Water Fun at Exploration Station

Final Design Review

Sponsored by:
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Submitted by:
H2O Innovations

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This project is dedicated in loving memory of Martin L. Meltz.

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Executive Summary

This report documents the design and fabrication processes involved for the creation of an interactive science exhibit for the Grover Beach Exploration Station. This is a student-led senior project advised by Sarah Harding, professor of mechanical engineering, as a part of California Polytechnic State University in San Luis Obispo's mechanical engineering program. The final product is a fully functioning, durable system that is capable of pumping and recycling water throughout use when users are in its vicinity.

The exhibit is to be considered in 4 main subsystems: basin, plumbing, frame, and sleep mode system. A fiberglass basin that holds all the water in the exhibit sits recessed inside a welded steel frame. Water is pumped through the bottom of the basin from within an enclosed storage area inside the frame, and is recycled back into the water reservoir by placement of two weir valves. A submersible pump powers the exhibit, and is controlled by passive infrared sensors that activate when human presence is sensed within 15ft. While the manufacturing process did reach completion, testing and verification did not. However, proposed testing plans are still included in the appendices of the report for informational purposes.

Divided into distinct sections, this report will enlighten the reader on each part of the design process. First, background research and preliminary design explains the methodology of developing the vision of the final design. Next, different design analysis techniques are given for each respective subsystem of the proposed exhibit. An in-depth description for manufacturing and testing of the completed exhibit is given for each subsystem. Finally, recommendations are given for future improvements to the exhibit, and what kinds of different decisions would be made in the design process if given a second iteration.

1. Introduction

H2O Innovations is comprised of four California Polytechnic State University (Cal Poly) engineering seniors: Nicholas Runyan, Raymond Morales, Heriberto Rodriguez, and Alejandro Gonzalez-Smith. Originally there were only three members, however Alejandro was brought onto our team in Spring to contribute to the manufacturing process. For our senior project, we are working with the Exploration Station to help bring an engaging new exhibit to their visitors. The Exploration Station is a nonprofit children's science museum located in Grover Beach, California. Our direct points of contact with the Exploration Station include office manager Deb Gleason, museum director Jim Middlemist, and technical advisor to the Exploration Station George Dubois. The Exploration Station caters to large groups during its hours of operation on Thursday through Sunday, hosting local school group science field trips, families looking for a place to take their children on the weekend, and various fundraiser events. They take much pride in the quality and quantity of fun and interactive exhibits within their building -- once the location of the Grover Beach fire station. Currently, the frame of the previously used water feature sits on the front patio. The committee would like to see this table either redesigned and renovated, or completely replaced with a new interactive and educational water feature exhibit.

Our goal is to create a functioning and durable water feature that meets a number of educational standards for children ages two to thirteen at the lowest possible cost. In this design review, we will discuss our final design for the Exploration Station water exhibit, as well as the associated manufacturing/testing plan, cost analysis of the exhibit, and pertinent safety information.

2. Background

Our research consists of an examination of past and current water exhibits on display, as well as the safety requirements for interactive museum features that must be met. We have also included thoughts and summaries on research we have conducted in regards to water purification methods, creation of water vortices, and a few interesting research papers on the topic of science exhibit design. We found these to be the most important topics to focus on when conducting background research because they address many of the needs and wants that our customers have, which will be explained in greater deal throughout this proposal report.

Current Exploration Station Installation

During our first interview with our sponsors, we were made aware of their current water table exhibit that is located on the front patio. We discussed the possibility of refurbishing/restoring the existing table by making the features more interactive, educative, and fun while also structurally reinforcing the table. We were given permission to use the current table in its entirety, to use components of it, or the freedom to design a completely new interactive water exhibit. The current water table exhibit is shown in **Figure 1**.

Figure 1: Current water table on the front patio of the Exploration Station. Exhibit is not currently in use.

After further conversation, we asked our sponsors why the water table exhibit is currently not in use. They mentioned that while it could still be used today in its condition and still holds water well, it lacks interactive and educational water features for children. Also, the table only has one main feature, a paddle wheel that visitors can manually crank to create a current flow to propel floating toys. It mentioned to us that at one point in time, the water table was a fun exhibit with the use of bubbles, rubber ducks, and other toys.

Following our discussion, we set out to the front patio of the Exploration Station to take a closer look at the existing water table, taking care to inspect individual features such as the paddle wheel, structural integrity, and material selection.

Figure 2: Paddle wheel feature on the Exploration Station water exhibit.

The water wheel is a neat idea that is user-operated to create a flow of water around the basin of the table, but it was observed that the condition is weathered and not as engaging as other modern water exhibit features from other science museums.

We then observed the frame of the water table and its condition. The frame of the exhibit is constructed with treated wood (2X4’s and 4X4’s), sheet metal, nuts, bolts, and nails. Some wooden members were missing around the legs of the supports and the remaining leg pieces were loose. **Figure 3** shows the frame along with the missing legs' trim pieces.

Figure 3: The support leg on the front right side of the exhibit is missing wooden trim piece for balance.

Although the frame still is standing, the wood around it appears to be weathered and lacks visual appeal. We also leaned on it and gave it some force to test its structural condition and observed that it did sway back and forth with a normal pushing force. The frame's structural resilience to a visitor leaning on it while full of six inches of water is a safety concern. The exposed wood members (4X4's) also seem to be a safety hazard as a visitor may hit a corner, trip, or scrape themselves on a rough edge. The fastening of the members by nuts, bolts, and nails have begun to loosen and loose holding strength thus, degrading structural integrity.

San Luis Obispo Children's Museum

Like the Exploration Station, San Luis Obispo Children's Museum serves to help young children learn scientific concepts in a fun way and ignite in them a passion for science. In 2014, a senior project group at Cal Poly under the team name *Free Flowin'* designed a water table exhibit for the San Luis Obispo Children's Museum [1]. For this proposal, we will be discussing the aspects of this table as they match our customers' needs and wants closely

Figure 4: Water table built by Cal Poly senior project group *Free Flowin'* in 2014.

The final design of the *Free Flowin'* table (shown in **Figure 4**) had a structural frame made out of wood with an acrylic lining stretched over it. It included features such as two water vortices positioned at the center and pipes at each end of the table. These pipes had several holes along the length of the pipe that shot jets of water in an arc. This design makes for a fun and engaging experience as the children enjoyed interacting with the water vortex by throwing plastic balls through the open top of the vortex and watching the plastic balls travel down and out the bottom. They also enjoyed interacting with the piping by covering up certain holes to redirect pressure and increase the flow rate and arc length of water out of each of the other holes along the length of the pipe. The scientific concepts that these features aim to teach are conservation of mass in the case of the water jets and angular momentum, linear momentum, and energy in the case of the water vortex.

Although it was an interesting design, their water table presented several unforeseen issues. The vortices were generated by pumping water at a rate of 700 gallons per hour into cylindrical containers open at the top surface. However, the pumps did not provide adequate power for the height of containers as they created a vortex that did not reach even half the height of the container. Furthermore, exhibit visitors were able to throw other objects besides the provided plastic balls, such as toy dinosaurs and sand into the vortices, disturbing the delicate flow conditions needed to maintain the shape of the vortex.

Interviewing San Luis Obispo Children's Museum

A meeting was held with Sheryl Flores at the San Luis Obispo Children's Museum to hear her perspective about the water table that team *Free Flowin'* built for them. When asked about her opinions on improvements that could be made to their design, she mentioned that the pumps used were not powerful enough to fill the containers with a water vortex and the water jets along the sides of the table were never operable during its time at the Children's Museum. The materials and adhesives used for the construction of the table limited the lifetime and durability of the exhibit. Not only did *Free Flowin'* neglect to use an appropriate or effective sealant for the basin of their exhibit, but the acrylic material that the basin consisted of began to warp during prolonged sun exposure. The bare frame of the water table was built with wood, which was unnecessarily heavy and soaked up much of the water from the leaks caused by poor sealing in the basin above it, leading to copious amounts of mold and rot.

Boss Displays Corporation

Boss Display designs and builds interactive durable and safe exhibits that challenge visitors intellectually and physically, helping to facilitate learning through exploration, experimentation, playful imagination, and shared experience with other visitors and family groups. We searched *Boss Display*'s portfolio and created a document with a number of their water exhibits that could be used as a benchmark and reference for our future ideation and design. We analyzed each of the exhibits to see how well these exhibits satisfy our customer needs/requirements (for example: weather resistant, transportable, low cost). We were also able to obtain a wide variety of examples of exhibits that demonstrated new and creative features that we could possibly incorporate into our design.

Figure 5: *Boss Display* exhibit located at *DoSeum* in San Antonio. [2]

CreativeMachines

CreativeMachines is a company based in Tucson, Arizona that work on a diverse set of projects spanning from monumental public art to science exhibits. There are other companies that make large scale water exhibits, but *CreativeMachines*'s water table is more comparable to what we can build with the resources available. Their water table features a water jet at one end of the table with the water flowing downstream to the other end where it passes through a ultraviolet filter and an ion generator before circulating back. Within the table are blocks that can serve to dam up the water or redirect it. The table uses a microcontroller to monitor the water level to prevent overflow in the case of large dams.

Figure 6: Water exhibit created by *CreativeMachines*. [3]

Filtration Systems

Water filtration is an important feature for the long-term use of an interactive water exhibit, however is not included in the scope of this project. This section contains information regarding a number of different water purification methods that could potentially be utilized in our design process.

UV Water Purification

The Children's Discovery Museum, in San Jose, and *CreativeMachines* both use an ultraviolet (UV) water filtration system for their water table. The benefits of UV water filtration system are its low electrical needs, easy maintenance, effectiveness in killing microorganisms, and the bonus that it is FDA approved. The cost of a UV water filter can range anywhere from $25 to $300, depending on the quality of filter desired.

The purification process involves passing UV light through water, which deactivates any pathogens that are present. The energy provided by the ultraviolet light is absorbed by the pathogens, disrupting their DNA and preventing them from reproducing. Different pathogens require different light intensities and exposure time to be exterminated. A typical UV light system provides a dose of 30 mJ/cm^2, which eradicates the most commonly found pathogens in water such as Vibrio Cholerae, Hepatitis A virus, and Salmonella Typhi.

The UV water filtration system is made up of three components. The first component is a lamp protected by a quartz sleeve. The quartz sleeve must be of very high quality in order for as much light to pass through it as possible. The lamp and sleeve are fitted into a stainless steel chamber. There exists an optimum flow rate for the water to travel through the chamber such that it gets sufficient exposure to UV light. The UV system requires a controller that powers the UV light and controls the electrical output. The turbidity, hardness, iron, and manganese in water interfere with the purification process so it might be necessary to pretreat the water with a sediment filter and a water softener. The turbidity of the water relates to its clarity and the amount of light that is scattered by particles inside the water when light is shined through it. The hardness of water is determined by the amount of mineral content it contains: the higher the concentration of manganese, calcium, and iron the greater the hardness of the water [4].

Ozone Oxidation Water Treatment

Ozone is a natural unstable gas that has a high oxidation potential, meaning that it can react with other substances and then disappear quickly. Some of the benefits of ozone are that it is better at disinfecting water with bacteria and viruses compared to chlorine, the treatment process does not add chemicals to the water, and it eliminates taste and odor problems. One of the disadvantages of ozone water treatment is that it is difficult to find someone that is proficient in ozone treatment and able to maintain the system. Furthermore, there are fire hazards and toxicity issues related with generating ozone. Like the UV water treatment, it may require pretreatment to reduce the hardness of the water.

The components of an ozone system are gas preparation, an electrical power supply, an ozone generator, an ozone contacting system, and a suitable venting system. To create ozone, ambient air is passed through a corona discharge generator. Corona discharge is an electrical current that splits oxygen molecules apart which then reform into three oxygen atoms. When ozone gas is passed through the water being treated it reacts with metals to create metal oxides, which do not dissolve in water, so post filtration is required. Ozone also reacts with bacteria, viruses, and Cysts cells, killing them quickly while keeping healthy minerals untouched. After ozonation, contaminants are removed and the ozone is converted back to oxygen [5].

Health and Safety

Any interactive exhibit whose primary audience is children will have a possibility of some kind of choking hazard, thus a concern that requires significant amount of precautions to be taken. We researched regulations in regards to children choking and found very useful information for testing and eliminating child choking hazards. In particular, we found rules and regulations from the United States Consumer Protection Safety Commission (USCPSC), who set guidelines on what can be classified as hazardous substance. For children under 3 years old, this is an object that presents a choking, aspiration, or ingestion hazard due to small size of parts. This was found on the *Electronic Code of Federal Regulations* [6], located in **Appendix B**, and is code(s): 1501.1-1501.5. This code includes the size requirements and test procedure for determining choking hazards.

Research Papers

In completing background research, we came upon two very useful research papers, one on the case study of expert opinions and the other on designing successful children's museums and five common pitfalls to be aware of when designing exhibits.

High Priority Design Values Used by Successful Children's Museum Exhibit Developers: A Multiple Case Study Analysis of Expert Opinions [7]

This research paper discusses the design values assigned to each exhibit and serves three purposes: 1) to expose the design values that are used by expert exhibit developers to create successful children's museum exhibits. 2) To see how developers prioritize their design values. 3) To identify the desirable outcomes developers hope visitors will experience as a consequence of their engagement with the exhibits. Interviews were also conducted with expert exhibit developers and the primary method of data gathering. Exhibit developers were selected from some of the top children's museums in the United States. Then all data collected from the developers were compiled into case studies. Each children's museum, along with its corresponding exhibit developers, were placed into individual cases studies and studied in detail.

Designing Science Museum Exhibits With Multiple Interactive Features: Five Common Pitfalls [8]
This research paper gave some important design considerations a design engineer should take into account when building an exhibit. Some of the pitfalls included: 1) Multiple interactive features of equal priority that overwhelm visitors. 2) Interactivity by multiple simultaneous users that leads to disruption. 3) Interactivity, even by a single visitor, can disrupt the phenomenon being displayed. 4) Interactive features can make a critical phenomenon difficult to find. 5) A secondary interactive feature can displace visitors' attention from the primary one. This paper helped us realize that the end product is solely about the user and we need to think about the user's experience/interaction and the specific interactive and educational experience we want to convey. It recommends creating a hierarchy when it comes to features in order to detour from overwhelming the user experience and limiting the number of features without taking away from the quality of the guests' experience.

Vortex Design [9]
After reading the report from *Free Flowin'* and learning about how the vortex feature was voted highly by children and their sponsors (this is why the vortex was the main feature on their table), we searched online on how to create a vortex water feature. There were many video's online to reference and guide us through the process. Creating a vortex did not seem very difficult nor labor intensive. Depending on the final design feature decision, we already have some preliminary research on how to construct a vortex. However, as a group we decided that we do not want to include a vortex in our design so as to offer visitors a different experience compared to other local museums.

Microcontroller Systems
Another aspect we researched was the involvement of electrical components that could be incorporated into this project. Because our team includes a computer engineer, we thought it would be great to use this resource to add an electronic component to this exhibit. The use of a microcontroller was determined to be a realistic possibility with our design with the following use.

Figure 7 shows an automated way to drain water from one container to another when the water level reaches a certain height. When the water level rises in the container to be drained, a component of the float switch goes up and that sends a signal to the microcontroller. The microcontroller then sends a signal to the power switch tail to turn on the relay inside it. The microcontroller is essentially turning on a 120 V line since the power switch tail is connected to an outlet providing that voltage. It's worth mentioning that 120 V is standard for most homes. The power supplied by 120 V is used to drive the submersible pump, which drains water from the container it's in. As soon as enough water has drained, the float switch turns off, in turn deactivating the relay inside the power switch tail, which then cuts power to the pump. There are various other methods to drain the water using a similar set up. For example, we can place another float switch at a lower level in the container to be drained so that the pump drains water starting at the higher float switch and finishing when it reaches the lower float switch. Additionally, many microcontrollers contain a timer built in which can be used to drain the water for a specific amount of time so that we only need one float switch to start the process.

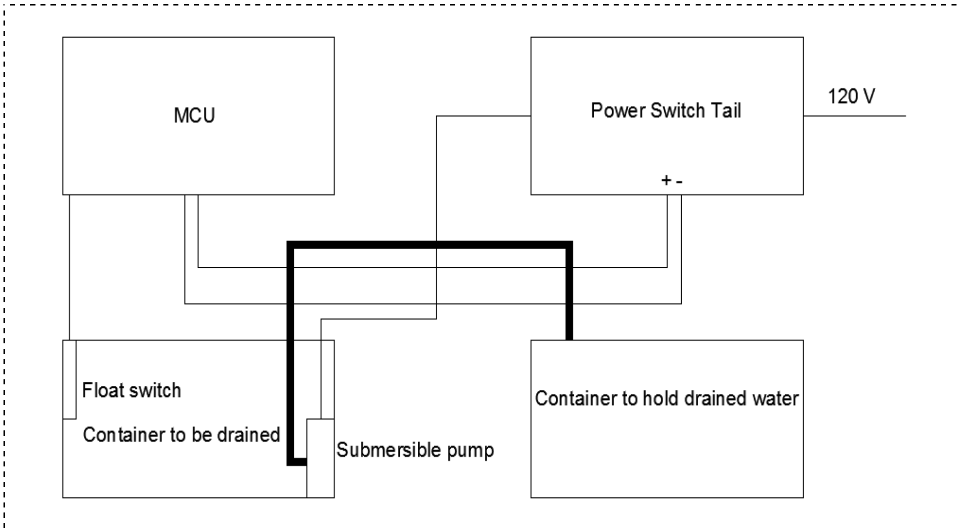

Figure 7: Wiring diagram for draining water from one container to another.

One of the most important items in regards to setting the scope of the project is developing the problem statement. The problem statement is used to center and focus the team at the beginning, keep the team on track during the design process, and is used to validate at the end of the project that the finished product does actually satisfy the problem. Our problem statement for this project is as follows:

Formal Problem Statement
The Exploration Station currently has an outdated water table exhibit not in use due to lack of interactive features and structural deterioration. Our goal is to design a new, low-cost water-themed science museum exhibit that is durable and easy to maintain. We want for this interactive water exhibit to be engaging for all age groups to interact, educate, and play.

Through research and interviews, we have developed a list of specific goals we shall strive to achieve with our newly designed water exhibit. Our goals were determined from our sponsors' needs and requirements list, which are:

- Deliver a safe exhibit for children
- Create a fun and engaging learning environment
- Conserve the use of water usage by recycling water
- Design a strong and durable table to withstand human interaction
- Use quality materials while still finding ways to save money
- Design an exhibit that can withstand local weather conditions
- Design a permanent exhibit that can be transported

This list of customer needs was used to develop a Quality Functional Deployment (QFD) chart to help generate relevant engineering specifications that will have a bearing on our preliminary design and analysis moving forward. The complete QFD can be viewed in **Appendix B**. By placing our customer's needs/wants on the left-most column, we then generated a number of engineering specifications and placed them on the upper row. The intersecting cell area between them is then assigned a value for how much the customer's need correlates with the respective engineering specification. A value of nine, three, or one can be assigned to the cell, with direct correlation between need and specification increasing with cell value. A blank cell means that there is no correlation between the need and specification. For example, the specification for meeting three Common Core or Next Generation science standards has a very high correlation with serving the customer's need of the exhibit serving an educational purpose, thus we assigned the intersecting cell between the two a value of nine.

Additionally, the QFD also allows us to assign a numerical and measurable standard to the engineering specification; a goal or benchmark for us to begin our design around. These values are placed along the same column as the engineering specification it is in reference to, but along the bottom-most row of the chart. The decisions for assigning each of these quantities (as well as the meanings for the assigned correlation values) will be explained in further detail later in this section.

The main takeaway, however, from the use of the QFD is that we were able to pinpoint which of the customer's needs held the most importance. This is determined by seeing the correlation between the number of engineering specifications considered relevant to each customer need. By summing the relevance across each row (for each customer need), we found that the three most critical customer needs to satisfy were to have a safe exhibit, keep the price as low as possible, and for the exhibit to ensure hands-on interaction from its visitors.

Engineering design specifications provide measurable and quantitative criteria for satisfying the customer's needs/requirements. The engineering specifications we chose were a result of the interview we conducted with our sponsors learning about what exactly they're looking for in an exhibit to enhance the learning experience of visitors. The engineering design specifications we developed for this project are listed below in **Table 1**, followed by an individual overview for each.

General Safety Specifications

A customer need that was highly emphasized by our sponsors was the high level of safety required as children of all ages will have hands-on interaction with this exhibit. Because public safety is a big factor, we developed several safety design specifications that ensure safety is the forefront of all design considerations during the design process. During the design, we plan to focus on all potential for danger to the public and coming up with solutions and alternatives to eliminate any safety hazards. We have developed a safety checklist to identify the areas and features of our potential exhibit designs that could prove harmful to the user (displayed in **Appendix A**). We intend to use the safety checklist to design around these potential hazards and mitigate the risks that our team could potentially see later down the road. The following six engineering specifications are summarized first as they have the highest risk factor level associated with them. For each engineering specification, the compliance columns specify how they are to be verified. A, T, S, and I are short for analysis, test, similarity to existing designs, and inspection, respectively. The column to the left of compliance assess the risk of meeting each target where L, M, and H indicate low, medium, and high risk respectively.

Exposed Hazards

The potential for exposed hazards during the construction and design phase can be easily overlooked when designing such a large-scale water exhibit. Another design specification we have developed is the need to eliminate any exposed hazards including, but not limited to: sharp edges and corners, wedges to get caught in, and risk of suction areas. We plan to test and be actively aware of possible exposed hazards that may continually arise throughout the building process. We can verify if there are any exposed hazards by looking at structure and design of other exhibits and by doing an analysis on the dimensions of the table to avoid spaces where visitors can get hurt.

Table 1: Engineering Specification Table					
Spec	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Sub-system/ components maintenance frequency	Once every two weeks	± 1 week	M	A, T, S, I
2	Time between water changes	Once every two weeks	± 1 week	M	T, S, I
3	Number of visitors exhibit can accommodate	8 visitors	± 2 visitors	M	S, I
4	Number of educational features	3 features	± 1 feature	L	I
5	Total cost of project	Under $2500	± $300	M	A, T, S
6	Exhibit size dimensions	8ft x 8ft x 3ft	± 8 cubic feet	L	A, S, I
7	Unique educational standards	3 standards	± 1 standard	M	I
8	Exposed hazards	0 exposed hazards	n/a	H	S, I
9	Choking hazard size	Within the standard cylinder dim[1]	n/a	H	S, I
10	Maximum water depth	3 inches	± 0.5 inch	H	A, T, S, I
12	Withstanding tipping force	Minimum lateral loading of 250 lbf	± 50 lbf	H	A, T
13	Supporting weight	Minimum vertical loading of 250 lbf	± 50 lbf	H	A, T

Choking Hazard Size
Since the water exhibit features have not been determined as of yet (this will be done in the next coming weeks with idea generation and researching), there is a possibility of incorporating balls/ and or toys into

[1] Dimensions for test cylinder specified by USCPSC, and can be referenced in **Appendix C**

the exhibit to enhance the fun and engaging experience. Since these toys present a potential choking hazard to small children, the second design specification regarding safety is to protect against choking hazards with balls, toys, and components. We aim to have a total of zero potential choking hazards, which are determined to "small parts" should they fit within the dimensions of the testing cylinder by the USCPSC, which can be found in **Appendix C**.

Maximum Water Depth
Maximum water depth is a specification that we considered because we wanted to limit the height of water in the above interaction area. This is an important safety consideration due to the possibility of a small child falling in while interacting and drowning. If we can limit the height of water in the above area by designing appropriately, this will be a safer exhibit for all children. The maximum water depth range we want to design for is between three and four inches. Another important benefit of having a maximum water height specification is that it's also related to the water conservation requirement stated by our sponsor. With this design specification, we are taking into account two customers simultaneously.

It is important to note that the engineering specification for "water overflow height" was removed due to the design decision to include weir drains in the basin of the exhibit to regulate water level height permanently at 3 in. This will be described in greater detail later in the report.

Water Overflow Height
Water overflow has been chosen to be an engineering specification because it is related to the water depth requirement. By designing the exhibit to begin draining or flowing over at approximately four inches of water depth, we are decreasing the possibility of the water accidentally raising too high and exceeding our specified water depth. This would prevent the operator from accidentally overfilling the exhibit with water and eliminate the need to constantly check water levels in the exhibit.

Withstanding Tipping Force
The designed water exhibit is meant to be hands-on, and consequently there is a potential chance that the table could be tipped over and crush the user. Parents and other guardians are known to interact with the exhibits alongside their children. While a child may not be strong or heavy enough to tip over a main frame of the exhibit, the guardians are more capable due to their larger weight (even if on accident by simply leaning on the display). We developed a specification for designing the exhibit to be able to withstand a tipping force of at least 250 lbf so it is less likely for an adult to tip over the entire exhibit causing bodily injury and/or death. We plan on physically testing this parameter during the testing phase.

Supporting Weight
An important factor involved in this project is the vertical loading of all exhibit components. Water is the key component in this exhibit and is a dense fluid. It is known that one gallon of water has a weight of approximately 8.35 pounds, therefore, as an example, thirty gallons of water (which is the size of a small aquarium) weighs approximately 250 pounds, and thus we need our exhibit to be able to support the weight of the water held in addition to the potential loading from an adult leaning on the side of the exhibit during interaction.

The remaining engineering specifications to be discussed are not classified as high risk for the scope of the project, as we did not determine them to directly affect the safety of the user. Regardless, they are still important design considerations to take into account for the successful fabrication of the water exhibit.

Sub-system/Components Maintenance Frequency
One of the important customer needs that was shared by the sponsors was the need to construct an exhibit that is easily maintained. A fully-operational water exhibit is comprised of many subsystems and working

parts that, depending on how it is designed, can require a varying amount of testing and maintenance. We want to design a product that would not require daily maintenance from the museum. In order to limit the amount of time spent on maintaining, we took into consideration the maintenance frequency and plan to reduce the amount of time needed to maintain its condition and working components. Our proposed service interval to maintain the system(s) and working components is to be once every two weeks. This seems like a normal maintenance interval which would not hinder the daily operations of the children's museum.

Time Between Water Changes

Another consideration brought up by the sponsors was the idea of filtering/treating the water to minimize water consumption. Water exhibits where children are constantly putting their hands in and touching everything can pose a contamination issue if the water is not changed or treated on a regular basis. With water conservation in mind during the design process, we are proposing a tentative water change cycle of approximately two weeks. This is completely dependent on the design path taken in regards to water purification, but we believe that this was a safe estimation to use as a starting point for the rest of the project.

Number of Visitors Exhibit Can Accommodate

Due to the large number of visitors that can visit the museum at any given time, the number of visitors that can interact on the exhibit at once was chosen as a design specification. Since the customer stated that they wanted the exhibit to be fun and engaging while also being hands on, we thought it was important for the exhibit to be able to handle a handful of people. Due to the nature of a fun and interactive exhibit, we thought it would be great to have families interact all at once to learn and play together. Our target specification for this project is to simultaneously accommodate eight users. We plan to design and size the exhibit in a way that will allow for no less than eight people to interact at once, which would also help reduce a crowd of children during large group events (such as field trips).

Number of Educational Features

In order to satisfy the customer's need of having a fun, interactive, and educational experience on the exhibit, we developed a specification on the number of exciting features to include in this new design. The current water table at exploration station only has one water feature (the paddle wheel used to create flow) which limits the user's ability to engage and learn about science. To create a new and modern engaging experience, we are proposing to have at least three key educational water features that will capture the attention of all visitors.

Total Cost of Project

One of the most important factors involved in this project is the allocated costs that will be needed to carry this exhibit from start to finish. Our team was awarded $2500 from the Baker-Koob foundation, and because of this we have specified a maximum budget of $2,500 for the successful completion of this project. When applying for the grant we took into account a similar water exhibit project that was created by team *Free Flowin'* that was built for the San Luis Obispo Children's Museum. Due to the similar scope and nature of *Free Flowin'*s project to ours, we estimated that the amount of money that they spent on their project would be an appropriate amount for our team to shoot for as a maximum value. We are committed to applying for outside funding to help offset the costs that our project might accrue. We also intend to utilize the resources that the Exploration Station has in terms of obtaining desired materials and components from local businesses. We intend to limit the amount of spending by carefully selecting the proper materials, using exploration station resources, using Cal Poly affiliated business partners, and price comparison shopping. Should additional funding beyond the $2500 be required, Jim Middlemist has agreed to cover these extra costs should we go overbudget during manufacturing.

Exhibit Dimensions
A design specification in which we have the most flexibility is the overall size of the exhibit. In talking with our sponsors and observing/learning about where the new design is going to be installed, we realize the front patio space is very large and we would need to set a size requirement on the exhibit. Taking into account the set budget, conservation of water, accommodation for size of interaction, and transportation factors, we are specifying a size requirement of interaction of 8ft X 8ft X 3ft. This is our preliminary size for the exhibit with size tolerance as described in the specification table.

Unique Educational Standards
The main goal of the Exploration Station is to educate its visitors on the wonders of science. As the water exhibit will be designed to target young audiences (ages two to thirteen), we want to be able to tie in the included features to convey concepts that the students are learning in school. We chose to target three educational standards (Common Core or Next Generation), each in respect to a different age group in the aforementioned range. The number of standards chosen is meant to be consistent with the number of interactive features that the exhibit will offer. We believed that one standard per feature would be appropriate in ensuring that everyone interacting with the table would be able to walk away having learned something, as well as being able to disperse the exhibit visitors as opposed to everyone crowding around one spot of the exhibit.

Preliminary Project Scope
We would like to discuss the scope of the project and what we plan to deliver as a finished product to our sponsors. There are certain elements of this project that are out of our control and items that we cannot provide that are needed for the completion of this project. This project involves various mechanical components that need to be designed, which require utilities such as electricity and a water source to operate the exhibit. We have previously discussed that the sponsors will supply electricity hookups to the site where needed for supplying power to the exhibit. There is currently a water source on the west end of the front patio that would have to be used to supply water. If any additional water piping system is needed, the sponsors would need to have that supplied to site. In regards to draining the exhibit, we will not be able to provide a drainage system/clean out/exterior drain. We can provide a hookup on the exhibit to connect a water hose or other component of similar function that can be used to drain the water to a desired location. The scope of our project includes, and is limited only to, the actual exhibit itself.

3. Design Development

The preliminary stages for developing our conceptual design began with ideation activities, carried through to concept prototyping, and ended with ideation selection and an analysis of the selected concepts. The purpose of the ideation activities was to come up with many ideas for subsystems of the water table and to make complete models in a collaborative manner. After we had concepts and sketches for the water exhibit we made prototypes to get a better sense of the layout of features and the dimensions of the table. To narrow down preliminary designs to feasible designs we used Pugh matrices to help guide decision making for the shape of the table and features to include. This section goes into detail about the ideation process and how we decided on the two possible solutions for the Exploration Station water exhibit that we had presented in November at the preliminary design review.

Concept Generation
3-5-6 Activity: Idea Generation Session #1
We used a brain writing technique known as the 3-5-6 technique to begin the ideation process. This activity involves three people (our team members), who will each have five minutes per round of uninterrupted time to draw or write down ideas on the subject matter at hand. The six represents the number of different topics that will be the main focus of the activity. By the end of this brainstorming

activity, our group had collectively developed eighteen individual sketches that we can work off of in future concept generation sessions to develop potential solutions. In this activity, we choose the following six categories to explore:

- Overall table shape
- General Exhibit features
- Features with toys
- Features with a user input
- Theme of exhibit
- Ease of maintenance solutions

Figure 8 shows two drawings that were completed during the brain writing activity. The picture on the left is a sketch that was completed for the exhibit shape category and the sketch on the right was done for the general features category.

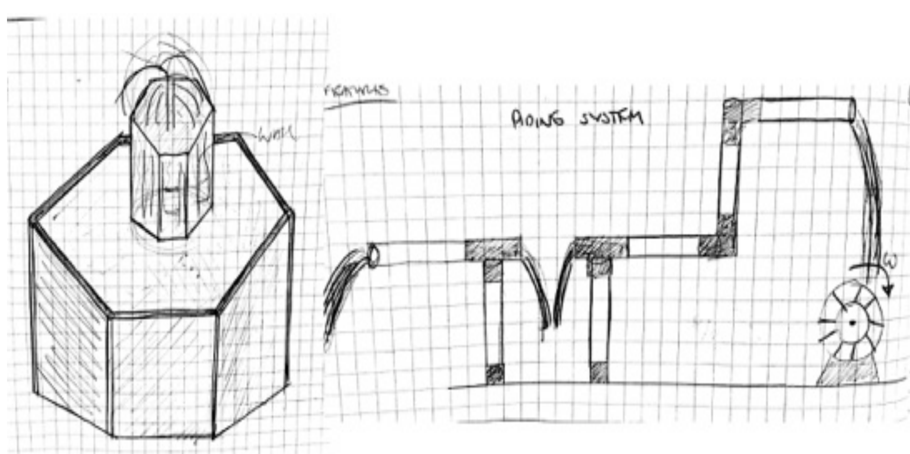

Figure 8: Hexagon exhibit design (left) and interchangeable water piping system (right).

The sketch on the left of **Figure 8** is hexagon base shape with a smaller hexagon topper positioned in the middle of the base. This exhibit shape is similar to the existing water exhibit at Exploration Station with some key differences. The existing water exhibit has an unusable center section serving no interactive purpose for visitors. With the addition of the smaller hexagon on top of the base, the center area of the exhibit could then be utilized to place another feature. The sketch on the right was completed for the general features category that could be incorporated into the design. A common, yet interactive, feature that was quite popular when conducting background research was the interchangeable water pipe system. We sketched how these water pipes would look, diverting water in multiple directions giving the user an educational and fun experience. This piping system could be merged with a water wheel to allow users to power a wheel with the water flow.

Detailed Designs of Features: Idea Generation Session #2

Our team wanted to build upon some of the popular ideas developed in the first ideation session to see how the features could be implemented or fabricated. Each team member picked a different result from the first ideation session and was tasked with creating a detailed solution for making the idea realistic. **Figure 9** shows two sketches that were completed during this ideation session.

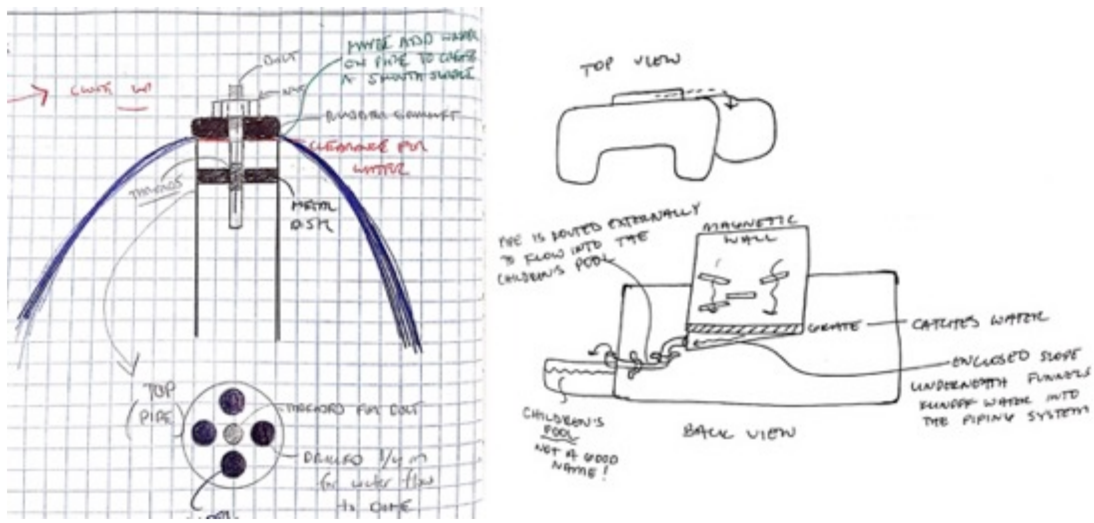

Figure 9: Cross sectional view of water dome (left) and magnetic water wall (right).

On the left of **Figure 9** is a sketch of the water dome feature that was created. This idea was chosen due to its popularity within the group and also the visitor excitement seen in a number of museum exhibit videos found online. Due to a lack of design guidelines or resources on construction of water domes, we needed to come up with a method on how we would approach building this feature and the individual components it includes. This drawing shows a cross sectional view of the water dome apparatus, the interconnecting parts, and how to create a small clearance in the vertical pipe to develop a thin laminar stream of water.

The sketch on the right shows a magnetic water wall attached to an exhibit. During an ideation session, our advisor mentioned incorporating an interactive magnetic vertical wall feature into the design. The drawing shows a magnetic water wall fixed onto the rear side of a table, with water flowing over the wall. This water is collected at the bottom of the wall through grates and is diverted externally through the plumbing system to the children's pool.

The detailed design activity helped us realize that it is easier to come up with new, creative, and unique ideas, than to model and design realistic components that make up the system with method of fixation. Additionally, it allowed us to take our popular ideas a step further into design. This will be useful if the designs analyzed were chosen to be a part of the final design concept.

Post-It Note Activity: Idea Generation Session #3

The last ideation session we completed was the post-it note activity. We chose this activity because we felt that it could help us piece together individual components and combine the ideas as a team to create several complete exhibit designs. This water exhibit project involves many sub-components such as the overall shape, features, and plumbing to be considered, so we used the post-it note activity to generate many ideas on the wall that can be easily moved as needed to group and develop solutions. The four main categories we chose to focus on were:

- Table shape
- Features
- Maintenance access
- Water Reservoir type

We each took time to sketch on post-it notes as many ideas and concepts we could develop for each category. Once we completed the sketches, we came up with a selection method on how the designs would be selected. Each member would choose a feature/or component of their liking that they feel would work well with the previous selections of the team. The first team member would choose a table shape, the second member would choose two features that could be incorporated into the shape, and the last member would choose the type of maintenance access door that could be installed given the table shape. **Table 2** displays the selections derived from all three rounds of ideation.

Table 2: Post-it notes activity selections

Round	Shape	Features	Maintenance Access
1	Block L	Spilling Buckets Interchangeable Pipes	Quick release hatch
2	Peanut	Lazy River Paddle Wheel	Lateral Quick Release Hatch
3	Racetrack	Water Jets Toys and Blocks	Sliding Doors

From these selections, each team member made a quick drawing on what we envisioned an exhibit consisting of these attributes would look like. The sketch for the first-round system is shown below in **Figure 10**.

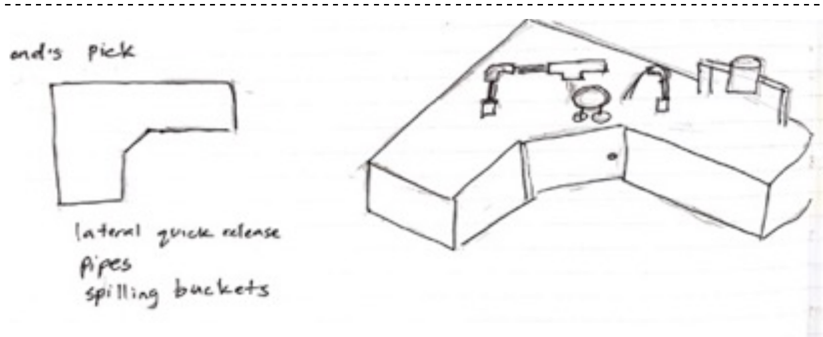

Figure 10: Block L shape design with interchangeable water pipes and spilling buckets.

This activity dampened the complexity of having many subsystems and represented the ideas for each as simple sketch (post-it notes). The spatial nature of this process allowed our team to form systems of combined attributes in very quick succession. At the end of this activity we had several concept designs that we could use or incorporate into our future design.

Prototyping In and Out of Class
Prototyping is the process of creating physical models of the concepts generated in the ideation processes. These are small-scale versions of what the basic concept could potentially look or function like. For the beginning phases of prototyping we primarily focused on the potential shapes and layout potential of the generated table concepts.

Below, **Figure 11** shows a hexagon shaped water exhibit with a usable area in the middle. The existing water table at the Exploration Station has the same shape, but with an unusable center area. For this prototype, we placed a water dome at the top of the middle area of the exhibit. The runoff from the water dome cascades down and supplies the water flow necessary for the magnetic water walls to be interactive for its users.

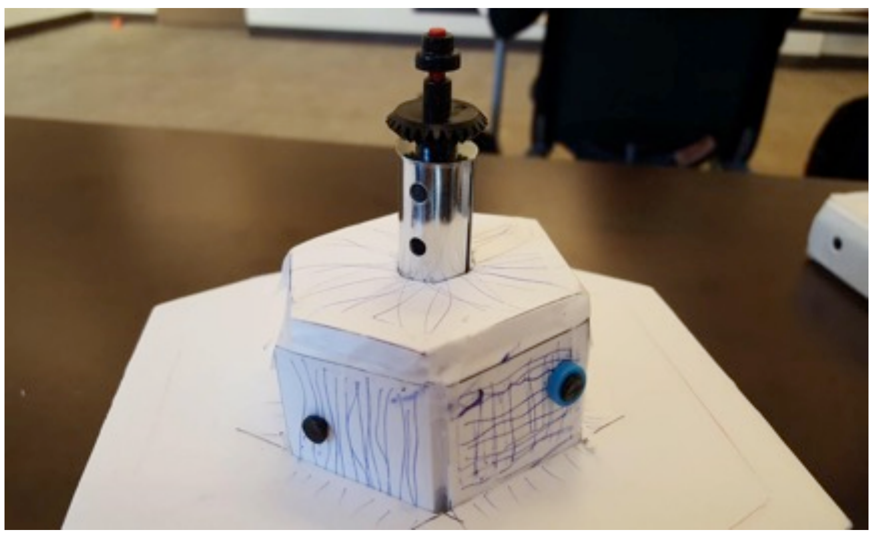

Figure 11: Hexagonal Prototype with Water Wall.

Our second prototype shown in **Figure 12** is B-shaped water table with three features: slides, interchangeable pipes, and a water wheel. We built this prototype to get a sense of the spacing of the features relative to each other and the dimensions of the table. This model was constructed at a 1:12 scale, and represents an area eight feet long, four feet high, and three feet wide. The shape proved to be useful and intuitive due to that it has locations that naturally fit the interactive features.

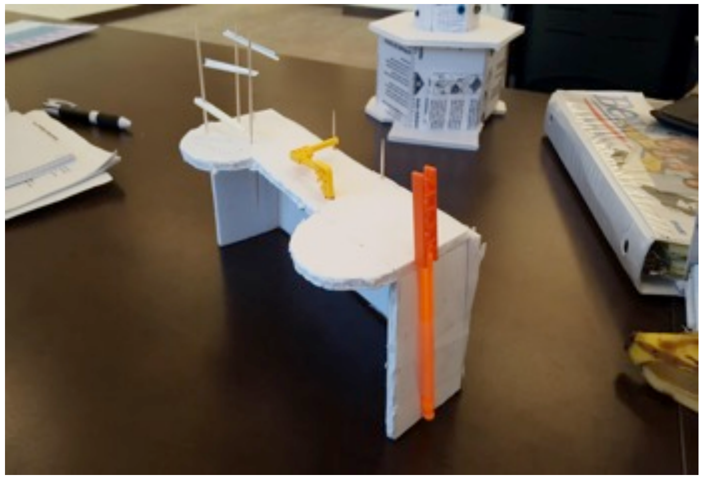

Figure 12: B-Shaped Prototype.

Figure 13 shows our prototype for a vertical magnetic water wall. The purpose of this prototype was to figure out how to fix it to the B shaped table as well as get an idea for the potential integrated funneling and draining system. The results of this prototype showed that the concept was feasible. However, just from inspection of the shape, we realized that the grate capturing system would have to be fairly large to accommodate and funnel the water that travels down the face of the wall.

Figure 13: Magnetic Water Wall

The prototyping phase allowed us to further develop some of our popular ideas and figure out methods these ideas could be implemented. We were encouraged with the exhibit shapes constructed and the layout of features. We took these prototypes into the next phase of the design process, which will be discussed in greater detail.

Idea Selection

After the ideation processes, we had surplus of concepts and ideas in our personal design logbooks, but needed a means of validating each against each other to find the most appropriate concepts for the scope of our project. We used different methods to validate the designs that had been generated. The most valuable method of accomplishing this was through the use of Weighted Pugh Charts. Utilizing the results of the Pugh Charts, our team collaborated to finalize multiple conceptual designs that were viable choices to move forward with as the future water exhibit for the Exploration Station. We welcomed the feedback and opinions of our sponsors in terms of which exhibit design they preferred, as it is something that they will feature at their museum for years to come. These processes of idea selection will be discussed in further detail next.

Pugh Charts

Pugh Charts are used as a means of ranking certain concepts against each other to find which best meet the criteria determined to be most pertinent to that category of concepts. We created Pugh Charts for the following categories: table shape, table features, and methods of accessing water reservoir that is inside the exhibit. Along the top row is the list of table shapes that our team had come up with, and running perpendicular in the first column is the list of criteria that we chose to best contribute to determining a successful table shape. The second column assigns a weighted importance factor to associate with each criteria. The importance factor value is added or subtracted from the concepts total point count when a plus sign or minus sign, respectively, is present in the same row. It is important to note that the existing feature will always score zero in all criteria to set a datum for other concepts to be compared from. **Figure 14** shows the generated Pugh Chart for potential table shapes.

TABLE SHAPES

Criteria \ Concept	Importance Factor	Exp Stn Hexagon	Hexagon w/ hat	Dog Bone	Circle	Baby B	Racetrack	Executive Desk	Peanut	S	H2O
Easy to Build	9	0	0	-	-	-	-	+	-	-	-
Stability	8	0	0	-	+	-	-	0	-	-	-
# of Users	8	0	0	0	0	+	+	+	+	+	-
Unusable Space	6	0	+	+	-	+	+	+	+	+	+
Storage Capacity	10	0	+	+	+	+	+	+	+	+	+
Plumbing Routing	4	0	+	+	+	+	+	+	+	0	0
Cool Factor	7	0	+	+	0	+	-	0	+	+	+
Safety	10	0	0	+	+	+	+	0	+	+	+
Maintenance Access	7	0	0	+	0	+	+	0	-	-	+
Sectioning/ Transportable	7	0	0	0	0	0	0	+	0	-	-
Option to Expand	3	0	0	+	0	+	+	+	-	-	-
Feature Layout	5	0	+	+	+	+	+	0	+	-	+
Total		0	32	43	9	43	31	40	23	2	10

Figure 14: Pugh Matrix at system level for potential table shapes.

Analysis of this Pugh Chart shows that there were five table shapes that scored significantly higher than the rest. These included the hexagon with hat, dog bone, baby b, racetrack, and executive desk shapes. This helped us narrow down our potential shapes list to only those that fit our needs for the scope of this project, most importantly the criteria of being safe, having significant storage capabilities, and being easy to fabricate. Once the analysis for table shapes was complete, our team completed another Pugh Chart for the potential features to add onto the exhibit, shown in **Figure 15**.

	Concept / Criteria	Importance Factor Factor	Water Wheel	Water Dome	Jet Feature	Piping System	Magnetic Wall	Maze
FEATURES	Fun	8	0	+	+	+	+	+
	Interactive/ Hands on	8	0		+	+	+	+
	Educational	8	0	0	+	+	+	+
	Safe	10	0	+	+	+	+	+
	Cool Factor	7	0	+	+	+	+	+
	Easy to build	9	0	+	-	+	-	-
	Cost	5	0	0	-	-	-	-
	Water usage	6	0	-	-	-	0	0
	Plumbing Setup	4	0	-	-	-	0	0
	Number of Users	8	0	+	+	+	+	+
	Total		0	32	25	43	35	35

Figure 15: Pugh Matrix at system level for potential integrated features.

Upon completion of this Pugh Chart, we found that every potential feature had scored significantly higher than the manually turned water wheel that served as the datum from the existing Exploration Station exhibit. While this result did not necessarily help us to rule out any of the concept features, it did show us that we did not have to limit ourselves in regards to using identical features in the final design concepts. This allowed our team to see the features and table shape subsystems as having a symbiotic relationship; choosing a table shape that best accommodated the features that we believed to be most engaging.

Final Design Considerations

Following the ideation and prototyping phases, a final decision had to be made for the actual exhibit that our team would carry through in the design and fabrication processes with. For this, we came up with two final design concepts. As the Exploration Station will have this exhibit featured in front of their museum for years to come, we wanted to make sure that their opinion was taken into account, and that they had a voice in the decision-making process. The following sections describe the two potential final designs that our team had generated going into PDR.

Baby B Design

The first of our two final design concepts is what our team has named the *Baby B*. **Figure 16** shows the artistic sketch that we have created to help visualize what the *Baby B* concept would look like. This concept is a "B" shaped table with an extended midsection to be used as a play area catering to smaller visitors (ages three to six) who might not be able to reach up to the taller features. This table shape earned the highest total score in its respective Pugh matrix.

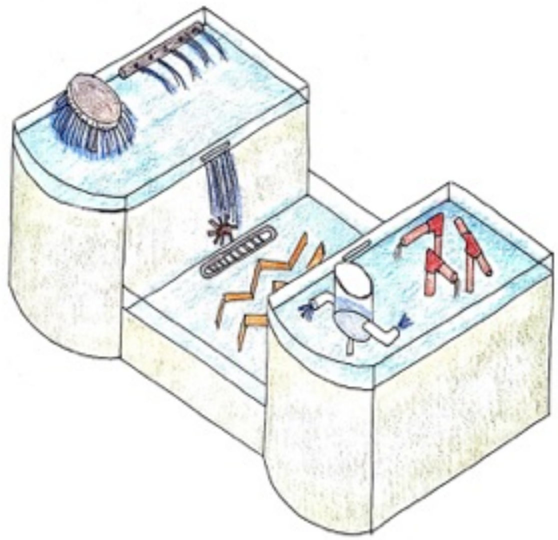

Figure 16: Drawing of feature layout for the *Baby B* final concept design.

Currently, our team is considering the use of steel for the construction of the frame, and thick acrylic for constructing the basin that will hold the water. The decision for material selection has not been made at this time, as material analysis has not been performed yet. Around the perimeter of the water basin area there will be a clear, Plexiglas railing to serve as a boundary for the water in the basin and allow for visibility. By lining the outer face of the exhibit with sheet metal or some form of grating, there would be an internal storage area for the water reservoir tanks, plumbing routing, and filtration systems. Our team considered internal storage to be an important feature for the exhibit to have, as we wanted to keep these potentially hazardous components away from the hands of the young visitors using the exhibit. Located on the outside wall of the exhibit would be a door for maintenance accessibility, as well as a quick shut off button for power in the event of an emergency.

This design had a very involved feature layout. On the raised, left hand side of the exhibit are microcontroller activated jets of laminar water (controlled by user input) and a water dome would be featured. On the other raised end of the exhibit there are interchangeable pipe features and a self-propelling rotary jet. On each of the raised ends, there is a slot cut out from the Plexiglas railing three inches from the bottom of the basin. This allows for water to flow from the upper level and down to fill the basin in the lower children's zone, via a waterfall. Water is pumped up from the inner reservoir to each of the raised ends in order to run the exhibit. To potentially decrease cost on pumps, we decided that there would only be one reservoir on one side of the exhibit, with water pressure being split and either(a) sent up to one of the upper basins, or (b) routed internally under the lower basin to the other upper basin on the other side of the exhibit. Additional maintenance access doors will be included in this region to fix any leaks or malfunctions that may occur in the pressure routing sections.

The children's zone receives water flow from both of the upper basins, and thus will drain back into the main reservoir that is stored in the internal storage area. This is accomplished by a grate that is located on the bottom of the basin, on one side near where the water pours into from the upper basins. The main feature included in the children's zone is an interactive and customizable maze track that allows for the user to create their own path to send toy boats through. In addition to the boats, there will be a number of toys that float and others that don't, in order to convey simple fluid concepts such as buoyancy.

Many of the features and exhibit layout were chosen due to satisfying our customer's needs and having potential to meet our engineering specifications. The chosen table shape creates a safe atmosphere for children to interact with while also being inclusive to users of a large range of age and height. Additionally, its size easily allows for eight users to interact simultaneously. In regards to interactive features (which this exhibit comfortably fits five on), each has an educational focus that teaches different fluid dynamic concepts, including: momentum, pressure, head, buoyancy, and steady/laminar flow.

The Hex Design
The second conceptual design we developed is the hexagonal hat. **Figure 17** shows an artistic rendering of how we envisioned the hexagon design.

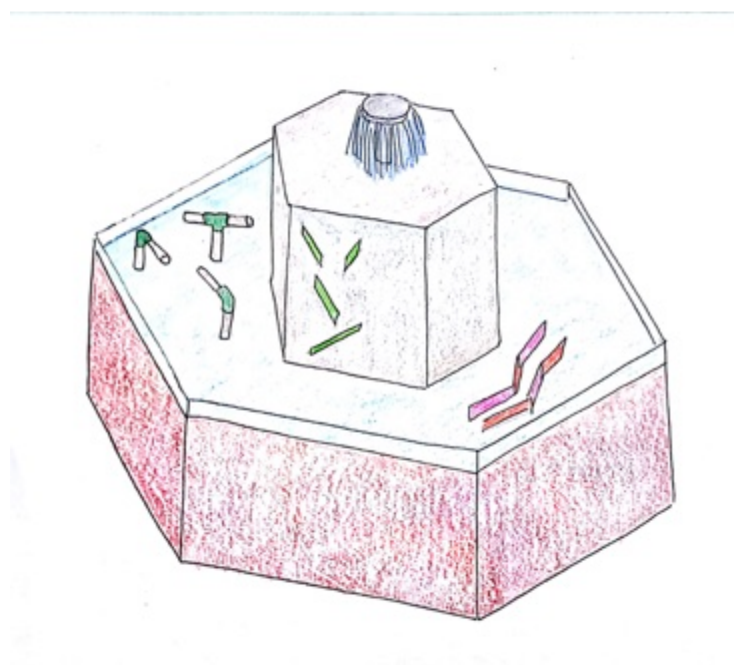

Figure 17: Drawing of feature layout for the *Hex* final concept design.

The overall concept shape is similar to the existing water exhibit at Exploration Station with some creative modifications and material choices. We liked the fact that the existing water table can accommodate many visitors and the geometry of the hexagon is not very complex. The one drawback regarding shape we noticed with the current table is the unusable center section that serves no interactive purpose. For this reason, we developed a unique design with an upper hexagon tier that could be used and made into an interactive feature for guests. We also intentionally designed this exhibit so the younger and middle-aged children would mostly interact on the bottom hexagon. We feel this would be a motivation for the smaller children to return to the science museum every year in order to work their way up the exhibit to interact on the magnetic water wall and water dome features located above.

We chose to use the upper hexagon hat to be the foundation of two features at the same time. At the very top of this hex hat, we choose to incorporate a water dome. This water dome will serve as a focal point to the exhibit and would be seen from a distance. Since this dome would be located on the top tier, taller visitors would be able to reach and touch it. With the water dome centered on top, this feature would supply water down the walls of the upper hex tier and to the lower basin. We wanted to take advantage of the water flowing down the upper hex walls, so we decided to implement a magnetic water wall feature that originated from our initial ideation sessions. These magnetic water walls would be located on every other side of the hexagon, resulting in three total walls. Originally the magnetic wall was around all six surfaces, but was reduced to three in order to reduce costs and keep the features and interactions spread evenly throughout the exhibit. This magnetic water wall feature would allow visitors to stick various objects to the wall to divert water through objects and canals creating unique paths for water to run down.

The lower hexagonal base would be the main interactive area for children. For this reason, we decided to put three key features on the bottom basin area. The first feature would be the interchangeable water piping system. This is interactive feature allows guests to design their own piping systems, diverting flow, and learning about pressure and flow rates. The second feature would be the water maze with various floating toys. Children can play with removable maze pieces, building different configurations, and propelling toy boats through the maze, especially if jet streams are provided. The last proposed feature would be the water wheel. This wheel would spin by itself with current flow of could also be rotated by the guests to see how energy transfers and the effect of water resistance.

For this design, our team is considering constructing the bottom and upper frame using a noncorrosive, durable metal alloy to support the water weight and possible the weight of guests leaning on the exhibit. As with the previous design, this decision for material selection is yet to be decided and will be considered more when doing further materials analysis. Around the perimeter of the lower hexagon water basin we are proposing to use a clear, thick Plexiglas railing to serve as a boundary for water and to create a modern look exhibit. We would like to cover the outer frame of the exhibit with sheet metal or some form of grating to block access to components. This hexagonal shape would allow adequate internal storage space for the water reservoir tanks, plumbing routing, and filtration. A maintenance door would be installed on the frame to allow for accessibility, as well as a quick shut off button for power in the event of an emergency.

Many of the features and exhibit design were chosen to satisfy our customer’s needs and potentially meeting our engineering specifications. This potential exhibit design creates a safe atmosphere for children to interact and offers motivation for younger kids to return.

4. Final Design

Updated Project Scope

Following the preliminary design review, when our sponsors chose to move forward with the hexagon shaped exhibit, our team went back to the drawing board to assess what we were capable of accomplishing during the allotted time given in the senior project timeline. Following the advice of our senior project advisor, we realized that the scope of the project was a bit too broad for our team. After considering the areas of the project that were most crucial to the longevity of the exhibit, we decided to cut back on the design of interactive features as well as the integration of an advanced filtration system. Our new final design will be able to have these features and filtration systems added in at a later date. We believe that the construction of a watertight, functional, and durable exhibit skeleton is the most important piece to focus on.

Our current design has a durable fiberglass basin, a steel frame capable of housing all necessary equipment internally, a submersible pump capable of sending water to a number of outlets across the basin (which can be later utilized for features), and programmed power saving sensors all included in an exhibit that will be aesthetically pleasing and be sure to draw a crowd. The three dimensional model of the proposed exhibit can be seen below in **Figure 18.**

Figure 18: Solidworks rendering of the proposed Exploration Station water exhibit.

The following sections explain the final design of the exhibit in detail. Each subsystem will be described in its own respective section. The purpose of these subsections is to describe the decision making process, proof of analysis, pertinent information regarding prototyping, and an individual cost breakdown for each system.

Basin

The basin of the exhibit has been the primary focus of our group throughout the design process, due to the lack of success of past senior projects in regards to developing a leak-proof basin that is durable enough to handle sun exposure when permanently located outside. The basin, made out of fiberglass, is the main water-holding and interaction area of the exhibit. It will fit snugly inside the hexagonal perimeter of the frame, with the top of the basin sitting just higher than the top face of the frame so as to allow for the presence of flanges. The basin walls are angled back 15deg from vertical (a manufacturing strategy to be described in further detail later in the report) and have a vertical height of 5in. There will be a number of holes placed strategically around the inside floor of the basin as outlet spouts for water circulation to and from the reservoir located underneath. **Figure 19** shows our Solidworks model of the fiberglass basin.

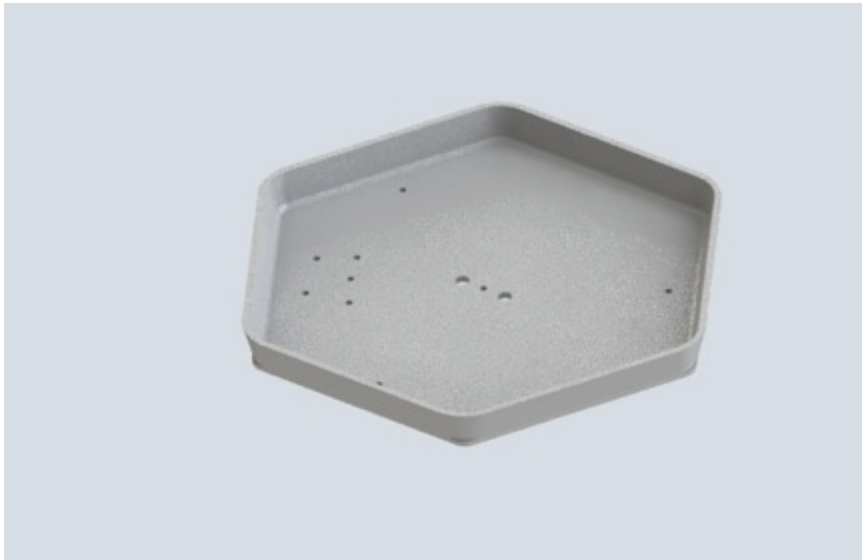

Figure 19: Solidworks rendering for basin.

Material Selection

We considered many different candidates for the material of the basin, including acrylic and sheet metal. Due to the flexible properties and difficulty in sealing of acrylic, and the conductive/thermal properties of sheet metal, both ideas were discarded. A fiberglass layup was determined to be the best material for the purpose of this exhibit for a few reasons.

Fiberglass resin is the material of choice for most marine applications, and is traditionally used to cover and form a watertight seal for the outside hull of boats. The material is fairly easy to work with, and can take the shape of whatever form or mold you can make out of solid materials. While many high-precision fiberglass layups might use an expensive foam mold, cheaper materials such as plywood and medium-density fiberboard (MDF) can also serve as appropriate substitutes to cut down on costs. Because it is a one-off part, and will not be reused, we chose to use one-half inch thick plywood to construct the basin relief prototype.

Prototyping

Our group is currently in the middle of prototyping the basin, and plans to have a completed prototype to test by the beginning of March. **Figure 20** shows the most recent prototype progress as of February 8, 2017. Preliminary prototyping costs came in at around $220. This may seem relatively high, but it is important to note that some of the materials purchased included reusable items such respirator masks, plastic spreaders, nitrile gloves, among other items, that we intend to use again when the time comes to create the final basin. We chose to use plywood instead of MDF in an effort to save on prototyping costs.

Figure 20: Basin prototype progress, as of February 8, 2017.

By creating a one-third scale model, we were able to get a good idea of the manufacturing process without using too much plywood or resin. Although the sides of the basin were scaled down, we left the height at its original fice inches to more realistically simulate the depth of the water in our prototype. Also, a full scale-down of the basin would have made the sidewall height only an inch and a half, which would have been more difficult to prep and glass.

Our team learned much about the difficulties associated with fabricating the relief. The primary issue we encountered was the complex geometry involved with the cuts along the plywood to make all the sidewalls fit snugly against one another. Due to the 15-degree draft angle, each of the tops of the boards stick out further away from the frame than they normally would. This made it very difficult to align and match up the entire face of the board that connects with other sidewalls. Our team compensated for this with the angled cuts along the front face of the sidewall. This brought each of the top faces of sidewalls closer together. While this did leave a small gap between the boards instead at the bottom of the corner (shown in **Figure 21**), we placed thin shims of balsa wood (found as scraps in the machine shop) into the corners where these gaps were found (shown in **Figure 22**). These shims were glued into place with wood glue, as a surface for the Bondo putty to grab onto. This process proved to be successful, as the Bondo was easily able to fill in the small gaps that were left around the shim, and the issue is not noticeable when looking at the outside surface of the relief (which is the important surface for the glassing process).

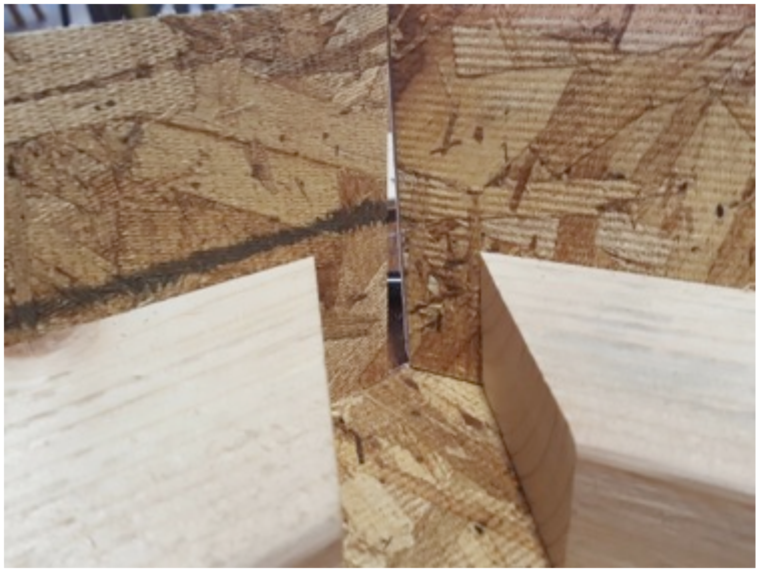

Figure 21: Relief prototype corner gap without shim.

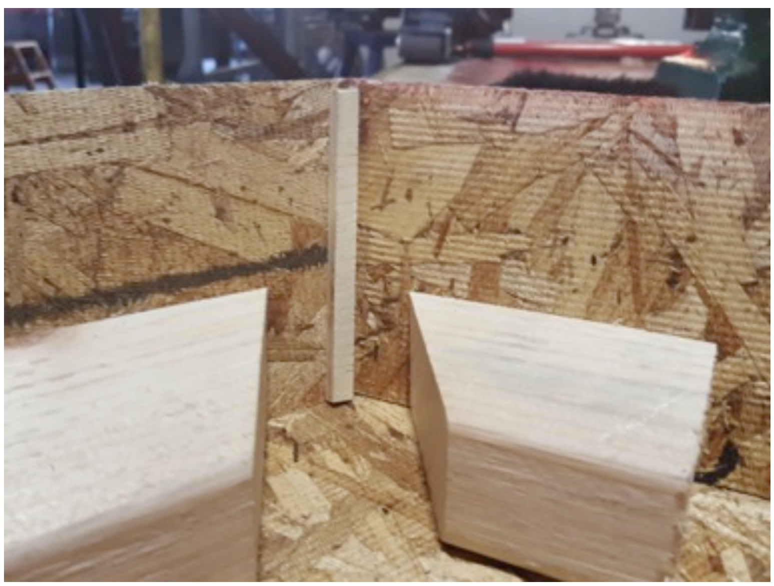

Figure 22: Relief prototype corner gap with shim glued into place.

Plumbing System

This water exhibit is going to be designed to have multiple water outlet pipes at the basin to allow adequate water flow for future features to be added once all the main sub-systems are completed. Before talking about each individual component, we want to show a general schematic of the exhibit with a general layout of the plumbing system. **Figure 23** is a schematic of the plumbing lines that will be routed to the interchangeable water pipes area.

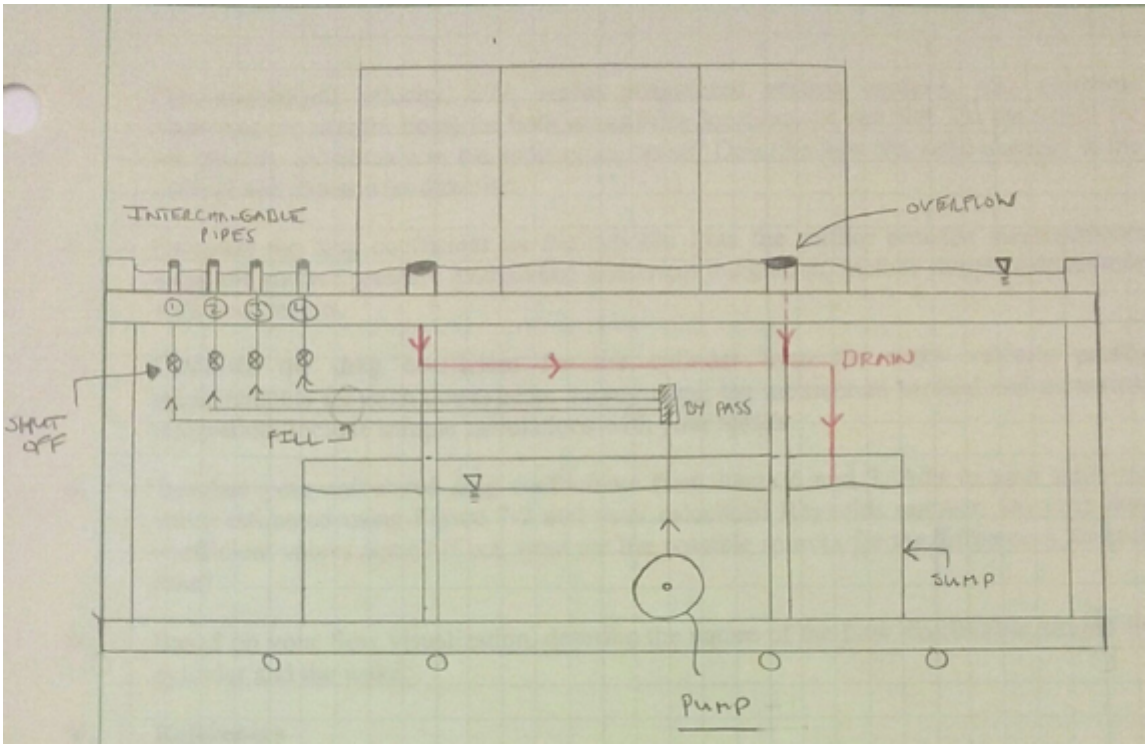

Figure 23: Plumbing line for interchangeable water pipes schematic.

Here you can also see the bottom reservoir that will store the water along with the submersible pump located within it. The pump's discharge pipe will be connected to a bypass valve, which will break the flow into four independent water lines that will feed up into the basin. Each of these lines will contain a shut off valve for adjustment based on the water flow rate. The next schematic of the plumbing system is that of the circulation jets to create the lazy river feature, which can be seen below in **Figure 24.** This feature was added after PDR and suggested by the sponsors to circulate the water around the exhibit.

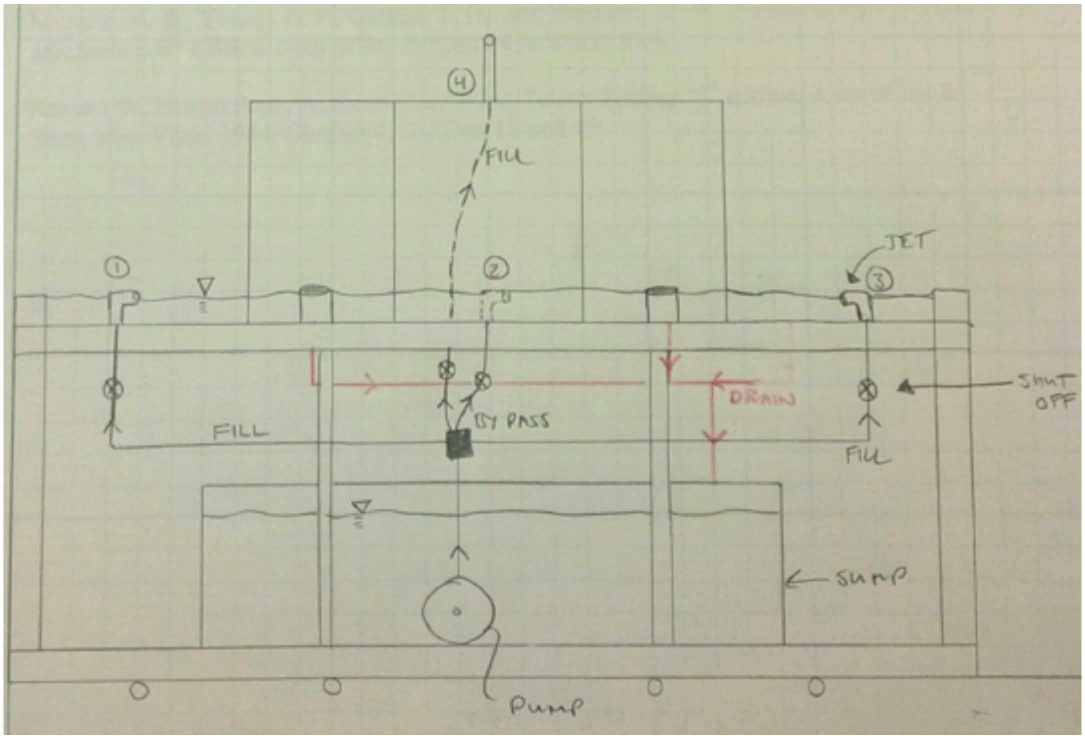

Figure 24: Plumbing lines for circulation jet schematic.

This drawing shows the plumbing lines for the circulation jets and also the outlet for the water dome feature on the upper hex. There are going to be three water jets located on the basin, which will circulate water in a river-like manner around the basin of the exhibit. Each of these piping lines will be also connected to the same pump located in the reservoir, so it is important we determine the required flow rates necessary for each outlet. Since the plumbing of this exhibit is quite involved and contains many components, we chose to break up these components and talk about them individually.

Prototyping Flow Rates

In order to begin the process for calculating required pump sizes and total flow rates, it was first important to make a few prototypes to determine the necessary flow rates needed at the outlets.

Interchangeable Pipes

Since a total of four water outlets are needed for the interchangeable pipes feature (and seen in **Figure 23**) and it is relatively easy and inexpensive to build, we created a prototype for one interchangeable water pipe feature in order to help us test to determine the flow rate needed in order to have sufficient water for interaction with this feature. Materials were purchased and the prototype was created as shown in **Figure 25**.

Figure 25: Prototype for the interchangeable water pipes feature

This piping system was created in order to simulate the real effects of the planned piping system. As you can see, the lower straight section of the pipe is added in order to account for the elevation difference between the pump and the outlet, which would increase the pressure needed by a pump. Also with the interchangeable piping section, we added elbows, tees, and straight piping sections to simulate the general conditions in the exhibit.
Once the prototype was completed, we set out to test the piping system in order to determine desired flow rate for the outlets. In order to test for flow rates, we hooked up the piping to a water hose and obtained a five-gallon bucket. We proceeded to time how long it took to fill a five-gallon bucket. **Figure 26** shows how the piping was connected to a water hose and setup to run the test.

Figure 26: Prototype for the interchangeable water pipes feature

We completed this using two methods: 1) assuming that every time we filled the bucket it was near five gallons collected 2) by actually measuring the inside of the bucket and calculating the volume we filled. With this prototype, we set out to test the pipes by running water through them until the desired flow rate was reached. Once the desired operating point was achieved (an operating point that has enough pressure and flow to provide sufficient water for interaction), we began filling the bucket and simultaneously timing with a stopwatch until filled to the required height. **Figure 27** shows us during testing with a view of the desired flow rate through the interchangeable pipes we have set for our system.

Figure 27: Prototype for the interchangeable water pipes feature

We ran multiple tests while trying to maintain the same flow rate each time and recorded the data. The flow rate results will be presented under the flow rate results section.

Circulation water jets

As can be seen in the schematic of the water circulation jets, a total of three jets installed in the basin are going to be installed at every other side of the hexagon basin in order to achieve the lazy river feature where boats and toys can float around the exhibit. A circulation jet with an outlet was also relatively easy and inexpensive to create, so we created a prototype for one water circulating pipe feature in order to help us test and determine the flow rate needed in order to have sufficient water flow around the exhibit. Materials were purchased and the prototype was created as can be seen in **Figure 28.**

Figure 28: Prototype for the circulating jets.

This circulating jet was designed to simulate the actual effects of the planned piping system. We added a ninety-degree elbow at the end that would sit right above the basin. The straight section of the pipe is added in order to account for the elevation difference between the pump and the outlet on the basin, which will increase the pressure and that will sit under the water level to generate a jet stream.
Similar to the interchangeable water pipes, we set out to test the circulating jet in order to determine desired flow rate for the jets. In order to test flow rates, we again used a water hose and obtained a five-gallon bucket. Since we do not have the basin to test the actual flow desired, we instead decided to test the jet in the bucket filled with a few inches of water (similar to the basins proposed filled height). We turned on the jet and adjusted the flow until we reached the rate at which the jet was creating a small wave in the bucket of water. We emptied the bucket and started filling and timing to determine the flow rate we were currently running the circulating jet. We only ran one trial with the circulating jet because the results for the interchangeable pipes were all near the same range (± 0.17 GPM between each trial run). We again used the same two methods as before: 1) assuming that every time we filled the bucket it was near five gallons collected 2) by actually measuring the inside of the bucket and calculating the volume we filled.

Prototyping Results
After recording data for each feature, excel was used to calculate the flow rates using both methods mentioned above. The experimental flow rates for the interchangeable pipes are tabulated in **Table 5**. In this table, the flow rates (Q) in inches cubed per second were averaged for the three trails and then converted to gallons per minute and gallons per hour.

Table 5: Flow rates based on measured volume of bucket for interchangeable pipes

Trial #	Fill time [s]	Measured volume [in^3/s]	Q [in^3/s]	Q avg [in^3/s]	Q avg [gal/min]	Q avg [gal/hr]
1	175.53	1076.5	6.13	6.49	1.69	101.21
2	163.92	1076.5	6.57		per pipe	per pipe
3	158.7	1076.5	6.78			

These results were obtained by measuring the inside of the bucket and calculating the volume of water filled. The average was taken and the flow rate per outlet was determined to be 101.21 GPH.
Next**, Table 6** shows the results based on assuming a standard five gallons were reached every time we filled the bucket.

Table 6: Flow rate based on bucket size for interchangeable pipes						
Trial #	**Fill time [s]**	**Fill volume [Gal]**	**Q [Gal/min]**	**Q avg [in^3/s]**	**Q avg [Gal/min]**	**Q avg [gal/hr]**
1	175.53	5	1.71	6.97	1.81	108.59
2	163.92	5	1.83		per pipe	per pipe
3	158.7	5	1.89			

Here it was determined that the flow rate was 108.59 GPH per outlet assuming five gallons each fill.
We did the same procedure with regards to the circulating jets and calculated the flow rates for both methods. The results for the measured volume can be seen in **Table 7.**

Table 7: Flow rates based on measured volume of bucket for circulating jets					
Trial 1	**Fill time [s]**	**Measured volume. [in^3/s]**	**Q [in^3/s]**	**Q avg [gal/min]**	**Q avg [gal/hr]**
	82.54	1076.5	13.04	3.39	203.25

Using this method, the required flow rate for the jet was determined to be 203.25 GPH for one jet pipe.
Using the second method, the results are tabulated in **Table 8.**

Table 8: Flow rate based on bucket size for Lazy river					
Trial 1	**Fill time [s]**	**Fill volume [Gal]**	**Q [in^3/s]**	**Q [Gal/min]**	**Q avg [gal/hr]**
	82.54	5	13.99	3.63	218.08

Using this method, the required flow rate was determined to be 218.08 GPH for one jet pipe. With this data, we needed to choose which values were more reasonable. Due to the fact that the measurements taken of the bucket were not very accurate because of the slope in the bucket sidewall (which resulted in the top and bottom of the bucket having different diameters), we decided to go with the larger flow rate to be more conservative and have the ability to adjust the flow down if needed. **Table 9** shows the final flow rate values that were determined using the testing results for each feature. The overall flow rate needed by all of the features combined is also included which comes out to be 1306.68 GPH.

Table 9 - Summary			
	Flow rate [GPH}	**Number of Outlets Req'd**	**Feature flow rate [GPH]**
Interchangeable pipes	108.59	4	434.36
Circulating jet	218.08	3	654.24
Water dome	218.08	1	218.08
Total exhibit flow rate			1306.68

This is one of the important values needed in order to properly select the appropriate pump and the other is the pressure head the pump is going to need to supply to the water. This will be discussed in the next section.

Detailed Flow Analysis
Now that the overall flow rate for all the features on the exhibit have been determined experimentally, the head required by the pump for this operating point can be calculated using fluid dynamics analysis. The pump that is selected needs to not only produce the desired flow rate of 1306.68 GPH, it must also supply enough head to overcome the head losses in the pipes due to friction, ball valves, and other components that will impede the flow. Required pump head is simply the height that the pump can elevate a column of water. **Figure 29** illustrates this concept.

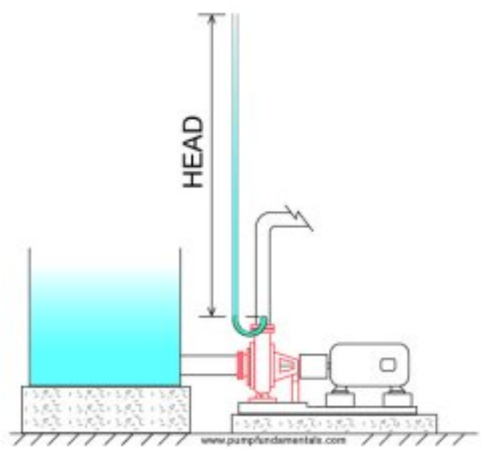

Figure 29: Pump pressure head concept.

With this type of analysis, we also take into account the frictional effects, which cause a reduction in this head due to the restrictions in the pipes and fittings.

When conducting the analysis, we modeled the system as viscous pipe flow. Two similar methods were used in order to determine the head required by the fluid from the pump in order to obtain the desired flow rates. We consulted two mechanical engineering professors regarding the analysis and got two different methods of approach.

Before discussing the results of the two methods, **Figure 30** is a detailed schematic of the interchangeable piping system being analyzed is shown in figure 30 (below). The points labeled here correlate to the points referred to in the calculations performed in **Appendix I**.

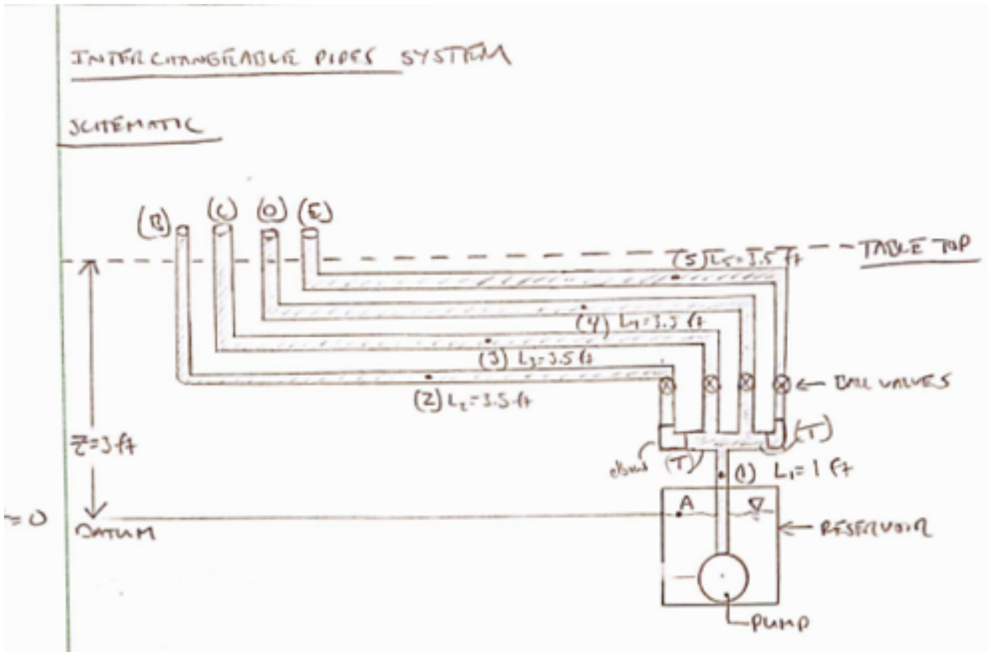

Figure 30: Interchangeable pipe system schematic

Because the calculations are quite complex and involved, we included of brief summary of the results and how this helped us determine the flow rates and head needed by a pump for this exhibit.

First method results

When performing the calculations for the first method, the losses from the pipes and restrictions for each individual outlet was taken into account and summed up to result in a net head loss the pump would feel. Using this method and adding the head loss due to each individual piping line, the total head that would be required from the pump came out to be 17.04 ft. of head. That means we would need to select a pump that could deliver the required flow rate of 1306.68 GPH at the head of 17.04 ft.

Second method results

After consulting a second professor that currently teaches fluid dynamics here at Cal Poly, we made a few modifications to the original calculations of the first method. Now, only the losses from the pump up a single outlet point where the outlet reaches the basin was taken into consideration. The reasoning for this is that every point right after the bypass sees the same amount of pressure from the pump, so as long as the required pressure is delivered to the node where each pipe separates, they will all feel the same pressure head by the pump at that node. Using this method and adding the head loss due to an individual piping line, the total head that would be required from the pump came out to be 7.00 ft. of head. That means we would need to select a pump that could deliver the required flow rate of 1306.68 GPH at the head of 7.0 ft.

Based on these two analysis and the fact that the professor for method two seemed to be well versed on the subject matter of fluid dynamics, we decided to go with method two in order to help us proceed and select an appropriate pump for the exhibit. So, moving forward, a pump with a minimum flow rate of

1306.68 GPH and head of 7ft. is needed to supply the proper flow rates and pressures needed to move the water throughout the exhibit.

Pump Selection
One of the key features for this this exhibit is to ensure that the pump selected be adequate to supply the desired flow rate at the required head to each outlet to ensure successful operation of each feature. In selecting a pump, we first start the search by reviewing the top ten best pumps list for 2016. Here we came across a pump that was capable of supplying the flow rate needed, and was reasonable priced. This pump was the Alpine Cyclone 3100 Pond & Waterfall Pump – 2,500 GPH (PAL3100) and can be seen in **Figure 31**

Figure 31: Alpine Cyclone 3100 Pond and Waterfall Pump

After looking into the pump further and reading about its features and specifications, we became even more impressed with this pump. Listed below are the features of the Alpine pump found on the guide manual:

Key Features
- The Alpine Cyclone 3100 Pond & Waterfall Pump is perfect for waterfalls and streams
- Energy saving split tube motor with 33 ft. power cord
- Pond pump can be used vertically or horizontally
- Can pass solids up to 0.24″
- Operates submerged or out of the water (external or submersed)
- Oil-free, magnetic-driven motor for long-term continuous use
- 3-year manufacturer's limited warranty
- Can buy replacement parts from the manufacturer
- Comes with an adapter (multi-fitting) to fit a variety out pipe diameters
- Pre-filter for large debris
- This pump is suitable for use in water temperatures from 32 degrees Fahrenheit to 95 degrees Fahrenheit.

We liked the fact that it comes with a 3-year warranty to protect it in the future if anything shall happen. It has the flexibility to be mounted vertically or horizontally, which could give us options on the installation. Another great feature is that this pump can be fully submerged or connected externally outside the water to pump water out. The discharge exit comes with an adapter to be able to connect various sized pipes, which could help with the install. If a part in the filter breaks after the warranty period, replacement parts can be purchased from the manufacturer. Also since the exhibit will be outside, this pump can handle extreme temperature ranges.

The last piece of information that needed to be checked before selecting this pump is the flow rate it could deliver at the specified head rating. As you may recall, we needed 1306.68 GPH at 7 ft. of head. Digging further into the pumps performance, we found in the operations manual the pump performance rating for each model they make. **Figure 32** shows the pumps performance information for all Alpine Cyclone models.

PUMP INFORMATION

ALPINE ITEM #	AMPS (MIN-MAX)	WATTS (MIN-MAX)	MAX FLOW	MAX HEIGHT	OUTLET CONNECTION	CORD LENGTH	GPH FLOW RATE							
							1ft	5ft	10ft	15ft	20ft	25ft	30ft	35ft
PAL2100	1.6	192	2100	20'	1 1/2"	33'	2070	1532	790	--	--	--	--	--
PAL3100	2.3	276	3100	21 1/2'	1 1/2"	33'	3070	2251	1390	479	--	--	--	--
PAL4000	2.55	306	4000	21'	2"	33'	3963	3052	2140	1229	317	--	--	--
PAL5200	3.55	426	5200	25'	2"	33'	5184	4230	3175	2121	1067	--	--	--
PAL6550	3.80	456	6550	26'	2"	33'	6505	5369	4132	2896	1659	422	--	--
PAL8000	4.50	540	8000	26'	2"	33'	7926	6439	4954	3467	1982	494	--	--
PAL10300	8	960	10300	40'	2 1/2"	33'	9885	8229	6168	4597	2756	1641	941	452

Figure 32: Pump performance for Alpine Cyclone

As can be seen in the chart viewing the specifications for the PAL3100, it shows that at 10 ft. of head the flow rate specified to be 1390 GPH, which is slightly more than the 1306.68 GPH needed. So based on this chart, this pump will produce more flow than is needed at an even greater head. Since we are planning to install flow restrictors (ball valves) on each pipe, we are not concerned with the extra flow since we have the ability to reduce it to the appropriate flow levels. Therefore, we are choosing the Alpine Cyclone 3100 Pond & Waterfall Pump – 2,500 GPH (PAL3100) as the pump for this exhibit and look forward to testing and determining its performance abilities. Further pump performance, ratings, and maintenance tips can be found in this report located in **Appendix H.**

Components and Features of Plumbing

Now that the prototyping, testing for flow rates, and pump have all been determined, we wanted to discuss a few other details that pertain to the plumbing system that will be incorporated under the exhibit.

Reservoir Tank

Since the ideal pump has been selected for this exhibit, it was time to set out and choose a reservoir tank. One of the customer's needs we recalled was the ability to easily maintain the water system by having access to the water reservoir and also the ability to drain the water easily at the periodic maintenance intervals. For this reason, chose to use a 50-gallon stock tank created by Rubbermaid, as shown in **Figure 33.** This tank fits within the dimension constraints inside the storage area, which has proven to be a limiting factor for reservoir selection. A hole will be drilled near the bottom of the tank to install a bulkhead fitting (reference **Figure 34**) that allows for water to be easily drained out when necessary. Bulkhead tank fittings are to be mounted through a hole in a wall, tank, or panel to serve as an inlet or outlet for faucets, pipes, and spigots. They absorb vibration and provide flexibility to reduce stress on your system.

Figure 33: 50-gallon Rubbermaid stock tank.

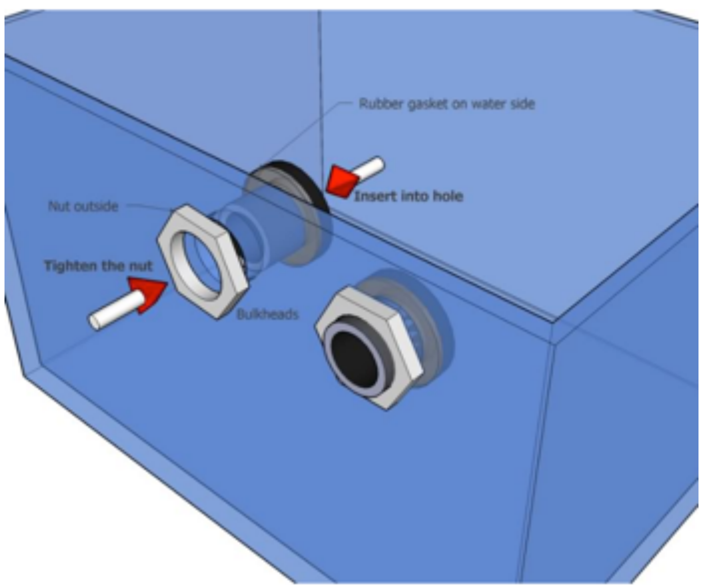

Figure 34: Bulkhead fitting schematic

Figure 35 shows the connection that would be made between the bulkhead fitting and the water valve that would compatible with a water hose.

Figure 35: Bulkhead fitting schematic

Originally, our group had planned to purchase a custom-made, glass reservoir tank. Due to cost restraints and issues regarding the potential for broken glass in the system, we abandoned that idea instead and chose the Rubbermaid tub. This has allowed us to greatly reduce the cost of the exhibit, and ensure the durability of the final product.

Plumbing Tubing
In regards to routing the plumbing between the pump and the various outlets, we choose not to use standard hard PVC pipe that is typically used in water applications. Instead of using standard hard PVC for our plumbing system we decided to use clear, flexible PVC tubing. We felt that flexible tubing would allow us to more easily run the piping, as we would no longer need to make lots of small cuts and seal lots of joints, as we would have with standard tubing. Furthermore, due to the limited space underneath the exhibit, we wanted to ensure maintenance would be easy, which is the case with flexible tubing.

Miscellaneous plumbing parts
Like most plumbing systems, many other fixtures are needed to make all the connections. In order to keep this section brief, yet informative, we wanted to touch on the other plumbing components. We are going to need to install ball valves to reduce the flow, couplers for connections, reducers for different diameters, and bypass valves for drains. Please see the bill of materials (Appendix XX) for further details and specific quantities.

Bill of Materials
The final design of the plumbing system, which includes all the prior components just discussed is estimated to cost $550.25. All of these parts would need to be ordered mostly from a local retailer. Most of the costs associated with this system are due to the reservoir and the rump required.

Sleep Mode System
Our sponsors expressed interest in having a system that would allow them to conserve energy by having the pumps turn on only when there people interacting with the exhibit. In order to have such a system you need sensors to detect when people are around. You also need a device that does something with the information received by the sensors. We are using a microcontroller to activate certain outlets in a power strip, which in turn will power the pump when the sensors detect motion. Normally all outlets of a power strip will be on at any time, but we are using a special power strip that will be discussed later in this

section. To begin we will compare three sensors that were possible candidates for this application: a distance sensor, a non-contact thermal sensor, and a passive infrared (PIR) sensor.

Distance Sensor
The first sensor that I want to discuss is the LV-MaxSonar-EZ MB1000. This sensor is a range finder that uses high frequency sound and the time that it takes sound to travel from the sensor to the object and back to measure the distance of an object. After experimenting with this sensor I found that it has a small measuring area so we will need a lot of sensors to cover the whole table. That is, the field of view of the sensor is very small, although it can detect objects up to 254 inches away. Another problem with this sensor is that it will trigger when any object is within a certain distance away from the exhibit, but we want the pumps to be activated only when people are near the exhibit.

Non-Contact Thermal Sensor
We want sensors that will exclusively detect people or that are most likely to activate when people are near the water table. This directed my attention towards thermal sensors and the first one I will be discussing is the Omron D6T-44L-06. This sensor is a non-contact thermal sensor with a sensing rage of 44.2° in the x-direction and 45.7° in the y direction. It measures the surface temperature of an object using the infrared radiation emitted by an object. This sensor can detect people nearby even if they aren't moving, but because of its limited field of view we require 9 sensors to cover 360°. The total cost for 9 sensors is $450, which is more than we can afford to spend on sensors, so will not be using these sensors.

Passive Infrared Motion Sensor
The Passive Infrared (PIR) motion sensor cost $2 and it has a horizontal field of about 120°.
It detects motion using the infrared radiation emitted by objects and it is optimized to detect humans. Like the D6T sensor this is also a thermal sensor, but it will not trigger when there is a person standing still in its field of view. However, through testing we observed that this sensor is extremely sensitive that evenly the slightest motion will be detected by it.

Chosen Sensor
We chose the PIR sensor because it is $48 cheaper than the non-contact thermal sensor and it has a wider field of view (~120°) which means that we will require less sensors to cover 360°. In this section we will go into a lot of detail about how the sensor works and the features that it includes.

There are two rectangular pyroelectric materials covered with a metal casing to protect against noise, temperature, and humidity inside the dome shown in **Figure 36**.

Figure 36: PIR sensor without dome.

Pyroelectric materials have the ability to create a temporary voltage when they undergo a temperature change. A temperature change in each material is achieved by the energy they get through infrared radiation of other objects. The metal casing has a window that allows infrared radiation to pass. Inside the metal casing there are two sensing elements that must generate different amounts of voltage for motion to be detected. This occurs when a warm object moves across the detection area of the sensor because one sensing element will be obtaining more energy before the other is exposed to the radiation of the warm object. This is how the passive infrared sensor detects motion and it is called passive because it does not use any energy for detecting purposes, rather it uses the energy of the objects in its field of view. The dome that covers the metal casing serves to increase the detection area by directing the incident light towards the window inside. If we did not have this lens then the detection area would be two rectangles inside the metal casing as shown in **Figure 37**. The effect that the lens has on incident light is shown in **Figure 38.**

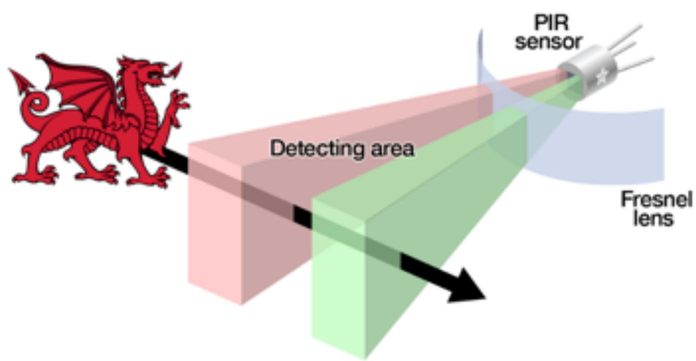

Figure 37: Detection area of motion sensor.

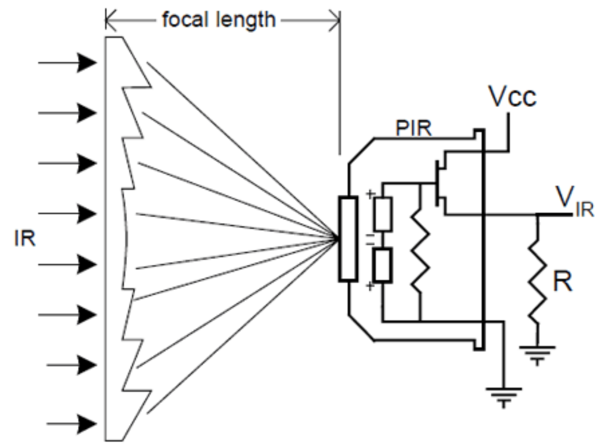

Figure 38: Effect of lens of incident radiation.

The PIR sensor has three adjustable features: the time that the sensor outputs high after it has detected motion, the max distance where it stops detecting motion, and whether it goes low automatically after being high for the specified amount of time. The time that the sensor outputs high for can be changed from 5 s to 5 min by adjusting the knob in bottom right shown in **Figure 39**. The max distance where the sensor will stop detecting motion can vary from 3 m to 7 m by adjusting the knob on the bottom left. To set the sensor to repeat trigger you need to move the yellow plastic casing one pin up so that the bottom pin is not covered. The settings that we will use for our application are for the sensors to detect motion within 3 m and output high for 5 min after they have detected motion so that pumps stay on for at least five minutes after motion has been detected. The sensors will be set to repeat trigger so that they continue outputting high if motion is detected at the end of the 5 min.

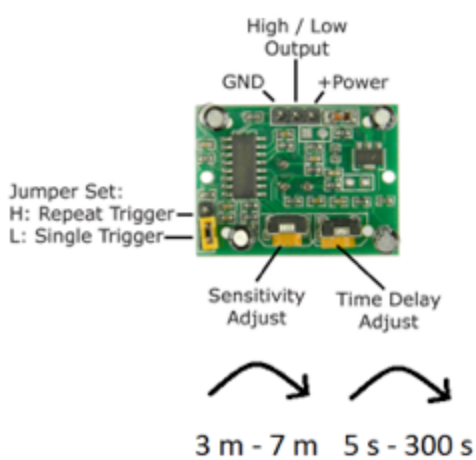

Figure 39: Adjustable features of PIR sensor.

Sensor Location

The location of each PIR sensors was changed due to the design modification with the casters leaving only 1½ inches from the floor to the base of the exhibit. We will be using six sensors now and they will be located in the middle of each HDPE panel, made visible by a hole drilled into the face. They will be protected from water and attached to the HDPE side walls using a 3D printed casing so that only the dome part of the sensor is visible. The casings will be printed at Cal Poly's Innovation Sandbox free of cost. **Figure XX** below shows the sensor location and placement on the HDPE sidewalls (denoted by red circles).

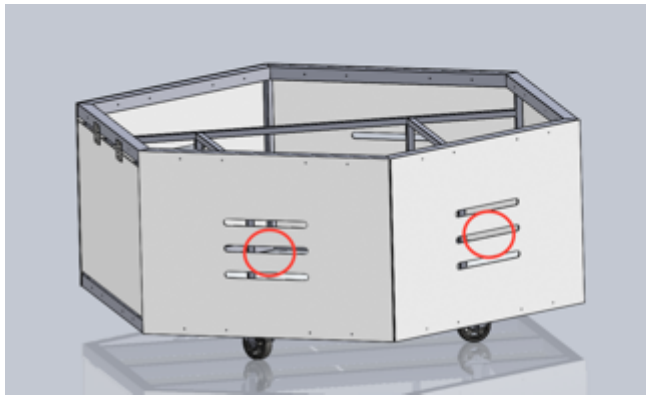

Figure 40: Location of PIR sensors on exhibit.

Internet of Things Relay

Now that we have discussed how the sensors work and their settings we will discuss another important component in this system, the Internet of Things (IoT) Relay shown in **Figure 41**. The IoT relay is a power strip with four outlets, but only two are on at any time. One pair is named the normally on and the other is labeled normally off. In order to turn on the normally off outlets you need to supply AC or DC to the power strip and that will change the state of the relay inside the power strip so the normally off outlets are getting 120 V. In our project we will be using a DC source provided by the digital pins in the Arduino.

Figure 41: IoT Relay.

Circuit Schematic of Sleep Mode System

The sensors and the IoT Relay are the main components of the sleep mode system along with the Arduino Uno, which will be getting input from the sensors and using this information to set the state of the relay in the power strip. The interconnection between each component is shown in **Figure 42**. As you can see from the figure the IoT relay has one wire connected to ground and the other is connected to digital pin 2. This digital pin will be an output because we want to apply either 5 V or 0 V to the relay in the power strip. When 5 V is applied then the normally off outlets will be on, but when 0 V is applied then the normally on outlets will be on. Each of the sensors has three pins, one connected to ground, one connected to 5 V, and the middle pin is connected to a digital pin in the microcontroller. These digital pins will be inputs because we will be reading from the sensors. In our prototype I have connected one sensor to pin 4 and the other to pin 8, but we will require 2 other sensors to cover 360°. Our plan is to put the sensors beneath the bottom surface of the table on a hanging platform to avoid getting water in the sensors. The IoT Relay will have to be inside the exhibit to power the pumps.

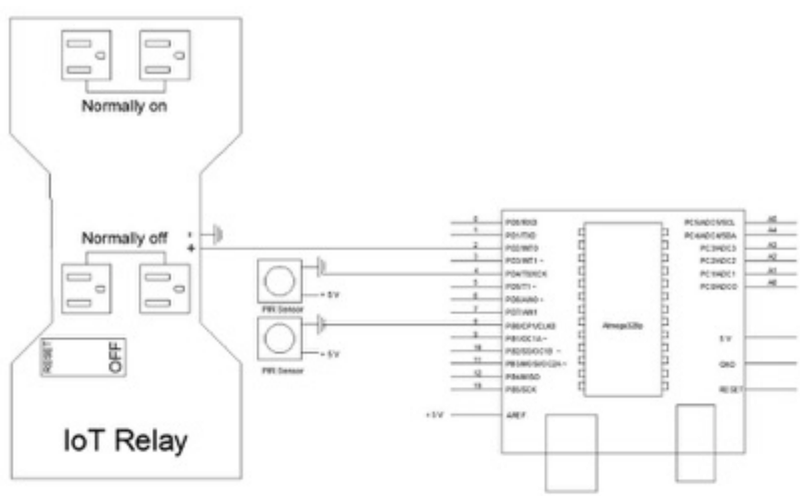

Figure 42: Circuit schematic of sleep mode system.

Flow Chart of Code

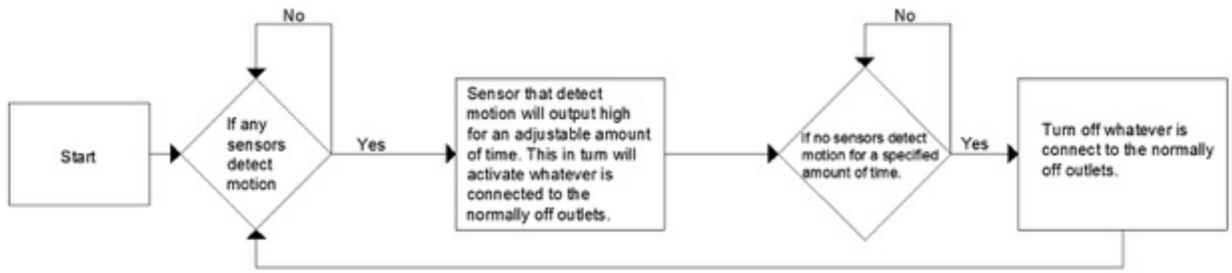

Figure 43: Flow chart of sleep mode system program.

The flow of execution of the program loaded into the Arduino will be explained using the flow chart in **Figure 43.**

First we wait for the sensors to calibrate for 30 seconds then when they become active we begin at the start and wait for motion to be detected by anyone of the sensors. If motion is detected by one sensor, then it will output high for 5 s and turn on the normally off outlets before waiting for a time period without motion. However, it is possible that various other sensors output high after the first sensor detects motion, which means that we will be stuck in the middle of the flow chart until the last sensor finishes outputting high. Next we wait for a period of time with no motion, which is set to 5 s in the program right now. If 5 s have passed with no motion, then the normally off outlets turn off and we go back to waiting for motion to be detected again. Otherwise, that means we detected motion in the middle of waiting for a pause so we go back to the middle of the flow chart. The actual code that the flow chart is representing is shown in **Appendix K**.

Testing

Moving forward with the sleep mode system there are several issues that we need to address. First, we need to figure how to mount the sensors on the exhibit and protect the electronic components behind the sensors in case they get wet. Second, we need to incorporate two more sensors to cover 360 and test that four sensors does indeed cover that whole perimeter of the exhibit. Third we need to get longer wires to have flexibility in where we put the sensors. The wires need to be well insulated and water resistant in case they get wet. Lastly, we need to test the sensors on a windy day and make sure that they are not triggered by the wind.

Frame Assembly

The current water exhibit at Exploration Station has deteriorated due to its material composition and exposure to the elements. For this reason, we wanted to ensure that the main supporting structure we built would have high strength, high durability, and weather resistant. For this reason, we choose to construct the frame using 2 x 2 in. square steel tubing as well as 1 x 1 in. square steel tubing (both 11 gauge). The interior of the frame has piece of aluminum sheet metal (which will be supported by 2x2 steel tubes) that serves as a platform for the storage area containing the 60-gallon water reservoir and submersible pump system, as well as all of the plumbing routing up to the basin.

The secondary part of the frame consists of the smaller hexagonal structure that sits atop the basin. This structure serves multiple purposes, including: acting as the frame for the magnetic water wall, housing the weir valves (water overflow drains), and serving as the platform upon which the potential water dome would eventually sit. The frame of the top hexagon, shown in **Figure 44**, is constructed with 1x1in stainless steel tubing, welded together, and covered with the same HDPE sidewalls as the main exhibit frame.

This framing system is going to be welding and painted which will be discussed later in the manufacturing section.

Overall Exhibit Size

Now that we have completed our design for the frame, we are now able state the dimensions of the exhibit. **Figure 44** shows an incomplete assembly drawing in order to have an understanding of the dimensions discussed below.

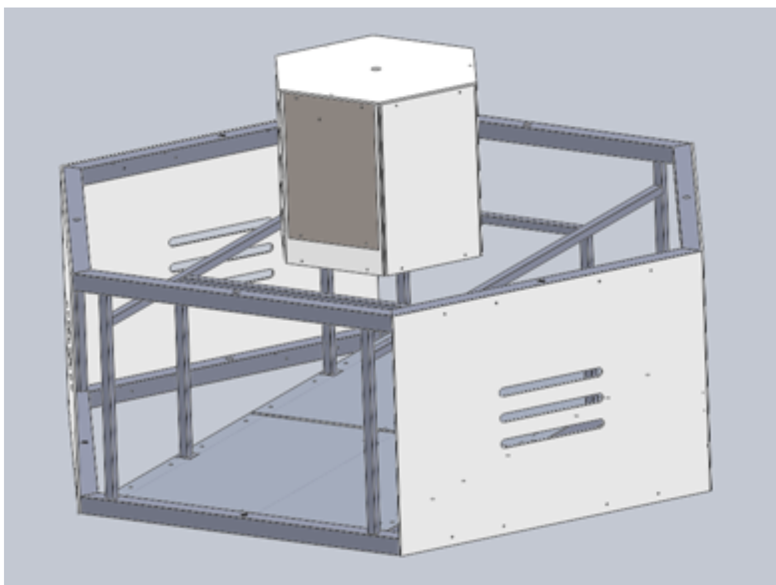

Figure 44: Frame assembly drawing.

Table 11 lists the dimensions proposed for the frame and exhibit, given in inches and approximations in feet for reference.

Table 11 – Hexagon Geometry		
	Length [in]	Approx. Length [ft]
Maximal diameter (bottom hex)	78	6.5
Minimal diameter (bottom hex)	64	5.3
Overall exhibit height (floor to top)	50	4.2
Inside storage height	20	1.7
Bottom hex interactive side length	39	3.25
Upper hex interactive side length	12	1.0

The maximal diameter is the distance from one corner of the bottom hex to the opposite corner (long diagonal). The minimal diameter is the distance from two parallel edges located on the bottom hex. The overall height is proposed to be from the floor up to the flat surface on the upper hex. The inside storage height is that from the bottom aluminum plate to the beam above in which the basin rest on. This is the effective height that is usable under the basin. The interactive side length is the active side where a visitor would interact on based on the upper or lower hex. This gives a good idea on the overall size of the exhibit that will replace the current water table.

Siding
Another important part of the exhibit is the exterior siding used to cover the frame. Again since we want the material used to be weather resistant and UV resistant, high-density polyethylene (HDPE) will be used for superior protection. HDPE is the industry standard for playgrounds because of its UV resistant properties without changing chemical structure. The sidewalls will be of quarter inch thickness and 28 x 39 in. By using this material as siding, the exhibit will have an aesthetically pleasing exterior, that is UV resistant, durable, that will also prevent users from accessing the interior of the exhibit where all of the electrical components, pump, and plumbing systems are located.

Access Door
This exhibit will need to have access to the underneath basin area for routine maintenance and if plumbing, electrical, or flow rates every need to be serviced. In order to make maintenance easy for the customers we incorporated two access doors with locking capabilities located on either side of the exhibit that allow for access to the interior of the exhibit. These access doors will be mounted onto trailer hitch pins for easy removal. The trailer pins are welded onto the backside of the frame, also, so that the user does not have to worry about having it drop when removing the access door.

Mobility and Leveling
A feature requested by the sponsors was the ability to transport the exhibit when needed. In the design process, we also came up with a requirement of the need to level the exhibit to have evenly distributed water flow over the top hex. We were able to come up with a solution that satisfied both the transportation requirement and also the leveling requirement with the same feature. The solution was with the selection of the GD-60S leveling stem casters, which can be seen in **Figure 45**.

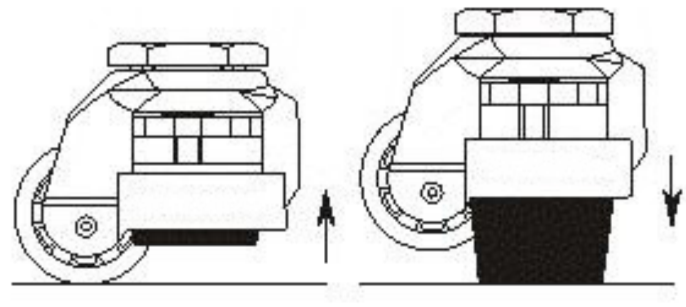

Figure 45: GD-60S leveling stem casters.

These casters swivel with bearings and also have a leveling component that firmly keeps the exhibit fixed in place. Each caster can support a load of 550 lb.-force. The entire frame will sit upon four leveling casters, which combined support 2,200 lb.-force and allow for transportation across the front patio. The leveling of the entire exhibit can be accomplished with little effort on the user's part.

In order to keep the exhibit as low to the ground as possible for children to interact, we decided to change the caster location on the main hexagon steel frame. We added another four 2”x2” square tubing beams on top of the bottom supports of the frame, all of which will have drilled holes to fix the casters into place. By moving the casters to this location, this will lower the entire exhibit another two inches, making the ground-to-basin-interaction height equal to 24 inches. We chose to place the casters symmetrically around the exhibit, and in locations that would minimize tipping in any direction. We do not believe tipping will be an issue regardless, as the frame-to-floor clearance will only be 1-1/2 inches.

The addition of these steel beams will add another 6 feet of square steel tubing to the frame, resulting in a price increase of approximately $17. The beams will be welded to the frame at the same time as the rest of the frame. The location for caster fixture beams is shown below in **Figure 46**.

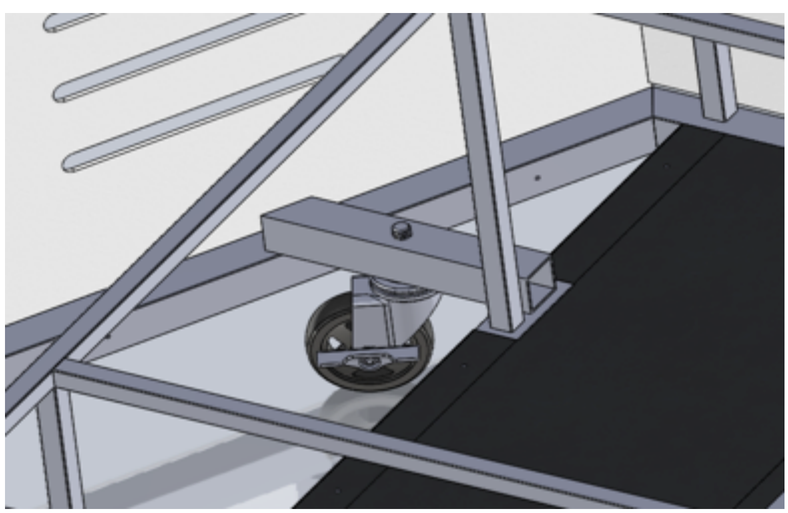

Figure 46: Caster location in frame assembly.

Structural Analysis

After we designed the frame, we conducted three types of structural analysis calculation to ensure that the frame is strong enough to support the load due to the water weight in the basin. The following analysis performed was buckling, deflection due to bending, and axial deformation due to a vertical load.

Buckling calculation
Buckling occurs in a vertical column when the critical load applied to the member is reached. However, it may happen that as the load is applied, the column buckles. Instead of remaining straight, it suddenly becomes sharply curved such as shown in **Figure 47**.

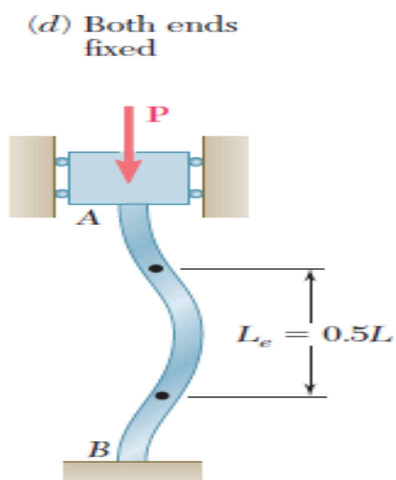

Figure 47: Buckling phenomena.

Clearly, a column that buckles under the load it is to support is not properly designed. In our design we have several vertical members, especially in the center of the frame as highlighted in **Figure 48**.

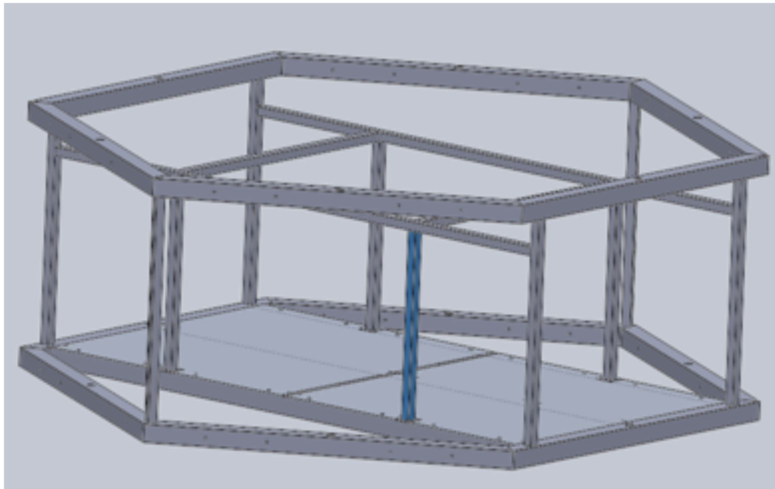

Figure 48: Vertical member in frame to undergo loading.

We purposely overestimated the load applied to one vertical column as 1500 lb-force to determine the critical load of this member. In reality the true load would be around one-half of that value.
Euler's buckling equation was used for this analysis (see Appendix I) and the results for one column under a 1500 lb-force load with other end conditions came to be:

$$P_{cr} = \frac{n\pi^2 EI}{{L_e}^2}$$
$$P_{cr} = 110{,}376\ lb_f$$

$$P_{allowable} = 1{,}104\ lb_f \text{ per beam}$$

This means the allowable load able to be supported by a single member without experiencing buckling came out to be 1,104 lbf. Since the actual weight is to be distributed among all the vertical members, each one of these members would share the load. Therefore, we are not concerned with buckling of the frame.

Deflection Due to Bending
The next type of analysis conducted was the deflection in the beam due to bending. Bending can be observed in **Figure 49** on the right side.

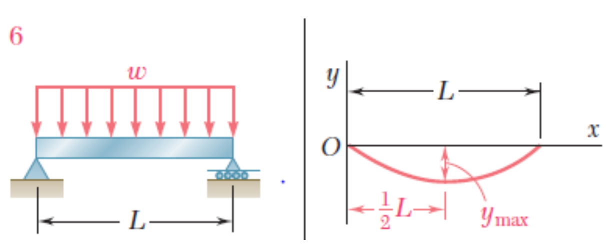

Figure 49: Bending phenomena under distributed load with two fixed ends.

We have a few cross members that will be supporting the load and we wanted to make the cross bars sure did not have a deflection greater than 0.1 in. that can be seen highlighted in **Figure 50**.

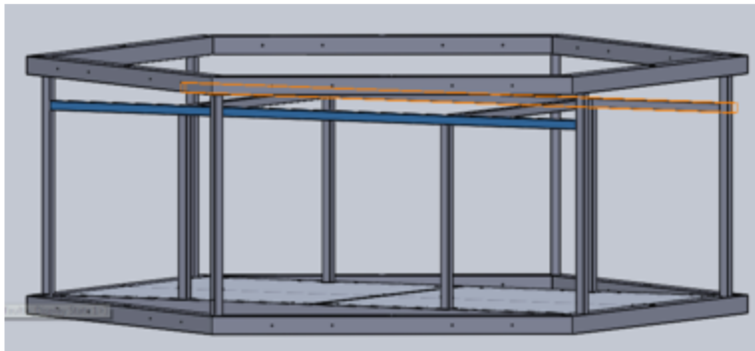

Figure 50: Vertical member in frame to undergo loading.

We again overestimated the vertical load to be 1500 lb-force acting directly in the center of the exhibit. Using the deformation equation of a simply supported prismatic elastic beam, the distributed load was determined to be:

$$= \frac{1500\ lb_f}{32\ in}$$
$$w = 46.875\ \frac{lb_f}{in}$$

So total deflection per beam is:

$$\delta = -\ 0.198\ in$$

Since this value was recalculated using the overestimated load of 1500 lb-force, we calculated once again based on more realistic values of 750 lbs force.

The new resulting deflection came to be:

$$= -\ 0.099\ in$$

This value was within reasonable range and is still a conservative value since in reality, the entire load is not acting as a concentrated load in the center area of the table as modeled, but truly as a distributed loads across the entire top surface of exhibit.

Axial Deflection (compression)
The final analysis we performed on the frame was the axial deflection (compression). This results from a load being applied to a member where the member actually compresses and shrinks while under the load. The same vertical member that was considered for buckling, is considered here for axial compression. We again overestimate the vertical load to be 1500 lb-force acting directly on the vertical column.

The axial compression based on the 1500 lb-force was determined to be:

$$\delta = -0.0029\ in$$

One vertical column carrying entire vertical load will compress 0.0029 in. This value was considered satisfactory even though the load was overestimated. Please see **Appendix I**. for the complete structural calculations.

Our team was awarded $2500 from the Baker-Koob grant, for participating in a project that is directly benefitting the community. We used this award value as a target to shoot for when designing the exhibit, as we did not want to underutilize the resources that were graciously being donated to us by the Baker-Koob foundation. However, during the design process, we quickly found ourselves using up the budget far more quickly than anticipated. Currently, our exhibit's price is very much over budget, with the system level cost breakdown shown in **Table 10.**

Table 11: Exhibit Cost Breakdown

SUBSYSTEM	SYSTEM DESCRIPTION	
Electronics	Components comprising the sleep mode system as well as anything used to power the exhibit.	$147.65
Basin	Main body of the exhibit, where all features will be held. Price includes the cost of creating a relief for the fiberglass	$1492.36
Plumbing	Pump and water routing system. Any component between the storage reservoir and outlet spouts in the basin.	$620.05
Frame	Structural form of the exhibit. Includes all raw steel material and anything that directly connects to it.	$1548.94
Outsourced Service	Any work that we paid someone else to perform (i.e. welding,)	$150.00
	Exhibit Cost	$3338.95

Currently, the most expensive expenditures of this include the materials required for fiberglass layup, square steel tubing, and HDPE sidewalls. While these are all technically luxury components, we are confident in their value to the overall exhibit.

5. Product Realization

While a large majority of fabrication responsibilities will be in our hands, some work will be outsourced to local trade workers in the San Luis Obispo. Due personal manufacturing skill level, namely in welding stainless steel, we did not want to be responsible for ruining those materials or providing a low-quality exhibit. However, there is a large amount of manufacturing that our team plans to do ourselves in the Cal Poly machine shops. The following sections will detail exactly what fabrication we will take into our own hands, and what work we intend to outsource, with respect to each subsystem. Please reference **Appendix K** for additional information regarding the manufacturing procedures for each subsystem.

Basin

George Leone, supervisor at the Cal Poly Hangar machine shop, has been a source of advice for the feasibility of using fiberglass for the basin. As a plumbing license holder, and having shaped and glassed surfboards since the 1970's, he is a reputable resource and bank of knowledge when it comes to using and forming composites. Under his supervision, we intend to manufacture the entire basin in the machine shop at Cal Poly. George has also been very helpful with educating us on safety information in regards to the process of making the fiberglass layup. Please reference the section of this report that touches on pertinent safety procedures during manufacturing.

To make the basin, we first created a relief mold so as to have a shape for the basin to form to. The relief consisted of plywood sheets and two-by-four common board, fastened together with wood glue and brad nails. All of the common board sidewalls were cut first, using the miter saw. We first cut the 15 degree draft angle by adjusting the bevel angle to 7.5 degrees, followed by the ends of the board by adjusting the end angle to 30 degrees and cutting with the draft angle flat on the table. This helped solve much of the problems that we were having during prototyping with the gaps in the corners of the mold from the sidewalls not lining up. After nailing together all of the sidewalls, we used two plywood sheets to construct the hexagonal topper. Two plywood sheets were required as the total length across the full size basin exceeds the stock 4x8 dimensions that plywood can be purchased in at Home Depot. We made two half-hexagon shapes, and joined them with 3 plywood joints along the length of the middle, as is shown below in **Figure 51.** The plywood top is fixed to the sidewalls, and any of the over hang is cut off using a jig saw and power sander. Finally, plywood flanges were attached around the entire perimeter of the sidewalls, and then cut down to a uniform stick-out length of 5 inches long using the jig saw.

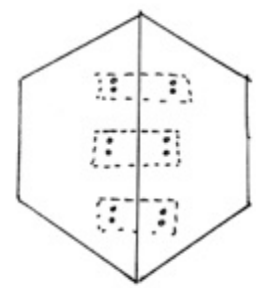

Figure 51: Visual for how to attach the two halves of the plywood hexagon. The dotted lines denote the strips of plywood located directly underneath the two halves. Circles denote where nails were applied.

Once the wooden mold was fastened together, we covered the entire surface of it in Bondo all-purpose putty. Bondo uses a benzoyl peroxide cream hardener to oxidize the putty and harden it to a sandable surface within 15 minutes. The putty was applied using plastic spreaders that we cleaned in acetone after every use in order to keep a clean, sharp edge. Because it was such a large surface area to cover using putty, we would lay on about 2-3 coats in different locations on the basin, sand those spots down to a medium-smooth finish using 80 grit sandpaper, and then continue to apply Bondo wherever there was wood showing. While using a power sander was helpful to remove most of the big grooves and dried pieces, it did require a delicate touch. If we were not careful, it was very easy for the power sander to completely eat through the layer of putty that was just laid down. Thus, sanding by hand was tedious, but the preferred method for working out the smaller surface defects in the mold. When applying Bondo in the corners (where the flange meets the side wall), we used the curvature of our thumb to run along the length of that connection and create a smooth fillet. A rounded surface here makes it much easier to remove the mold from the fiberglass. Once the Bondo coating was to our satisfaction, we used 150 grit sandpaper to work out many of the small grooves and lines, followed by 320 grit and 400 grit to finish down to a very smooth finish surface.

After sanding down the Bondo layers, we took the basin mold up to the paint booth at Hangar for the next step of surface preparation. Here, we used a spray gun to apply Dura Technologies ("DuraTec") sanding primer to the entire surface of the basin. After opening the DuraTec, we mixed the liquid with a large paint stick, making sure that we scraped the bottom of the can to pick up any particulates that might have settled. 1 pint of DuraTec was mixed with an additional 5% ratio of Dura Technologies thinner (to allow for easier spraying and faster cure time) and a 2% ratio of methyl ethyl ketone peroxide (MEKP) catalyst. Without the added MEKP, the DuraTec would never dry and adhere to the surface. With the pressure line set to about 35 psi, a first light coat was applied, left to flash off for about 3 minutes, and then followed up with 3 heavier coats. After spraying approximately 3 pints of the sanding primer onto the basin, it was left to cure overnight. Immediately after spraying, the gun was taken apart and cleaned using copious amounts of acetone, as drying DuraTec can clog and ruin a spray gun within minutes. Then, we did one last pass of sandpaper, ascending from 80 through 150, 320, and finally 400 grit. **Figure 52** shows our team in the spray booth applying the DuraTec sanding primer. It is important to note that we utilized the use of gloves and organic vapor masks to ensure our safety during the spraying process.

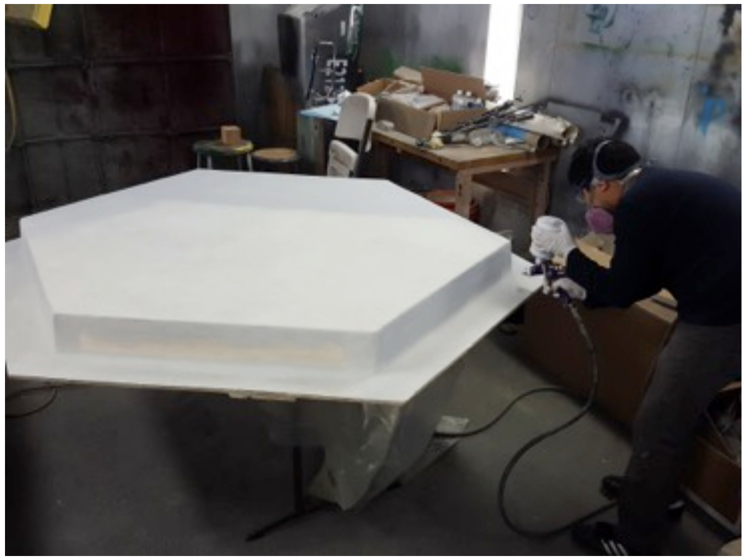

Figure 52: Heriberto in the Hangar paint booth using the spray gun to apply DuraTec sanding primer.

By now, the basin mold is incredibly smooth, but if fiberglass was to be applied, it would not be able to release. One of the last steps in the surface preparation process was to apply a mold release wax called "Part-All" to the entire surface area. Using two pieces of an old t shirt, wax is first applied onto an area about 4 square feet, left to dry for one minute, and then immediately buffed off using the other dry cloth. We applied 6 total coats, and the basin was left to dry for one hour after every two coats. Next we applied polyvinyl alcohol (PVA) mold release laminate. The PVA was poured directly into our spray gun without any other additives, and sprayed onto the basin using a wide spray fan at approximately 25 psi. 8 coats of the PVA were sprayed on, allowing for 5-8 minutes of drying in between each. While the PVA does dry sufficiently quickly, it was important to not rush the process and let it puddle up on the surface. At this point, the remaining PVA was dumped out of the spray gun, and distilled water was poured in. One extremely light coat of distilled water makes all of the PVA spread and smooth out, creating the perfect surface finish for the laminate (because PVA is water soluble). Once the basin was left to fully dry, the surface preparation was completed. **Figure 53** shows what the basin looked like once the final layer of PVA was applied. If desired, the user could use their fingernail to peel off a tiny bit of the edge of the laminate just to check thickness of the mold release layer.

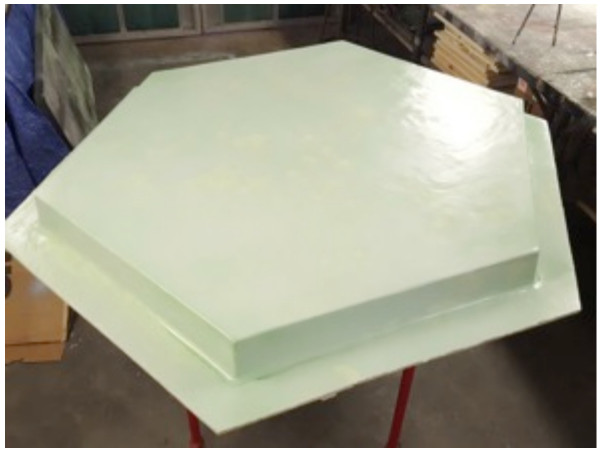

Figure 53: Basin mold with after the final layer of PVA mold release was applied.

Upon the completion of the surface preparation, the fiber glassing process was started. This first required us to apply a layer of gel coat to the mold. “Nile blue” pigment was mixed into the can of “brilliant white” gel coat until the correct color of gel coat was achieved. Then, MEKP catalyst was mixed with the liquid gel coat and a thick layer was brushed on with a 3” brush over the entire surface area of the basin. Reference **Appendix F** for a chart with guidelines on mixing ratios for MEKP with polyester resin. Special attention was paid to the sidewalls, because we wanted to avoid runoff from gravity that could thin out the gel coat in these areas. While allowing the gel coat to dry in the sunlight for approximately 1 hour, the matte fiberglass cloth was ripped by hand into squares approximately 1.5ft x 1.5ft. It is important that we tore off the edges of the cloth, so that it is only exposed cat hair on all edges of the square pieces. This is so that no large bumps form when resin is applied over the hard edge, and thus the pieces of cloth lay over each other more seamlessly.

Multiple people were required during the application of the resin. MEKP is mixed into the resin, and one person’s job during this process is to coat the cloth with resin, and lay that piece down onto the mold. Then, everyone else would use 1” paintbrushes to remove any bubbles that might have formed, using a poking motion from the middle of the cloth out to the edges. This process is continued until the entire mold has been covered with 2 full layers of fiberglass cloth. Finally, one layer of 6-ounce cloth was laid over the entire exhibit to have a final clean surface finish on the outermost layer before being allowed to cure overnight. When pulling the mold from the fiberglass, we used a rubber mallet, a paint scrape, and many wooden wedges made by just running scrap wood through the band saw. We first found a spot along the edge of the fiberglass that we were able to pull up with our hands, and used the paint scrape to separate other spots adjacent to it. The wedges were set into these places and then hammered into place to release much of the fiberglass. We used the rubber mallet to hit the top of the mold, which helped to shake around the fiberglass and release more smoothly. The fully released fiberglass basin is shown below in **Figure 54**.

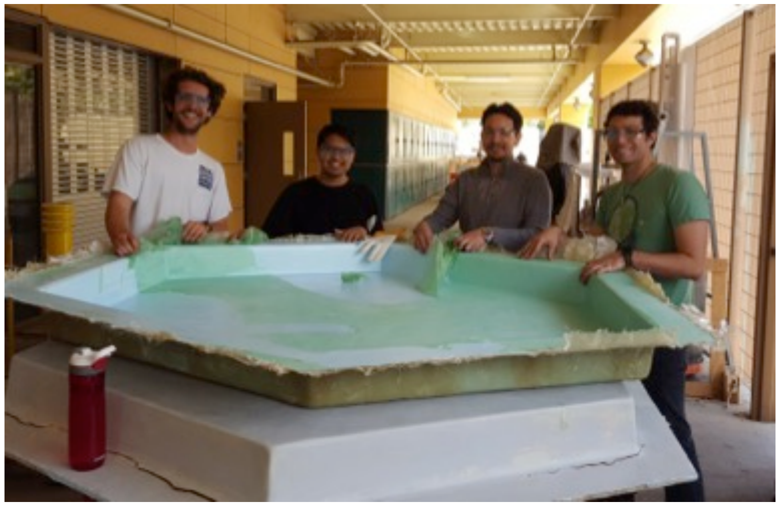

Figure 54: Team Water Fun standing next to the freshly released fiberglass basin. The green hue is from the PVA mold release laminate that was then peeled off.

Frame

After acquiring the steel for the frame of the exhibit, the metal was cut to the proper size and angle using a chop saw. 12 pieces of the 2in x 2in steel tubing were cut with 30 degree angles at each end to allow the metal to fit together in a regular hexagonal pattern (six pieces were used for the upper hexagon, and six for the lower one). The ends were then briefly sanded using a belt sander to remove rough edges and make the cuts more uniform due to the chop saw's low precision. 5/16in holes were then drilled into these bars (using a drill press) to allow the siding to be attached later with 1/4in bolts. Instead of using an angle finder and clamping the sides together in a regular hexagon, the metal was placed around the outline for the fiberglass basin. This was to ensure that the frame and basin would fit together properly. After laying out one hexagon (six pieces) the tubing was then tacked together to allow us to remove the basin relief during the actual welding process. Once the first hexagon had been welded, the bars for the second hexagon were placed on top of the first one and tacked to allow us to replicate the shape. With both hexagons completed we were then able to move on to the next step of the frame.

Six vertical members of 24in were then cut from 1in x 1in stock to hold the two hexagons apart. A small hole was drilled into each member to vent gasses during welding and prevent a dangerous pressure buildup. Magnetic squares and a level were used to properly align each vertical member before they were tacked together and welded. The frame was then measured before cross members (2in x 2in for the reservoir supports and 1in x1in for the basin supports) were cut, drilled, and welded into place.

Finally caster support members were cut from 2in x 2in stock and welded in four of the frame's corners to lower the overall height of the frame basin. This addition was requested by our sponsor to make the exhibit as accessible as possible for small children.

With the main frame completed we were able to attach casters to the caster support members, and attach siding. The Casters were simply bolted to the frame, while the siding needed additional preparation. Siding was clamped to the frame and bolt-holes were drilled using the holes in the frame to guide the drill. Trailer hitch pins were tacked in place on the two door sides to allow for the door panels to be easily removed for access to the internal components. Due to the custom nature of the basin, and therefore frame, each side panel must be paired with the correct side to fit properly. The sides of the frame are labeled as follows: the door side with a vent hole facing upwards is side one, and the rest of the sides are numbered sequentially as you move counterclockwise around the frame.

After preparing the siding, the frame was then scrubbed clean to allow us to apply a protective coating to prevent rust. First a coat of primer was painted on all sides of the frame. After 24 hours (once the primer had fully dried), a topcoat of grey Rust-Oleum paint was applied. With the protective coating in place the panels could be reattached to the frame. **Figure 55** shows the completely painted frame below.

Figure 55: The completed frame prior to Rust-Oleum paint application.

The smaller hexagonal frame was built using a similar process, however instead of welding it ourselves (as we did with the large frame) we outsourced the work to professional welder Chris Gentry. The smaller frame was made of stainless steel to resist rusting when partially submerged in the basin. This material choice made the welding process more difficult, and after saving money by welding the frame ourselves, we decided to not risk damaging the materials or producing low quality welds.

Electrical System

All of the components in the electrical system were either bought or donated, so it was just a matter of putting the parts together and programming the microcontroller. The activation time and triggering distance of the sensors had to be adjusted by turning the knob corresponding to the triggering distance counterclockwise and the one corresponding to the activation time clockwise using a screwdriver. Each sensor has three connections to which we soldered 22-awg wires onto. The switch that we included also has three connections, but we only had to solder wire onto the ends. The last component that required soldering is the 9 V battery because the wires of the battery clips are fragile and we did not get a reliable connection when we attached them directly to the breadboard. The arduino nano has female PCB header connectors so we used DuPont wire and a breadboard to make intermediate connections between the microcontroller and the other electrical components shown on the wiring diagram. The wiring diagram does not show the breadboard in order to make the connections clearer.

In order to program the Arduino we used the Arduino Development Environment and we made the app using the MIT App Inventor 2. The MIT App Inventor 2 is a website that provides a graphical user interface that allows you to make apps with minimal programming knowledge. The block diagram for the app we made is shown below in **Figure 56**.

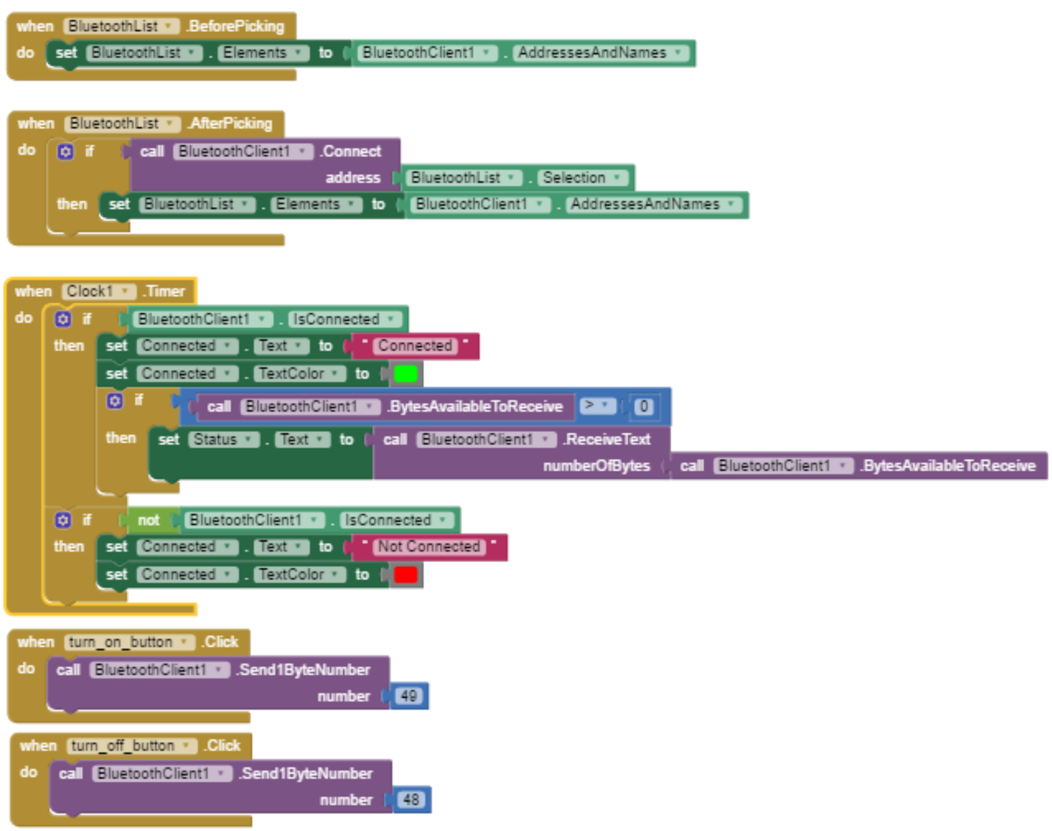

Figure 56: Block Diagram for Sleep Mode App

The first block provides a list of the Bluetooth devices that your phone can connect to. The second block establishes a connection between your smartphone and the Bluetooth module. The third block checks whether a connection was established. If a connection was made, then it updates the status of the connection and changes its color to green. It also check to see if we get any text sent from the Arduino. It will send text when you decide to turn on or turn off a pump and the status of pump will be updated in your phone screen. The last two blocks send data to the Arduino when either button on the screen is pressed. If the 'Turn ON' button is pressed the decimal value 49 is sent to the Arduino, which is the ascii value for the character '1' and if the 'Turn OFF' button is pressed, the decimal value 48 is sent which is the ascii value for '0'. When the microcontroller receives this data it either turns on or turns off digital pin 13 depending on what data it receives, then it sends text to your smartphone to update the status of the pump.

There are three important tutorials that we followed in order to interface the Arduino with the motion sensors[14], Bluetooth module[15], and for making the Android app[16]. The app provided is called the *Sleep Mode App* and its file type is apk. This app can be installed and used on any Android device. Before transferring the app from your computer to your smartphone you need to install a file manager app to facilitate locating the app. We recommend installing the file manager app called *My Files*. Next you can transfer the app from your computer to your smart phone. We explain how to use the app in the operations manual, but a brief summary follows. First, you need to turn on the Arduino Nano by flipping the switch. If there is a flashing LED in the microcontroller, then it is receiving power from the 9 V battery. Second, open the Sleep Mode App and connect to the Bluetooth module by clicking the Bluetooth symbol and selecting the Bluetooth device Y. Once you are connected you can use the buttons in the app to set the state of the pump.

Plumbing System

In order to construct the plumbing system for the exhibit, we were able to find most of the plumbing supplies at the local Home Depot. These supplies included: PVC pipes, reducers, expansions, tee's, 4 way fittings, PVC braided tubing, hose clamps, bulkhead fittings, drain valves, and various adapters. In addition to the immediate plumbing parts used, a variety of plumbing tools were needed such as: PVC glue, Pipe cutters, Teflon tape, and drills cutters for supply holes.

When installing the drain in the water storage reservoir below the exhibit, a 1-¾" hole was drilled into the side of the poly stock tank using a Hole Dozer Hole Saw along with a power drill. The edges of the holes were finished with a metal file to ensure that the fitting would fit flush with the surface. After filing, the PVC bulkhead was inserted into the hole and tightened. Next two PVC adapters along with the ½ drain valve were installed into the bulkhead fitting with Teflon tape wrapped around all threads. This completed the install of the required drain on the reservoir. **Figure 57** shows a picture of the installed bulkhead and drain assembly in the reservoir.

Figure 57: Drain assembly installed in reservoir tank.

In order to supply water to the eight water outlets on the upper basin, a rigid PVC supply fixture was to be designed to distribute the single high volume flow rate discharge from the pump into eight individual flows that could each be regulated by ball valves. In order to accomplish this task, it was determined to construct a rigid PVC piping system to be connected directly into the discharge outlet of the pump. Individual water lines would be provided and PVC hoses would be attached to this rigid fixture, running hoses to each outlet on the basin. **Figure 58** shows the rigid PVC supply fixture created to supply water to each individual outlet.

Figure 58: Rigid supply fixture connected to pump shown during operation.

To construct this supply fixture, a 1-½" to 1-¼" " threaded fitting was attached to pump discharge outlet. Next, 1-¼" PVC pipe sections were cut for various sections of the rigid fixture. A 1-¼" tee was installed in the middle to have 4 outlets on the left side and 4 outlets on the right side (symmetrical). Next, 4-ways fittings and tee fittings were installed on both sides of the fixture along with four other straight PVC pipes. This horizontal piece was designed to be 32" in width in order to rest and be supported by the sides of the reservoir in which the pump sits. Next, smooth walled adapters were added to each outlet in order to reduce the pipe from 1-¼" to ¾" . All of the PVC pipe sections along with the smooth walled adapters were joined together using PVC primer and glue. Next ½" risers and ball valves were installed to each outlet using Teflon tape to seal any potential leaks. Finally ½" hose fittings were added to each outlet using Teflon tape in order to make the connections to the PVC vinyl hoses. This completed the construction of the rigid PVC supply fixture.

After the holes were drilled in the fiberglass basin, it was time to install the PVC bulkheads that would create a tight seal to prevent leaks and also make connections to attach vinyl tubing supply lines. **Figure 59** shows a picture taken after drilling a few of the smaller holes in the fiberglass basin to accommodate the ¾" bulkhead fittings. With a few initial holes drilled, we were able to test fit the bulkheads into place to determine fit.

Figure 59: Holes drilled in fiberglass basin to test fit bulkhead fittings.

There were a total of ten ¾" PVC bulkheads installed on the exhibit. Four were installed for the interchangeable pipe feature, three for the circulating jets, one for the basin drain, and two for the water dome (one on the basin and one on the upper hex). These were simply installed by placing the seal side of the bulkhead on the top of the basin surface and the washer and nut components on the bottom side of the basin surface. The nut was tightened in a counterclockwise direction unless as tight as possible by hand. Next, the ¾" bulkhead was attached on the upper hex, top HDPE panel for the water dome feature. Lastly, two large 2" bulkheads were installed near the center of the basin to create the overflow (weir drains) needed to maintain the water level. These bulkheads were installed in a similar fashion. In order to maintain the 3" water height in the basin, 2" couplers were installed into these 2" bulkheads using Teflon tape on the thread. Once these couplers were installed, the heights of the drains are nearly at 3" and will ensure the water level does not exceed this height. In addition, 2" couplers were installed on the underside of the weir valves in order to drain water back into the reservoir.

To connect the rigid PVC supply fixture to each individual water outlet (bulkhead fitting), we used ¾" inner diameter PVC braided tubing to make the connections. We used this tubing for ease of installation and to eliminate permanent PVC hard piping that would be difficult to repair.

To make the connections, we measured the length of tubing needed from each bulkhead fitting to the designated supply outlet on the supply fixture. Once measured, we cut the tubing using the PVC pipe-cutting tool. With tubing cut to length, nylon fittings were installed on the inlet side of the bulkheads (underside) using Teflon tape. The tubing was press fitted onto the nylon tubing; for leak protection, a metal clamp was placed around this hose/fitting connection. The same types of connections were made at the rigid supply fixture for the inner four outlets. In regards to the outer four outlets, we noticed leaks coming from these connections and wanted to eliminate them. To do this, we removed the black press fitting on the rigid supply fixture, and replaced it with a ½" smooth grey pipe riser. In order to slip the ¾" vinyl tubing over the ½" riser, we applied small amounts of hand soap to lubricate both ends. Once lubricated, the tubing was press fitted onto the riser followed with a metal clamp. This eliminated any leaks coming from the outer four outlet supply connections that would continuously drip outside of the reservoir.

Manufacturing to be Completed
Some steps in the manufacturing process are still considered unfinished at the time of Senior Expo. Among these include:

- Resign and printing of the 3D sensor casings.
- Installation of the sensor casings. This will also require drilling the appropriate mounting points on the plastic siding.
- Apply silicon sealing for the leaks at the 3 bulkhead fittings in the middle area of the basin. This will take place the weekend after Senior Expo, as a 24-hour cure time is required for the sealant.

6. Design Verification

Prior to assembly of the exhibit, our team had designed a number of testing procedures to qualify the success of the finished product satisfying the engineering specifications outlined (see **Table 1: Engineering Specification Table**), as those provided a measurable means of meeting our customer's needs. To see these specifications, please reference **Appendix J** for our Design Verification Plan (DVP). To see a complete list of testing procedures, please reference **Appendix L**.

Due to time constraints, our team was not able to completely test each subsystem in the depth that we would have liked. However, some informal tests were accomplished by the time that senior expo had come around. The following sections describe the testing that was completed, and the results found from those tests.

Sensor Sensitivity and Calibration Testing
The triggering distance of the sensors can be changed from 9ft to 21ft and we tested one sensor at its lowest setting because that is the setting that will be used for all sensors. We tested this by starting 20ft away from the sensor and walking towards it while monitoring whether motion was detected using the Sleep Mode App. The max distance where motion was detected at the lowest setting of the sensor was 15ft, unlike the datasheet of the sensor stated. Although this test failed, it does not mean that using these sensors is unreasonable. There might be situations where the pump will inconveniently turn on due to the sensitivity of the sensors, but that is one of the reasons we included a switch: to shut down the microcontroller.

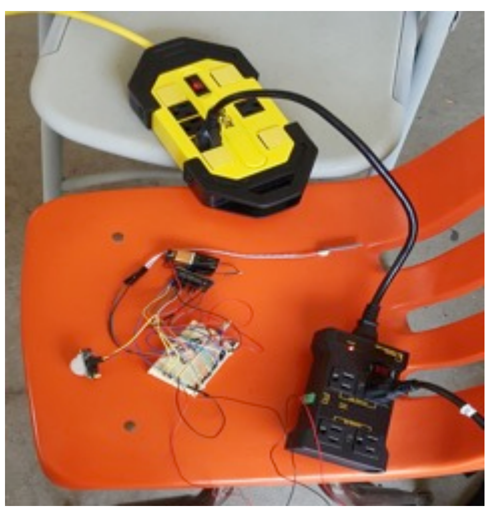

Figure 60: Testing triggering distances for PIR sensors.

Plumbing System Outlet Valve Flow Rates
Since the reservoir, pump, and PVC piping components were completed early and the final fiberglass basin would not be completed until later in the quarter, we felt it would be good to test for the desired flow rates from an outlet hose without the basin to get a basin on performance. We completed this test similar to the method we used when testing the prototype back before CDR. This method consisted of recording the time it takes to fill a five gallon bucket assuming that every time we filled the bucket it was near five gallons collected. **Figure 61** shows a picture during a flow rate testing trial conducted by our group.

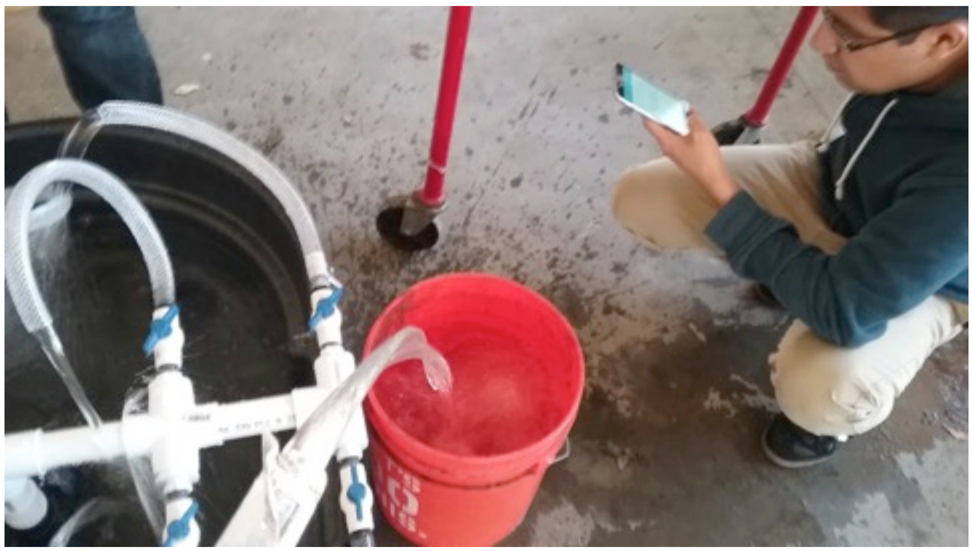

Figure 61: Measuring flow rates from an outlet tube.

To begin the test, we connected all supply pipes to each outlet and turned on the pump. We then dialed back each ball valve to put some backpressure on each line to reduce cavitation. Next, we raised two long hoses up to waist level to increase the head required by the pump and to simulate the actual height of the basin. Once the pump reached steady state, we began filling the bucket and simultaneously timing with a stopwatch until filled to the required height. The figure above shows the flow rate from one hose at waist level height filling the bucket. We did three trials to using the same method.

After performing the flow rate test for this individual hose, we calculate the flow rate and it was approximately 7 GPM. The desired flow rates needed from the prototyping phase were between 1.69-1.89 GPM. So based on this preliminary testing, the flow rates are well above the calculated values and the pump is delivering enough flow to each outlet. This gave us confidence in the pump selected and plumbing fixture design, so we were able to focus on other aspects of the exhibit. The next major test for flow rates would be when all hoses and connections are made with the basin to give an accurate representation of the head and flow rate that the pump would need to supply and overcome.

Hazard-Prevention and Safety Design
Due to the fact that small children will be interacting directly with the exhibit, our team wants to ensure that there are no hazardous features on the exhibit when we give it to the Exploration Station. During the design process, we wanted to find ways to avoid having these issues arise. Primarily, the main hazards

associated with our exhibit were based on the proximity of water to electrical equipment and a few other concerns regarding the frame of the exhibit. Please reference **Appendix A** for our safety hazard checklist.

Electrical

To avoid potentially dangerous scenarios of electrical equipment coming into contact with the water from the exhibit, we have included a ground fault circuit interrupter (GFCI) into our design. Located inside the storage area of the frame, the GFCI steps into action when an electrical surge is happening somewhere in the system. The entire load is directed towards the GFCI, saving the person who otherwise would have been electrocuted. GFCIs are a one-time use device that will need to be replaced once tripped. The GFCI that we will be purchasing costs $46 on Amazon.com.

Frame

The structural components of the frame of the exhibit are made entirely of steel. The exhibit is anticipated to sit outside, subject to the heat from the sun all day. Thus, it will easily become very hot after a short amount of time, especially in the summer and fall months. Our team wanted to avoid the possibility of the user touching the hot metal sides of the frame and burning their hands. This is one reason why we chose to use HDPE side panels along the exterior of the exhibit. This heat resistant plastic will allow for the children to run up and lean against the exhibit. Additionally, the top hexagonal surface will be covered with a flange from the fiberglass basin, so that the entire top surface is not a hazard as well.

In addition to the steel structural components becoming hot in daylight, the frame also poses a potential hazard in that it has a self-contained 60-gallon reservoir with a submersible pump located inside of it. This could potentially be considered a drowning hazard if a small child was able to get inside of it. We designed the frame to prevent this however, by installing locking pins for a trailer hitch on the accessibility doors, so that nobody can get into the internal components without pliers to pull off the pin. Because the entire frame will only sit on top of 2 inches of caster clearance, we are not concerned with anyone being able to get into the internal components by going underneath the exhibit.

The exhibit will be located outdoors on a concrete patio, and due to the short sidewall heights in both the basin and the reservoir, overflow and spillage can be a concern. The operator should post signs in the area around the exhibit reminding visitors to only walk when using the exhibit. Supervision and enforcement of this precaution is strongly encouraged.

Basin

The fiberglass basin has two main safety concerns associated with it. First, the tub sits directly into the frame with nothing actually fixing it into place besides the weight of the water held inside. Because of this, if small enough fingers were to reach into the area between the fiberglass and the steel frame, then they could be potentially pinched. This is not something we are overly concerned with

Plumbing

The Alpine Cyclone pump used to power the plumbing system is a submersible pump that runs on a 120V power source (standard wall outlet). Due to the close proximity of water to electrical sources, shock hazard is a real threat. First and foremost, all electrical equipment should always remain plugged into the GFCI during exhibit use, so that if an electrical hazard was to take place, then the user would be protected by the GFCI breaking the circuit. In the event that a GFCI is tripped, it is imperative that the hardware is replaced with a new one. Additionally, the electrical equipment should always be protected in a water resistant casing, and stored at an elevated surface away from locations where puddles can form.

7. Conclusions and Recommendations

Should our team have the opportunity to go back and proceed with a second iteration of exhibit design and manufacturing, there are a number of changes that we would make. First, it is recommended that (should the shape of hexagon be decided on again) then the team should design and machine our own lugs for fixing together pieces of the frame. The number of issues that this geometry created for our team throughout the project was fairly considerable. When the frame steel was cut using the chop saw, inconsistencies in finish tolerances led to us having to improvise the forming of joints. Had we been able to use 60° square lugs (which we were not able to find on the internet) then it would have made frame assembly much easier, and if compatible materials for beams and lugs were chosen, then the two could have been welded together for additional support.

Another change that our team would make is using a material other than stainless steel for the frame of the smaller hexagonal structure in the middle of the basin. The weight of the frame is a concern, and causes a lot of unwanted deflection in the very middle, which can be considered one of the causes for the leaks that we are currently experiencing from the bulkheads in that area. Using another material, such as PVC or some other kind of plastic would be less expensive, easier to manufacture, and place less stress on the extremely valuable basin that it is resting upon.

Additionally, the drains that we have installed do not allow for very much flow out of the basin and the reservoir. More functional drains with a wider valve opening size would be installed in these locations to allow for more efficient draining of the system. Also, for the drain on the reservoir, we did not take into account that the user cannot just attach a hose and funnel the water wherever they want. A certain amount of head is required to move a fluid, and having the outlet tap at the bottom of the tank does not allow for this.

Support for the basin is another item that we would want to make changes to if given a second iteration for the project. First, a lower catalyst ratio would be used in the resin mixture to extend the cure time. We found that many bubbles had begun to harden before we were truly able to work them out of the cloth on the mold, and thus caused future problems for the structure of the basin. Additionally, another layer or two of resin would be applied, increasing the rigidity of the system, and adding extra layers of thickness. Doing this would have required another 5 gallon bucket of resin and a few more yards of cloth, however, which is completely out of our price range to make feasible. A final way to increase supports to the basin would be adding an additional cross bar in the supporting area directly underneath the basin to help with the vertical deformation experienced at the center region of the basin.

The most critical change that we would make if given a second chance is that we would have asked for far more funding than we did. Not enough detailed preliminary design was accomplished before sending off the application for grant funding, and we can confidently say that we were very wrong with how much money was really going to be required to fund all of the parts. The materials just for carrying out the fiber glassing process of the full size basin cost almost $400 alone (one-fifth of our entire budget). Had we done more research in the preliminary design stages and had a better sense for the quantity of materials required for fabrication in each subsystem, we would have asked for a more realistic amount of funding for our project.

This final design report documented the entirety of the Water Fun senior project experience, ranging from the preliminary identification of our sponsor's needs and wants, to the description of how to operate the final product. Throughout the design process, we have learned invaluable lessons regarding working as a team, communicating with outside organizations, timing and project planning, manufacturing, composite materials, and the mental stamina required to complete a 10 month-long project. Though the vision and scope of the project has changed many times throughout the year, we are very proud with the exhibit that we are supplying to the Exploration Station, and are confident in its value to be utilized for many years to come.

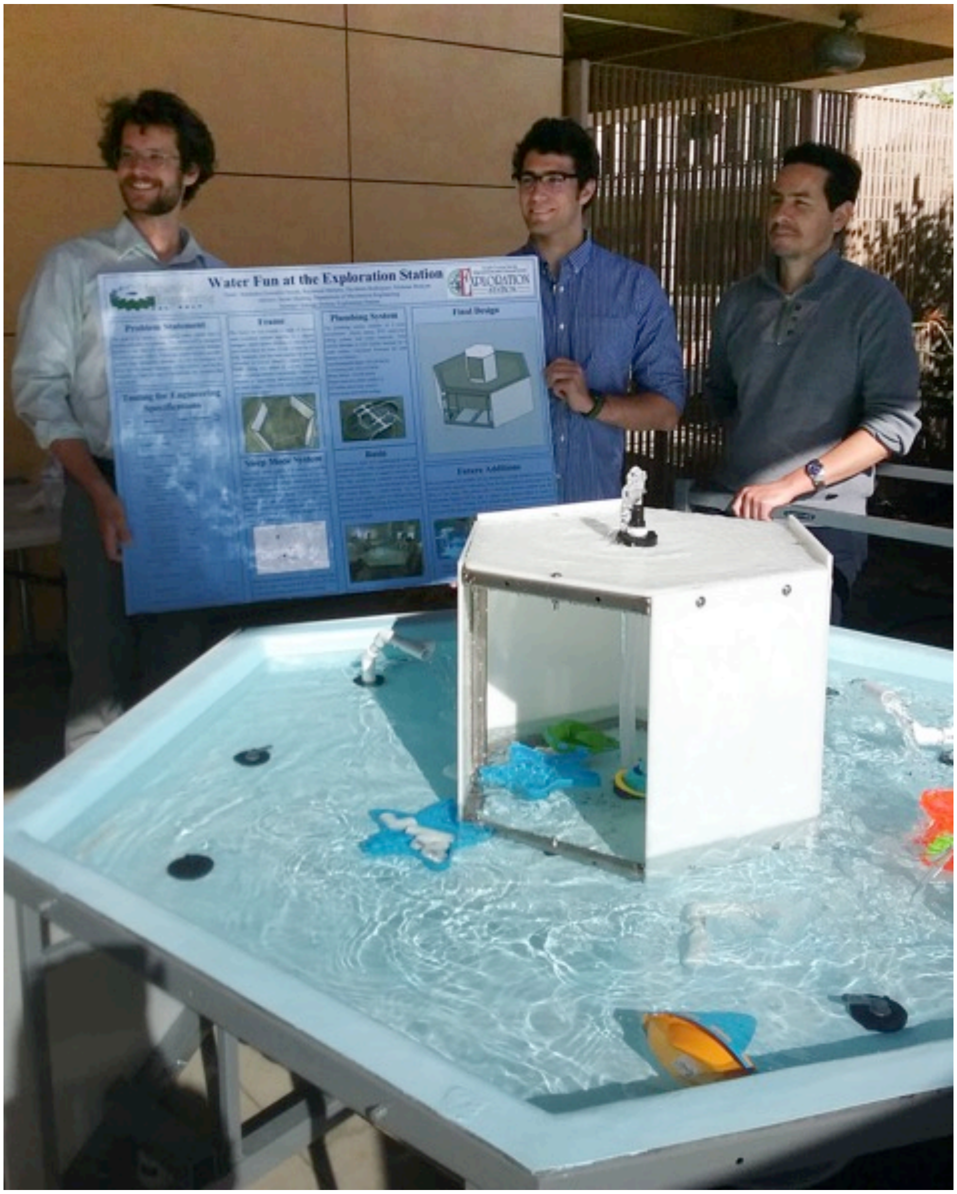

Figure 62: H2O Innovations final product for the Exploration Station

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Appendices

Appendix A – Safety Checklist

Appendix B – Quality Function Deployment

Appendix C – Electronic Code of Safety Regulation

Appendix D – Table of Popular Exhibit Features (with Descriptions)

Appendix E – Gantt Chart

Appendix F – MEKP Catalyst Mixing Chart for Polyester Resin

Appendix G – Hand Calculations

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Appendix I – Excel Sheet Calculations

Appendix J – Design Verification Plan

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Appendix O – Operator's Manual

Appendix A: Safety Checklist

ME 428/429/430 Senior Design Project 2016-2017

DESIGN HAZARD CHECKLIST

Team: ______________________ Advisor: ______________

Y	N	
☐	X	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	X	2. Can any part of the design undergo high accelerations/decelerations?
☐	X	3. Will the system have any large moving masses or large forces?
☐	X	4. Will the system produce a projectile?
☐	X	5. Would it be possible for the system to fall under gravity creating injury?
☐	X	6. Will a user be exposed to overhanging weights as part of the design?
X	☐	7. Will the system have any sharp edges?
☐	X	8. Will any part of the electrical systems not be grounded?
X	☐	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	X	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	X	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	X	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	X	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	X	14. Can the system generate high levels of noise?
X	☐	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
X	☐	16. Is it possible for the system to be used in an unsafe manner?
☐	X	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

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

Figure 4: Design Hazard Checklist, Page 1

#	**Description of Hazard**	**Corrective Actions**	**Date to be Completed**
7	The exhibit frame is made of steel bars, and thus may have sharp edges that users could bump into or run their hand over.	We have grinded down the observable sharp edges, and plan on using the plastic siding as a protective means of enclosing those edges which might harm the user.	May 2017
9	Our system will need to be connected to a 120V power source in order to run the necessary pumps.	Electricity connections will be contained within the inside storage area, so as to keep hands away from tampering with the power source.	May 2017
15	The water exhibit will be located outside for the entirety of its lifetime. Grover Beach can experience high temperatures, as well as ocean fog and intense winds.	Potentially having a cover for the exhibit when it is not in use. Will not permanently solve the issue of degradation, but will be a good start.	May 2017
16	As there is the lower basin for smaller children, it is possible that users could step over the railing and into the exhibit itself.	Having signage that says urging users to not step into the lower basin. Also maybe having another Plexiglas railing near the top of the exhibit going across the length of the lower basin so that users cannot actually climb in, but can still interact below.	May 2017

Appendix B: Quality Function Deployment

Stakeholders
1 Exploration Station Vistors
2 Fixture Repairmen/Women
3 Teachers/Educators
4 Sponsors

Measures: A = Maintenance frequency; B = Time between water change; C = Visitors to accommodate; D = Number of features; E = Total cost; F = Size Dimension (box); G = Unique educational standards; H = Exposed hazards; I = Choking hazard size; J = Max water depth; K = Depth of main basin; L = Withstanding tipping force; M = Supported weight; N; O

Competition Performance: 1 = Water Exhibit at SLOCM; 2 = Denver Science Museum; 3; 4; 5

Customer	Grouping	Voices	Item No.	Importance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	1	2	3	4	5
2		Easily Maintained	1	12	9	9		3	3	3		1		1	1					1				
3		Educational Puproses	2	10	1	3	9	9	1		9									3	9			
4		Safe	3	15	3	3	9	1	3		3	9	9	9	3	9	9			3	9			
4		Transportable	4	5	3	1	1	1	3	3		1				3	3			1				
		Weatherproof	5	9	9				9	3		1								1				
2		Durable	7	10	9				9	3										1	9			
4		Low Cost	8	9	9	3	1	3	9	9				3			3			3				
1		Fun and Engaging	9	13			9	9	3		3									9	9			
1		Hands-On Interaction	10	10			9	9	3	1	3	3	3	3	1	1	1			3	9			
4		Water Recycling	11	7	9	9		1	9	1				3						1	9			
			12																					
			13																					
			14																					
			15	100																				

Strong - 9 ◎
Medium-3 ○
Weak - 1 △
Relationship Strength

Company Ratings: Good 5, 4, 3, 2, Bad 1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Targets	once every 2 weeks	once every 2 weeks	at least 8	3	under $2000 (low as possible)	5ft x 5ft x 3ft	2	none	no small parts, less than 1.25inx2.25in	3in	5 in	minimum 250lbf	minimum 250lbf			
Weighted Importance	52	28	36	36	52	23	18	15	12	19	5	13	16	0	0	274
% Importance	19	10	14	13	19	8.4	6.57	5.5	4.4	6.9	1.8	4.7	5.8	0	0	

Appendix C: Electronic Code of Federal Regulations

ELECTRONIC CODE OF FEDERAL REGULATIONS

e-CFR data is current as of October 24, 2016

Title 16 → Chapter II → Subchapter C → Part 1501

Title 16: Commercial Practices

PART 1501—METHOD FOR IDENTIFYING TOYS AND OTHER ARTICLES INTENDED FOR USE BY CHILDREN UNDER 3 YEARS OF AGE WHICH PRESENT CHOKING, ASPIRATION, OR INGESTION HAZARDS BECAUSE OF SMALL PARTS

Contents

Authority: Secs. 2(f)(1)(D), (q)(1)(A), (s), 3(e)(1), and 10; 74 Stat. 372, 374, 375 as amended; 80 Stat. 1304-05, 83 Stat. 187-89 (15 U.S.C. 1261, 1262, 1269).

Source: 44 FR 34903, June 15, 1979, unless otherwise noted.

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§1501.1 Purpose.

Section 1500.18(a)(9) of this chapter classifies as a banned hazardous substance any toy or other article intended for use by children under 3 years of age that presents a choking, aspiration, or ingestion hazard because of small parts. This part 1501 describes certain articles that are subject to §1500.18(a)(9); lists certain articles that are specifically exempted; and provides a test method for determining whether an article is hazardous to children under 3 because it, or one of its components that can be detached or broken off during normal or reasonable foreseeable use, is too small.

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§1501.2 Scope.

(a) This regulation (§1500.18(a)(9) and the criteria described in §1501.4 below) applies to all toys and other articles intended for use by children under 3 years (36 months) of age that are introduced into interstate commerce after the effective date. Such articles include, but are not to limited to: squeeze toys; teethers; crib exercisers; crib gyms; crib mobiles; other toys or articles intended to be affixed to a crib, stroller, playpen, or baby carriage; pull and push toys; pounding toys; blocks and stacking sets; bathtub, wading pool and sand toys; rocking, spring, and stick horses and other figures; chime and musical balls and carousels; jacks-in-the-box; stuffed, plush, and flocked animals and other figures; preschool toys, games and puzzles intended for use by children under 3; riding toys intended for use by children under 3; infant and juvenile furniture articles which are intended for use by children under 3 such as cribs, playpens, baby bouncers and walkers, strollers and carriages; dolls which are intended for use by children under 3 such as baby dolls, rag dolls, and bean bag dolls; toy cars, trucks, and other vehicles intended for use by children under 3. In addition, such articles include any other toys or articles which are intended, marketed or labeled to be entrusted to or used by children under 3 years of age.

(b) In determining which toys and other articles are intended for use by children under 3 years (36 months) of age, for purposes of this regulation, the following factors are relevant: the manufacturer's stated intent (such as on a label) if it is a reasonable one; the advertising, promotion, and marketing of the article; and whether the article is commonly recognized as being intended for children under 3.

(c) This regulation does not apply to toys or articles which are solely intended for use by children 3 years of age or older. In addition, it does not apply to all articles to which children under 3 years of age might have access simply because of presence in a household. Certain articles which are specifically exempted from this regulation are listed in §1501.3 below.

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§1501.3 Exemptions.

The following articles are exempt from this regulation (§§1500.18(a)(9) and 1501.4 below):

(a) Balloons;

(b) Books and other articles made of paper;

(c) Writing materials such as crayons, chalk, pencils, and pens;

(d) Children's clothing and accessories, such as shoe lace holders and buttons;

(e) Grooming, feeding, and hygiene products, such as diaper pins and clips, barrettes, toothbrushes, drinking glasses, dishes and eating utensils;

(f) Phonograph records;

(g) Modeling clay and similar products;

(h) Fingerpaints, watercolors, and other paint sets;

(i) Rattles (as defined at 16 CFR 1510.2); and

(j) Pacifiers (as defined at 16 CFR 1511.2(a)).

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§1501.4 Size requirements and test procedure.

(a) No toy or other children's article subject to §1500.18(a)(9) and to this part 1501 shall be small enough to fit entirely within a cylinder with the dimensions shown in Figure 1, when tested in accordance with the procedure in paragraph (b) of this section. In testing to ensure compliance with this regulation, the dimensions of the Commission's test cylinder will be no greater than those shown in Figure 1. (In addition, for compliance purposes, the English dimensions shall be used. The metric approximations are included only for convenience.)

(b)(1) Place the article, without compressing it, into the cylinder. If the article fits entirely within the cylinder, in any orientation, it fails to comply with the test procedure. (Test any detached components of the article the same way.)

(2) If the article does not fit entirely within the cylinder, subject it to the appropriate "use and abuse" tests of 16 CFR 1500.51 and 1500.52 (excluding the bite tests of §§1500.51(c) and 1500.52(c)). Any components or pieces (excluding paper, fabric, yarn, fuzz, elastic, and string) which have become detached from the article as a result of the use and abuse testing shall be placed into the cylinder, one at a time. If any such components or pieces fit entirely within the cylinder, in any orientation and without being compressed, the article fails to comply with the test procedure.

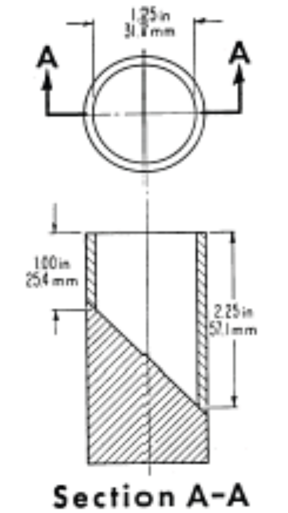

FIG I-SMALL PARTS CYLINDER

View or download PDF

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§1501.5 Enforcement procedure.

The Commission will enforce this regulation, unless it determines that an emergency situation exists, only in accordance with Chapter 2, Guide 2.05—Letter of Advice/Notices of Noncompliance of the CPSC Enforcement Policy and Procedural Guides, issued in January 1990 and available from the Office of the Secretary, Consumer Product Safety Commission, Washington, DC 20207. Under the procedure described in this chapter, firms must be informed by letter that they or their products may be the subject of enforcement action and must be provided ten days within which to submit evidence and arguments that the products are not violative or are not covered by the regulation, prior to the initiation of enforcement action by the Commission or by its delegated staff member. The function of approving such enforcement actions is currently delegated by the Commission to the Assistant Executive Director for Compliance and Enforcement (copies of the existing delegation documents are also available from the CPSC's Office of the Secretary).

[56 FR 46986, Sept. 17, 1991]

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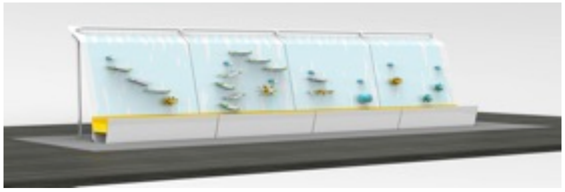
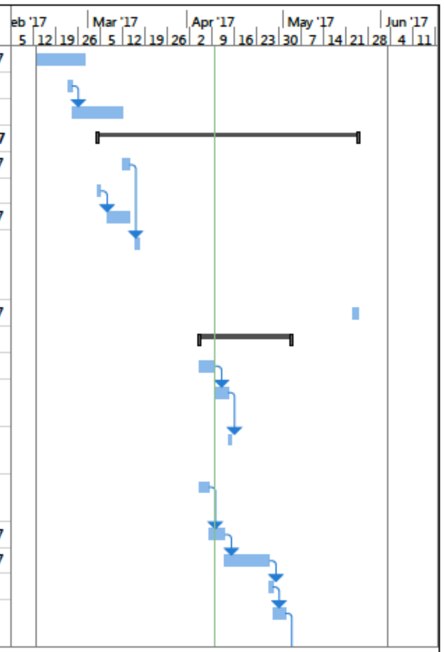
Appendix D: Table of Popular Exhibit Features (with Descriptions)

Feature Name	Feature Image	Description
Water Dome		Water at steady flow travels up and out of a straight vertical pipe. A fitting on the top of the straight pipe redirects water laterally, and cascading down in a thin sheet of laminar flow.
Self Powered Rotary Jet		User fills water into the cylinder. The weight of the water creates a high pressure down at the bottom of the cylinder, which then transmits to rotational motion. Water is sprayed from the rotating cylinder and causes the cylinder to decrease velocity over time (less pressure inside as the water level decreases).
Maze		Interchangeable maze blocks allow for user to create their own path to send buoyant objects through.

Magnetic Water Wall		Steel wall with thin amount of water flowing down its face. Users have a multitude of toys and funneling pieces that have magnets attached to them that they can place upon the wall and redirect the flow of water.
Pipe Flow		A series of interchangeable pipes that users can pull off and attach other pipes to redirect the flow of water in whichever direction they use. Often in combination with water wheels and buckets to demonstrate water's use in mechanical systems.

Appendix E: Gantt Chart
(1/3)

ID		Task Mode	Task Name	Duration	Start	Finish
1			Finish Basin Prototype	12 days	Mon 2/13/17	Mon 2/27/17
2			Order Parts	1 day	Thu 2/23/17	Thu 2/23/17
3			Wait for parts to arrive	14 days	Fri 2/24/17	Sat 3/11/17
4			**Electrical System**	**65 days?**	**Sat 3/4/17**	**Wed 5/24/17**
5			Build second prototype of SMS	2 days?	Sun 3/12/17	Mon 3/13/17
6			Make casing for sensors	1 day?	Sat 3/4/17	Sat 3/4/17
7			Wait to receive 3D printed casing	7 days	Tue 3/7/17	Mon 3/13/17
8			Test sensors outside on a windy day to verify distance and triggering	1 day	Thu 3/16/17	Thu 3/16/17
9			Install sleep mode system	2 days	Tue 5/23/17	Wed 5/24/17
10			**Basin**	**25 days**	**Wed 4/5/17**	**Wed 5/3/17**
11			Fiber glass prototype	5 days	Wed 4/5/17	Sun 4/9/17
12			Install risers and fittings for each outlet and drain	4 days	Mon 4/10/17	Thu 4/13/17
13			Test that there is no leakage in prototype	1 day	Fri 4/14/17	Fri 4/14/17
14			Buy MDF, wood, resin, sand paper	3 days	Wed 4/5/17	Fri 4/7/17
15			Cutting the mold	5 days	Sat 4/8/17	Wed 4/12/17
16			Sanding mold	2 wks	Thu 4/13/17	Wed 4/26/17
17			Fiber glass full scale model	1 day	Thu 4/27/17	Thu 4/27/17
18			Install risers and fittings for each outlet and drain	4 days	Fri 4/28/17	Mon 5/1/17



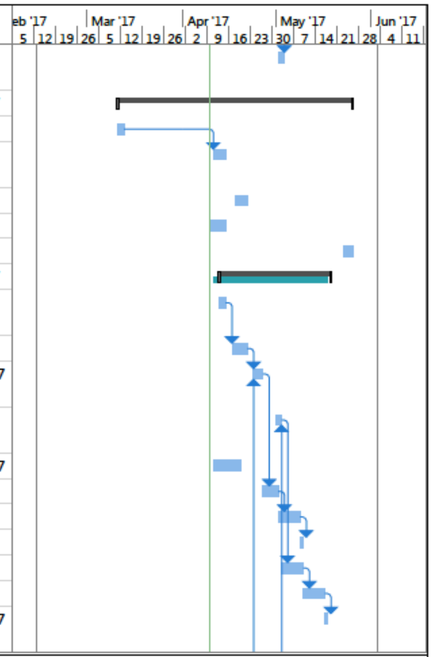
Project: Water_Fun.mpp
Date: Mon 4/10/17

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 1

Appendix E: Gantt Chart
(2/3)

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish
19			Test that there is no leakage and that water level is maintained	2 days	Tue 5/2/17	Wed 5/3/17
20			**Plumbing system**	**60 days**	**Sat 3/11/17**	**Thu 5/25/17**
21			construction of pvc piping system	2 days	Sat 3/11/17	Sun 3/12/17
22			testing pump and pvc for flow rates	4 days	Tue 4/11/17	Fri 4/14/17
23			Install drain valve on reservoir	4 days	Tue 4/18/17	Fri 4/21/17
24			Order remaining parts	5 days	Mon 4/10/17	Fri 4/14/17
25			Final plumbing install with tubing	3 days	Tue 5/23/17	Thu 5/25/17
26			**Siding**	**28 days**	**Thu 4/13/17**	**Thu 5/18/17**
27			determine amount required and order parts	2 days	Thu 4/13/17	Fri 4/14/17
28			wait for parts to arrive	1 wk	Mon 4/17/17	Fri 4/21/17
29			cutting all side walls for upper hex	3 days	Mon 4/24/17	Wed 4/26/17
30			cutting all side walls for bottom hex	2 days	Mon 5/1/17	Tue 5/2/17
31			designing slots for top hex	7 days	Tue 4/11/17	Wed 4/19/17
32			machining slots out (top hex)	1 wk	Thu 4/27/17	Mon 5/1/17
33			drilling holes (top hex)	1 wk	Tue 5/2/17	Mon 5/8/17
34			Round sharp corners (top hex)	1 day	Tue 5/9/17	Tue 5/9/17
35			machining slots out (bottom hex)	1 wk	Wed 5/3/17	Tue 5/9/17
36			drilling holes (bottom hex)	1 wk	Wed 5/10/17	Tue 5/16/17
37			Round sharp corners (bottom hex)	1 day	Wed 5/17/17	Wed 5/17/17



Project: Water_Fun.mpp
Date: Mon 4/10/17

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			

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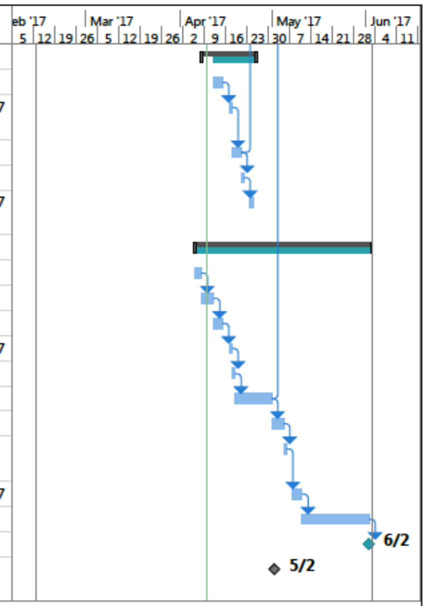
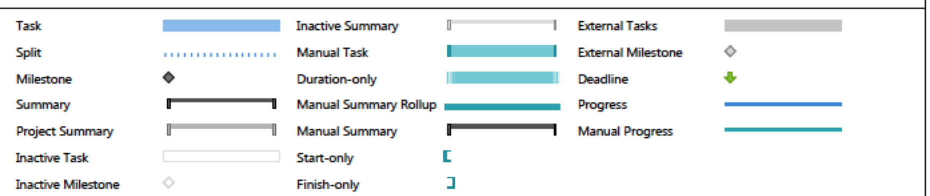
Appendix E: Gantt Chart
(3/3)

ID	Info	Task Mode	Task Name	Duration	Start	Finish
38			**Top Hex**	**14 days**	**Sat 4/8/17**	**Tue 4/25/17**
39			Cut metal	3 days	Wed 4/12/17	Fri 4/14/17
40			Machine holes for all the side walls	1 day	Mon 4/17/17	Mon 4/17/17
41			Weld stainless steel tubing	3 days	Tue 4/18/17	Thu 4/20/17
42			Grind down all welds	1 day	Fri 4/21/17	Fri 4/21/17
43			Round sharp corners on top frame	1 day	Mon 4/24/17	Mon 4/24/17
44			**Frame**	**46 days**	**Thu 4/6/17**	**Fri 6/2/17**
45			Order steel	2 days	Thu 4/6/17	Fri 4/7/17
46			Wait for steel to arrive	4 days	Sat 4/8/17	Tue 4/11/17
47			Cut metal	3 days	Wed 4/12/17	Fri 4/14/17
48			Machine holes for frame	1 day	Mon 4/17/17	Mon 4/17/17
49			Send metal to welder	1 day	Tue 4/18/17	Tue 4/18/17
50			Wait for frame to be welded	2 wks	Wed 4/19/17	Sun 4/30/17
51			Grind down all welds on frame	4 days	Mon 5/1/17	Thu 5/4/17
52			Machine holes for all the side walls	1 day	Fri 5/5/17	Fri 5/5/17
53			Fix on doors, siding, and casters	3 days	Mon 5/8/17	Wed 5/10/17
54			Testing	16 days	Thu 5/11/17	Thu 6/1/17
55			Final Design Review	0 days	Fri 6/2/17	Fri 6/2/17
56			Project Hardware and Safety Demo	0 days	Tue 5/2/17	Tue 5/2/17



Project: Water_Fun.mpp
Date: Mon 4/10/17



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Appendix F: MEKP Catalyst Mixing Chart for Polyester Resin

Catalyst Chart

Volume of Catalyst to Be Used with Polyester Resins

Methyl Ethyl Ketone Peroxide-Percent by Weight

	1%			1.25%			1.5%			1.75%		
Resin(1) Volume	Drop	cc	oz	Drop	cc	oz	Drop	cc	oz	Drop	cc	oz
4 ounce	32	1-1/4	1/32	40	1-1/2	3/64	48	1-3/4	1/16	56	2	1/16+
8 ounce	64	2-1/2	1/16	80	3	3/32	96	3-1/2	1/4	112	4	1/8+
1 Pint (16 oz.)	128	5	1/8	160	6	3/16	192	7	1/4	225	8	1/4+
1 Quart (32 oz.)		9	1/3		12	3/8		14	1/2		16	1/2+
1/2 Gal. (64 oz.)		18	2/3		24	3/4		28	1		32	1-1/8
1 Gal. (128 oz.)		37	1-1/4		47	1-1/2		56	2		65	2-1/8
5 Qt. (156 oz.)		46	1 5/8		58	2-7/8		70	2-1/2		81	2-3/4

(1) One Gallon Polyester Resin = 9.2 pounds

(2) Specific Gravity MEKP = 1.13

(3) Drop from 1 oz. Fiberglass Supply Catalyst Container, 300 Drops = 10cc.

Caution:

Organic Peroxides can decompose explosively.
Always wear safety glasses and protective gloves.
Keep away from heat, sparks and open flame.
Keep away from acids, sanding dust, copper, brass, iron, bases and promoters.
After use, inspect area for spills.
Store in original closed container at recommended storage temperature.

KEEP AWAY FROM CHILDREN

Fiberglass Supply, Inc.
314 West Depot, Bingen, WA 98605-0345
(509) 493-3464

Appendix G: Frame Structural Hand Calculations (1/4)

Buckling calculation

Moment of Inertia for square tubing:

$$I = \frac{1}{12} bh_{out}^3 - \frac{1}{12} bh_{in}^3$$

$$I = \frac{1}{12}(1\ in)(1\ in)^3 - \frac{1}{12}(0.76\ in)(0.76\ in)^3$$

$$I = 0.0555 in^4$$

Euler's buckling equation for one column with other end conditions:

$$P_{cr} = \frac{n\pi^2 EI}{L_e^2}$$

n= 1 (only 1 column)

E= 29 X E^6 psi

I= 0.0555 in^4

L_e = 0.5L = 0.5(24 in) = 12 in

$$P_{cr} = \frac{(1)(\pi^2)(29\ X\ 10^6\ psi)(0.0555\ in^4)}{(12\ in)^2}$$

$P_{cr} = 110{,}376\ lb_f$

Assume a factor of safety of 100:

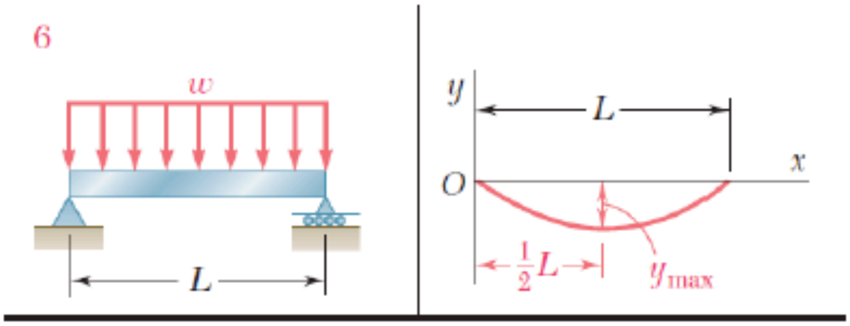
$$P_{allowable} = \frac{P_{critical}}{F.S}$$

$$P_{allowable} = \frac{110{,}376\ lb_f}{100}$$

$P_{allowable} = 1{,}104\ lb_f$ Per beam

Appendix G: Frame Structural Hand Calculations (2/4)

Deflection Analyisis



Using the deformation equation of a simply supported prismatic elastic beam, the deflection is:

$$\delta = -\frac{5wl^4}{384EI}$$

The distributed load estimated as:

$$w = \frac{1500\ lb_f}{32\ in}$$

$$w = 46.875\ \frac{lb_f}{in}$$

F=1500 lb_f

L= 32 in

E= 29 X E^6 psi

I= 0.0555 in^4

w = 46.875 lb_f/ in

The deflection for a single beam is:

$$\delta = -\frac{5\left(46.875\ \frac{lb_f}{in}\right)(32\ in)^4}{384\left(29\ X\ 10^6\ \frac{lb_f}{in^2}\right)(0.0555\ in^4)}$$

$$\delta = -0.398\ in$$

Since there are two main upper supporting beams, this deflection should be distributed among two beams equally. So total deflection per beam is:

$$\delta = -\ 0.198\ in$$

Appendix G: Frame Structural Hand Calculations (3/4)

Repeat calculation for Force = 750 lbf.

The distributed load estimated as:

$$w = \frac{750\ lb_f}{32\ in}$$

$$w = 23.4375\ \frac{lb_f}{in}$$

F=750 lb_f

L= 32 in

E= 29 X E^6 psi

I= 0.0555 in^4

w = 23.4375 lb_f/ in

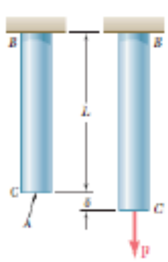
The deflection for a single beam is:

$$\delta = -\frac{5\left(23.4375\ \frac{lb_f}{in}\right)(32\ in)^4}{384\left(29\ X\ 10^6\ \frac{lb_f}{in^2}\right)(0.0555\ in^4)}$$

$$\delta = -0.199\ in$$

Since there are two main upper supporting beams, this deflection should be distributed among two beams equally. So total deflection per beam is:

$$\boxed{\delta = -\ 0.09\ in}$$



Deformation of members under axial loading (Compression)

General deformation equation:

$$\delta = \frac{PL}{AE}$$

Appendix G: Frame Structural Hand Calculations (4/4)

Assume entire load on 1 vertical column:

P= -1500 lb_f

L= 24 in

A= 1 in^2 – $(0.76\ in)^2$ = 0.4224 in^2

E= 29 X 10^6 lb_f/in^2

$$\delta = \frac{(-1500\ lb_f)(24\ in)}{(0.4224\ in^2)\left(29\ X\ 10^6\ \frac{lb_f}{in^2}\right)}$$

$$\delta = -0.0029\ in$$

One vertical column carrying entire vertical load will compress 0.0029 in.

Appendix H: Pump Controller Arduino Code

```
/*
* Description: This program is used to control the IoT Relay
*            through a bluetooth connection. If a 49 is received
*            then the pump turns on. If a 48 is received then it
*            turns off.
*     Author: Heriberto Rodriguez
*       Date: 6/1/17
*/

#include <SoftwareSerial.h>
SoftwareSerial mySerial(4, 2); // RX, TX

// pin controlling the IoT Relay
int iot_relay_pin = 13;

// state of the pump: 49 pump on, 48 pump off
int state;

void setup()
{
 // The HC-06 defaults to 9600 to the datasheet
 mySerial.begin(9600);

 pinMode(iot_relay_pin, OUTPUT);
}

void loop()
{
 // checks if there is data coming from the serial port
 if (mySerial.available() > 0)
 {
  state = mySerial.read();
 }

 // if a 48 was received, turn off the pump
 if (state == '0')
 {
  digitalWrite(iot_relay_pin, LOW);  // turn off normally off outlets
  mySerial.println("PUMP: OFF");   // update the status text of the pump
  state = 0;
 }
 // if a 49 was received, turn on the pump
 else if (state == '1')
 {
  digitalWrite(iot_relay_pin, HIGH);  // turn on normally off outlets
  mySerial.println("PUMP: ON");      // update the status text of the pump
  state = 0;
 }
}
```

Appendix I: Excel Sheet Calculations

Dinner_top [in]	Dinner_bottom [in]	Davg [in]
11.375	10	10.6875

in	Fill Height (in)	Volume (in^3)
89.7	12	1076.5

conversion from in^3/s to gal/min	0.25974

Measurements for interchangeable pipes		
Trial #	Fill time [s]	height [in]
1	175.53	12
2	163.92	12
3	158.7	12

Flowrate for each time [in3/s]
6.132986801
6.567369285
6.783384835

Measurements for interchangeable pipes							
Trial #	Fill time [s]	Measured volume (in^3)	Q (in^3/s))	Q avg (in^3/s)	Q avg (gal/min)	Q avg (gal/hr)	Velocity of flow (in/s)
1	175.53	1076.5	6.13	6.49	1.69	101.21	21.37
2	163.92	1076.5	6.57		per pipe	per pipe	
3	158.7	1076.5	6.78				

Flowrate based on bucket size for inter. pipes							
Trial #	Fill time [s]	Fill volume (Gal)	Q (Gal/min))	Q avg (in^3/s)	Q avg (Gal/min)	Q avg (gal/hr)	Velocity of flow (in/s)
1	175.53	5	1.71	6.97	1.81	108.59	22.93
2	163.92	5	1.83		per pipe	per pipe	
3	158.7	5	1.89				

Measurements for lazy river flow						
Trial #	Fill time(s)	Measured volume (in^3)	Q (in^3/s))	Q avg (gal/min)	Q avg (gal/hr)	Velocity of flow (in/s)
1	82.54	1076.500	13.042	3.388	203.254	23.534

Outer diameter 1/2 in pvc pipe [in]	0.84
Inner diameter 1/2 in pvc pipe [in]	0.622

Area of inside pipe 1/2in pipe (in^2)
0.303857983

Inside diameter of elbow [in]	0.84
Aera of inside elbow [in^2]	0.5541769441

Measurements for lazy river	
Fill time [s]	82.54
Flowrate [in3/s]	13.04244213

Measurements for lazy river flow						
Trial #	Fill time (s)	Measured volume (in^3)	Q (in^3/s))	Q avg (gal/min/jet)	Q avg (gal/hr)	Velocity of flow (in/s)
1	82.54	1076.5	13.04	3.39	203.25	23.53
				per jet		

Flowrate based on bucket size for Lazy river						
Trial #	Fill time (s)	Fill volume (Gal)	Q (Gal/min))	Q avg (gal/hr)	Q (in^3/s))	Velocity of flow (in/s)
1	82.54	5	3.63	218.08	13.99	25.25

Appendix J: Design Verification Plan

Water Fun DVP												
Report Date			Sponsor					Component/Assembly			REPORTING ENGINEER:	
TEST PLAN									TEST REPORT			
Item No	Specification or Clause Reference [1]	Test Description [2]	Acceptance Criteria [3]	Test Responsibility [4]	Test Stage [5]	SAMPLES TESTED	TIMING		TEST RESULTS			NOTES
						Quantity	Start date	Finish date	est Result [6	Quantity Pass	Quantity Fail	
1	ES #12	Withstand tipping force	Exhibit (w/ water) can withstand an additional minimum applied lateral force of 250 lbf	Team	DV/PV	6	6/1/2017					
2	ES #13	Supporting weight	Exhibit (w/ water) can withstand an additional minimum applied vertical loading of 250 lbf	Team	DV	1	5/15/2017					
3		Leaking in main basin	No sign of leaking after 24 hour holding test.	Team	DV/PV	1	5/21/2017					
4		Leaks in plumbing system	No sign of connection leaks after running at higher power rating than required.	Team	DV/PV	1	5/24/2017	5/26/2017				Make sure no leaks between fitting connections
5		Appropriate water volume in reservoirs during operation, preventing water level from going below the pump	Pump is fully submerged in reservoir for a 5 hour test at desired performaoe required	Team	DV/PV	1	5/26/2017	5/29/2017				We will need to fill the water level in basin and reservoir to operating level before turning on the pump to run the exhibit. For the reservoir, this means that the water level height needs to be above the pump and keep it fully submerged while running.
6		Required flowrates coming out of each of the outlet valves without basin installed	Each outlet valve in the basin has the correct flowrate of XXX gpm by the time the exhibit has reached steady state.	Team	DV	8	4/15/2017	4/15/2017	passed	1		Completed. Determined we do achive the required flowrates based on holding the hose at height of basin
6		Required flowrates coming out of each of the outlet valves "with" basin installed	Each outlet valve in the basin has the correct flowrate of XXX gpm by the time the exhibit has reached steady state.	Team	DV	8	4/15/2017			1		
7	ES #8	Exposed hazards on exterior of exhibit	No sharp edges or dangerous objects exposed to user	Team	PV	2	5/20/2017					
8	ES #10	Water height in basin of exhibit	at same height during a 5 hour operation of the system	Team	DV	1	5/26/2017	5/29/2017				height remains constant using wier valves
9	ES #14	Mobility of exhibit	Exhibit should move easily and remain fixed in place by changing the mode of the caster without getting stuck in one mode	Team	PV	1	5/15/2016					
10		Functional GFCI	Test GFCI using	Team	DV	1	3/15/2016	3/31/2017	4/19/2017	1		completed. Test/reset button

APPENDIX K: Manufacturing Procedure Plans

Page No.	Subsystem	Part
2	Basin	Wood Relief
3	Basin	Prototype
4	Basin	Surface Prep, Part 1
5	Frame	Skeleton
6	Frame	Small Hexagon
7	Plumbing	Plumbing system for water supply
8	Plumbing	Drilling reservoir and installed bulkhead fitting with drain valve
9	Sleep Mode	PIR Sensor

APPENDIX K: Manufacturing Procedure Plans

<table>
<tr>
<td>Sub-system:
Basin

Part:
Wood Relief

Description of process and tools used:
Miter Saw
Table Saw
Band Saw
Nail Gun
Wood Glue
Angle Finder
5/16” OSB
1x6” Pine Common Board

Cut common board side walls to length and appropriate height using miter saw. Used compound angle finder online to select the miter angles for cutting. Table saw was used to cut the plywood boards to size. Needed two plywood sheets (cut into half hexagons) to span the full top area of the basin. Nailed everything together with nail gun after setting wood glue bond.</td>
<td>Total shop time (day):
4 days (14 working hours)

Machine Time (if applicable):
1 day for cutting common board side walls (4 hours) with miter saw
1 day for cutting the plywood tops (4 hours) with table saw
1 day for connecting the side walls together, connecting the two sides of the plywood top together, and connecting the two pieces into one (3 hours)
1 day for connecting bottom flange pieces (3 hours)</td>
</tr>
<tr>
<td>Problems manufacturing:

Plywood tops were not exact size for the area required, we needed to use a jig saw to cut down the excess 1” to make it flush.
Small gaps were left in the compound angle corners. Needed to fill in with the shims and wood glue.
Angles did not come out to exactly 120 degrees in each corner once everything was nailed together. Two of the corners were a little larger than 120 and two of the sides were a little under 120.</td>
<td>Successes manufacturing:

Optimized the use of our leftover materials when adding on the bottom flange pieces. The whole basin was made using 3 common boards and 2 plywood sheets.</td>
</tr>
</table>

Sub-system: Basin Part: Prototype Description of process and tools used: Spray gun Duratec sanding primer compressed air tap MEKP catalyst acetone wooden mold Ensured spray gun was working by first spraying acetone through it. Used this as a chance to calibrate and get the correct fan size on spray. Mixed together duractec with catalyst (16:1) loaded into the spray gun, and sprayed for about 20 minutes. First pass went on, then waited 3 minutes for it to flash off, then consecutive coatings were applied about every 30 seconds for 15 minutes. After the 15 minutes, duractec began to tack up, the rest of the primer was applied with a brush while the spray gun was immediately dismantled and cleaned with acetone. The mold was left to cure for 24 hours before sanding down.	Total shop time (day): 1 day (2 working hours) Machine Time (if applicable): ● 30 minutes using spray gun.
Problems manufacturing: Not prepared for how fast paced it was going to be. Also had to borrow a few materials from george during the process (like the acetone and a cup for the excess acetone)	Successes manufacturing: George was impressed with how it came out. His help was really beneficial in showing up how the process works. We are confident we would be able to do it again independently in the future.

APPENDIX K: Manufacturing Procedure Plans

Sub-system: Basin Part: Wood Relief Surface Prep, Part 1 Description of process and tools used:	Total shop time (day): Machine Time (if applicable):
Problems manufacturing:	Successes manufacturing:

APPENDIX K: Manufacturing Procedure Plans

Sub-system: Frame Part: Frame skeleton Description of process and tools used: Chop saw Drill press Mig welder Angle grinder 2"x2" 11 gauge steel beam 1"x1" 11 gauge steel beam	Total shop time (day): 6 days (22 working hours) Machine Time (if applicable): ● 2 days (3 hours each) cutting hexagon members to length ● 2 days (2.5 hours each) drilling siding mounting holes on drill press ● 1 day (6 hours) welding together upper and lower hexagon pieces ● 1 day (4 hours) welding together the two hexagon pieces with vertical supports, preparing lower cross bars by cutting and drilling mounting holes
Problems manufacturing: Had to improvise the corner geometry to match up with the completed basin mold. Beams were laid around the top of the basin and tacked together before being fully welded. Bridging gaps during welding. Chop saw blade led to fairly imprecise and inconsistent cuts. Not sure how to weld stainless.	Successes manufacturing: Did it ourselves, saved approximately $600 by not outsourcing the welding work. After grinding down the welds, we think they are aesthetically pleasing. Super stable and does not wobble now that the top and bottom hexagons are joined together.

Sub-system: Frame Part: Small Hexagon Description of process and tools used: Chop saw 1”x1” 11 gauge stainless steel beam	Total shop time (day): 1 day (2 working hours) Machine Time (if applicable): ● 1 day (2 hours) using chop saw to cut all stainless steel members to length
Problems manufacturing: No problems in manufacturing.	Successes manufacturing: We chopped the metal to size.

Sub-system: Plumbing Part: Plumbing system for water supply Description of process and tools used: PVC cutting tool PVC glue Teflon tape Crescent wrench Cut vertical 1-¼" pipe to length attached to reducer connected to pump. Using width of reservoir, cut 1-¼" PVC pipe sections between Tee's and 4 way splitters so that once assembled, the arms of the plumbing system will rest and be supported on the sides of the reservoir. Assembled pipe sections with tee's and 4 way's. Glued 1-¼"- ¾" reducers into tee's and 4 way's. Installed ¾" to ½" reducers, ½" risers, ½" ball valves, and ½" pipe nipple to ball values using teflon tape on threads and tightened fittings.	Total shop time (day): 2 days (8 hours) Machine Time (if applicable): ● 2 hours cutting pipe and smoothing edges ● 2 hours gluing pipes and applying teflon tape to fittings.
Problems manufacturing: Finding all fittings, couplers, and adapters for construction. 1-¼" PVC pipes were difficult to cut using the PVC cutting tool since 2" was the maximum cutting diameter for the tool. Needed a lot of force to cut the pipe. 	Successes manufacturing: Easy to assemble once cut. All fittings fit together nicely and entire piping section connected directly to pump. Gluing was fast and easy process. Applying teflon to threads and tightening fittings together was relatively fast and easy process.

Sub-system: Plumbing Part: Drilling reservoir and installed bulkhead fitting with drain valve. Description of process and tools used: Cordless drill with 1-¾" hole drill bit Pipe wrench Teflon Tape Round file Bulkhead fitting Drilled a 1-¾" hole in reservoir siding using cordless drill. Used a round file to debur edges around hole for bulkhead installation. Cleaned surface around hole. Installed bulkhead and tightened using pipe wrench. Installed ¾"-½" reducer fitting, ½" riser, and 1/2 " brass drain valve using teflon tape between threads, and then tighten all fittings.	Total shop time (day): 1 day (1 hour) Machine Time (if applicable): 10 minutes - hole saw
Problems manufacturing: None	Successes manufacturing: Hole saw drilled easily through Polyethylene reservoir siding. Minimum filing needed to finish edges, so bulkhead would sit flush Easy to install teflon tape in between fittings and tighten fitting together

Sub-system: Sleep Mode Part: PIR sensor Description of process and tools used: In order to assemble the circuit we needed a screwdriver to adjust the time delay and activation distance of the sensors and a soldering iron to connect the different electrical components together. Over spring break we added a bluetooth module to the circuit so that we are able to get feedback from the sensors when we are testing them. Using this bluetooth module we can see when the sensors have finished calibrating and when they are active/inactive through an app on an android phone.	Total shop time (day): 1 day (1 working hour) Machine Time (if applicable):
Problems manufacturing: We did not encounter any problems with putting the circuit together, but we still need to build some sort of shelf for the electrical components to sit on and so that they are protected from water. We also need to get casings for the sensors so that they are waterproof. After we complete all this we can install the electrical system into the exhibit.	Successes manufacturing: Adding the bluetooth module will be helpful for testing the sensors because we can get feedback from them without connecting the pump to the IoT relay.

APPENDIX L: TESTING PROCEDURE FORM

Water Fun at Exploration Station: Testing Overview				
No.	**Description**	**Completed Date**	**Notes**	**Pass/Fail?**
1	Withstand tipping force			
2	Supporting weight			
3	Leaking in main basin			
4	Leaks in plumbing system			
5	Appropriate water volume in reservoirs during operation, preventing water level from going below the pump			
6	Required flowrates coming out of each of the outlet valves without basin installed			
7	Required flowrates coming out of each of the outlet valves with basin installed			
8	Exposed hazards on exterior of exhibit			
9	Water height in basin of exhibit			
10	Mobility of exhibit			
11	Functional GFCI			
12	Functionality of sensors			

Date: Testing Sheet

Test #1 Sub-system: Frame Part: Frame Goal of testing: Determine if exhibit can withstand tipping force. Materials: Completed Exhibit Level Surface 3+ adult males	Testing performed: Place fully assembled exhibit (including frame and basin) on a level surface. Lock casters to prevent frame from rolling away to ensure that the proper variable is being tested. Fill both basin and reservoir with water to simulate actual exhibit conditions. First test a side that has an access hatch. Have one adult male place hands firmly at the top edge of the frame and lean towards the exhibit using as much of his weight as possible. If the exhibit does not move, have another adult male perform the same procedure. Repeat the process until the exhibit tips (note the total weight of all adults pushing before tipping occurred), or until at least XXX lbs of bodyweight has been applied laterally.
Problems Testing:	Successes Testing:

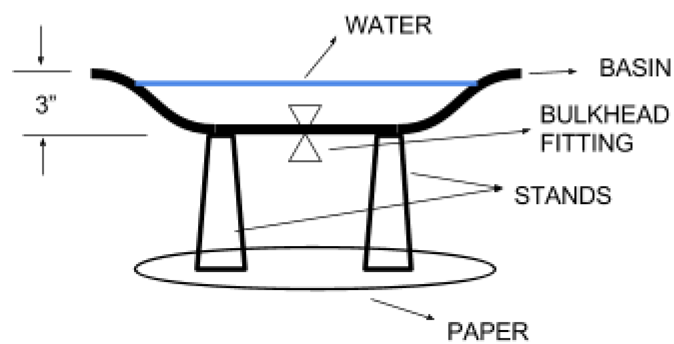
Date: Testing Sheet

Test #2.1 Sub-system: Frame Part: Frame Goal of testing: Verify that frame can support desired weight. (Distributed) Materials: Frame Sturdy members (such as sheets or beams) Weights Ruler or measuring tape.	Testing performed: Place frame on a flat surface and record the initial distance between the ground and the top rail of the frame on all six sides. Place members across frame spanning the largest distance. Place one weight at the center of the member and record the new distance between the ground and top rail on all six sides. Add weight and repeat measurement until the frame fails (by exceeding the deflection criteria of XXX) or until the weight reaches the design load of XXX and record the final weight. If the cross member should fail before the frame, or before the design load has been reached, then repeat test with either a sturdier member, or multiple members together. Repeat test with members spanning all sides.
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test #2.2 Sub-system: Frame Part: Frame Goal of testing: Verify that frame can support desired weight. (Point Load) Materials: Frame Strong, load bearing cable. Weights Ruler or measuring tape.	Testing performed: Place frame on a flat surface and record the initial distance between the ground and the top rail of the frame on all six sides. Secure cable around one section of the upper rail of the frame. Secure a weight to the opposite side of the cable, ensuring that the weight is supported entirely by the cable (and that it is not resting on anything else). Measure the distance between the ground and the top of that member. Add weight and repeat measurement until the frame fails (by exceeding the deflection criteria of XXX) or until the weight reaches the design load of XXX and record the final weight. Repeat the test for the remaining five sides.
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test #3 Sub-system: Basin Part: Completed completed fiberglass basin with bulkheads installed Goal of testing: Ensure that the basin is completely leak-proof.	Testing performed: Once the bulkheads are installed and fitted properly, place the basin on two stands (or as many as needed to support the bottom without completely covering it). This will leave the bottom face open, and allow us to see if there are any drips occurring from the underside. Fill the basin up to the 3” operating water height. Place a large piece of paper on the ground underneath the basin. This will allow us to see if there are any drips that happen over time that we just don’t notice during the time which we are observing. Let the water sit in the basin for 24 hours to ensure that the seals on the bulkheads can withstand prolonged submersion in water. Reference the following diagram for assistance in testing: 
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test #4 Sub-system: Plumbing system Part: Fittings and hose connections Goal of testing: To ensure that there are no leaks between PVC pipe fitting connections and between PCV hose and pipe connections.	Testing performed: Ensure that all pipe fittings and connections are tighten properly. Install all PVC hoses in between piping system and outlet spickets on basin. Install metal clamps around all PCV tubing connections to ensure a tight fit around pipes. Once all connections, bulkheads, clamps, and tubing are properly installed, open all 8 ball valves 100% to ensure maximum flow. Turn on pump and allow waterflow to come to steady state. Run pump/system for 30 minutes and monitor all connections for any signs of water leakage. If no signs of leaks within 30 minutes, test is a success.
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test # 6 Sub-system: Plumbing Systems Part: Pump performance Goal of testing: Obtain Required/calculated flowrates coming out of each of the outlet valves “**without**” basin installed Flowrates needed: Interchangeable pipes: 1.69 GPM Circulating Jets: 1.81 GPM	Testing performed: All ball valves were closed ¼ of a turn to apply some back pressure on the pump. 8 PVC hoses were connected to each ball valve (6 short hoses and 2 long hoses) and 7 of the hoses were redirected back to the reservoir to maintain water level in reservoir. The pump was turned on and allowed to reach steady state. The 2 long hoses were both raised to an approximate basin height (waist level) until steady state was achieved. One water hose was redirected into a 5 gallon bucket and a timer was used to record the time it took to fill the bucket. 5 trials were performed using this same technique. 
Problems Testing: The final basin was not completed and installed as of yet. In order to not waste PVC tubing, we did not want to cut all the tubing to the basin height for a more realistic testing scenario. This still leaves some concerns on the actual head the pump will see and final testing will be performed when basin is finished and installed.	Successes Testing: Passed Flowrates Achieved: Interchangeable pipes: 6.84 GPM Circulating Jets: 6.84 GPM

Date: Testing Sheet

<table>
<tr>
<td>Test # 7

Sub-system:
Plumbing Systems

Part:
Pump performance

Goal of testing:
Obtain Required/calculated flowrates coming out of each of the outlet valves “with” basin and plumbing installed.

Flowrates needed:
Interchangeable pipes: 1.69 GPM
Circulating Jets: 1.81 GPM</td>
<td>Testing performed:
Ensure that all pipe fittings and connections are tighten properly. Install all PVC hoses in between piping system and outlet spickets on basin. Install metal clamps around all PCV tubing connections to ensure a tight fit around pipes. Once all connections, bulkheads, clamps, and tubing are properly installed. Close all ball valves ¼ of a turn to apply some back pressure on the pump. Turn on pump and allow water flow to reach steady state. Connect water hose and coupler to each outlet spigot and redirected hose into a 5 gallon bucket off the side of the exhibit. Use a timer to record the time it takes to fill the bucket. 3 trials will be performed using this same technique per each outlet.

</td>
</tr>
<tr>
<td>Problems Testing:</td>
<td>Successes Testing:</td>
</tr>
</table>

Date: Testing Sheet

Test #9 Sub-system: Basin Part: Completed fiberglass basin with weir valves installed Goal of Testing: Ensure that the water level height within the basin does not exceed the operating height of 3 inches. Materials Required:	Testing performed: Stand a ruler upright in the basin. The starting water level height should be 3 inches (and should be held constant during the test by the weir valves). After all plumbing lines are properly installed into the basin outlet taps, run the pump at operating capacity for approximately 30 minutes. Ensure during this entire time that the water level height does not exceed the height of the weir valves, and that water is being funneled back down into the reservoir. When the pump is initially turned on, you might see the water level rise a bit above the height of the weir valve, but this should begin to fix itself as the system reaches stability.
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test #10 Sub-system: Frame Part: Casters Goal of testing: Verify that frame is mobile when casters are unlocked, and secure when casters are locked. Materials: Completed frame 2-3 adults	Testing performed: First unlock the casters. Have one adult attempt to move the exhibit (by pushing). If the frame moves, then it passes this test. Lock the casters. Have one adult attempt to move the exhibit (by pushing). If the exhibit does not move, add another adult (pushing on the same side). If the exhibit still does not move, then add a third adult. Note the number/size of the adults pushing before the exhibit moves (if the number is less than three adults).
Problems Testing:	Successes Testing:

Date: Testing Sheet

Test #11 Sub-system: Electrical system Part: GFCI outlet Goal of testing: Ensure functionality of ground fault circuit interruptor prior to use in exhibit.	Testing performed: Connect all electrical devices and pumps to GFCI outlet relay. Turn all power on and run all systems. Press the test button on the GFCI outlet plug (at wall outlet) and check to make sure that all power to the relay is off and circuit has tripped, therefore cutting off all electrical power to exhibit. 
Problems Testing: None	Successes Testing: Completed. When tested and test button was depressed, all power to exhibit was terminated and possibility of electrical shock is removed when tripped.

Date: Testing Sheet

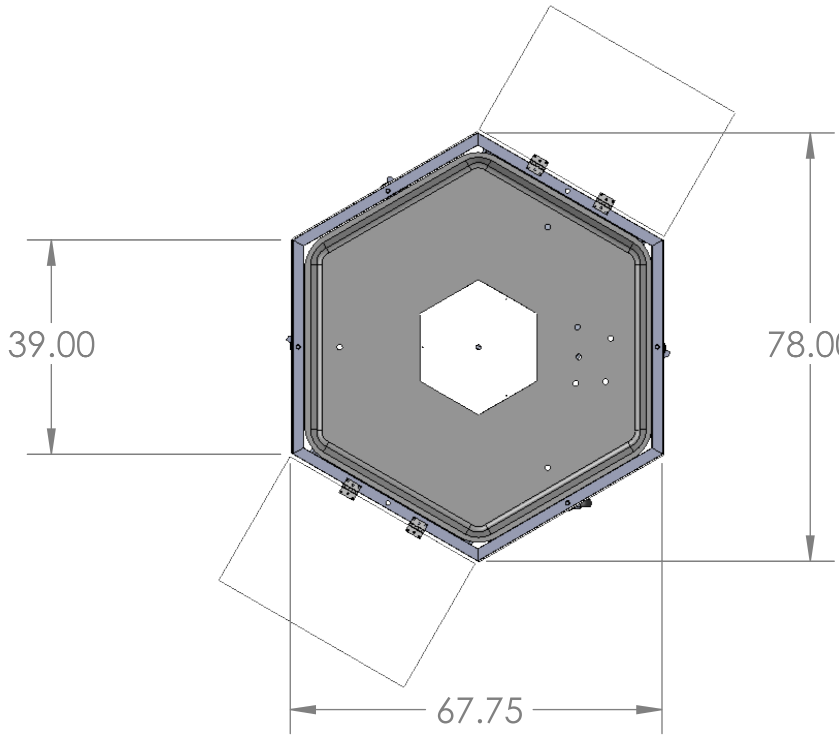
Test #12 Sub-system: Sleep Mode System Part: PIR Sensor Goal of testing: Determine the activation distance for the sensors.	Testing performed: We connected our circuit together and then connected the pump to the IoT relay. We placed the sensor on top of a chair so that it was about 2 feet above the ground. We wanted to know at what distance the sensors stop detecting motion so we walked toward the sensor starting at a distance of 20 ft away from the sensors and observed that they activated when we were about 9 ft away as stated in the datasheet.
Problems Testing: No problems with testing the sensors yet, but we still need test them after we get the casing for the sensors to see if their field of view is modified by the casing.	Successes Testing: We confirmed that the sensors activate when we are about 9 ft away from them.

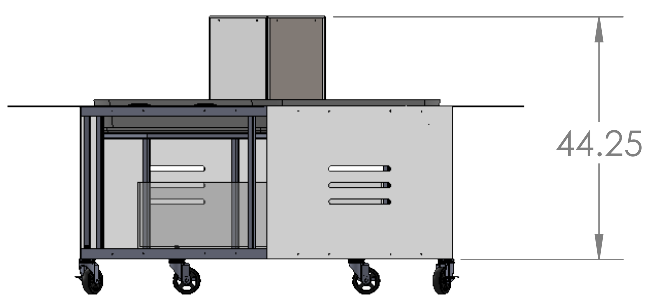
APPENDIX M - CONDENSED BILL OF MATERIALS							
SUBSYSTEM	**ITEM DESCRIPTION**	**QTY**	**COST/UNIT**	**ITEM COST**	**TAX**	**SHIPPING**	**TOTAL COST**
TOTAL EXHIBIT COST	$3,338.95						
ELECTRONICS	Atmega328p	2	$3.50	$7.00	$0.56	$0.00	$0.00
	24 AWG Wire	144	$0.21	$30.24	$2.42	$14.01	$46.67
	IoT Relay	1	$17.49	$17.49	$1.40	$0.00	$18.89
	Tripp lite 8 outlet GFCI power strip	1	$45.65	$45.65	$3.65	$0.00	$49.30
	Motion Sensor Dector	5	$2.20	$11.00	$0.88	$0.00	$11.88
	Electrical Tape	1	$3.29	$3.29	$0.26	$0.00	$0.00
	Duracell MN160	4	$2.19	$8.76	$0.70	$0.00	$9.46
	Toggle switch	10	$1.06	$10.60	$0.85	$0.00	$11.45
	Breadboard	1	$7.99	$7.99	$0.64	$0.00	$0.00
BASIN	OSB pannel (49" x97"x1/2")	2	$15.30	$30.60	$2.35	$0.00	$32.95
	2"x4" Beams	1	$3.69	$3.69	$0.30	$0.00	$3.99
	Gorilla Wood Glue	1	$3.97	$3.97	$0.32	$0.00	$4.29
	Marine Laminating Polyester Resin	5	$42.00	$210.00	$16.80	$0.00	$226.80
	Surfacing Agent	1	$17.99	$17.99	$1.44	$0.00	$19.43
	MEKP Catalyst	2	$20.00	$40.00	$3.20	$0.00	$43.20
	Gel Coat	2	$45.00	$90.00	$7.20	$0.00	$97.20
	Fiberglassing Cloth (6oz x 38" E Cloth)	6	$6.00	$36.00	$2.88	$0.00	$38.88
	Mask Respirator	1	$17.00	$17.00	$1.36	$0.00	$18.36
	Bondo Wood Filler	4	$11.97	$47.88	$3.83	$0.00	$51.71
	Plastic Bondo Spreader	2	$3.97	$7.94	$0.64	$0.00	$8.58
	black neoprene gloves	1	$8.99	$8.99	$0.72	$0.00	$9.71
	1-1/4 Flathead Wood Screws	1	$5.58	$5.58	$0.45	$0.00	$6.03
	BASIN 4x8 sheet of plywood	2	$15.30	$30.60	$2.35	$0.00	$32.95
	4x8 sheet of plywood	2	$15.30	$30.60	$2.35	$0.00	$32.95
	Bondo Wood Filler gallon size	2	$24.30	$48.60	$3.89	$0.00	$52.49
	black neoprene gloves	1	$8.99	$8.99	$0.72	$0.00	$9.71
	acetone	1	$13.00	$13.00	$1.04	$0.00	$14.04
	2 gallon plastic bucket	1	$3.97	$3.97	$0.32	$0.00	$4.29
	5 gallon bucket	1	$2.97	$2.97	$0.24	$0.00	$3.21

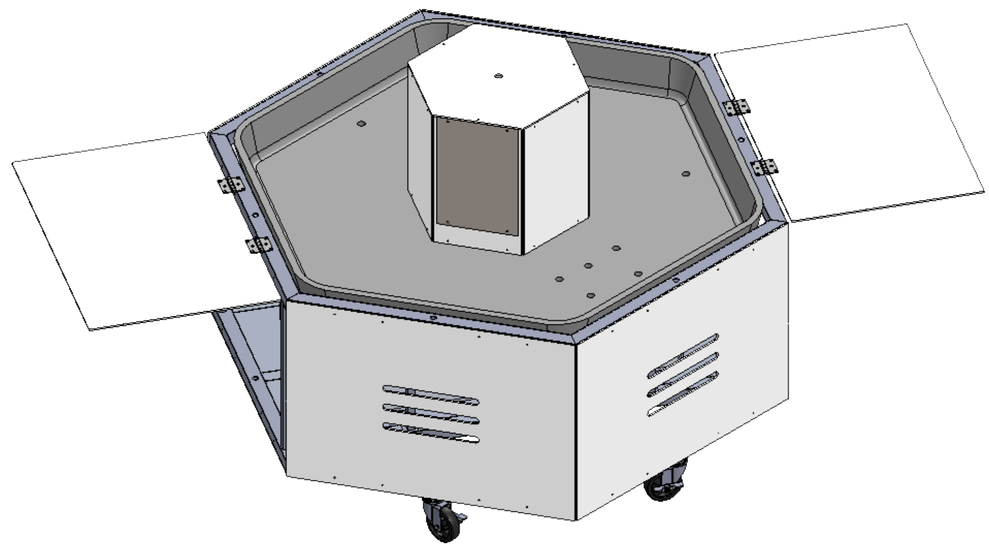
APPENDIX M - CONDENSED BILL OF MATERIALS							
SUBSYSTEM	**ITEM DESCRIPTION**	**QTY**	**COST/UNIT**	**ITEM COST**	**TAX**	**SHIPPING**	**TOTAL COST**
	1x6 common board 8ft beams	6	$5.07	$30.42	$2.43	$0.00	$32.85
	1" nails	1	$4.29	$4.29	$0.34	$0.00	$4.63
	latex gloves	1		$0.00	$0.00	$0.00	$0.00
	hvlp spray gun	1	$14.39	$14.39	$1.15	$0.00	$15.54
	Duratec Sanding Primer (1 gallon)	1	$98.00	$98.00	$7.84	$0.00	$105.84
	small mixing cups	1	$1.50	$1.50	$0.12	$0.00	$1.62
	stir sticks	1	$1.00	$1.00	$0.08	$0.00	$1.08
PLUMBING	Everbilt 1.0 in. O. D. x 3/4 in. I.D. x 10 ft. PVC Clear Vinyl Tube	3	$4.93	$14.79	$1.18	0	$15.97
	Everbilt 1/2 - 1-1/4 in. Hose Repair Clamp	24	$0.85	$20.40	$1.63	0	$22.03
	Alpine Cyclone Pump 3100 gph	1	$164.99	$164.99	0	12.49	$177.48
	3/4" Heavy Duty Polypropylene Bulkhead with Santoprene™ Gasket	1	$5.60	$5.60	0	12.02	$17.62
	3/4 in. Brass 1/4 Turn MPT x MHT No-Kink Hose Bibb	1	$10.23	$10.23	$0.82	0	$11.05
	1/2 in. PVC Sch. 40 FPT x FPT Ball Valve	8	$2.42	$19.36	$1.55	0	$20.91
	1/2 in. x Close PVC Riser	16	$0.39	$6.24	$0.50	0	$6.74
	Orbit 58248N Brass Hose Y With Shut Off	1	$6.49	$6.49	$0.52	0	$7.01
	Orbit 4-Port Brass Lawn & Garden Hose Faucet Manifold w/ Shut off Valves - 91705	1	$12.23	$12.23	$0.98	0	$13.21
	1-1/2 in. x 3/4 in. PVC Sch. 40 Reducer Bushing	1	$2.36	$2.36	$0.19	0	$2.55
	3/4 in. x Close Lead-Free Red Brass Pipe Nipple	1	$6.73	$6.73	$0.54	0	$7.27
	Rubbermaid Structural Foam Stock Tank	1	$77.99	$77.99	6.04	0	$84.03
	PVC cutting tool	1	$11.98	$11.98	0	0	$11.98
	PVC glue	1	$8.02	$8.02	0	0	$8.02
	1 1/4 " PVC tubing	2	$2.61	$5.22	0	0	$5.22
	1/2 " PVC couplers	8	$0.38	$3.04	0	0	$3.04

APPENDIX M - CONDENSED BILL OF MATERIALS							
SUBSYSTEM	**ITEM DESCRIPTION**	**QTY**	**COST/UNIT**	**ITEM COST**	**TAX**	**SHIPPING**	**TOTAL COST**
	1 1/4 " PVC T's	3	$1.98	$5.94	0	0	$5.94
	1 1/4 " PVC 4 way	2	$2.58	$5.16	0	0	$5.16
	1 1/4 " to 3/4" reducers	7	$1.32	$9.24	0	0	$9.24
	3/4" to 1/2" PVC adapters	7	$0.96	$6.72	0	0	$6.72
	1 1/4 " to 1" reducers	1	$1.32	$1.32	0	0	$1.32
	1" to 1/2"	1	$0.98	$0.98	0	0	$0.98
	1.5" to 1 1/4" PVC adapter	1	$2.78	$2.78	0	0	$2.78
	tax on late design from home depot				4.68		4.68
	3/4" Heavy Duty Polypropylene Bulkhead with Santoprene™ Gasket	10	$5.60	$56.00	0	28	$84.00
	3/4" to 1/2" PVC adapters	20	$0.96	$19.20	0	0	$19.20
	2" Heavy Duty Polypropylene Bulkhead with Santoprene™ Gasket	2	$14.17	$28.34	$2.27	13.26	$43.87
	threaded to pvc smooth adaptor 2"	4	$1.10	$4.40	$0.35	0	$4.75
	2" pipe	4	$4.00	$16.00	$1.28	0	$17.28
FRAME	GD-60S Leveling Stem Caster	4	$46.00	$184.00		$36.51	$220.51
	plywood	1		$0.00		$0.00	
	2x2" Square Steel tubing (11gauge)	10	$25.00	$250.00	$1.81	$0.00	$26.81
	2x2" Square Steel tubing (11gauge)	60	$2.53	$151.80	$0.20	$0.00	$152.00
	1x1" Square Steel tubing (11gauge)	60	$1.25	$75.00	$0.10	$0.00	$75.10
	1x1" Square tube Stainless Steel Beam (0.120)	20	$3.60	$72.00	$0.29	$0.00	$72.29
	1/4-20 Round head screw (3" length)	11	$1.18	$12.98	$0.09	$0.00	$13.07
	1/4-20 Round Head screw (2" length)	6	$1.18	$7.08	$0.09	$0.00	$7.17
	1/4-20 Round Head screw (1" length)	8	$1.18	$9.44	$0.09	$0.00	$9.53
	1/4-20 Hex Nut	1	$5.37	$5.37	$0.43	$0.00	$5.80
	HDPE White Sheet	1	$380.55	$380.55	$27.59	$380.55	$788.69
	Steel Mortise Mount Hinges	4	$7.63	$30.52	$0.61	$0.00	$31.13

APPENDIX M - CONDENSED BILL OF MATERIALS							
SUBSYSTEM	**ITEM DESCRIPTION**	**QTY**	**COST/UNIT**	**ITEM COST**	**TAX**	**SHIPPING**	**TOTAL COST**
	Padlockable Hasp	4	$5.62	$22.48	$0.45	$0.00	$22.93
	1 gal. Rusty Metal Flat Rust Preventive Primer (Case of 2)	1	$58.76	$58.76	$4.70	$0.00	$63.46
	1 gal. Smoke Gray Gloss Protective Enamel (Case of 2)	1	$55.96	$55.96	$4.48	$0.00	$60.44
OUTSOURCED	**Service Description**	**Performed by**	**Cost**				
	Welding Frame	Chris Gentry Welding	$150.00				
	3 D printing cases	Innovation Sandbox	$0.00				



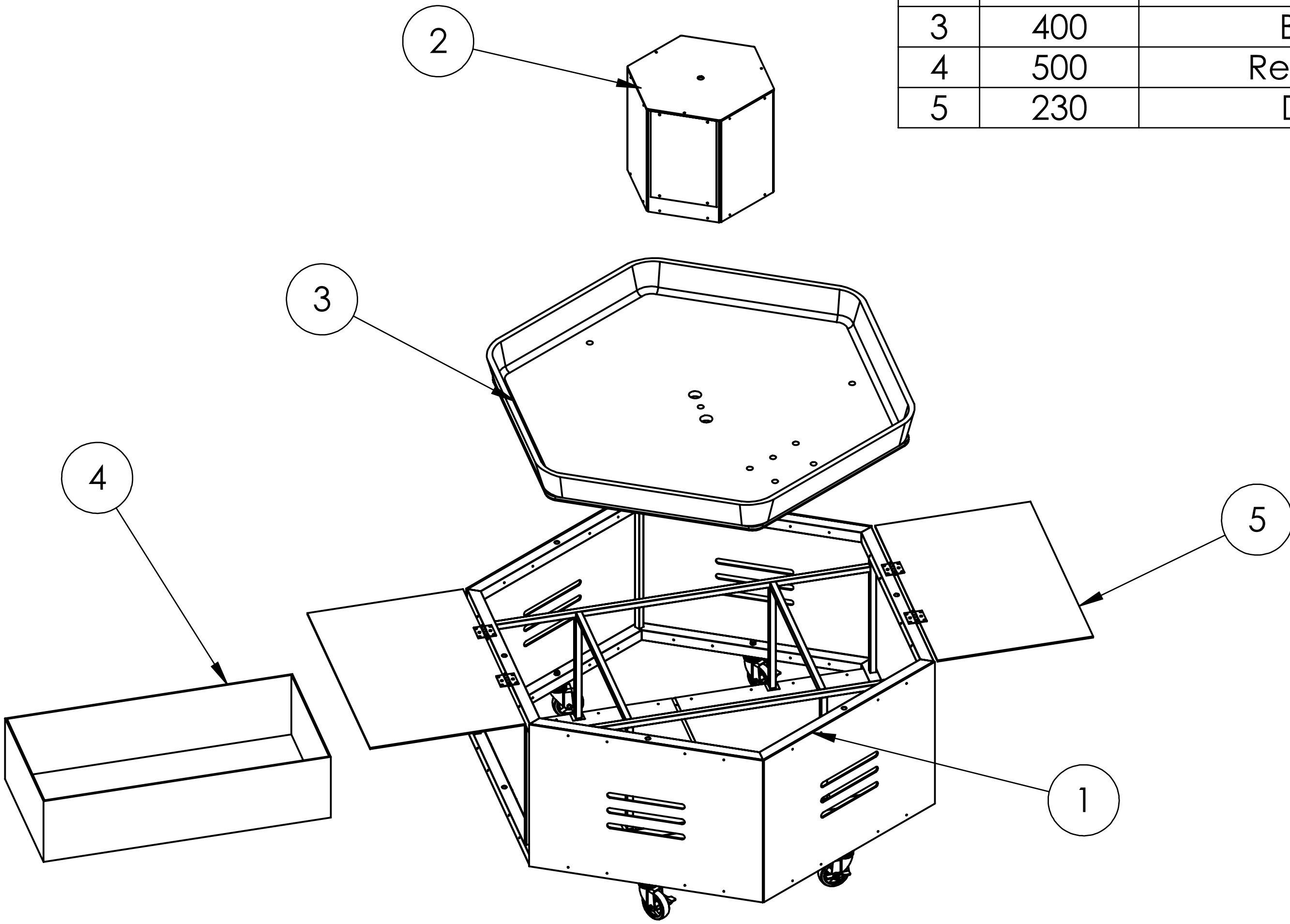




SCALE FOR FULL
EXHIBIT MODEL = 1:25

Water Fun AT EXPLORATION STATION	TITLE: Exhibit Assembly	SHEET 1 OF 1 / SCALE: 1:35	INTERPRET DRAWING PER ANSI Y14.5 2009	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/6/17	MATERIAL: Various Material	DWG. NO.: 100	REV / SIZE A

Item No.	Part No.	Description	Quantity
1	200	Frame	1
2	300	Top Hex	1
3	400	Basin	1
4	500	Reservoir	1
5	230	Door	2



Water Fun
AT EXPLORATION STATION

TITLE:
Exhibit Exploded Assembly

SHEET 1 OF 1

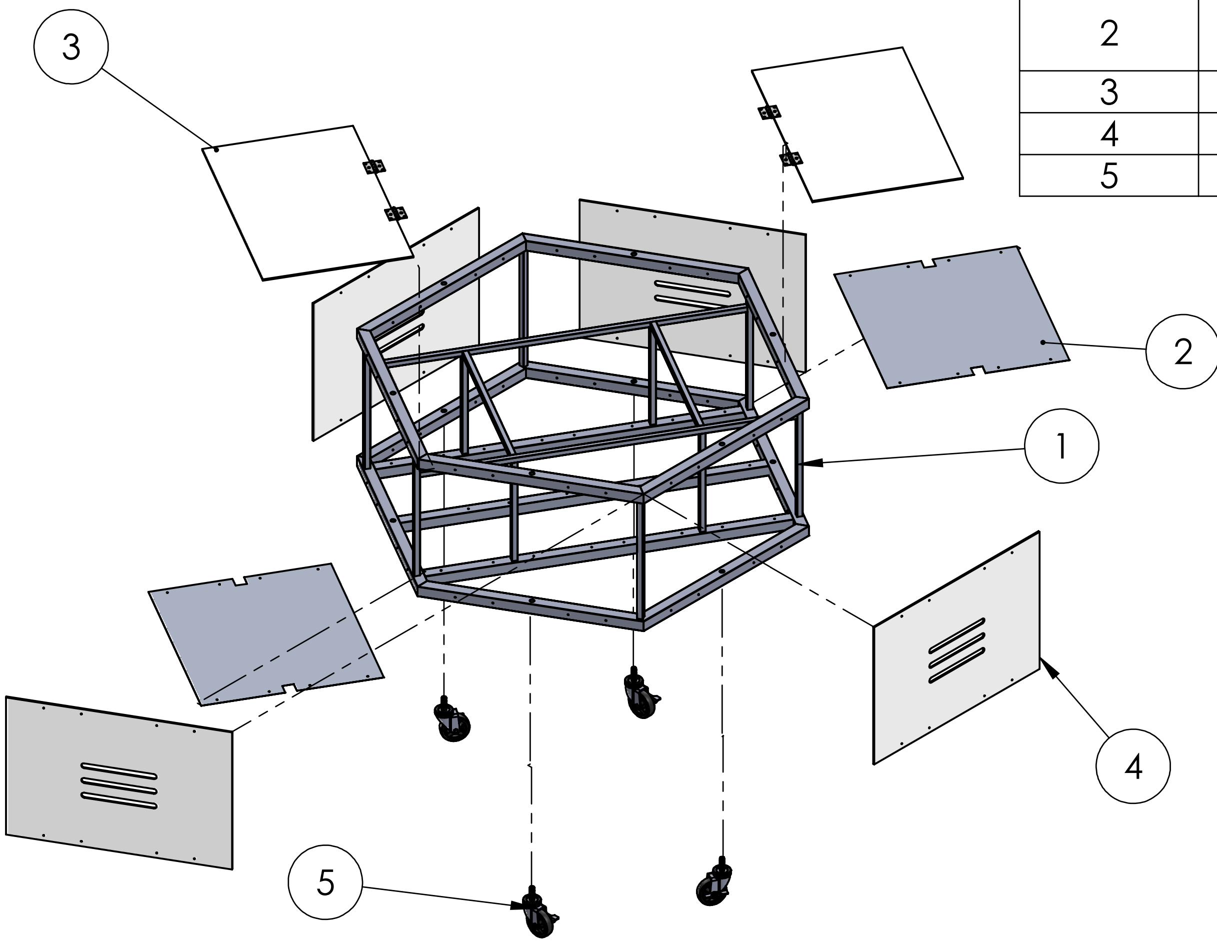
SCALE: 1:30

INTERPRET DRAWING PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:	DATE:	MATERIAL:	DWG. NO.:	REV	SIZE
NICHOLAS RUNYAN	2/6/17	Various	101		A



ITEM NO.	PART NO.	DESCRIPTION	QUANTITY
1	210	STEEL TUBE SUPPORT ASSEMBLY	1
2	220	SHEET METAL FLOOR	2
3	230	DOOR ASSEMBLY	2
4	240	SIDE WALL	4
5	250	LEVELING CASTER	4

Water Fun
AT EXPLORATION STATION

TITLE:
FRAME ASSEMBLY EXPLODED

SHEET 1 OF 1

SCALE: 1:32

INTERPRET DRAWING PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY: NICHOLAS RUNYAN

DATE: 2/6/17

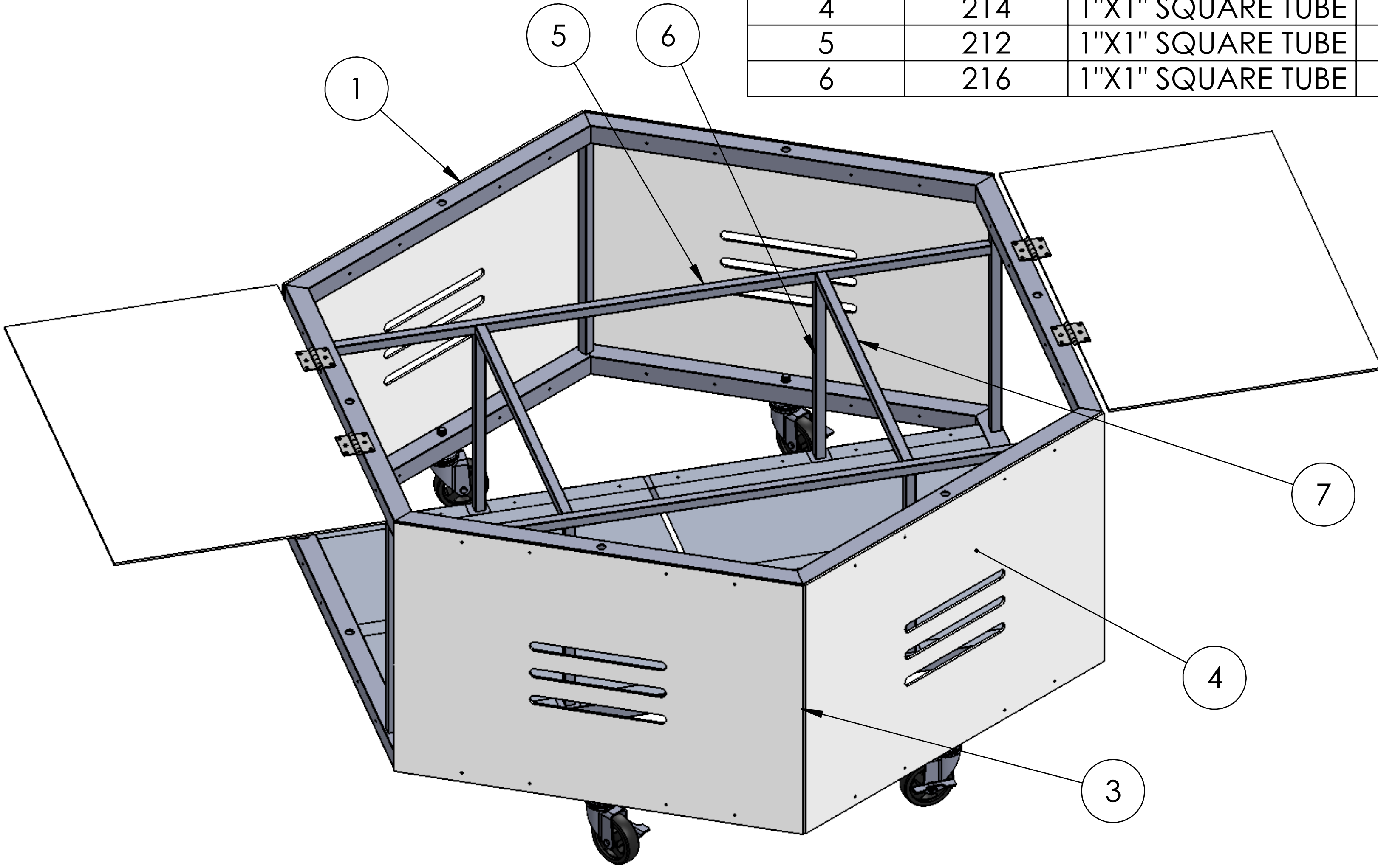
MATERIAL: Various

DWG. NO.: 201

REV

SIZE A

ITEM NO.	PART NO.	DESCRIPTION	LENGTH	QUANTITY
1	211	2"X2" SQUARE TUBE	39"	12
2	215	1"X1" SQUARE TUBE	24"	6
3	213	2"X2" SQUARE TUBE	63.5"	3
4	214	1"X1" SQUARE TUBE	65"	2
5	212	1"X1" SQUARE TUBE	20	4
6	216	1"X1" SQUARE TUBE	31"	2



Water Fun
AT EXPLORATION STATION

TITLE:
STEEL SUPPORT
MEMBER LIST

SHEET 1 OF 1

SCALE: 1:15

INTERPRET DRAWING
PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:
NICHOLAS RUNYAN

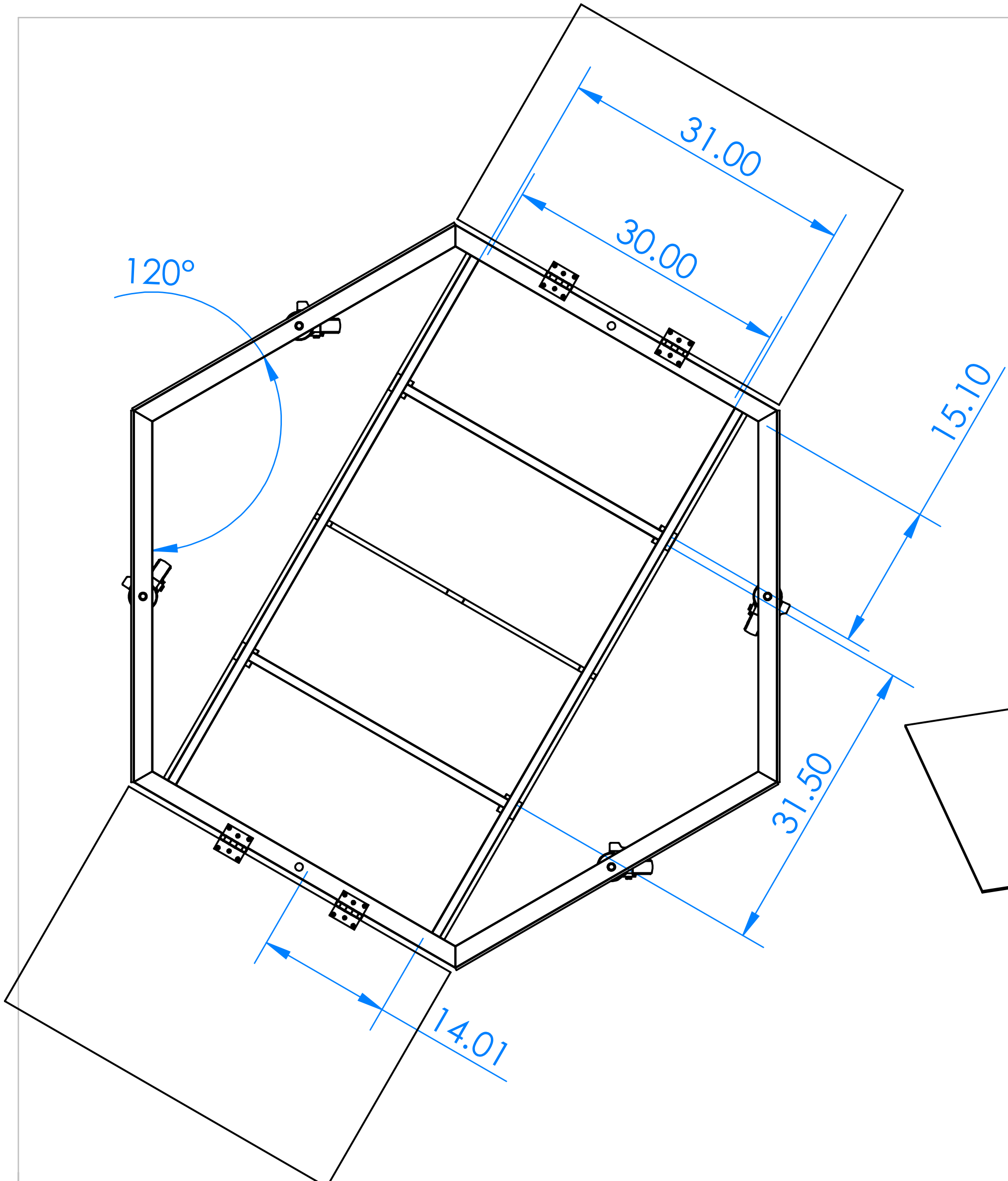
DATE:
2/6/17

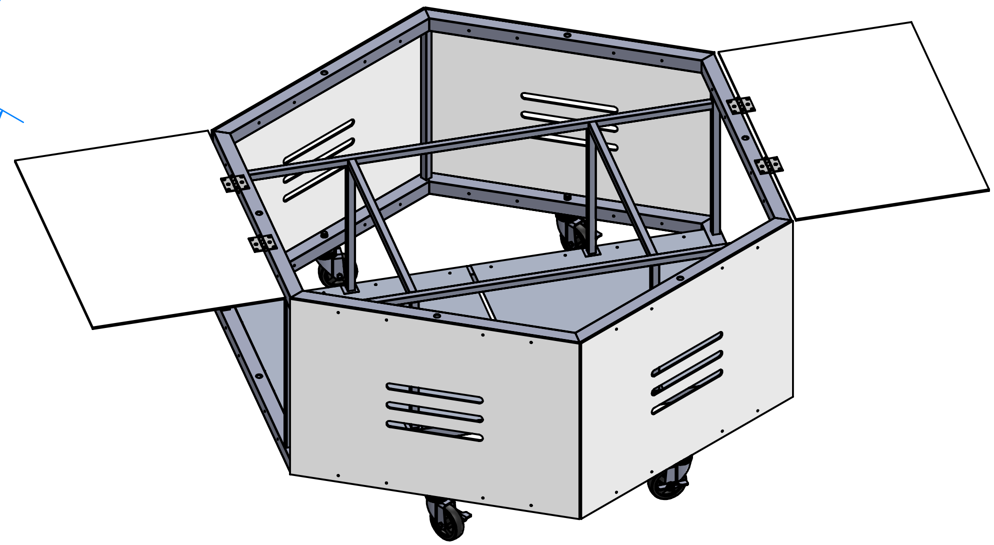
MATERIAL:
STEEL TUBING

DWG. NO.: 210

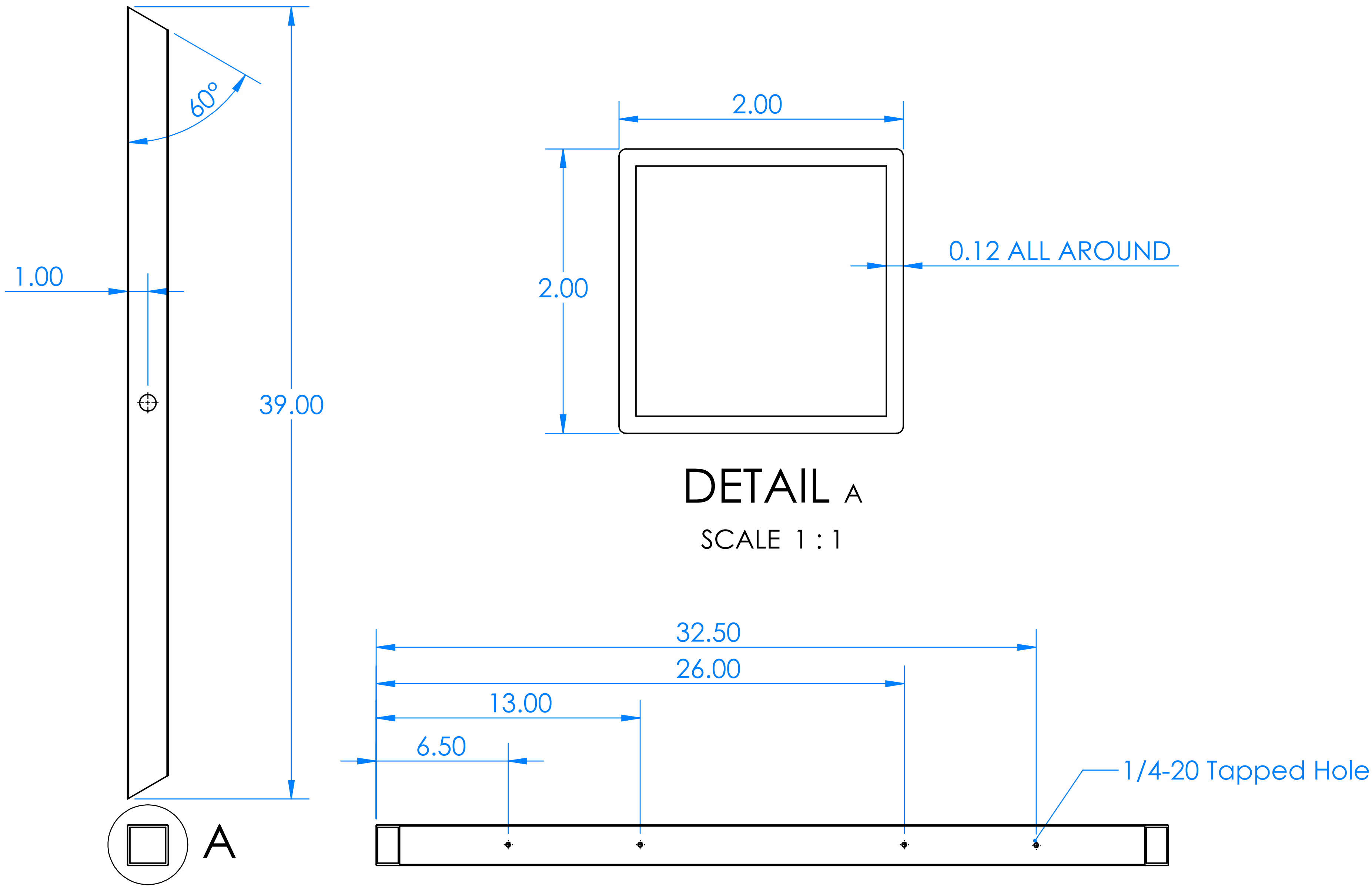
REV

SIZE
A





Water Fun AT EXPLORATION STATION	TITLE: STEEL SUPPORT MEMBER SPACING	SHEET 1 OF 1 SCALE: 1:15	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN DATE: 2/6/17	MATERIAL: STEEL TUBING	DWG. NO.: 210B	REV SIZE A



Water Fun
AT EXPLORATION STATION

TITLE:
2" x 2" Steel Angle Cut Beam

SHEET 1 OF 1

SCALE: 1:7

INTERPRET DRAWING PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:
NICHOLAS RUNYAN

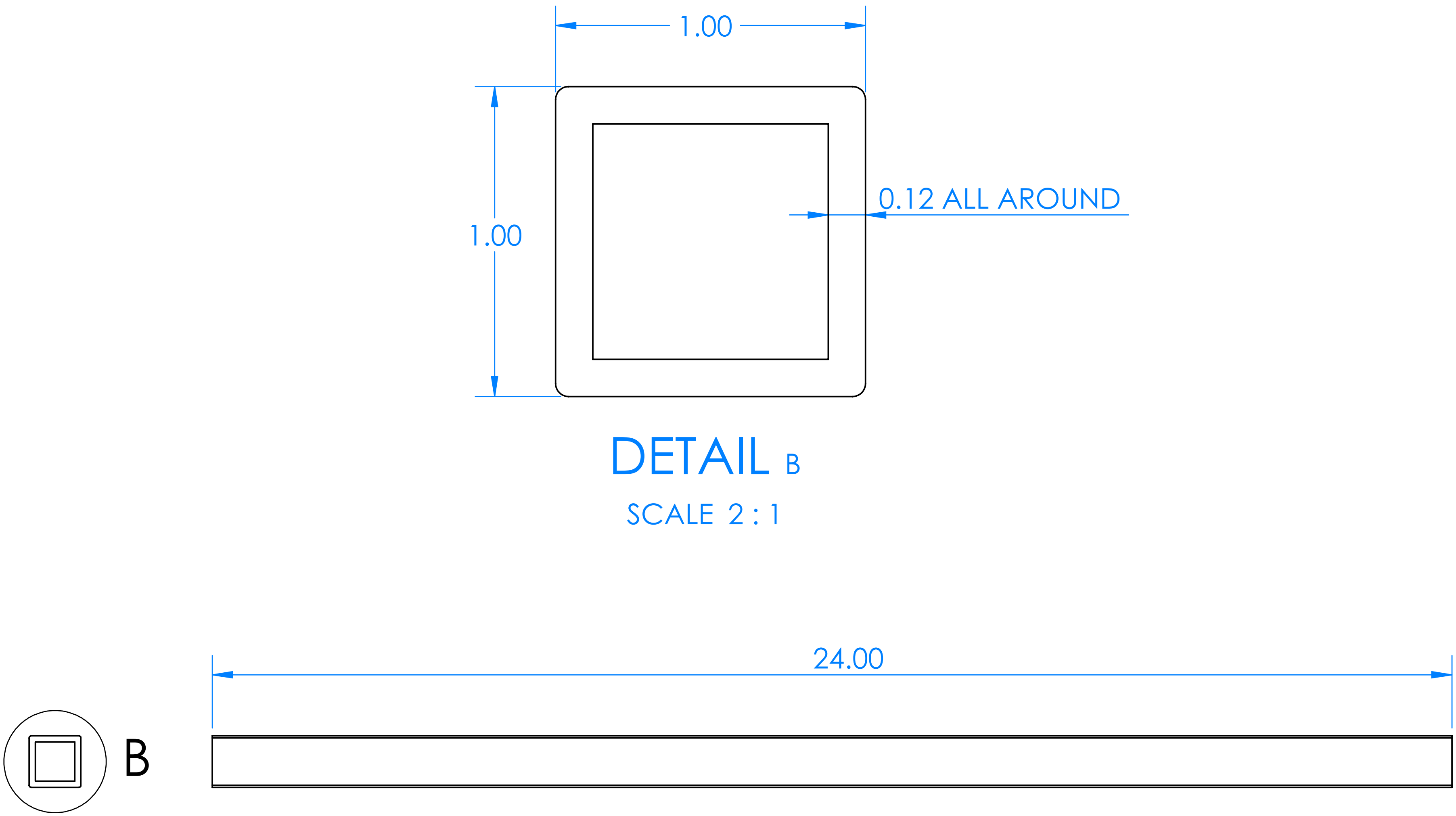
DATE:
2/6/17

MATERIAL:
11 GAUGE STEEL TUBING

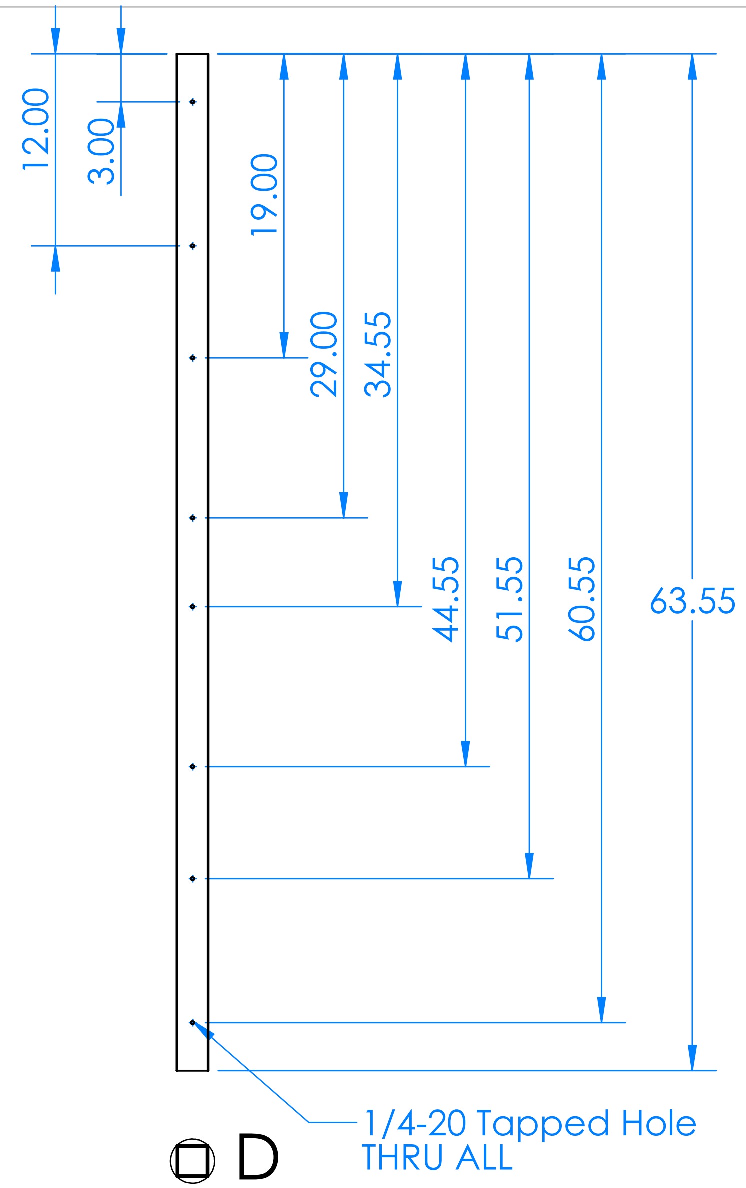
DWG. NO.: 211

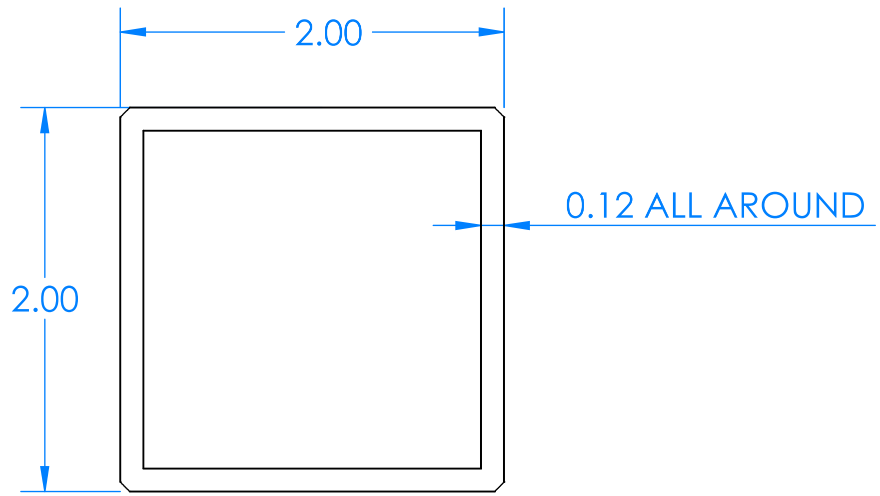
REV

SIZE
A



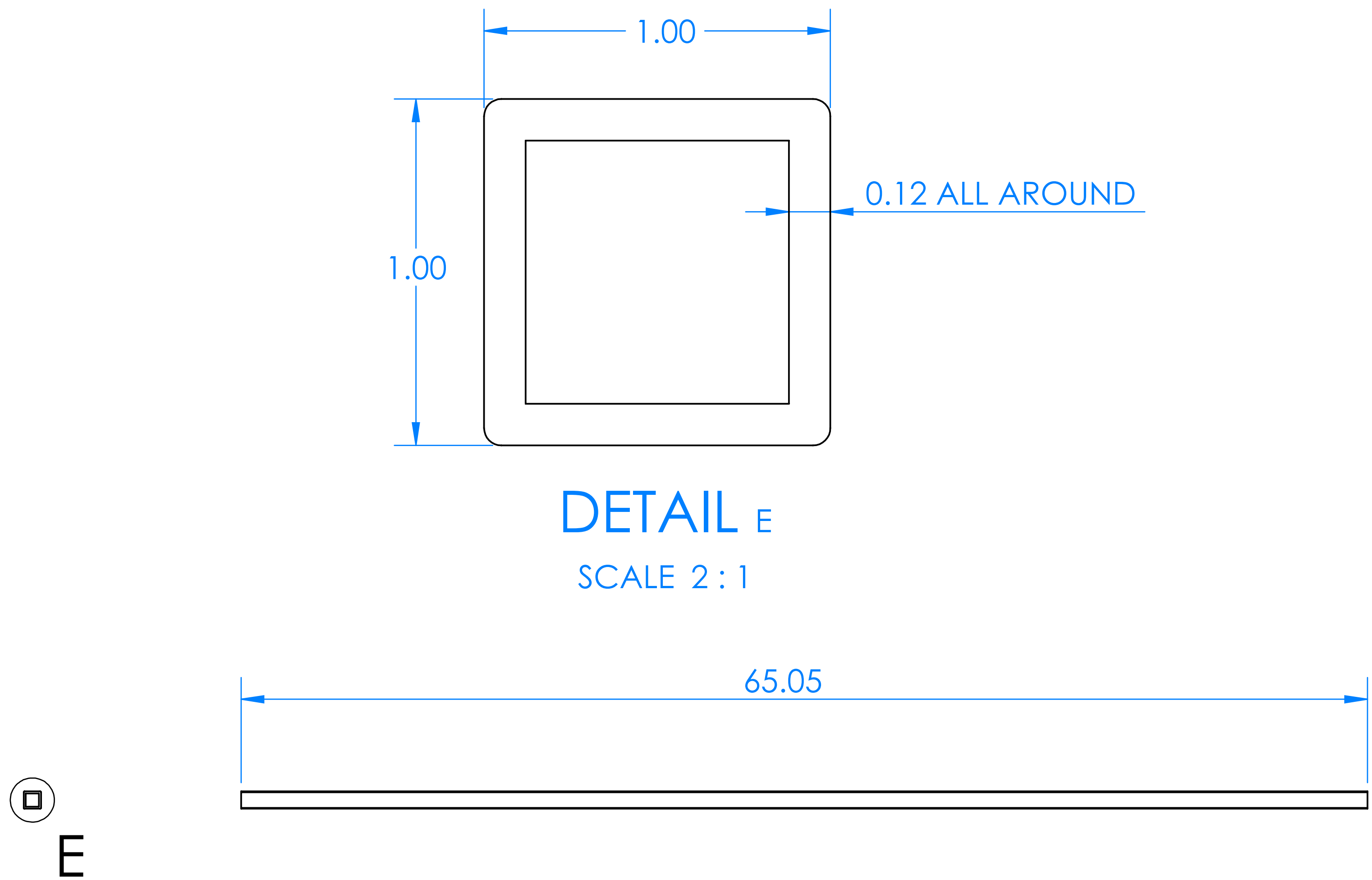
Water Fun AT EXPLORATION STATION	TITLE: 1" x 1" VERTICAL BAR	SHEET 1 OF 1 SCALE: 1:7	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN DATE: 2/6/17	MATERIAL: 11 GAUGE STEEL TUBING	DWG. NO.: 212	REV SIZE A



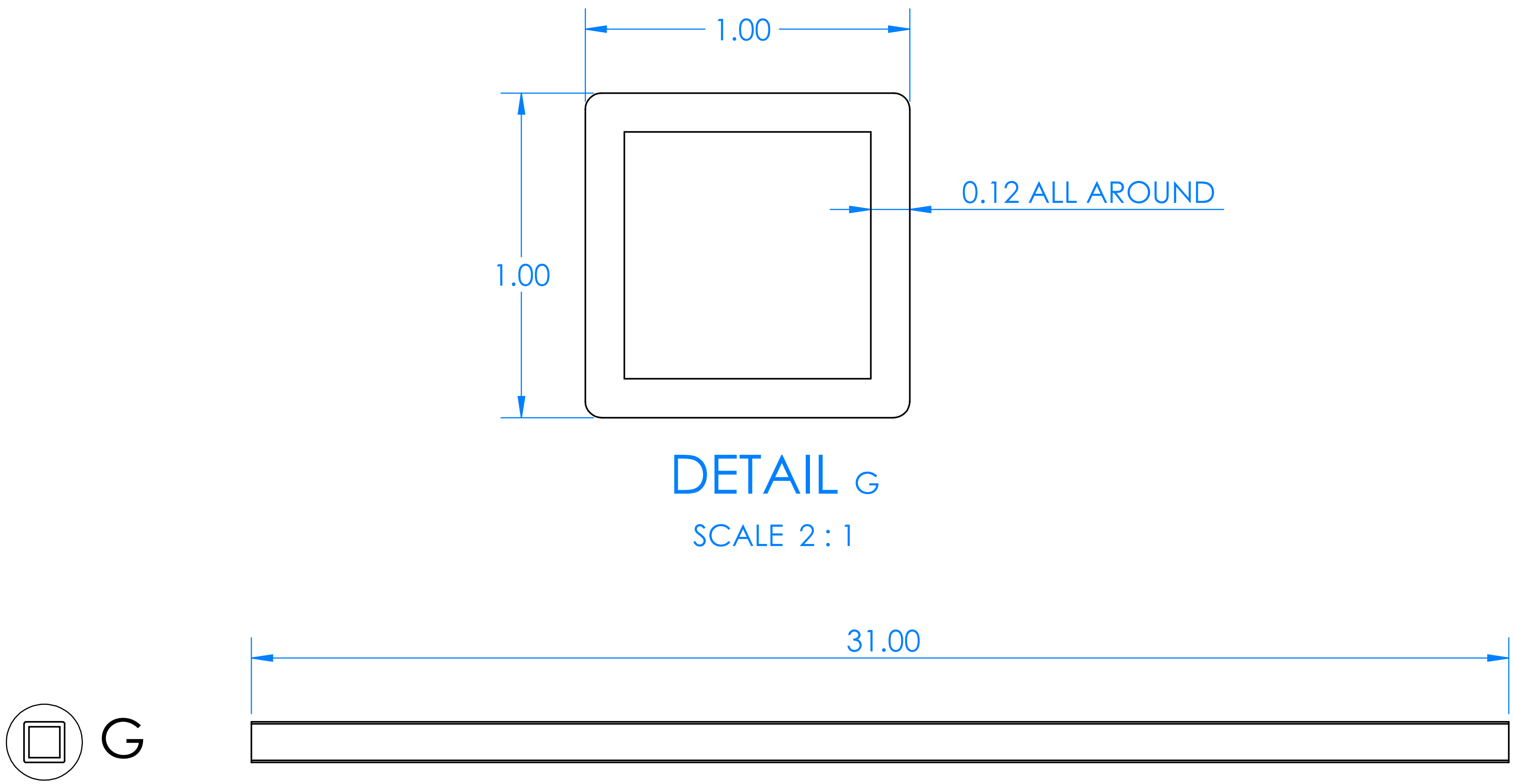


DETAIL D
SCALE 1 : 1

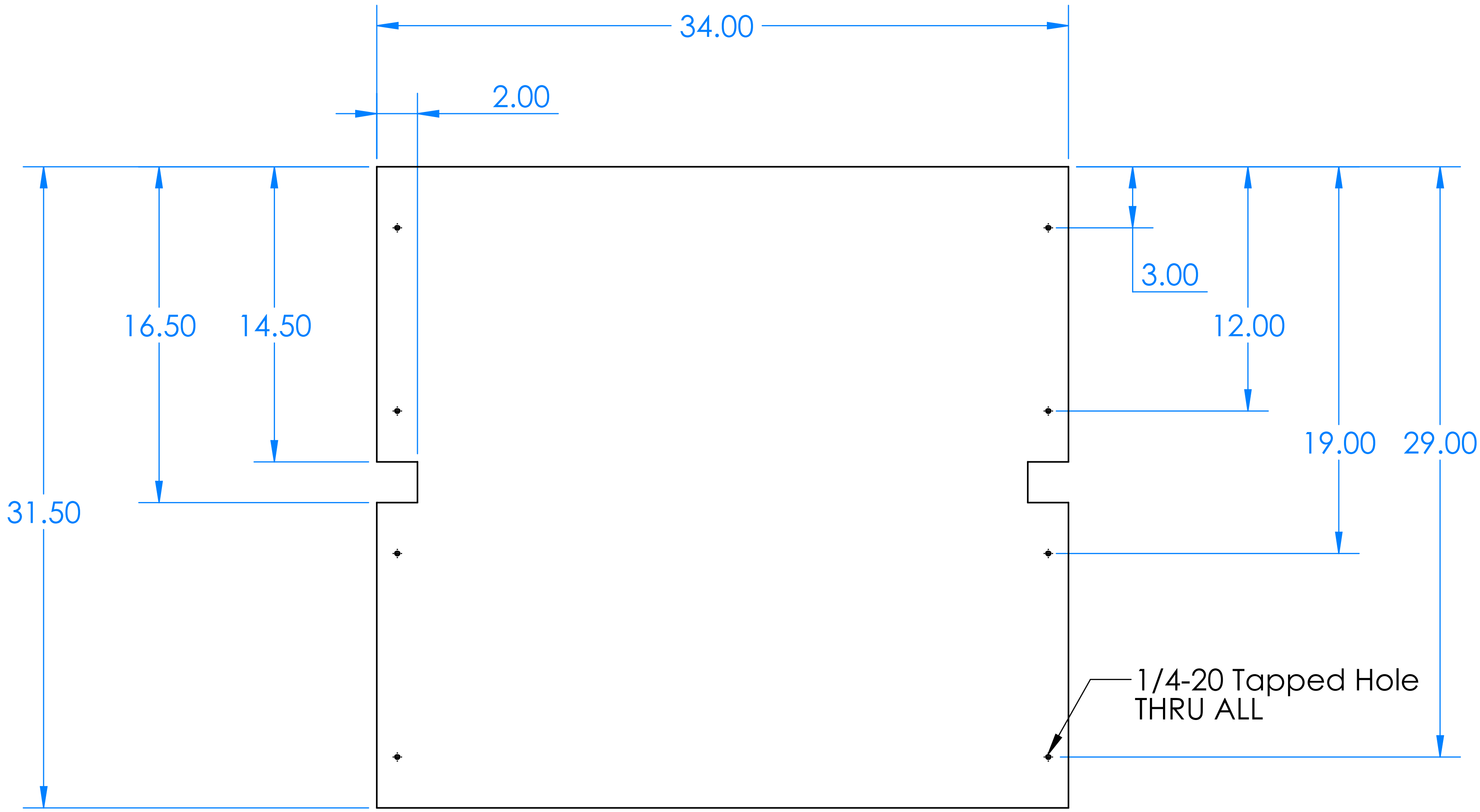
Water Fun AT EXPLORATION STATION	TITLE: 2" x 2" UNDER SUPPORT BAR	SHEET 1 OF 1 SCALE: 1:7	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN DATE: 2/6/17	MATERIAL: 11 GAUGE STEEL TUBING	DWG. NO.: 213	REV SIZE A



Water Fun AT EXPLORATION STATION	TITLE: 1" x 1" UPPER SUPPORT BAR	SHEET 1 OF 1 / SCALE: 1:10	INTERPRET DRAWING PER ANSI Y14.5 2009 / UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN / DATE: 2/6/17	MATERIAL: 11 GAUGE STEEL TUBING	DWG. NO.: 214	REV / SIZE A

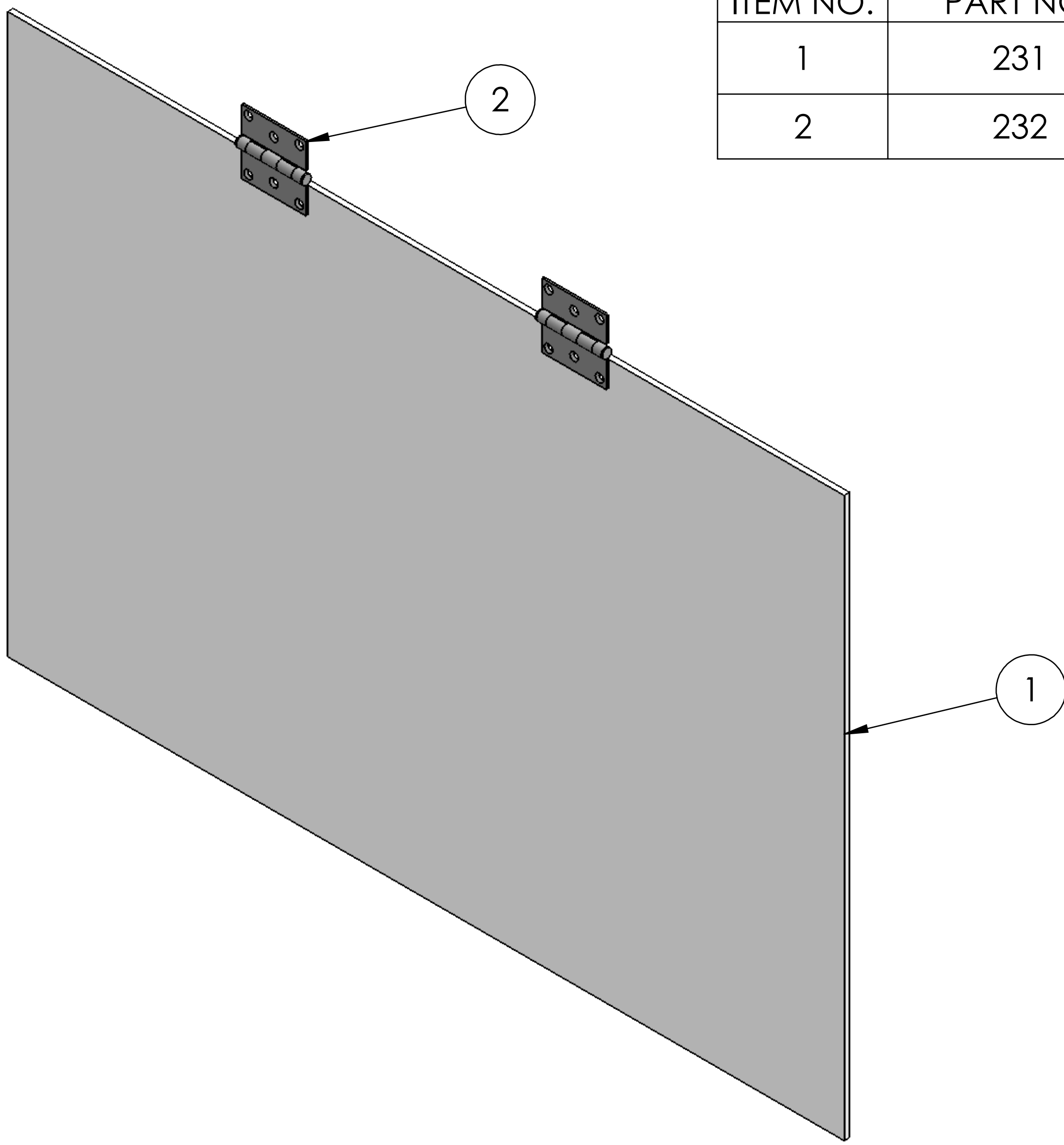


Water Fun AT EXPLORATION STATION		TITLE: 1" x 1" HORIZONTAL CROSS BAR	SHEET 1 OF 1 SCALE: 1:4	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/6/17	MATERIAL: 11 GAUGE STEEL TUBING	DWG. NO.: 216	REV / SIZE A

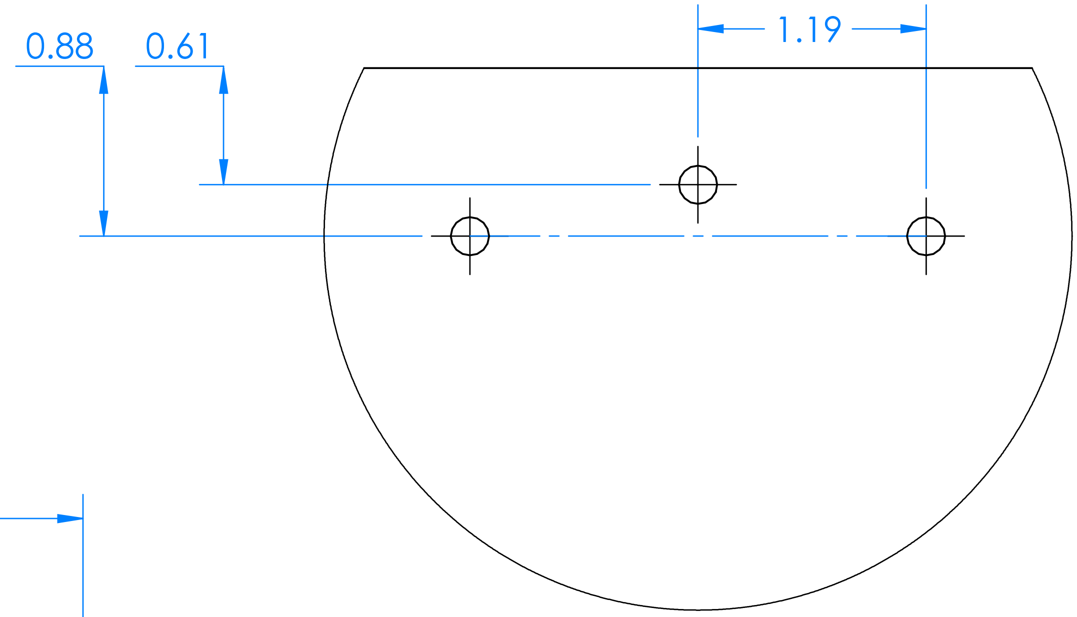


Water Fun AT EXPLORATION STATION	TITLE: SHEET METAL FLOORING	SHEET 1 OF 1 / SCALE: 1:8	INTERPRET DRAWING PER ANSI Y14.5 2009 — UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/6/17	MATERIAL: ALUMINUM SHEET (0.019' THICKNESS)	DWG. NO.: 220 — REV — SIZE A

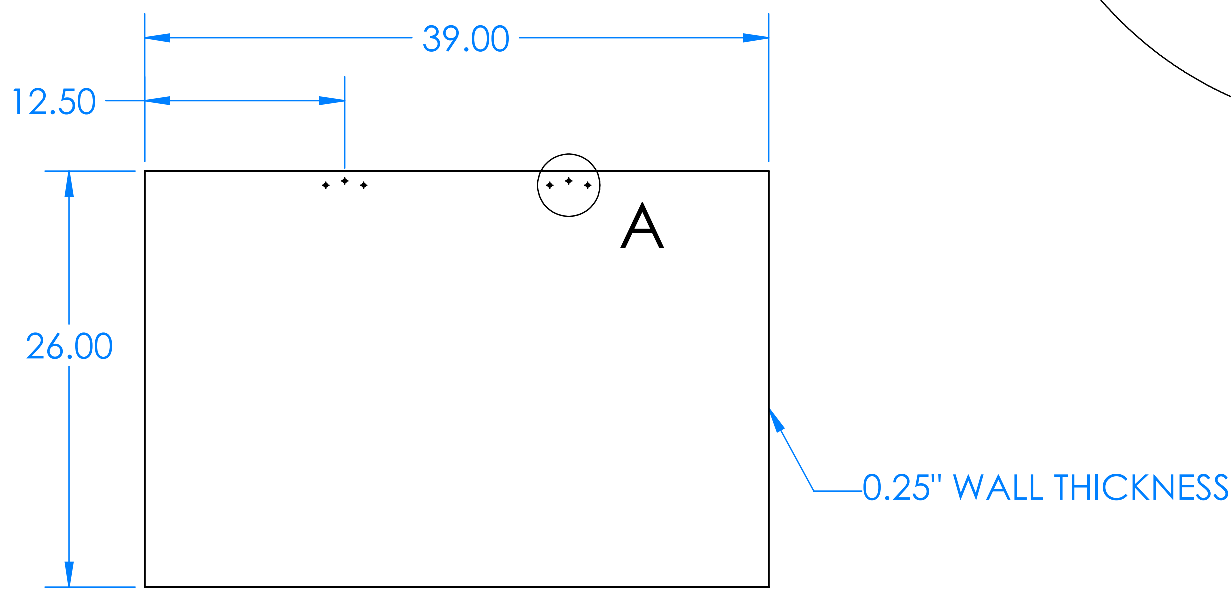
ITEM NO.	PART NO.	DESCRIPTION	QUANTITY
1	231	HDPE SIDING FOR DOOR	1
2	232	MORTISE HINGE	2



Water Fun AT EXPLORATION STATION	TITLE: DOOR ASSEMBLY	SHEET 1 OF 1 / SCALE: 1:6	INTERPRET DRAWING PER ANSI Y14.5 2009 — UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/6/17	MATERIAL: VARIOUS	DWG. NO.: 230 REV SIZE A

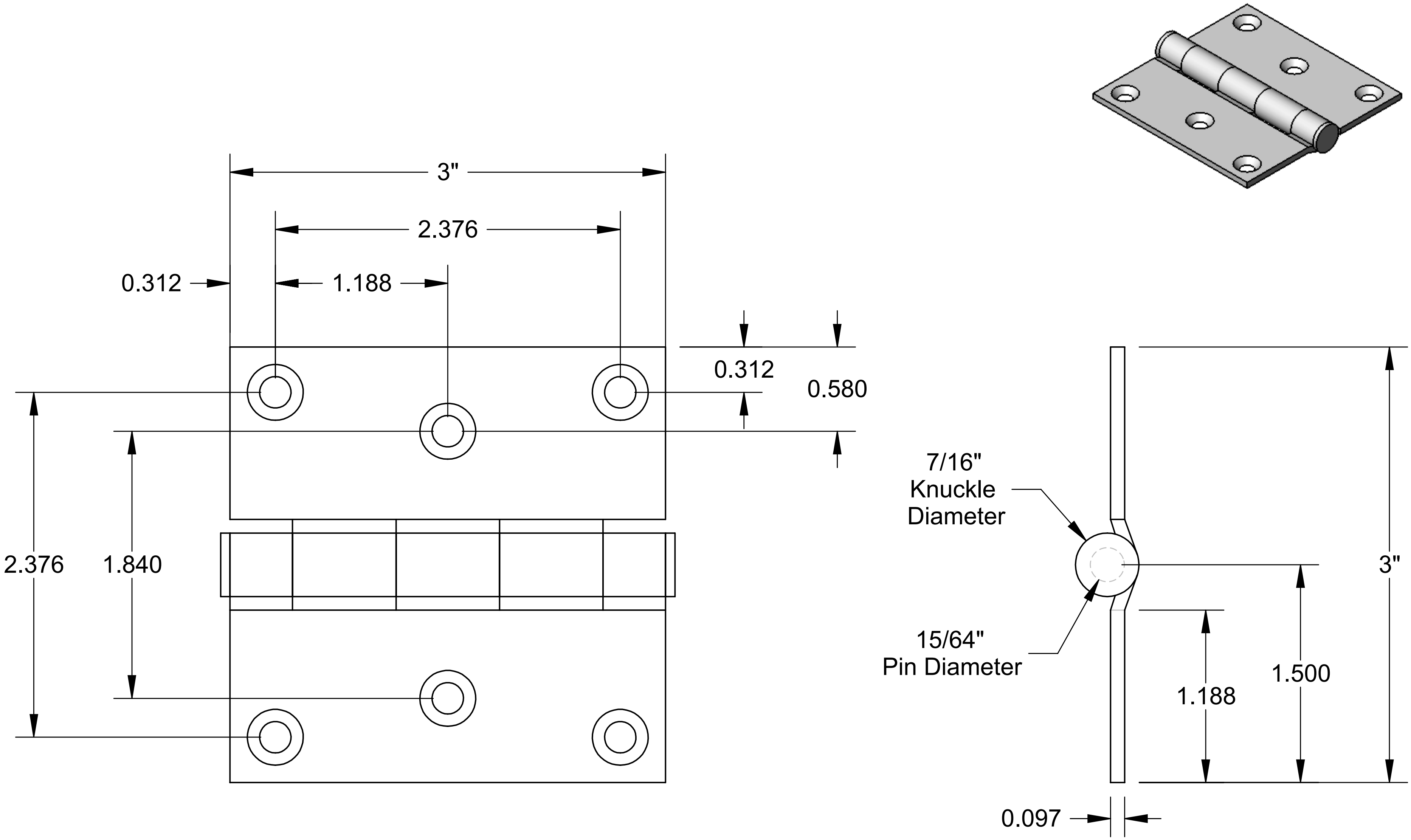


DETAIL A
SCALE 1 : 1



Water Fun
AT EXPLORATION STATION

TITLE: HDPE SIDING FOR DOOR	SHEET 1 OF 1 SCALE: 1:12	INTERPRET DRAWING PER ANSI Y14.5 2009	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/6/17	MATERIAL: HIGH DENSITY POLYETHELYNE	DWG. NO.: 231 · REV · SIZE A



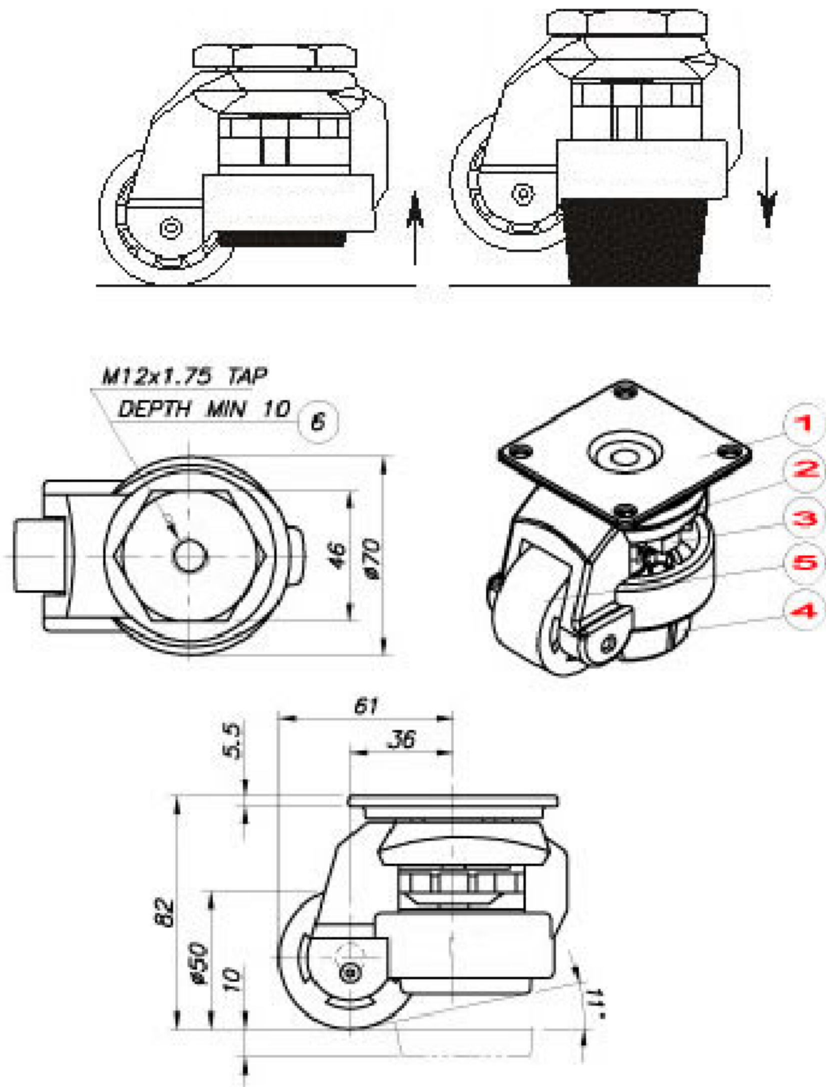
Hinge uses #9 flat head screws.

Dimensions are in inches, unless noted.

McMASTER-CARR® CAD	PART NUMBER	1494A42
http://www.mcmaster.com	Mortise-Mount Template Hinge	

Materials		
Names	**Basic Materials**	**Optional Materials**
Plate	Pressed steel / khaki	-
Frame	Aluminum / Ivory	Aluminum / Black
Handle	ABS / Orange	-
Pad	NBR / Black	NBR / Gray
		Antistatic NBR / Black
		Polyurethane / Natural
		Antistatic Polyurethane / Natural
Wheel	Nylon 6	-
Powder coat & Zinc Galvanized		

SPECIFICATION INFORMATION
FOUND ONLINE ONE THE GILMAN
KRAMER WEBSITE



Water Fun
AT EXPLORATION STATION

TITLE:
LEVELING CASTER

SHEET 1 OF 1

SCALE: N/A

INTERPRET DRAWING
PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:
NICHOLAS RUNYAN

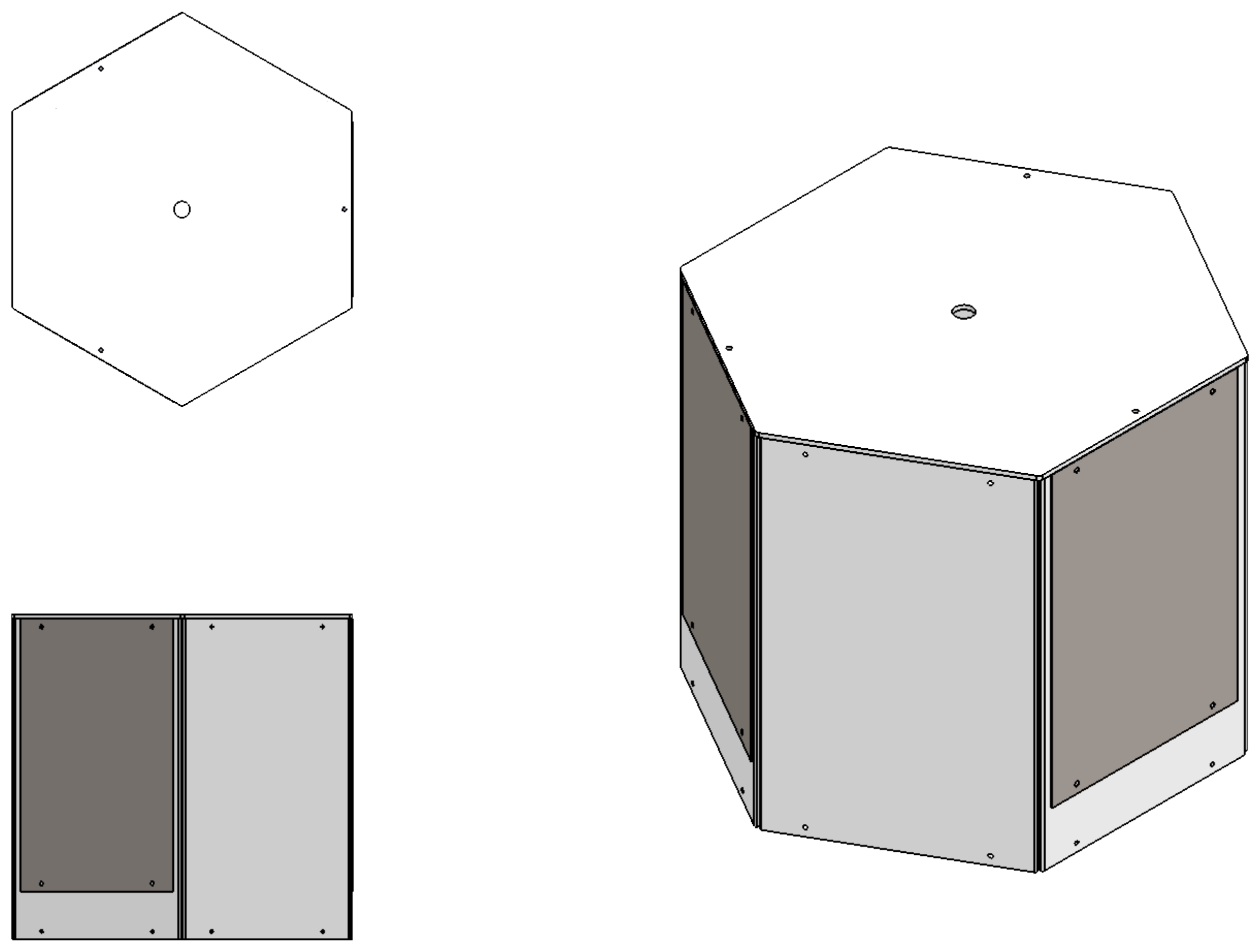
DATE:
2/8/17

MATERIAL:
VARIOUS

DWG. NO.: 250

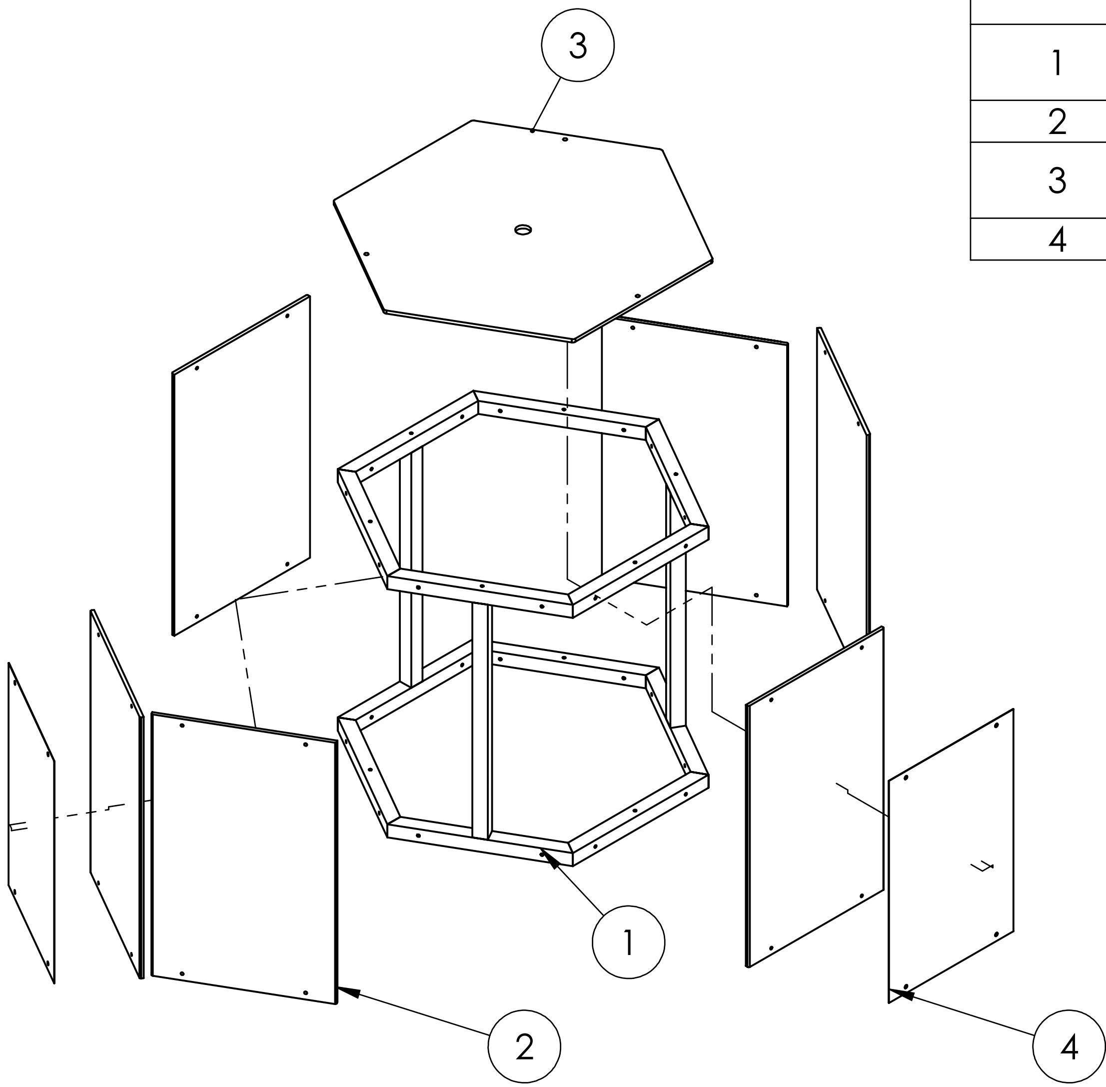
REV

SIZE
A



Water Fun AT EXPLORATION STATION	TITLE: TOP HEXAGON ASSEMBLY	SHEET 1 OF 1 SCALE: 1:8	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN DATE: 2/8/17	MATERIAL: VARIOUS	DWG. NO.: 300	REV SIZE A

ITEM NO.	PART NO.	DESCRIPTION	QUANTITY
1	310	HEXAGONAL INNER FRAME	1
2	320	HDPE WALLS	6
3	330	HDPE HEXAGONAL TOPPER	1
4	340	SHEET STEEL	3



Water Fun
AT EXPLORATION STATION

TITLE:
TOP HEXAGON EXPLODED ASSEMBLY

SHEET 1 OF 1

SCALE: 1:12

INTERPRET DRAWING PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY: NICHOLAS RUNYAN

DATE: 2/8/17

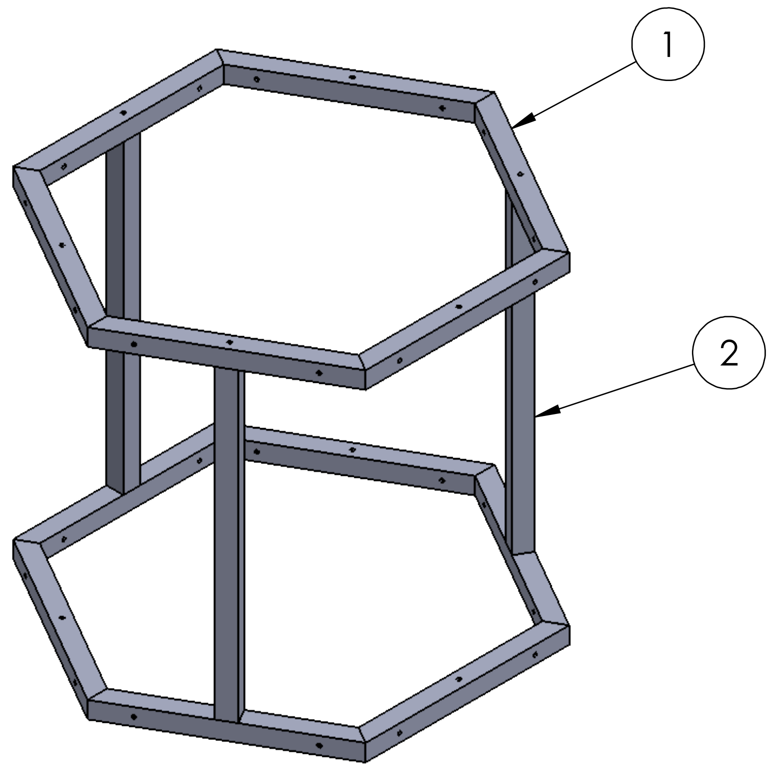
MATERIAL: VARIOUS

DWG. NO.: 301

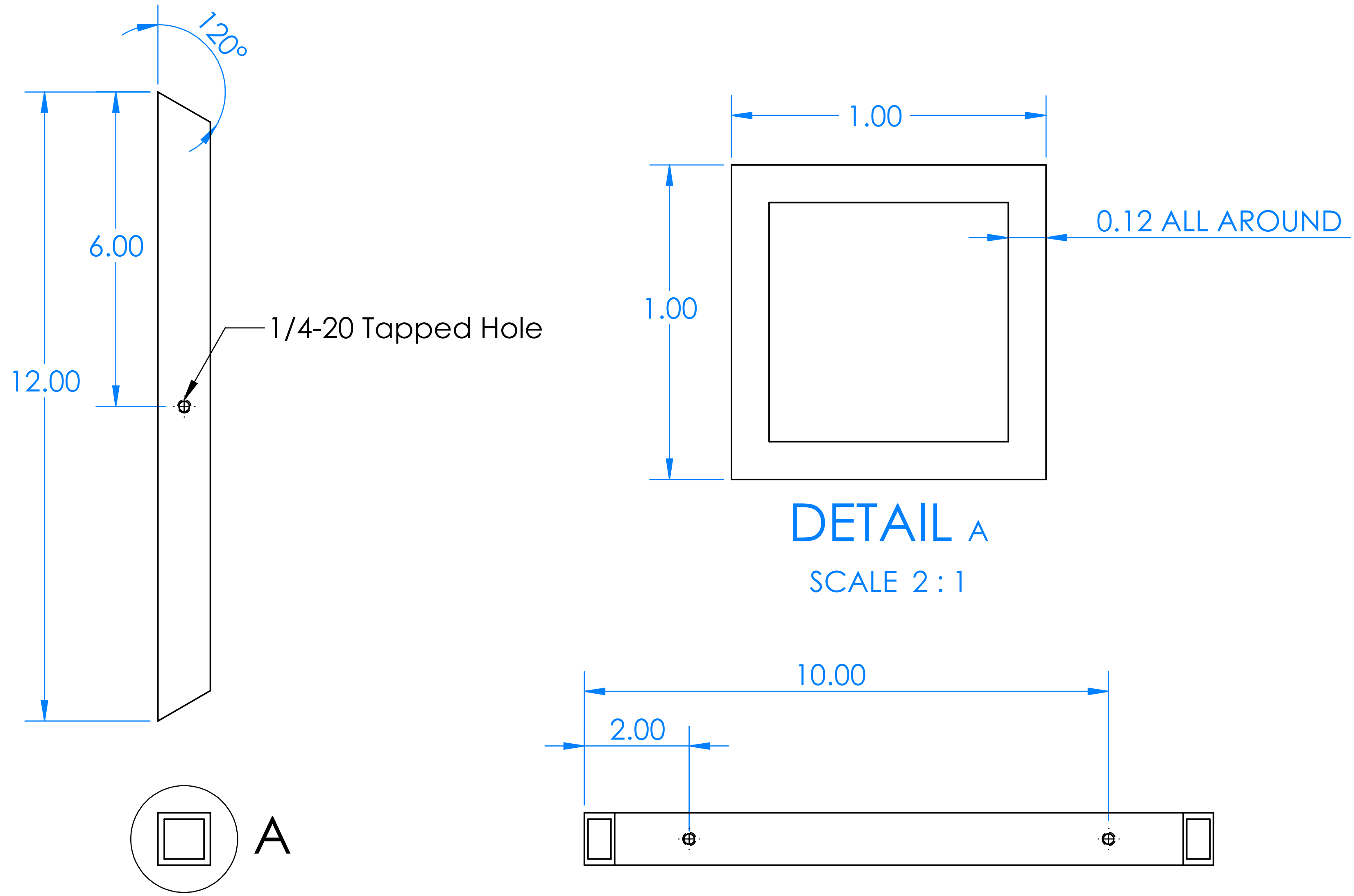
REV

SIZE A

ITEM NO.	PART NO.	DESCRIPTION	QUANTITY
1		12" ANGLED TUBE	12
2		19" VERTICAL TUBE	3



Water Fun AT EXPLORATION STATION	TITLE: TOP HEX INTERNAL STRUCTURE	SHEET 1 OF 1 / SCALE: 1:8	INTERPRET DRAWING PER ANSI Y14.5 2009	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/8/17	MATERIAL: 1" x 1" STEEL TUBING	DWG. NO.: 310	REV	SIZE A



Water Fun
AT EXPLORATION STATION

TITLE:
TOP HEXAGON
ANGLE CUT TUBE

SHEET 1 OF 1

SCALE: 1:3

INTERPRET DRAWING
PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:
NICHOLAS RUNYAN

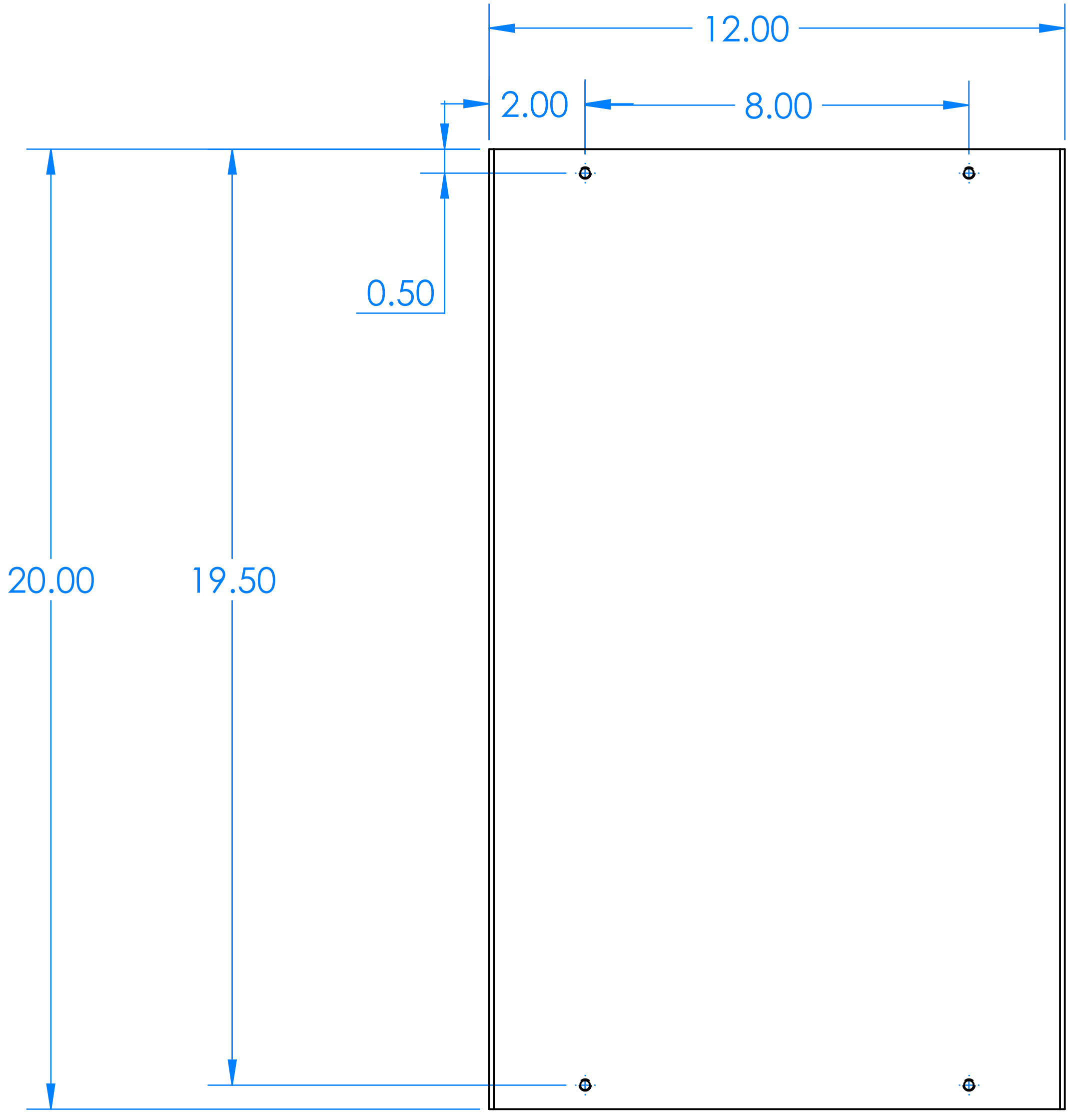
DATE:
2/8/17

MATERIAL:
1" x 1" STEEL TUBING

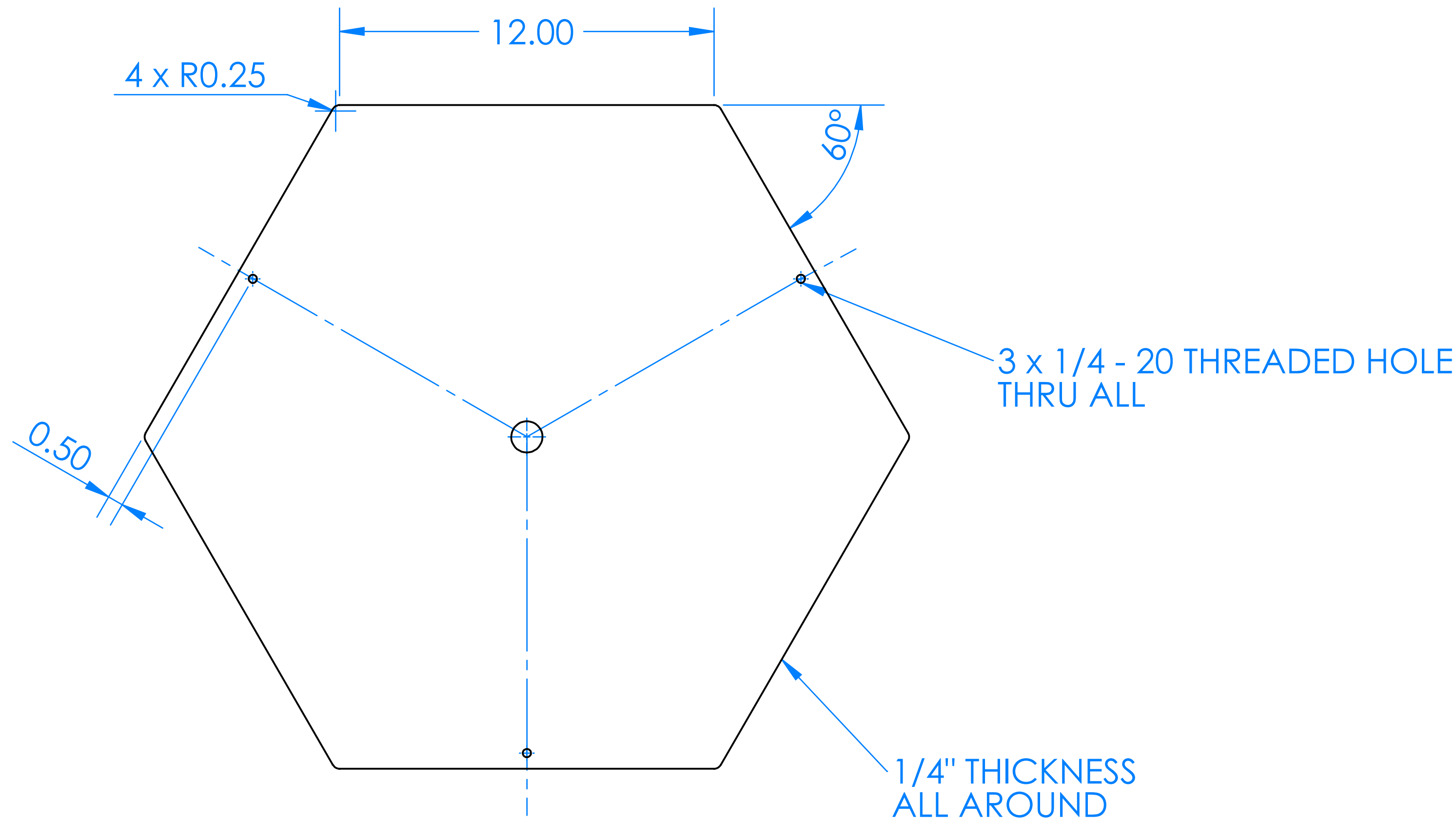
DWG. NO.: 311

REV

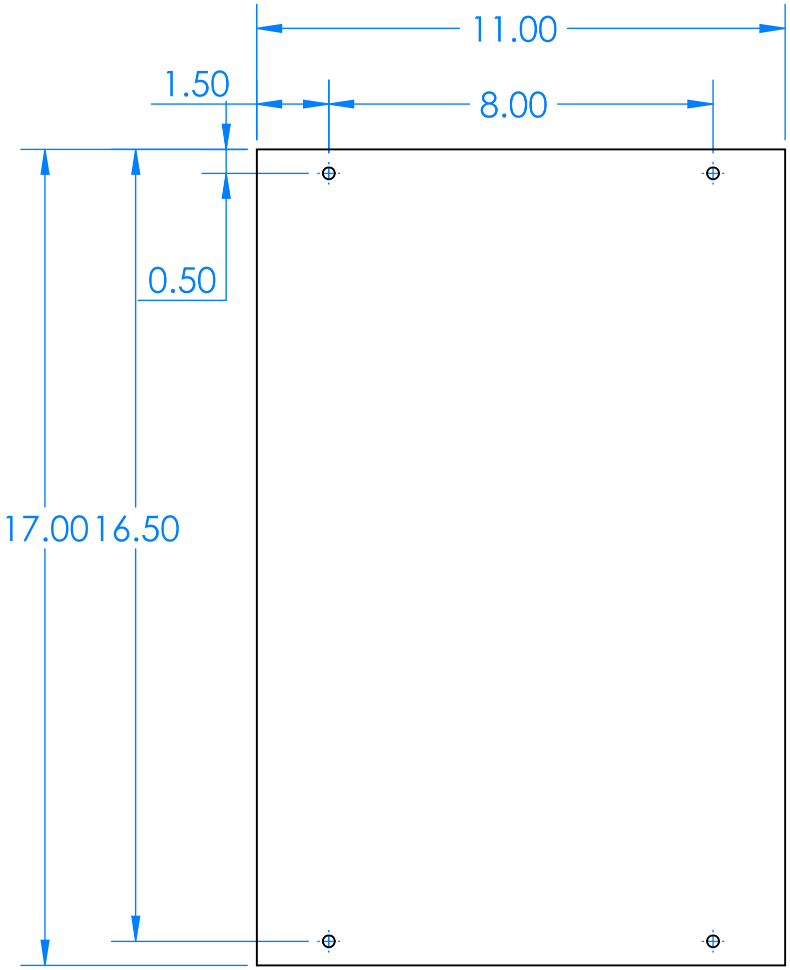
SIZE
A



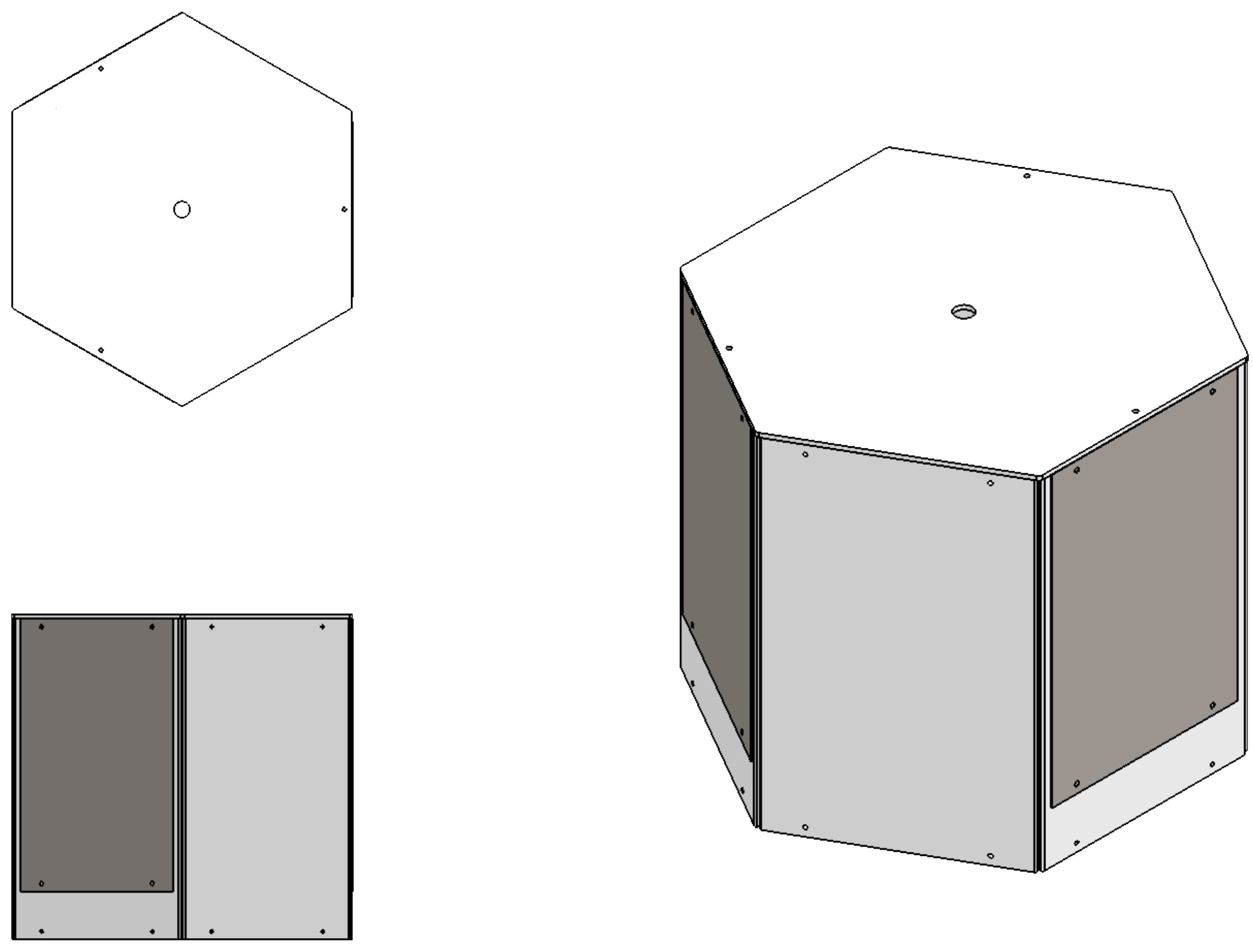
Water Fun AT EXPLORATION STATION	TITLE: SIDE WALLS	SHEET 1 OF 1 / SCALE: 1:3	INTERPRET DRAWING PER ANSI Y14.5 2009 — UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/8/17	MATERIAL: HIGH DENSITY POLYETHYLENE	DWG. NO.: 312 — REV — SIZE A



Water Fun AT EXPLORATION STATION	TITLE: TOP HEXAGON LID	SHEET 1 OF 1 / SCALE: 1:6	INTERPRET DRAWING PER ANSI Y14.5 2009 — UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN — DATE: 2/8/17	MATERIAL: HIGH DENSITY POLYETHYLENE	DWG. NO.: 313	REV — SIZE A



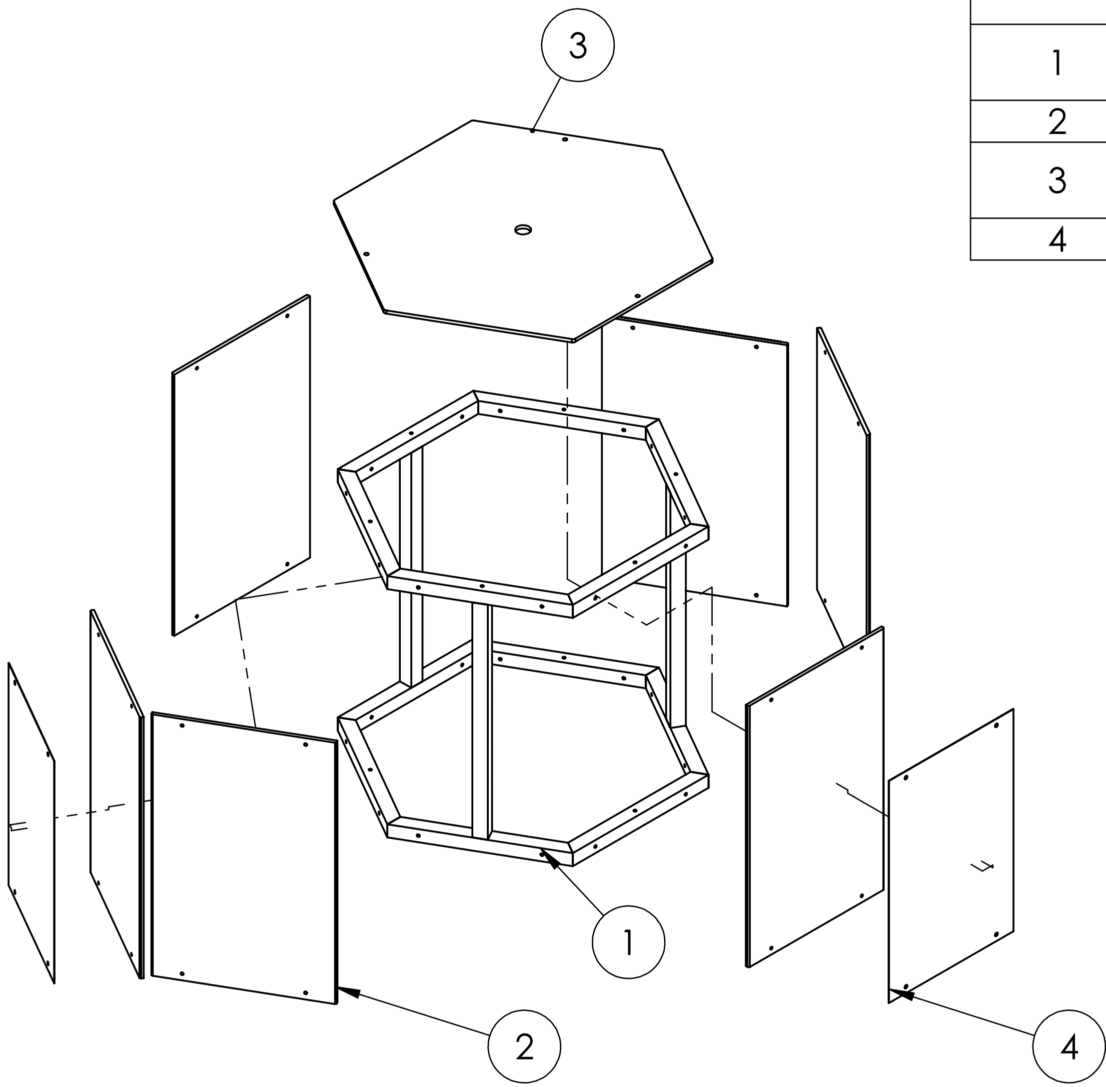
Water Fun AT EXPLORATION STATION	TITLE: SHEET METAL FOR TOP HEXAGONAL WALL SIDING	SHEET 1 OF 1 SCALE: 1:6	INTERPRET DRAWING PER ANSI Y14.5 2009 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/8/17	MATERIAL: 24 GAUGE SHEET METAL	DWG. NO.: 314 REV SIZE A



Water Fun
AT EXPLORATION STATION

TITLE: TOP HEXAGON ASSEMBLY	SHEET 1 OF 1 SCALE: 1:8	INTERPRET DRAWING PER ANSI Y14.5 2009	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005

DRAWN BY:	DATE:	MATERIAL:	DWG. NO.:	REV	SIZE
NICHOLAS RUNYAN	2/8/17	VARIOUS	300		A



ITEM NO.	PART NO.	DESCRIPTION	QUANTITY
1	310	HEXAGONAL INNER FRAME	1
2	320	HDPE WALLS	6
3	330	HDPE HEXAGONAL TOPPER	1
4	340	SHEET STEEL	3

Water Fun
AT EXPLORATION STATION

TITLE:
TOP HEXAGON
EXPLODED ASSEMBLY

SHEET 1 OF 1

SCALE: 1:12

INTERPRET DRAWING
PER ANSI Y14.5 2009

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

DRAWN BY:
NICHOLAS RUNYAN

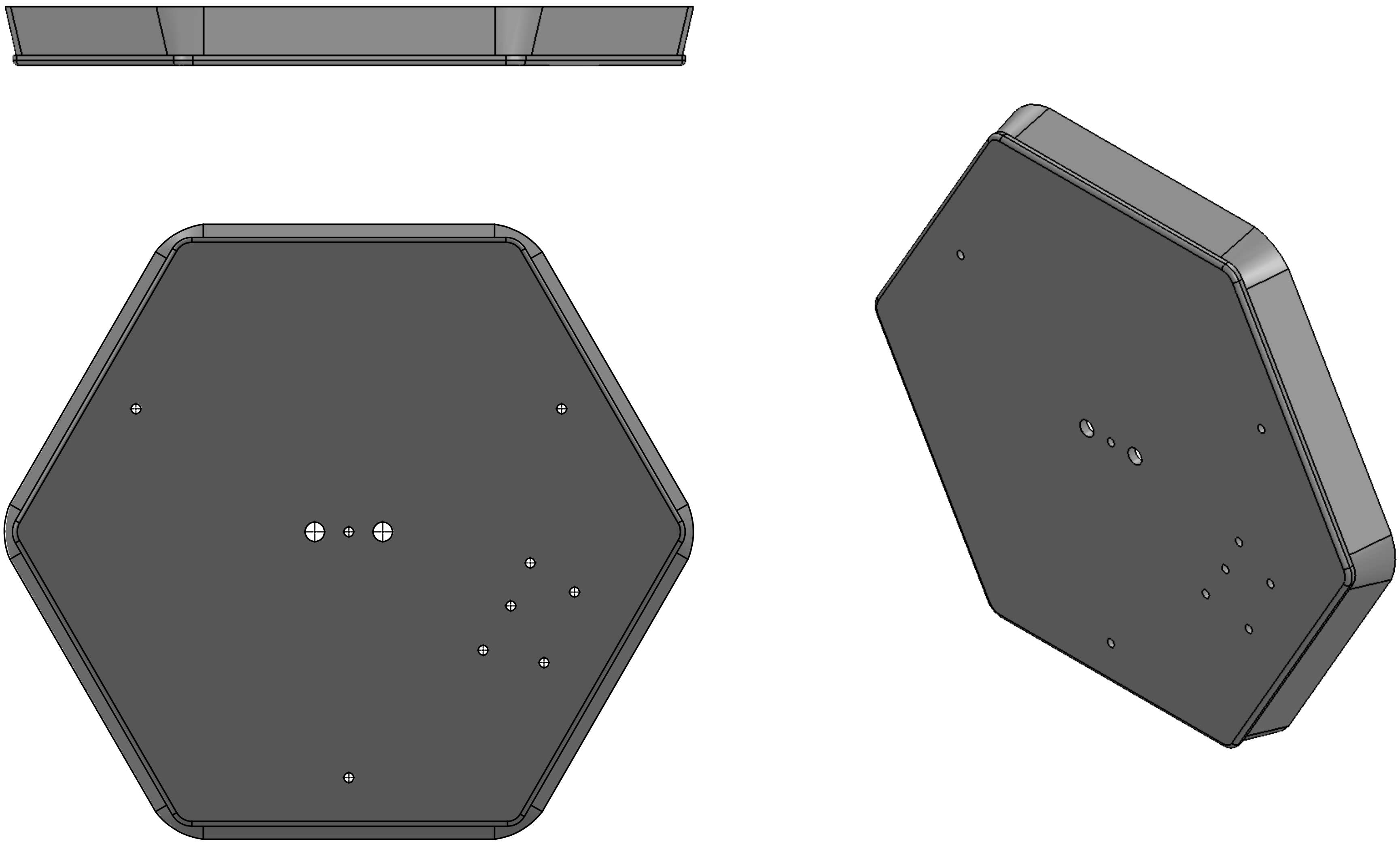
DATE:
2/8/17

MATERIAL:
VARIOUS

DWG. NO.: 301

REV

SIZE
A



Water Fun
AT EXPLORATION STATION

TITLE: EXHIBIT BASIN	SHEET 1 OF 1 SCALE: 1:16	INTERPRET DRAWING PER ANSI Y14.5 2009	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005
DRAWN BY: NICHOLAS RUNYAN	DATE: 2/9/17	MATERIAL: POLYESTER RESIN	DWG. NO.: 400 REV SIZE A

HC-SR501 PIR MOTION DETECTOR

Product Discription

HC-SR501 is based on infrared technology, automatic control module, using Germany imported LHI778 probe design, high sensitivity, high reliability, ultra-low-voltage operating mode, widely used in various auto-sensing electrical equipment, especially for battery-powered automatic controlled products.

Specification:

- Voltage: 5V – 20V
- Power Consumption: 65mA
- TTL output: 3.3V, 0V
- Delay time: Adjustable (.3->5min)
- Lock time: 0.2 sec
- Trigger methods: L – disable repeat trigger, H enable repeat trigger
- Sensing range: less than 120 degree, within 7 meters
- Temperature: – 15 ~ +70
- Dimension: 32*24 mm, distance between screw 28mm, M2, Lens dimension in diameter: 23mm

Application:

Automatically sensing light for Floor, bathroom, basement, porch, warehouse, Garage, etc, ventilator, alarm, etc.

Features:

- Automatic induction: to enter the sensing range of the output is high, the person leaves the sensing range of the automatic delay off high, output low.
- Photosensitive control (optional, not factory-set) can be set photosensitive control, day or light intensity without induction.
- Temperature compensation (optional, factory reset): In the summer when the ambient temperature rises to 30 ° C to 32 ° C, the detection distance is slightly shorter, temperature compensation can be used for performance compensation.
- Triggered in two ways: (jumper selectable)
  - non-repeatable trigger: the sensor output high, the delay time is over, the output is automatically changed from high level to low level;
  - repeatable trigger: the sensor output high, the delay period, if there is human activity in its sensing range, the output will always remain high until the people left after the delay will be high level goes low (sensor module detects a time delay period will be automatically extended every human activity, and the starting point for the delay time to the last event of the time).
- With induction blocking time (the default setting: 2.5s blocked time): sensor module after each sensor output (high into low), followed by a blockade set period of time, during this time period sensor does not accept any sensor signal. This feature can be achieved sensor output time “and” blocking time “interval between the work can be applied to interval detection products; This function can inhibit a variety of interference in the process of load switching. (This time can be set at zero seconds – a few tens of seconds).
- Wide operating voltage range: default voltage DC4.5V-20V.
- Micropower consumption: static current <50 microamps, particularly suitable for battery-powered automatic control products.
- Output high signal: easy to achieve docking with the various types of circuit.

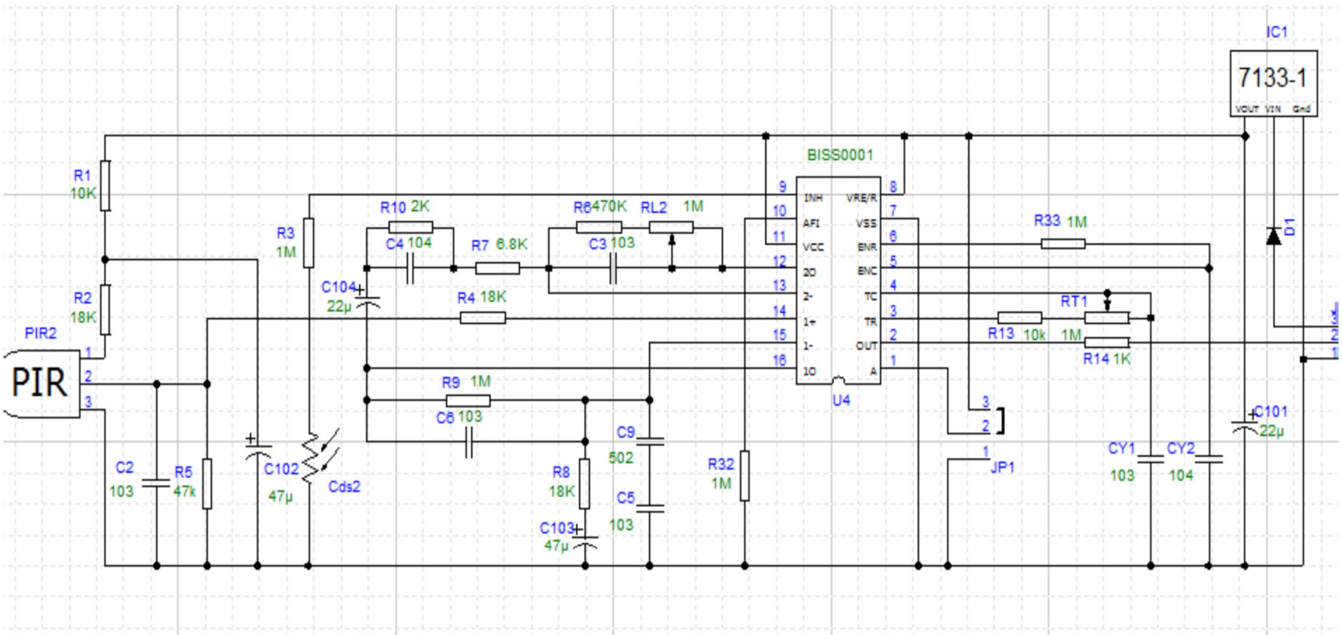
Adjustment:

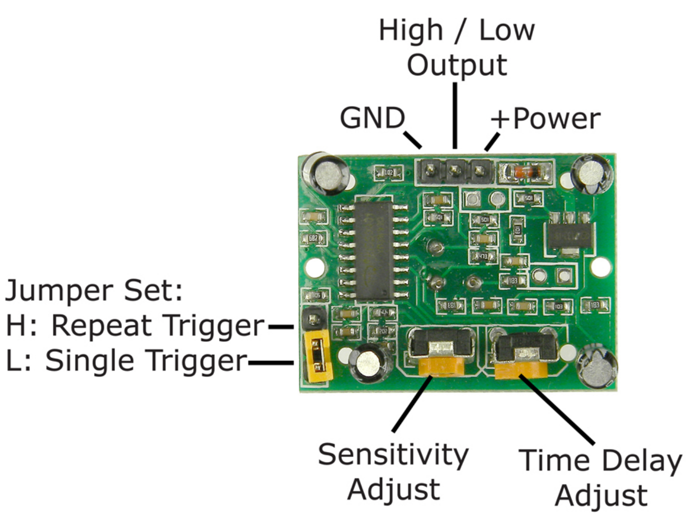
- Adjust the distance potentiometer clockwise rotation, increased sensing distance (about 7 meters), on the contrary, the sensing distance decreases (about 3 meters).
- Adjust the delay potentiometer clockwise rotation sensor the delay lengthened (300S), on the contrary, shorten the induction delay (5S).

Instructions for use:

- Sensor module is powered up after a minute, in this initialization time intervals during this module will output 0-3 times, a minute later enters the standby state.
- Should try to avoid the lights and other sources of interference close direct module surface of the lens, in order to avoid the introduction of interference signal malfunction; environment should avoid the wind flow, the wind will cause interference on the sensor.
- Sensor module with dual probe, the probe window is rectangular, dual (A B) in both ends of the longitudinal direction
  - so when the human body from left to right or right to left through the infrared spectrum to reach dual time, distance difference, the greater the difference, the more sensitive the sensor,
  - when the human body from the front to the probe or from top to bottom or from bottom to top on the direction traveled, double detects changes in the distance of less than infrared spectroscopy, no difference value the sensor insensitive or does not work;
- The dual direction of sensor should be installed parallel as far as possible in inline with human movement. In order to increase the sensor angle range, the module using a circular lens also makes the probe surrounded induction, but the left and right sides still up and down in both directions sensing range, sensitivity, still need to try to install the above requirements.

HC-SR501 PIR MOTION DETECTOR





1 working voltage range :DC 4.5-20V

2 Quiescent Current :50uA

3 high output level 3.3 V / Low 0V

4. Trigger L trigger can not be repeated / H repeated trigger

5. circuit board dimensions :32 * 24 mm

6. maximum 110 ° angle sensor

7. 7 m maximum sensing distance

Product Type	HC--SR501 Body Sensor Module
Operating Voltage Range	5-20VDC
Quiescent Current	<50uA
Level output	High 3.3 V /Low 0V
Trigger	L can not be repeated trigger/H can be repeated trigger(Default repeated trigger)
Delay time	5-300S(adjustable) Range (approximately .3Sec -5Min)
Block time	2.5S(default)Can be made a range(0.xx to tens of seconds
Board Dimensions	32mm*24mm
Angle Sensor	<110 ° cone angle
Operation Temp.	-15-+70 degrees
Lens size sensor	Diameter:23mm(Default)

Application scope

•Security products

•Body induction toys

•Body induction lamps

•Industrial automation control etc

Pyroelectric infrared switch is a passive infrared switch which consists of BISS0001 ,pyroelectric infrared sensors and a few external components. It can au open all kinds of equipments, inculding incandescent lamp, fluorescent lamp, intercom, automatic, electric fan, dryer and automatic washing machine, etc. It is widely used in enterprises, hotels, stores, and corridor and other sensitive area for automatical lamplight, lighting and alarm system.

Instructions

Induction module needs a minute or so to initialize. During initializing time, it will output 0-3 times. One minute later it comes into standby.
Keep the surface of the lens from close lighting source and wind, which will introduce interference.
Induction module has double -probe whose window is rectangle. The two sub-probe (A and B) is located at the two ends of rectangle. When human body r to right, or from right to left, Time for IR to reach to reach the two sub-probes differs.The lager the time diffference is, the more sensitive this module is. Wh body moves face-to probe, or up to down, or down to up, there is no time difference. So it does not work. So instal the module in the direction in which mos activities behaves, to guarantee the induction of human by dual sub-probes. In order to increase the induction range, this module uses round lens which ca from all direction. However, induction from right or left is more sensitivity than from up or down.

D6T

MEMS Thermal Sensors

High Sensitivity Enables Detection of Stationary Human Presence

- **OMRON's unique MEMS and ASIC technology achieve a high SNR.**
- **Superior noise immunity with a digital output.**
- **High-precision area temperature detection with low cross-talk field of view characteristics.**

⚠ Refer to *Safety Precautions* on page 4.

Ordering Information

Thermal Sensors

Element type	Model
4×4	**D6T-44L-06**
1×8	**D6T-8L-06**

Accessories (Sold separately)

Type	Model
Cable Harness	**D6T-HARNESS-02**

Ratings, Specifications, and Functions

Ratings

Item	Specification
Power supply voltage	4.5 to 5.5 VDC
Storage temperature range	–10 to 60°C (with no icing or condensation)
Operating temperature range	0 to 50°C (with no icing or condensation)
Storage humidity range	85% max. (with no icing or condensation)
Operating humidity range	20% to 85% (with no icing or condensation)

Characteristics

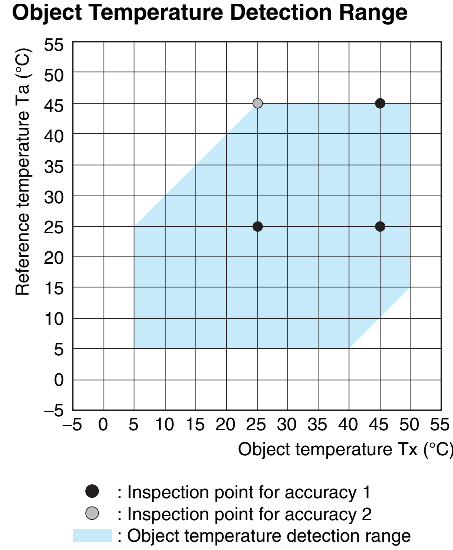
Item		D6T-44L-06	D6T-8L-06
View angle *1	X direction	44.2°	62.8°
	Y direction	45.7°	6.0°
Object temperature output accuracy *2	Accuracy 1	±1.5°C max. Measurement conditions: Vcc = 5.0 V (1) Tx = 25°C, Ta = 25°C (2) Tx = 45°C, Ta = 25°C (3) Tx = 45°C, Ta = 45°C	
	Accuracy 2	±3.0°C max. Measurement conditions: Vcc = 5.0 V (4) Tx = 25°C, Ta = 45°C	
Current consumption		5 mA typical	

Functions

Item	Specification
Object temperature detection range *2	5 to 50°C
Reference temperature detection range *2	5 to 45°C
Output specifications	Digital values that correspond to the object temperature (Tx) and reference temperature (Ta) are output from a serial communications port.
Output form	Binary code (10 times the detected temperature (°C))
Communications form	I2C compliant
Temperature resolution (NETD)	0.14°C

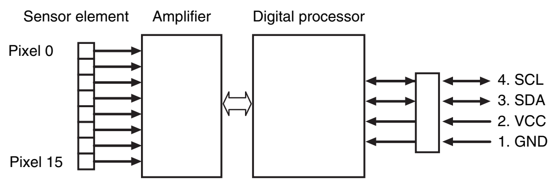
*1. Refer to *Field of View Characteristics.*
*2. Refer to *Object Temperature Detection Range.*

Object Temperature Detection Range



Connections

Thermal Sensor Configuration Diagram



Note: The 1×8 type has pixels 0 to 7.

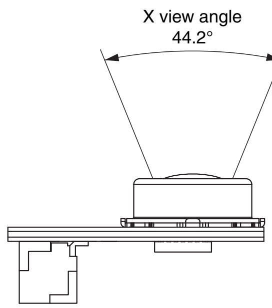
Terminal Arrangement

Terminal	Name	Function	Remarks
1	GND	Ground	
2	VCC	Positive power supply voltage input	
3	SDA	Serial data I/O line	Connect the open-drain SDA terminal to a pull-up resistor.
4	SCL	Serial clock input	Connect the open-drain SCL terminal to a pull-up resistor.

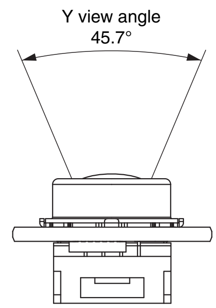
Field of View Characteristics

D6T-44L-06

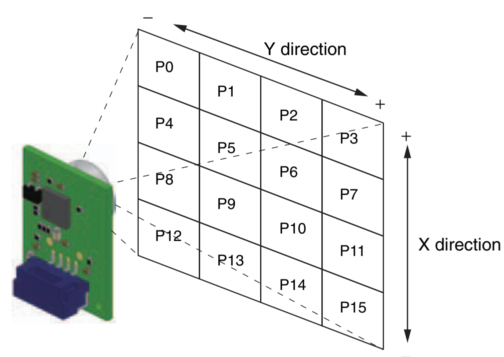
Field of view in X Direction



Field of view in Y Direction



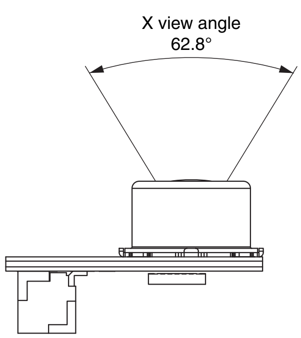
Detection Area for Each Pixel



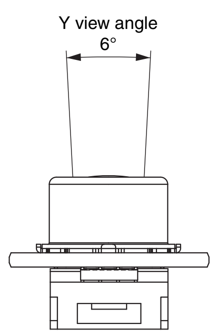
Note: Definition of view angle: Using the maximum Sensor output as a reference, the angular range where the Sensor output is 50% or higher when the angle of the Sensor is changed is defined as the view angle.

D6T-8L-06

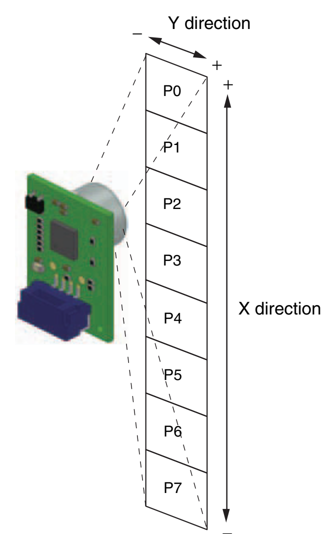
Field of view in X Direction



Field of view in Y Direction



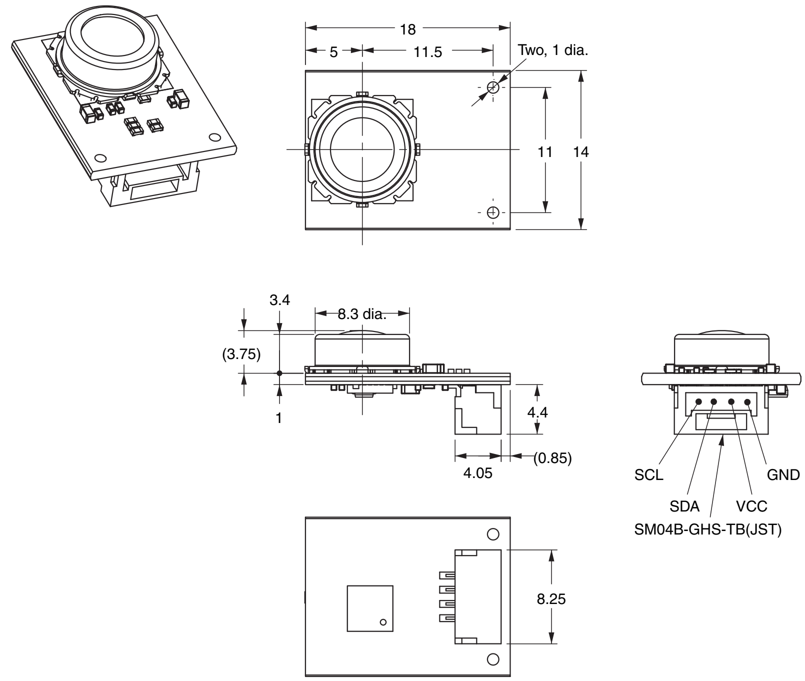
Detection Area for Each Pixel



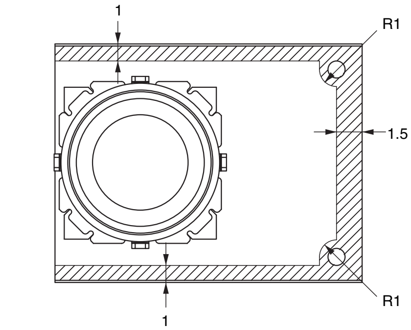
Note: Definition of view angle: Using the maximum Sensor output as a reference, the angular range where the Sensor output is 50% or higher when the angle of the Sensor is changed is defined as the view angle.

Dimensions (Unit: mm)

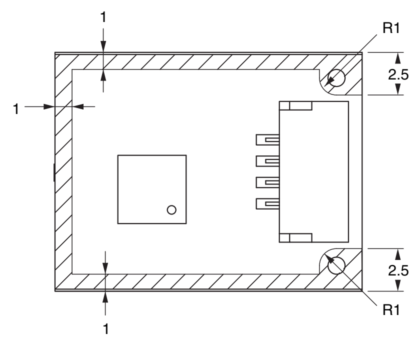
D6T-44L-06



Supporting and Mounting Area (Shaded Portion)
Top View

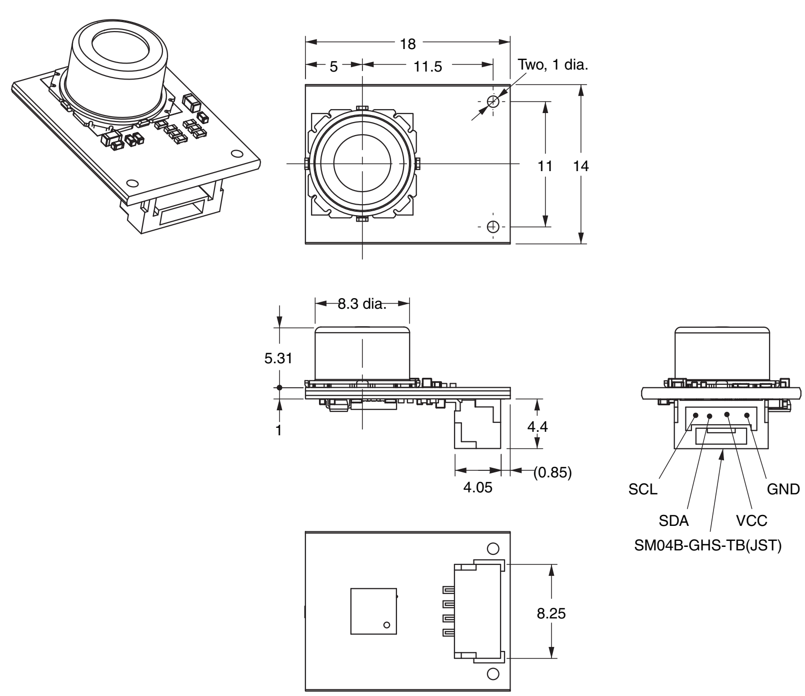


Bottom View

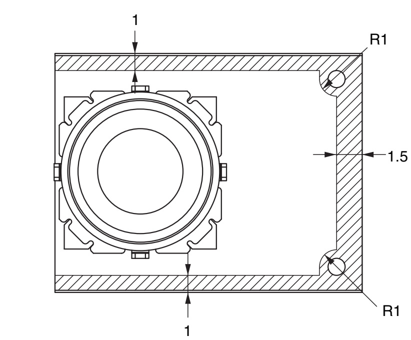


Note: Due to insulation distance limitations, do not allow metal parts to come into contact with the Sensor.

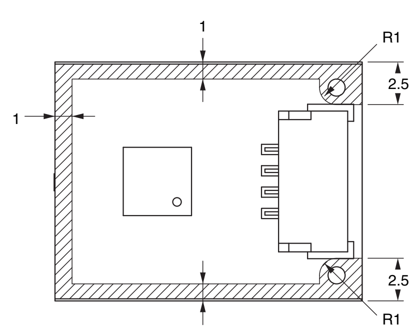
D6T-8L-06



Supporting and Mounting Area (Shaded Portion)
Top View



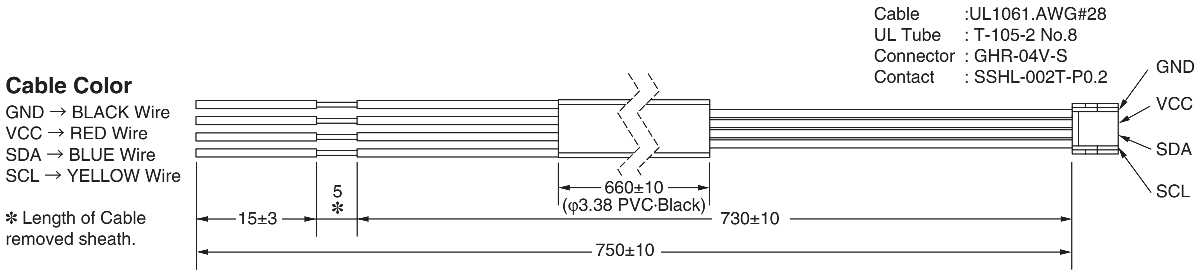
Bottom View



Note: Due to insulation distance limitations, do not allow metal parts to come into contact with the Sensor.

Note: Unless otherwise specified, a tolerance of ±0.3 mm applies to all dimensions.

D6T-HARNESS-02 (Optional - sold separately)



Safety Precautions

Precautions for Correct Use

● **Installation**

- The Sensor may not achieve the characteristics given in this datasheet due to the ambient environment or installation location. Before using the Sensor, please acquire an adequate understanding and make a prior assessment of Sensor characteristics in your actual system.

● **Operating Environment**

- Do not use the Sensor in locations where dust, dirt, oil, and other foreign matter will adhere to the lens. This may prevent correct temperature measurements.
- Do not use the Sensor in any of the following locations.
  - Locations where the Sensor may come into contact with water or oil
  - Outdoors
  - Locations subject to direct sunlight.
  - Locations subject to corrosive gases (in particular, chloride, sulfide, or ammonia gases).
  - Locations subject to extreme temperature changes
  - Locations subject to icing or condensation.
  - Locations subject to excessive vibration or shock.

● **Noise Countermeasures**

- The Sensor does not contain any protective circuits. Never subject it to an electrical load that exceeds the absolute maximum ratings for even an instance. The circuits may be damaged. Install protective circuits as required so that the absolute maximum ratings are not exceeded.
- Keep as much space as possible between the Sensor and devices that generates high frequencies (such as high-frequency welders and high-frequency sewing machines) or surges.
- Attach a surge protector or noise filter on nearby noise-generating devices (in particular, motors, transformers, solenoids, magnetic coils, or devices that have an inductance component).
- In order to prevent inductive noise, separate the connector of the Sensor from power lines carrying high voltages or large currents. Using a shielded line is also effective.
- If a switching requlator is used, check that malfunctions will not occur due to switching noise from the power supply.

● **Handling**

- This Sensor is a precision device. Do not drop it or subject it to excessive shock or force. Doing so may damage the Sensor or change its characteristics. Never subject the connector to unnecessary force. Do not use a Sensor that has been dropped.
- Take countermeasures against static electricity before you handle the Sensor.
- Turn OFF the power supply to the system before you install the Sensor. Working with the Sensor while the power supply is turned ON may cause malfunctions.
- Secure the Sensor firmly so that the optical axis does not move.
- Install the Sensor on a flat surface. If the installation surface is not even, the Sensor may be deformed, preventing correct measurements.
- Do not install the Sensor with screws. Screws may cause the resist to peel from the board. Secure the Sensor in a way that will not cause the resist to peel.
- Always check operation after you install the Sensor.
- Use the specified connector (GHR-04 from JST) and connect it securely so that it will not come off. If you solder directly to the connector terminals, the Sensor may be damaged.
- Make sure to wire the polarity of the terminals correctly. Incorrect polarity may damage the Sensor.
- Never attempt to disassemble the Sensor.
- Do not use the cable harness to the other product.

OMRON Corporation
Electronic and Mechanical Components Company
Contact: www.omron.com/ecb
Cat. No. A216-E1-03
1014(0612)(O)

LV-MaxSonar®-EZ™ Series

High Performance Sonar Range Finder

MB1000, MB1010, MB1020, MB1030, MB1040

With 2.5V - 5.5V power the LV-MaxSonar-EZ provides very short to long-range detection and ranging in a very small package. The LV-MaxSonar-EZ detects objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution. Objects from 0-inches to 6-inches typically range as 6-inches[1]. The interface output formats included are pulse width output, analog voltage output, and RS232 serial output. Factory calibration and testing is completed with a flat object. ***[1]See Close Range Operation***

Features

- Continuously variable gain for control and side lobe suppression
- Object detection to zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- Interfaces are active simultaneously
- Serial, 0 to Vcc, 9600 Baud, 81N
- Analog, (Vcc/512) / inch
- Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Designed for protected indoor environments
- Sensor operates at 42KHz
- High output square wave sensor drive (double Vcc)

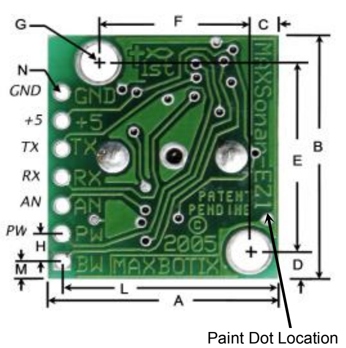
Benefits

- Very low cost ultrasonic rangefinder
- Reliable and stable range data
- Quality beam characteristics
- Mounting holes provided on the circuit board
- Very low power ranger, excellent for multiple sensor or battery-based systems
- Fast measurement cycles
- Sensor reports the range reading directly and frees up user processor
- Choose one of three sensor outputs
- Triggered externally or internally

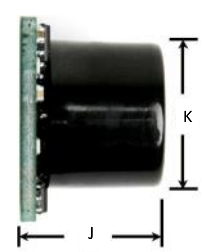
Applications and Uses

- UAV blimps, micro planes and some helicopters
- Bin level measurement
- Proximity zone detection
- People detection
- Robot ranging sensor
- Autonomous navigation
- Multi-sensor arrays
- Distance measuring
- Long range object detection
- Wide beam sensitivity

LV-MaxSonar-EZ Mechanical Dimensions



A	0.785"	19.9 mm	H	0.100"	2.54 mm
B	0.870"	22.1 mm	J	0.610"	15.5 mm
C	0.100"	2.54 mm	K	0.645"	16.4 mm
D	0.100"	2.54 mm	L	0.735"	18.7 mm
E	0.670"	17.0 mm	M	0.065"	1.7 mm
F	0.510"	12.6 mm	N	0.038" dia.	1.0 mm dia.
G	0.124" dia.	3.1 mm dia.	weight, 4.3 grams		



Part Number	MB1000	MB1010	MB1020	MB1030	MB1040
Paint Dot Color	Black	Brown	Red	Orange	Yellow

Close Range Operation

Applications requiring 100% reading-to-reading reliability should not use MaxSonar sensors at a distance closer than 6 inches. Although most users find MaxSonar sensors to work reliably from 0 to 6 inches for detecting objects in many applications, MaxBotix® Inc. does not guarantee operational reliability for objects closer than the minimum reported distance. Because of ultrasonic physics, these sensors are unable to achieve 100% reliability at close distances.

Warning: Personal Safety Applications

We do not recommend or endorse this product be used as a component in any personal safety applications. This product is not designed, intended or authorized for such use. These sensors and controls do not include the self-checking redundant circuitry needed for such use. Such unauthorized use may create a failure of the MaxBotix® Inc. product which may result in personal injury or death. MaxBotix® Inc. will not be held liable for unauthorized use of this component.

About Ultrasonic Sensors

Our ultrasonic sensors are in air, non-contact object detection and ranging sensors that detect objects within an area. These sensors are not affected by the color or other visual characteristics of the detected object. Ultrasonic sensors use high frequency sound to detect and localize objects in a variety of environments. Ultrasonic sensors measure the time of flight for sound that has been transmitted to and reflected back from nearby objects. Based upon the time of flight, the sensor then outputs a range reading.

Pin Out Description

Pin 1-BW-*Leave open or hold low for serial output on the TX output. When BW pin is held high the TX output sends a pulse (instead of serial data), suitable for low noise chaining.

Pin 2-PW- This pin outputs a pulse width representation of range. The distance can be calculated using the scale factor of 147uS per inch.

Pin 3-AN- Outputs analog voltage with a scaling factor of (Vcc/512) per inch. A supply of 5V yields ~9.8mV/in. and 3.3V yields ~6.4mV/in. The output is buffered and corresponds to the most recent range data.

Pin 4-RX– This pin is internally pulled high. The LV-MaxSonar-EZ will continually measure range and output if RX data is left unconnected or held high. If held low the sensor will stop ranging. Bring high for 20uS or more to command a range reading.

Pin 5-TX- When the *BW is open or held low, the TX output delivers asynchronous serial with an RS232 format, except voltages are 0-Vcc. The output is an ASCII capital "R", followed by three ASCII character digits representing the range in inches up to a maximum of 255, followed by a carriage return (ASCII 13). The baud rate is 9600, 8 bits, no parity, with one stop bit. Although the voltage of 0-Vcc is outside the RS232 standard, most RS232 devices have sufficient margin to read 0-Vcc serial data. If standard voltage level RS232 is desired, invert, and connect an RS232 converter such as a MAX232. When BW pin is held high the TX output sends a single pulse, suitable for low noise chaining. (no serial data)

Pin 6-+5V- Vcc – Operates on 2.5V - 5.5V. Recommended current capability of 3mA for 5V, and 2mA for 3V.

Pin 7-GND- Return for the DC power supply. GND (& Vcc) must be ripple and noise free for best operation.

Range "0" Location

The LV-MaxSonar-EZ reports the range to distant targets starting from the front of the sensor as shown in the diagram below.

The range is measured from the front of the transducer.

In general, the LV-MaxSonar-EZ will report the range to the leading edge of the closest detectable object. Target detection has been characterized in the sensor beam patterns.

Sensor Minimum Distance

The sensor minimum reported distance is 6-inches (15.2 cm). However, the LV-MaxSonar-EZ will range and report targets to the front sensor face. Large targets closer than 6-inches will typically range as 6-inches.

Sensor Operation from 6-inches to 20-inches

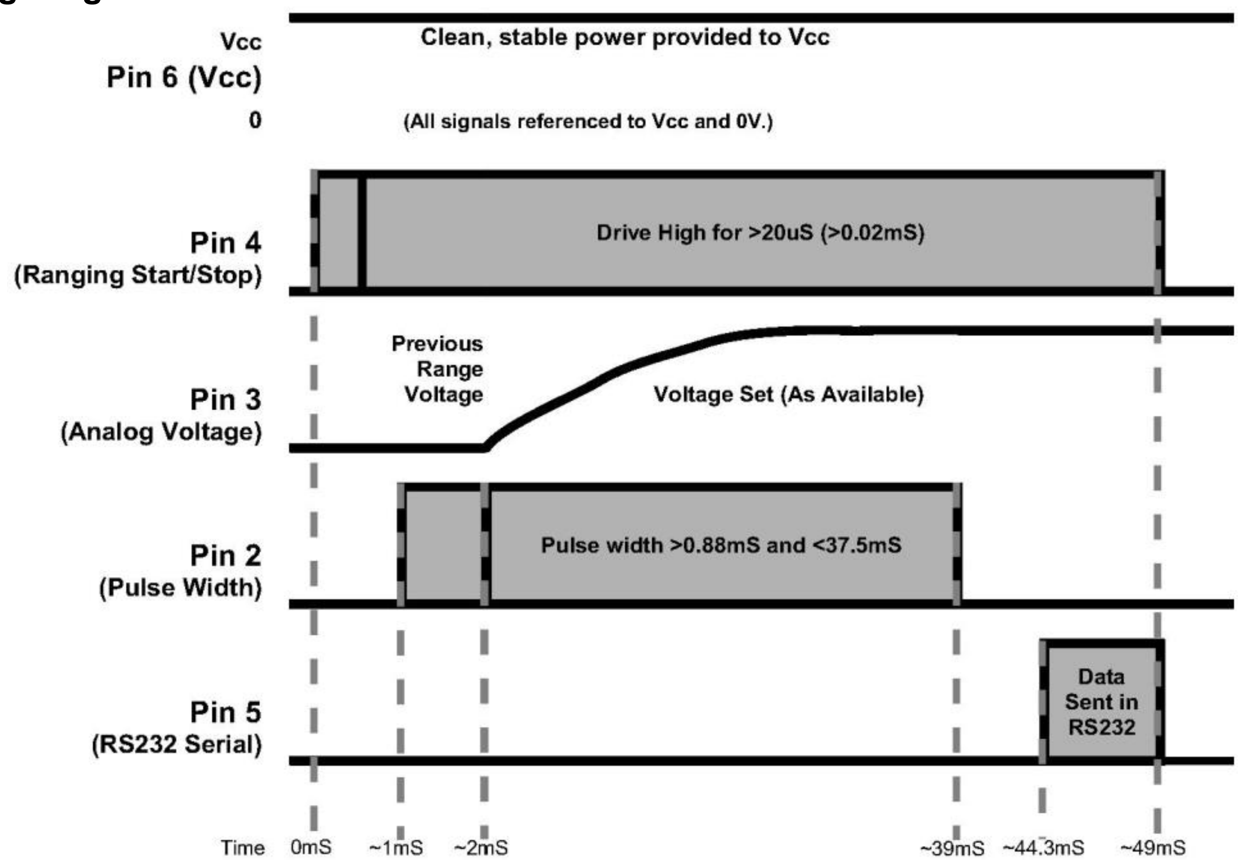
Because of acoustic phase effects in the near field, objects between 6-inches and 20-inches may experience acoustic phase cancellation of the returning waveform resulting in inaccuracies of up to 2-inches. These effects become less prevalent as the target distance increases, and has not been observed past 20-inches.

General Power-Up Instruction

Each time the LV-MaxSonar-EZ is powered up, it will calibrate during its first read cycle. The sensor uses this stored information to range a close object. It is important that objects not be close to the sensor during this calibration cycle. The best sensitivity is obtained when the detection area is clear for fourteen inches, but good results are common when clear for at least seven inches. If an object is too close during the calibration cycle, the sensor may ignore objects at that distance.

The LV-MaxSonar-EZ does not use the calibration data to temperature compensate for range, but instead to compensate for the sensor ringdown pattern. If the temperature, humidity, or applied voltage changes during operation, the sensor may require recalibration to reacquire the ringdown pattern. Unless recalibrated, if the temperature increases, the sensor is more likely to have false close readings. If the temperature decreases, the sensor is more likely to have reduced up close sensitivity. To recalibrate the LV-MaxSonar-EZ, cycle power, then command a read cycle.

Timing Diagram



Timing Description

250mS after power-up, the LV-MaxSonar-EZ is ready to accept the RX command. If the RX pin is left open or held high, the sensor will first run a calibration cycle (49mS), and then it will take a range reading (49mS). After the power up delay, the first reading will take an additional ~100mS. Subsequent readings will take 49mS. The LV-MaxSonar-EZ checks the RX pin at the end of every cycle. Range data can be acquired once every 49mS.

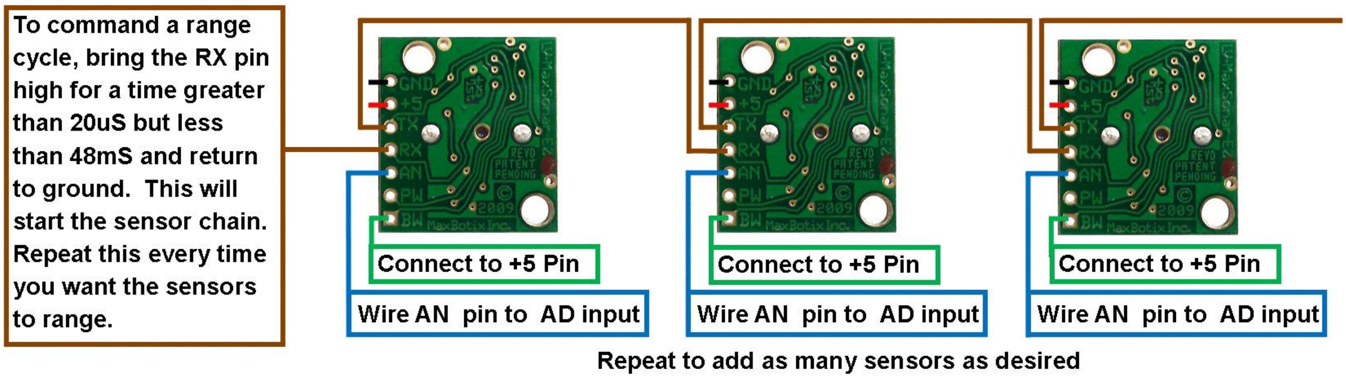
Each 49mS period starts by the RX being high or open, after which the LV-MaxSonar-EZ sends the transmit burst, after which the pulse width pin (PW) is set high. When a target is detected the PW pin is pulled low. The PW pin is high for up to 37.5mS if no target is detected. The remainder of the 49mS time (less 4.7mS) is spent adjusting the analog voltage to the correct level. When a long distance is measured immediately after a short distance reading, the analog voltage may not reach the exact level within one read cycle. During the last 4.7mS, the serial data is sent.

The LV-MaxSonar-EZ timing is factory calibrated to one percent at five volts, and in use is better than two percent. In addition, operation at 3.3V typically causes the objects range, to be reported, one to two percent further than actual.

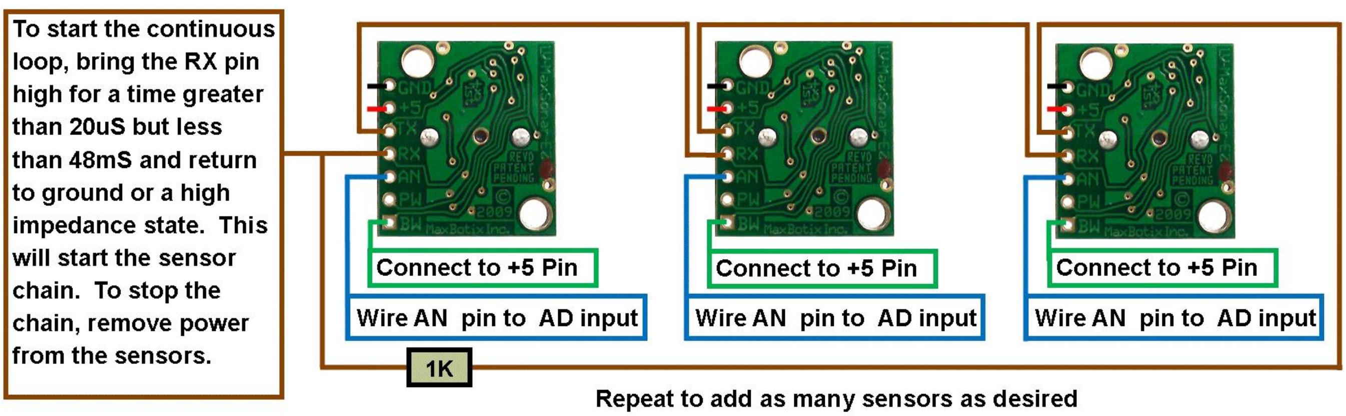
Using Multiple Sensors in a single system

When using multiple ultrasonic sensors in a single system, there can be interference (cross-talk) from the other sensors. MaxBotix Inc., has engineered and supplied a solution to this problem for the LV-MaxSonar-EZ sensors. The solution is referred to as chaining. We have 3 methods of chaining that work well to avoid the issue of cross-talk.

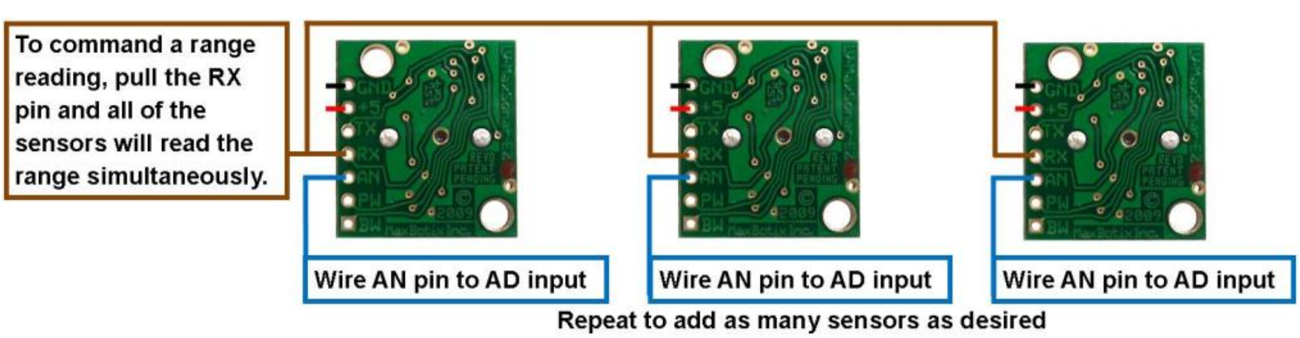
The first method is AN Output Commanded Loop. The first sensor will range, then trigger the next sensor to range and so on for all the sensor in the array. Once the last sensor has ranged, the array stops until the first sensor is triggered to range again. Below is a diagram on how to set this up.



The next method is AN Output Constantly Looping. The first sensor will range, then trigger the next sensor to range and so on for all the sensor in the array. Once the last sensor has ranged, it will trigger the first sensor in the array to range again and will continue this loop indefinitely. Below is a diagram on how to set this up.



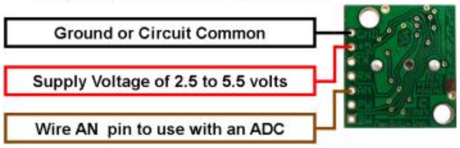
The final method is AN Output Simultaneous Operation. This method does not work in all applications and is sensitive to how the other sensors in the array are positioned in comparison to each other. Testing is recommend to verify this method will work for your application. All the sensors RX pins are conned together and triggered at the same time causing all the sensor to take a range reading at the same time. Once the range reading is complete, the sensors stop ranging until triggered next time. Below is a diagram on how to set this up.



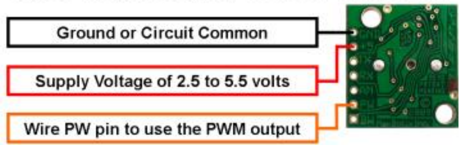
Independent Sensor Operation

The LV-MaxSonar-EZ sensors have the capability to operate independently when the user desires. When using the LV-MaxSonar-EZ sensors in single or independent sensor operation, it is easiest to allow the sensor to free-run. Free-run is the default mode of operation for all of the MaxBotix Inc., sensors. The LV-MaxSonar-EZ sensors have three separate outputs that update the range data simultaneously: Analog Voltage, Pulse Width, and RS232 Serial. Below are diagrams on how to connect the sensor for each of the three outputs when operating in a single or independent sensor operating environment.

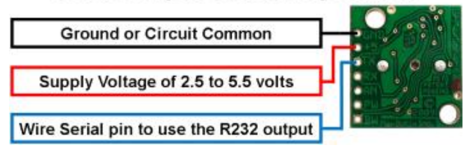
Analog Output Sensor Operation



Pulse Width Output Sensor Operation



Serial Output Sensor Operation



Selecting an LV-MaxSonar-EZ

Different applications require different sensors. The LV-MaxSonar-EZ product line offers varied sensitivity to allow you to select the best sensor to meet your needs.

The LV-MaxSonar-EZ Sensors At a Glance

People Detection Wide Beam High Sensitivity		Best Balance		Large Targets Narrow Beam Noise Tolerance
MB1000	MB1010	MB1020	MB1030	MB1040

The diagram above shows how each product balances sensitivity and noise tolerance. This does not effect the maximum range, pin outputs, or other operations of the sensor. To view how each sensor will function to different sized targets reference the LV-MaxSonar-EZ Beam Patterns.

Background Information Regarding our Beam Patterns

Each LV-MaxSonar-EZ sensor has a calibrated beam pattern. Each sensor is matched to provide the approximate detection pattern shown in this datasheet. This allows end users to select the part number that matches their given sensing application. Each part number has a consistent field of detection so additional units of the same part number will have similar beam patterns. The beam plots are provided to help identify an estimated detection zone for an application based on the acoustic properties of a target versus the plotted beam patterns.

Each beam pattern is a 2D representation of the detection area of the sensor. The beam pattern is actually shaped like a 3D cone (having the same detection pattern both vertically and horizontally). Detection patterns for dowels are used to show the beam pattern of each sensor. Dowels are long cylindered targets of a given diameter. The dowels provide consistent target detection characteristics for a given size target which allows easy comparison of one MaxSonar sensor to another MaxSonar sensor.

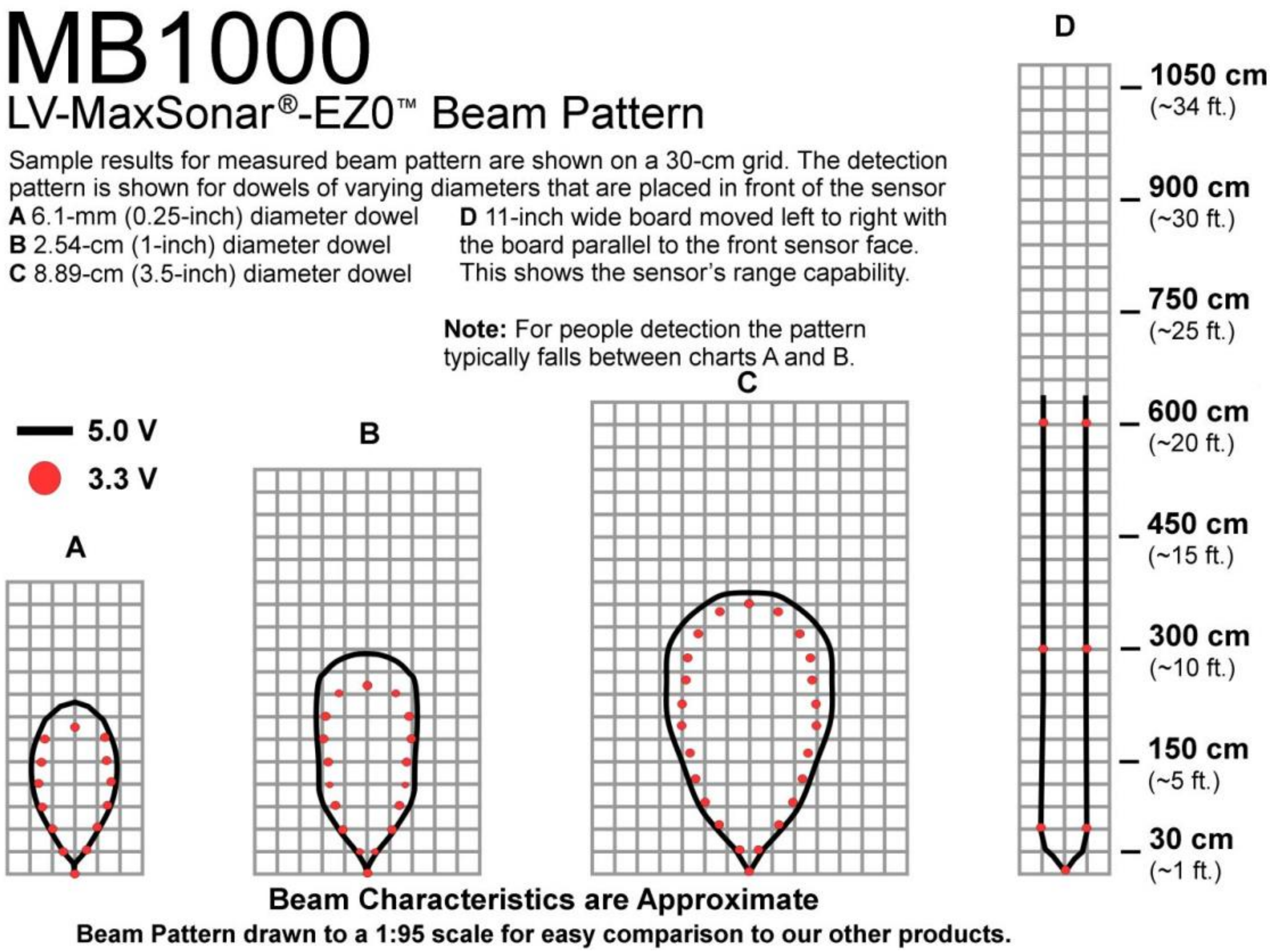
People Sensing: For users that desire to detect people, the detection area to the 1-inch diameter dowel, in general, represents the area that the sensor will reliably detect people.

For each part number, the four patterns (A, B, C, and D) represent the detection zone for a given target size. Each beam pattern shown is determined by the sensor's part number and target size.

The actual beam angle changes over the full range. Use the beam pattern for a specific target at any given distance to calculate the beam angle for that target at the specific distance. Generally, smaller targets are detected over a narrower beam angle and a shorter distance. Larger targets are detected over a wider beam angle and a longer range.

MB1000 LV-MaxSonar-EZ0

The LV-MaxSonar-EZ0 is the highest sensitivity and widest beam sensor of the LV-MaxSonar-EZ sensor series. The wide beam makes this sensor ideal for a variety of applications including people detection, autonomous navigation, and wide beam applications.



MB1000 Features and Benefits

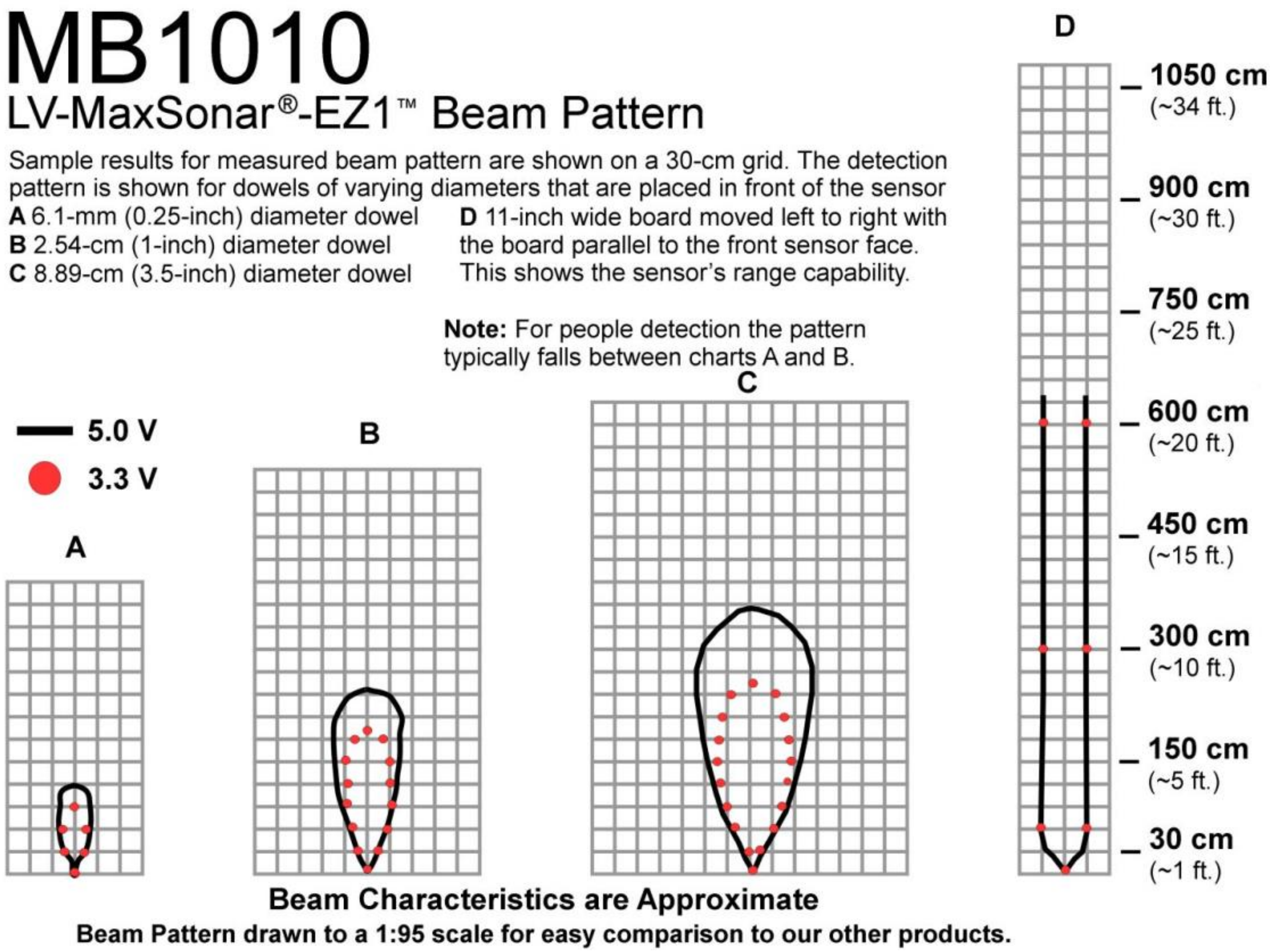
- Widest and most sensitive beam pattern in LV-MaxSonar-EZ line
- Low power consumption
- Easy to use interface
- Will pick up the most noise clutter when compared to other sensors in the LV-MaxSonar-EZ line
- Detects smaller objects
- Best sensor to detect soft object in LV-MaxSonar-EZ line
- Requires use of less sensors to cover a given area
- Can be powered by many different types of power sources
- Can detect people up to approximately 10 feet

MB1000 Applications and Uses

- Great for people detection
- Security
- Motion detection
- Used with battery power
- Autonomous navigation
- Educational and hobby robotics
- Collision avoidance

MB1010 LV-MaxSonar-EZ1

The LV-MaxSonar-EZ1 is the original MaxSonar product. This is our most popular indoor ultrasonic sensor and is a great low-cost general-purpose sensor for a customer not sure of which LV-MaxSonar-EZ sensor to use.



MB1010 Features and Benefits

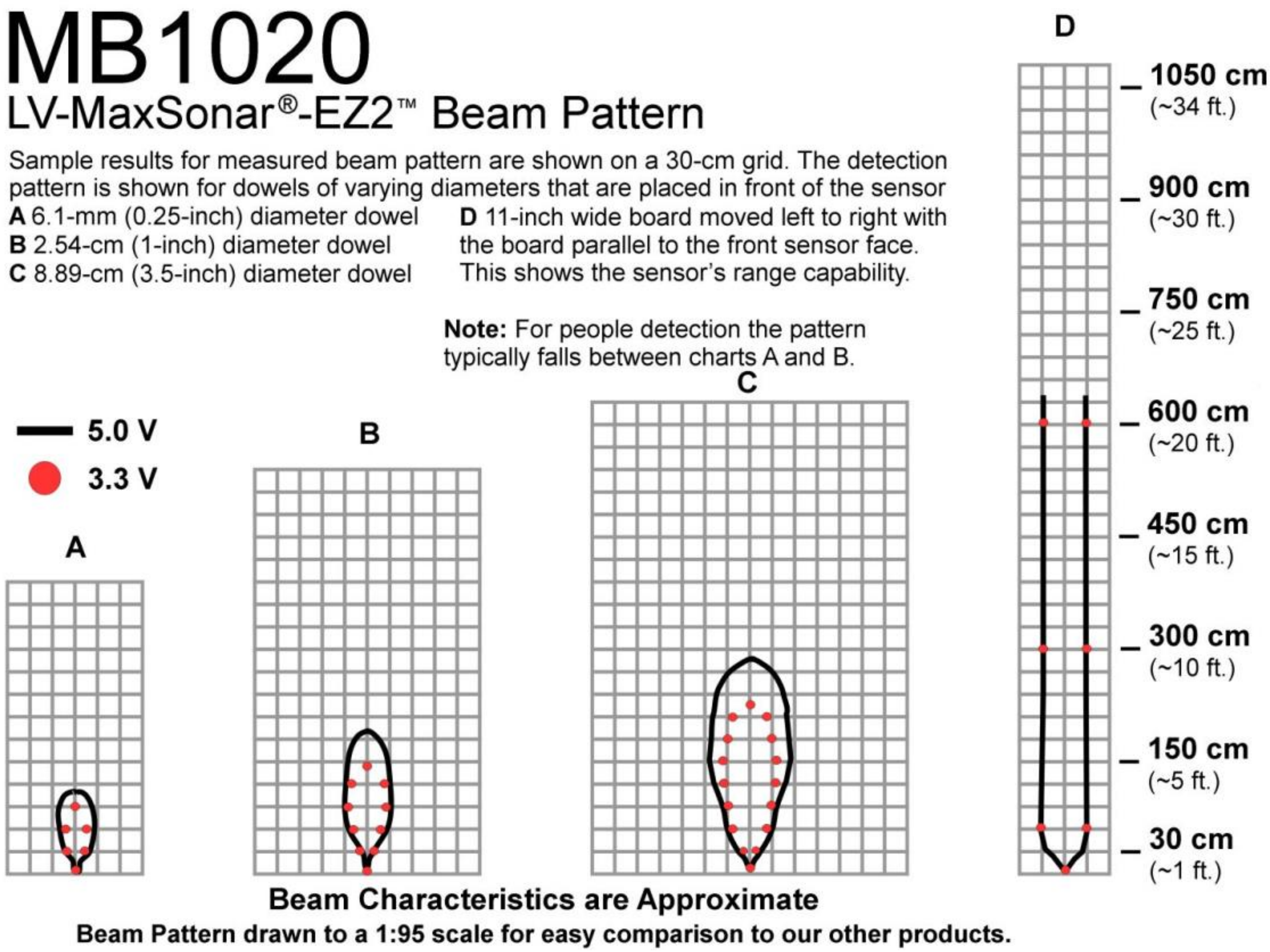
- Most popular ultrasonic sensor
- Low power consumption
- Easy to use interface
- Can detect people to 8 feet
- Great balance between sensitivity and object rejection
- Can be powered by many different types of power sources

MB1010 Applications and Uses

- Great for people detection
- Security
- Motion detection
- Used with battery power
- Autonomous navigation
- Educational and hobby robotics
- Collision avoidance

MB1020 LV-MaxSonar-EZ2

The LV-MaxSonar-EZ2 is a good compromise between sensitivity and side object rejection. The LV-MaxSonar-EZ2 is an excellent choice for applications that require slightly less side object detection and sensitivity than the MB1010 LV-MaxSonar-EZ1.



MB1020 Features and Benefits

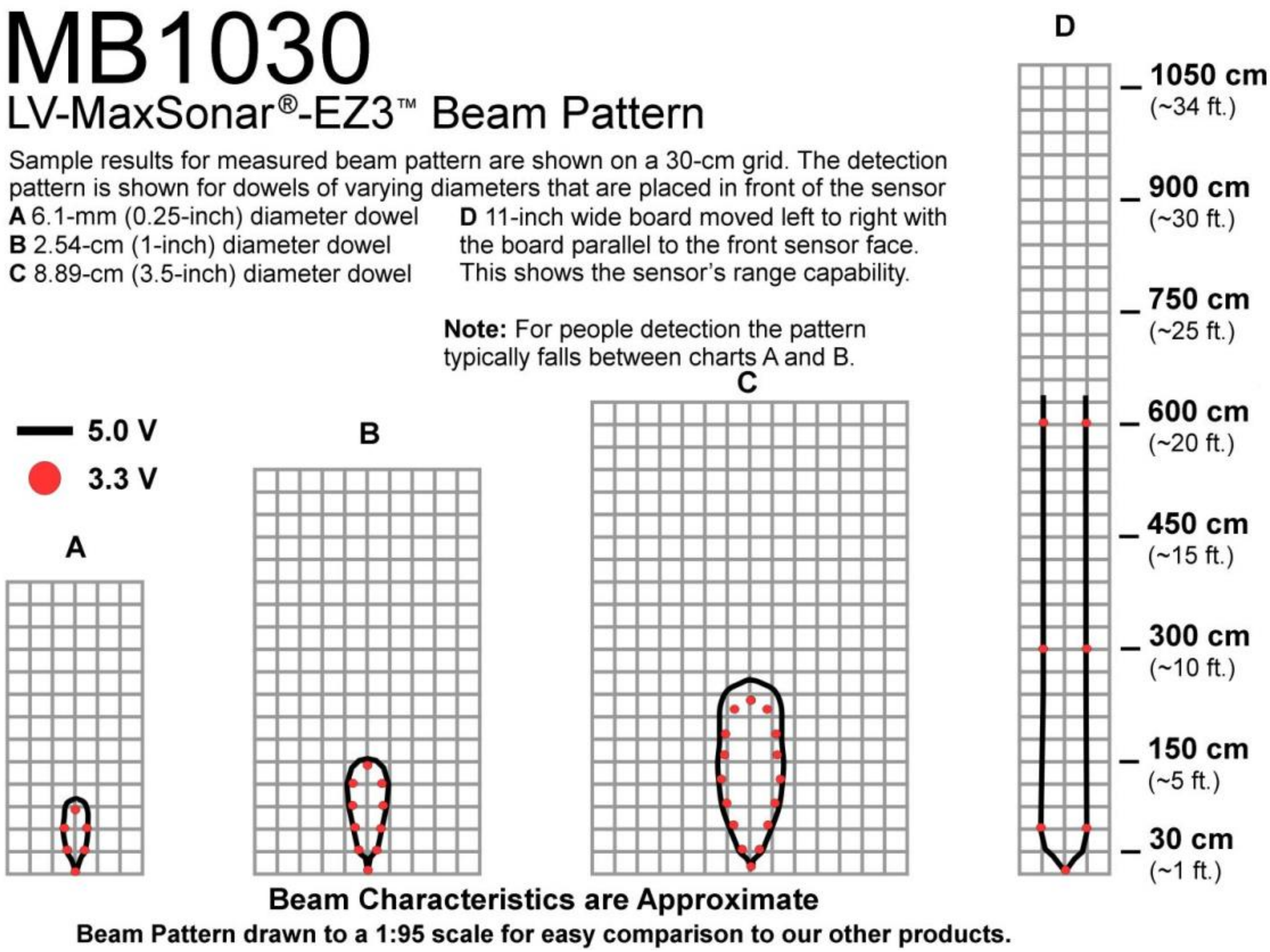
- Great for applications where the MB1010 is too sensitive.
- Excellent side object rejection
- Can be powered by many different types of power sources
- Can detect people up to approximately 6 feet

MB1020 Applications and Uses

- Landing flying objects
- Used with battery power
- Autonomous navigation
- Educational and hobby robotics
- Large object detection

MB1030 LV-MaxSonar-EZ3

The LV-MaxSonar-EZ3 is a narrow beam sensor with good side object rejection. The LV-MaxSonar-EZ3 has slightly wider beam width than theMB1040 LV-MaxSonar-EZ4 which makes it a good choice for when the LV-MaxSonar-EZ4 does not have enough sensitivity for the application.



MB1030 Features and Benefits

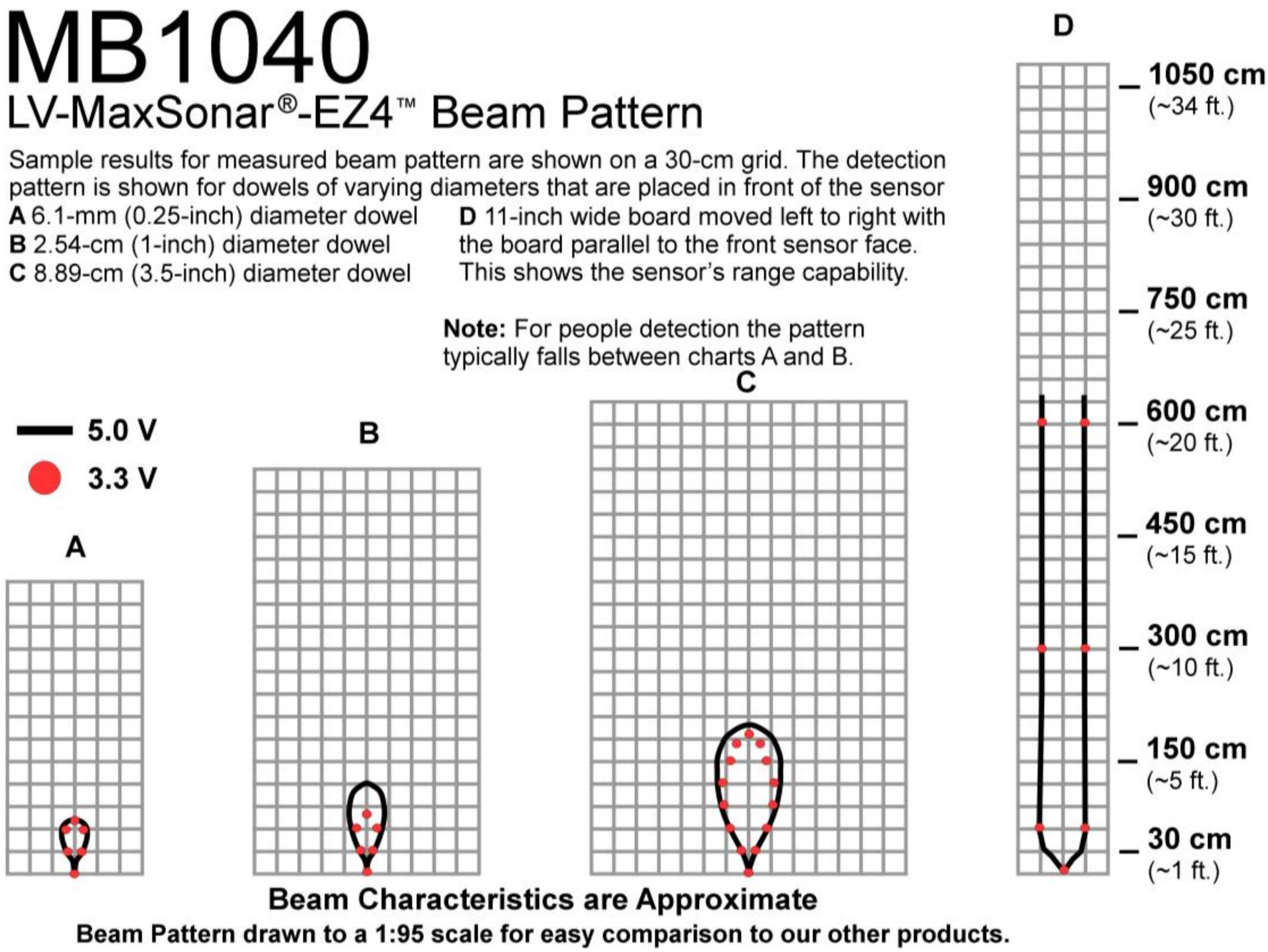
- Excellent side object rejection
- Low power consumption
- Easy to use interface
- Great for when MB1040 is not sensitive enough
- Large object detection
- Can be powered by many different types of power sources
- Can detect people up to approximately 5 feet

MB1030 Applications and Uses

- Landing flying objects
- Used with battery power
- Autonomous navigation
- Educational and hobby robotics

MB1040 LV-MaxSonar-EZ4

The LV-MaxSonar-EZ4 is the narrowest beam width sensor that is also the least sensitive to side objects offered in the LV-MaxSonar-EZ sensor line. The LV-MaxSonar-EZ4 is an excellent choice when only larger objects need to be detected.



MB1040 Features and Benefits

- Best side object rejection in the LV-MaxSonar-EZ sensor line
- Low power consumption
- Easy to use interface
- Best for large object detection
- Can be powered by many different types of power sources
- Can detect people up to approximately 4 feet

MB1040 Applications and Uses

- Landing flying objects
- Used with battery power
- Autonomous navigation
- Educational and hobby robotics
- Collision avoidance

Have the right sensor for your application?
Select from this product list for Protected and Non-Protected Environments.

Protected Environments

1 mm Resolution
HRLV-MaxSonar-EZ

1 in Resolution
LV-MaxSonar-EZ
LV-ProxSonar-EZ

1 cm Resolution
XL-MaxSonar-EZ
XL-MaxSonar-AE
XL-MaxSonar-EZL
XL-MaxSonar-AEL

1 mm Resolution
HRUSB-MaxSonar-EZ

1 in Resolution
USB-ProxSonar-EZ

Non-Protected Environments

1 mm Resolution
HRXL-MaxSonar-WR
HRXL-MaxSonar-WRS
HRXL-MaxSonar-WRT
HRXL-MaxSonar-WRM
HRXL-MaxSonar-WRMT
HRXL-MaxSonar-WRL
HRXL-MaxSonar-WRLT
HRXL-MaxSonar-WRLS
HRXL-MaxSonar-WRLST
SCXL-MaxSonar-WR
SCXL-MaxSonar-WRS
SCXL-MaxSonar-WRT
SCXL-MaxSonar-WRM
SCXL-MaxSonar-WRMT
SCXL-MaxSonar-WRL
SCXL-MaxSonar-WRLT
SCXL-MaxSonar-WRLS
SCXL-MaxSonar-WRLST
4-20HR-MaxSonar-WR

1 cm Resolution
XL-MaxSonar-WR
XL-MaxSonar-WRL
XL-MaxSonar-WRA
XL-MaxSonar-WRLA
I2CXL-MaxSonar-WR

1 mm Resolution
HRXL-MaxSonar-WRC
HRXL-MaxSonar-WRCT

1 cm Resolution
XL-MaxSonar-WRC
XL-MaxSonar-WRCA
I2CXL-MaxSonar-WRC

1 cm Resolution
UCXL-MaxSonar-WR
UCXL-MaxSonar-WRC
I2C-UCXL-MaxSonar-WR

Chemical Shield

F-Option. Available for WR models except UCXL. For additional protection when necessary in hazardous chemical environments.

Accessories — More information is online.

MB7954 — Shielded Cable

The MaxSonar Connection Wire is used to reduce interference caused by electrical noise on the lines. This cable is a great solution to use when running the sensors at a long distance or in an area with a lot of EMI and electrical noise.

MB7950 — XL-MaxSonar-WR Mounting Hardware

The MB7950 Mounting Hardware is selected for use with our outdoor ultrasonic sensors. The mounting hardware includes a steel lock nut and two O-ring (Buna-N and Neoprene) each optimal for different applications.

MB7955 / MB7956 / MB7957 / MB7958 / MB7972 — HR-MaxTemp

The HR-MaxTemp is an optional accessory for the HR-MaxSonar. The HR-MaxTemp connects to the HR-MaxSonar for automatic temperature compensation without self heating.

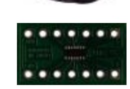
MB7961 — Power Supply Filter

The power supply filter is recommended for applications with unclean power or electrical noise.

MB7962 / MB7963 / MB7964 / MB7965 — Micro-B USB Connection Cable

The MB7962, MB7963, MB7964 and MB7965 Micro-B USB cables are USB 2.0 compliant and backwards compatible with USB 1.0 standards. Varying lengths.

MB7973 — CE Lightning/Surge Protector



The MB7973 adds protection required to meet the Lightning/Surge IEC61000-4-5 specification.

South County Family Educational and Cultural Center EXPLORATION STATION

Water Fun at Exploration Station Operations Manual

Overview
This manual provides a description of how to turn on the pump using a bluetooth-controlled Android app, advice on proper draining of the basin and reservoirs, and a discussion on some of the safety hazards that the users should be aware of.

1 INTRODUCTION

1.1. Introduction and Purpose

This instructional manual applies to the plumbing and electrical system of the exhibit, as these are the subsystems with the most user interface for maintenance and operation. Our team created an app so that the user may turn on/off the pump using Bluetooth commands. In order to be able to use this app the user must use an Android device and ensure that they have connected the electrical components properly.

1.2 Glossary

- GFCI - Acronym for "ground fault circuit interrupter. The GFCI serves as a safety device that will shut off power to the system when it senses that current is flowing through an "unintended" path, such as through water or a person.
- IoT Relay - Acronym for "Internet of Things" Relay. This power strip has a relay inside that determines which two outlets are providing power.
- Apk file - This is the file type for the Sleep Mode App that can be installed in an Android device.

2. BLUETOOTH SYSTEM OVERVIEW

2.1 System Application

The plumbing system consists of a submergible pump that is used to direct water flow to eight different outlets in the exhibit. In order to ensure that the pump controller app works correctly the pump needs to be connected to one of the normally off outlets of the IoT relay, which is the black power strip. The IoT relay needs to be connected to one of the outlets in the yellow power strip as shown in the wiring diagram in Figure 2. Once these connections are made the user needs to download the .apk file provided by us to install the app. We recommend downloading the 'My Files' app first which is used to manage files in your smart phone so that you can transfer the apk file from your computer to your phone and locate easily. When you install the Sleep Mode App and open it you should see the interface shown in **Figure 1a**.

The interface consists of the Bluetooth symbol that can be pressed to list the Bluetooth devices available as shown in **Figure 1b** and two buttons for setting the state of the pump. Turn on the Arduino Nano by flipping the switch in the circuit. If the Arduino Nano has a flashing LED, then it is on. The name of the Bluetooth module provided by us is Y. When you select this device your phone will attempt to connect to the Bluetooth module. If it connected properly, the text below the Bluetooth symbol will turn green and it will say *connected*. Once you have established a connection you can press the 'Turn ON' button to turn on the pump and the 'Turn OFF' button to turn it off.

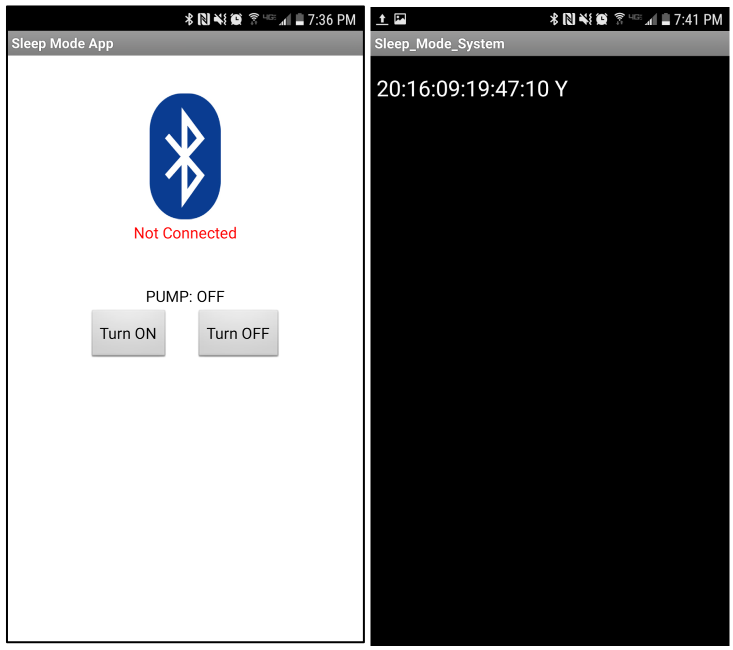


Figure 1. (a) Sleep mode app interface; and (b) List of Bluetooth devices available.

2.2. System Organization

The main goal of our system organization is to deliver power to the pump in a safe and efficient manner. Below, **Figure 2** shows how the electrical components in our system are organized, and serves as a resource for the user to follow the path of each of the wires in the system when performing maintenance or rewiring procedures.

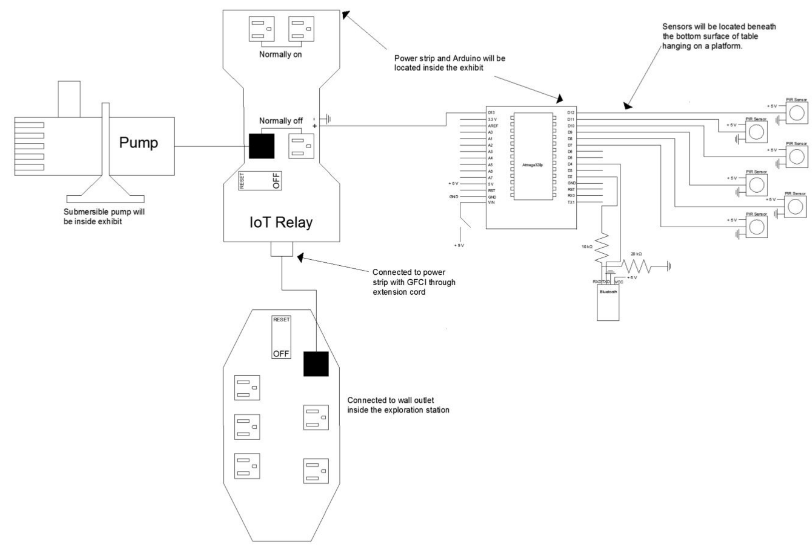


Figure 2. Wiring diagram for the electrical subsystem.

3. Advice on the Draining of the Exhibit

If there are any leaks present in the fiberglass basin, then special precaution must be taken to ensure that overflow does not occur in the reservoir during non-use time. When draining these two systems, the user should take the following steps:

1. Fully drain the reservoir by utilizing the brass ball-valve drain outlet installed on the bottom side of the reservoir. Use a large, 5 gallon bucket to catch the water draining out, and pour the water either into an external storage tank, or into a planter to repurpose the water used in the exhibit
2. Once the water from the reservoir has been fully drained, leave the bucket in the same location used to catch the draining water. Turn on supply power to the pump, to begin filling the basin up with water again. Run the pump until the water level height in the reservoir reaches the top of the pump and then shut off the pump. At this point, repeat step 1 until the basin is once again empty.
3. At this point, the user has two options with how they want to proceed.
    a. Disengage the entire piping network from the top of the pump, and slide the reservoir out of the inside storage area. Dump the contents of the reservoir down a storm drain or use to water plants around the Exploration Station.
    b. Open the drain valve located at the bottom of the reservoir, allowing the water to flow directly onto the ground and into a storm drain. This step could also be followed until the water level height in the reservoir reaches an appropriate level to take step 3a.

4. Safety Hazards

The exhibit does have some safety hazards to take into consideration when it is being operated/ in use by museum visitor. This section will outline those hazards, and comment on ways to avoid injury when the exhibit is in use. Please reference FDR for additional information regarding safety hazards.

4.1. Sharp Edges

The frame of our exhibit is made of welded steel tubing, and thus is susceptible to having sharp edges to be caught on. When using the exhibit, take care not to lean directly on the structural frame. If the user is required to use the inside storage area for any reason (repairs, refilling tank, etc.) then it is advised that they take a close inspection of the area to ensure that no burrs have formed on the surface since the last time this action was taken. Burrs and sharp edges are most likely to be located at weld joints and drilled-hole locations.

4.2. Electrical Hazards

The *Alpine Cyclone* pump used to power the plumbing system is a submersible pump that runs on a 120V power source (standard wall outlet). Due to the close proximity of water to electrical sources, shock hazard is a real threat. First and foremost, all electrical equipment should always remain plugged into the GFCI during exhibit use, so that if an electrical hazard was to take place, then the user would be protected by the GFCI breaking the circuit. In the event that a GFCI is tripped, it is imperative that the hardware is replaced with a new one. Additionally, the electrical equipment should always be protected in a water resistant casing, and stored at an elevated surface away from locations where puddles can form.

4.3. Slipping Hazards

The exhibit will be located outdoors on a concrete patio, and due to the short sidewall heights in both the basin and the reservoir, overflow and spillage can be a concern. The operator should post signs in the area around the exhibit reminding visitors to only walk when using the exhibit. Supervision and enforcement of this precaution is strongly encouraged.