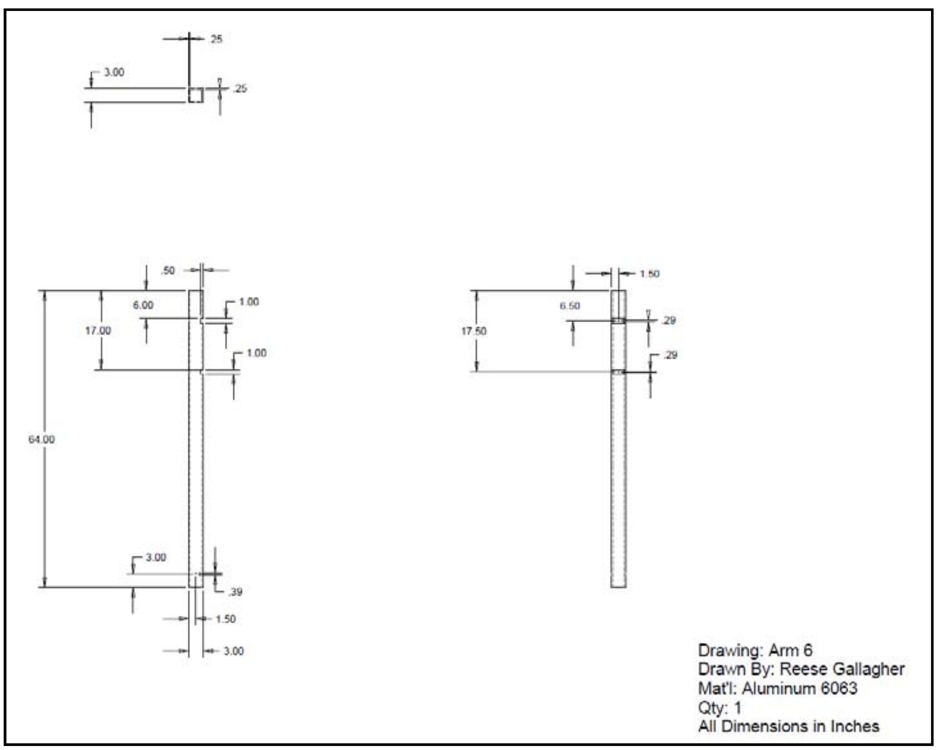

Figure 16.4: Arm 6 Dimensional Drawing

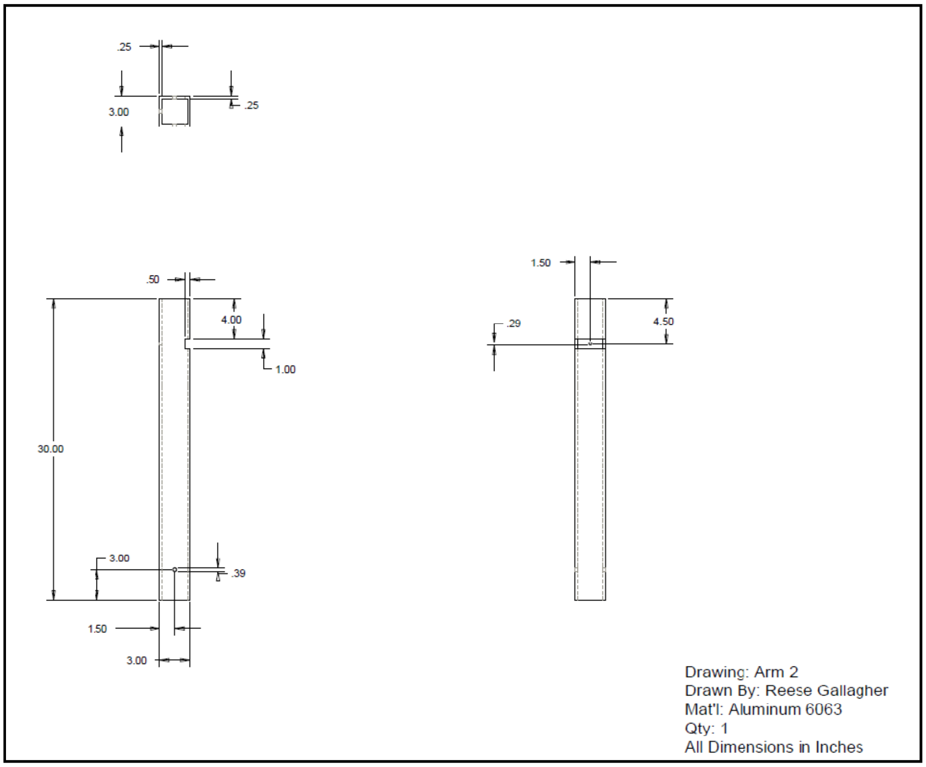

Figure 16.5: Arm 2 Dimensional Drawing

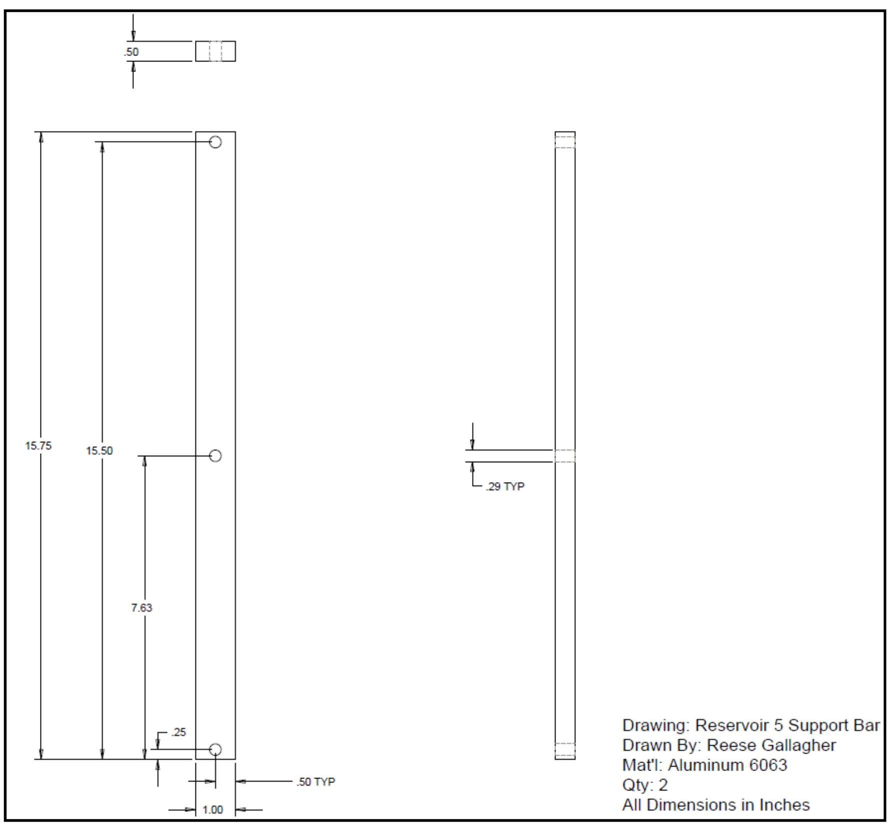

Figure 16.6: Reservoir 5 Support Bar Dimensional Drawing

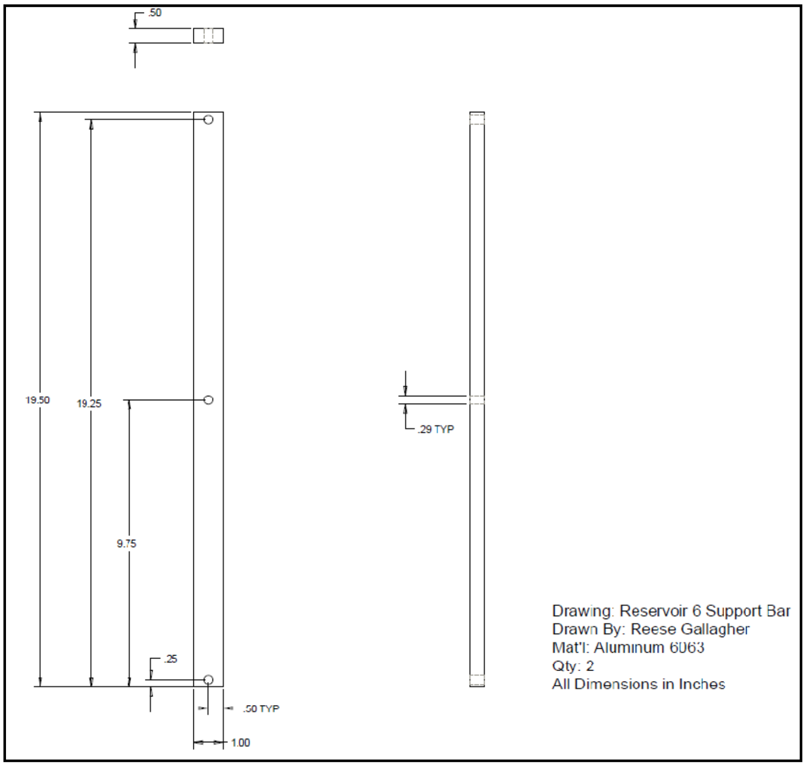

Figure 16.7: Reservoir 6 Support Bar Dimensional Drawing

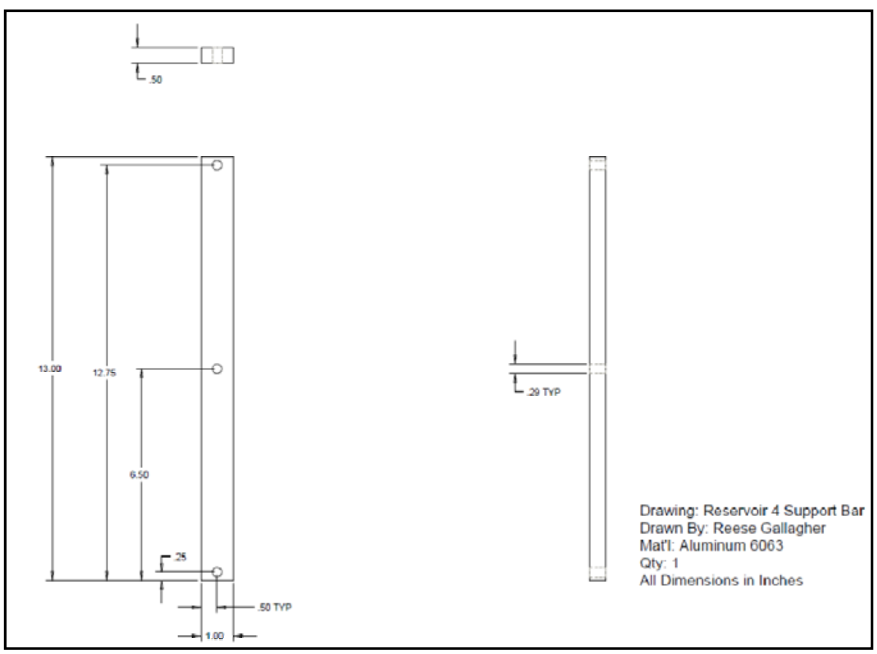

Figure 16.8: Reservoir 4 Support Bar Dimensional Drawing

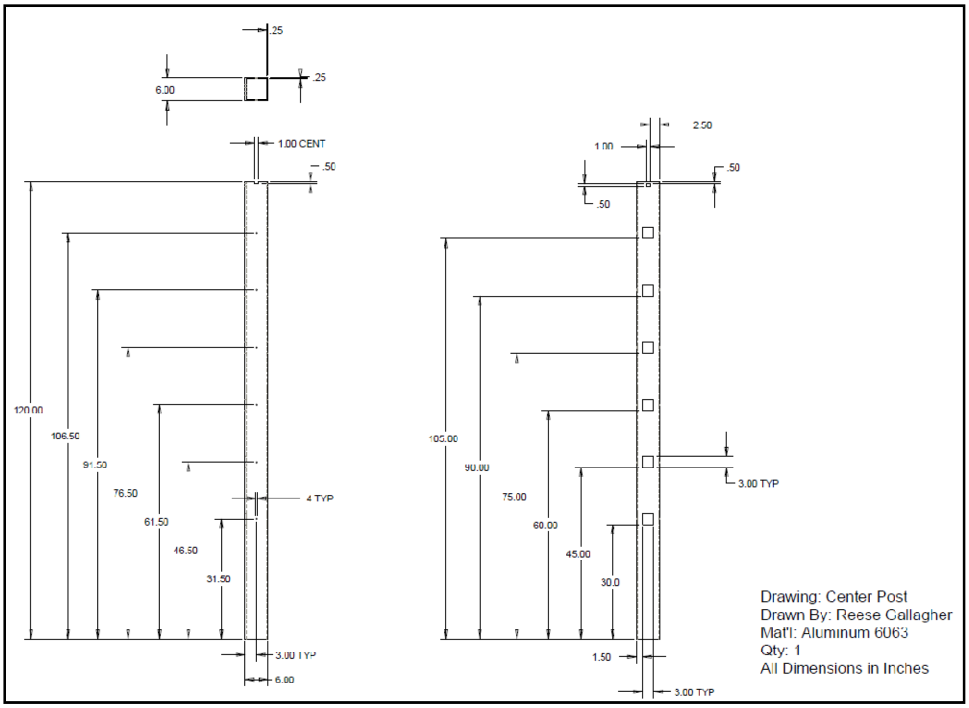

Figure 16.9: Center Post Dimensional Drawing

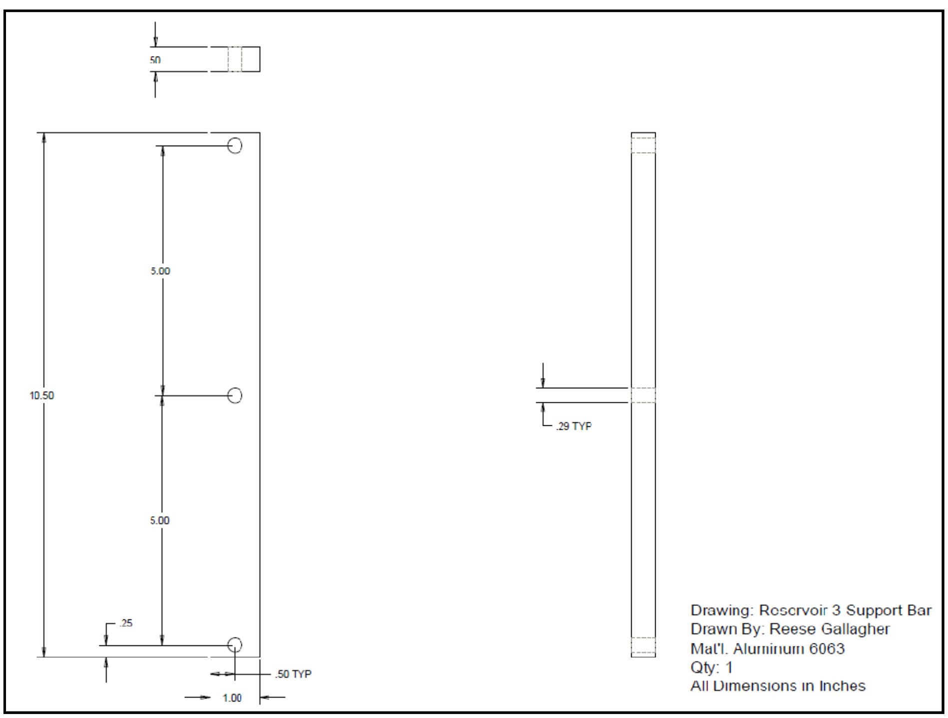

Figure 16.10: Reservoir 3 Support Bar Dimensional Drawing

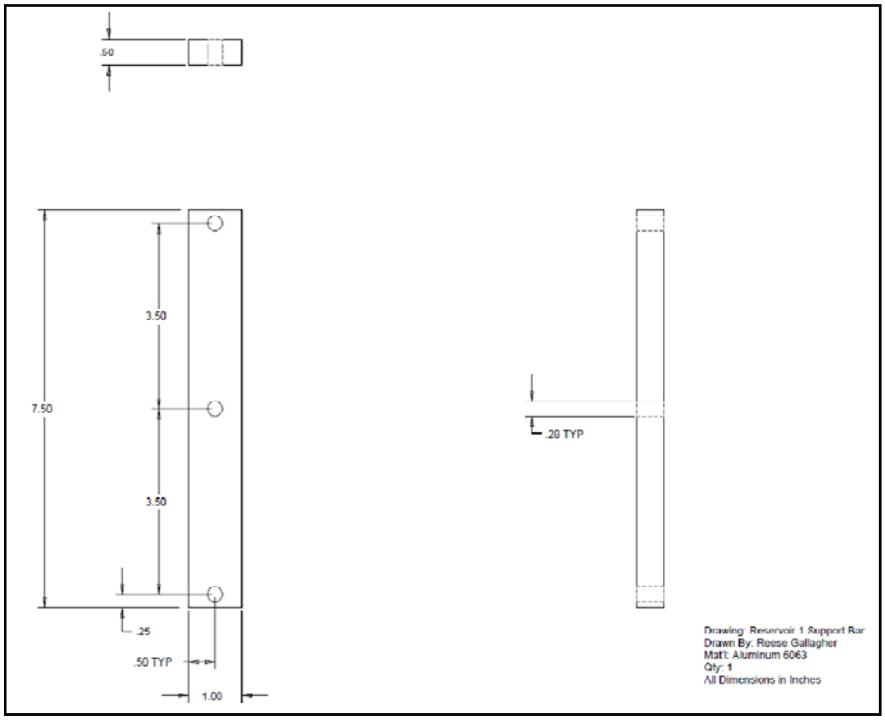

Figure 16.11: Reservoir 1 Support Bar Dimensional Drawing

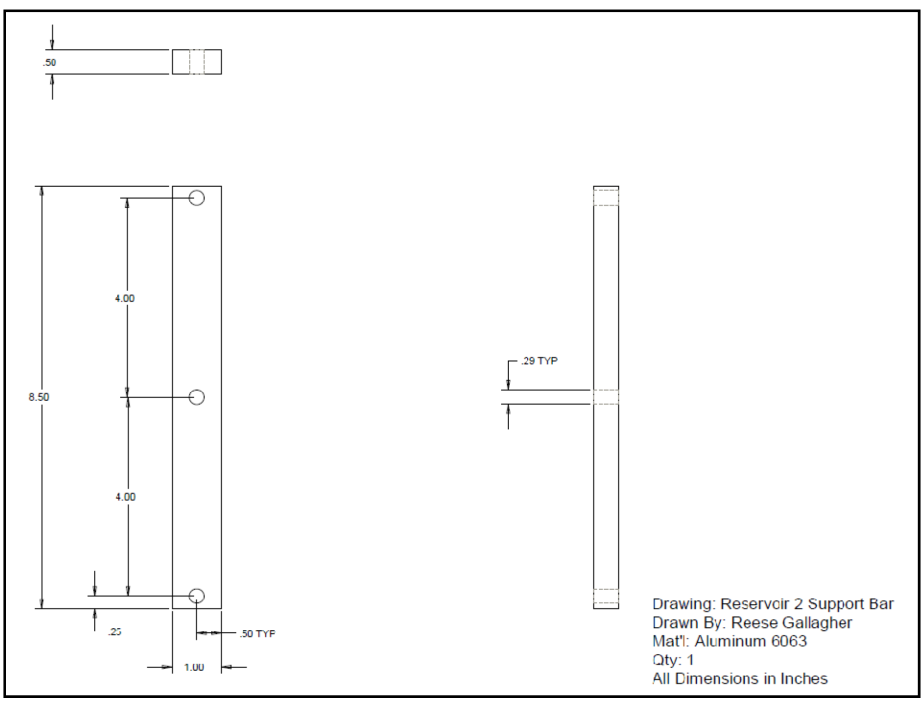

Figure 16.12: Reservoir 2 Support Bar Dimensional Drawing

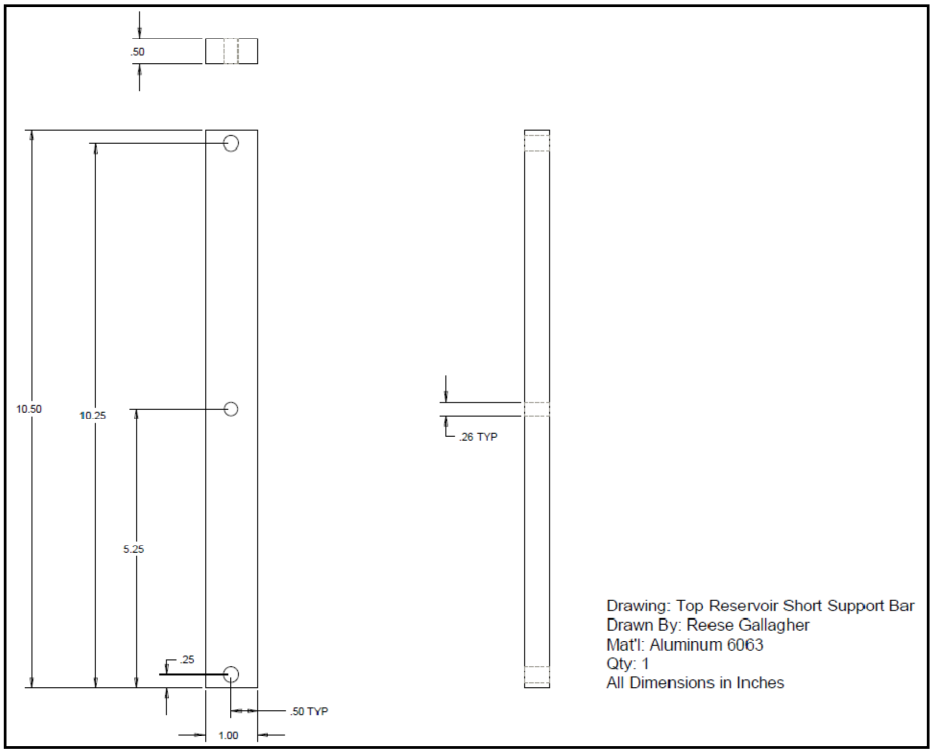

Figure 16.13: Top Reservoir Short Support Bar Dimensional Drawing

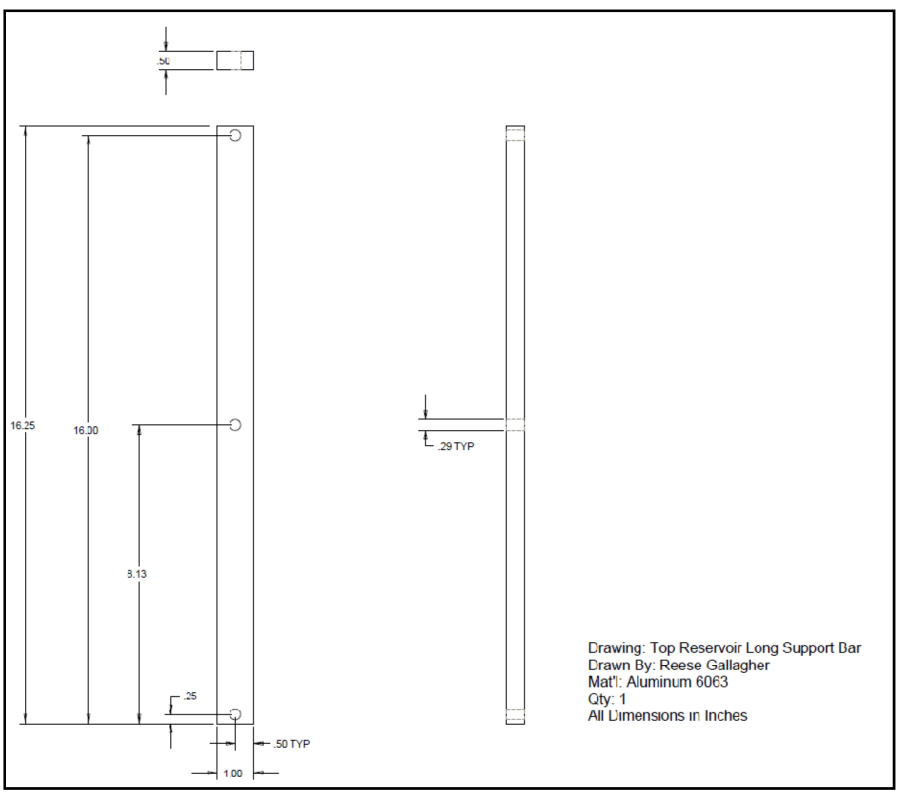

Figure 16.14: Top Reservoir Long Support Bar Dimensional Drawing

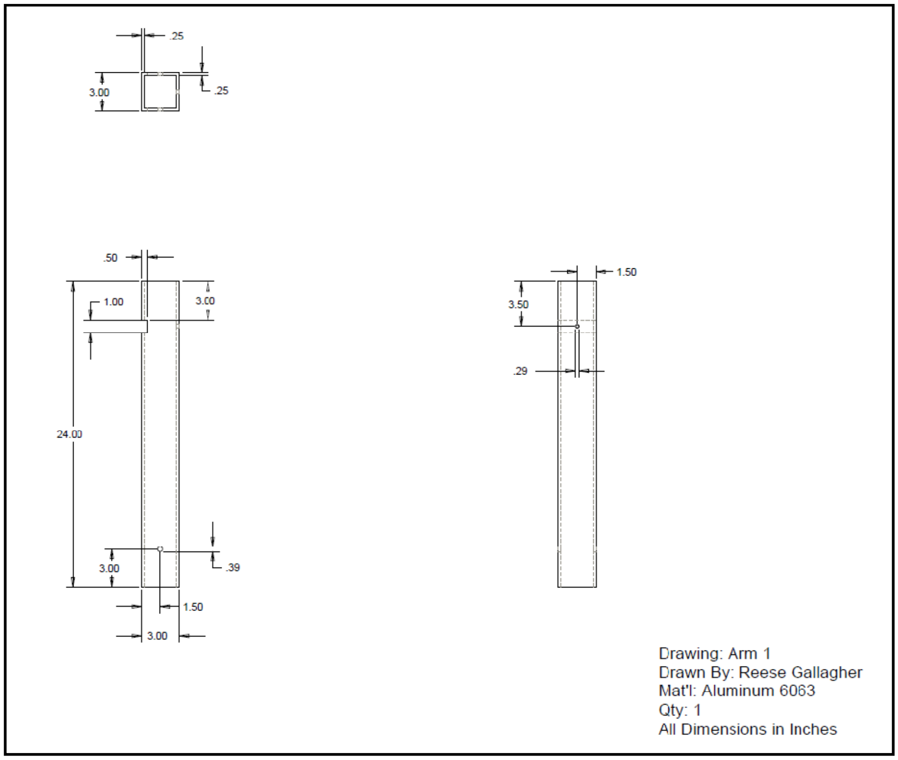

Figure 16.15: Arm 1 Dimensional Drawing

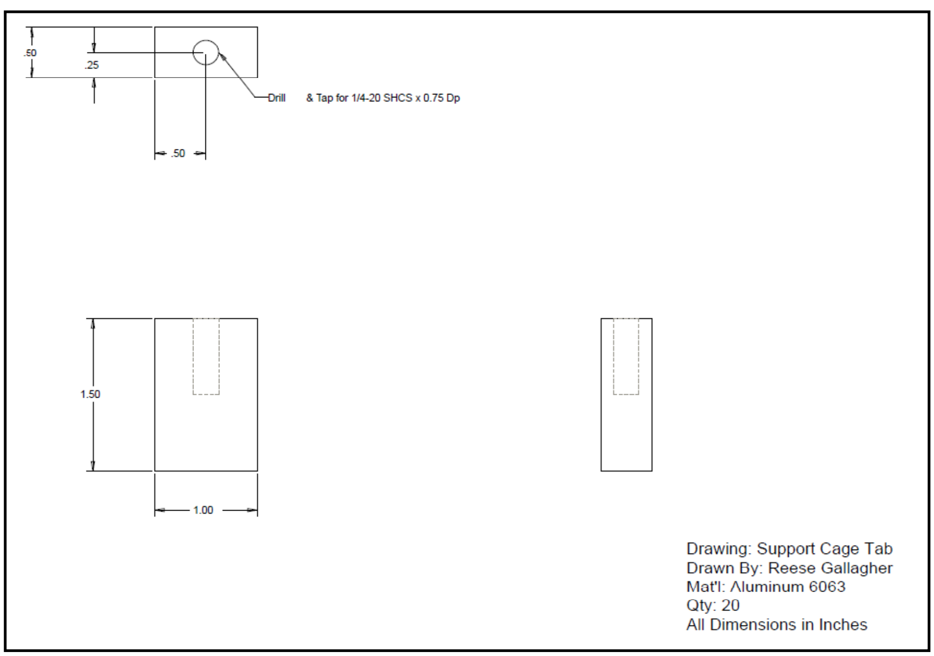

Figure 16.16: Support Cage Tab Dimensional Drawing

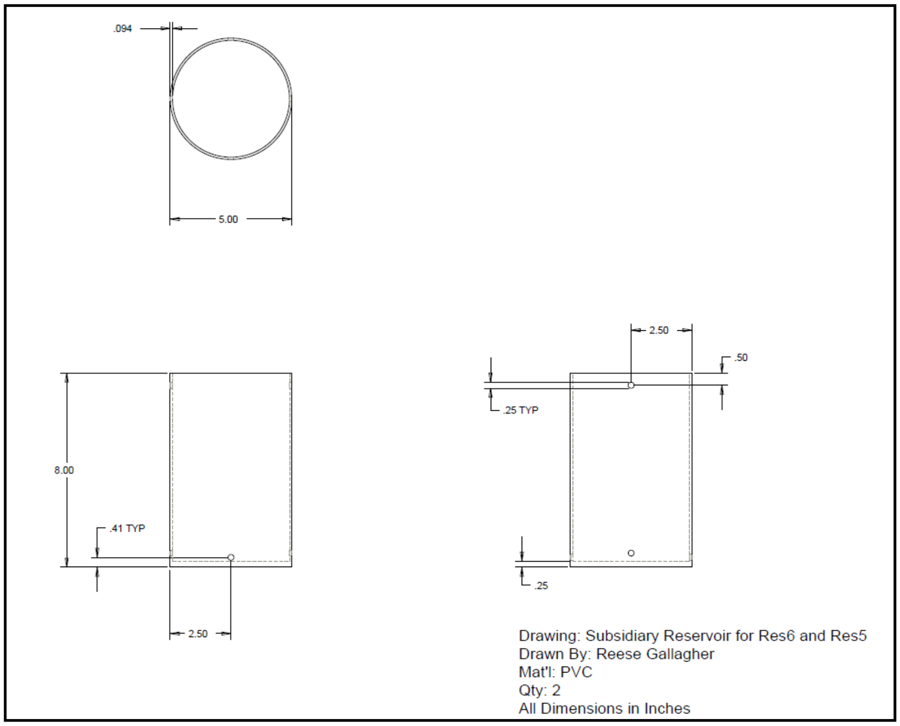

Figure 16.17: Subsidiary Reservoir for Res5 and Res6 Dimensional Drawing

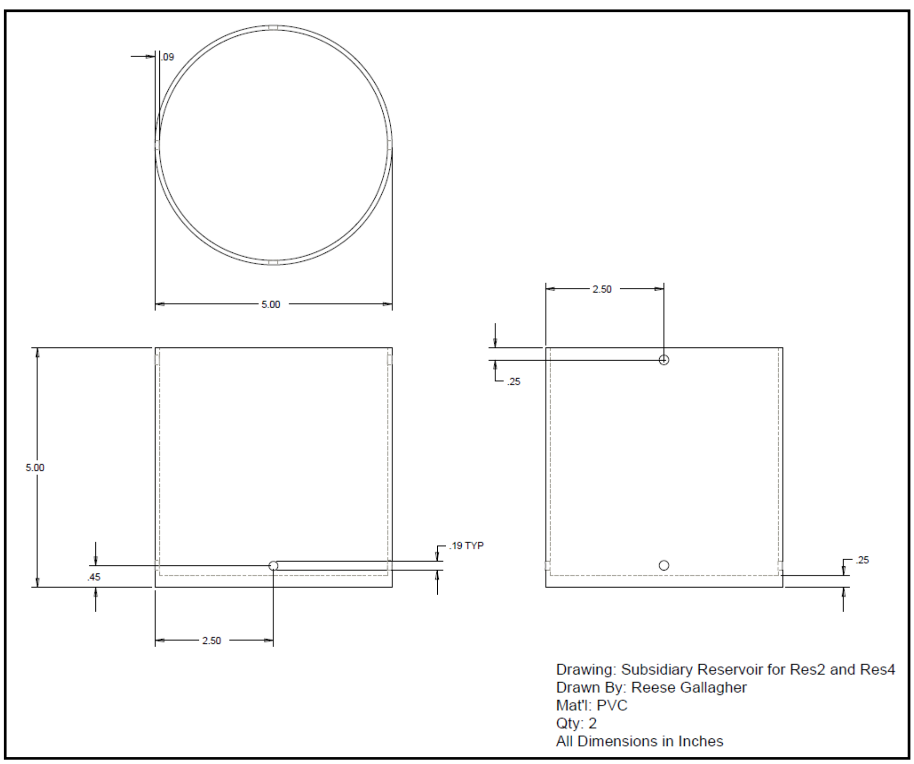

Figure 16.18: Subsidiary Reservoir for Res2 and Res4 Dimensional Drawing

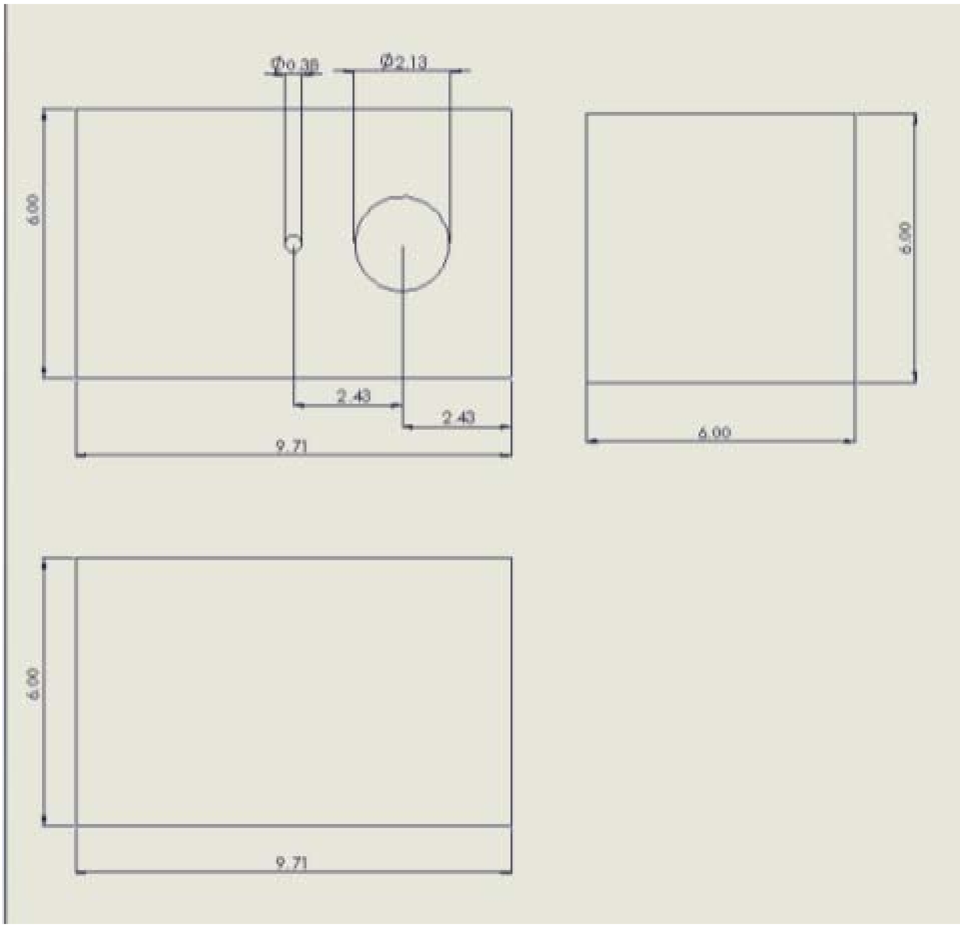

Figure 16.19: Reservoir 1 Dimensional Drawing

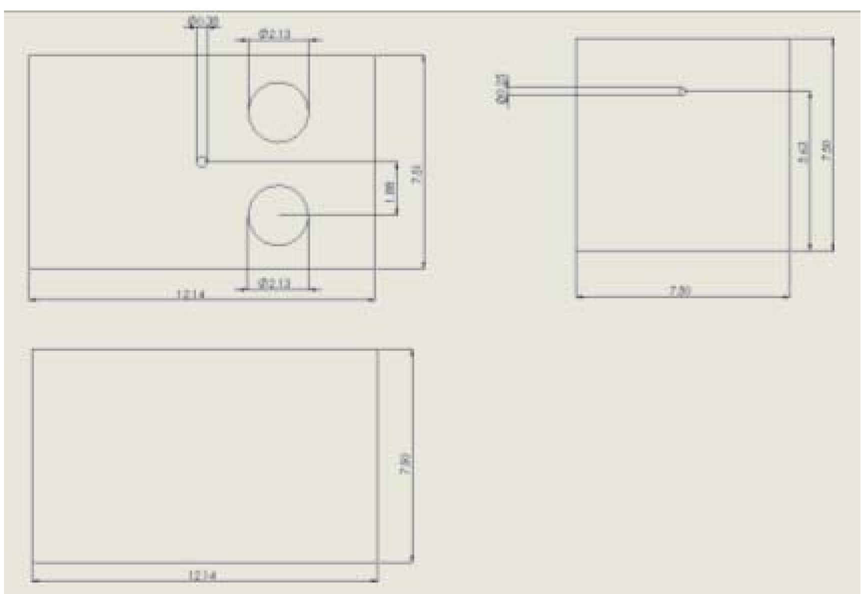

Figure 16.20: Reservoir 2 Dimensional Drawing

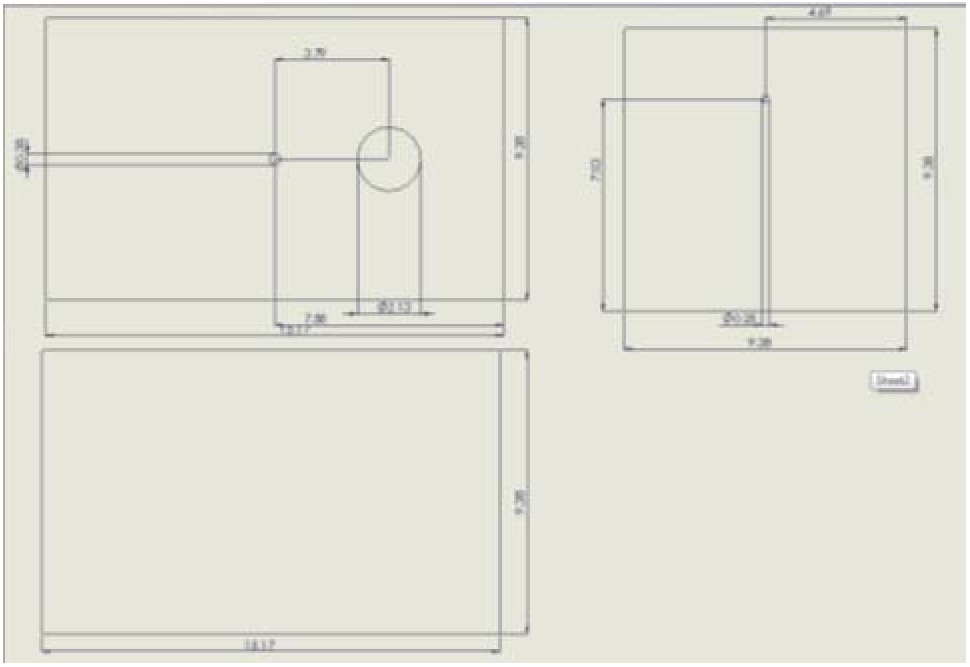

Figure 16.21: Reservoir 3 Dimensional Drawing

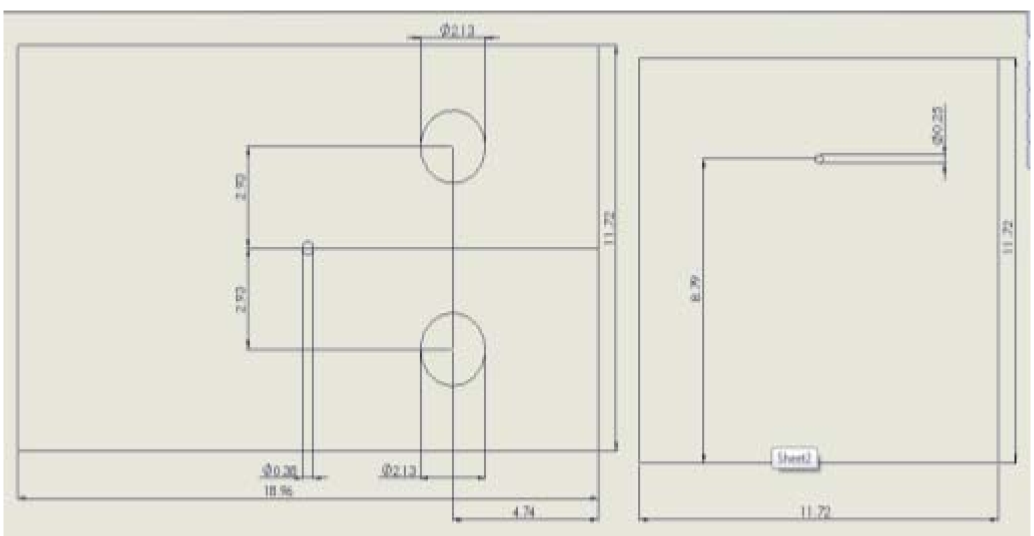

Figure 16.22: Reservoir 4 Dimensional Drawing

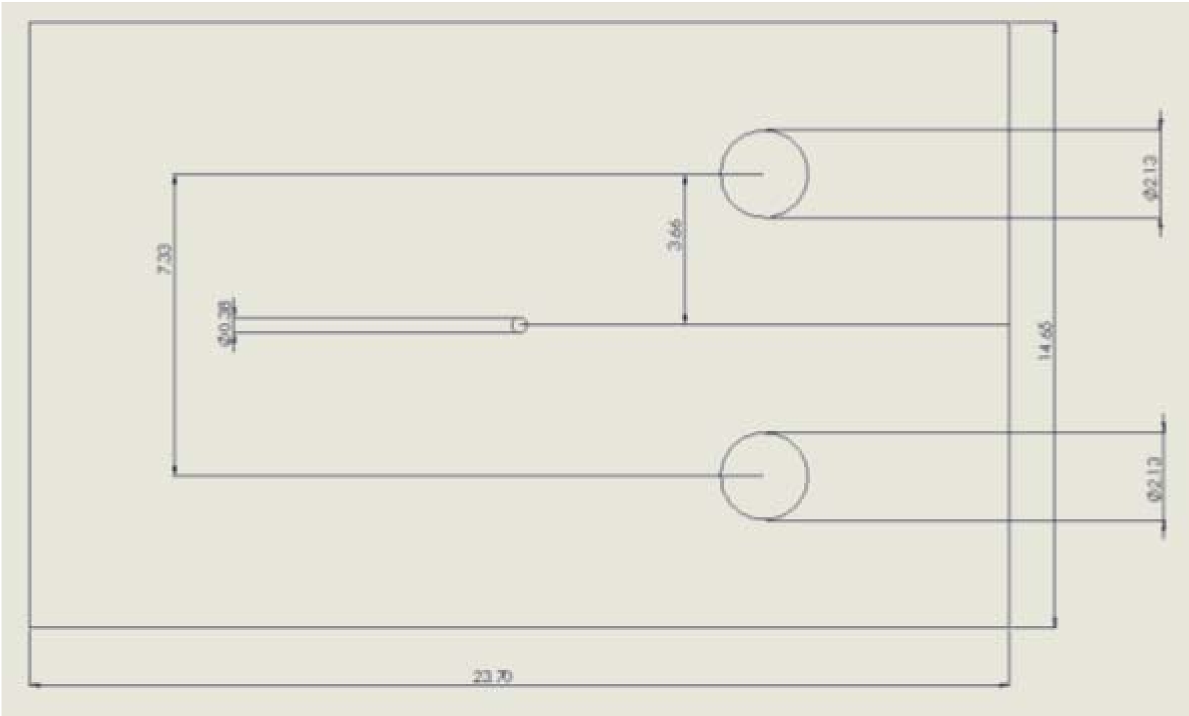

Figure 16.23: Reservoir 5_1 Dimensional Drawing

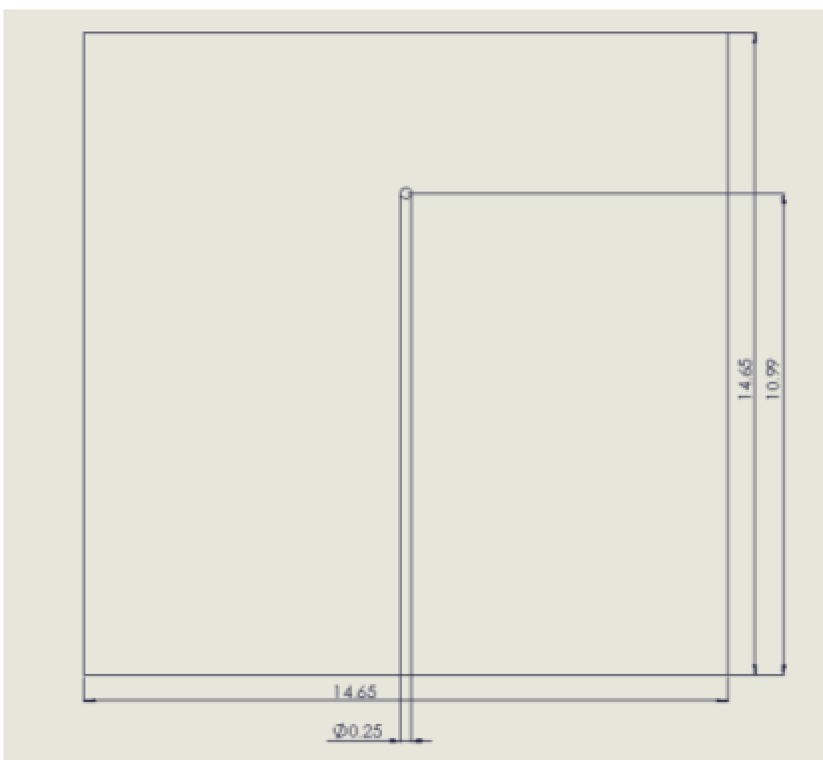

Figure 16.24: Reservoir 5_2 Dimensional Drawing

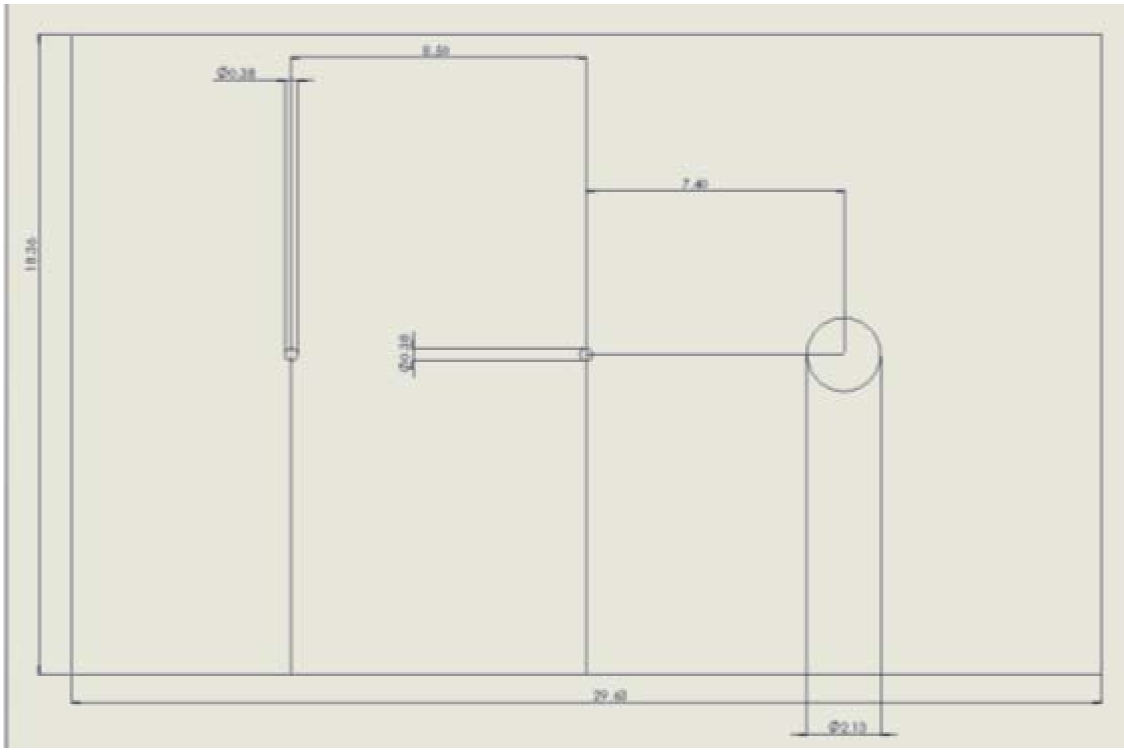

Figure 16.25: Reservoir 6_1 Dimensional Drawing

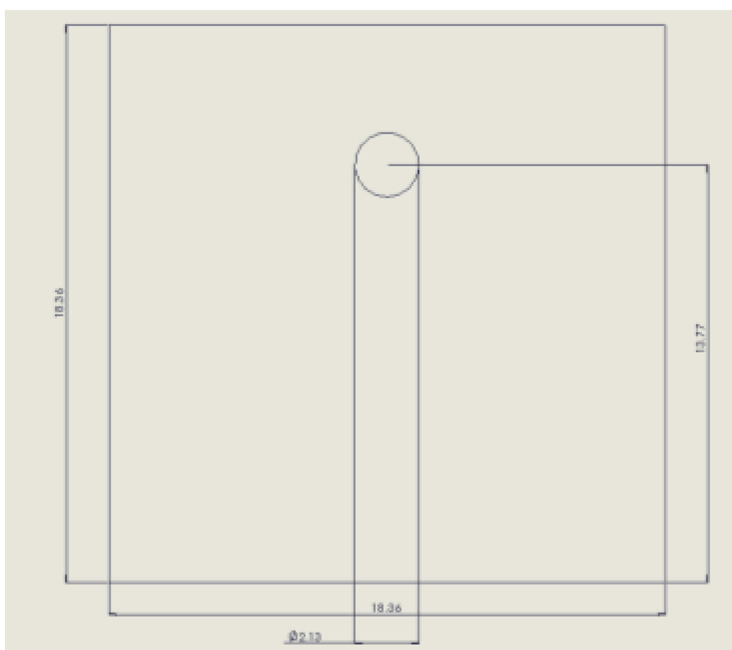

Figure 16.26: Reservoir 6_2 Dimensional Drawing

Attachment Designs

Several attachment designs are required in order to join various components together. These designs were created with the main focus being on simplicity, safety, and overall joint strength. The attachment method for connecting the center post to each arm is shown in Figure 17. For this method, a 3x3" square section is milled out of the 6x6" tubular center post, with ¼" thickness. The 3x3" tubular arm is then inserted into this hole until flush on the opposite side. A 3/8" hole is then drilled through both center post and arm. A 3/8" bolt is then inserted through this hole in order to secure the arm's position relative to the center post.

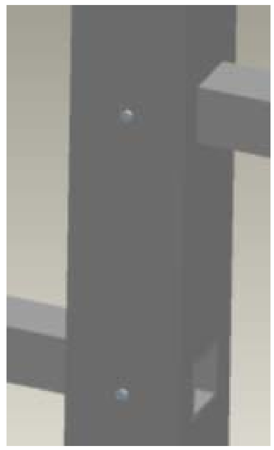

Figure 17: Center Post-Arm Attachment

The attachment method for connecting each arm to its reservoir is shown in Figure 18 and Figure 18.1 below. This method creates a cage around each reservoir along with inserting a bolt through each reservoir into its arm in order secure the reservoir. The cage components mainly consist of solid beams of 6063 aluminum with 1x2" cross sections. Two parallel beams are positioned directly underneath each reservoir and span its width. Each beam is inserted into a 1x2" slot cut into the arm in order for the beams to be flush with the arm's top surface. The distance between beams is equal to 1/3 the total reservoir length. A 3/8" hole can then be drilled through the reservoir, beam, and arm and a galvanized steel bolt can then be used in order to secure these three components together. Proper gaskets must be used in order to ensure no leakage. Currently designed is the use of a rubber gasket. All tabs attached to each beam's end have equivalent cross section dimensions to the beams and measure 3" in length. These tabs are connected through a 2" long ¼-20 flat head cap screw.

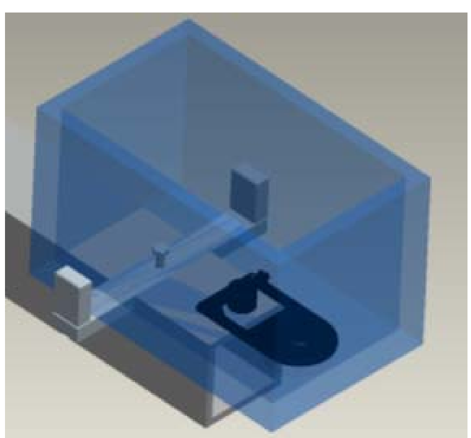

Figure 18: Arm-Reservoir Attachment Top View

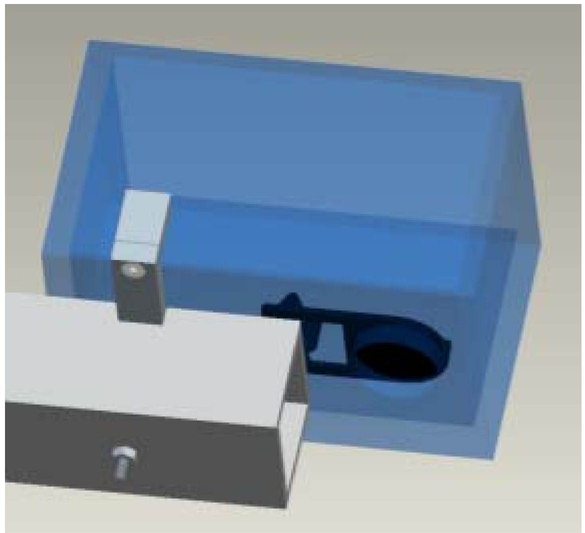

Figure 18.1: Arm-Reservoir Attachment Bottom View

Shown in Figure 19 and Figure 19.1 is the attachment method for connecting the top reservoir to the center post. This approach uses a similar method to the arm-reservoir attachment shown in Figure 18. Two 1x2" holes are drilled into the center post at a distance of 2" from the center post's top in order to allow for a beam to be slide through these holes. Two 1x2" slots are notched into the top of the center post in order to allow for one beam to be positioned within each slot. A 3/8" hole can then be drilled through both beams and reservoir and a bolt is then used to secure these three components together. Proper sealing must be used in order to ensure no leakage. The use of a rubber gasket in between the bolt's washer and head is the proposed sealing method.

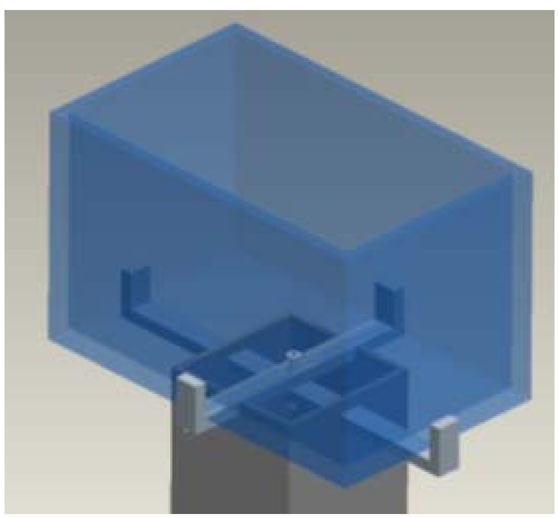

Figure 19: Center Post-Top Reservoir Attachment Top View

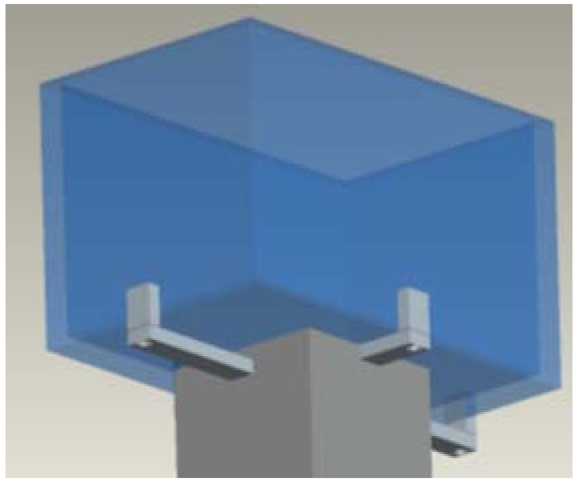

Figure 19.1: Center Post-Top Reservoir Attachment Bottom View

The attachment method for anchoring the center post to the ground is shown in Figure 20. The main material for attachment will be concrete with a 4" layer of stones at the bottom of the 46" hole. The reasoning behind the specified 46" depth is that footings in the Ann Arbor region must be below the 42" frost line [12]. The 4" layer of stones is to provide water drainage and to have a separation layer between the actually ground and the post. Also, as a rule of thumb, the whole diameter must be 2-3 times the diameter of the post being anchored [16]

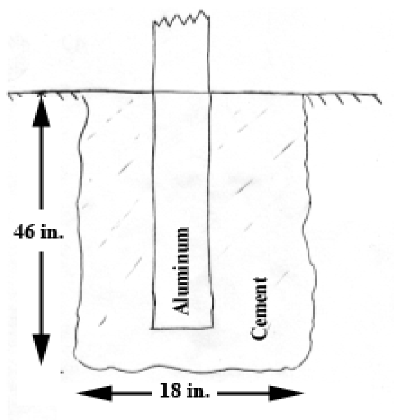

Figure 20: Center Post-Ground Attachment

Valve Mechanisms

The normally open mechanism, shown in Figure 21 below, will be used on several of our reservoirs in order to acquire the necessary flow patterns. Which reservoirs this mechanism will be implemented on is discussed later in this section. The basic components to this mechanism entail a flapper, fishing line, and a half water filled float (weight). This design is only implemented when the flow control of a reservoir needs to be controlled by a reservoir directly beneath it.

When the bottom reservoir is empty, the weight creates tension in the line, which in turn opens the flapper valve. This then allows water to flow out of the top reservoir via transparent tubing. However, when the bottom reservoir is full, there will be slack in the line since the float is only half filled with water, thus allowing it to float due to its buoyancy from the half air filled float. This slack in the line allows the flapper to close the top reservoirs port, stopping any water transfer via tubing. Adding weight to the rubber flap may be required in order to force it to close when there is slack in the line.

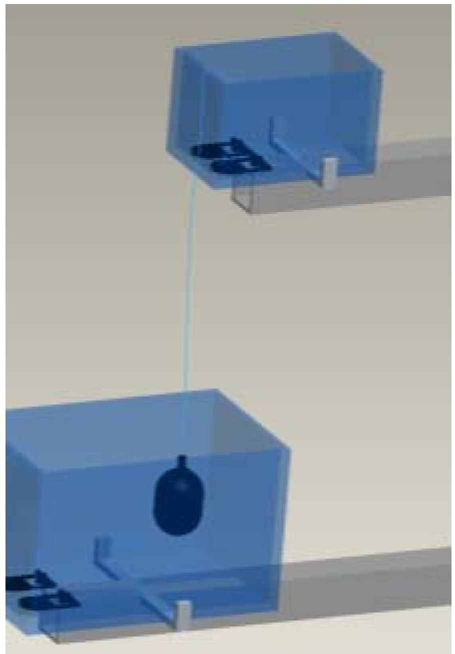

Figure 21: Normally Open Mechanism

The free body diagrams, associated with the normally open mechanism, are shown in Figures 22 and 23 below. The flapper free body diagram takes into account the top reservoirs water force ($\rho_{water}gh_{max}A$, where ρ_{water} is the density of water, g is the acceleration of gravity, h_{max} is the height of the column of water over the flapper, and A is the surface area of water exposed to the column of water) and the line tension (T). Taking into account the moments created by these two forces, it can be concluded that the line tension must be equal to $\rho_{water}gh_{max}A/2$. The main variable is due to the max water height which changes with each reservoir this mechanism is used with.

The weight free body diagram takes into account the line tension, buoyancy forces created by displacing water, and the weight of the water within the float. The weight being used is a partially filled float. This allows the weight to be buoyant when the bottom reservoir is filling, thus allowing slack in the line. This design will also allow the float to act as a weight, creating line tension, when the bottom reservoir begins to empty since there is no longer a buoyant force present.

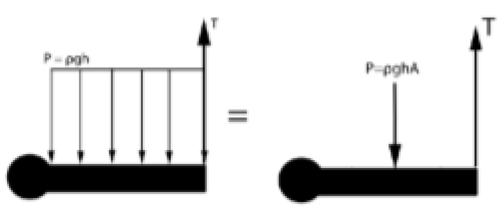

Figure 22: Free Body Diagram of Flapper

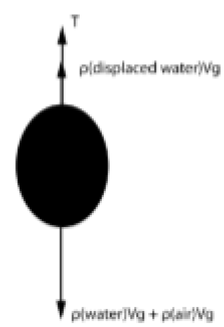

Figure 23: Free Body Diagram of Weight

The normally closed mechanism, shown in Figure 24 below, is an essential mechanism in order to create rushing flow within our fountain. Which reservoirs this mechanism will be implemented on is discussed later in discussion of the flow pattern. This mechanism uses a float, fishing line, and a flapper in order to create the desired effects.

When the water level is low, the flapper stays shut since there is negligible tension on the fishing line. However, as the water level increases within the reservoir, the line tension also increases with due to the buoyancy force created by the displaced water. When the water level reaches a given threshold, approximately 90% of max height, the buoyancy force will overcome the force of water on the flapper and open the valve. The force of flowing water through the flapper will continue to keep the valve open until the majority of water has emptied.

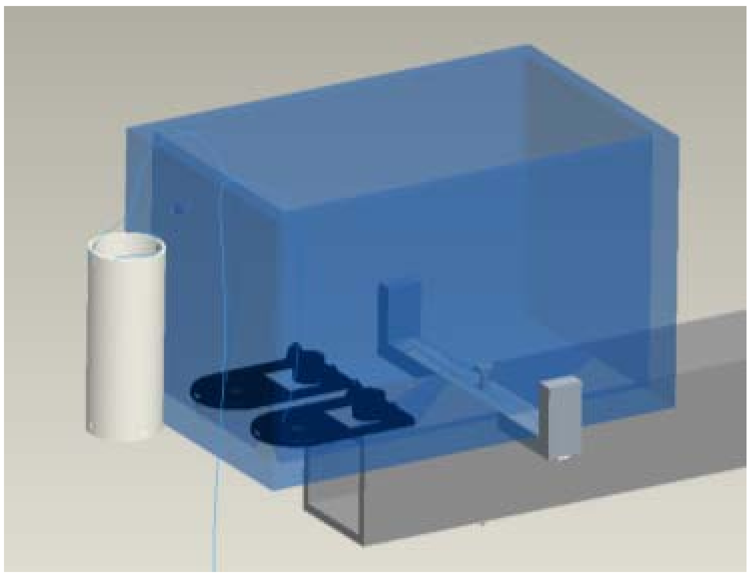

Figure 24: Normally Closed Mechanism

Flow Pattern

It is important to first describe the valves and reservoirs in the system before the flow through the system can be understood. Figure 25 shows the names of reservoirs and valves

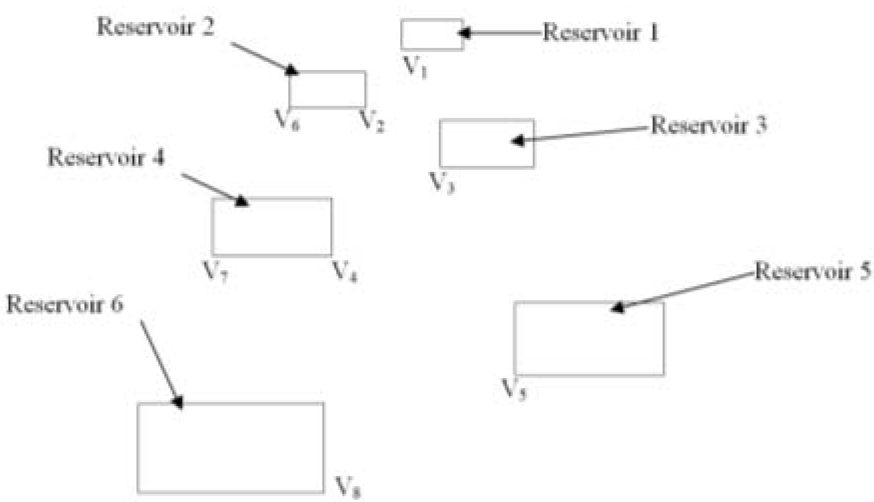

Figure 25: Reservoir and valve designation diagram. The top reservoir is not pictured but is always full and water is continually transferred to Reservoir 1

There are four normally open valves ($V_{1\text{-}4}$) these valves are closed when the water level in the tank below reach half capacity. They open again when the water level in the lower tank dips below half capacity. For all of these valves, clear tubes allow for water to flow from one tank to another quietly. The other four valves are normally closed valves ($V_{5\text{-}8}$). These valves open when the water level in the reservoir reaches 90% of the total volume. The valve is kept open because the water flow through the valve prevents the valve from closing. Once almost all the water from the tank has emptied, the valve will close.

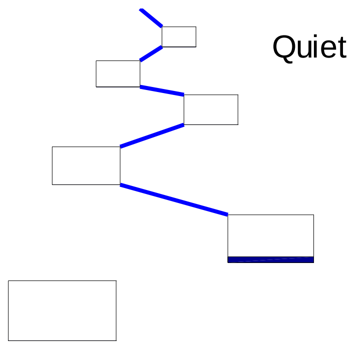

Figure 26.1: Flow Pattern 1

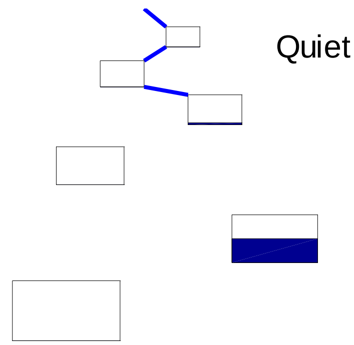

Figure 26.2: Flow Pattern 2

The process begins with all the tanks empty. Water flows through the normally open valve and accumulates in reservoir 5 (seen in Figure 26.1). When the water level reaches half of the capacity of reservoir 5 (seen in Figure 26.2), V_3 closes and water accumulates in reservoir 3 (seen in Figure 26.3).

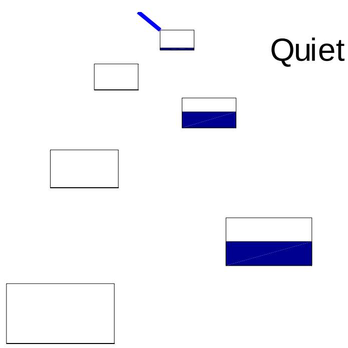

Figure 26.3: Flow Pattern 3

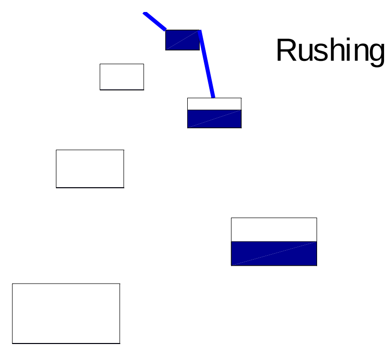

Figure 26.4: Flow Pattern 4

Once the water level in reservoir 3 reaches half capacity, V_1 closes and water accumulates in reservoir 1 (seen in Figure 26.3). When reservoir 1 fills, it overflows into reservoir 3 (seen in Figure 26.4), which then overflows into reservoir 5.

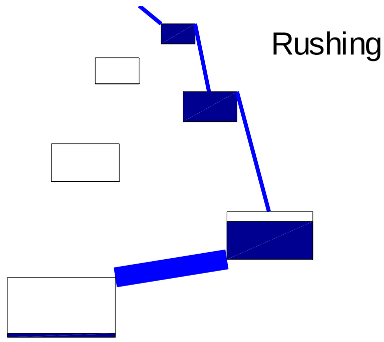

Figure 26.5: Flow Pattern 5

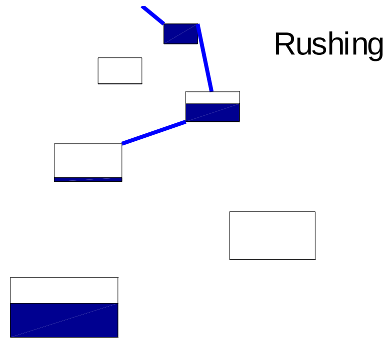

Figure 26.6: Flow Pattern 6

Reservoir 5 fills to 90% and V_5 opens (seen in Figure 26.5), causing a large rush of water to flow into reservoir 6. When this happens, reservoir 6 reaches half capacity, and closes V_4. Water then begins to accumulate in reservoir 4 (seen in Figure 26.6).

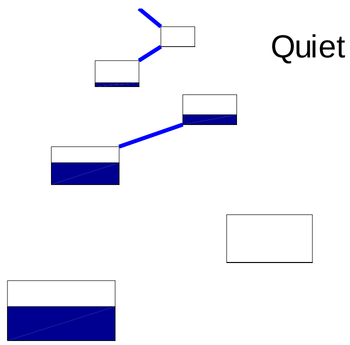

Figure 26.7: Flow Pattern 7

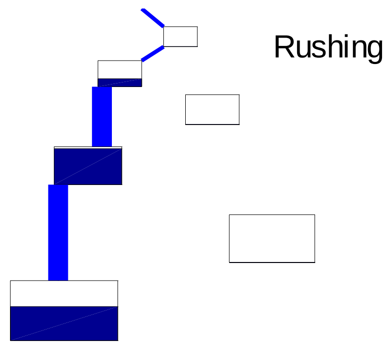

Figure 26.8: Flow Pattern 8

When the water volume in reservoir 4 reaches half capacity, V_2 closes (shown in Figure 26.7). Water then accumulates in reservoir 2. Once reservoir 2 reaches 90% full, V_6 opens (seen in Figure 26.8)and causes all the water in the reservoir to fall into reservoir 4, which causes V_7 to open and water falls into reservoir 6 (seen in Figure 26.9).

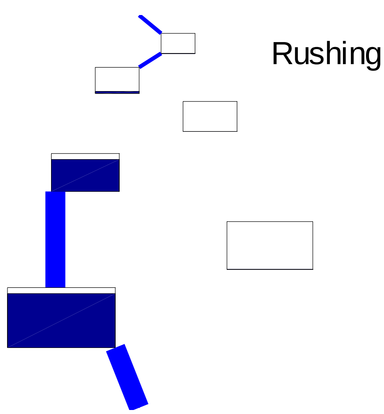

Figure 26.9: Flow Pattern 9

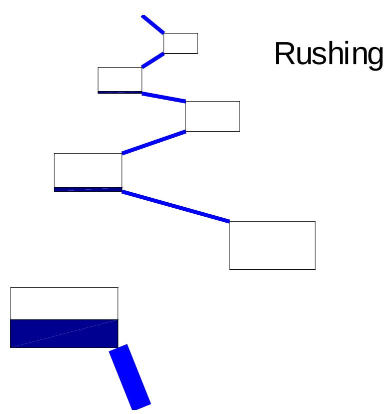

Figure 26.10: Flow Pattern 10

All of the water in reservoir 2 and 4 flows into reservoir 6. This sudden increase in water brings the water level in reservoir 6 to 90%. This causes V_8 to open, and all of the water in reservoir 6 rushes out into the pool below (seen in Figure 26.10). At this point, the reservoirs are mostly empty and the process starts again. This whole process will take approximately 10 minutes using a pump with a flow rate of 250 gallons per minute per hour as shown in the MATLAB timing calculations (See Appendix AIV). The pump selected for the final design is rated at 120 W [17].

Important aspects of the customer desires are for the fountain to be quiet and rushing, time-varying, and fascinating. Beyond these explicit requirements, taking into account the intended final location of this fountain in a plaza outside the University of Michigan Depression Center, it is important that the fountain be conducive to conversation, private reflection and meditation. In evaluating the design of the flow pattern, we can determine whether or not the design meets these explicit and implicit customer requirements.

As seen from the description of the flow pattern, this fountain displays the concept of a quiet rushing fountain. Water is sometimes moving through tubes, being almost silent; sometimes water is falling from one reservoir to another, capturing the rushing aspect of the design. These quiet modes and rushing modes alternate during the cycle, ensuring that there is a time-varying experience for the viewer. The complexity of the flow pattern, combined with elegantly simple mechanisms creates an experience for the viewer that captures their imagination and attention. Quite different from a traditional fountain, this design allows for the viewer to watch for a long period of time. Finally, this fountain is not a constant source of noise or annoyance in the serene and tranquil environment envisioned for the future Richard Scott Noble Plaza. The quiet portion of the design, allows for comfortable relaxation or conversation. The rushing and overflow of water creates a way to escape from the stresses of life in the complex man-made world, and retreat into a place surrounded by natural beauty and simplicity.

Engineering Design Parameter Analysis

Structural Analysis

The main purpose of the engineering parameter analysis for the fountain superstructure is to evaluate and aid in the decision-making process regarding design choices, such as material selection, and the maintenance of a safety factor in the final design. The analysis of the super structure was performed on its two main components: the main beam and the six reservoir-holding arms. The level of detail involved in this analysis helps to ensure that the selected design parameters allow the fountain to function without reaching failure modes. Detailed analysis information, including a step-by-step walkthrough, is available in Appendix IV.

The main mode of failure for the fountain arms is yield due to bending and shear stress from the weight of the water and reservoirs. Torsional stress is also caused by wind hitting the reservoir faces. This analysis led to the determination of the different stresses generated in the arms of the fountains. Using this analysis, it was possible to determine the maximum stress seen by an arm, 33 MPa. Using this maximum stress value, a functional material, age hardened aluminum 6063 alloy, was chosen for the fountain. It was important that the chosen material meet this structural requirement with a minimum safety factor of 2, as without meeting this requirement, there is a risk of failure within the super structure. Much of the analysis was done using a predetermined beam cross section. This cross section, 3 in. x 3 in. with a ¼ in. wall thickness, was picked logically based on the most commonly available cross sections for retail metal stock. Having made this decision, it was possible to pick a material that could be easily purchased, and would not need special manufacturing.

The analysis of the fountain main post was similar to that of the fountain arms. The primary failure methodologies studied were yielding and buckling. Similarly, this analysis leads to the same conclusion regarding material selection and helped ensure that the fountain superstructure met the minimum safety factor of 2. It is important to understand that this safety factor was not chosen arbitrarily, but is used commonly for civil engineering applications [18].

The level of detail present in this analysis is high enough to ensure that all the different failure modes have been considered, at least at the material selection level. It is important to understand that although the analysis is performed for the final design, simplifications and assumptions were made in order to allow for a timely completion of said analysis. These simplifications include the modeling of the fountain arms as cantilevered beams. In order to compute the stresses bypassed by these simplifications, local stress concentration analysis, using Finite Element computations, is in Appendix IV. Details regarding other simplifications and assumptions are included in the step-by-step walkthrough of the analysis in Appendix IV.

The relationship of the performed analysis to the final design is the use of worst-case scenario possibilities. To ensure the validity of the analysis to a real application, the worst-case scenario helps mitigate risk when considering the simplifications used when performing the analysis. This worst case scenario in effect amplifies the confidence level when considering the fountain under normal use, but when the fountain is affected by extreme conditions, the worst-case scenario analysis helps to ensure the structural survival of the fountain. This worst case analysis still ensures a safety factor of 2 with scenarios such as an extra 70 kg. weight, such as a human, hanging off the edge of the fountain or the effect of winds moving in opposite directions within feet in wind shear like situations.

Reservoir Analysis

To ensure proper functionality of the reservoirs it was essential to analyze the possible failure modes and design against any of these possible failure modes should they pose an issue. The reservoirs must be able to handle extreme weather conditions, cyclic loading, and must be leak resistant.

To ensure that the reservoirs hold water without leaking, selection of a proper adhesive was essential. After comparing various adhesives for joining the acrylic reservoir base and walls, it was determined that Weld-On 16, made by IPS would be the most suitable solution for ensure a water-proof, high-strength bond. The Weld-On 16 data sheet states that the adhesive has a bond strength of 15.2 MPa after curing for 1 week [19]. Through the analysis presented in Appendix IV we have concluded that this bond strength will be sufficient to ensure structural integrity of the reservoir joints.

Since the fountain is going to be placed outdoors, it is essential to design against extreme weather conditions such as wind and temperatures. Our sponsor has requested that this fountain operate during the winter months, so analysis was done on the effect of thermal strain on the reservoir material. This analysis is presented in Appendix IV. From our analysis it was determined that the thermal strains, even under extreme conditions, would be negligible and have no effect on the reservoir reliability.

Operating the fountain during the winter also requires that the water cannot freeze either during the fountain cycle or in the base pool. Alternatives to water, such as salt water or antifreeze, were considered but all came with safety and operational concerns. Because of this, we determined that heating the water in the base pool would be the optimal solution from preventing the water in the fountain from freezing. To determine the specific amount of heat necessary, we used an approximate model of the complex system to determine the heat loss from the system. This analysis, located in Appendix IV, showed that most of the heat loss would occur from the pool of water itself and very little from the fountain cycle due to the relatively short cycle time. From the analysis it was determined that the design would require about 3.3 kW of heat if the air and ground temperatures were the average low air temperature throughout the winter. We estimate that heating the fountain would cost on average $865 per winter.

To further analyze the reservoir system, the forces due to wind were analyzed. Since typical winds (5-10 m/s) would have very little impact on the design, it was determined that extreme wind conditions should be analyzed. A wind speed of 30 m/s was chosen for analysis, which is near the maximum wind speed experienced in Southeastern Michigan [20].

The main concern with the wind forces is that if exerted on a single side of a reservoir the force could cause it to break. To analyze the forces we first calculated the wind pressure on the largest side of the reservoir and determined the force that results from that wind pressure. This analysis, presented in Appendix IV shows that there is no risk of a reservoir failing due to high wind gusts.

Tube Sizing

Without properly sizing the tubing between reservoirs, the fountain cycle will not properly function, causing water to accumulate in some reservoirs or empty too quickly from others. Using simple fluid dynamics equations and the flow rates required by the design to achieve proper functionality and cycle time, the diameter of tubes was determined. The detailed analysis for this sizing can be found in Appendix IV. The tubing from reservoir to reservoir will have an inner diameter of 1.25 in. and an outer diameter of 1.625 in based on the available tubing options.

Material Selection

A detailed material selection was performed for the arm material and reservoir material using CES, SimaPro, and safety considerations. The full analysis can be seen in Appendix VII, and is briefly described below

Arm Material Selection

The arm material is constrained dimensionally by design, and cannot fail under cyclic loading of a fixed water weight. It must also be able to survive outdoors. From these constraints, hard constraints and material indices were created to down-select amongst the vast array of materials. Both age-hardening and non-age hardening wrought Aluminum alloys fit the application well, however due to the availability of 3in. x 3in. cross-section ¼ in. wall thickness Aluminum, alloy 6063 (an age-hardening wrought Al-alloy) was chosen. This alloy, described as Ultra-Corrosion-Resistant Architectural Aluminum, should function well for the fountain superstructure.

The arm material has a relatively larger impact on the environment than the reservoir material; however, the superstructure is expected to last for the entire life cycle of the fountain. Since 6063 Aluminum alloy was the only readily available material that matched dimensionally and satisfied the constraints from material selection, an alternative material need not be used based on the environmental impact analysis.

The arms will be shaped using a mill because of the small batch size and ability to create the variety of cuts required by the design. The arms will be attached to the reservoirs, reservoir cradles, and the center post by threaded fasteners to allow for easy assembly and quick replacement.

Main Post Material Selection

To select the proper material for the main beam of the structure, we needed to first examine the possible failure modes. We determined that compressive strength and yield strength were both important, since large winds could cause a large moment at the base of the main post. We again, limited our search to materials that could survive the outdoor conditions experienced in Michigan, such as minimum and maximum service temperature, water resistance and UV resistance. We used the minimum cost column material index to refine our search for materials. Finally to account for bending, we selected only materials with high compressive and yield strengths. We found that the only materials that reasonably fit the main support application were non-age hardening wrought Al alloys, age hardening wrought Al alloys, and cast Al alloys. When we looked into the availability of materials of the size and shape described we found that Ultra-Corrosion-Resistant Architectural Aluminum (Alloy 6063) would be the best material to use for center support structure in the final design.

Reservoir Material Selection

The material used to create the reservoirs is constrained by factors such as outdoor durability, resistance to fracture and transparency with the objective of reducing the overall cost. Because of the strenuous hard constraints such as transparency, water resistance, and UV resistance, few materials were available for use in this specific application. Polymethyl methacrylate (PMMA) was chosen from the materials that satisfied all of the hard constraints due to its relatively low cost and high fracture toughness.

Compared to the arm material, PMMA has a small effect on the environment. If these reservoirs will be replaced after an expected period of 10 years, then the environmental effect over the entire life cycle is greatly increased. Because of the limited selection of materials, and the small difference between PMMA and other competing materials in terms of life cycle environmental effect, PMMA will be used for the final design.

In order to create the reservoirs, PMMA will be shaped using a laser cutter and joined using a rigid adhesive. This shape and assembly method was chosen due to the small batch size and varying reservoir sizes.

Material Concerns

It is important to note that Al Alloy 6063 is an age-hardening wrought Al alloy, meaning that it cannot be welded without losing the strength gained by age-hardening, and therefore, any connections must be fastened.

Prototype Description

The purpose of the Quiet Rushing Fountain prototype is to validate the final design. In order to meet this goal, the validation of meeting customer requirements is necessary. These top-five customer requirements include the quiet/rushing aspect of the fountain, a fascinating fountain, a child safe fountain, a fountain with low maintenance costs as well as outdoor functionality. Of these requirements, it was not possible to meet some, such as low maintenance and outdoor functionality due to fact that the prototype is being designed for an indoor application. It is not critical for the prototype evaluation to fabricate a prototype fountain that works in the cold Michigan winter, especially when it would not be used outdoors. Thus, the main focus of the prototype is to capture as many aspects of the final design as possible.

The basic layout of the prototype design, as seen in Figure 27 below, is the same as the final design. The biggest observable difference between the final design and the prototype is the number of reservoirs. In order to capture the operation of all the mechanisms, only four reservoirs are required, since the bottom two are just repeats of the top reservoirs. These four reservoirs are the same size as the top four reservoirs of the final design. Also, the total height of the superstructure is reduced from ten feet to four feet. A height of four feet is a manageable height for the prototype, as it allows for space to hold all four reservoirs. Another major difference between the prototype and the final design is the materials used for the fountain super structure. The final design uses the 6063 Aluminum alloy while the prototype uses wood. Wood is a material which is easy to machine, but also has the required structural capabilities to ensure failure of the prototype super structure will not occur. The prototype reservoirs will be made of Plexiglas, as with the final design, to ensure that the fascination aspect is also present for the prototype. The use of Plexiglas allows the viewers of the prototype to visually inspect the different mechanisms that are visible in the prototype.

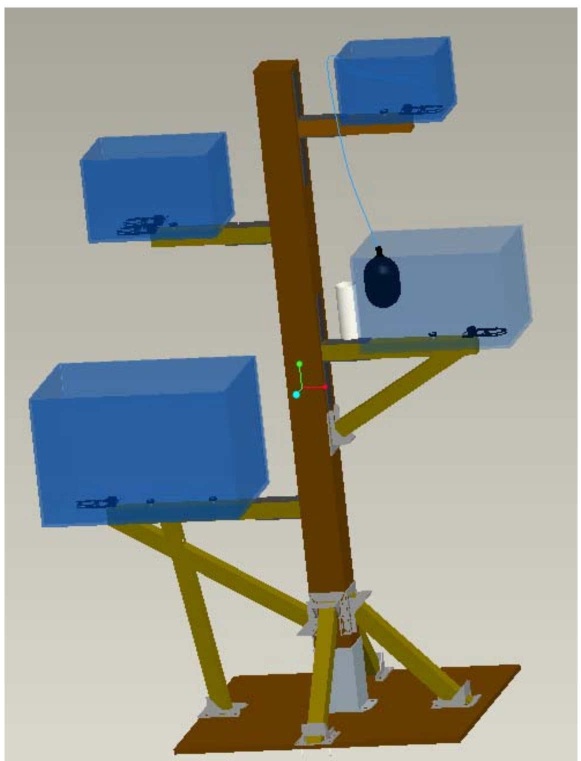

Figure 27: Prototype Fountain

Another way to meet the fascination requirement is having all the mechanisms that are included in the final design in the prototype as well. The prototype will function in a similar fashion to the final design. The flow pattern of the prototype will operate as if the middle two reservoirs have been removed from the final design, but sizing-wise, as if the bottom two were removed. Removing the flow patterns of these reservoirs, does not remove any flow patterns from the final fountain design, thus retaining all the fascination and quiet/rushing aspects of the final design.

This prototype design will help us evaluate the feasibility of the final fountain design, as it essentially mimics all of the major principles of the final design. The prototype will also help evaluate the mechanisms in the final fountain design, and ensure that there is indeed a quiet/rushing aspect to the fountain flow pattern. These specifications in turn can be used to determine if the fountain is fascinating. Although it is not possible to test child safety, it is possible to determine whether the prototype is child safe by ensuring that there are no failures within the fountain. This holds true for the evaluation of the final design. Ensuring the prototype is safe for children, can help determine whether the final design will be child safe.

Fabrication Plan

The following sections cover, in detail, the steps required to fully manufacture a prototype. This section is split into two sub-sections, Machining and Assembly. Refer to Appendix VIII for a full safety report regarding the fabrication process.

Machining

The following section constitutes the step-by-step directions required to machine the required prototype components.

Reservoirs
Utilize a laser cutter to cut out pieces of each reservoir from Plexiglas. The actual reservoir pieces will be cut, along with holes for bolts and our drain (flapper) mechanism. Refer to the following engineering drawings (Figures 28.1-6) for specific dimensions.

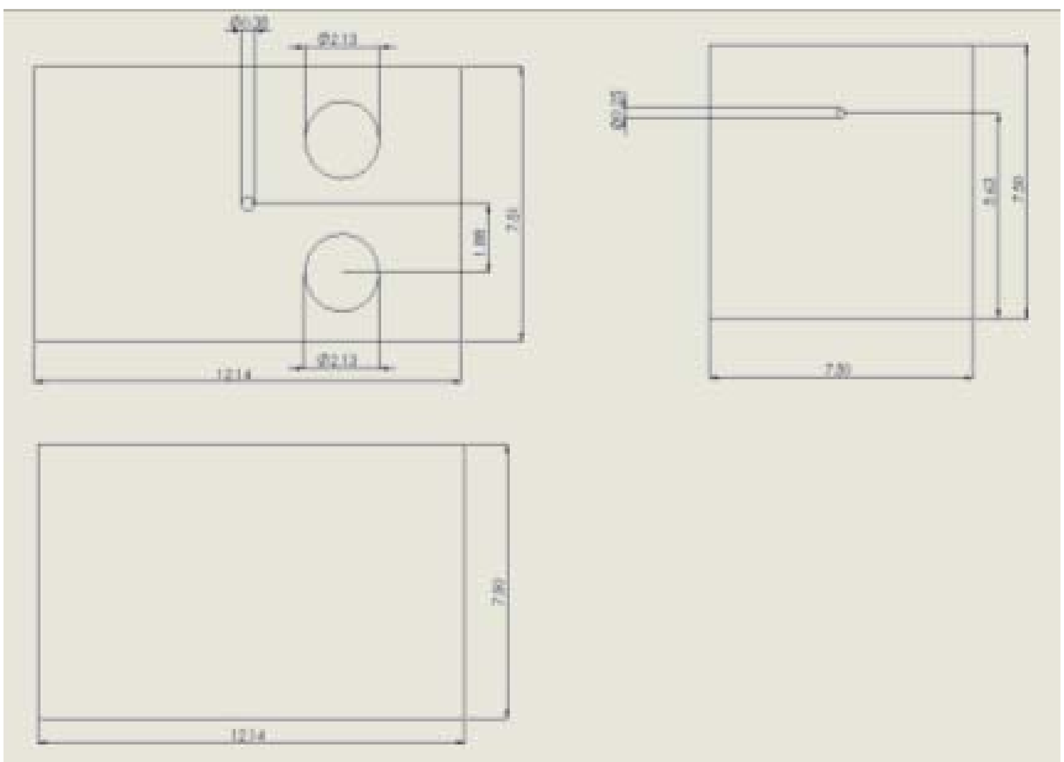

Figure 28.1: Reservoir 2 Base and Sides

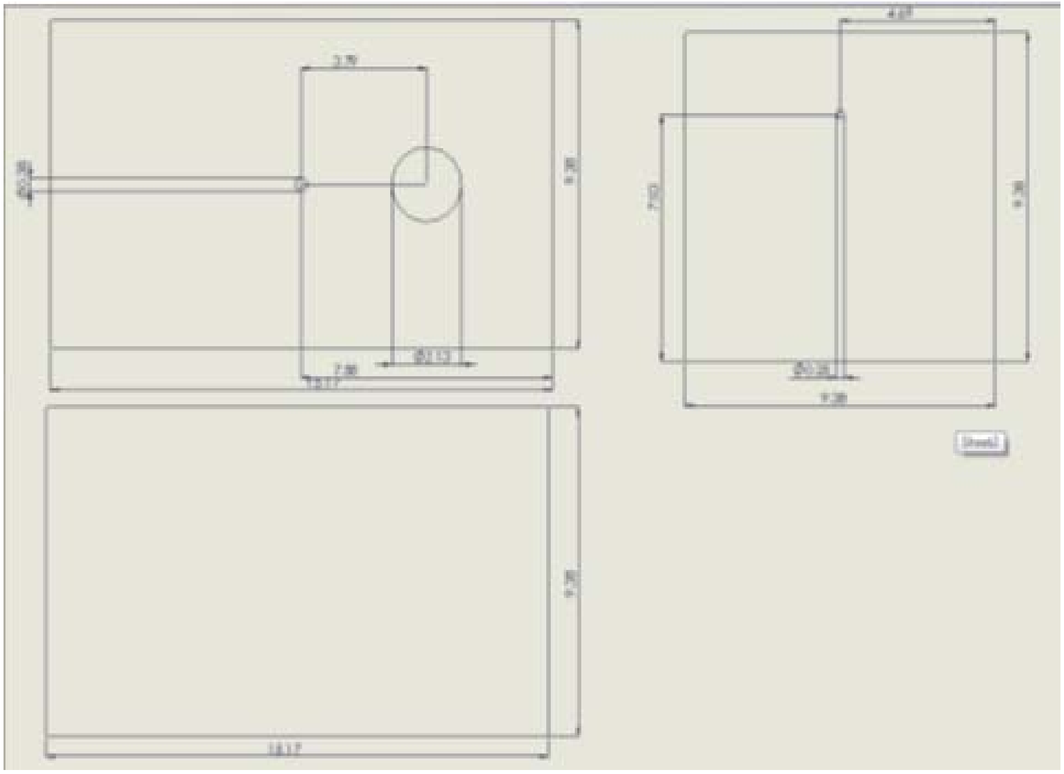

Figure 28.2: Reservoir 3 Base and Sides

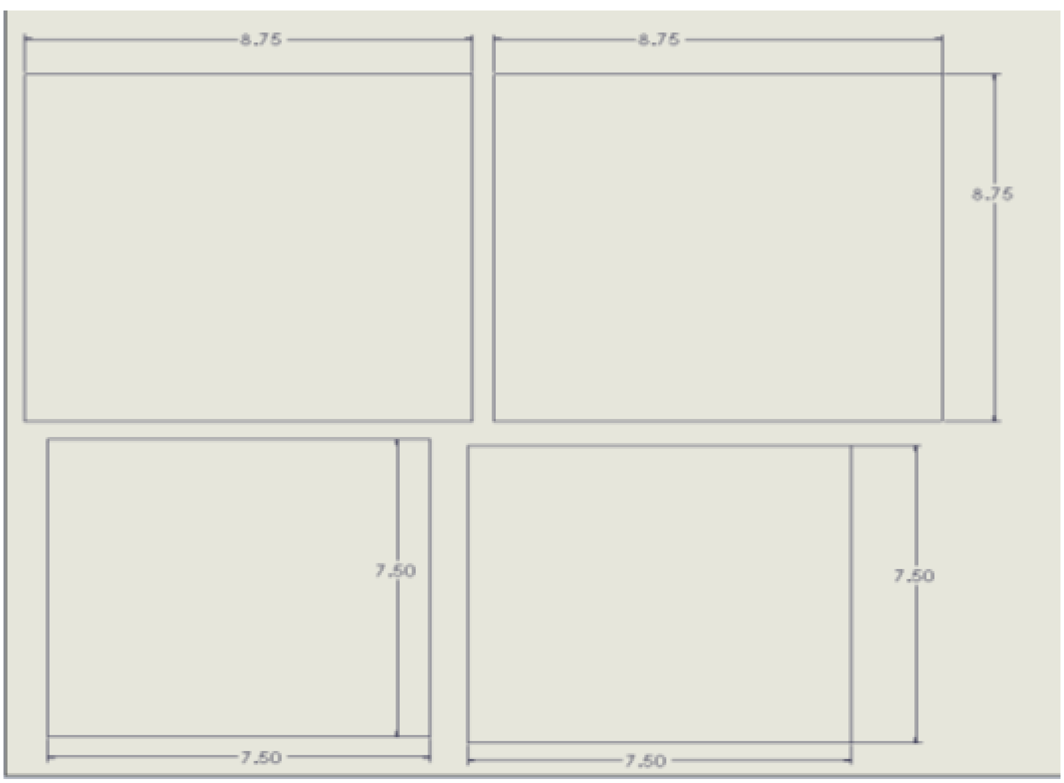

Figure 28.3: Reservoir 2 and 3 Square Sides

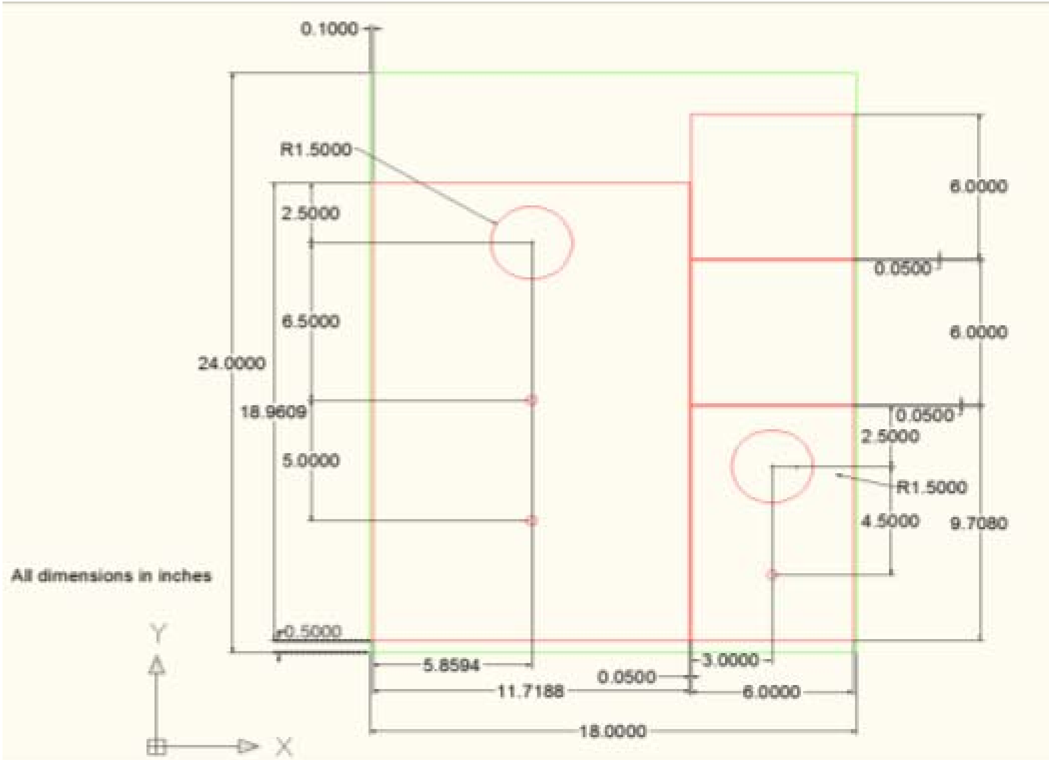

Figure 28.4: Reservoir 1 and 4 Base and Reservoir 1 Square Sides

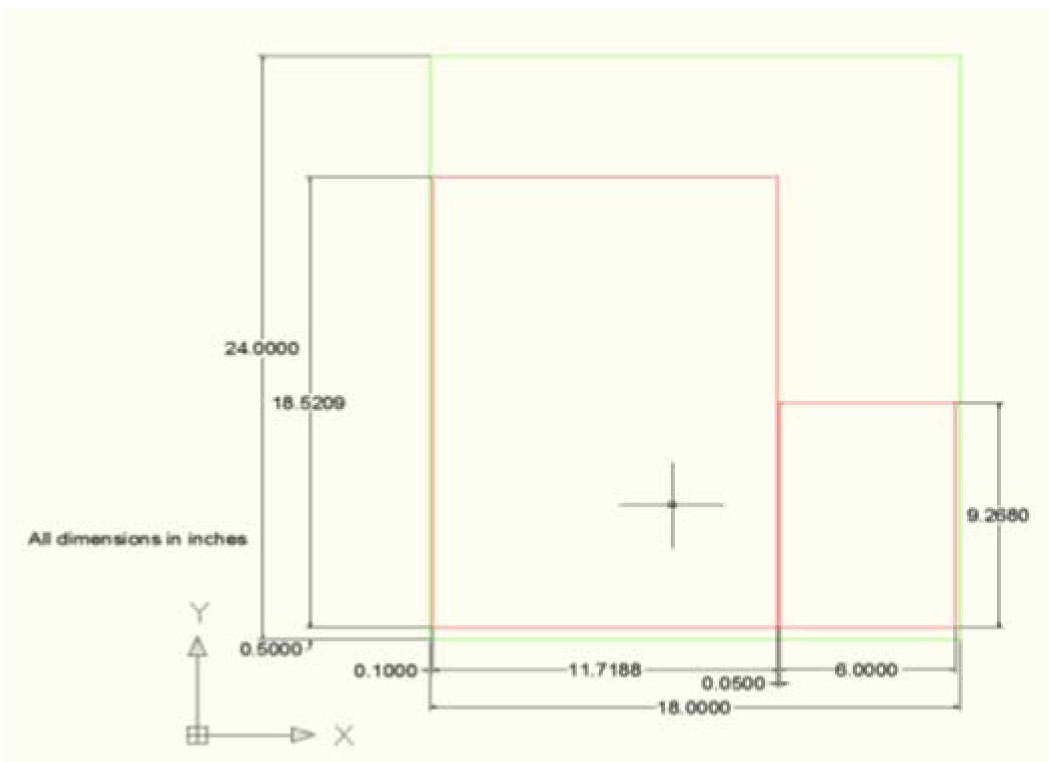

Figure 28.5 Reservoir 1 and 4 Sides

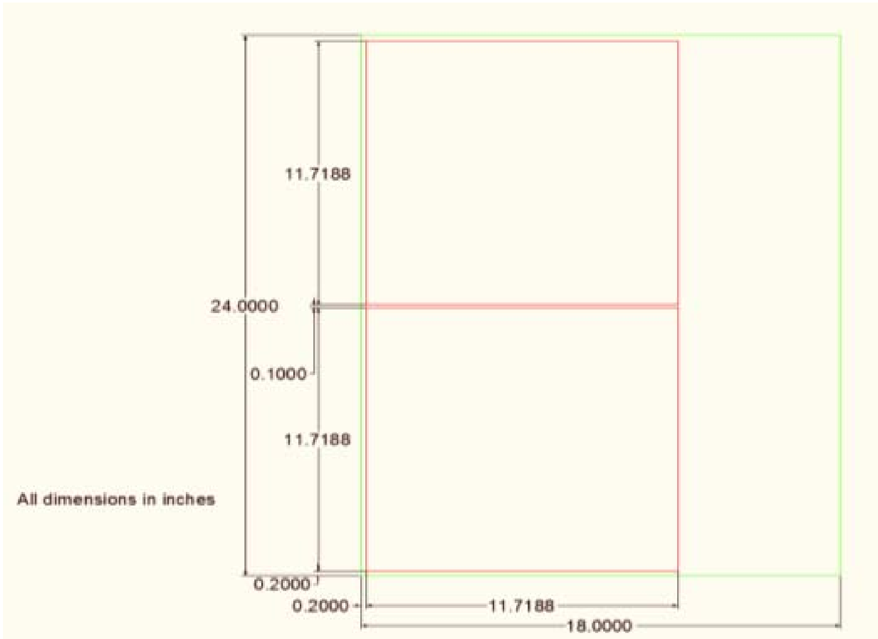

Figure 28.6: Reservoir 4 Square Sides

Base Plate

Mark the location of the four required holes to mount the post bracket, using the bracket as a reference. Check the provided engineering drawing for reference. After ensuring that the holes are in the correct place, use a hand drill with a 0.25 in. drill bit to drill these four holes. These holes will be used in the assembly process to fasten the main post and bracket to the base plate. Use the following image and the engineering drawing as a reference (Figures 29.1-2).

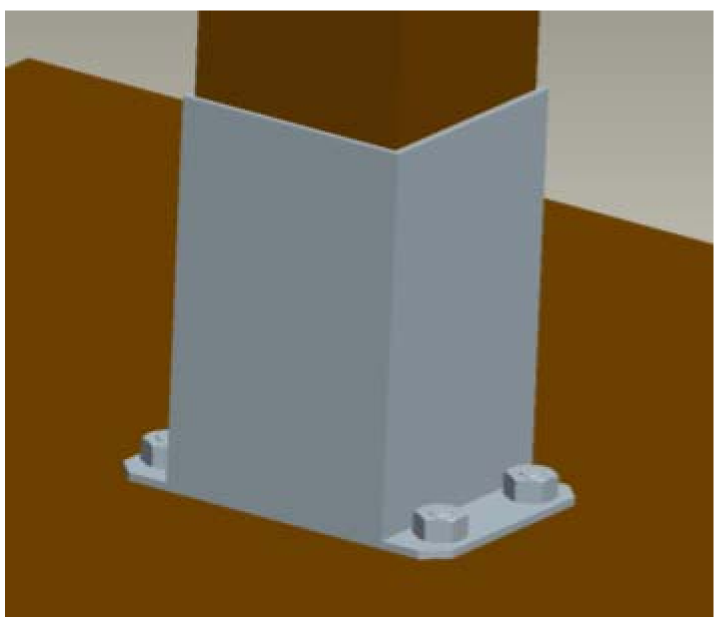
Figure 29.1: Base Plate attachment illustration

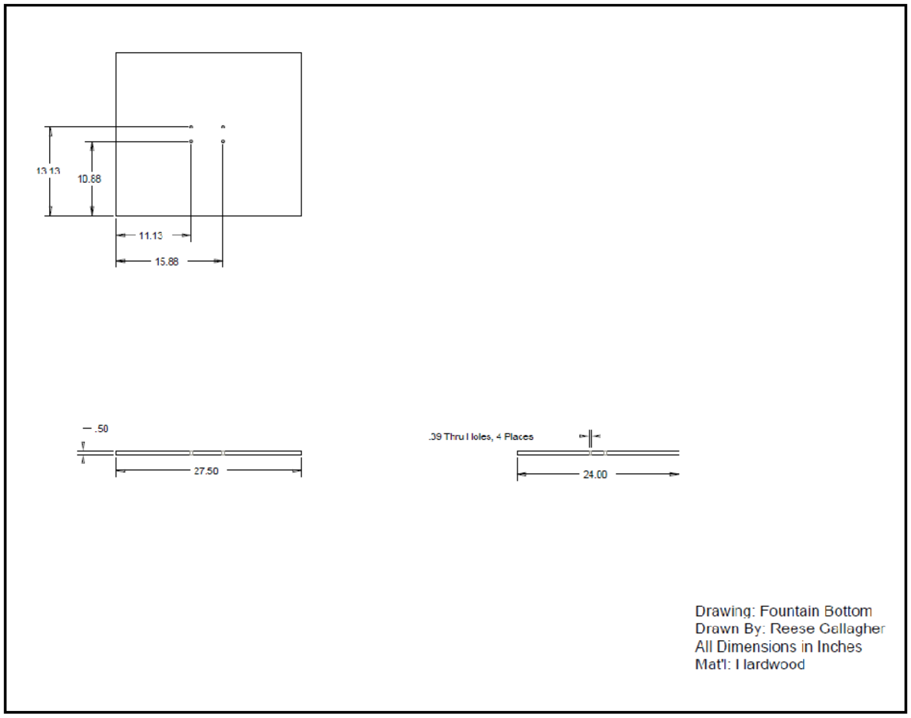

Figure 29.2: Base plate dimensional drawing

Main Post

Start by cutting the main beam (4 in. x 4 in.) into two 5 ft. pieces. One 5 ft. piece can now be inserted into the purchased post bracket. In order to insert the wood into the post bracket, simply slide it in to the opening on the post bracket and all the way to the bottom. Once the main post is inserted into the bracket, use the appropriate Size - 6 screws to attach the main post to the bracket. Using a hand drill and a Phillips screw bit, insert the screws from the side of the post bracket into the main post. Refer to the following engineering drawing for sizing details shown in Figure 30.

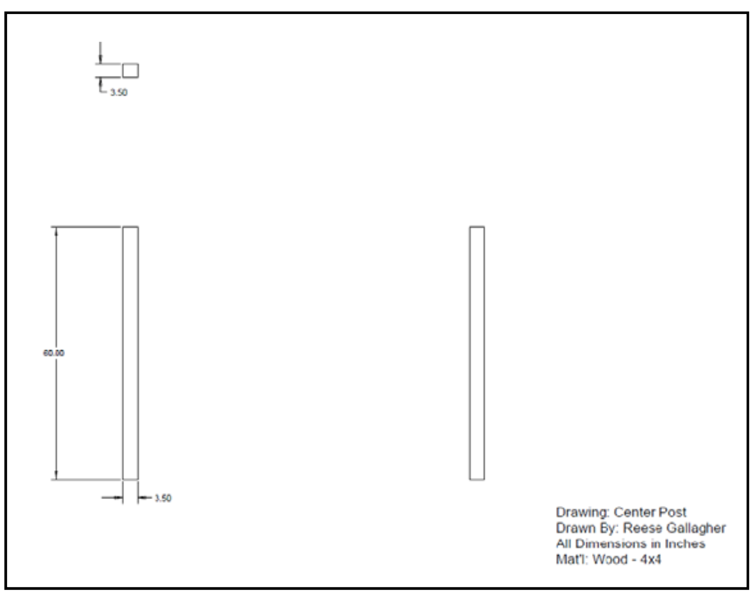

Figure 30: Main Post dimensional drawing

Arms

Start by cutting the wood for the arms (2 in. x 2 in.) into the required lengths. Ensure proper dimensions, and refer to the engineering drawings for the length of each arm. At the end of this stage there will be four arms, and extra scraps of wood. Do not discard these scraps, they will be used later for the triangle supports of the arms. Follow the machining directions for the triangle arm supports. Refer to the following engineering drawings for arm sizing (Figures 31.1-4).

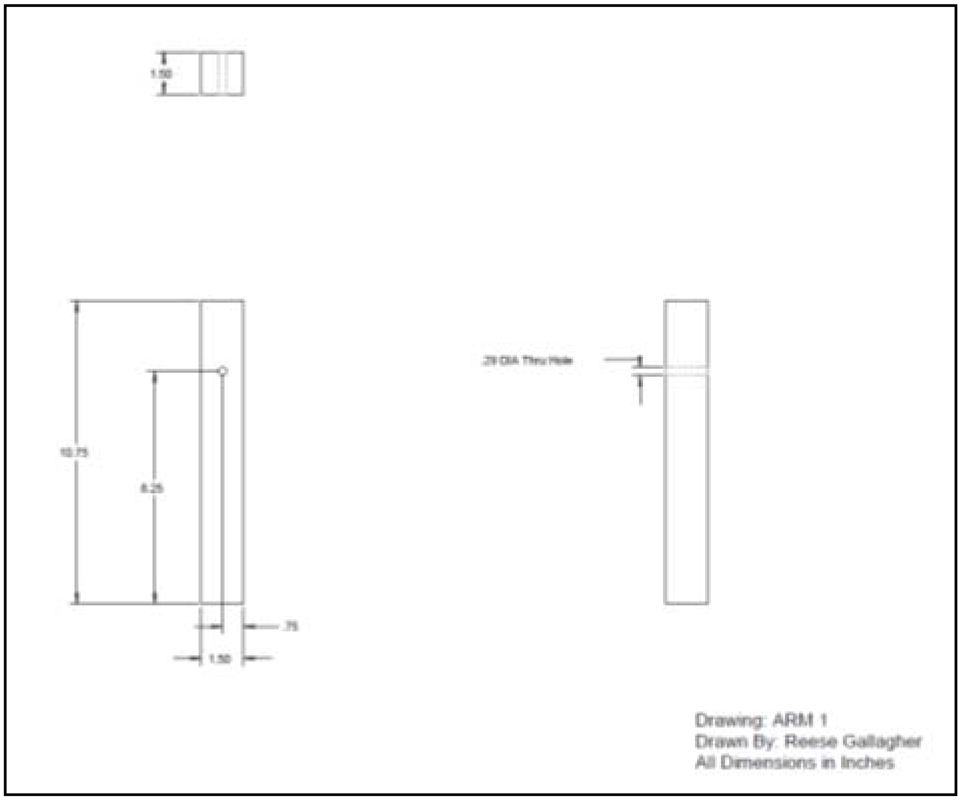

Figure 31.1: Arm 1 dimensonal drawing

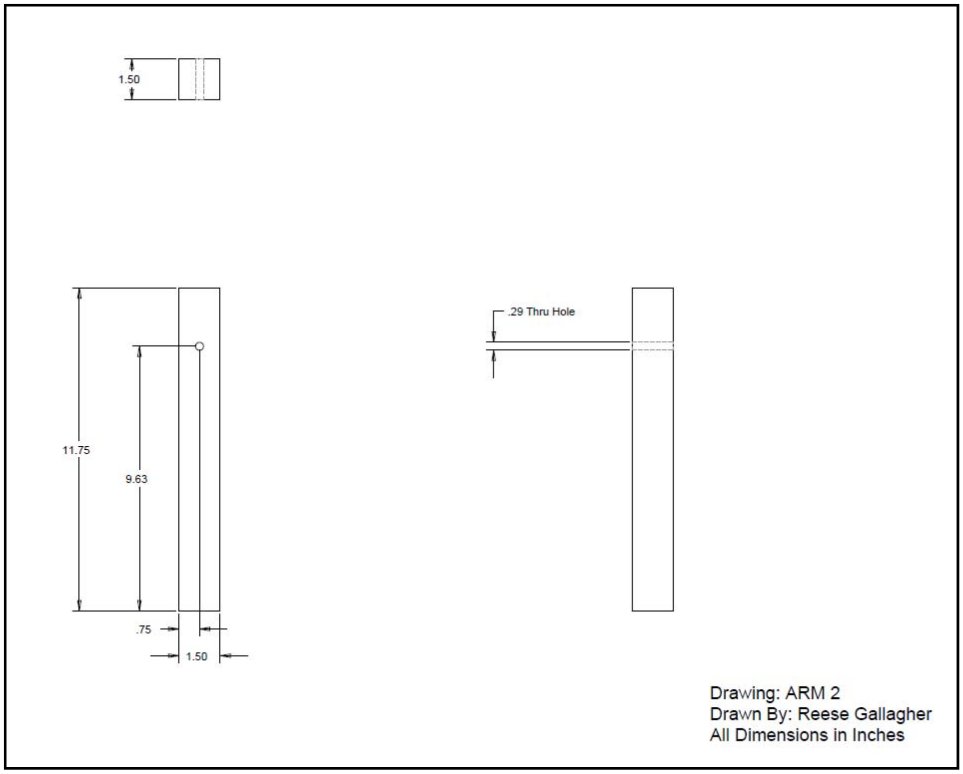

Figure 31.2: Arm 2 dimensional drawing

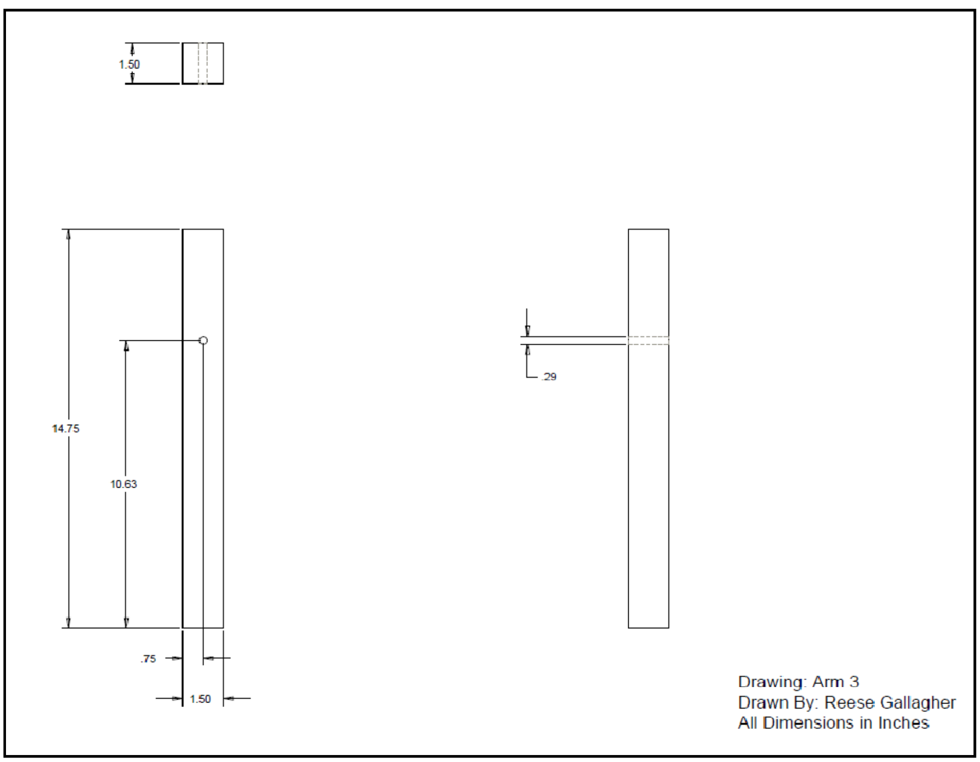

Figure 31.3 Arm 3 dimensional drawing

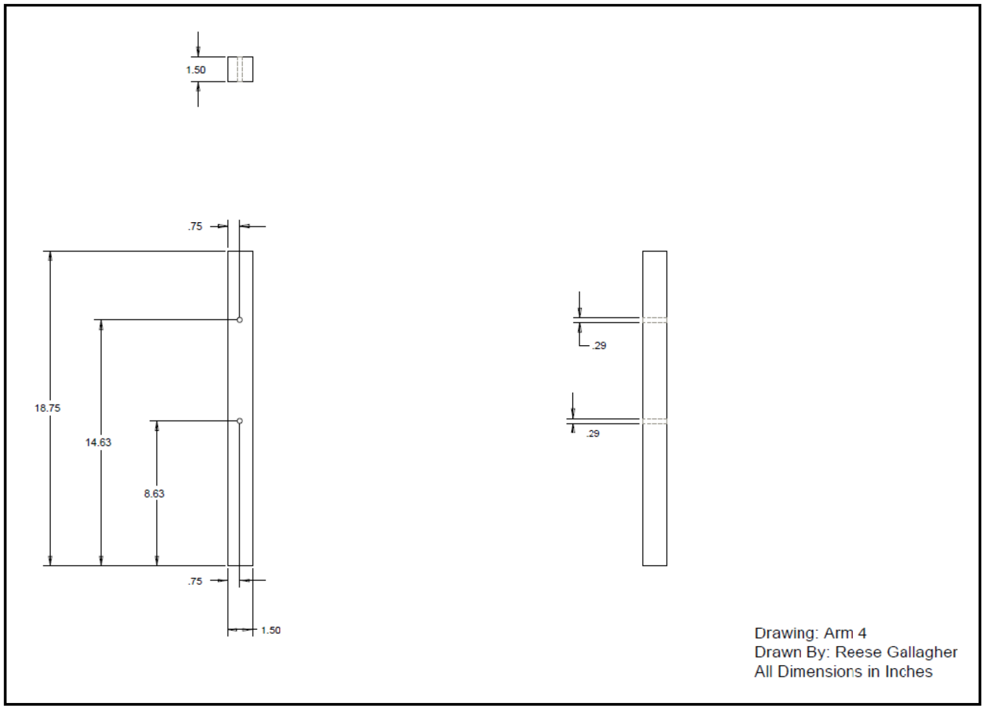

Figure 31.4 Arm 4 dimensonal drawing

Once all the arms are cut to the appropriate sizes, attach the L-Brackets to each arm. Using the engineering drawing as a reference, attach the L-Brackets to each arm as shown below in Figure 32. Use the Size-6 screws and a hand drill with a Phillips screw bit to drill the screws in place. Make sure to drill into each hole in the L-Bracket to ensure a tight and secure joint. At this stage the arms are ready for assembly with the main post.

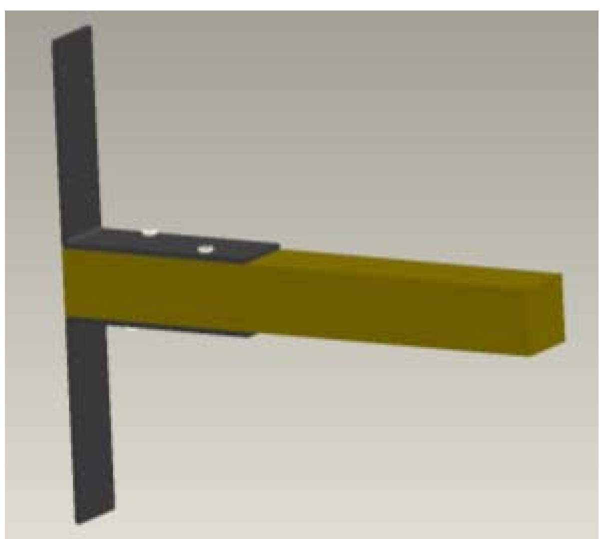

Figure 32: L-Bracket to arm attachment diagram

5.5 Arm Supports

In order to ensure the adequate stability of each arm, supports will be machined out of the 2 in. x 2 in. wood. Using the engineering drawings as a reference, have the pieces of wood cut to the appropriate lengths.

Using the engineering drawings in Figures 33.1-4 as a reference, use a hand saw to cut 45 degree angles at each end of the supports. Once 45 degree angles have been cut on both ends of the pieces of wood, mount the 45 degree brackets to each end of the support beam. This bracket can be affixed to the support beams using the Size – 6 screws. Refer to the engineering drawings on instructions regarding how to mount the brackets onto the support beams in Figure 33.1.

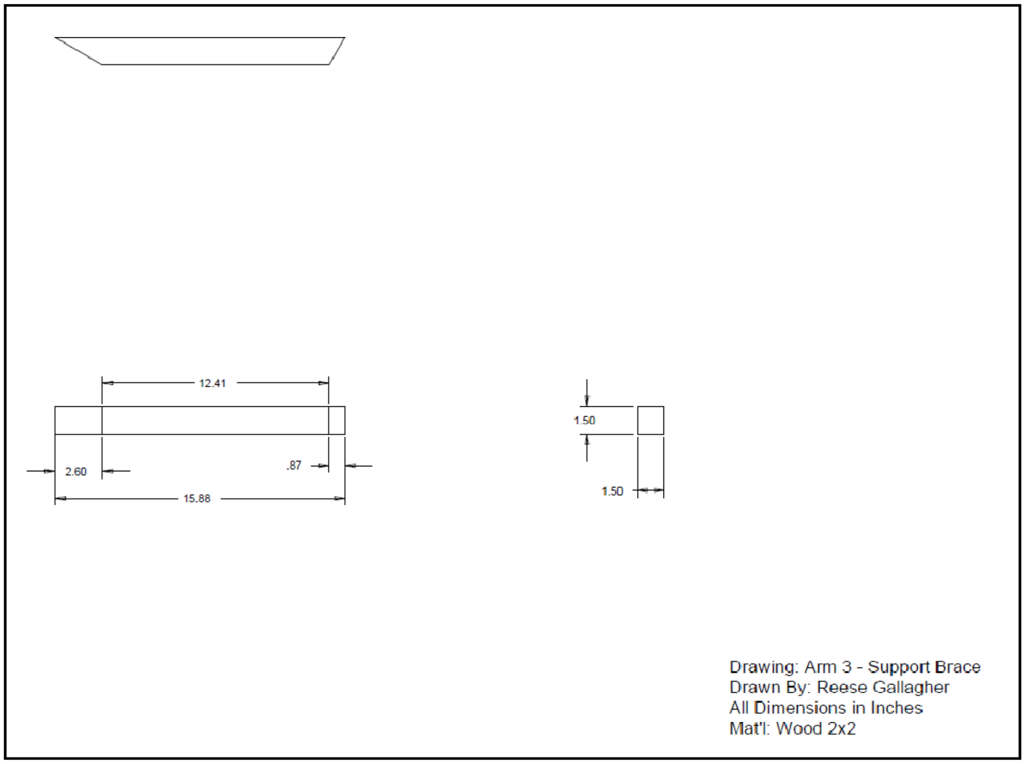

Figure 33.1: Arm 3 Support Brace dimensional drawing

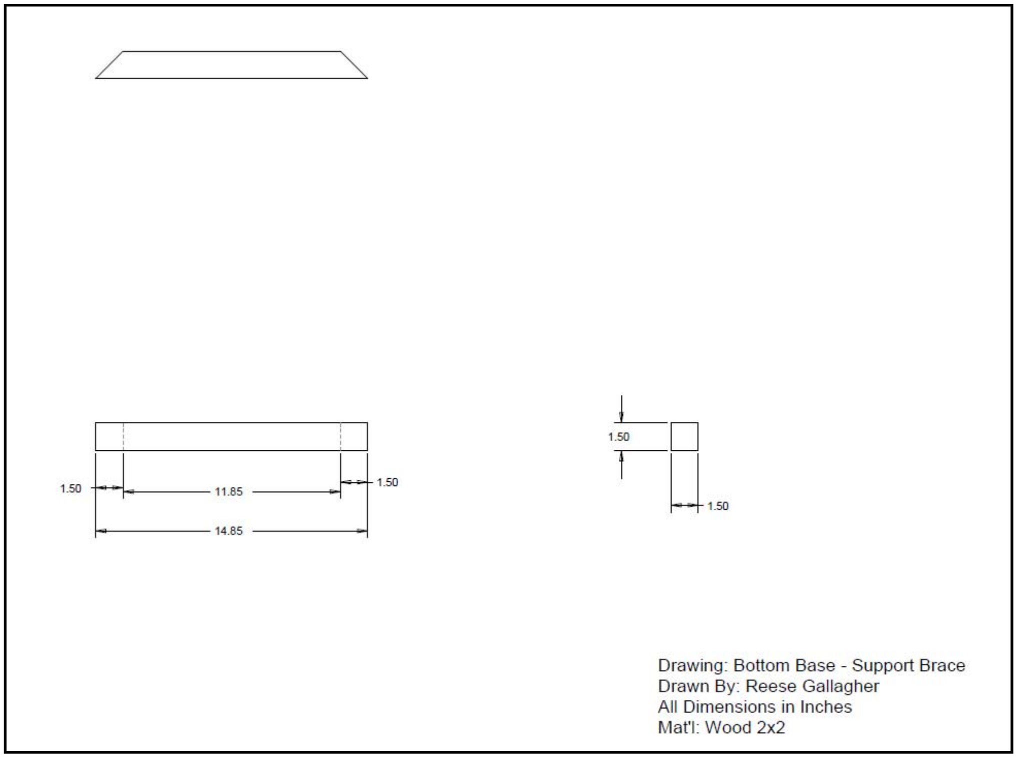

Figure 33.2 Bottom Bace Support Brace dimensional drawing

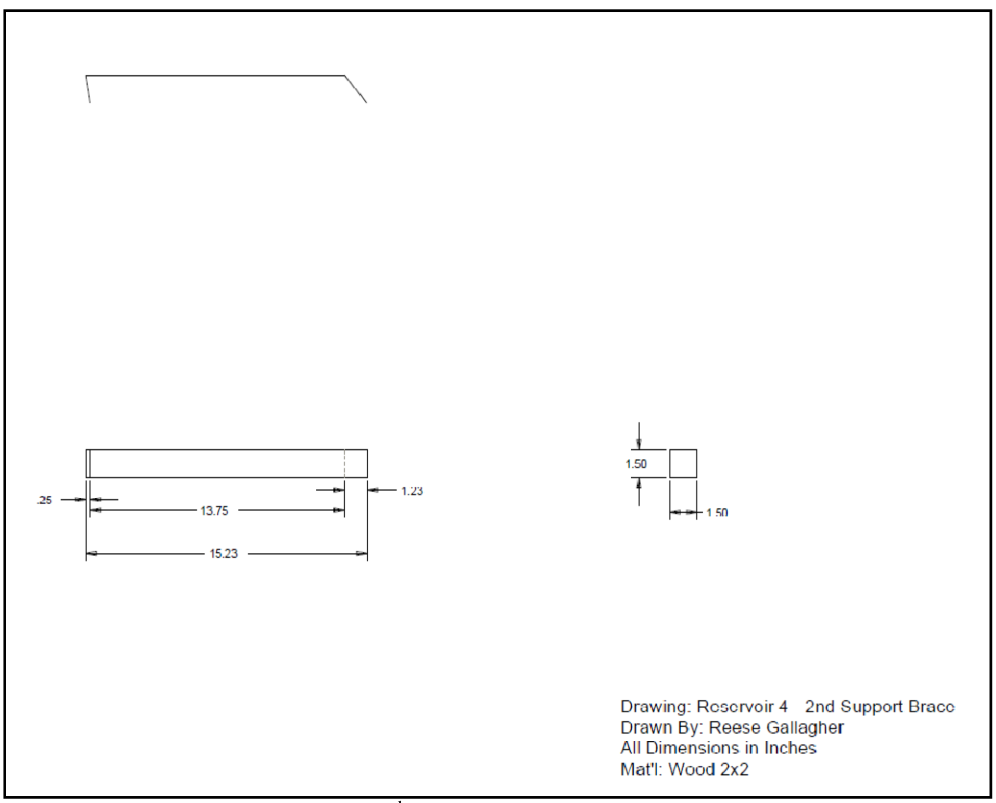

Figure 33.3: Reservoir 4 2nd Support Brace (prt. 1) dimensional drawing

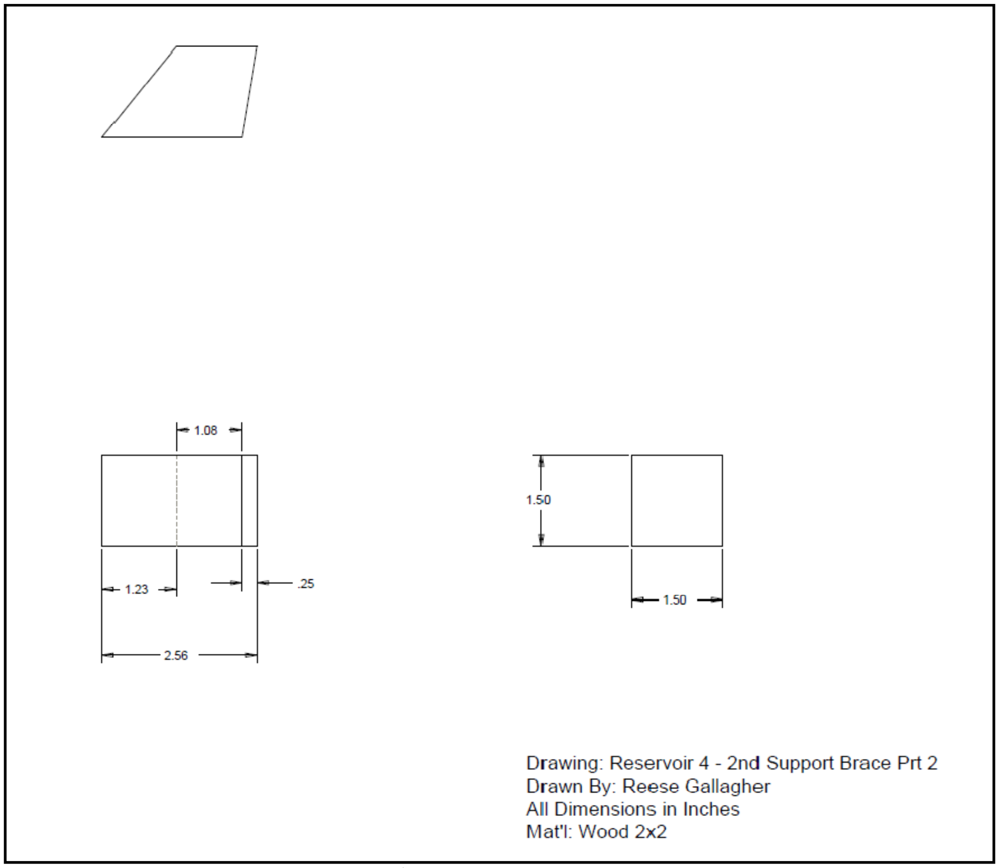

Figure 33.4: Reservoir 4 2nd Support Brace (prt. 2) dimensional drawing

Prototype Assembly

The following section constitutes the set of directions required to assemble the prototype.

Reservoir Assembly

After the parts are properly cut, using the provided engineering drawings, they will be joined together using Weld-On 16 adhesive. The adhesive will take about two days to cure completely. After this, another layer of adhesive should be applied to the joints to assure a leak proof design.

Arm Attachment

Begin by attaching the brackets on the arms to the appropriate locations on the main beam. Two arms will be attached on each side of the main beam. At the appropriate locations, using Size – 6 screws, attach the arms with brackets to the main post. Drill through all the holes on the brackets to ensure a proper secure fit. This assembly step can be performed with the use of a hand drill and a Phillips screw bit. Note: It is easier to attach the arms to the main post, with the main post lying on the floor and not in an upright imbalanced position. After this arm attachment is complete, the prototype should appear as shown in Figure 34.

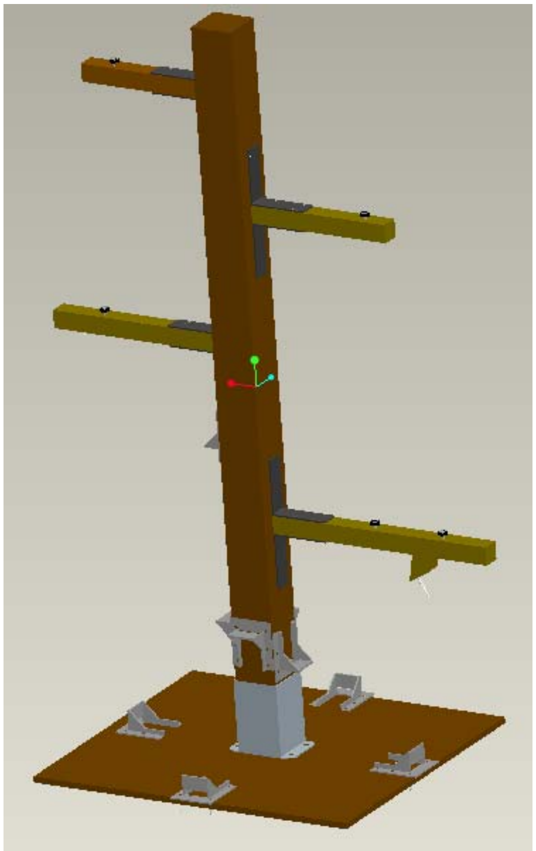

Figure 34: Bracket and Arm Attachment

Arm Support Attachment

To attach the arm supports to the main post, line up the supports between the arms and the main post, so a triangle is formed between the three pieces of wood as shown in Figure 35. Ensure that the support is flat on the arm and the main post at the 45 degree cuts. Using the 45 degree brackets and Size – 6 screws, attach all the supports to both the arm and the main support. This attachment phase can be done using a hand drill and a Phillips screw head. The assembly should appear as shown in Figure 36 at this point.

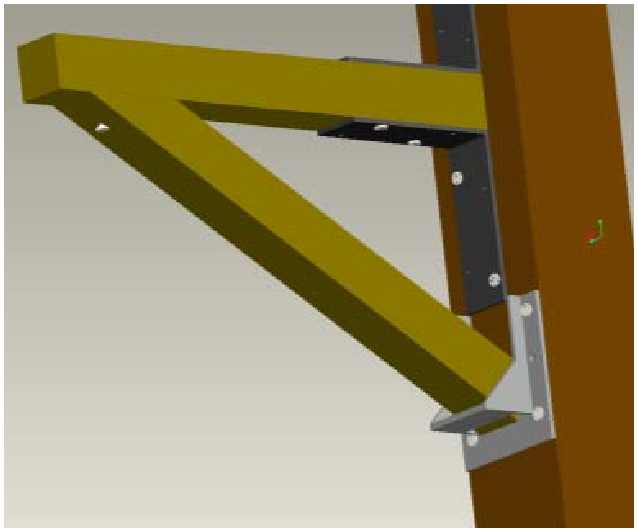

Figure 35: 45 Degree Brace Assembly Illustration

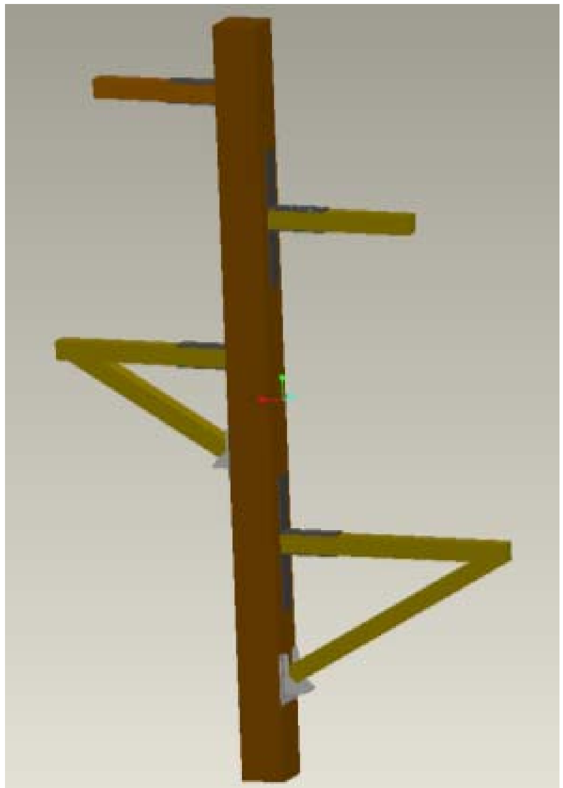

Figure 36: Arms, Main Post and Arm Supports Assembled

Base Plate Attachment

To attach the main post to the base plate, use the already-drilled holes in the base plate. Insert .25 in. bolts through the base plate, with the head of the bolt touching the ground and the long side pointing out. Use caution, and do not step onto these bolts. Now lower the main post with the bracket attached onto the bolts, ensure that the bolts pass through the holes in the main post mounting bracket. Using .25 in. nuts and washers, fasten the bracket in place to the mounting plate. This assembly process can be completed with the use of a wrench. The base bracket should appear as shown in Figure 37.

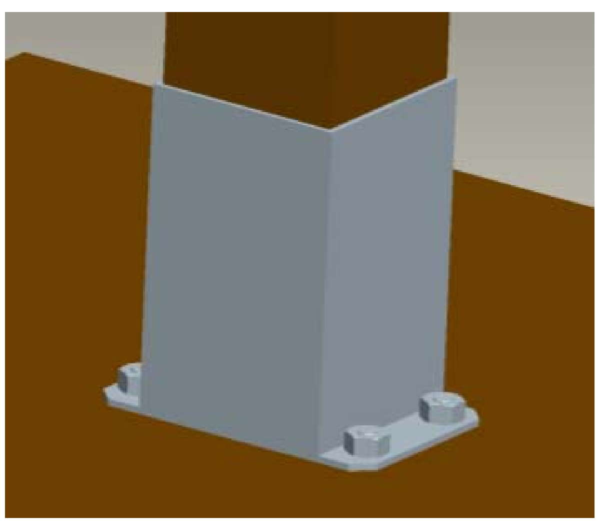

Figure 37: Base Bracket after attachment to the base plate

To complete the assembly process, attach the brackets for the base support so that the support beams can fit snugly into the brace when assembled. Remove the main post from the base plate, place the support beam in and reattach the main post to the base plate, effectively locking the main post in place. At the conclusion, the base should appear as shown in Figure 38.

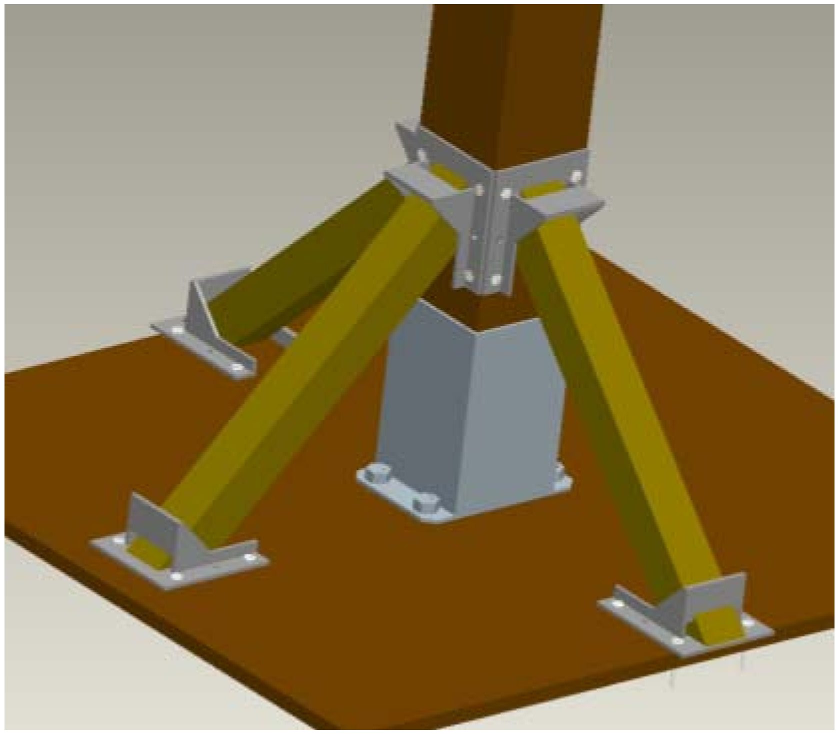

Figure 38: Base Brace support structure

Reservoir Attachment

Ensure proper assembly of each of the reservoirs before this stage. Refer to engineering drawing to match the reservoirs to an arm. The smallest reservoir is attached to the top arm and the largest to the bottom. Using the engineering drawing, ensure that the reservoirs are positioned correctly on the arm. Align the 0.25 in hole in the reservoir to the location of the bolt hole in the arm. Insert a 0.25 in. bolt through this hole with a rubber washer and a metal washer as shown in Figure 39. Attach a nut and tighten. This assembly can be completed using a wrench. It is important to keep the reservoirs safe during the attachment process. Thus, this task takes two people or more to complete.

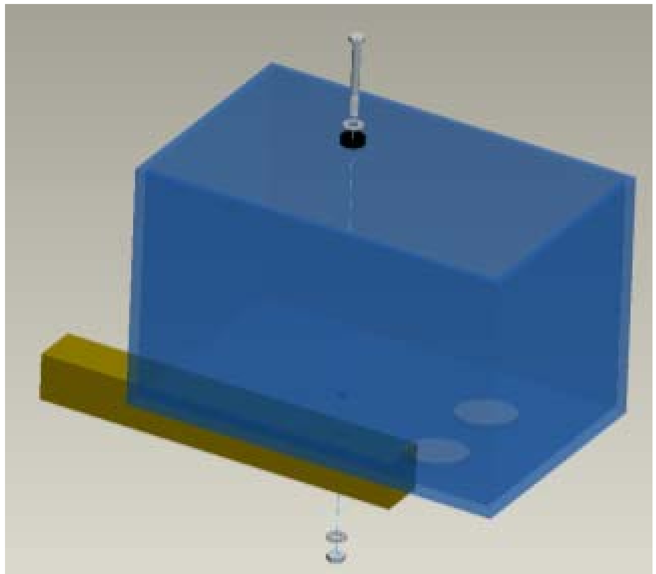
Figure 39: Reservoir Attachment using bolt, washers, and nut

Mechanism Assembly – Flapper & Weight

Using fishing line, tie a knot on the link hanging off the flapper that is attached to the reservoir. Using the engineering drawings, measure out the appropriate length of the fishing line. Attach the other end of the fishing line to the float bob, use a knot to create the attachment.

Mechanism Assembly – Flapper & Moving Container

Using fishing line, tie a knot on the link hanging off the flapper that is attached to the reservoir. Attach the other end of the fishing line to the Plexiglas container. Tie a knot around the hole near the top of the Plexiglas container. Before tying this knot, ensure that the fishing line passes through the hole on the side of the reservoir.

Flapper & Funnel Attachment

Using the engineering drawings as reference, determine the placement of the flappers on the insides of the reservoirs. The movable section of the reservoir should completely fit over the hole in the reservoir. Position the flapper so that it matches the engineering drawing. Using superglue, attach the flapper ring to the reservoir bottom. Let the attachment cure for 2 hrs. Apply Weld-On 16 over this area to ensure attachment to the acrylic. Using the same technique, attach a funnel to the bottom of three specified holes.

Upon completion of the prototype fabrication and assembly stages, the finished product should look like the Figure 40 below with all the mechanisms in place. When machining and assembling this fountain, be aware of safety issues. As mentioned previously, Appendix VIII contains a detailed safety report documenting all the manufacturing and fabrication activities as their pertained to the construction of our prototype.

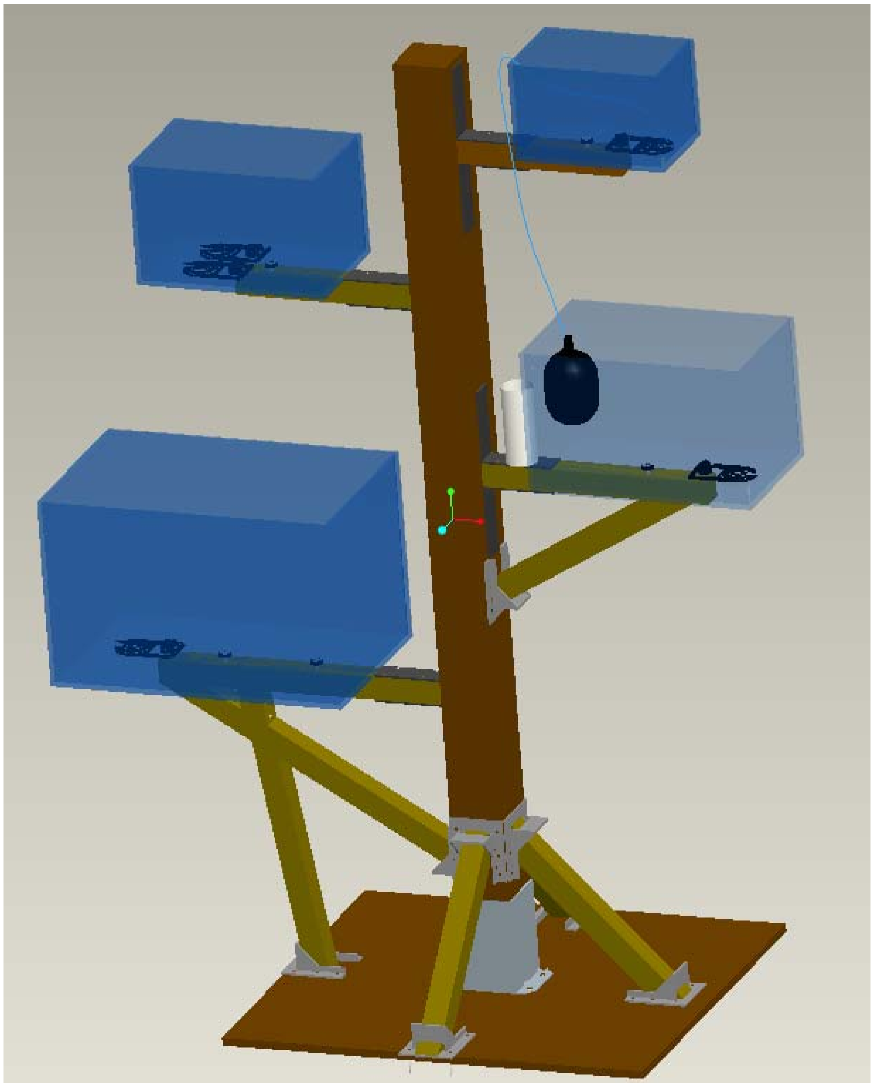

Figure 40: Final Appearance of the prototype assembly

Final Design Manufacturing Changes

Since the final design and the prototype differ significantly, the manufacturing process for the final design and the prototype are drastically different, especially if the final design product were mass manufactured.

The biggest difference between the prototype and the final design is the material used. The superstructure of the prototype is made of wood, while the final design has a metallic superstructure, made of 6063 Aluminum. The machining process for cutting and drilling aluminum is different than that for wood; also the attachment methods for the arms are different for the final design. For mass manufacturing, all these parts would have to be individually cut in mass quantities, and then assembled later with the use of skilled workers or an automated manufacturing line. Following the final design description, the mass manufacturing would begin with the machining of the superstructure components. The reservoir components would also be independently laser cut. Once the reservoirs are cut using the laser cutter, they can then be assembled using the adhesive. This assembly stage would have to be done by hand due to the intricacy of the process and the need to let the reservoirs set before they can be moved.

Once all the individual superstructure components are manufactured, they could then be shipped to the fountain site along with the completed reservoirs. At the fountain site, a base would be dug and concrete would be poured. The superstructure would then be assembled into the foundation. The reservoirs would be attached and the mechanisms placed into each reservoir. The required pump would be installed at this point along with all the piping. An artist could then be commissioned to improve the aesthetics accordingly.

Even though the fountain is a unique piece, it could be mass manufactured. The cost of the fountain would not decrease greatly because many of the parts have to be individually manufactured or assembled. The fountain itself has to be assembled on site and cannot just be shipped. All these manufacturing stages vary the cost of the final design, from approximately $400 for the prototype to approximately $10,000 for the final design. Table 4 is a breakdown of the projected cost, using estimations for labor cost and material costs, for the final design.

	Cost	Quantity	Total
Materials			
Main Post Aluminium	$400 per 15 ft	1	$400
Arm Aluminium	$100 per 6 ft	1	$100
Smooth Plexiglas	$90 per square ft	42	$3,780
Mechanism Materials	$30 per reservoir	7	$210
Machining			
Plexiglas	$40 per hour	8	$320
Arms	$40 per hour	10	$400
Assembly			
Reservoirs	$40 per hour	10	$400
Mechanisms	$40 per hour	5	$200
On Site Assembly			
Pour Basin	$40 per hour	10	$400
Pour Fountain Base	$40 per hour	4	$160
Assemble Superstructure	$40 per hour	16	$640
Assemble Reservoirs	$40 per hour	2	$80
Install Mechanisms	$40 per hour	10	$400
Install Pump	$40 per hour	1	$40
Fine Tuning	$40 per hour	3	$120
Sub-Total			$7,650
Contingency (25%)			$1,913
Total			**$9,563**

Table 4: Expected fabrication costs

Prototype Validation Plan

Validation of engineering specifications for our prototype is essential in proving that our final design will meet the proposed engineering target values. However, not all engineering specifications stated can be validated on the prototype due to various constraints that are discussed later. The engineering specifications that will be validated on the prototype are listed below.

1. Number of Chambers
2. Mechanism Variety
3. Reservoir Transparency
4. Volumetric Flow Rate

Validating that the final design can incorporate seven reservoirs is a trivial task. By simply making seven reservoirs, including the top reservoir, and placing them into their correct positions, the final design will achieve this engineering specification's target value, within its limits. Therefore, the reasoning behind having four reservoirs for our prototype was based primarily on the ability to display mechanism variety. Any number less than four and all the flow transfer mechanisms could not be properly shown.

Both mechanism types that will be used for our final design will be incorporated into our prototype. This will verify that our final design will meet the specified target value, for mechanism variety, within its limits. Along with not only meeting the target value for mechanism variety, but by creating these mechanisms it will provide an opportunity to verify their functionality.

Assuring the transparency of all of the reservoirs is essential to the aesthetic element of the design. Allowing for transparent reservoirs gives the observer a view of the internal workings of the fountain and also creates as sense of interaction. One of our main concerns with assuring the transparency of the reservoirs is the possibility of obstruction caused by the use of the adhesive during manufacturing. To quell against this abnormality, it will be essential to assure that the adhesive is properly contained within the necessary regions of the reservoirs.

Volumetric flow rate can be determined from the pump sizing and fountain height for the prototype and final design. Since the volumetric flow rate will determine the cycle time, the prototype will validate the expected cycle time for the final design in order to create the predicted flow patterns. These four specifications are possible to validate through a prototype.

Although it is possible to validate four major specifications through the construction of a prototype, there are other specifications that are not present in the prototype or that cannot be equated through the prototype to the final design. Below is a list of these engineering specifications.

1. Particle concentration
2. Pump power consumption
3. Component aesthetics
4. Maximum pool water depth

It will not be possible to measure the particle concentration in the water at the expo and it would also be fruitless, as the conditions at the final design location and the prototype test location are very different. The pump that will be used for the prototype has a built-in filter and will keep out the majority of foreign particles present in the water. For the final design, it will also be important to ensure that the water is filtered before it enters the fountain cycle.

One of the main concerns of maintenance costs would be power consumption. Although the power consumption of the prototype can be easily calculated using the data provided by the pump's manufacturer, it will not be possible to validate the power consumption of the final design. It is possible to predict power consumption for the final design using the fountain height, the recommended volumetric flow rate, and the pump wattage rating. Using a standard electricity cost of $0.11 per KW-hr [15], the total cost to run a pump capable of functioning for the final design, will only cost approximately $0.20 per day. This is a total cost of approximately $770 for 10 years of constant fountain operation.

The visibility of unsightly components was an engineering factor related to aesthetic appeal. As stated before, an artist will be commissioned to create a more natural aesthetic appeal of the fountain, this would allow for the covering of some of these unsightly components. The prototype, however does not have this modification, and therefore the visibility of these components cannot be validated.

The maximum pool water depth is a specification used to ensure the safety of children around the plaza. It will not be possible to validate this specification through the prototype as the pool used in the prototype will not be similar to the reflecting pool designed for the final design. The prototype pool will only contain enough water to keep the pump primed throughout the entire cycle of the fountain. The final design will contain a far greater amount of water and thus cannot be validated through the prototype design.

Prototype Validation Results

Fabrication and testing of the prototype was successful and confirmed the functionality of the desired fountain cycle. The prototype worked as desired and provided insight into the viability of the final design through the validation of engineering specifications of the fountain.

The validation of the number of reservoirs, the variety of mechanisms, and the reservoir transparence was possible through the fabrication of the prototype itself. In prototype fabrication plans, it was ensured that all these specifications were met and thus were validated. The volumetric flow rate was validated through the timing of the fountain cycle. Using a volumetric flow rate of approximately 90 gallons per hour, it was possible to ensure the fountain cycle time of approximately 8 minutes. This specification was validated through the preliminary fountain testing, and this specification was held constant from that point onwards.

The viability of the final design was confirmed through the ties between the prototype and the final design. The reservoirs used in the prototype were the same as those that will be used as the first four in the final design. Using this method, it was also possible to validate the variety of mechanisms and their functionality. This ensures that the flow pattern desired will be the resulting flow pattern in the final design. The validation of the prototype specifications and their direct relation to the final design parameters properly facilitates the viability of the final design.

Design Critique

From the prototype we were able to validate some of the strengths of the final design. The prototype demonstrated that the final design would be able to achieve the quiet and rushing aspect of the design. The prototype had a cycle time of approximately 8 minutes split evenly with quiet and rushing. Another strength of the design is the robustness of the cycle. Upon testing disruptions to the cycle, the fountain always returned to the same functional state, under all tested interruptions. Even with precipitation filling all of the chambers, the fountain will return to normal operation. Furthermore, we expect the fountain to function in light rain and possibly even during heavy rain.

The design also meets the customer requirement of fascination. The transparent reservoirs gave the viewers an opportunity to observe the flow of water throughout the system and fostered fascination. Even though fascination is very subjective, from presenting our prototype at the Design Expo, most observers verbally mentioned the fact that the design was specifically fascinating.

The water flow mechanisms all functioned properly in the reservoirs, which are full scale in the prototype, verifying that the final design will be able to achieve the desired flow pattern. Finally, because the prototype superstructure was built using a structurally inferior material compared to the final design, we were able to verify that the final design should be able to support the expected loads of the fountain.

Although our prototype demonstrates that our design is fully functional from the standpoint of mechanisms for water flow and structural rigidity there are some aspects that can be improved. First of all, the design of the flapper mechanisms also lacks robustness. For the flappers there tends to be small leakage of water and which can easily be by fixed by adding a thin seal around the inner surface of the flapper. There is also considerable refinement needed for balancing the flappers so they are able to open and close at the proper time intervals. For the prototype, washers were inserted in the flappers to achieve a proper weight, but an alternative would be to weigh down the flappers with custom made weights.

Secondly, there was occasional difficulty in assuring that the subsidiary reservoirs would return back to their original position. This was mainly the result of the small diameter mouths of the subsidiary reservoirs. This issue has been fixed in the final design. There is also friction between the fishing wire and the edge of the reservoirs. This can be averted by smoothing this edge, adding a small sheave, or using a wire with lower friction.

The design lacks considerable aesthetic appeal. Since it will be located in a very natural environment, with trees and shrubbery, it should reflect a similar environment. Even though most of the artistic design will be handled by an outside artist, there are still a few simple things that can be done. One of the methods to improve upon aesthetics is to add vines and other types of plants on the fountain to help combine it with the plaza.

Finally, to achieve the proper flow rate from the pump a flow restrictor was placed at the outlet of the tube. This method is very reliable, but considerably lowers the life of the pump due to the increased load on the pump. To alleviate this problem, a pump will be selected for the final design which will allow for the proper flow rate at the outlet height.

Recommendations

Based on our evaluation of the prototyping process, the design itself, and viewer input at the Design Expo, there are a number of recommendations for the final design that would help improve it. Although, the final design could be built and still meet its functional requirements without using these recommendations

Fountain Aesthetics

Based on feedback from many people at the design expo, the prototype design was not considered especially aesthetically pleasing regardless of how fascinating it was. The final design should be aesthetically pleasing in its own right, but should also be integrated with the plaza. This integration can be accomplished by having a natural transition zone, incorporating the reflecting pool at the base of the fountain. It would be worth hiring a landscape architect and an artist to add an artistic touch to the design. We recommend using a natural motif with the fountain as a tree. This can involve using artistic devices or structures to cloak the fountain into the form of a tree. The superstructure, which is already shaped as a tree, provides an easy method to reform the aesthetics of the fountain.

A detail-level recommendation is hiding many of the tubes that pass between reservoirs. Although tubes hanging between reservoirs can act like vines if the tree motif is initiated, hiding them could be a better option aesthetically. Beyond aesthetics, these tubes can be easily pull or broken by children. Having the tubing run through the hollow cross section of the arm to the corresponding reservoir may be the safer and more aesthetically pleasing option.

The use of flapper valves makes the fountain look like a purely mechanical object. Painting these valves to match the colors of the plaza or adding shapes or reforming the flapper to resemble a more natural object, such as a leaf or a lily pad, is recommended. This transformation could also be based on the advice of an artist or a landscape architect. Another common comment from viewers was the use of injected food coloring at various stages to allow viewers to visually inspect the water flow pattern. This is a valid recommendation, but still requires a method to extract the dye once it reaches the pool, otherwise the entire fountain would eventually be the same color. These improvements have the potential to significantly help improve the aesthetic element of the fountain and improve the viewer’s experience at the plaza.

Fountain Mechanisms

Based on mechanism calculations, Appendix IV, and also the functionality of each mechanism, parts were chosen for each mechanism. For the final design, with the large number of reservoirs, it could be possible to add a mechanism that was changed after Design Review 3.

The mechanism of a float pulling the flapper in the same reservoir was replaced by the subsidiary reservoir mechanism. The re-instatement of this mechanism could potentially make the fountain flow patter more captivating and more intricate. This re-design would involve the use of parts that do not already exist. This re-design would require the use of a high-volume float bob that could make use of enough buoyant force to pull its flapper open.

The problem with the re-instatement of this mechanism lies in the changes it would cause to the other mechanisms regarding the changes in flow patterns and different water volumes in the reservoirs. We recommend the use of an extra mechanism only if the fountain is not fascinating enough after a long period of time.

Child Safety

Based on the initial customer requirements and the fascination of children with the fountain at the Design Expo, child safety is a very important concern. With this issue in mind, it is of the utmost importance to prevent children from accessing the fountains structure, the fountains mechanisms, or the pool of water the fountain draws from and drains into.

Beyond the safety precautions already in place in the proposed final design, there are three recommendations regarding child safety that we would like to make. First, install a fence approximately three feet high around the outside of the fountain pool. This is to ensure that the younger viewers get a clear view of the fountain without the risk of bypassing the fence and reaching the fountain itself unattended. A gate on this fence would allow children to reach the fountain with supervision and enjoy it as much as other viewers.

The second recommendation is a placement of signs around the fountain warning adults not to leave children unattended as this could cause adverse situations where infants can crawl to unsafe areas, such as the fountain pool, in case the gate to the fountain has been left open.

Finally, the pump should be kept in a location that is not accessible to the viewers. The pump should be kept in a cage, attached to the bottom of the fountain. A mesh over this cage is also advised, as people have a tendency to throw coins into the fountain, and this mesh could prevent these coins from entering the pump's mechanical system.

Taking into account these recommendations, can greatly improve the functionality of the fountain to a state where it not only meets, but surpasses all the customer requirements.

Conclusions

With the dedication of Richard Scott Noble Plaza at the UM Depression Center, David Noble desires to place a unique fountain as the centerpiece. The concept behind this fountain is that it will create a fascinating display through the flow of water dictated by the force of water itself through different modes. By creating a fountain that is at times quiet and at times rushing, a captivating visual display for the visitor can be produced.

With the information gathered from our literature reviews as well as various customer and sponsor interviews, various customer requirements and engineering specifications were determined to be important to the problem. Using these requirements and specifications rough concepts were produced to address important design factors. Dozens of concepts were filtered down to the five best concepts. These five concepts were then combined to create the Alpha Design. After consultation with the project sponsor, the Alpha Design was fundamentally altered and optimized into a final design.

Upon completing the phase of engineering analysis and optimization we have shown that the customer and engineering requirements can be fully met. The engineering analysis was also the method used to justify engineering decisions including material selection. In order to allow for time to build and test the final prototype, some rough experimentation was performed to test concepts and designs. The final prototype was constructed based on the fabrication plans. It was then tested and adjusted to maintain proper functionality. The elements of the prototype that were linked to the final design were also validated to ensure a viable final design. This set of steps constitutes a plan that allowed for a successful solution to this design problem.

Based on the validation of the prototype, the final design can now be recommended for construction and placement at the Richard Scott Noble Plaza. A set of recommendations along with a prototype design critique have also been created to pass on information regarding the fabrication and operation of the fountain for the plaza. With these suggestions and the description of the final design, everything is in place for the incorporation of a quiet rushing fountain at the Richard Scott Noble Plaza.

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Appendices

AI. Quality Function Deployment

This Quality function Deployment displays the customer requirements and engineering specifications as well as any interactions or relations. Also included is a benchmarking done to evaluate current fountain designs against the customer requirements.

System QFD

Project:	Quiet Rushing Fountain
Date:	1-24-09
	Input areas are in yellow

Survey Legend	
A	No Current product
B	Traditional Fountain
C	Overflowing Trickling Fountain

#	Engineering specification	Max Water Depth (-)	Edge Radius (-)	Max Base Height (+)	Material Yield Strength (+)	Material Fracture Toughness (+)	Grid Mesh Size (-)	(8)	Reservoir Transparency (+)	(10)	# of Chambers	Particle Concentration	Durability (where applicable)	Volumetric Flow Rate	Visibility of Unsightly Components	Power Consumption	Mechanism Variety
1																	
2	Max Water Depth (-)																
3	Edge Radius (-)																
4	Max Base Height (+)	9															
5	Material Yield Strength (+)																
6	Material Fracture Toughness (+)		3		9												
7	Grid Mesh Size (-)																
8																	
9	Reservoir Transparency (+)																
10																	
11	# of Chambers	3						9									
12	Particle Concentration																
13	Durability (where applicable)							3				3					
14	Volumetric Flow Rate	3						3									
15	Visibility of Unsightly Components								3		3						
16	Power Consumption													3			
17	Mechanism Variety							3			9				3		
18																	
19																	
20																	

#	Customer Needs	Customer Weights	Kano Type	Max Water Depth (-)	Edge Radius (-)	Max Base Height (+)	Material Yield Strength (+)	Material Fracture Toughnes	Grid Mesh Size (-)	Reservoir Transparency (+)	# of Chambers	Particle Concentration	Durability (where applicable	Volumetric Flow Rate	Visibility of Unsightly Compx	Power Consumption	Mechanism Variety	1 Poor	2	3 Acceptable	4	5 Excellent
1	Child Safe	7		9	9	9		3	3					1				B			C	
2	Child Resistant	6			3		3	3	1		1				3		3				BC	
3	Outdoor Functionality	10		3			9	9	3	3	1		9	3	3	1	1			C	B	
4	"Fascinates"	8				1				9	9			9	3		9		BC			
5	Quiet/Loud - Time Dependent	10			3						9	3		9			1	B		C		
6	Cascading Water Flow	6		3							1			9			3	B			C	
7	Asthetically Appealing	5		1	1	3			3	9	9	3	1	3	9		9			B	C	
8																						
9	Minimal Maintenance/Operational Costs	8		3			1	1	9	1	9	3	9	3	3	9	9			C	B	
10	Same style as proposed "Plaza"	5			3	3			3	3	3			1	3		3		B	C		
11																						
		Raw score		140	131	101	116	137	159	170	316	69	167	297	156	82	260					
		Scaled		0.443	0.415	0.32	0.367	0.434	0.503	0.538	1	0.218	0.528	0.94	0.494	0.259	0.823					
		Relative Weight		6%	6%	4%	5%	6%	7%	7%	14%	3%	7%	13%	7%	4%	11%					
		Rank		8	10	12	11	9	6	4	1	14	5	2	7	13	3					
	Technical Requirement Units			m	mm	m	Mpa	Mpa m^1/2	mm	N/A	N/A	ppm	N/A	(m^3)/hr	%	Watts	Types					
	Technical Requriement Targets			0.5	2	1	Varies	Varies	10	Transparent	6	10-50	Very Good	1.5	0.05	200	3					
	Technical Requriement USL			0.75	N/A	1.5	Varies	Varies	15	Transparent	10	100	Very Good	3	0.1	400	6					
	Technical Requriement LSL			0.25	0.5	0.5	Varies	Varies	5	Transparent	5	N/A	Good	1	N/A	100	1					

Traditional Fountain

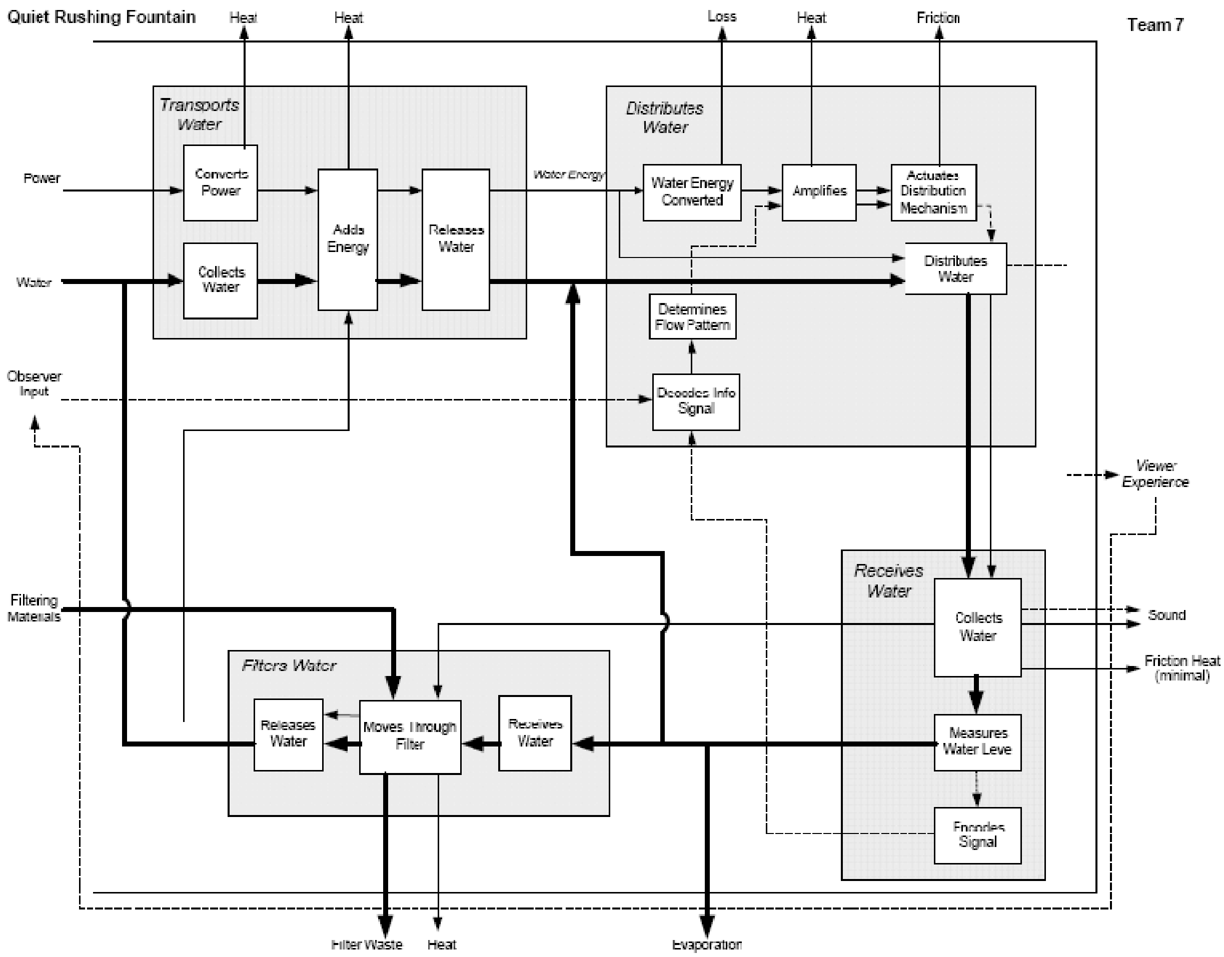
http://www.missourifishfarms.com/aquaculture_equipment/pond_lake_fountains.htm

Overflowing Trickling Fountain

http://www.global-b2b-network.com/b2b/26/12/877/116092/stone_water_fountain.html

AII. Functional Decomposition

A visual representation of the functional decomposition is shown below. Through this visualization it is possible to understand the main functions of the fountain and potential designs. This functional decomposition also details the inputs and the outputs at each functional stage and for the overall fountain design. This decomposition is used to evaluate potential designs with regards to meeting different functional requirements.



AIII. Brainstormed Designs

Figure AIII.1 shown below uses a Rube Goldberg type of design in order to fascinate its' observers. However, the change is in the complexity, or the amount of mechanical components involved, within the fountain. Instead of having eight sides complete with their own intricate mechanisms, the simplified design below has only two sides. The reason behind this simplification is that having a fountain with eight sides and various mechanisms may overload the viewer with intercity. This concept would still utilize the golden ratio in determining dimensional sizes of reservoirs and various components (i.e. wall size, base size)

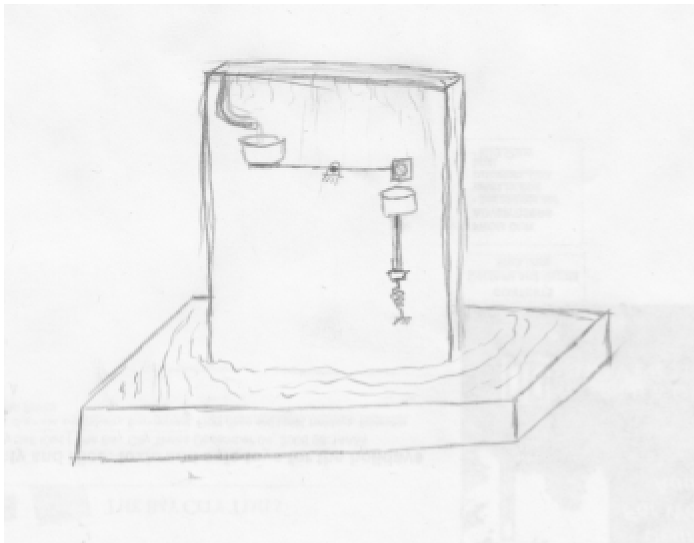


Figure AIII.1: Brainstormed Design – Rube Goldberg II

When determining other mechanisms for to produce fascinating moment balances and water transportation, the use of pulleys was discussed. Figure AIII.2 shown below is not a complete model, but still provides the basic concept of how our team envisioned using pulleys within our fountain. The idea is to use multiple pulley systems interweaved within one another in order to transport water. This design would successfully achieve the customer requirement for fascinating its' observers due to the inherent moving motions of the various pulley systems.

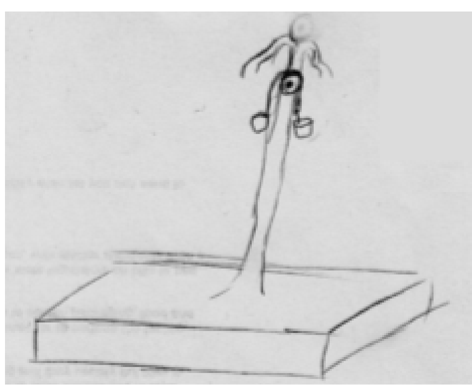


Figure AIII.2: Brainstormed Design – Pulley I

Figure AIII.3 utilizes a pulley concept along with several other components in order to create a unique and fascinating variable flow mechanism. In this design, there are two ways water can flow from the top reservoir. The first is through a faucet like device which drains into a lower reservoir. As water rises within the top reservoir, a cork device unplugs a secondary port within the top reservoir, releasing additional water into the reservoir below. As the bottom reservoir fills up, the pulley acts in a reverse direction, forcing the cork back into its port within the top reservoir. This cycle then continues to repeat itself.

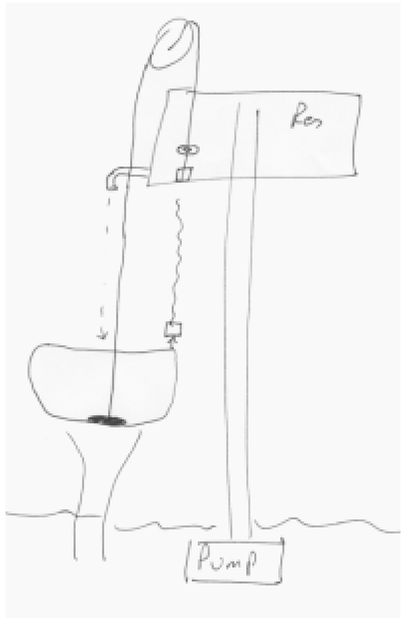


Figure AIII.3: Brainstormed Design – Pulley II

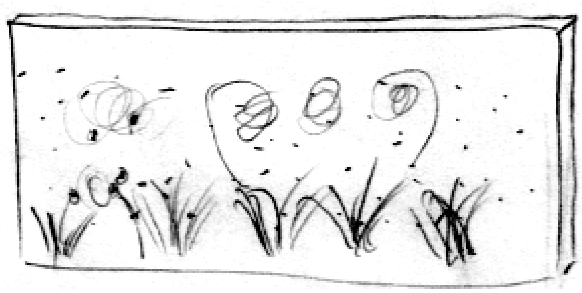


Figure AIII.4: Brainstormed Design – Pellets

This design, shown in Figure AIII.4 above, incorporates small pellets, acting within a closed tank with water in it. It is similar to a snow globe that has "snow" pellets floating around in water. This type of set up would allow for the viewer to see turbulence in the system that would be generated by water jets (black lines at the bottom).

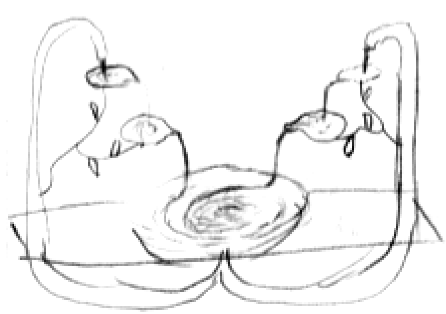


Figure AIII.5: Brainstormed Design – Natural and Organic

This concept, shown in Figure AIII.5 above, incorporated the more natural and organic designs for the Richard Scott Noble Plaza. This includes having reservoirs look like large leaves or lily pads and using a stone basin a the bottom to funnel water.

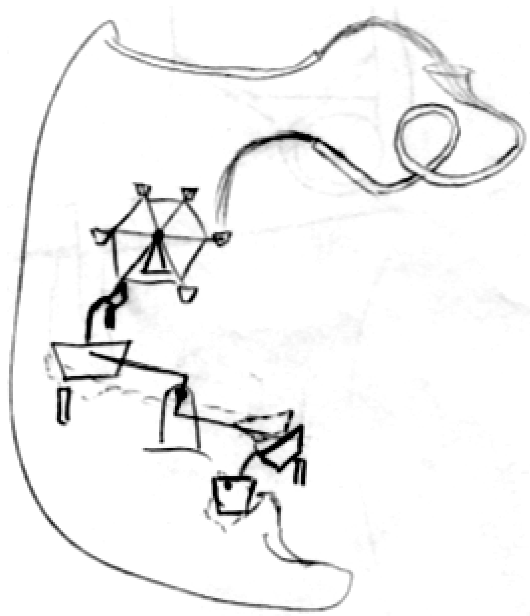


Figure AIII.6: Brainstormed Design – Rube Goldberg III

This concept, shown in Figure AIII.6 above, uses the Rube Goldberg concept, having the water twist and turn and creating a stimulating visual display. It also includes a water jump and water loop to add to fascination.

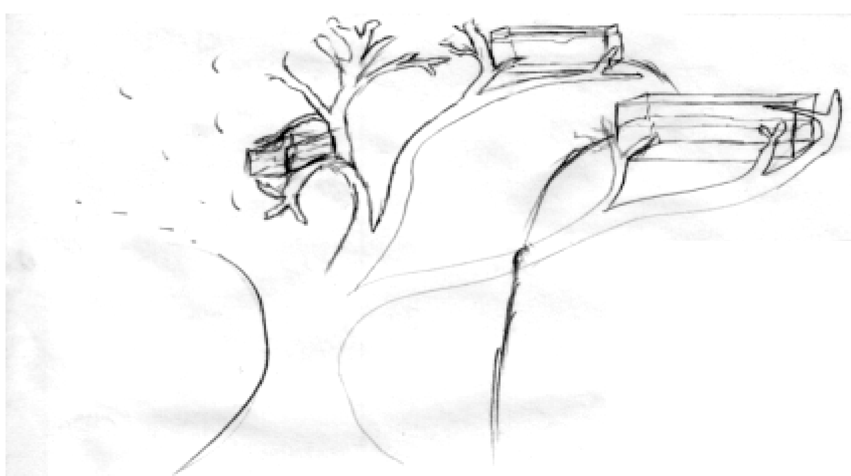


Figure AIII.7: Brainstormed Design – Tree Fountain

The design shown in Figure AIII.7, attempts to create the base or stem of the fountain to appear like a tree. This sort of design could possibly lend itself well to fitting into the plaza's natural style. The reservoirs would be held up by branches and water would cascade between reservoirs.

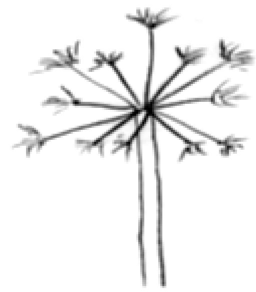


Figure AIII.8: Brainstormed Design – Dandelion

This concept, shown in Figure AIII.8 above, is seen in many modern fountains. Water is sprayed out from small tubes and creates what looks like a dandelion. This creates an interesting and more unique way of distributing water. It also has the ability to be more quiet than an normal fountain.

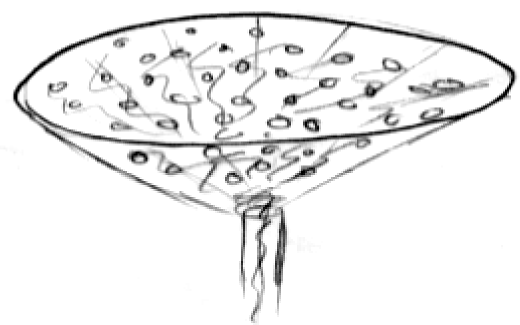


Figure AIII.9: Brainstormed Design – Funnel

This concept, shown in Figure AIII.9 above, is a transparent funnel with rocks attached to create an effect similar to a babbling brook. The water would fall in and trickle down to the center tube to continue to another section of the fountain.

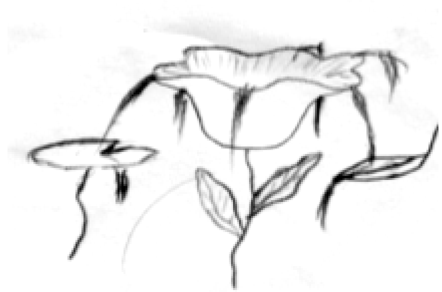


Figure AIII.10: Brainstormed Design – Flower

This fountain concept, shown in Figure AIII.10, again incorporates the natural look by using the main reservoir as a flower which overflows at certain point onto leaves and lily pads.

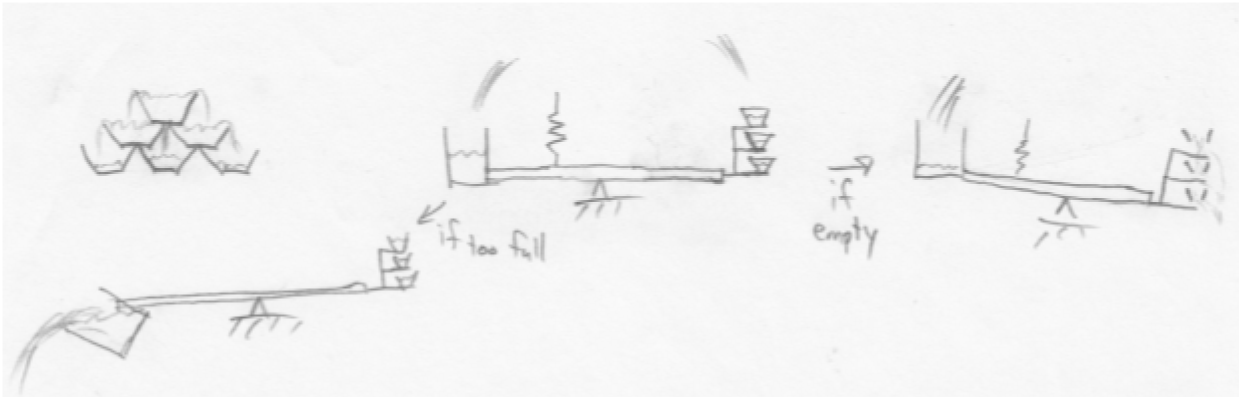


Figure AIII.11: Brainstormed Design – Champagne Glasses

This concept, seen in Figure AIII.11 above, takes inspiration from cascading champagne glasses. The water is poured into the top and overflows into the glasses below. When the bucket on the opposite side pours out and empties, the water is released from each glass by dropping the bottom out.

Figure AIII.12: Brainstormed Design – Soundl

This concept, seen in Figure AIII.12 above, attempts to incorporate sound into the fountain by having levers, activated by falling water collide with wind chimes and create a pleasing and relaxing sound to the ear.

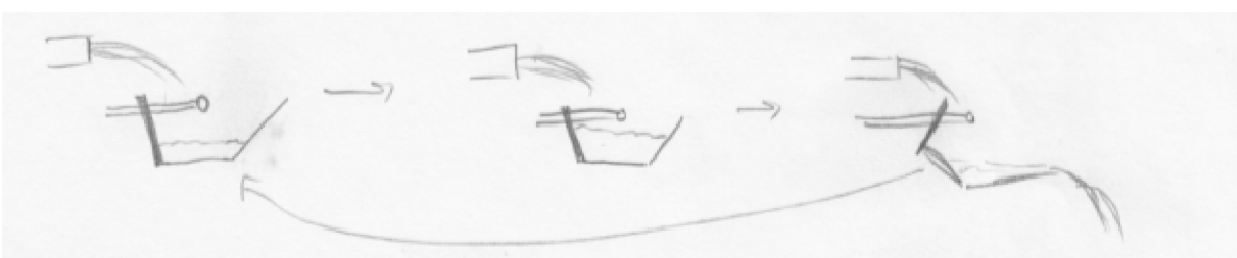


Figure AIII.13: Brainstormed Design –Overflowing Buckets

This concept details the mechanism of a bucket filling and emptying similar to those seen in water parks. As seen in Figure AIII.13 above, When the bucket is empty it is stable upright, when it fills, it begins to tip and all the water falls out, returning to the empty state.

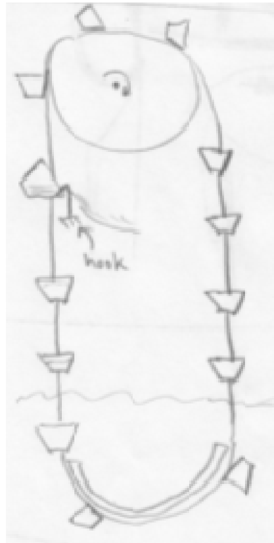


Figure AIII.14: Brainstormed Design – Waterwheel

This idea develops upon the water wheel concept. As seen in Figure AIII.14 above, water is scooped up from the base reservoir and as it approaches the top of the fountain, a hook pulls the side of the cup and causes the water to pour out.

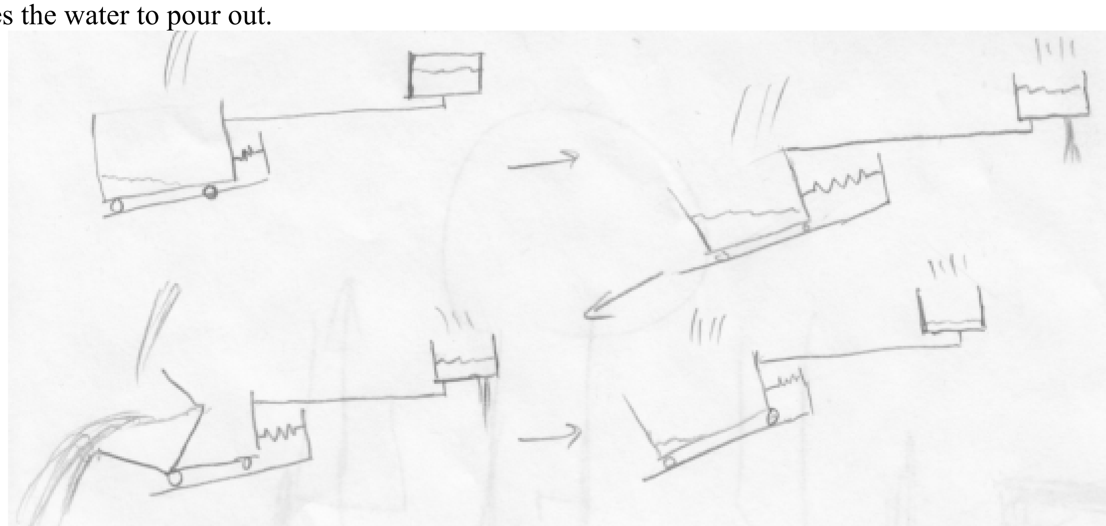


Figure AIII.15: Brainstormed Design – Funnel

The design seen in Figure AIII.15 is a different way to create buckets that fill and empty using mechanical components. The big bucket fills and pulls against a spring, causing the bottom of the small reservoir to slide out. When the big bucket is full, it tips over and empties, starting the process over again.

AIV. Parameter Analysis

Structural Analysis

To start the engineering analysis of the fountain's final design and prototype, we can use the approximate diagram shown below in Figure AIV.1. This approximation accounts for the worst-case scenario, where the weight of the fountain reservoirs is applied at the very tip of the fountain arms.

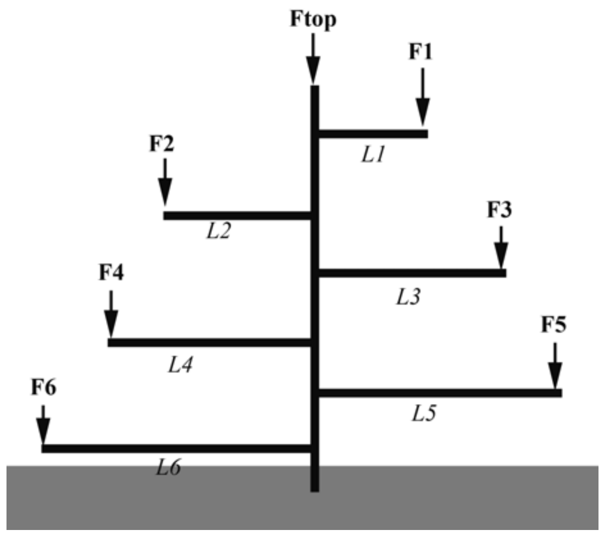


Figure AIV.1: Simplified Fountain Structural Diagram

In this diagram each separate arm can be modeled as seen in Figure AIV.2 below. This diagram is created using the assumption that each arm behaves as a cantilevered beam. Each beam also has a weight which causes a force, distributed uniformly through the length of the arm.

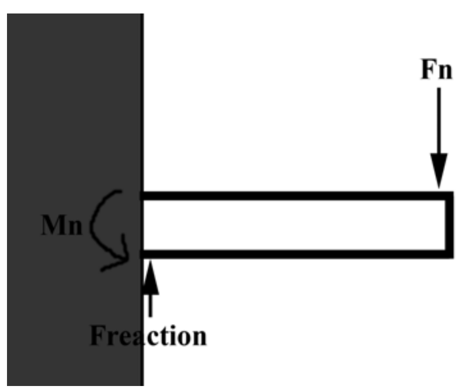


Figure AIV.2: Simplified Arm Structural Diagram

Basic free-body diagram analysis leads us to the equations,

$$F_{reaction} = F_n = Mass_{(reservoir+water)}g$$

$$M_n = L_n F_n$$

In this equation, L_n is the length of the fountain arm from the location where the reservoir force is applied to the location where the cantilevered beam is attached.

Given the following fountain design parameters, shown in Table AIV.1 below, it is possible to calculate all the reaction forces and reaction moments generated by the support of the fountain arms. This data is shown in Table AIV.1. The mass of the water in the reservoir is calculated assuming the reservoir is full of water, which is the worst-case scenario for the fountain.

Arm	Reservoir Volume (cu. ft)	Mass of Water & Reservoir (kg)	Arm Length (m)
1	0.2023	5.7292	0.2466
2	0.395	11.1864	0.3082
3	0.7715	21.8489	0.3853
4	1.5069	42.6754	0.4816
5	2.9431	83.3486	0.602
6	5.7483	162.7919	0.7525

Table AIV.1: Arm Design Parameters

Table AIV.2 below shows the calculated forces and moments on the arms using the equations and relationships mentioned above.

Arm	Fn	F-Reaction	Moment
1	56.15	56.15	13.85
2	109.63	109.63	33.79
3	214.12	214.12	82.50
4	418.22	418.22	201.41
5	816.82	816.82	491.72
6	1595.36	1595.36	1200.51

Table AIV.2: Arm Reaction Forces and Moments

Using these reaction moments and reaction force values, we can use determine the stress in the arms due to bending. The equation used to determine the maximum stress due to bending is

$$\sigma_{max} = \frac{Mc}{I}$$

Where σ_{max} is the maximum stress, $M$is the reaction moment, c is the distance from the neutral axis of the beam to the location of the maximum stress (which is located on the outside edge of the beam), $I$is the area moment of inertia of the beam. Based on researching commonly available materials on McMaster-Carr (mcmaster.com) it was possible to determine the most commonly available beam cross section, a square cross-section with a ¼ in. thickness is the beam available widely, and in various cross section sizes and lengths. For analysis of the arm, the chosen cross section was a 3 in. x 3 in. with ¼ in wall thickness. A cross sectional view of the beam used for the arms is shown in Figure AIV.3 below.

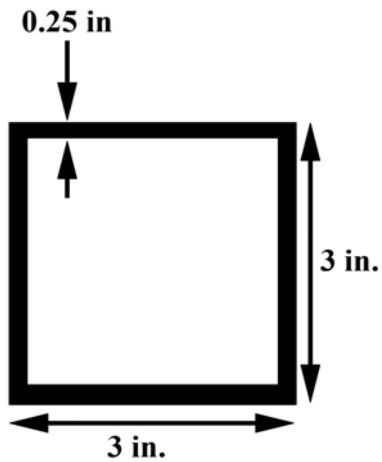


Figure AIV.3: Arm Beam Cross Section View

Using this given cross section, it is possible to calculate the area moment of inertia of the beam.

$$I = \frac{1}{12} {b_{outer}}^4 - \frac{1}{12} {b_{inner}}^4.$$

In this equation, b is the length of each side. In order to account for a hollow cross section, we can simply subtract the missing area moment of inertia from the overall moment of inertia. Using this moment of inertia, we can calculate the maximum stress caused by bending in each arm. Figure AIV.4below shows how the reaction moments are distributed throughout the cantilevered beam. This shows us that the maximum moment will be located at the location where the cantilevered beam is affixed.

Figure AIV.4: Moment Distribution on a Cantilevered Arm

Using this understand principle, we can determine the maximum stresses in each arm. These stresses can be seen in Table AIV.3below.

Arm	**Maximum Stress - Bending (MPa)**
1	0.47
2	1.1
3	2.4
4	5.7
5	13.6
6	32.5

Table AIV.3: Maximum Stress (due to bending) in Each Arm – Final Design

For prototype analysis, we can consider the same bending stresses but for the first four reservoirs with a solid cross section arm. This change in cross section changes the value of I and also the value of c in the maximum bending stress equation. I for a solid square cross section is

$$I = \frac{1}{12} {b_{outer}}^4$$

Where b_{outer} is the length of a side of the cross section, for the prototype the cross section is 2 in. x 2 in. as seen in Figure AIV.5 below

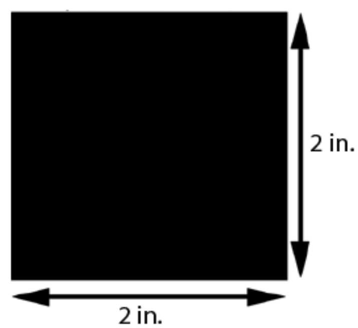


Figure AIV.5: Prototype Arm Beam Cross Section View

Using this arm cross section, the maximum bending stress for the prototype arms can be calculated. Table AIV.4 below lists the maximum stresses due to bending.

Arm	**Maximum Stress - Bending (MPa)**
1	0.64
2	1.55
3	3.78
4	9.22

Table AIV.4: Maximum Stress (due to bending) in Each Arm – Prototype

We can further analyze the bending stress for a scenario with a 70 kg person hanging on the edge of an arm. This analysis changes the reaction moments encountered by the arms. Using the same set of equations with the same cross sectional area, the stresses with a 70 kg person hanging on the arms are listed in Table AIV.5 below.

Arm	**Maximum Stress - Bending (MPa)**
1	6.22
2	7.99
3	10.09
4	15.06
5	25.03
6	49.49

Table AIV.5: Maximum Stress (due to bending) in Each Arm
(with a 70 kg person hanging at the tip)

Shear stress is also a component of the total stress experienced by each arm. This stress can be calculated by the equation

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

where τ is the shear stress, $V$is the shear force experienced by the arm, Q is the static moment of inertia, I is the area (secondary) moment of inertia, and t is the thickness in the material perpendicular to the shear. For our given cross section,

$$Q = \left({b_{outer}}^2 - {b_{inner}}^2\right)\frac{1}{2}b_{outer}.$$

The area moment of inertia remains the same as before,

$$I = \frac{1}{12}{b_{outer}}^4 - \frac{1}{12}{b_{inner}}^4.$$

Using the known forces and the other required variables; we can calculate the stress in each arm due to shear. Table AIV.6 below shows the values of shear stress in each arm.

Arm	**Stress due to Shear (KPa)**
1	0.38
2	0.74
3	1.45
4	2.83
5	5.52
6	10.79

Table AIV.6: Stress (due to shear) in Each Arm

Similarly we can calculate the stress due to shear for the prototype arms with the different cross section, using the following equation for a solid cross section

$$Q = \left({b_{outer}}^3\right)\frac{1}{2}.$$

With these changes, the stresses due to shear in the arm for the prototype are listed in Table AIV.7 below.

Arm	**Stress due to Shear (Pa)**
1	0.87
2	1.69
3	3.31
4	6.47

Table AIV.7: Stress (due to shear) in Each Arm - Prototype

The observed shear stresses are very small compared to bending stress, but due to the superposition property of stresses in a uniform direction, we can add the stressed due to shear and the stresses due to bending to determine the total stress experienced by the arm.

Another structural aspect to consider is the torsion of the arm due to the force of wind against the reservoir. The drag force caused by the wind hitting the wall of a reservoir can cause a torque of the fountain arm in a direction perpendicular to the other stresses experienced. In order to calculate the force of the wind on the reservoir, we can make a simple aerodynamic assumption that the reservoir acts like a flat plate. Holding this assumption, we can determine the drag force using the equation;

$$F_{drag} = \frac{1}{2}\rho V^2 C_{D_0} A.$$

In this equation F_{drag} is the drag force, ρ is the density of the fluid generating this force, which in this case is air, and $V$is the oncoming velocity of the air. Since the reservoirs are not moving, the maximum velocity of 70 mpg is the average wind velocity during a tornado. This is the worst-case scenario and results in the highest torsion created. C_{D_0} is the parasite drag coefficient associated with a certain type of assembly. For a flat plate, perpendicular to the flow, the value of the parasite drag coefficient is 1.28. A is the reference area, essentially the area of the surface that is exposed to the oncoming flow. Using the drag force, it is then possible to determine the torque created by this force using the equation below;

$$T = F_{drag} R$$

Where T is the torque generated, and R is the distance from the centerline of the arm on which the torque acts. The point at which the force acts can be assumed to be the center of the side of the reservoir, which implies that $R$is half the length of the side of the reservoir.

Upon determining the torque that acts on the fountain's arms, it is possible to determine the stress caused by Torsion at the fixed end of the cantilevered beam. The stress is given by the equation;

$$\tau = \frac{T}{J} R$$

Where τ is the torsional stress, T is the torque, J is the torsion constant, which for a square cross section is;

$$J = \frac{\pi}{32}\left({b_{outer}}^4 - {b_{inner}}^4\right)$$

Using these equations, we can determine the stress due to the torsion caused by a 70 mph wind against the reservoir. Table AIV.8 shows the calculated values for torsional stress on all six arms.

Arm	Drag Force (N)	Torque Generated (N-m)	Torsional Stress (KPa)
1	29.93	3.68	80.5
2	46.72	7.19	157
3	73.07	14.07	108
4	113.82	21.41	600
5	178.29	53.67	1180
6	278.6	104.84	2296

Table AIV.8: Torsional Stress (on arms) due to Wind

The torsional stress due to wind drag can be disregarded for the prototype, as the prototype will be used indoors and will not be subject to these types of wind forces.

In similar fashion, there are three types of structural modes that can create stress in the main post of the fountain. These three methods are the bending stress, buckling, and torsion caused by the wind on the reservoirs. The bending stress analysis is similar to that used for the fountain arms, but the worst case scenario for the main beam is when only one side (the heavier side of the fountain is loaded) causing the beam to bend over to one side. Figure AIV.6 shows a visual of such a scenario.

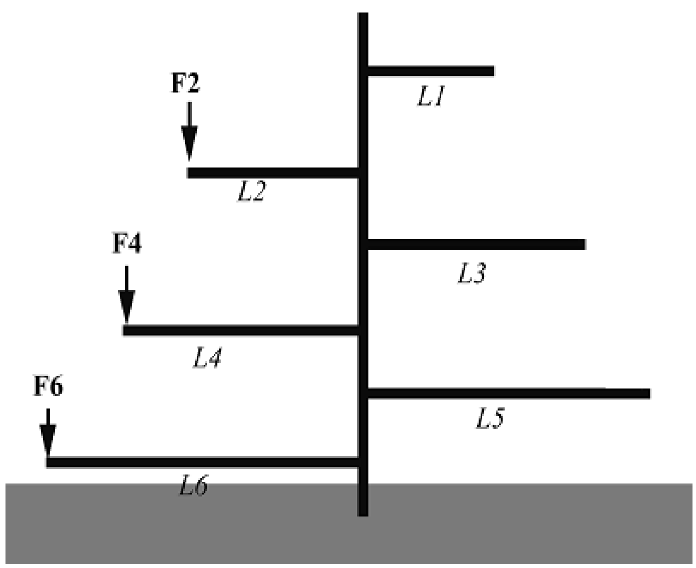


Figure AIV.6: Extreme Bending Scenario for Main Beam

Using the analysis method mentioned in the previous section regarding the arms, it was possible to determine the maximum stress due to bending in the main post, using an updated area moment of inertia. Using this relationship, the maximum bending stress is 13.59 MPa.

The fountain's center post also requires stress analysis due to each arms reaction forces being applied to the center post at each attachment location. In order to accurately and efficiently consider each arms reactions forces on the center post in order to determine the max stress achieved, ProE's Finite Element Software (FEA), Mechanica, was used.

Instead of using the h-method for meshing a part, Mechanica utilizes the p-method or also referred to as the adaptive mesh method. The p-method manipulates the finite element structure created for a part until a user specified accuracy or convergence is reached. In most cases, where convergence analysis is necessary, the p-method is the more efficient method since manual user iterations are not required [13].

A 3D model of the center post was used for the FEA and each arm's resultant forces were applied at the attachment locations, an example of the applied force orientation is shown in Figure AIV.7 below. The center post's bottom surface was constrained from rotating and translating in all three directions (x,y,z) in order to simulate being anchored to the ground.

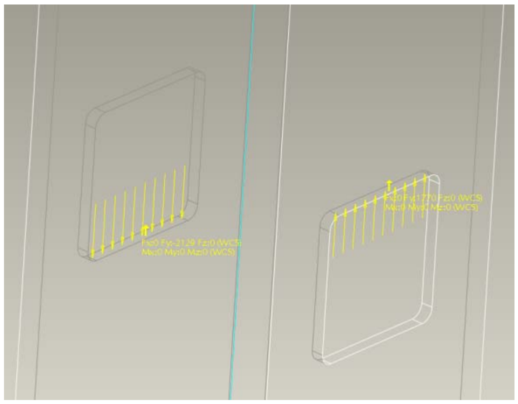


Figure AIV.7: Bottom Arm's resultant forces on center post

Minimum node constraints were applied to all curves around the center post's rectangular holes in order to ensure an adequate number of p-mesh's around this location. The bottom attachment hole's nodal constraints are shown below in Figure AIV.8.

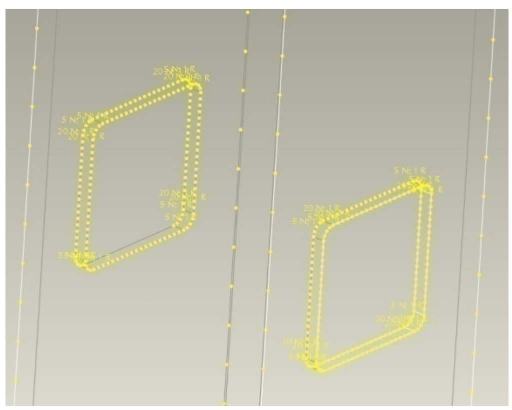


Figure AIV.8: Nodal Constraints around rectangular holes

The von mises stress results for the center post are shown in Figure AIV.9 below. A convergence value of 5% was used for all finite element analyses. The max von mises stress occurs at the bottom arm's attachment location.

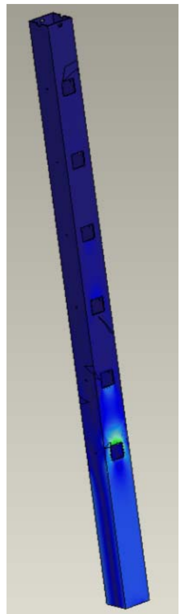


Figure AIV.9: Finite Element Analysis Von Mises stress results for center post

The max von mises stress, under normal operating conditions, is 5.6 ksi and is shown in Figure AIV.10. The location is on the rectangular hole's upper radius, where an upward reaction force is being applied by the bottom arm. Therefore, this analysis proves the center post has a safety factor of 2.3 under normal operating conditions, since the yield strength of Al 6063 is 13,000 ksi. This is an adequate safety factor for the center post considering the material is well known and the operational conditions are reasonably constant [14].

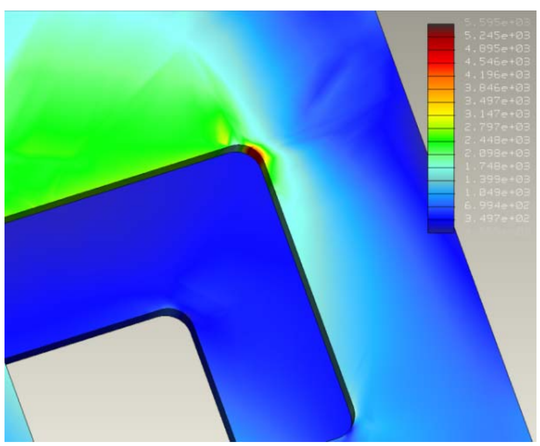


Figure AIV.10: Max Von Mises Stress, normal operating conditions, of 5.6 ksi

The same finite element analysis was repeated under the condition of a 70 kg person climbing on the bottom reservoir. The max von mises stress occurred in the same location, as seen in Figure AIV.11, with a magnitude of 8.42 ksi. This results in a safety factor of 1.5 while the person is climbing on the fountain. This again is an adequate safety factor considering this condition's chance of occurrence and since the safety factor is 1.5, it proves the center post will withstand a 70 kg person hanging on the bottom arm. The bottom arm was chosen due to the higher probability that the person would climb onto this reservoir first, and possibly only climb onto this reservoir seeing that it's at the lowest height compared to the other reservoirs. The bottom arm was also chosen to have the 70kg person condition applied since the max von mises stress occurred at the bottom arm's attachment location during normal operating conditions.

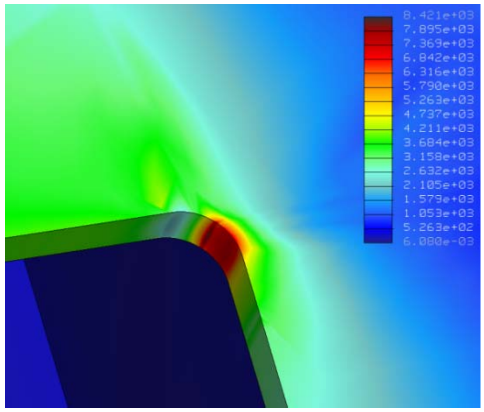


Figure AIV.11: Max Von Mises Stress, with child hanging on arm, of 8.42 ksi

Buckling analysis for the main beam was performed by using the critical stress for a beam (with one free and one fixed end to buckle). The equation,

$$F_{cr} = \frac{\pi^2 EI}{(Kl)^2}$$

Where F_{cr} is the stress at which the main post will fail by buckling. E is the elastic modulus of the material. I is the moment of inertia on the beam cross section. K is the column effective length factor, which for a beam with one fixed and one free end is 2.0. L is the length of the beam, which in this case is 3.048 m. Evaluating the buckling criterion, the failure force is reached at 140 kN. The maximum compressive stress in the beam is 3210.94 N. This force value is obtained by summing all the reaction forces on the main post due to the fountain arms, and considering the fact that the main post will buckle beneath arm 6, where all the compressive forces come into effect. Essentially, the safety factor of the main post in buckling is approximately 100.

The final failure mode on the main beam is the torsional stress caused by wind blowing against the reservoir walls. Summing all the torques on each reservoir wall, which is clearly the worst case scenario, and would only happen in extreme cases of wind shear (where the wind would blow one way on one side of the fountain and another way on the other side) as seen in Figure AIV.6

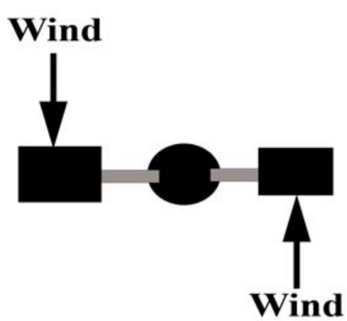


Figure AIV.12: Extreme Wind Shear Scenario – Top View

Summing all the torques, and using the same torsional stress equation as with the fountain arms, but a different torsional constant, the maximum stress due to torsion in the main beam is 1.03 MPa.

Fatigue is another mechanism of failure for metals. For 6063 Aluminum, Figure AIV.13 below shows the fatigue S-N curve for fully reversed loading.

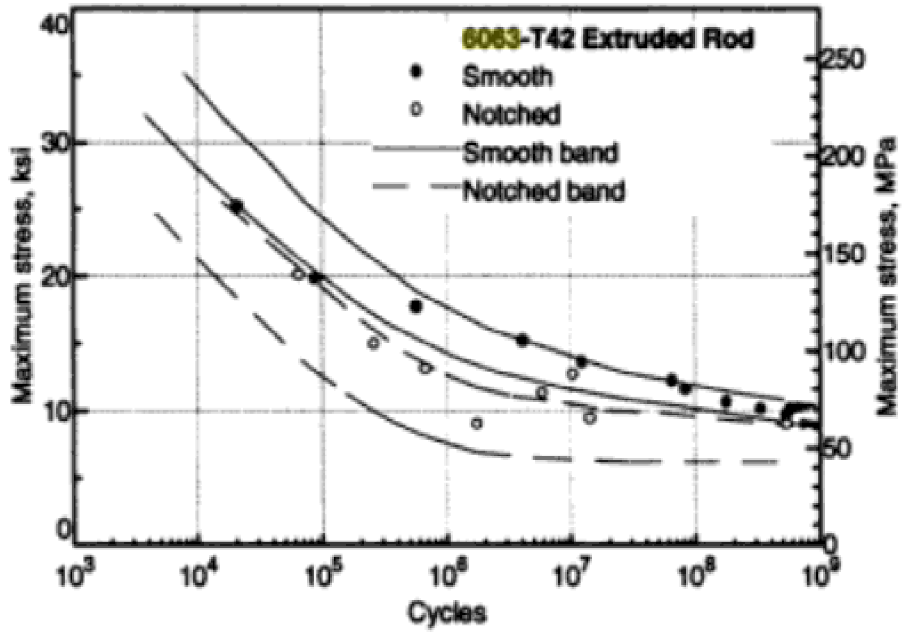


Figure AIV.13: S-N Curve for Al 6063.
Source: Fatigue Data Book, ASM International

This curve shows that below approximately 40 MPa of fully reversed loading, which the fountain final design meets. With the addition of a 70 kg person climbing on the fountain the loading goes over 40 MPa, but even with this loading, a person could climb the fountain approximately one million times before the fountain would fail, which provides for a reasonable assumption that fatigue will not cause the fountain to fail.

Reservoir Analysis

As we look into the structure of the reservoir, we have to look into the durability and dependability of the adhesive that is used to join two pieces of Plexiglas together. To begin our analysis, we looked at worst case scenarios when the reservoirs would be completely filled with water. Table AIV.9 shows the maximum mass (kg) of water in each of the reservoirs along with the volume (ft^3).

Arm	Reservoir Volume (ft^3)	Mass of Water & Reservoir (kg)
1	0.20	5.7
2	0.39	11.2
3	0.77	21.8
4	1.50	42.7
5	2.94	83.3
6	5.75	162.8

Table AIV.9: Reservoir sizes and loads

T o determine the hydrostatic pressure distribution inside the reservoir we used:

$$p = \text{Y}z$$

Where p is the gauge pressure at the bottom of the reservoir, Y is the specific weight, and z is the depth. Table AIV.10 summarizes the values for pressure and area of each side.

		Area	
Reservoir	**Pressure at bottom (kPa)**	**Side 1 (m^2)**	**Side 2 (m^2)**
1	1.49	0.038	0.023
2	1.87	0.059	0.036
3	2.33	0.092	0.057
4	2.92	0.143	0.089
5	3.65	0.224	0.138
6	4.56	0.350	0.216

Table AIV.10: Water pressure on reservoir bottom edges (both sides)

The reservoir joints were analyzed to ensure that the reservoirs would not fail when filled with water. Figure AIV.14 shows a generic reservoir from which we based our height, width, and length dimensions off of.

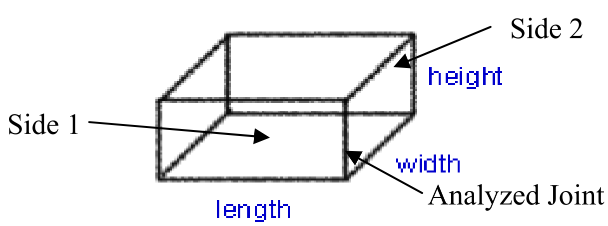


Figure AIV.14: Reservoir design depicting the various sides

Using the pressure values that we obtained, we calculated the average force on reservoir walls and then compared these values with the amount of force the applied adhesive could handle, as show in Table AIV.10 and Table AIV.11.

$$F_{ave} = \frac{1}{2} PA$$

$$F_{adhesive} = 2ht\sigma$$

Here *t* is the thickness of the acrylic (0.5 inches for the final design) and σ is the aged bond strength of Weld-on 16 (15.2 MPa [19]).

	Average Force on Wall (kN)		**Maximum Adhesive Force (kN)**
Reservoir	**Side 1**	**Side 2**	
1	0.09	0.06	192
2	0.18	0.11	240
3	0.35	0.22	300
4	0.69	0.42	376
5	1.34	0.83	470
6	2.62	1.62	587

Table AIV.11: Reservoir forces and adhesive strength

By comparing the information presented in Table AIV.11, it can be determined that the glue is sufficient for the loadings of water on the reservoir walls.

Wind forces on the reservoirs were also analyzed to determine the effects that wind pressure would have on the reservoirs. The following equation was used to determine the wind pressure on the reservoir wall.

$$p = \frac{\rho V^2}{2}$$

Here, p is the stagnation pressure and V is the velocity of the air. The average force was assumed to be the pressure times the area of the wall.

To determine if the reservoir would fail from the wind pressure under extreme conditions we chose to use a 30 m/s wind speed which is near to the highest wind speeds recorded in South Eastern Michigan [20].

Table AIV.12 gives the area and stagnation pressure and the forces of each reservoir side.

Reservoir	**Area (m)**	**Pressure (Pa)**	**Force (N)**	**Reservoir**
1	0.038	522	20	1
2	0.059	522	31	2
3	0.092	522	48	3
4	0.143	522	75	4
5	0.224	522	117	5
6	0.350	522	183	6

Table AIV.12: Wind forces on each side of the reservoirs

Since our sponsor has requested that this fountain also be operational during the winter months, thermal strains will occur on the reservoir material from the warmer water temperatures. It was also assumed that during the summer months there will be no strain on the reservoirs since the temperature of the water will be the temperature of the air which will be the temperature of the reservoir material.

To analyze the thermal strains we used the equation:

$$\delta = \alpha \Delta T$$

where δ is the strain, α is the thermal expansion coefficient in strain/^{0}C, and ΔT is the change in temperature. Since we will be using PMMA Plexiglas, a thermal expansion coefficient of $5*10^{-5}/^{\circ}$C [21] was used. A graph of strain vs. temperature is show in Figure AIV.15.

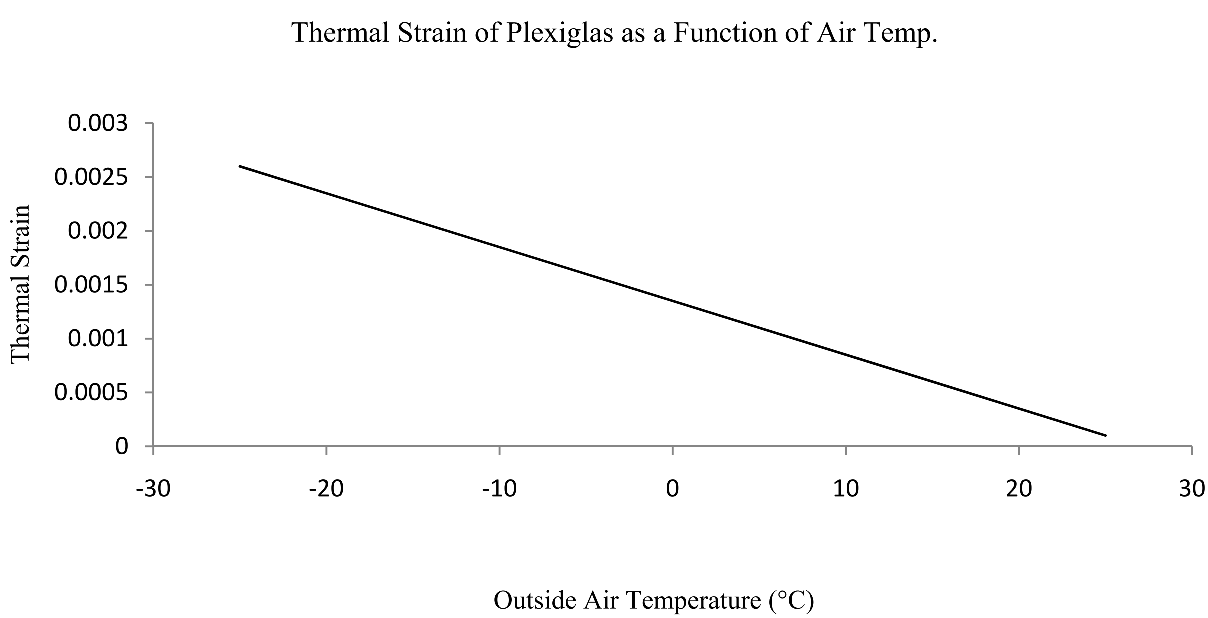


Figure AIV.15: Linear relationship of strains encountered on the Plexiglas from -25°C to 25°C

From Figure AIV.15 it is clear that the strains on the material are very small, therefore negligible, even at extremely low temperatures.

Water heating

To assure that the fountain is fully operational and functional during the winter months, analysis of heat loss in the main pool and reservoirs needs to be done to ensure that the water does not freeze either in the fountain or in the pool.

We analyzed the heat loss from the main pool of water consisting of heat loss from top through convention and from the bottom cement base through conduction and from the reservoirs from convection. To analyze the convection from the top, Newton's Law of Cooling was used:

$$q = \frac{kf * A * < Nu >_L}{L} * (T_s - T_\infty)$$

$\boldsymbol{kf}$	Thermal Conductivity of air	$\boldsymbol{T_s}$	Water Temp
$\boldsymbol{A}$	Top Area	$\boldsymbol{T_\infty}$	Air Temp.
$< Nu >_{\boldsymbol{L}}$	Nusselt Number		
$\boldsymbol{L}$	Characteristic Length		

For analysis purposes all the values were analyzed for extreme cases. For the pool, a size of 16'x10'x1' was considered. The air temperatures were taken from monthly average low temperatures in Ann Arbor [22] and the temperature of the water was assumed to be about 34°F.

In order to find the amount of heat loss, the Nusselt number for the equation needed to be calculated. To calculate the Nusselt number we first needed to find the Reynolds number, from which we could determine the type (laminar or turbulent) over the pool. The Reynolds number was calculated using equation:

$$Re_L = \frac{V * L}{\nu}$$

V =5 m/s
L =4.88 m
$\boldsymbol{\nu}$ =11.42*10^{-6} m^2/s

Where V is the velocity of the air, L is the length of the pool, and ν is the viscosity of the fluid. For the air velocity a value of 5m/s (11mi/h) was chosen to reflect the average wind speeds seen in Ann Arbor during the winter months. From the calculations a Reynolds number of 2.13 x 10^6 was determined. Since this is determined to be turbulent flow over the pool, the following equation for mixed flow find the Nusselt number.

$$< Nu >_L = \left(.037 * Re_L^{4/5} - 871\right) * Pr^{1/3}$$

Pr = .69
Nu_L = 3011

The value of the Nusselt number was then used in the Newton's Law of Cooling equation to determine the heat loss rate.

Heat loss from the sides of the pool through conduction was analyzed. The amount of heat loss can be determined using equation:

$$q = \frac{kA}{L} * \left(T_i - T_g\right)$$

Where k is the thermal conductivity of the cement, A is the total surface area of conduction, L thickness of the cement walls, T_i is the temperature of the water, and T_g is temperature of the ground, which was assumed to be about the same as the temperature of the air. For cement, the thermal conductivity (k) is 1.4 W/mK.

To analyze the reservoirs, surface convention was considered to be the main factor contributing to the heat loss. Equations:

$$q = A_{ku} * < Nu >_D * \left(\frac{Kf}{D}\right) * (T_i - T_\infty)$$

$$q = -M * C_p * \frac{(T_i - T_{SL})}{\Delta t}$$

A_{ku} =	Surface area of reservoir	T_∞ =	Air Temp
Nu_D =	Nusselt number (semi-bounded fluid streams)	M =	Mass of Water
D =	Characteristic Length of reservoir	C_p =	Heat Capacity
K_f =	thermal conductivity	T_{SL} =	Water temp (pool)
Ti =	Water Temp. (Reservoir)	Δt =	Total Time

Were related using Q to determine T_i. To analyze these equations the Reynolds and Nusselt numbers needed to be determined. The equations:

$$Re_D = (u_{f,\infty} * D)/v_f$$

$$< Nu >_D = a_1 * Re_D^{a_2} * Pr^{1/3}$$

$u_{f,\infty}$ = Air velocity (5m/s)		a_1 = .102
D =	Max Length of Reservoir	a_2 = .675
v_f =	fluid viscosity	Pr = .69

Show the Reynolds and Nusselt numbers for a semi-bounded fluid stream. Table AIV.13 shows the volume and mass of water in each reservoir. From these values we were able to determine the Reynolds and Nusselt numbers. Heat loss from surface convention was calculated assuming an air temperature of -30 °C which is lowest temperature recorded in Ann Arbor. Table AIV.14 shows minimum necessary pool water temperature to ensure that the water does not freeze if it spent the entire cycle time in a single reservoir.

Reservoir	D (m)	Volume (m^3)	Mass (kg) (Water)
1	0.25	0.01	5.73
2	0.31	0.01	11.19
3	0.39	0.02	21.85
4	0.48	0.04	42.67
5	0.60	0.08	83.34
6	0.75	0.16	162.78

Table AIV.13: Reservoir dimensions and water mass when full

Reservoir	Re Number	Nusselt Number	Aku (m^2)	Ti (°C)
1	1.07E+05	192	0.04	2.24
2	1.34E+05	215	0.06	1.57
3	1.68E+05	240	0.09	1.11
4	2.09E+05	268	0.14	0.79
5	2.62E+05	300	0.22	0.56
6	3.27E+05	336	0.35	0.40

Table AIV.14: Reynolds, Nusselt, and Temperature of Reservoirs

From this analysis it was then determined that most of the heat loss will occur through the main pool of water which would need to be 3 °C. We then calculated the average expected heat loss for the winter months and estimated an electricity cost of 11 ¢/kWh [15]. Table AIV.15 shows the calculated heat rates, losses and costs for each month, resulting in an expected heating cost of $865 per winter.

Month	Average Air Temperature (°C)	Assumed Water Temperature (°C)	Convection Heat Rate (W)	Conduction Heat Rate (W)	Time (hr)	Total Heat Loss (kW hr)	Expected Cost Per Month
Dec	-6	3	1900	814	744	2019	$222
Jan	-8	3	2322	995	744	2468	$271
Feb	-7	3	2111	905	672	2026	$223
Mar	-3	3	1266	543	744	1346	$148

Table AIV.15: Average heat rate, loss, and cost in winter months

Mechanism Analysis

To calculate the necessary volumes of the subsidiary reservoirs and the bob mechanisms, we must estimate the amount of force required to open the flapper when the reservoir is completely full. To do this we will operate under the following simple assumptions:

1. Once the seal is broken, the flapper will open completely. This is a valid assumption in that the pressure holding the flapper down will be greatly reduced. This assumption held true during testing of the prototype.
2. Only vertical forces play a role in opening the flapper. Given assumption 1, this conservative assumption is valid so long as there is no significant deformation caused by horizontal forces which break the seal. Again, this is a conservative assumption and will not cause a solution suggesting weight that will be insufficient.
3. The weight of the flapper plays no role in opening the flapper since breaking the seal will allow for the weight to be lifted.
4. Friction is negligible.

To set up the problem, Figure AIV.16 illustrates the mechanism set up:

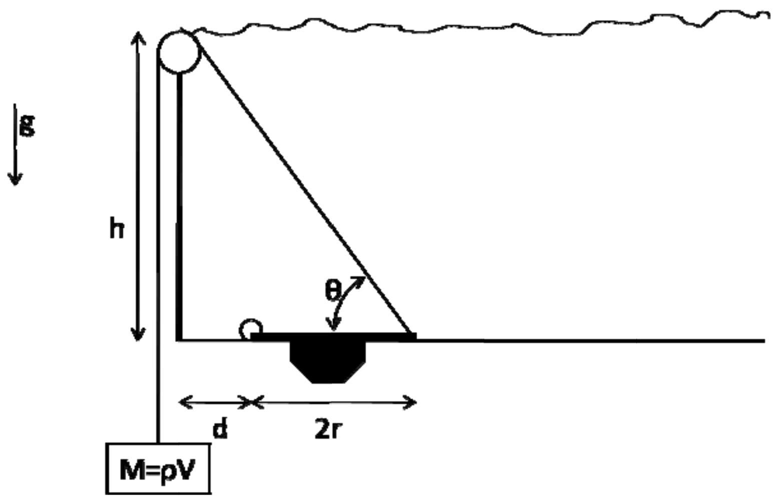


Figure AIV.16. Illustration of mechanism set up shows dimensions and orientation of components

Analysis begins with a free body diagram of the flapper, ignoring the weight of the flapper as described in assumption 3. This free body diagram is shown in Figure AIV.17

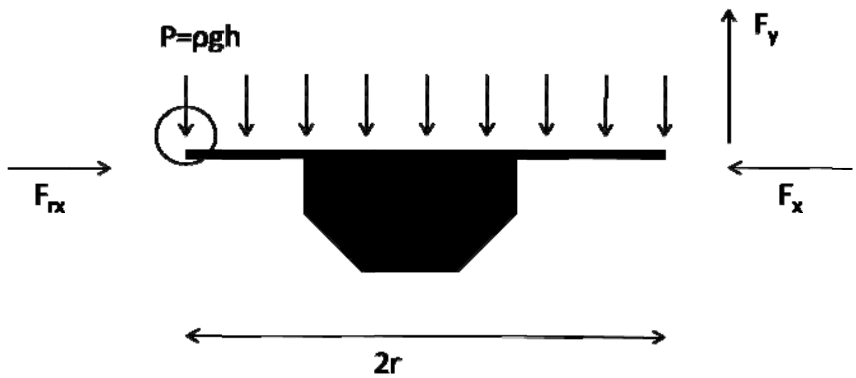


Figure AIV.17. Free body diagram shows the forces used in calculating required weight

Here the horizontal forces cancel so there is a balance between F_y and the force from the pressure.

$$F = \rho g V$$

$$F_y = F \sin\theta$$

$$F_y = \rho g V \sin\theta$$

The variable V is the volume of water (either in the subsidiary reservoir or in the float) that is pulling the flapper open. The density of water is ρ and g is the acceleration of gravity.

Balancing the forces on the flapper,

$$\rho g V \sin\theta = A\rho g \square = \pi r^2 \rho g \square$$

$$V = \pi r^2 \frac{\square}{\sin\theta}$$

Simplifying this,

$$V = \pi r^2 \frac{(d+2r)\tan\theta}{\sin\theta} = \pi r^2 \frac{(d+2r)}{\cos\theta}$$

$$V = \pi r^2 \frac{(d+2r)}{\left(\frac{(d+2r)}{\sqrt{(d+2r)^2 + \mathrm{h}^2}}\right)}$$

$$V = \pi r^2 \sqrt{(d+2r)^2 + \mathrm{h}^2}$$

For this design, r=1.5 in, d=1 in, and h varies for each reservoir. The required volumes are summarized in Table AIV.15.

Reservoir	Reservoir Height [in]	Subsidiary Reservoir Volume [in^3]
1	6.00	51
2	7.50	60
3	9.38	72
4	11.7	88
5	14.6	108
6	18.3	132

Table AIV.16. Summarizes the height and subsidiary reservoir volume required for each reservoir

Fountain Cycle Analysis

Based on the various mechanisms used, a MATLAB model was generated to track the water flow pattern within the fountain. As seen in Figure AIV.18 below, the cycle lasts 10 minutes. The water volumes and the volumetric flow rates at specific points in the fountain cycle can be used to perform further analysis, including the tubing sizing of the fountain.

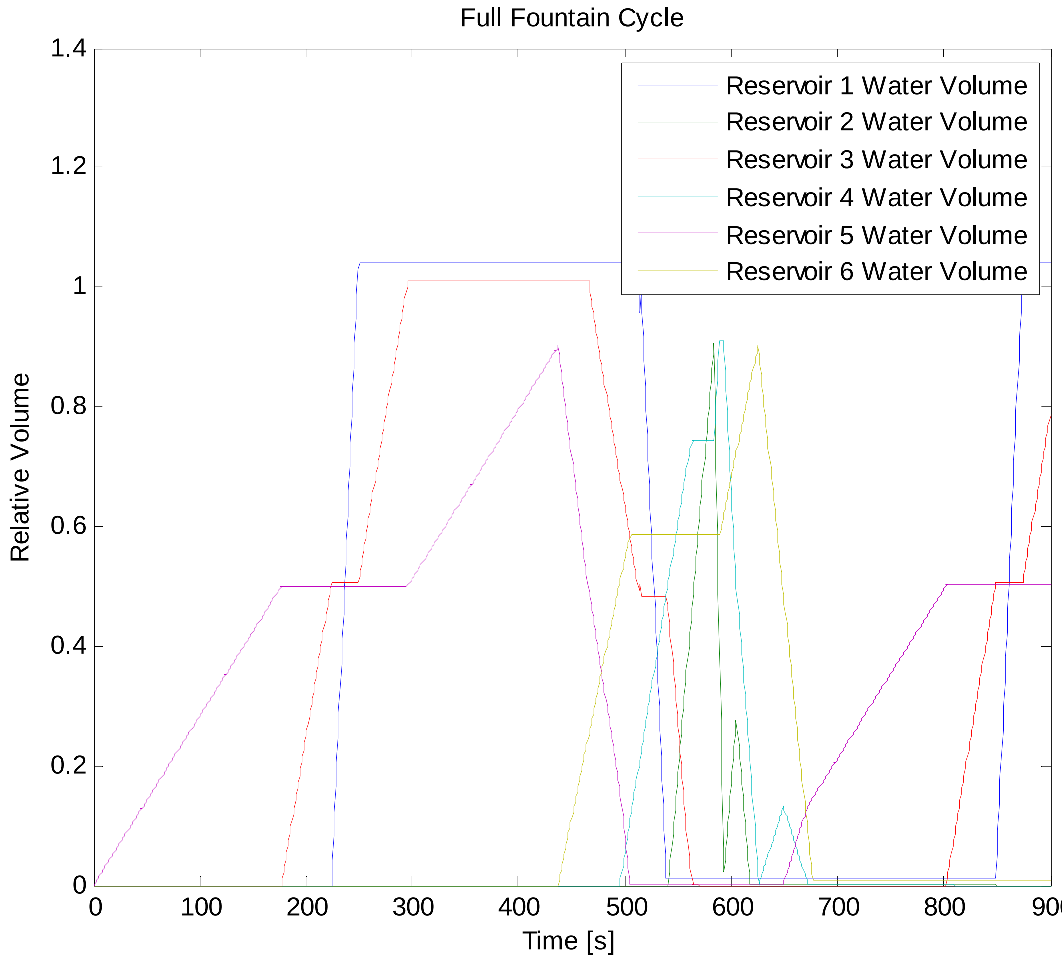


Figure AIV.18: The fountain cycle over time. The cycle begins to repeat at ~660 seconds or 11 minutes

Pipe Hole Sizing Analysis

The sizing of the holes and pipes between reservoirs can be done using elementary fluid mechanics. Using fluid momentum conservation, the equation:

$$\rho u^2 A = PA = \rho g l A.$$

Where ρ is the density of water, u is the velocity of water, A is the area the water passes through, P is the water pressure over the area, g is the gravitational constant, l is the height of the column of water over the prescribed area, A. This equation can be simplified down to

$$u = \sqrt{gl}.$$

Using the conservation of mass, given the volumetric flow rate of water, V, through the MATLAB simulation, we get the equation

$$A = \frac{V}{u}.$$

Using this equation we can determine the minimum cross-sectional area required for a tube passing between two reservoirs. The minimum required areas and the resulting pipe diameters are listed in Table AIV.16 below.

Pipe Between Reservoirs	Cross Sectional Area (sq. in)	Required Diameter (in.)
1 - - 2	0.63	0.89
2 - - 3	0.63	0.89
3 - - 4	0.52	0.81
4 - - 5	0.52	0.81
5 - - 6	1.21	1.24

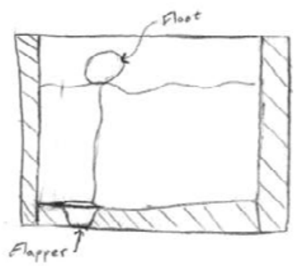
Table AIV.16: Minimum necessary cross-sectional area to achieve designed flow rates.

AV. Bill of Materials

Supplier	Part #	Part Name	Qty	Material	Size	Ind Cost ($)	Function
McMaster Carr	9775K16	Spherical Float	3	Polypropylene	6" Dia	$6.79	Float for Reservoirs 6,5,4
McMaster Carr	9775K14	Spherical Float	1	Polypropylene	5" Dia	$6.96	Float for Reservoir 2
McMaster Carr	2360K11	Flapper	8	Rubber		$3.76	Flow Control for Reservoirs
McMaster Carr	88875K763	Square Tube	4	6063 Al	3x3" ,0.25" th, 6' Lg	$73.38	Supporting Arms
McMaster Carr	88875K783	Square Tube	3	6064 Al	6x6" ,0.25" th, 6' Lg	$124.59	Center Post
McMaster Carr	92198A650	Hex Head Cap Screw	6	18-8 Stainless Steel	3/8"-16 Thread, 7" Lg	$2.85	Attaching Arms to Center Post
McMaster Carr	90099A031	Nylon-Insert Heavy Hex Locknut (5 per qty)	2	18-8 Stainless Steel	3/8"-16 Thread Size	$10.99	Attaching Arms to Center Post
McMaster Carr	98370A021	Thick Flat Washer (10 per qty)	2	18-8 Stainless Steel	3/8" Screw Size	$7.89	Attaching Arms to Center Post
		Fast Setting Cement	60		50 lb Bag	$10.00	Anchoring Fountain
		Submersible Pump					
McMaster Carr	9442T3	Clear Nylon Line	1	Nylon	0.022" Dia, 30 lb , 750' Lg	$11.74	Connecting Flappers with Floats or Weights
McMaster Carr		Weights					Flow Control - Connects to Flapper
McMaster Carr	8975K64	Multipurpose Aluminum	3	6061 Al	1/2" Th X 1" W X 6' Lg	$25.17	Reservoir Attachment
McMaster Carr	92210A557	Flat Head Sckt Cap Screw (10 per qty)	12	18-8 Stainless Steel	1/4"-20 Thread, 3-1/2" Lg	$11.55	Reservoir Attachment
McMaster Carr	90098A110	Nylon-Insert Extra-Wide Thin Hex Locknut (25 per qty)	1	18-8 Stainless Steel	1/4"-20 Thread Size	$12.26	Reservoir Attachment
McMaster Carr	92210A542	Flat Head Sckt Cap Screw (50 per qty)	1	18-8 Stainless Steel	1/4"-20 Thread, 1" Length	$13.09	Reservoir Attachment
		Plexiglas					
McMaster Carr	5894K17	Tubing (1 foot per qty)	20	Tygon PVC	3/8" - 1/16" Wall Thickness	$2.43	Reservoir to Reservoir Water Conduit
		Tubing Connections					
		Fountain Base Materials (cement, bricks, sealant, etc)					
McMaster Carr	5233K72	Tubing (1 foot per qty)	13	PVC	1" - 1/8" Wall Thickness	$1.12	Base to Top Reservoir Water Conduit
Raypak	CSPAX155	Water Heater	1			$495.00	Heat water at fountain base
Fountain Mountain	FT-1250	Water Pump	1			$54.50	Move water from fountain base to top
Stren	SSBFS50-14	Fishing Line	1		125 yds.	$11.99	Connects mechanisms to flapper valves
		Prototype					
Home Depot	74507993080	Plexiglas	7	Acylic	18"x24"x.22"	$14.97	Material for Reservoirs
Home Depot	812181004049	Arm Wood	2	Cedar	96" x 2" x 2"	$5.88	Wood for arms
Home Depot	90489093488	Main Post	1	wood	120"x4"x4"	$11.97	Main Post
Scrap		Wood	1	Scrap Wood	27.5" x 24" x 0.5"	$0	Base Plate
Carpenter Bros.		Gaskets	5	Rubber	2 in Diameter		To prevent leaking from bolt location
Little Giant Co.	14942702	Submersible Pool Cover Pump	1	Polyethylene	58 W , 300GPH at 5'	$67.83	To recycle water throughout the system
Fluid Master	46600	Flapper Valve	5	Rubber			For sealing and flow purposes
Outcast	4338835616	Fishing Line	1	nylon	125yds	$2.59	Connects mechanisms to flapper valves
Home Depot	4431504700	L - Bracket	8	Steel	4" x 1.5" 0.25"	$1.99	Attaches arms to main base
Home Depot		Post Bracket	1	Steel		$12.99	For anchoring the main post to base
Home Depot		Tubing	1	Plastic	20ft .5" thickness	$5.99	For carrying water from reservoirs
Meijer	88230600900	Blue Pool (Catch Reservoir)	1	Plastic		$6.99	Catches and stores any water from fountain
Meijer	88230600324	Forst Pool (Safety Resrvoir)	1	Plastic		$34.99	Used as in case of failure of main pool
Home Depot		Funnel	3	Plastic		$.99	will restric/direct flow through flappers
Home Depot	78864900002	Spherical Float	6	Plastic	5" Dia	$3.95	Opening and closing the flapper valves
Home Depot	30699080748	Washers	50	Steel	.25"	$4.24	To weigh down the flappers
McMaster Carr	92198A650	Hex Head Cap Screw	6	18-8 Stainless Steel	3/8"-16 Thread, 7" Lg	$2.85	Attaching Arms to Center Post

AVI. Engineering Changes

Was:



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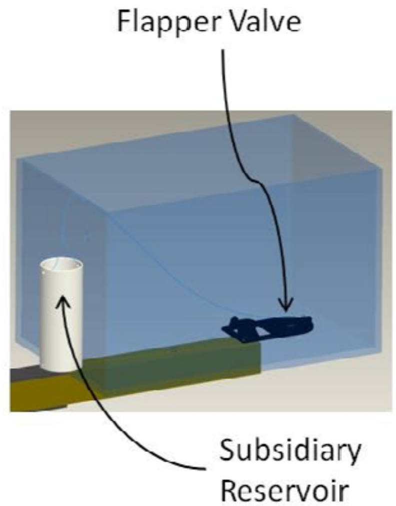
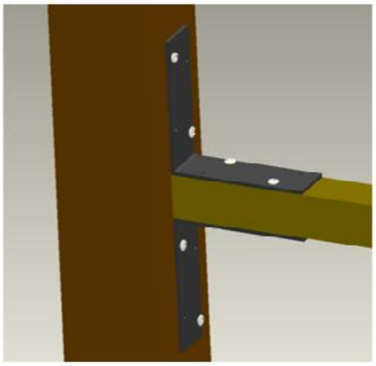


Notes:
The original float mechanism did not lift the flapper because there was not nearly enough buoyant to overcome the water pressure. The new design has the same function of a normally closed valve that stays open until the tank empties.

RQR

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Normally Closed Valve Mechanism	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

Was:



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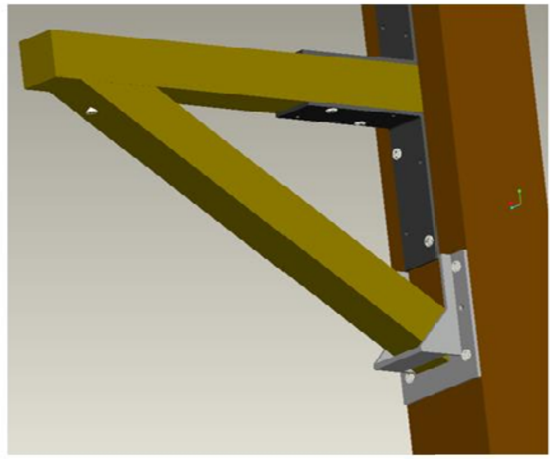
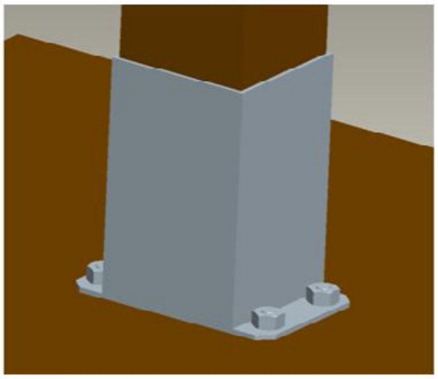


Notes:
This was necessary to prevent excessive bending or possible failure of the arm.

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Prototype Lower Arm Supports	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

RQR

Was:



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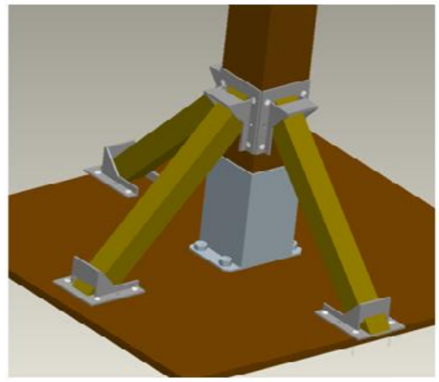


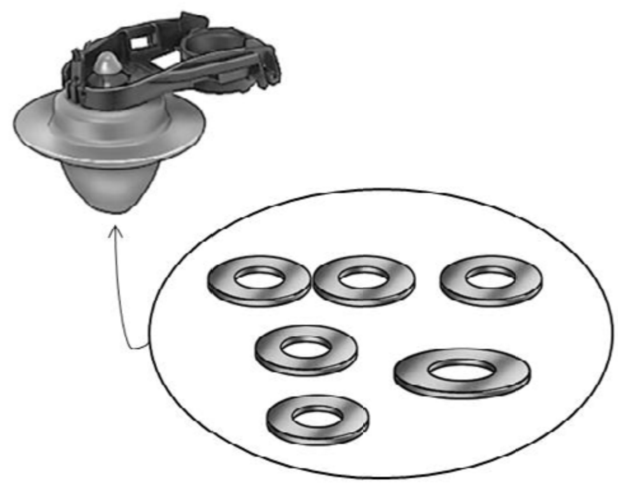
Notes:
This was needed to ensure that the center beam bracket would not break the base wood during high stress situations

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Base braces and weight	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

RQR

Was:

Is:



Notes:

The flappers, though they normally close, do not outweigh the floats or subsidiary reservoirs and extra weight needs to be added to ensure that they close.

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Flapper	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

RQR

Was:

Unspecified

Is:

Fountain Tech FT-1250
Uses 3/4" and 1" inside diameter tubing

Item#	Watts	Max-Head	GPH	20"	40"	60"	80"	100	120"	140"	160"
FT-1250	120	156"	1280	1150	1020	900	800	650	400	260	0

Notes:
Important component to be specified for bill of materials and final design, ensuring proper flow rate.

RQR

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Pump	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

Was:

Tygon PVC
Inner diameter: 1/2 in
Outer diameter: 5/8 in

Is:

Tygon PVC
Inner diameter: 1.25 in
Outer diameter: 1.625 in

Notes:
The flow was restricted between reservoirs, preventing proper operation of the cycle without restricting flow from the pump. Increasing tube diameter will allow for proper operation of the fountain at the desired flow rates.

RQR

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Tubing	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

Was:

Is:

Notes:
Excess water due to subsidiary reservoirs needed to be collected and held in the inner pool and a large pool was needed to contain this small pool due to safety concerns.

RQR

Rushing Fountain	
Project: Quiet Rushing Fountain	
Ref Drawing: Prototype Safety Water Pool	
Engineer: Ryan Rudy	19/04/2009
Proj. Mgr: G. Hulbert	19/04/2009
Mgmt./Sponsor: D. Noble	19/04/2009

AVII. Design Analysis Assignment

Functional Performance

1. Reservoir Material
   a. Identify the function, objective, and the constraints.
      i. Function: Water Storage
      ii. Objective: Minimize Cost
      iii. Constraints: Transparent, durable outdoors, resistant to fracture

   b. Determine appropriate material indices

      Because of hard constraints and the materials available, selection of material followed directly from constraints and minimizing cost.

   c. Using CES software, identify top five material choices

      Because of necessary hard constraints of transparency/optical quality, and outdoor durability (Fresh water durability, UV durability, operational temperature ranges, etc.), only 4 materials passed all constraints. The four materials that pass all of the hard constraints are listed be in Table AVII.1:

Material	Price*Density [$/ft^3]	Fracture Toughness [ksi*in$^{1/2}$]
Polymethyl methacrylate (PMMA)	82 - 91.3	0.637 - 1.460
Soda-lime glass	98.4 - 116	0.501 - 0.637
Borosilicate glass	264 - 397	0.455 - 0.637
Silica glass	387 - 645	0.546 - 0.728

Table AVII.1: Possible Reservoir Materials

   d. Explain reasons for your final choice

      PMMA was chosen because it has both the lowest cost and the highest fracture toughness, while fulfilling all of the hard constraints placed on the material.

2. Arm Structure Material
   a. Identify the function, objective, and the constraints.
      i. Function: Beam in bending
      ii. Objective: Minimize Cost
      iii. Constraints: L is fixed, F is fixed, beam cannot yield under cyclic loading, Cross-Section fixed, must be durable outdoors

   b. Determine appropriate material indices

      Beam bending under cyclic loading is the main mode of failure. A reasonable safety factor of 2 will be included to ensure the safe operation of the design.

$$\sigma_e \geq \frac{Mc}{I} SF$$

      With force, length, and cross-section fixed,

$$\sigma_e \geq 94\text{MPa} = 13.6\text{ ksi}$$

The minimizing the cost function for the is objective

$$Cost = P\rho AL$$

With cross-section and length fixed, cost is a function of price and density.

c. Using CES software, identify top five material choices
Using CES, The hard constraints were placed first. These hard constraints are listed in Table AVII.2:

Constraint	Minimum	Maximum
Fatigue Strength	13.6 ksi	
Maximum Service Temperature	120 °F	
Minimum Service Temperature		-20 °F
Fresh Water Durability	Very Good	
Salt Water Durability	Good	Very Good
Weak Acids Durability	Average	Very Good
Weak Alkalis Durability	Average	Very Good
UV Durability	Very Good	

Table AVII.2: Hard constraints used for CES

Arranging the materials that pass this criteria list by the value of Price*Density, Table AVII.3 is created:

Material	Estimated Price*Density [$/ft^3]
Age-hardening wrought Al-alloys	184 - 219
Non age-hardening wrought Al-alloys	184 - 219
Cast Al-alloys	190 - 226
Silica glass	387 - 645
Zinc die-casting alloys	452 - 646

Table AVII.3: Eligible Arm Materials Arranged from Low to High Cost

d. Explain reasons for your final choice
Age-hardening wrought Al-alloys, Non age-hardening wrought Al-alloys, and cast Al-alloys all carry the same low approximate cost, however in analyzing the availability of 3in. x 3in. cross-section ¼ in. wall thickness Aluminum, only alloy 6063 (an age-hardening wrought Al-alloy) was available for choice. This alloy, described as Ultra-Corrosion-Resistant Architectural Aluminum, should function well for our intended application.

Environmental Performance
For the environmental performance evaluation, see Figures AVII.1-4.

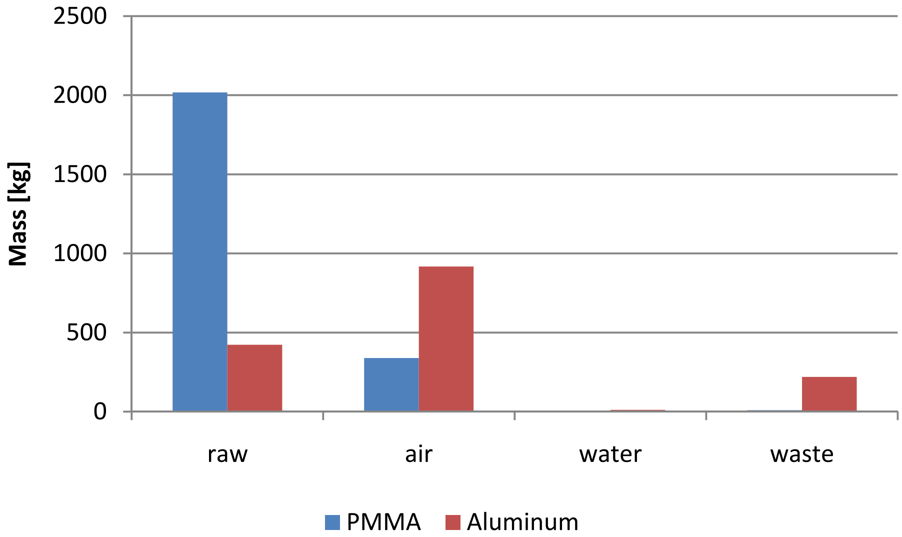


Figure AVII.1: Environmentally harmful byproduct sums from PMMA and Aluminum production

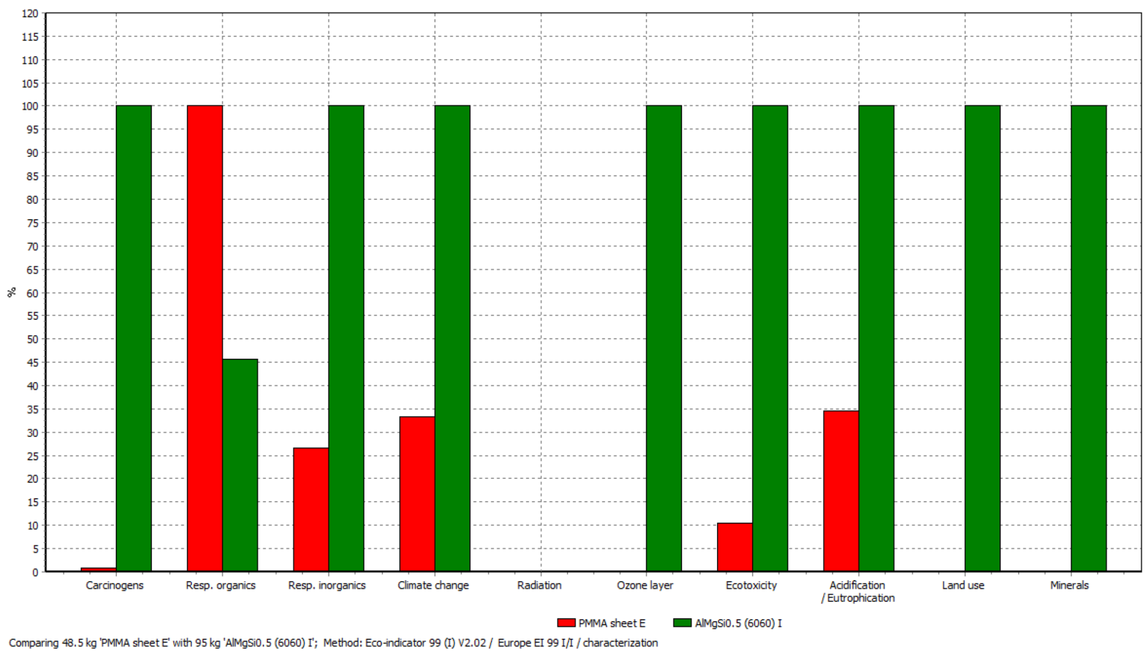


Figure AVII.2: SimaPro PMMA and Aluminum Eco-indicator characterization

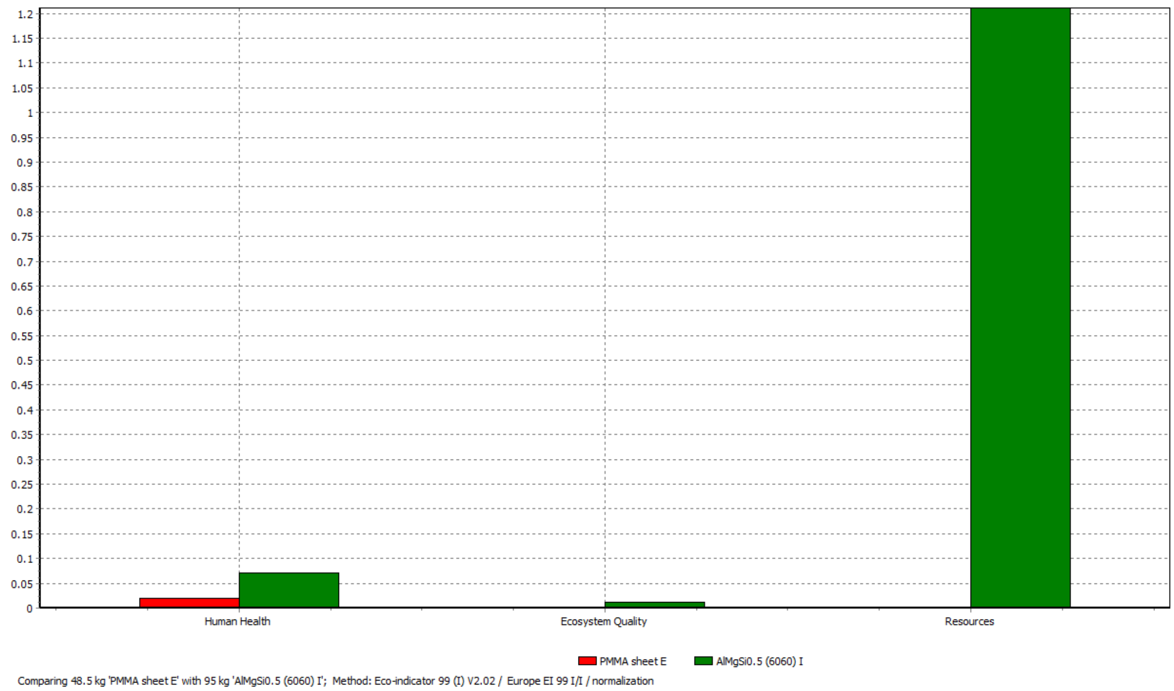


Figure AVII.3: PMMA and Aluminum environmental impact

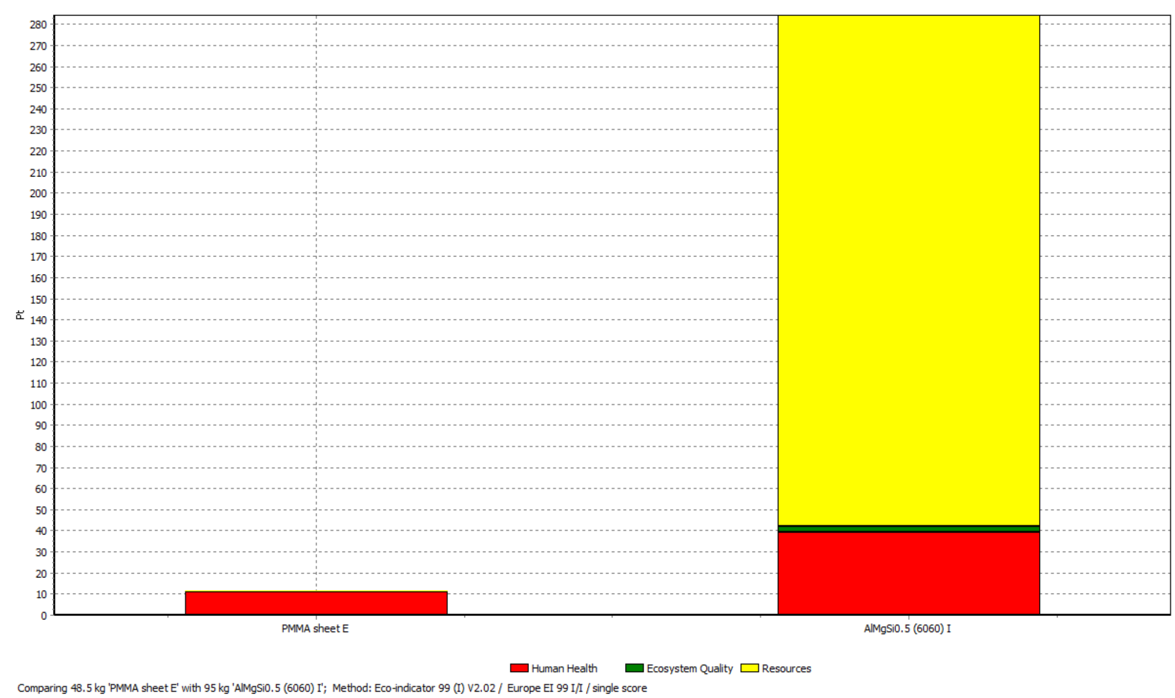


Figure AVII.4: Eco-indicator 99 point values for PMMA and Aluminum

From the information available from SimaPro it appears that the aluminum used for the arms and center post will cause the largest environmental impact.

In considering the full life cycle on the order of 100 years, the PMMA imposes a much larger environmental impact since the reservoirs have an expected lifespan of approximately 10 years. As such, the effect on human health would jump from around 10 points to over 100 points. The superstructure should not need to be replaced over the lifespan of the fountain. As such, both PMMA and aluminum pose similar environmental impact over the full life cycle.

For other top choices for the arm material in CES, there is little difference in environmental impact as compared to 6060 Al. Taking into account that the aluminum selected above is readily available, there is very little reason to select a different material.

Manufacturing Process Selection

We expect the maximum production volume for this project to be between 1,000 and 10,000 units. The application for the University of Michigan Depression Center need not apply to other consumers. The potential aesthetic appeal of the fountain lends the design to easily transition into other markets, making it possible to reach 1,000 to 10,000 units.

The aluminum arms and center post will be shaped using a milling process because it provides flexibility to create the variety of cuts required in the design, such as the holes in the main post to place the arms and the cavities at the end of each arm for the reservoir cradle to rest. This process is economical for the relatively smaller scale that we expect to produce.

The aluminum arms and center post will be joined using threaded fasteners. This allows for easy replacement of components and quick, cost effective assembly.

The reservoirs will be shaped and assembled rather than injection molded due to the high tooling costs necessary for a mold for each reservoir. PMMA will be shaped using a Laser Cutter due to the ability to create clean cuts in PMMA without risking damage to the material, the ability to easily cut holes in PMMA, and the ability to automate the process once cut files have been created.

PMMA will be joined using a rigid adhesive. The reservoirs need to be water-tight and the area of application of an adhesive needs to be small to ensure that the reservoirs remain transparent. All other processes would not be feasible for the assembly of these reservoirs.

AVIII. Safety Report

1. Executive Summary

The purpose of this report is to discuss the potential safety hazards and the elimination of those hazards for the Quiet Rushing Fountain prototype and testing. The major safety issues with our project lie in the fabrication aspects. This includes the fabrication of all the different parts using tools available in the Mechanical Engineering machine shop. All the machining will be done on wood and Plexiglas. All the metals used in this process will be pre-purchased. These purchased materials include L-brackets, bolts, and other fastening items. Another possible safety issue comes up with the use of water and testing using water in the machine shop. Also the use of an electric submersible pump in a wet environment brings up the issue of a short circuit.

Manufacturing Elements

The major safety hazards with manufacturing arise with the use of the machine shop. In order to eliminate these hazards, rules of the machine shop, proper machine usage habits, and other rules enforced by Bob Coury will be observed. These rules included things as basic as always using safety glasses, always tucking in shirts, and specific things such as ensuring all tools are used as intended and no unsupervised use of the machine shop takes place.

Design Elements

The best way to ensure safety and eliminate risks in the prototype is to ensure all the design aspects ensure that there will be no structural failures in the fountain design. Structural analysis of the fountain, using a safety factor of three will ensure that there are no failures in the assembly process of the prototype. This safety factor is determined using worst case scenario possibilities. This is to ensure that even if the fountain is loaded in an unorthodox way, there will be no failure in the design. If there is a situation where the design will fail, the materials used; wood and Plexiglas, pose a minimal risk if all standard safety procedures are followed.

Assembly Elements

Prototype assembly is a low risk process, but has risks associated with it nonetheless. The largest risk is the use of a submersible pump in a pool of water. To ensure that all risks are eliminated in the use of this electrical device in water, it is important to ensure that the person operating this pump stays in a dry environment, and ensures that the electrical outlet as well as the cord and plug of the pump remain dry. It is also important to ensure there are no frayed wires attached to the pump that would be directly exposed to water. Following the product safety sheet included with the purchased pump will ensure that all risks and either minimized or eliminated.

Testing Elements

Testing is a hazardous part of the fabrication process. Test will not only be performed at the completion of the assembly project, but also at the completion of each fabrication sub stage. One of the major testing stages is the testing of the Plexiglas reservoirs. In order to ensure safety, testing the reservoirs and seals with water will only take place in an environment where water does not pose a hazard to electrical equipment. General safety measures will also be used to ensure that there is no injury to persons during this testing phase. During the test of the prototype, all general safety measures will be observed. All tests will be performed in an isolated environment, where water will not damage any electrical equipment or pose any problems to electrical equipment.

2. Experimental Plans Prior to Design Completion

The experimentation prior to data collection only involves timing the mechanisms involved with the fountain. In order to ensure that the prototype behaves as planned, it is vital to time each individual mechanism and make sure this works. The data collected during this phase will be times for each mechanism found in the reservoirs. These times will then be summed to compare with the prototype design cycle time.

The main safety risk in this experimentation involves the failure of a mechanism or a reservoir. The FMEA analysis for the individual purchased components is available in Appendix B. This experimentation process will take place in a contained environment. A location with easy water drainage, such as a bath tub, will be used. In addition, safety precautions, such as the use of safety glasses, will be in place to ensure safety in case of the failure of mechanisms or the reservoirs. By taking these steps, we have ensured that the experimentation prior to design completion is at the lowest risk possible.

3. Prototype Materials & Purchased Components
The following is an inventory of all the purchased materials. Appendix B provides a detailed FMEA analysis on the materials deemed dangerous.

3.1 Reservoirs
Material: Acrylic Glass
Stock Shape & Dimensions: 18 in x 24 in x 0.22 in
Source: Home Depot

Description:
The reservoirs hold water for functioning of the fountain. The water level in each reservoir needs to allow for the viewer to see the inner workings of the fountain so it must be transparent. The reservoirs will be fixed in place by the acrylic adhesive, Weld-On 16.

3.2 Arms
Material: Wood
Stock Shape & Dimensions: 96 in x 2 in x 2 in
Source: Home Depot

Description:
The arms support the reservoirs and carry the loads of the water.

3.3 Main Beam
Material: Wood
Stock Shape & Dimensions: 120 in x 4 in x 4 in
Source: Home Depot

Description:
All arms will be attached to the main beam and the beam will support the loads of the entire structure.

3.4 Base Plate
Material: Wood
Stock Shape & Dimensions: 27.5 in x 24 in x 0.5 in
Source: Scrap

Description:
The base plate ensures that the prototype is structurally stable and does not move, lean, or tip over.

3.5 Gaskets
Material: Rubber
Stock Shape & Dimensions: 2 in. D

Source: Carpenter Bros. Hardware

Description:
The gaskets are used to ensure that there is no leak in the reservoir from hole for the bolt that attaches the reservoir to the arm.

3.6 Submersible Pump
Quantity: 1
Vendor: Little Giant Pump Company
Part: 14942702

Description:
The pump will move water from a bottom catch reservoir to the top reservoir and is powered by a wall outlet. The pump is rated for 400 gal/hr at 3 ft.

3.7 Flapper Valve
Quantity: 5
Vendor: FluidMaster
Part:46600

Description:
The flapper allows for a tight seal at the bottom of the reservoir and can open to provide flow through the hole.

3.8 Fishing Line
Quantity: 1
Vendor: Outcast
Part: 4338835616

Description:
The fishing line allows for a way to link the mechanical components such as floats and reservoirs to the flapper valve without adding excess visual complexity.

3.9 L-Bracket
Quantity: 8
Vendor: Home Depot
Part: 4431504700

Description:
The L-brackets are used to fix and attach the arms to the main beam. The L-brackets are made of an unknown steel alloy. 4 in. x 1.5 in. 0.25 in.

3.10 Post Bracket
Quantity: 1
Vendor: Home Depot
Part: Mailbox Bracket

Description:
The post bracket fixes the main post to the base plate. The post bracket is made of steel.
3.11 Tubing
Quantity: 20 ft.

Vendor: Home Depot

Description:
Tubing will connect the reservoirs and will run from the pump to the top reservoir to transport water through the fountain cycle. The tubing is made of plastic.

3.12 Catch Reservoir
Quantity: 1
Vendor: Meijer

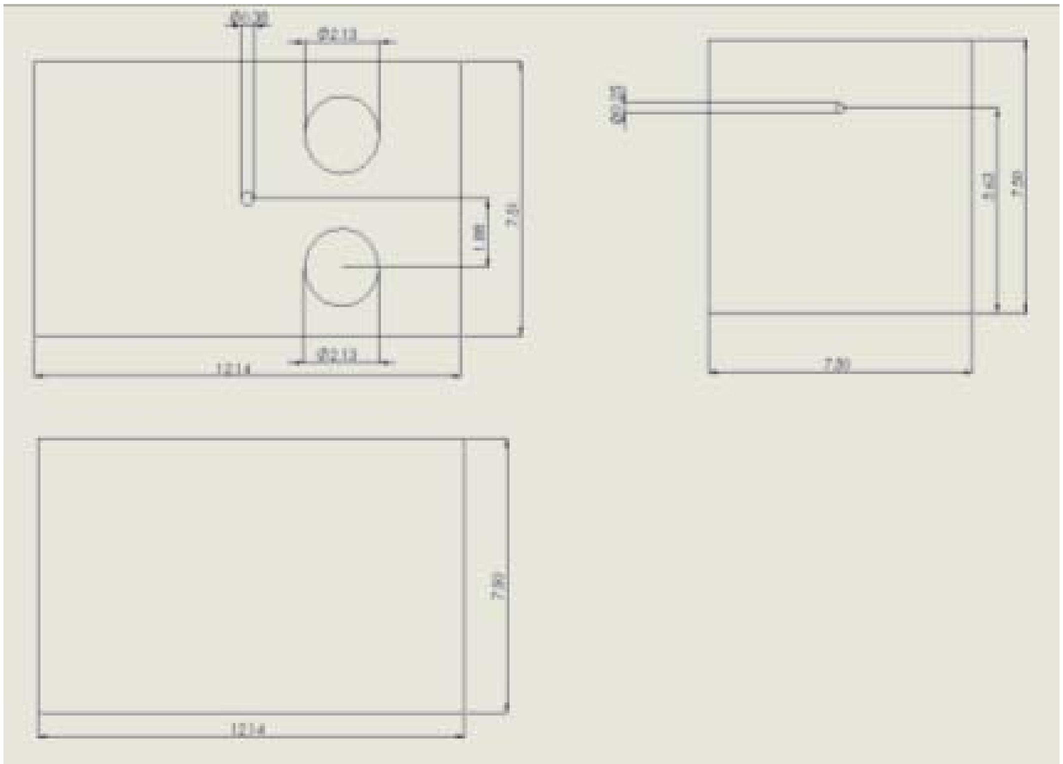
Description:
The pool will catch any leaking water that comes down from the fountain. This pool is made of plastic.

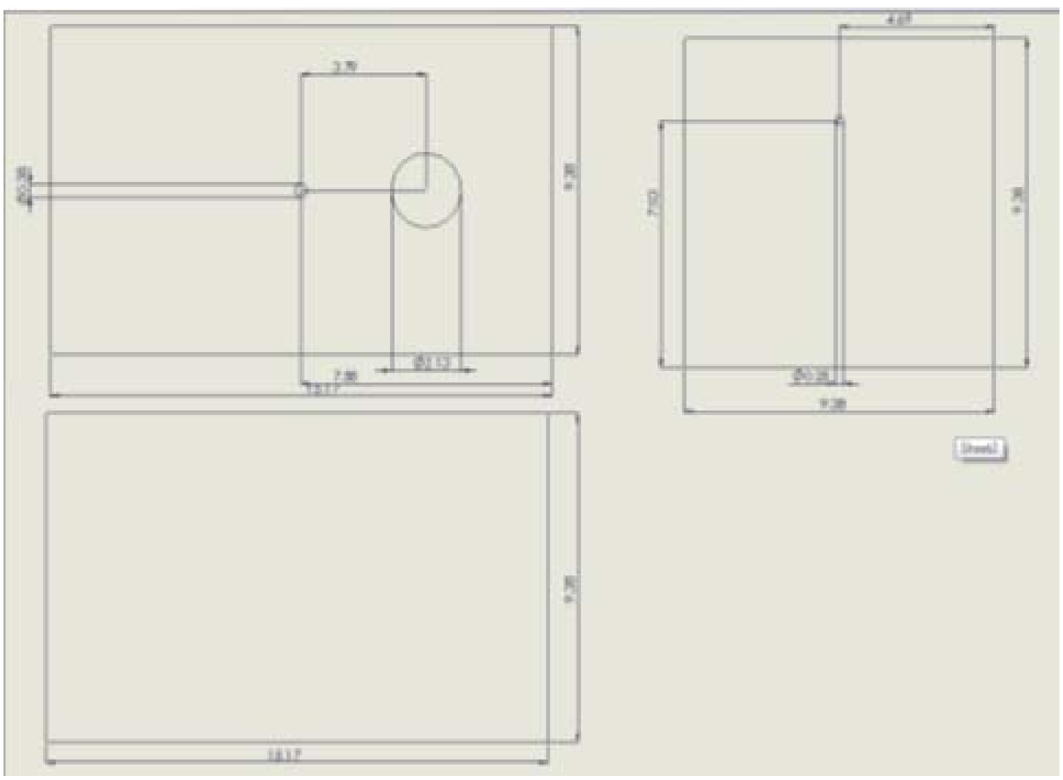
3.13 Pool
Quantity: 1
Vendor: Meijer
Part:
Description:
The pool will catch all water, should there be some sort of failure in the catch pool or any water transport mechanism. This pool is made of plastic.

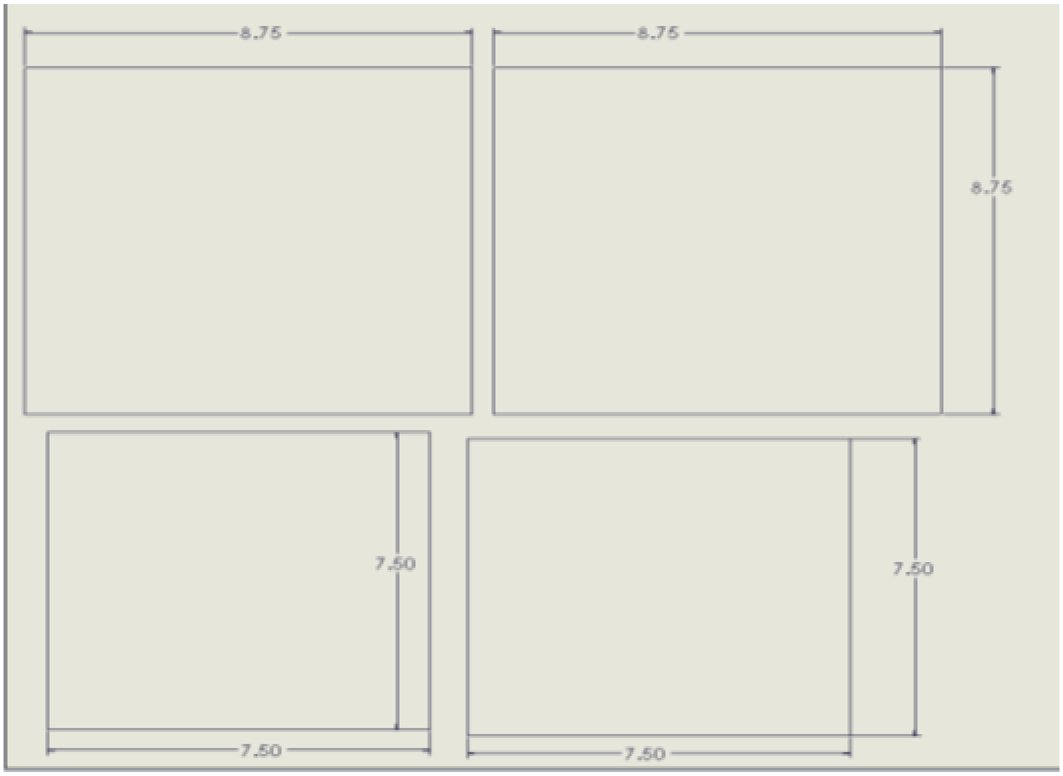
3.14 Funnel
Quantity: 3
Vendor: Home Depot

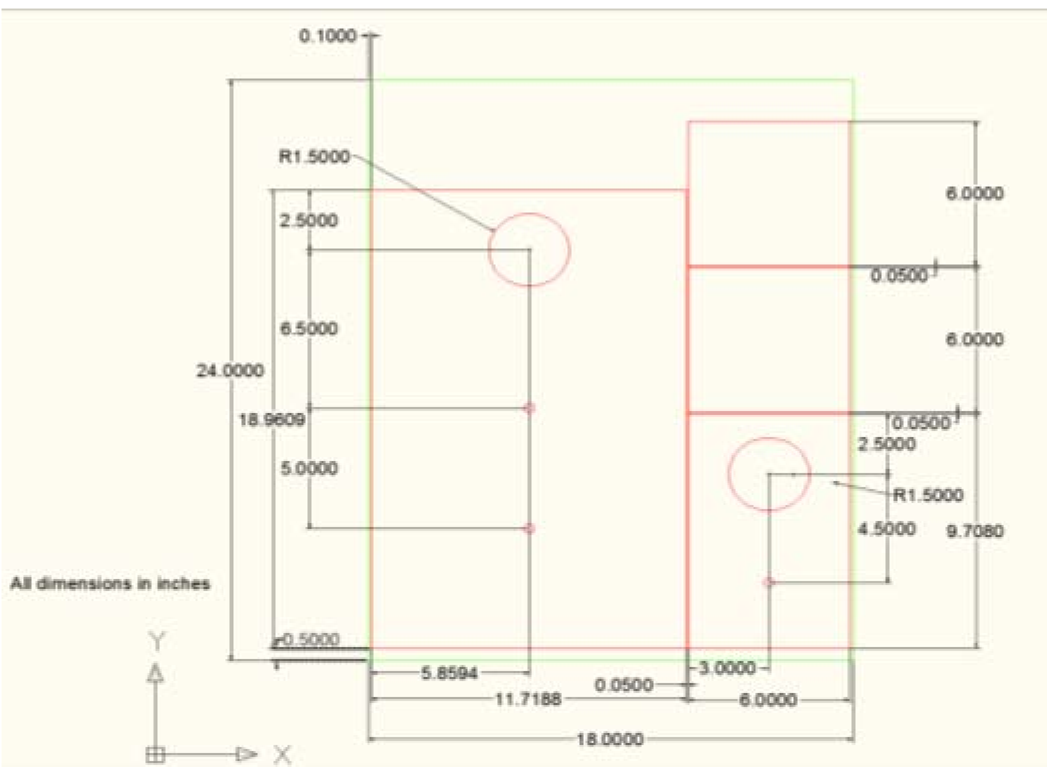
Description:
The funnel will restrict the flow through certain flappers, allowing for flow to be more quiet during transport. The funnel is made of plastic.
To ensure the safety of the operation of this prototype FMEA Analysis has been done for the electric pump and other components as they pose a safety risk due to various failure modes. Appendix B contains the FMEA Analysis

4. Engineering Drawings of Designed Parts
4.1 Reservoirs
Detailed drawings with dimensions are given below for each reservoir. In most cases each sheet does not represent all the components from a single reservoir. This is because the space was optimized to reduce the material costs.

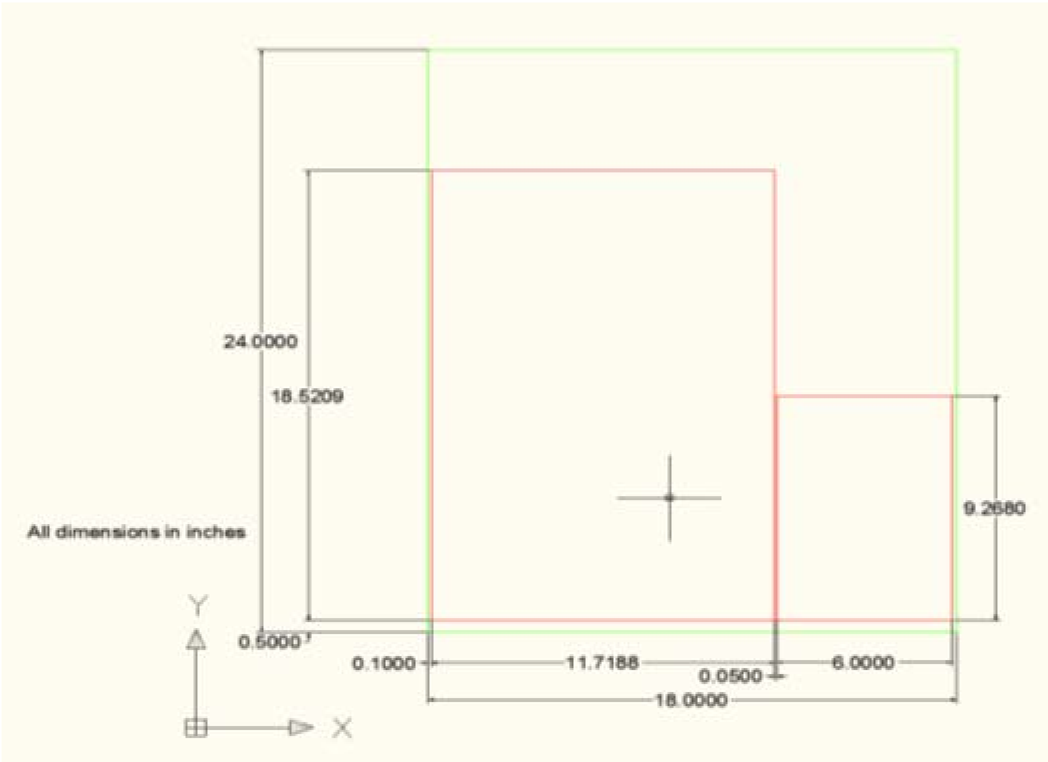


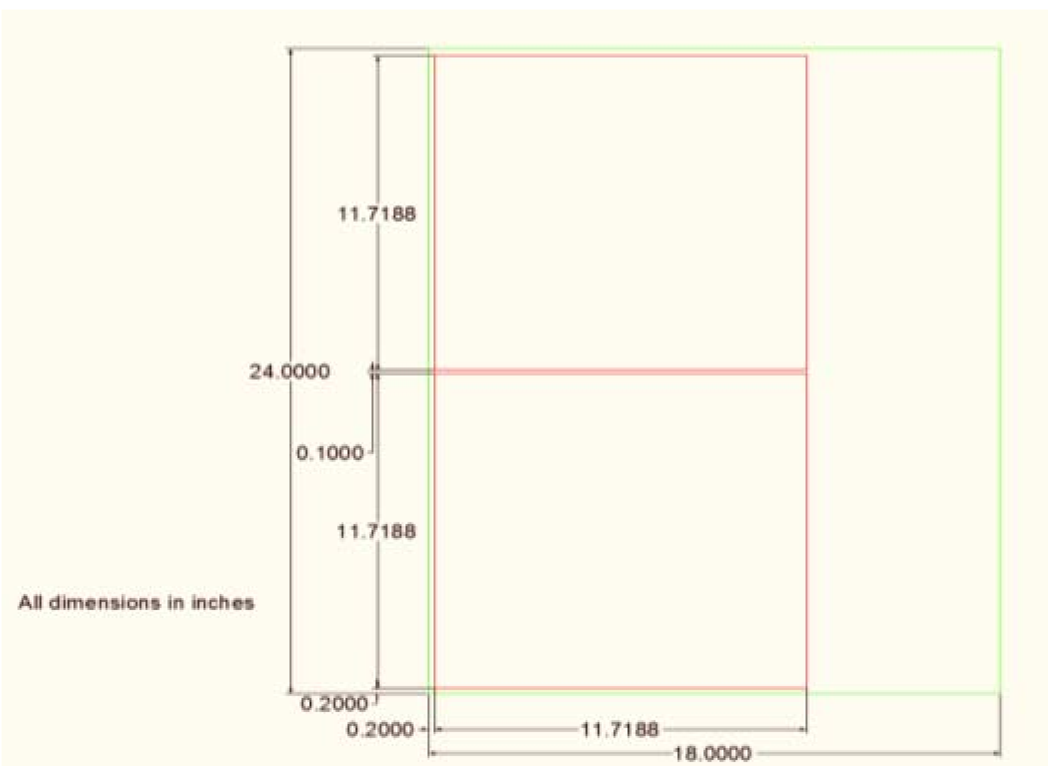


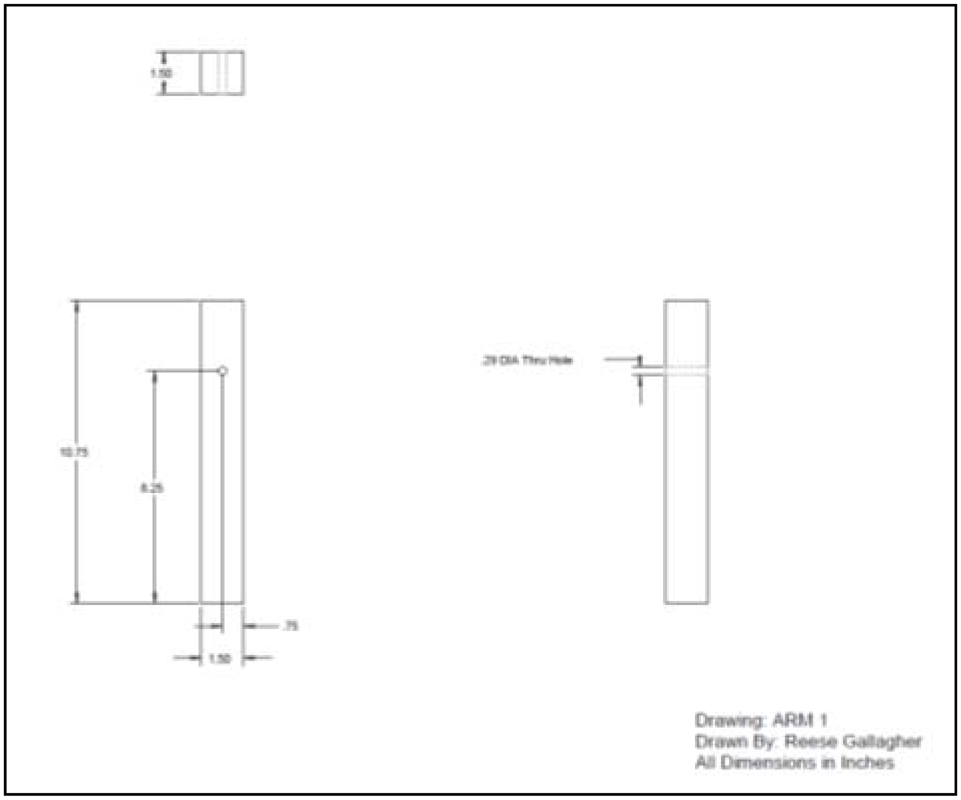

8.75
8.75
8.75
7.50
7.50
7.50
7.50

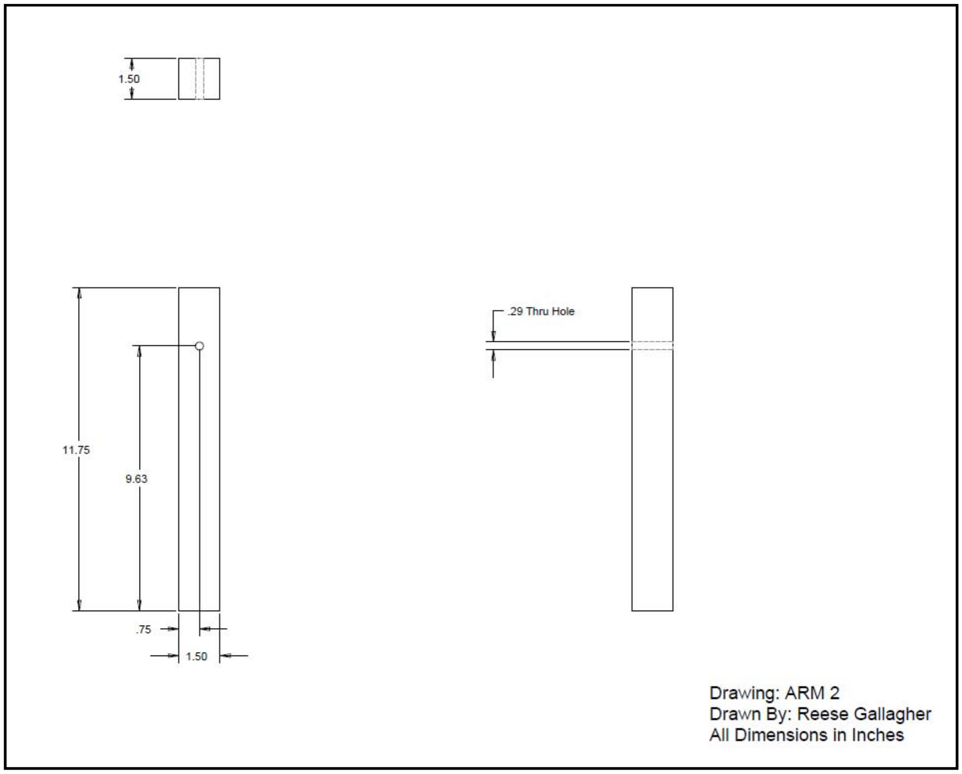

0.1000
R1.5000
2.5000
6.5000
24.0000
18.9609
5.0000
All dimensions in inches
0.5000
6.0000
0.0500
6.0000
0.0500
2.5000
R1.5000
4.5000
9.7080
5.8594
11.7188
0.0500
3.0000
6.0000
18.0000
Y
X

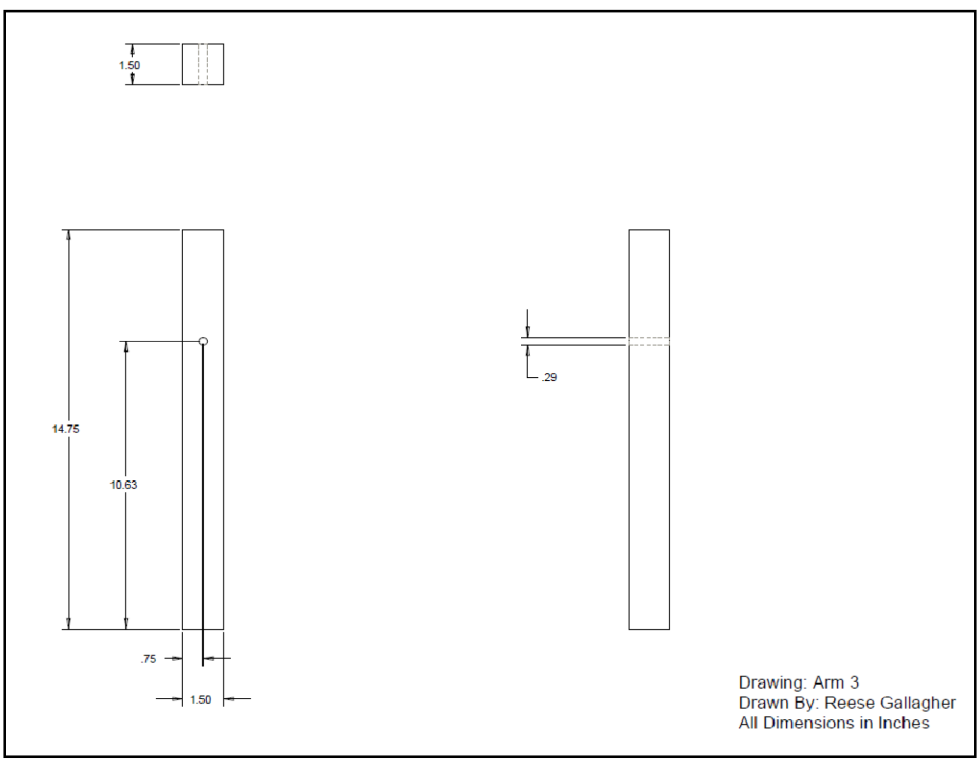
Risk assessment was completed using the Designsafe software for the reservoir components and the Plexiglas material. This report is included for reference in Appendix C.

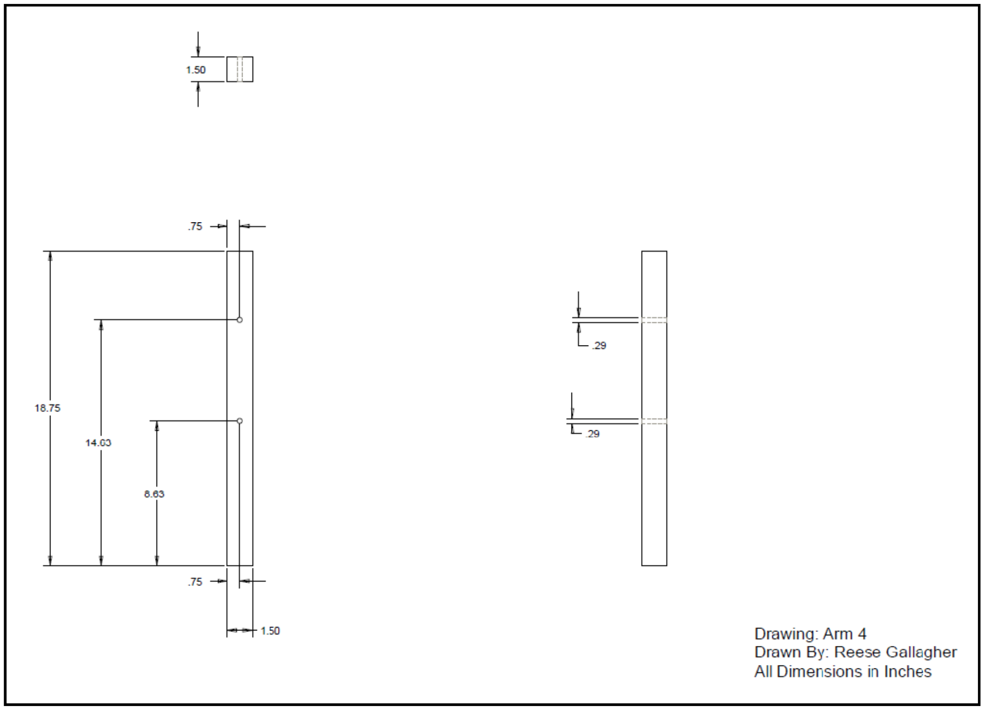


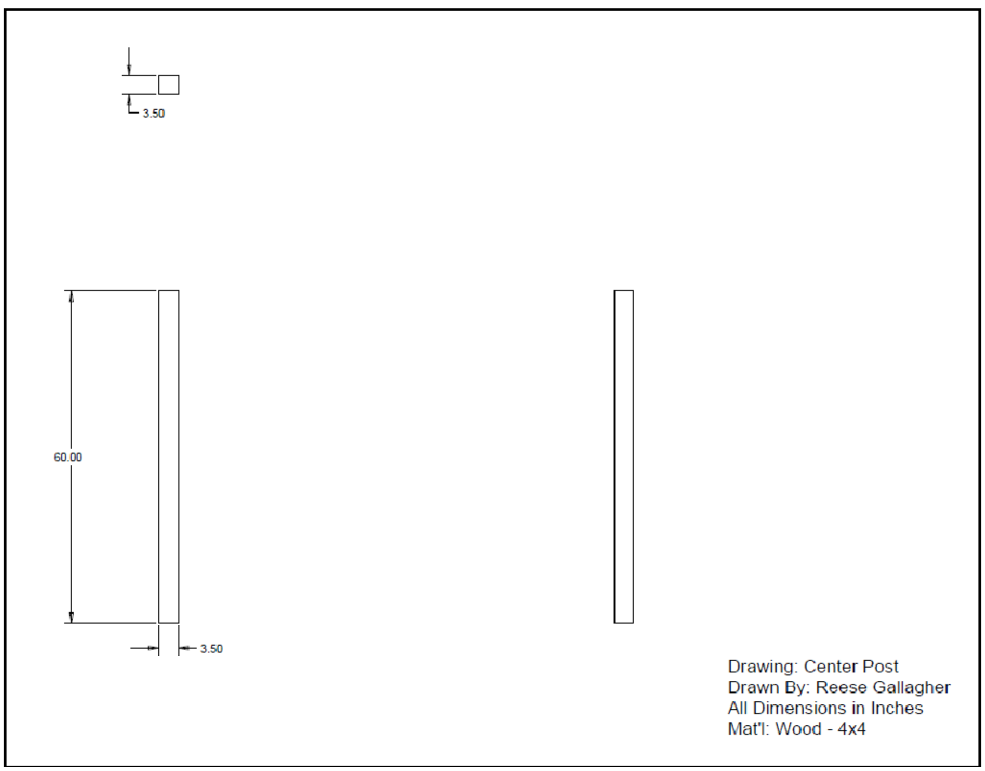


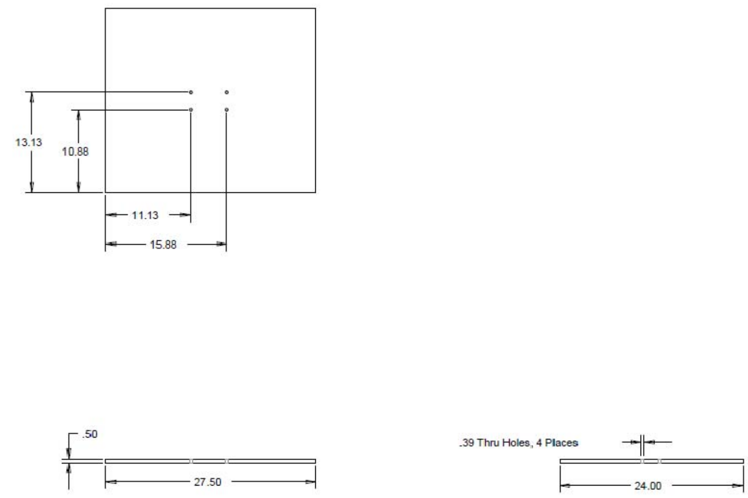

1.50
.29 DIA Thru Hole
10.75
8.25
.75
1.50
Drawing: ARM 1
Drawn By: Reese Gallagher
All Dimensions in Inches


1.50
11.75
9.63
.75
1.50
.29 Thru Hole
Drawing: ARM 2
Drawn By: Reese Gallagher
All Dimensions in Inches

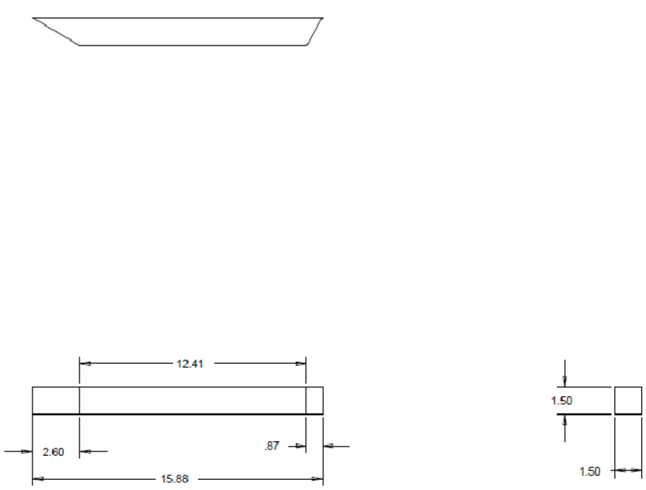

1.50
14.75
10.63
.75
1.50
.29
Drawing: Arm 3
Drawn By: Reese Gallagher
All Dimensions in Inches


1.50
.75
18.75
14.03
8.63
.75
1.50
.29
.29
Drawing: Arm 4
Drawn By: Reese Gallagher
All Dimensions in Inches

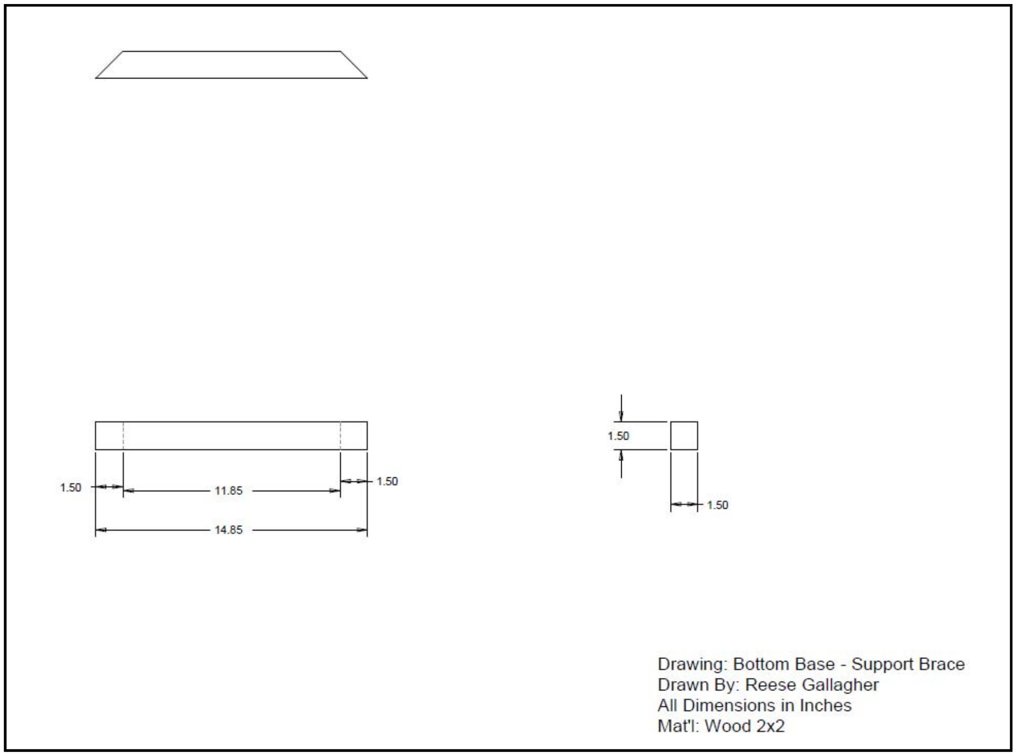

3.50
60.00
3.50
Drawing: Center Post
Drawn By: Reese Gallagher
All Dimensions in Inches
Mat'l: Wood - 4x4

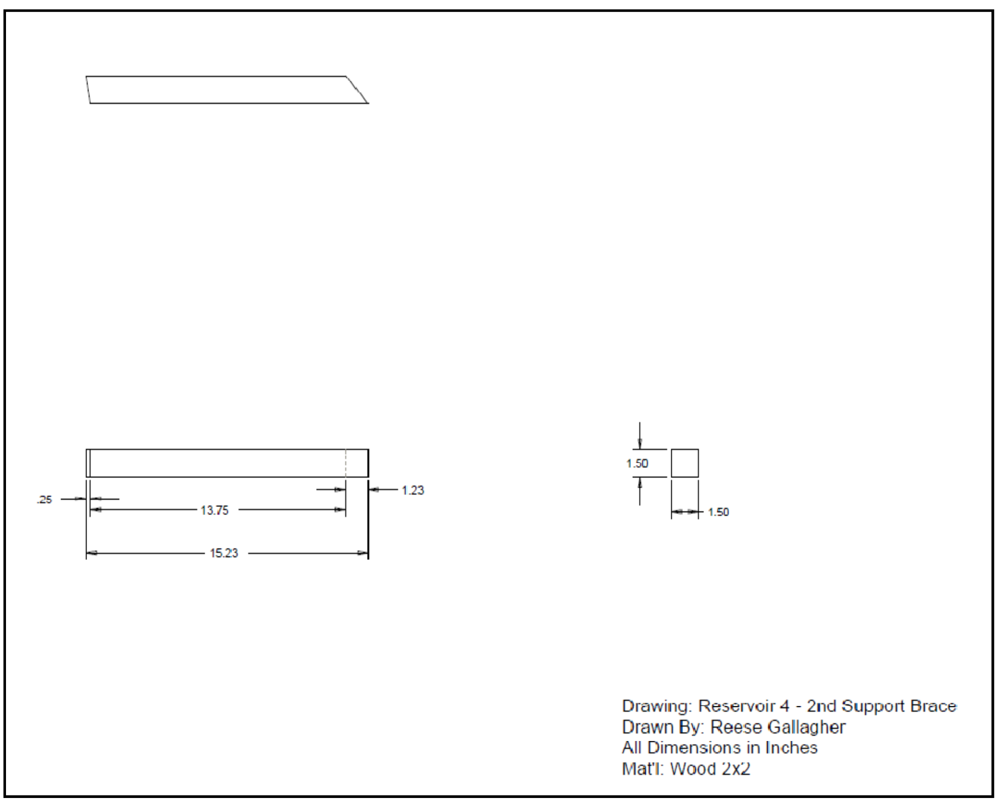


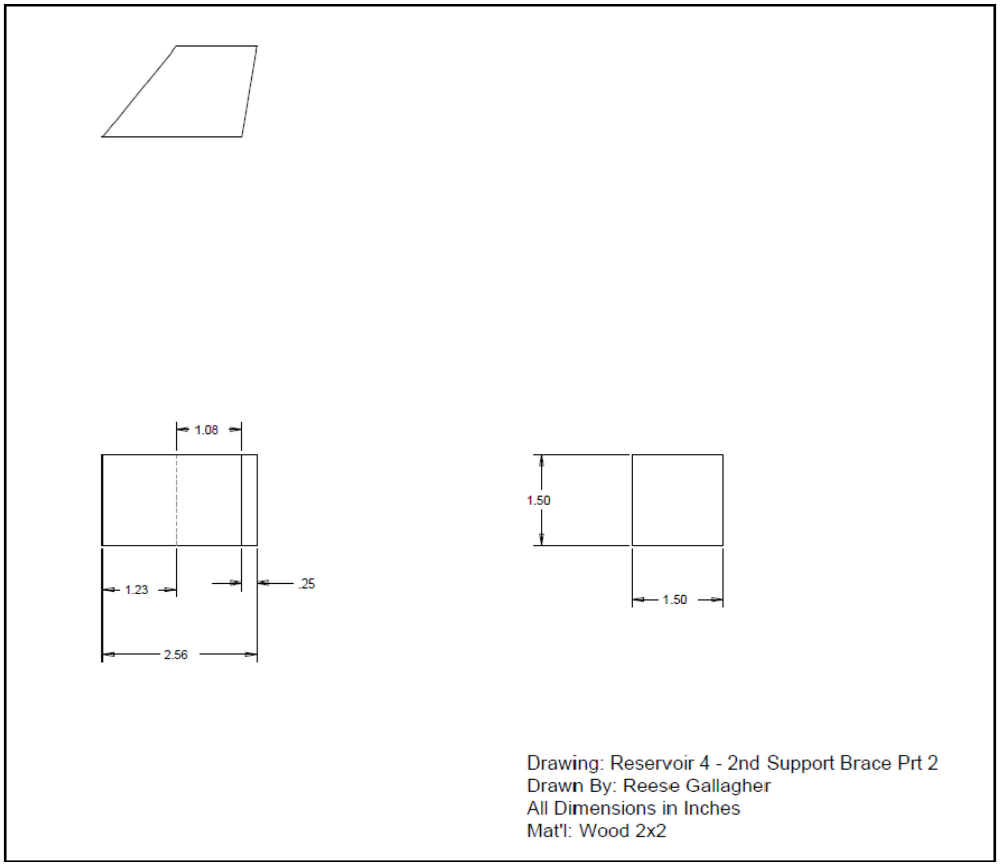
Drawing: Fountain Bottom
Drawn By: Reese Gallagher
All Dimensions in Inches
Mat'l: Hardwood



Drawing: Arm 3 - Support Brace
Drawn By: Reese Gallagher
All Dimensions in Inches
Mat'l: Wood 2x2


1.50
11.85
1.50
14.85
1.50
1.50
Drawing: Bottom Base - Support Brace
Drawn By: Reese Gallagher
All Dimensions in Inches
Mat'l: Wood 2x2


.25
13.75
1.23
15.23
1.50
1.50
Drawing: Reservoir 4 - 2nd Support Brace
Drawn By: Reese Gallagher
All Dimensions in Inches
Mat'l: Wood 2x2



5. Fabrication & Manufacturing Activities

5.1 Reservoirs

The manufacturing of the reservoirs will take place in the ME 450 machine shop. At the shop we will utilize a laser cutter to cut out pieces of each reservoir from Plexiglas. The actual reservoir pieces will be cut, along with holes for bolts and our drain (flapper) mechanism.

Safety precautions considered during the cutting process include the practice of standard safety procedures, including the use of safety glasses and ensuring the presence of Bob while cutting is taking place. The laser cutter has a built in shield that prevents shards of Plexiglas from flying out as dangerous projectiles. This shield also prevents the user from accidently coming in contact with the cutting mechanism.

5.2 Base Plate

Mark the location of the four required holes to mount the post bracket, using the bracket as a reference. Check the provided engineering drawing for reference. After ensuring that the holes are in the correct place, use a hand drill with a 0.25 in. drill bit to drill these four holes. These holes will be used in the assembly process to fasten the main post and bracket to the base plate.

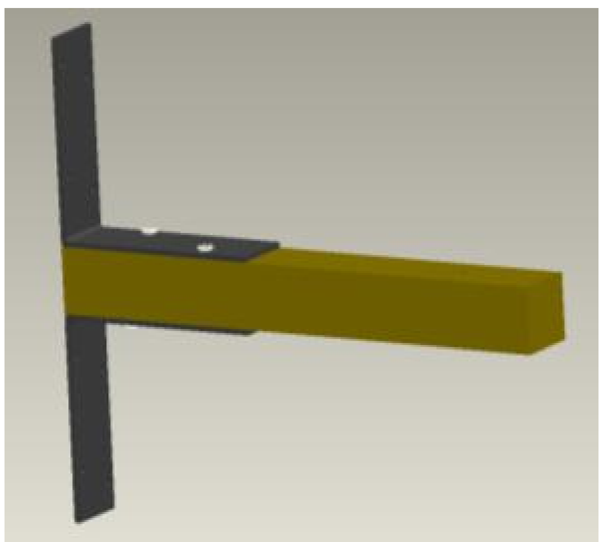
5.3 Main post

Start by cutting the main beam (4 in. x 4 in.) into two 5 ft. pieces. This can be done at Home Depot where the material was purchased. One 5 ft. piece can now be inserted into the purchased post bracket. In order to insert the wood into the post bracket, simply slide it in to the opening on the post bracket and all the way to the bottom. Once the main post is inserted into the bracket, use the appropriate Size - 6 screws to attach the main post to the bracket. Using a hand drill and a Phillips screw bit, insert the screws from the side of the post bracket into the main post. This step can be performed outside of the machine shop. Safety precautions include the use of hand gloves and safety glasses.

5.4 Arms

Start by cutting the wood for the arms (2 in. x 2 in.) into the required lengths. This step can be performed at Home Depot, where the material was purchased. Ensure proper dimensions, and refer to the engineering drawings for the length of each arm. At the end of this stage there will be four arms, and extra scraps of wood. Do not discard these scraps, they will be used later for the triangle supports of the arms. Follow the machining directions for the triangle arm supports and get the wood cut at Home Depot.

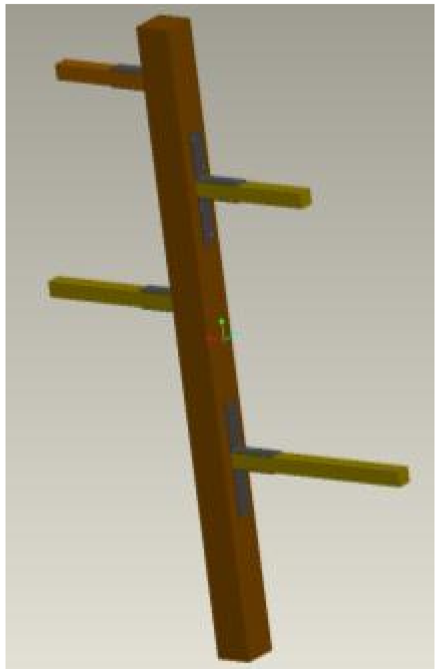
Once all the arms are cut to the appropriate sizes, attach the L-Brackets to each arm. Using the engineering drawing as a reference, attach the L-Brackets to each arm as shown below. Use the Size-6 screws and a hand drill with a Phillips screw bit to drill the screws in place. Make sure to drill into each hole in the L-Bracket to ensure a tight and secure joint. This operation can be performed outside of the machine shop while taking safety measures such as using safety glasses, and using safety gloves. At this stage the arms are ready for assembly with the main post.

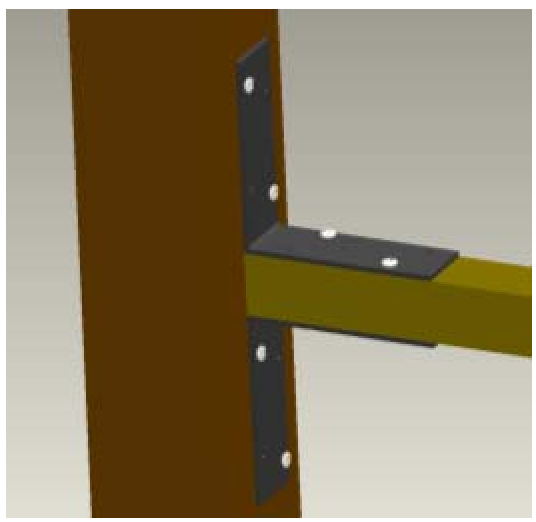


5.5 Arm Supports

In order to ensure the adequate stability of each arm, supports will be machined out of the 2 in. x 2 in. wood. Using the engineering drawings as a reference, have the pieces of wood cut to the appropriate lengths at Home Depot.

Using the engineering drawings as a reference, use a hand saw to cut 45 degree angles at each end of the supports. Caution: while using the hand saw use safety glasses, and wood working gloves to ensure safety. Also perform these operations in pairs to ensure supervision. Once 45 degree angles have been cut on both ends of the pieces of wood, mount the 45 degree brackets to each end of the support beam. This bracket can be affixed to the support beams using the Size – 6 screws. Refer to the engineering drawings on instructions regarding how to mount the brackets onto the support beams. This operation can be performed outside of the machine shop using a hand drill with a Phillips screw bit. Use the proper safety precautions when performing this operation.





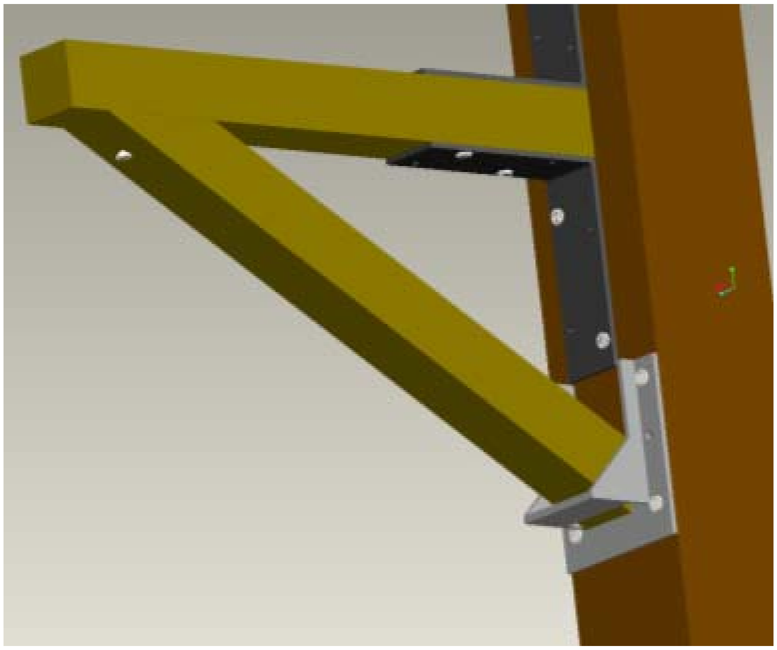
6. Prototype Assembly
6.1 Reservoir Assembly
After the parts are properly cut, they will be joined together using Weld-On 16 adhesive. To use the adhesive hand gloves will be used as a safety precaution to offer protection to the user. Since according to the manufacturer, this product is extremely toxic if inhaled, we will be applying the adhesive under a fume hood or in a well ventilated area. While working in this area, all basic safety precautions will be observed. The adhesive will take about two days to dry. After this, we will apply another layer of adhesive to the joints to assure a leak proof design.

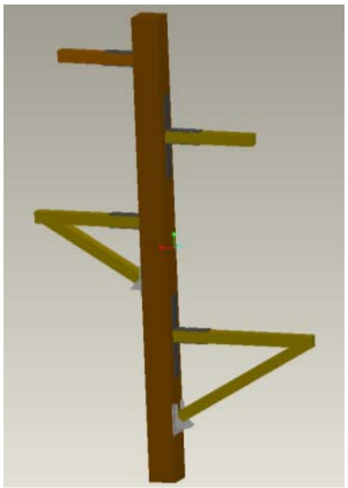
6.2 Arm Attachment
Refer to the arm to main beam engineering drawing for arm to main post assembly dimensions. Begin by attaching the brackets on the arms to the appropriate locations on the main beam. Two arms will be attached on each side of the main beam. At the appropriate locations, using Size – 6 screws, attach the

arms with brackets to the main post. Ensure to drill through all the holes on the brackets to ensure a proper secure fit. This assembly step can be performed outside of the machine shop with the use of a hand drill and a Phillips screw bit. Note: It is easier to attach the arms to the main post, with the main post laying on the floor and not in an upright imbalanced position.

6.3 Arm Support Attachment

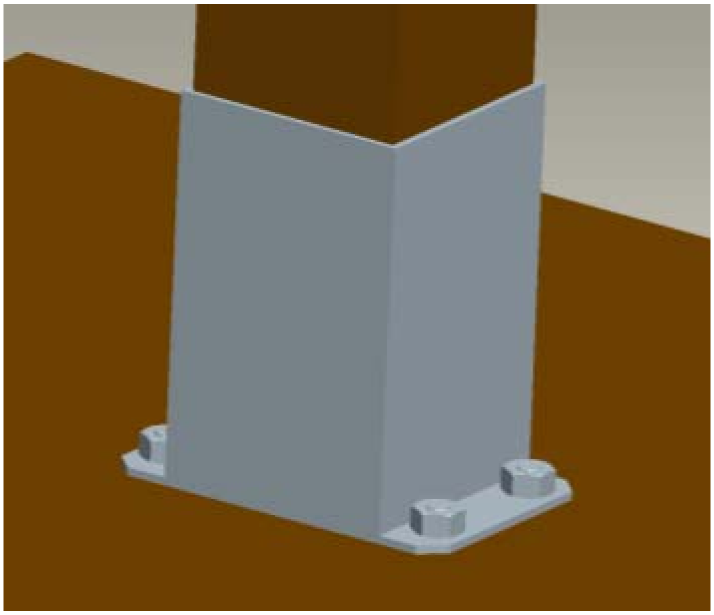
To attach the arm supports to the main post, line up the supports between the arms and the main post, so a triangle is formed between the three pieces of wood. Ensure that the support is flat on the arm and the main post at the 45 degree cuts. Using the 45 degree brackets and Size – 6 screws, attach all the supports to both the arm and the main support. Using all the holes on the bracket to ensure a tight and secure joint. This attachment phase can be done outside of the shop using a hand drill and a Phillips screw head.

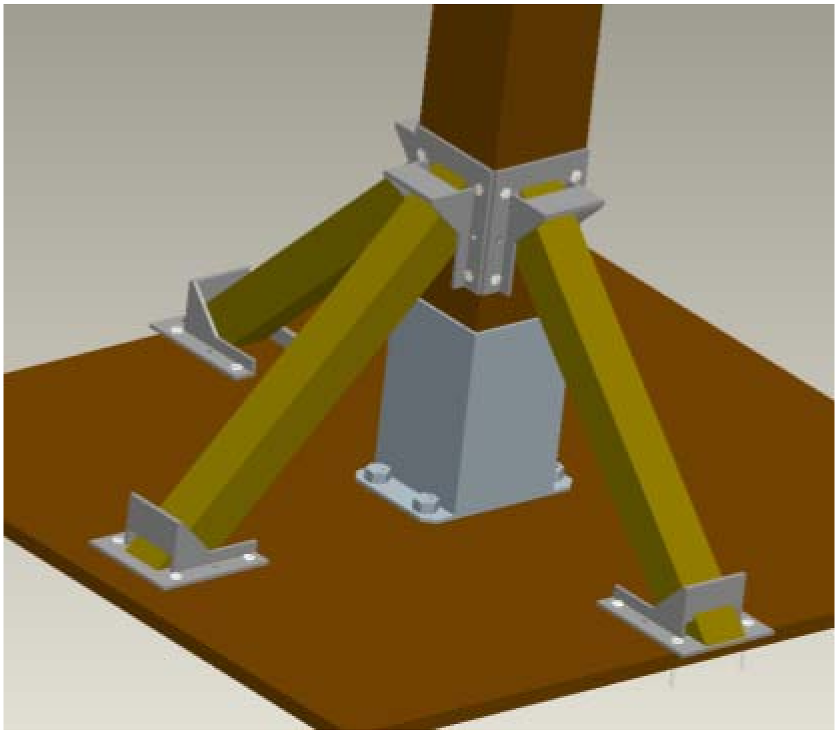




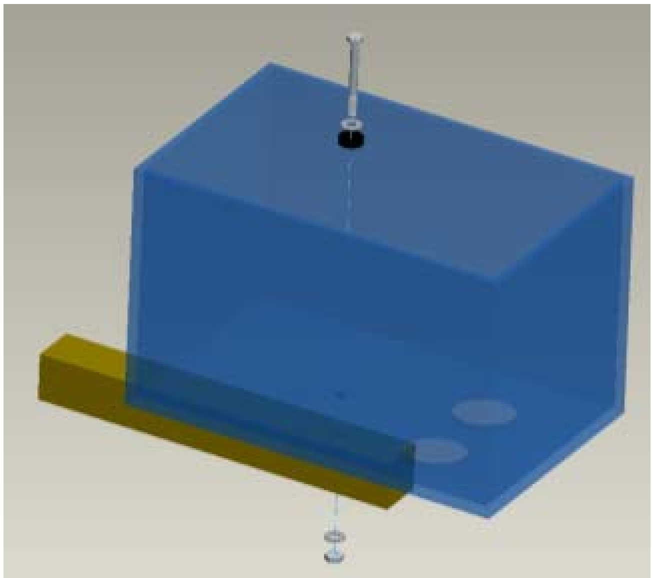
6.4 Base Plate Attachment

To attach the main post to the base plate, use the already-drilled holes in the base plate. Insert .25 in. bolts through the base plate, with the head of the bolt touching the ground and the long side pointing out. Use caution, and do not step onto these bolts. Now lower the main post with the bracket attached onto the bolts, ensure that the bolts pass through the holes in the main post mounting bracket. Using .25 in. bolts and washers, fasten the bracket in place to the mounting plate. This assembly process can be completed outside of the machine shop with the use of a wrench.





6.5 Reservoir Attachment
Ensure proper assembly of each of the reservoirs before this stage. Refer to engineering drawing to match the reservoirs to an arm. The smallest reservoir is attached to the top arm and the largest to the bottom. Using the engineering drawing, ensure that the reservoirs are positioned correctly on the arm. Alight the 0.25 in hole in the reservoir to the location of the bolt hole in the arm. Insert a 0.25 in. bolt through this hole with a rubber washer and a metal washer. Attach a nut and tighten. This assembly can be completed outside of the machine shop using a wrench. It is important to keep the reservoirs safe during the attachment process. Thus, this task takes two people or more to complete.



6.6 Mechanism Assembly – Flapper & Weight

Using fishing line, tie a knot on the link hanging off the flapper that is attached to the reservoir. Using the engineering drawings, measure out the appropriate length of the fishing line. Attach the other end of the fishing line to the float bob, use a knot to create the attachment. This assembly stage poses no safety issues and can be completed anywhere.

6.7 Mechanism Assembly – Flapper & Moving Container

Using fishing line, tie a know on the link hanging off the flapper that is attached to the reservoir. Using the engineering drawings as a reference, measure out the appropriate length of the fishing line. Attach the other end of the fishing line to the Plexiglas container. Tie a knot around the hole near the top of the Plexiglas container. Before tying this know, ensure that the fishing line passes through the hole on the side of the reservoir. This assembly step can be completed anywhere without the use of any tools.

6.8 Flapper & Funnel Attachment

Using the engineering drawings as reference, determine the placement of the flappers on the insides of the reservoirs. The movable section of the reservoir should completely fit over the hole in the reservoir. Position the flapper so that it matches the engineering drawing. Using Weld-On 16, attach the flapper ring to the reservoir bottom. Caution: Follow the safety instructions on the Material Safety Data Sheet for Weld-On. See Appendix A. Let the attachment cure for 2 hrs. Using the same technique, attach a funnel to the bottom of three specified holes. Allow the

7. Design Testing and Validation

The final design will be tested in the X50 lab. The main goal of this validation project is to ensure the cyclical pattern with a set cycle time. To validate the system, we will run the system using the submersible pump and water with the actual prototype mechanisms. This test will allow us to determine the exact cycle time of the prototype and allow us to compare it to our predicted cycle.

The prototype will also display some of the aesthetic properties of the final design. These properties include the use of transparent reservoirs and completely visible mechanisms to provide the user with the ability to understand how the fountain works and present the fascination through the different mechanisms present in the fountain.

We hope to have Bob Coury or Prof. Hulbert present to our first test on Tuesday, April 14. This first test will take place in the X50 lab. In this test will be have the fountain fully operational. We will also be able to do all the validation tests at this point.

Containment measures for this prototype test include the use of two inflatable pools used to retain all the water used in the fountain. The second pool used, provides a secondary containment mechanism in case the primary pool fails. The secondary pool is also large enough to contain any splashing that may occur due to the inherent nature of the rushing aspect of the fountain. The submersible pump will be placed in the primary pool and use the water that returns to the same pool.

No constant source of water will be needed to maintain the fountain. The initial amount of water required will be transported to the fountain using a bucket or a hose from the nearest sink. An emergency bucket of water will be kept at the side to ensure that the pump remains primed in case of water spillage into the secondary containment pool.

In addition to water containment, the electrical outlet used for the submersible pump will be kept at least 10 ft. away from the pool to ensure that no water splashed onto the cord or onto the outlet. Using these safety precautions will help ensure a safe and successful test of the prototype.

Safety Report Appendix A – Material Safety Data Sheets
A.1 Weld-On 16

IPS
WELD-ON

MATERIAL SAFETY DATA SHEET

Date Revised: APR 2008
Supersedes: JAN 2008

Information on this form is furnished solely for the purpose of compliance with the Occupational Safety and Health Act and shall not be used for any other purpose.
IPS Corporation urges the customers receiving this Material Safety Data Sheet to study it carefully to become aware of the hazards, if any, of the product involved.
In the interest of safety, you should notify your employees, agents and contractors of the information on this sheet.

SECTION I

MANUFACTURER'S NAME	**Transportation Emergencies:**
IPS Corporation	CHEMTREC: (800) 424-9300
ADDRESS	**Medical Emergencies:**
17109 S. Main St., P.O. Box 379, Gardena, CA. 90248	3 E COMPANY (24 Hour No.) (800) 451-8346
	Business: (310) 898-3300

CHEMICAL NAME and FAMILY	**TRADE NAME:**
Acrylic cement	WELD-ON 16 for Acrylic
Mixture of Acrylic Resin and Organic Solvents	FORMULA: Proprietary

SECTION II - HAZARDOUS INGREDIENTS

One of the ingredients listed below is listed as a carcinogen (‡) by IARC and NTP	**CAS#**	**APPROX %**	**ACGIH-TLV**	**ACGIH-STEL**	**OSHA-PEL**	**OSHA-STEL**
Synthetic Acrylic Resin	NON/HAZ	5 - 20	N/A		N/A	
Methylene Chloride (‡)	75-09-2	30 - 60*	50 PPM		25 PPM	125 PPM
Methyl Acetate	79-20-9	0 - 35*	200 PPM	250 PPM	200 PPM	
Methyl Ethyl Ketone	78-93-3	0 - 40*	200 PPM	300 PPM	200 PPM	300 PPM
Methyl Methacrylate Monomer	80-62-6	0 - 5	100 PPM		100 PPM	

All of the constituents of Weld-On adhesive products are listed on the TSCA inventory of chemical substances maintained by the US EPA, or are exempt from that listing.

*Title III Section 313 Supplier Notification: This product contains toxic chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act of 1986 and of 40CFR372. This information must be included in all MSDS's that are copied and distributed for this material.

PROPOSITION 65 NOTICE

This product contains chemicals known to the state of California to cause cancer.

This material is an aspiration hazard and defats the skin. The ingredients are toxic by inhalation and ingestion and may be absorbed through the skin. Exposure by these routes may cause central nervous system depression, liver and kidney damage and may sensitize the heart muscle. Methylene Chloride may interfere with the oxygen carrying capacity of the blood. Methylene Chloride is a possible human cancer hazard based on test results with laboratory animals. Methylene Chloride has been listed as a potential carcinogen by IARC and NTP. Methylene Chloride is not believed to pose a measureable risk to man when handled as recommended. Under some circumstances, mutagenic changes have been observed with Methyl Methacrylate in animal studies. Precautions should be taken to avoid unnecessary exposure to this cement.

SHIPPING INFORMATION

DOT Shipping Name:	Flammable liquid, toxic, n.o.s. (Methyl acetate, Dichloromethane)
DOT Hazard Class:	3; Subsidiary Risk: 6.1
Identification Number:	UN 1992
Packaging Group:	II
Label Required:	Flammable Liquid & Toxic (Domestic & International)

SHIPPING INFORMATION FOR CONTAINERS LESS THAN ONE GALLON

DOT Shipping Name:	Consumer Commodity
DOT Hazard Class:	ORM-D

SPECIAL HAZARD DESIGNATIONS

	HMIS	**NFPA**	**HAZARD RATING**
HEALTH:	3	2	0 - MINIMAL
FLAMMABILITY:	3	3	1 - SLIGHT
REACTIVITY:	0	0	2 - MODERATE
PROTECTIVE			3 - SERIOUS
EQUIPMENT:	B - H		4 - SEVERE

B = Eye, Hand/Skin Protection (Normal use or application & small spill clean-up activities)
H = Eye, Hand/Skin and Respiratory Protection plus Impermeable Apron (When risk of immersion, dipping and/or splashing is present)

SECTION III - PHYSICAL DATA

APPEARANCE	**ODOR**	**BOILING POINT (°F/°C)**
Clear, thin liquid	Ketone like odor	104°F (40°C) Based on first boiling component: Methylene Chloride
SPECIFIC GRAVITY @ 73°F ± 3.6° (23°C ± 2°)	**VAPOR PRESSURE (mm Hg.)**	**PERCENT VOLATILE BY VOLUME (%)**
Typical 1.10 ± 0.040	355 mm Hg. @ 68°F (20°C) based on first boiling component, Methylene Chloride	Approx. 80-95%
VAPOR DENSITY (Air = 1)	**EVAPORATION RATE (BUAC = 1)**	**SOLUBILITY IN WATER**
2.93 based on Methylene Chloride	Approx. 14.5 based on Methylene Chloride	Solvent slightly miscible Resin precipitates

VOC STATEMENT: Maximum VOC emissions as applied and tested per SCAQMD Rule 1168, Test Method 316A: <250 Grams/Liter (g/l). Meets VOC emission limits for Plastic Cement Welding.

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	**FLAMMABLE LIMITS**	**LEL**	**UEL**
21°F (-6°C) T.C.C. based on MEK	(Percent by Volume)	1.8	11.5

FIRE EXTINGUISHING MEDIA

Dry chemical, carbon dioxide or foam. Water may be an ineffective extinguishing agent.

SPECIAL FIRE FIGHTING PROCEDURES

The use of a SCBA is recommended for fire fighters. Water spray may be useful in minimizing vapors and cooling containers exposed to heat and flame. Avoid spreading burning liquid with water used for cooling purposes.

UNUSUAL FIRE AND EXPLOSION HAZARDS

Avoid hot surfaces and other sources of ignition.

SECTION V - HEALTH HAZARD DATA

PRIMARY ROUTES OF ENTRY: X Inhalation X Skin Contact ____ Eye Contact ____ Ingestion

EFFECT OF OVEREXPOSURE

ACUTE:

Inhalation: Exposure to vapors may result in nausea, drowsiness, dizziness, headache, fatigue, other CNS effects and heart arrhythmias (irregular heart beats). Can cause irritation of eyes and nasal passages. Exposure to high concentrations may impair blood's ability to transport oxygen. Prolonged or repeated exposure to vapors may cause liver and kidney damage.

Skin Contact: Repeated or prolonged contact may result in defatting of skin, irritation, contact dermatitis, rash, itching, swelling. May be absorbed through skin.

Eye Contact: Direct exposure may result in irritation with corneal or conjuctival inflammation if not removed promptly. Vapors may irritate eyes.

Ingestion: Moderately toxic. Irritant to digestive tract, may induce signs of central nervous system depression. Do not induce vomiting and obtain prompt medical attention.

CHRONIC:

Inhalation ‡ This material is an aspiration hazard and defats the skin. The ingredients are toxic by inhalation and ingestion and may be absorbed through the skin. Exposure by these routes may cause central nervous system depression, liver and kidney damage and may sensitize the heart muscle. Methylene Chloride may interfere with the oxygen carrying capacity of the blood. Methylene Chloride is a possible human cancer hazard based on test results with laboratory animals. Methylene Chloride has been listed as a potential carcinogen by IARC and NTP. Methylene Chloride is not believed to pose a measurable risk to man when handled as recommended. Under some circumstances, mutagenic changes have been observed with Methyl Methacrylate in animal studies. Precautions should be taken to avoid unnecessary exposure to this cement.

Ingestion Ingestion of alcohol may increase the potential for development of toxic effects or reactions resulting from Methylene Chloride exposure.

REPRODUCTIVE EFFECTS	TERATOGENICITY	MUTAGENICITY	EMBRYOTOXICITY	SENSITIZATION TO PRODUCT	SYNERGISTIC PRODUCTS
N. AP.	POSS.	N. AP.	POSS.	N. AP.	N. AV.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: This material may aggravate an existing dermatitis. Individuals with pre-existing diseases of the heart, liver or kidney may have increased susceptibility to the toxicity of excessive exposures.

EMERGENCY AND FIRST AID PROCEDURES

Inhalation: Remove patient to fresh air and if breathing stopped, give artificial respiration. If breathing is difficult, give oxygen. Contact physician immediately.

Eye Contact: Immediately flush eyes with flowing water for 15 minutes and contact a physician.

Skin Contact: Wash skin with soap and water. Remove contaminated clothing and shoes. Launder clothing before reuse. If irritation develops, get medical attention.

Ingestion: Give 1 or 2 glasses of water or milk. Do not induce vomiting. Call physician or poison control center immediately.

SECTION VI - REACTIVITY

STABILITY			CONDITIONS TO AVOID
	UNSTABLE		Stable under normal conditions of storage and handling. Avoid contact or exposure to fire, heat, sparks, electric arcs, open flame and hot surfaces which can cause thermal decomposition.
	STABLE	X	

INCOMPATIBILITY (MATERIALS TO AVOID) Strong alkalies, oxygen, nitrogen, peroxide, potassium and reactive metals.

HAZARDOUS DECOMPOSITION PRODUCTS

This product gives out carbon monoxide (CO), carbon dioxide (CO^2), Phosgene gas and smoke upon combustion or contact with reactive metals.

HAZARDOUS POLYMERIZATION			CONDITIONS TO AVOID
	MAY OCCUR		Keep away from heat, sparks, open flame and other sources of ignition.
	WILL NOT OCCUR	X	

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Evacuate area, ventilate and avoid breathing vapors. Dike area to contain spill. Clean up area (wear protective equipment) by mopping or with absorbent material and place in closed containers for disposal. Avoid contamination of ground and surface waters. Do not flush to sewer. If spill occurs indoors, turn off heating and/or air conditioning systems to prevent vapors from contaminating entire building.

WASTE DISPOSAL METHOD

Recovered liquids may be sent to a licensed reclaimer or incineration facility. Contaminated material must be disposed of in a permitted solid waste management facility. Follow local, State and Federal regulations. Material should not be allowed to drain into domestic sewer or storm drains. Consult disposal expert.

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (Specify type)

Atmospheric levels should be maintained below established exposure limits contained in Section II. If airborne concentrations exceed those limits, use of a NIOSH approved positive-pressure, full-facepiece SCBA or positive-pressure, full-facepiece supplied air respirator (with an auxiliary positive pressure SCBA) is recommended. Even for emergency and other conditions where short term exposure guidelines may/may not be exceeded, use of an approved positive pressure self-contained breathing apparatus (SCBA) is recommended.

VENTILATION

Use only with adequate ventilation. Do not use in close quarters or confined spaces. Open doors and/or windows to ensure airflow and air changes. Use local exhaust ventilation to remove airborne contaminants from employee breathing zone and to keep contaminants below 25 ppm TWA. Use only explosion-proof ventilation equipment. Monitoring should be performed to determine exposure level(s) IAW (in accordance with) 29 CFR 1910.1052.

PROTECTIVE GLOVES PVA coated or Latex-Nitrile rubber for dipping/immersion. Surgical gloves or solvent resistant barrier creme should provide adequate protection in normal adhesive bonding usage.

EYE PROTECTION Splashproof chemical goggles, face shield, safety glasses (spectacles) with brow guards and side shields, etc. as appropriate for exposure.

OTHER PROTECTIVE EQUIPMENT AND HYGIENIC PRACTICES

Impervious apron and a source of running water to flush or wash the eyes and skin in case of contact.

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

Store in a shaded place below 80°F (27°C) . Keep away from all sources of heat, sparks, open flame and other sources of ignition. Close container after each use. Use with adequate ventilation. Avoid contact with eyes, skin and clothing. Train employees on all special handling procedures before they work with this product. product.

OTHER PRECAUTIONS

Follow all precautionary information given on container label, product bulletins and our solvent cementing literature. All material handling equipment should be electrically grounded.

Safety Report Appendix B – FMEA Analysis

Project #: 7 **Date:** 4/6/2009

Project Title: Quiet Rushing Fountain

Team Members: Reese Gallagher, Amol Mody, Harpreet Oberoi, Ryan Rudy

Part Number, Name, Functions	Potential Failure Mode	Potential Effect of Failure	**Severity (S)**	Potential Causes/Failure Mechanisms	**Occurrence (O)**	Design Controls &Tests	**Detection (D)**	Recommended Actions	**RPN (=S x O x D)**
#1: Acrylic Glass. Used for constructing reservoirs	Fracture, Cracking, Material Yield	Sharp shards, projectile debris,	8	Improper Machining or Assembly, Manufacturing Defects	2	Built to withstand experienced forces, visual inspection	1	Inspect each part for cracks. Visually supervise machining.	**16**
#2: Wood. Used for construction of Arms (works with #1)	Fracture, Material Yield, Deformation, Fatigue, Cracking	Sharp pieces of wood, projectile debris, damage to other parts	8	Defect in Part, Improper Machining, High Stress	3	Built to withstand experienced forces. Visual inspection for cracks and defects.	1	Inspect each part for defects. Ensure proper machining. Do not load beyond yield limits	**24**
#3: Wood. Used for construction of Main Beam (works with #2)	Fracture, Material Yield, Deformation, Fatigue, Cracking	Sharp pieces of wood, projectile debris, damage to other parts	9	Defect in Part, Improper Machining, High Stress	3	Built to withstand experieced forces. Visual inspection for cracks and defects.	1	Inspect each part for defects. Ensure proper machining. Do not load beyond yield limits	**27**
#4: Wood. Used for Prototype Base Plate (works with #3)	Material Yield, Fatigue, Cracking	Sharp pieces of wood, damage to other parts	7	Defect in Part, Improper Machining, High Stress, Improper Placement	1	Built to withstand experieced forces. Visual inspection for cracks and defects.	1	Inspect each part for defects. Ensure proper machining. Do not load beyond yield limits	**7**
#5: Gaskets. Used to prevent leaks in revesoirs (works with #1)	Incomplete Seal, loose fit	Water leak	5	Manufacturing defect, Improper Placement	4	Visual inspection, physical inspection of tightness	1	Inspect each part visually, inspect placement. Test for leaks with small amounts of water	**20**

<u>#6: Flapper Valve</u>. Used as the main valve in each mechanism (works with #1)	Incomplete Seal, loose fit	Water leak	3	Manufacturing defect, Improper Placement	4	Visual inspection, physical inspection of tightness	1	Inspect each part visually, inspect placement. Test for leaks with small amounts of water	**12**
	Fatigue, Cracking	Water leak, Lack of Valve functionalit y	7	Manufacturing defect, Improper Placement, High Stresses	2	Visual inspection, built to survive cyclical loading	1	Inspect each part visually, inspect placement. Test for leaks with small amounts of water	**14**
<u>#7: Fishing Line</u>. Used to initiate each mechanism (works with #6)	Material Yield, Fatigue, Carcking	Mechanism s disconnecte d, stop working	7	Defect in product, high stresses applied.	2	Visual inspection of line.	2	Inspect each part visually for frayed sections	**28**
<u>#8: L-Bracket:</u> Used to affix arms to main post (works with #2,3)	Material Yield, Fatigue	Superstruct ure Fails	10	Defect in product, high stresses applied.	1	Visual Inspection of Bracket. Bracket can withstand considerable stresses.	1	Ensure there are no cracks, bends, deformations in brackets. Mount bracket properly.	**10**
<u>#9: Post Bracket:</u> Used to affix main post to base plate (works with #3,4)	Material Yield, Fatigue	Superstruct ure Fails	10	Defect in product.	1	Visual Inspection of Bracket. Bracket can withstand considerable stresses.	1	Ensure proper mounting with main post. Check for cracks, bends on bracket	**10**
<u>#10: Submersible Electrical Pump:</u> Used to pump water to the top of the fountain.	Electrical exposure to water	Hazardous enviorment with electricity passing through water	10	Defect in product, frayed wires, wire disconnected.	1	Visual Inspection of Pump	1	Triple check all wires. Ensure no direct exposure of electricity to water.	**10**
	Mechanical failure of pump	Pump fails to function.	10	Defective product. Pump not primed. Foreign object in pump.	2	Visual Inspection of Pump. Safety casing to ensure the passage of only water.	1	Ensure that the pump is always completely submerged in water. Make sure not foreign objects enter the pump.	**20**

Safety Report Appendix C – Designsafe Analysis

C.1 Reservoirs Machining

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : cutting / severing Possible sharp edges could be unsafe	Slight Remote Unlikely	Low	standard procedures	Slight Remote Negligible	Low	
All Users All Tasks	chemical : irritant chemicals Weld-On is a possible skin and eye irritant	Slight Remote Unlikely	Low	warning label(s)	Slight Remote Negligible	Low	
All Users All Tasks	lasers : eye exposure Laser cutter uses a laser	Serious Remote Negligible	Low	standard procedures, E-stop control	Serious None Negligible	Low	
All Users All Tasks	lasers : UV skin exposure laser cutter uses a laser	Serious Remote Negligible	Low	standard procedures, E-stop control	Serious None Negligible	Low	

C.2 Reservoir Assembly

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : break up during operation Reservoir adhesive fails and reservoir side fall off	Slight Remote Unlikely	Low	fixed enclosures / barriers	Minimal None Unlikely	Low	
All Users All Tasks	electrical / electronic : water / wet locations Water from reservoir causes collection of water near power source	Serious Remote Unlikely	Moderate	separate hazard / people in time or space	Serious None Unlikely	Low	
All Users All Tasks	slips / trips / falls : slip Water leaks cause slip	Serious Remote Unlikely	Moderate	separate hazard / people in time or space	Serious None Unlikely	Low	
All Users All Tasks	fluid / pressure : fluid leakage / ejection Fluid leaks from tube or reservoir	Minimal Occasional Possible	Moderate	fixed enclosures / barriers	Minimal None Possible	Low	

C.3 Superstructure Machining

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : cutting / severing Cutting wood with a saw	Serious Remote Unlikely	Moderate	standard procedures, safety glasses, gloves, footwear	Slight Remote Unlikely	Low	
All Users All Tasks	mechanical : unexpected start Saw trigger pulled unexpectedly	Serious Remote Unlikely	Moderate	two hand controls, safety glasses, footwear, gloves	Slight Remote Unlikely	Low	
All Users All Tasks	slips / trips / falls : debris Saw dust accumulating on ground	Slight Remote Unlikely	Low	separate hazard / people in time or space	Slight None Unlikely	Low	
All Users All Tasks	fire and explosions : dust Saw dust accumulating	Serious Remote Negligible	Low	separate hazard / people in time or space	Slight None Unlikely	Low	
All Users All Tasks	noise / vibration : noise / sound levels > 80 dBA high noise levels from saw	Slight Occasional Possible	Moderate	scheduled rest periods, hearing protection, job rotation	Slight Remote Unlikely	Low	

Team Biographies

Personal Biography – Reese Gallagher

I'm from Traverse City, Michigan, about four hours Northwest from Ann Arbor. Mechanical Engineering was the obvious choice for me, in terms of a degree, due to my natural tendencies for designing and building various "things" during my childhood.

I attended a small community college, located in Traverse City, for two years in order to acquire my general elective credits (english, math, science) at a lower cost. I then transferred to the College of Engineering at the University of Michigan. I plan on studying abroad in England next winter term then graduating at the term's completion. I'm also planning on continuing my education and applying to several graduate schools for a Master's degree in Mechanical Engineering. Obtaining a Ph.D in mechanical engineering might also be in my future, seeing that I enjoy teaching as well.

My sports and hobbies include: guitar, cycling (road and mtb), wakeboarding, running, beach volleyball, boating, soccer, music recording, FEA and CFD (might sound nerdy….but the stuff is sweet), football etc..
I just recently joined the U of M cycling team for road racing and will be competing this semester against colleges all across the country. I also compete in beach volleyball competitions during the summer time and plan on competing in several triathlons (and maybe a marathon) during this upcoming summer. If all goes as planned, I will be doing research with Professor Volker Sick during the summer in regards to analyzing the kinetic energy of fluids throughout an internal combustion engine.

Personal Biography – Amol Mody

I was born in Bombay, India and raised in Ann Arbor, Michigan, graduating from Huron High School. When I started at the University of Michigan, Aerospace Engineering was my primary subject of interest. At the end of my second year, with a hesitation to graduate in three years, I declared Mechanical Engineering as my second major simply because I was interested in a few of the classes and wanted to stay at Michigan for a full four year period. Ever since my junior year of high school, when I was an exchange student in Germany, I've had a keen interest in German studies. This led to me completing a German Minor during my time here.

Since Aerospace is still my primary interest, I've spent my summers doing internships related to Aerospace fields. In the summer of 2007 I did an internship at PACE Aerospace in Berlin, Germany. I worked on a project involving flight profile optimization calculations and various other short term assignments. The past summer, I worked at GE Energy in Greenville, South Caroline on the Clearance team for Gas Turbines. Starting in May, I will begin my full time job in GE Energy's Commercial Leadership Program (a two year rotational program to train GE's future 'commercial leaders') in Schenectady, NY.

My interested include sports and music amongst others. I enjoy playing and watching almost every sport and have an extremely competitive drive. I also play the cello, during my high school years, I was part of an orchestra that was invited to play (and we did accept the invitation) at Carnegie Hall. After starting at U of M, I have not had the amount of time I would've liked to pursue the cello seriously. After I graduate, I plan on rekindling this interest. Until last semester, I was the treasurer of Sigma Gamma Tau (the aerospace engineering honor society). I continue to be an active member of this organization.

Personal Biography – Harpreet Oberoi

I was born in Chandigarh, India and my parents moved to Warren, Michigan when I was one years of age. I came to the University of Michigan undecided on which Engineering path to pursue. I eventually settled on Mechanical Engineering because of its ability to offer a wide variety of career opportunities as compared to other engineering majors that are more focused on a certain aspect instead of the “big picture”.

As of right now, I am currently exploring job opportunities in Mechanical Engineering for after Graduation. Sometime in the near future my plans are to further my education by getting a masters in Mechanical Engineering.

Some of my sports interests include: tennis, track, and basketball. Back in high school I used to run track and play tennis. Also, I love to play pick-up basketball and a very big Detroit Pistons fan.

Personal Biography – Ryan Rudy

I was born and raised in Ann Arbor, Michigan, graduating from Huron High School. I entered the University of Michigan intending to study Chemical Engineering, however, after thinking about my interests in physics, mechanics, and design I realized that Mechanical Engineering would be the right fit for me.

I’ve spent the past two summers doing research at Ford Motor Company and the Army Research Laboratory (ADELPHI). At the Army Research Laboratory I began analysis and design for a MEMS tactile sensor for use in their millimeter-scale robotic systems. I have continued this work with Dr. Kenn Oldham of the University of Michigan over the past semester. This upcoming summer I expect to return to the Army Research Laboratory in order to fabricate and test my designs developed this year. In the fall I will return to the University of Michigan to pursue a master’s degree in Mechanical Engineering.

I enjoy watching and playing most sports and have an eclectic music collection with anything from Frank Sinatra to Led Zeppelin, Buddy Guy to Jack Johnson. I have recently become a member of Asian Intervarsity Christian Fellowship and plan on being more involved in the future.