Final Report

Team 7

Solar Sausage for Desalination

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ABSTRACT

The Solar Sausage for Desalination is a desalination system utilizing the newly developed Solar Sausage technology at Florida State University. Sponsored through the Florida Agriculture and Mechanical University – Florida State University combined College of Engineering, this project is one of two senior design projects that is both an engineering and entrepreneurial project. This project aims to produce potable drinking water from saline water using focused solar energy concentrated by the Solar Sausage's parabolic-like reflective material in such a way so that the product could be easily mass produced at a low cost. Drinking water can be sparse, if even existent, in certain locations around the world. Specifically, developing countries are affected by the lack of access to clean drinking water. An entire community can be positively affected by providing the opportunity to receive clean drinking water.

The Solar Sausage for Desalination offers an aid to the growing necessity of access to clean drinking water. The modular design is simplistic and versatile. The Solar Sausage for Desalination is easy to use, can adapt to most environments, and uses components that can be easily replaced or exchanged in developing countries across the globe. The desalination systems would be deployed to various locations worldwide where clean drinking water is limited or nonexistent. The desalination system would be sent in a package form with additional items to be used for replacements and during operation and construction. The Solar Sausage for Desalination uses a batch distillation process and can produce up to three gallons per day. This sufficiently satisfies the hydration requirements for five adults at a cost of $0.61 per gallon when initially installed.

ACKNOWLEDGMENTS

The group would like to thank Dr. Shih and Dr. Gupta for the direction and guidance throughout the project. Thank you to Dr. Devine for the well-timed feedback following meetings and presentations as well as marketing advice for our entrepreneurial project. Also, a special thanks to Dr. Lin for his valuable input and assistance with each aspect of the project. Finally, the group would like to thank Ian Winger for assisting in the construction of the Solar Sausage as well as supplying the materials for it.

1. Introduction of Project

This project attempts to use engineering to satisfy a basic necessity in the world. Much of the developing world lacks access to clean drinking water. By applying engineering principles and skills to develop a desalination system using the Solar Sausage, a product can be produced to aid those in need of potable water. Developing a marketable product introduces a unique entrepreneurial aspect to this project helping to shape the design process and focus. Team 7 aims to create a solar desalination system utilizing the Solar Sausage technology that can be easily mass produced at a low cost.

1.1 Solar Sausage

The Solar Sausage is a technology still in its infancy stage. Developed by Mr. Ian Winger through the Physics department at Florida State University, the Solar Sausage is an inexpensive alternative to current parabolic reflectors on the market. The Solar Sausage is an inflatable solar collector composed of plastic material for the exterior and a reflective mylar sheet that creates the reflective membrane. The reflective membrane divides the Solar Sausage into an upper and lower section. The reflective mylar sheet is glued in between two sheets of the plastic and encased at the ends. When fully inflated, a cylindrical shape emerges. The pressure differential between the two chambers creates the focal point as shown (Figure 1). By adjusting the pressure in the top and bottom hemisphere, the shape of the reflective membrane can be altered. With a greater pressure in the top hemisphere of the Solar Sausage, a parabolic-like shape is created on the reflective material.

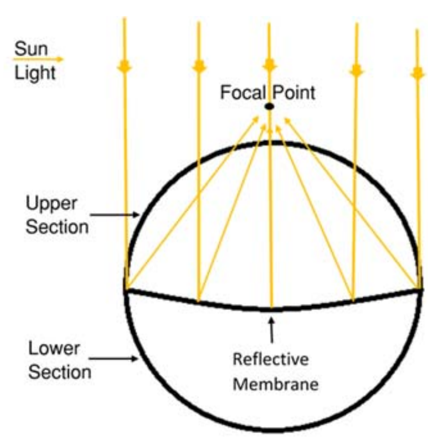


Figure 1: Cross Sectional View of the Solar Sausage.

The focal point supplies large amounts of heat to a concentrated area. The focused sunlight results in a large concentration of the solar energy. This can be utilized by placing photovoltaic cells along the focal point, or as in this project, a trough containing salt water.

1.2 Project Specifications

The developing world is in need of a desalination system that is inexpensive, durable, and can produce potable water to those with access to an abundance of saline water. The goal of this project is to create a solar desalination system using the Solar Sausage technology. As an entrepreneurial project, this needed to be done in such a way to promote mass production of the product at a low cost.

When looking into the details of this project, clear design requirements became evident. These requirements are as follows:

1. The design must provide a sufficient amount of potable water for a small family (approximately 4-5 people).
2. The design must stay within the allowable budget of $5,000.00.
3. The design must be simplistic in nature so that locals could easily be trained to operate and maintain the system.
4. The Solar Sausage must be easily transported and installed.

Although the Solar Sausage technology has previously been used in large Solar Sausage "farms," a modular design appealed to the entrepreneurial aspects of this project. Narrowing the requirements and focusing on providing one family with water from the Solar Sausage for Desalination allowed for greater entrepreneurial opportunity. The design was intentionally kept simplistic and inexpensive to avoid going over budget, but specifically to provide a simplistic product that could be easily understood and maintained by consumers. The durable design needed to be easily transported and installed to account for global varying weather conditions.

2. Background and Literature Review

The fundamental concept behind this project is water desalination. This process has been used for many years by using the sun's energy to convert saline water into drinkable water. The Solar Sausage for Desalination uses techniques mainly in heat transfer and useful solar conversion.

The trough of our system takes the heat input from the Solar Sausage and uses conduction heat transfer through the trough and water, convection heat transfer from the water to the surrounding air and onto the condenser, and heat conduction again through the condenser. Radiation heat transfer from the sun to our system is also involved. These heat transfer methods have been studied for years and were used to desalinate the water in this system. Although using the Solar Sausage for this application has not been practiced before, desalination is used everywhere in all scales of practice from homes to large desalination plants.

The Solar Sausage was originally designed by Ian Winger. In 2009 Winger brought the first prototype to an FSU committee meeting and requested funding. The prototype was three feet long and had a diameter of two feet [1]. It was only one of many designs throughout the previous years. Winger was given $15,000 in order to further research and improve the Solar Sausage design. The Solar Sausage has been used in many engineering applications since, including this project. The Solar Sausage is an inflatable solar concentrator that takes the sun's heat and focalizes it onto a focal line. This process of solar concentration has been practiced for many years as well. This was adapted into the Solar Sausage for Desalination system by focusing the sun onto the open trough, starting the desalination process.

3. Concept Generation

The Solar Sausage technology has been applied to commercial power generation. A tube runs the length of the top of the Solar Sausage, referred to as the receiving tube. The focal point, created by the Solar Sausage, is concentrated on the tube heating a circulating fluid. The fluid undergoes a phase change to vapor. The vapor's pressure is dropped across a turbine generating power.

The first two designs used the receiving tube method to heat a fluid. The first design uses a heat exchanger and the second design uses direct heat transfer.

3.1 Heat Transfer Method

The heat transfer method uses a low melting point eutectic salt and a thermal syphoning. The eutectic salt is heated in the receiving tube. The density change in the salt causes thermal syphoning and the salt begins to circulate [2]. The eutectic salt circulates through a heat exchanger that is filled with saline water, heating the saline water (Figure 2). The resulting water vapor rises and goes to a condensing tank.

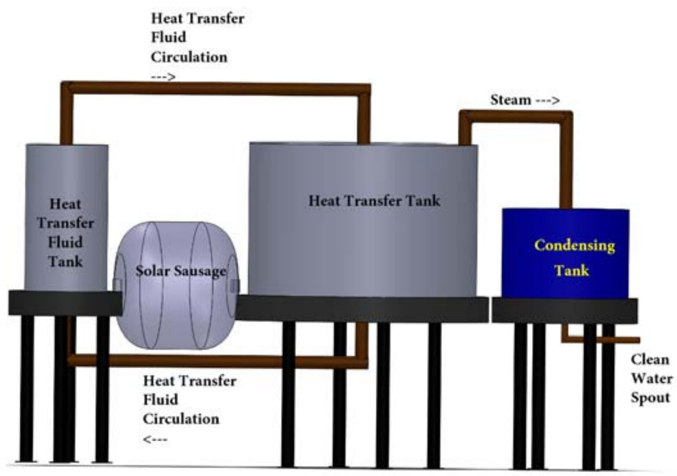


Figure 2: Heat Exchanger Method.

3.2 Direct Heating Method

The second design heats the saline water directly in the receiving tube, as opposed to using a heat exchanger. A storage tank raised in the air drives the saline water through the receiving tube. At the end of the receiving tube the saline water phase has changed to steam. The steam exits into a condenser, where salt is deposited into the bottom. The water vapor rises into the collection dome where it is condensed and collected (Figure 3).

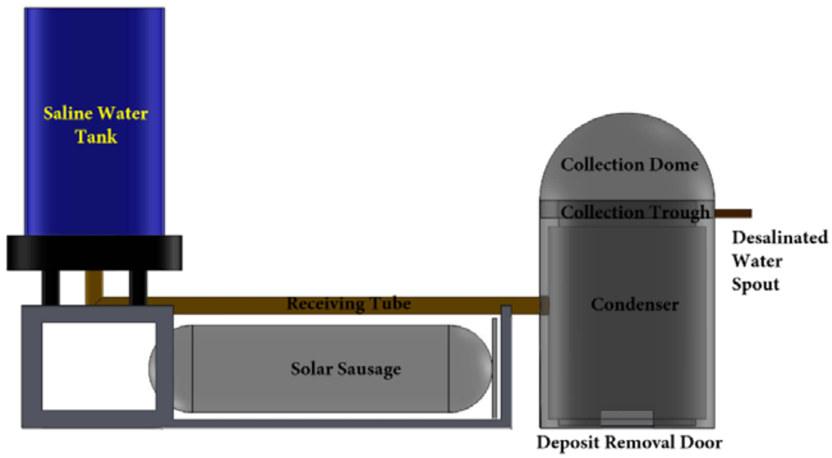


Figure 3: Direct Heating Method.

3.3 Open Trough Method

The third design was uses the direct heating method and improves on the second design. The receiving tube in the direct heating method will corrode over time from the flow of saline water through it. Decreasing the lifetime of the system or requiring replacement receiving tubes. The direct heating method requires a control system to regulate the flow of saline water, increasing the complexity of the desalination. The solution to these disadvantages is the use of on open trough. Using a trough and batch distillation greatly decreases corrosion since saline water no longer flowing [2]. The operator is able to fill the trough up manually and with no flow the need for a control system to regulate flow is eliminated. The use an open trough requires the condenser to sit directly above the trough.

These improvements led to the development of the third design using the open trough method (Figure 4). The open trough fills with water fed to it from the saline water tank. The Solar Sausage heat the trough surface causing the water to evaporate. The steam rises into the condenser which is located right above the open trough. As the steam condenses the droplets drip down into troughs located on both sides of the condenser. As the clean water builds up in the troughs it forces its way out of the clean water spout located on the one side of the condenser.

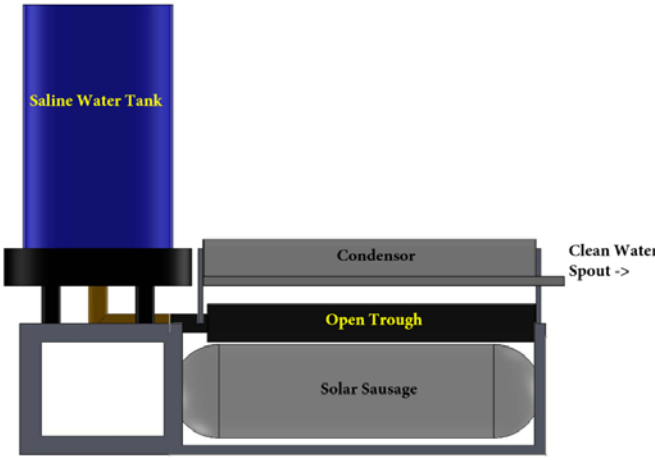


Figure 4: Open Trough Method.

3.4 Evaluation of Designs

Each design has their distinct advantages and disadvantages. Some of the disadvantages for the direct heating method have been eliminated in the open trough design.

3.4.1 Heat Exchanger Method

The design has the advantage in that its operating hours extend beyond 3pm. As the eutectic salt will continue to circulate and stay at high temperatures far beyond peak sun hours, which would allow for an increase in the production capacity. There are numerous disadvantages to this system; that being its lack of portability, cost, and use of non-environmental friendly compound. The exchanger is a closed system in itself requiring an extra tank increasing the size of the size of the system and decreasing its portability. The heat changer will requires large amounts of metal tubing with good thermal conductivity and extremely malleable, materials with these properties are expensive leading to higher cost. The utilization of a eutectic salt, introduces a corrosive element to an area where they do not have proper facilities or training to dispose of it, this increases the systems negative impact on the environment.

3.4.2 Direct Heating Method

There are many advantages in the simplicity and portability of this design, but there are also numerous disadvantages. This design uses gravity to drive the water through the receiving tube eliminating the needs for a pumping system, lowering the cost. The direct heating method eliminated the needs for the heat transfer fluid tank as in the first design decreasing the cost. The system could be easily disassembled, due to the simplicity of its components increasing its portability.

There are numerous disadvantages to this design including saline buildup and a limited operating time. Saline will build up in the receiving tube and will also corrode the tube, this will require some king of cleaning method or the inclusion of extra receiving tubes decreasing the simplicity and increasing the cost of this design. As the water level in the saline water tank decreases the velocity of the fluid in the receiving tube decreases, which will result in a higher temperature steam at the receiving tube exit changing the condensing requirement. Since this design utilizes direct heat transfer its operating time is limited to peak sun hours.

3.4.3 Open Trough Method

This design has many advantages, the first being that it does not have its own free standing condensing tank. By having the condensing dome, from the second design, directly over the open trough the space required for the system to operate or to be transported greatly decrease. This increases the portability and increases the simplicity. The open trough provides an easy way to remove the saline buildup, after each use someone can simply scrape the saline out of the open trough simplifying the system. As in the second design since it utilizes direct heat transfer it can only operate between peak sun hours. The second disadvantage being that the trough covers a large a large portion of the Solar Sausage's reflective material compared to the receiving tube in the second design. This would require a larger solar sausage increasing the cost and size of the system.

3.5 Design Selection

Table 1 shows the criteria chosen, as well as the weight of each. The criteria are decreasing in weight from top to bottom and this weight is multiplied by each concept's ability to satisfy the criteria. The overall score for each concept is determined by the sum of all of the decision making factors and the highest score shows the best design. Cost, portability, and water output are the most important factors. Cost is crucial because the Solar Sausage is meant to be a more cost efficient alternative to harnessing solar energy. This is an entrepreneurial project that will ideally be mass produced in the most cost efficient way possible. Portability is important because these desired locations have natural disasters and other forces that may ruin the system. Therefor the mechanism must be able to be deconstructed, stored away, and then reassembled easily. Lastly, the system should be to produce a sufficient amount of water yet be simple requiring few components and can be easily maintained by villagers.

Table 1: Weighted decision matrix for design selection.

Decision Making Factors	Weighting	Heat Exchanger	Direct Heat Transfer	Open Trough
Cost	9	4	8	9
Portability	8	1	7	6
Water Output	8	8	8	7
Simplicity	6	4	6	9
Eco Friendly	5	9	9	9
	Weighted Decision	177	273	284

3.5.1 Selected Design

Using the weighted decision matrix, Table 1, the criteria, design and product specification to judge each design. The team selected **“Design 3: Open Trough Method”.**

4. Final Design

Entrepreneurship is finding a need and turning the solution into a business. For the Solar Sausage Desalination system to offer a solution to the world's lack of fresh water. The system must be accessible to as many people as possible. To accomplish this the system must be easily mass produced at a low cost, assembled and operated. This led to the design constraints

- The system must be easily constructed/deconstructed as well as transported/stored.
- The system must be durable and able to withstand moderate weather conditions.
- The system must be simple and easy to operate and maintain for the consumer.
- Materials capable of operating with saline water as the working fluid must be used.
- No electricity will be used for any components in the system.

A modular design was chosen for ease of manufacturing and assembly [3]. Additionally the system was designed of readily available materials purchased through vendors. This reduced machining time and increased the chances of wholesale prices being available. The modular Solar Sausage Desalination system can be seen below with its labeled components (Figure 5). The main components are the Solar Sausage, stand, storage tank, trough, and condenser.

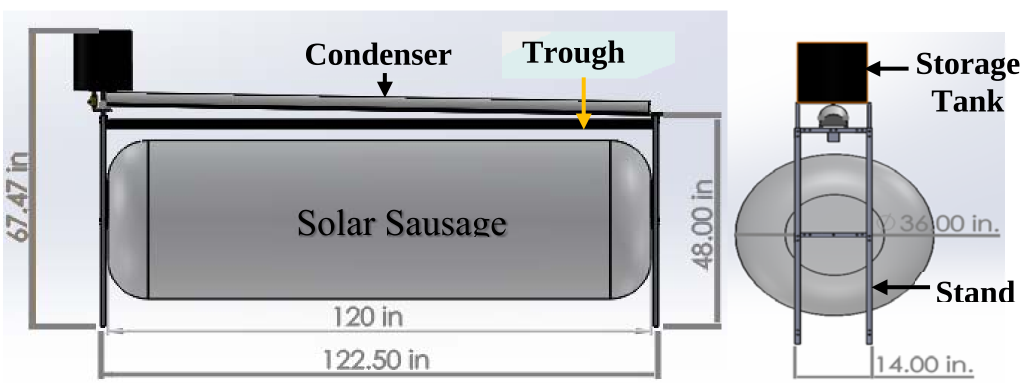


Figure 5: Master Assembly of the Solar Sausage Desalination System.

4.1 Materials

The Solar Sausage Desalination system must be easily transported and installed, which requires it to be lightweight. The system must also be structurally sound and durable ensuring a long operating time. The stands will support the system and its components and the material chosen for this was Aluminum as opposed to steel because it better suit the design constraints as can be seen in Table 2 [4].

Table 2: Stand material decision matrix.

Structural Material Decision Matrix								
	Density		**Machinability**	**Tensile Strength**		**Cost**		
	kg/m^3	Rating	Rating	Mpa	Rating	$/ton		**Total**
Aluminum	2770	8	10	276	4	$2,017.50	8	204
Steel	7854	3	7	415	9	$766.00	10	175
Weight		9	6		4		7	

A considerable amount of heat transfer takes place across the trough and the condenser. Materials with good thermal conductivity were needed to construct these components. Aluminum was chosen as opposed to copper to construct these components because it better suit the design constraints as can be seen in Table 3.

Table 3: Trough and condenser material decision matrix.

Condenser and Trough Material Decision Matrix							
	Emissivity		**Machinability**	**Cost**		**Availability**	
	ε	Rating	Rating	$/ton	Rating	Rating	Total
Aluminum	0.09	6	10	$ 2,017.50	8	10	240
Copper	0.15	9	9	$ 6,621.00	4	6	178
Weight		4	6		7	10	

4.2 Components

As mentioned above there are five main components to the system. These components include the Solar Sausage, stand, storage tank, trough, and condenser. The components were designed to minimize the necessary parts and manufacturing time, manufacturing times are shown in Table 4. It took less than six hours to manufacture the entire system. The manufacturing of the components and will be discussed in the order they were constructed below. The CAD drawings used for manufacturing can be found in Appendix A.

Table 4: Solar Sausage desalination system components with manufacturing time.

Desalination System Components		
Component	Number of Parts	Manufacturing Time (minutes)
Stand (x2)	9	96
Trough	3	55
Storage Tank	4	55
Solar Sausage	4	180
Condenser	7	217
Total Manufacturing Time (minutes)		588

4.2.1 Stands

The stand when constructed has a height of 48 $in.$ and a width of 14 in. The stands support all the other components of the project and were constructed first. The parts for each stand and their manufacturing time can be seen in Table 5.

Table 5: Stand parts, their material and manufacturing time.

Stand			
Components	Manufac. Time (minutes)	Material	Number Required
Leg	15	Al6061 T6	2
Upper Cross Bar	5	Al6061 T6	1
Lower Cross Bar	5	Al6061 T6	1
L-Plate	2	Al3003H14	4
Circle Hooks	0	Galvanized Steel	1
Total Manufacturing Time (minutes)			48

Manufacturing

The legs and both cross bars are made of 1 $in.$ square aluminum tubing and only required simple $\frac{3}{8}in.$ holes to be bored through them. The L-plates were cut using a water jet from an aluminum plate, greatly reducing the manufacturing time. A L-plate was chosen to connect the legs and cross bars because they can be used to square the legs and cross bars, making the stand easier to assemble. The lower cross bars have circle hooks bolted to the holes in the middle. Two of the legs had brass barstock tees welded to the top of them perpendicular to the holes (Figure 6).

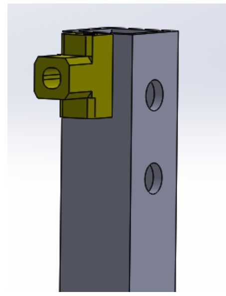


Figure 6: Barstock Tee welded to the top of the leg.

4.2.2 Trough

The trough is constructed of a 2 $in.$ by 2 $in.$ aluminum channel and has a wall thickness of .125 $in.$ Accounting for wall thickness the trough is capable of holding 1.5 $gallons$ of water.

Manufacturing

The trough is constructed of two 60 $in.$ aluminum channels and two trough walls. The channels were purchased and the trough walls were cut out of the same material as the L-plate using a water jet (see Table 5). The two aluminum channels are welded together at the center giving the trough a total length of 120 $in.$ (Figure 7). A trough wall was welded at each end of the trough, allowing it to be bolted to the stands and hold water (Figure 7). The stands and trough bolted together create a free standing structure capable of supporting large loads.

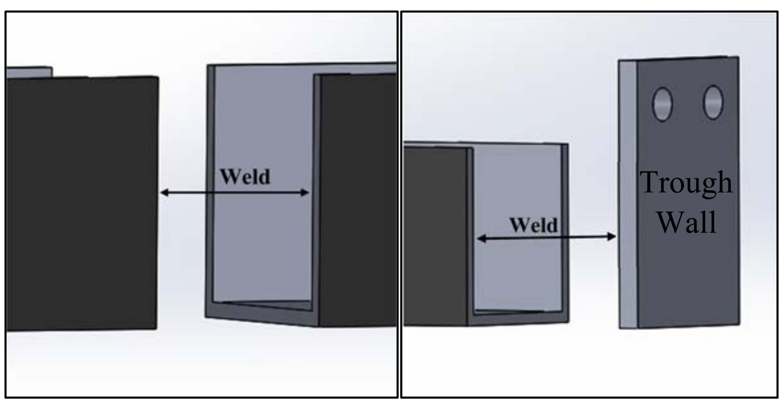


Figure 7: Trough components and their welds.

4.2.3 Solar Sausage

The Solar Sausage concentrates incoming solar radiation and focuses it into a single point 3/8th inch wide called the focal point. In laboratory settings, the focal point has reached a temperature of 752°F [2]. The Solar Sausage has a length of 120 in and diameter of 36 in giving a total reflective surface area of 4080 in^2 (Figure 5).

Manufacturing

The Solar Sausage is constructed of a two rectangular pieces of transparent plastic and one rectangular piece of Mylar Polyester. Through a series of folds and the use of industrial hot melt glue, the three pieces are bonded together to form the Solar Sausage. Pressure ports are cut into the upper and lower chamber at one end, then the ends are folded and sealed giving it the sausage-like appearance. The team attached an adhesive tie down on each side of the Solar Sausage half way down where the folds are joined together. The team also attached a steel wire loop to each end allowing it to be attached to the circle hook on the lower cross bar of the stand. The Solar Sausage will be inflated through the use of foot pumps and pressure regulated using needle-valves. Pressure gauges attached to top of the legs of one stand will be used to monitor the

Sun Tracking

To maximize the heat input into the system the focal point must remain as close to the center of the trough as possible. The sun tracking system used is adapted from a system used in commercial application that translates the lateral motion of a bar to rotational motion about the Solar Sausage's axis. For the system, a $72\ in.$ long, $1.5\ in.$ square aluminum tube is used to hold the Solar Sausage in place. The bar had two $\frac{3}{8}\,in.$ diameter holes bored in them for eye bolts. The rest of the parts, the 2 steel connecting wires and the two adhesive tie down were purchased and simply installed minimizing the manufacturing time.

4.2.4 Storage Tank

The storage tank has a capacity of $5\ gallons$ (being a 5 gallon bucket) and is black to maximize heat absorption from the sun. The upper section of the storage tank has a felt filter that removes particles larger than $100\ microns$. A manual $.5\ in$ ball valve controls the flow of saline water into the trough.

Manufacturing

The storage tank is made of four components: a $½\ in.$ ball valve, the storage tank platform, a through-wall fitting, and a five gallon bucket. The bucket, ball valve, and through-wall valve were purchased. The storage tank platform was constructed of a $13.65\ in.$ by $6\ in.$ metal plate, with a $1.5\ in.$ bore through the center that has two legs welded to it at the ends (Figure 8). The legs have $3/8\ in.$ holes bored into them so the storage tank platform can be inserted to the top of the stand legs with the pressure sensors.

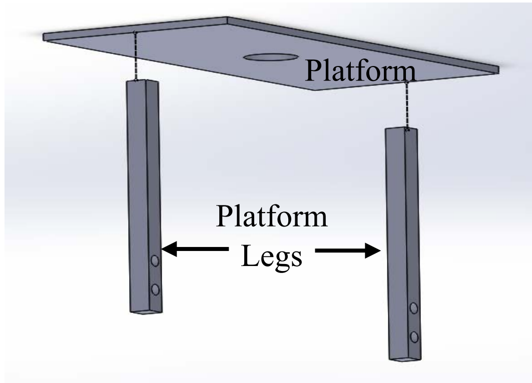


Figure 8: Storage tank platform..

4.2.5 Condenser

The condenser has a width of $5\ in.$ and a radius of $2.5\ in.$. The condensing dome has a length of $120\ inches$ giving a total surface area of $960\ in^2$. The end of the channels that extend $4\ in.$ past the collection dome will have $\frac{1}{4}\ in.$ diameter holes bored in them where the desalinated water will be collected. The end of the condenser by the storage tank is raised two inches to create a sufficient gradient to drive the water to the holes for collection (Figure 5).

Manufacturing

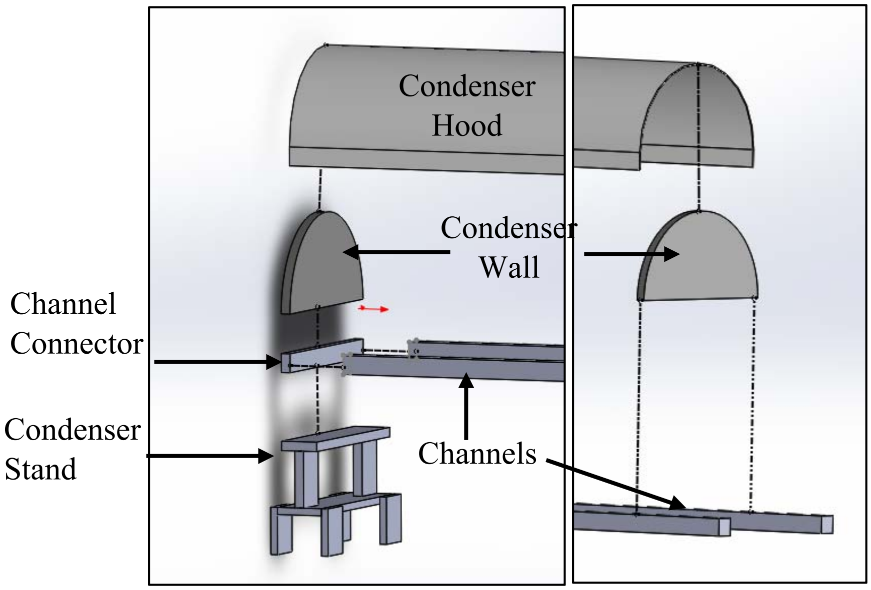
The condenser was constructed last. The condenser was not necessary for testing until evaporation can be achieved which requires the stands. The total time to manufacture the parts and weld them together was 217 minutes (Table 6).

Table 6: Condenser Components and their manufacturing time.

Condenser Parts			
Components	Manufac. Time (minutes)	Material	Number Required
Channel	40	Al6063	2
Condenser Wall	10	Al6061 T6	2
Channel Connector	6	Al6061 T6	2
Condenser Stand	60	Al3003 H14	1
Condenser Hood	45	Al3003 H14	1
Total Manufacturing Time (Minutes)			217

All components except for the channels were cut from a water jet. The channels came in lengths of $96\ in.$ segments. Two $28\ in.$ channel segments were cut and welded to the $96\ in.$ segments giving the channels the desired length. The rest of the components had to be welded together. All parts of the condenser had to be welded together making the condenser the most expensive components of the desalination system. The assembly of the parts are shown in Figure 9 below.

Figure 9: Exploded view of each end of the condenser.



4.3 Design Analysis

The heat delivered to the trough will be concentrated solar insulation. The solar insulation at the equator is about $317\ \frac{\text{Btu}}{\text{hr}\cdot\text{ft}^2}$ [5]. This number various with the with latitude, the solar insulation, S_θ at a given latitude can be calculated

$$S_\theta = 317\cos\theta\,\frac{Btu}{hr\cdot ft^2} \qquad (1)$$

Tallahassee has a latitude of $\theta = 30°$, giving Tallahassee a local insulation of $S_{30°} = 217\ \frac{Btu}{hr\cdot ft^2}$. As mentioned above the Solar Sausage has a total reflective surface area, $A_{reflective}$, of $4080\ in^2$ or $28.33\ ft^2$. In order to find the heat delivered to the trough, the three points of loss had to be known. It was known that there was a 16% loss when entering the project ($\eta_{entering}$), a 10% reflective membrane ($\eta_{reflective}$), and a 12% loss when exiting the membrane ($\eta_{exiting}$). Knowing this information, the heat delivered to the trough was found using Eqn. 5 below.

$$\dot{Q} = (S_\theta)(A_{reflective})(1-\eta_{entering})(1-\eta_{reflective})(1-\eta_{exiting}) \qquad (5)$$

The Solar Sausage delivers $\dot{Q} = 4943.5\ \frac{Btu}{hr}$ to the trough. The saline water in trough temperature will not be allowed to exceed 220°F. The maximum evaporation rate can be determined using the latent heat of evaporation, $h_{fg@220°F}$, and the heat into the system, $\dot{Q}$ [6].

$$\dot{m}_{evap} = \frac{h_{fg@220°F},}{\dot{Q}} \qquad (2)$$

The maximum rate of evaporation was calculated to be $\dot{m}_{evap} = 5.56\ \frac{lbm}{hr}$ (.67 $\frac{gallons}{hr}$). The peak operating hours are between 10 am to 3 pm, a five hour window. During this five hour window the system is capable of producing a maximum of 3.35 $gallons$ meeting our goal of 3 $gallons$. Supporting calculations can be found in Appendix B.

4.4 Project Assembly

The solar sausage, trough, and condenser will arrive constructed. The stand must first be constructed by the operator followed by the storage tank. The components are constructed and secured together with 3/8 in. hex bolts and nuts. The system is assembled in the order discussed.

4.4.1 Stand

The stand, comprised of two legs and two crossbars, is 48 $in.$ tall and 14 $in.$ wide. The legs and crossbars are constructed of 1 inch square aluminum tubing. The legs and cross bars are aligned to with L-plates and bolts. Two stands will have to be constructed.

Stand Construction

First, align the upper and lower cross bars between the two legs (Figure 10). The lower cross bar has the circle hook in the middle. The holes must be parallel to the legs in order to connect. Two of the legs have a barstock tee with a pressure gauge welded to them, these legs will be used on the same stands. The pressure gauges should be on the outside of the stand.

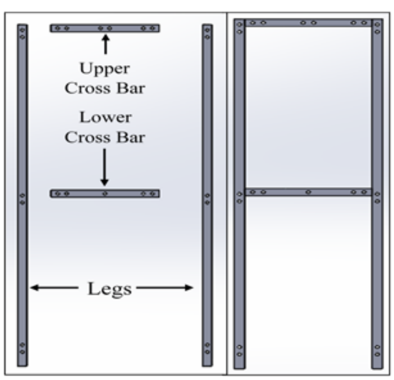


Figure 10: Leg and Cross bar alignment.

After the legs and cross bar are aligned, use the L-plates to square them. Once they are square, they are bolted together (Figure 11). This needs to be done at all four places the legs and cross bars meet, this completes construction of the stand. Prior to bolting together the legs with the pressure gauges to the upper cross bar, insert the legs of the storage tank platform into the legs. Then bolt the legs to the upper cross bar with the L-plates.

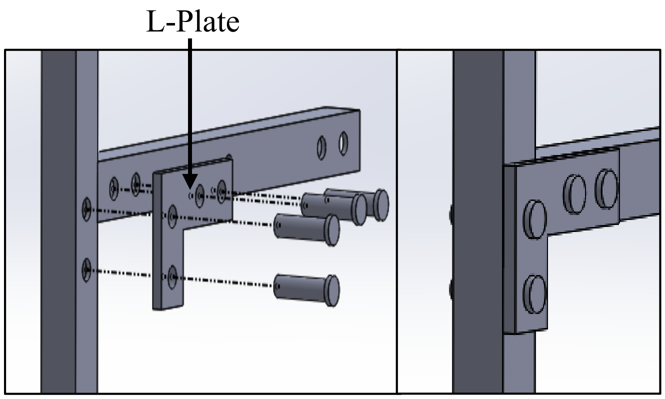


Figure 11: Use of the L-plates.

4.4.2 Storage Tank

The storage tank has three components: the bucket, the storage tank platform and the ball valve (Figure 12). First, the storage tank platform legs must be inserted into the top of the legs while maintaining the holes' alignment (Figure 12). Use the L-plates to bolt the platform in place followed by the upper cross bar, completing construction of the stand. With the platform in place, set the bucket on the storage tank being sure to align the hole in the bucket and platform. Once aligned fit the male piece of the ball valve with an O-ring, and insert through the bottom of the platform and the storage tank. On the inside of the bucket, fit the male piece with another O-ring and secure with a compression. This secures the bucket to the platform completing construction of the storage tank.

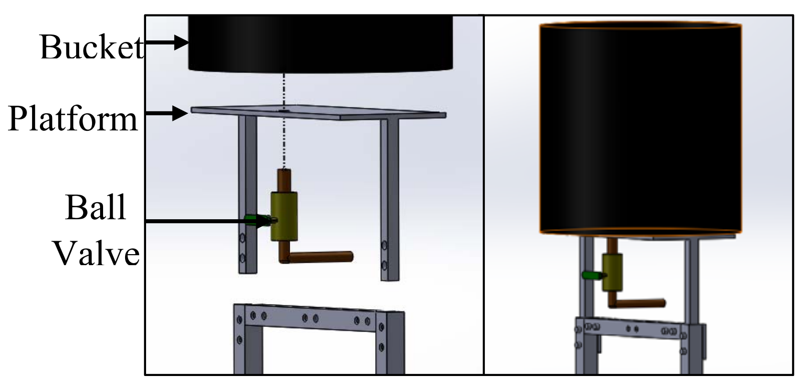


Figure 12: Exploded and assembled views of the storage tank.

4.4.3 Trough

The trough will be installed after the stands and storage tank have been constructed. The trough attaches at each end to the upper cross bar of the stand (Figure 13). Each end of the trough has two holes so that it can be bolted to the upper cross bar. Be sure the circle hook of the lower cross bar is facing the trough.

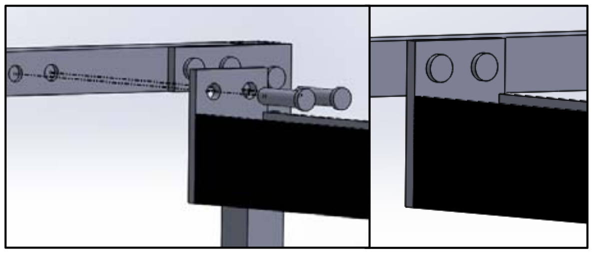


Figure 13: Exploded and assembled views of the trough.

4.4.4 Condenser

Once the trough is attached, the condenser can now be placed on the stand. The condenser sets on top of the stand (Figure 14). The end with the risers sits on the side with the storage tank.

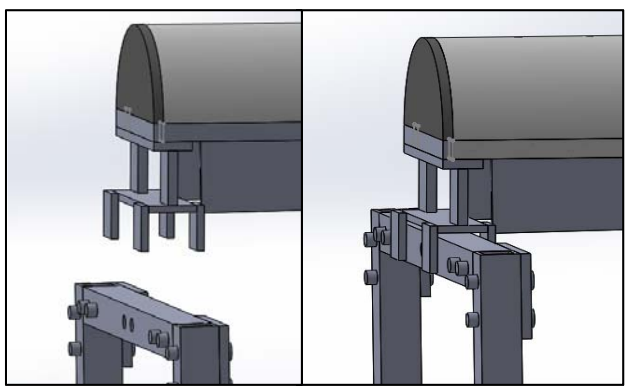


Figure 14: View of condenser alignment to resting on the stand.

4.4.5 Solar Sausage

The Solar Sausage attaches to the lower cross bar between the two stands. Each lower cross bar has a circle hook facing the inside. The ends of the Solar Sausage have loops made of $1/8\ in.$ wire rope that simply slip over the circle hook to attach the Solar Sausage.

Sun Tracking

The sun tracking system is easy to attach to the Solar Sausage. The sun tracking bar will be placed underneath the Solar Sausage with the closed eye bolts shut. The steel wires have slide-bolts at each end. The operator will the attach one of the slide-bolts to the closed eye bolt. Once attached the operator will run the wire underneath and across the Solar Sausage and clip the slide-bolt to the tie down glued onto the Solar Sausage. This step will be repeated for the second wire but on the other side of the sun tracking bar (Figure 15).

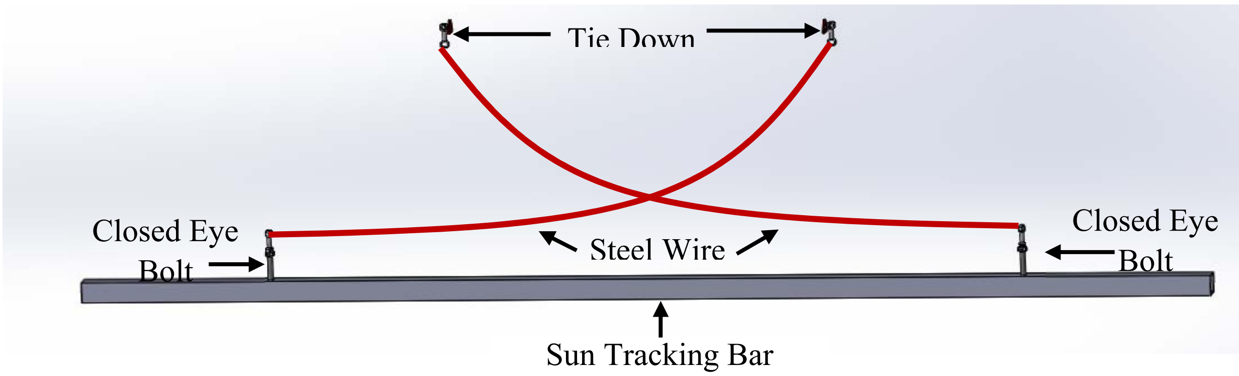


Figure 15: Sun Tracking System.

4.5 Operation

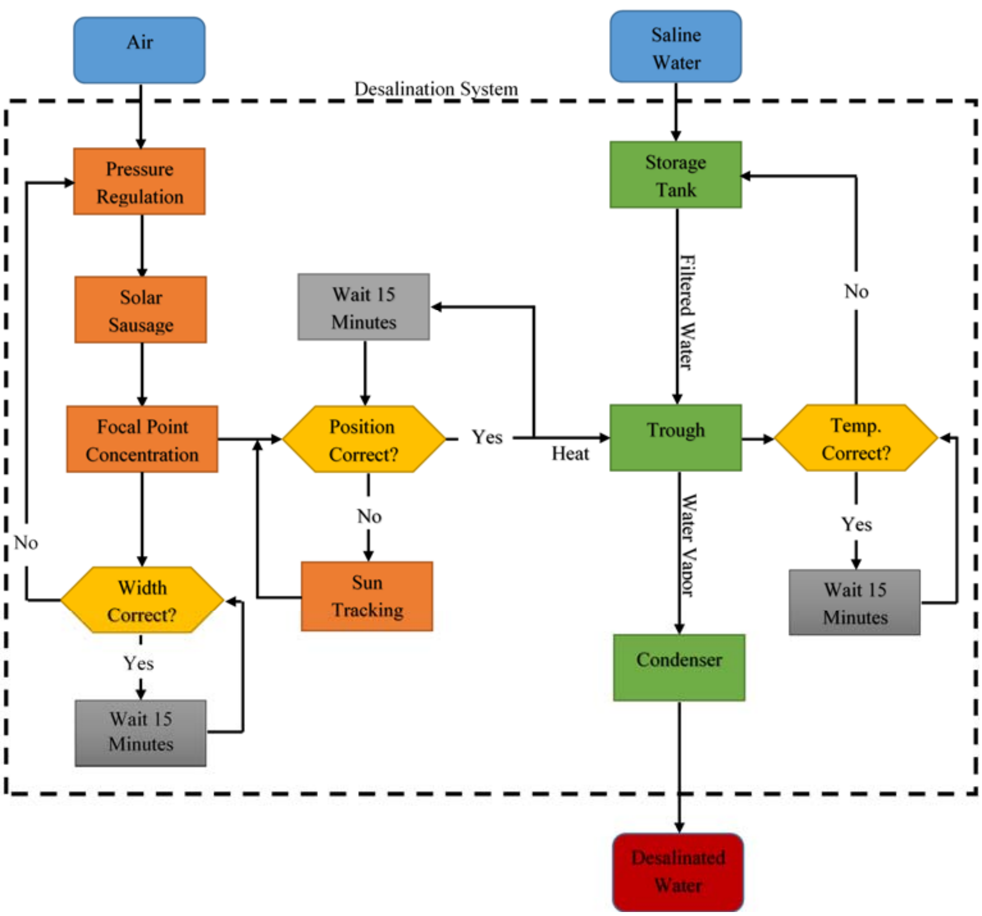


Figure 16: Functional diagram of the desalination system.

There are two subsystems within the desalination system shown inside the dashed box above in Figure 16, the solar concentration system (displayed in Orange), and the distiller (displayed in green). The solar concentration system delivers heat to the distiller, supplying the necessary energy for distillation. The operator is responsible for supplying the system with air and saline water; these inputs are displayed in blue. The outputted, desalinated water is displayed in red. The operator will attend to both systems simultaneously, performing the system checks consecutively.

4.5.1 Operating Instructions

1. Assemble system using Project Assembly.
2. Put filter in storage tank (bucket).
3. Fill up the storage tank (bucket) with collected salt water to allow for pre-heating.
4. Attach the ends of the Solar Sausage to the crossbar hooks.
5. Attach each of the two small tubing to either side of the T-valve. Connect one of the small tubes to the Solar Sausage and the other to the foot pump. Connect the long tubing to the top of the T-valve and the bottom of the pressure gauge. Attach a tubing from the pressure valve to the side of the pressure gauge to allow for release of air as needed. (Make sure valve is closed.)
6. Repeat Step 5 for other Solar Sausage chamber.
7. Begin pumping air into the top half of the Solar Sausage using the foot pumps provided. Be sure to fill the top chamber to 1.0 psi using the corresponding pressure gauge.
8. Next, pump air into the bottom section of the Solar Sausage using the foot pump. Monitor the pressure gauge so that the bottom section is filled to 0.5 psi as well.
9. Look underneath the trough and move the Solar Sausage to identify the focal point. This focal point should entirely fit along the bottom of the trough. If it is wider than the trough, see Step 10; otherwise, move to Step 11.
10. Using the foot pump, pump more air into the upper section of the Solar Sausage. Monitor the focal point. For ideal conditions, the focal point should be as thin and focused as possible.
11. Using the Aluminum bar below the Solar Sausage, adjust the Solar Sausage's angle so that the focal point rests in the center of the trough. Move the bar in the opposite direction of the desired direction of the focal point.

12. Using the valve on the storage tank, release approximately one inch of water from the storage tank into the trough.
13. Check the system every fifteen minutes.
    a. Maintain the focal point. This can be done by adjusting the aluminum bar below the Solar Sausage. Also, be sure the Solar Sausage's inflation is still consistent.

4.6 Reliability

The prototype produces 3 $gallons$ per day and performs well. The system was tested in different weather conditions regarding temperature, wind effects, and sunlight exposure. The prototype should perform the same whether used 1 or 10,000 times assuming all parts aren't damaged or have been replaced if so.

4.6.1 Part Replacement

The components and parts used were selected and designed so they can be easily substituted or replaced using common items found in developing countries. This would mean that long-range import is not required. The storage tank is to be composed of a five gallon bucket, an item attainable around the world. The storage tank can be substituted for any comparably-sized container, offering multiple alternative options. An alternative can be used to replace the filter so long as it is comparable to the filter provided. Comparable items include canvas bags and cloths that can be found worldwide.

4.7 Economics

The Solar Sausage for Desalination is designed for deployment into developing countries to assist families in obtaining clean, drinking water. This product was designed at low cost for mass production. The Solar Sausage for Desalination is to be as low-cost as possible in order to provide for a greater number of people requiring access to clean water.

4.7.1 System Cost

The parts for the system were purchased at market price bringing the total cost of the system to just below $855.26, see Table 7. This greatly increased the cost of the system compared to if the parts were purchased at wholesale prices. The cost per component can be found below in Table 7. The condenser is the most expensive component because of the cost of welding. The Solar Sausage cost $10 in material. The parts to keep the Solar Sausage inflated and in line with the sun made up the majority of the cost.

Table 7: Cost per component for the system.

Cost Per Part			
Part	Cost/Part	# Needed	Total Cost
Stand	$ 58.50	2	$ 117.00
Trough	$ 121.78	1	$ 121.78
Storage Tank	$ 92.49	1	$ 92.49
Condenser	$ 197.38	1	$ 197.38
Solar Sausage	$ 326.61	1	$ 326.61
		Total	$ 855.26

5. Design of Experiment

The testing was conducted on many different occasions each focusing particularly on one component while still going through the procedure and checking of the other components. For example, in the testing of the Solar Sausage's deliverance of heat to the trough, the inflation of the Solar Sausage and inspection of its pressure gauges were still performed.

5.1 Solar Sausage Inflation

The inflation of the Solar Sausage was checked by creating the focal point onto our trough. This result showed that the upper and lower chambers need to be inflated to about $1\ psi$ and $0.5\ psi$, respectively. This pressure differential of 1/10th of a psi varied from our expected 1/100th of a psi previously assumed through testing conducted by Ian Winger. This was due to our target focal point being elevated farther from the Solar Sausage than the target focal point when tested by Ian Winger. This complete process took around 30 minutes to complete.

5.2 Pressure Gauges

During the inflation, the pressure gauges unexpectedly had incoming pressures that exceeded their limit and permanently damaged the instruments. This led to the decision of using a long tube between the pump and gauge in order to create more head losses and prevent excessive pressure spikes from entering the gauge directly.

5.3 Temperature

The Pistol-Grip Infrared Thermometer was used to conduct thermal testing of the trough and a common oven thermometer (provided with the system in the final packaging) was used for the water temperature readings. With the focal point aligned, temperature readings were taken throughout the length of the trough. This showed that the temperature is highest in the center and decreases moving towards the stands in either direction. This was expected since the Solar Sausage's reflective material is most flush in the center and is pinched on either end making wrinkles and thus losing its efficiency locally. The temperatures at the center and sides of the trough was approximately $127°F$ and $120°F$, respectively. The temperature of the water taken from the oven thermometer was found to be $120°F$.

5.4 Output Clean, Drinking Water

The ExStik II Salinity Meter was used in the testing of the water leaving the channels from the condenser. This instrument read salinity levels less than 100 ppm proving the outputted water was clean and drinkable as expected. The condenser was evaluated by testing the condenser over steam cooking devices which generated steam into its lower surface. This was the only component tested apart from the system due to weather and construction delays. By pouring a gallon of water into the cookers, recording the time condensing, then removing the excess water and measuring both the condensed and left over water, the condensation rate was found. The result was much lower than expected having around 2% of the water input actually condense and collect.

6. Environment, Safety, and Ethics

The Solar Sausage for Desalination harnesses solar energy to use natural processes, such as evaporation, to produce clean drinking water. This idea allows for an environmentally conscious design. The design results in zero emissions during operation. Designing this system in a simplistic and versatile way aided in the entrepreneurial endeavors of this project, while also promoting recycling and reuse. Many of the components to the Solar Sausage for Desalination can be replaced with readily available materials in developing countries. This promotes reuse of older items such as canvas bags, spare materials, and plastic containers.

Since the Solar Sausage for Desalination is tasked with producing clean drinking water, the water produced must satisfy government regulations in order to be considered safe to consume. To avoid any potential pollutants from the Aluminum used to construct the trough and condenser and potential metal corrosion, a Stainless Steel coating has been applied to all material in which the fresh water will come into contact with. Also, heat-resistant gloves will be provided with each desalination system since many of the components will be heated to temperatures known to cause serious burns on skin. The heat-resistant gloves alleviate this concern for those operating this system.

7. Project Management

7.1 Schedule

The progression of the project was very close to what was expected by the group. By the end of the fall semester, the tasks set on the Gantt chart had been completed. For the most part, the spring semester has followed closely to the Gantt chart as well. However, there are some minor complications that have caused delay in the testing portion of the project. The machining of the condenser took longer than expected and therefore the testing of the entire system was delayed. Other parts of the system such as the focal point and pressure regulation system were tested previously to ensure there would be minimal issues when the condenser arrived. Overall, the group's progression was very similar to that expressed in the Gantt chart.

7.2 Resources

A couple parts of the system prototype required machining. Most of the machining was done in the engineering machining facility. The group was able to perform most of the minor laboring tasks such as painting and construction. There is a machining process to build the solar sausage, but the students built the prototype by hand in order to gain a better idea of the process and significant attributes. Overall, the resources used to build the system were minimized so that the group could get more hands on experience.

7.3 Procurement

The group was given a budget of $5,000 to create the solar desalination system. Table 8 shows that only $1,485.62 was spent, which is about 30% of the total budget. A majority of the budget was spent on labor, since the group was unable to perform certain tasks such as welding or heavy machining. Since this is an entrepreneurial project, the group aimed to keep the system low cost so that it could ideally be mass-produced and marketed. The leftover funding could be spent on further research and optimization techniques. There is still a lot of room for improvement and design alterations.

Table 8: Master Budget broken down with individual percentages of the total.

Master Budget		
Category	Spent ($)	% of Budget*
Raw Materials	$ 464.85	9.30%
Accessories	$ 592.84	11.86%
Testing Supplies	$ 247.93	4.96%
Labor	$ 180.00	3.60%
Total	**$ 1,485.62**	**29.71%**
**Out of a budget of $5000*		
Funds Available		$ 3,514.38

All purchasing was recorded and submitted to the advisor. They can also be found in the appendix of this report. Most of the materials were ordered from Metals Supermarket and McMaster Carr. Table 9 below shows the purchase orders. The procurement table below shows the number of items ordered from each vendor and the amount of money that was spent. Some additional items were purchased at local vendors.

Table 9: Purchase orders by vendor, date, and amount spent.

Vendor	Date	Amount Spent
McMaster-Carr	12/15/215	$230.85
Metals Supermarket	12/15/2015	$268.86
McMaster-Carr	2/19/2015	$88.37
Metals Supermarkets	2/19/2015	$92.17
Amazon	3/5/2015	$120.66
McMaster-Carr	3/5/2015	$188.41
McMaster-Carr	3/25/2015	$167.27
Metal Supermarkets	3/25/2015	$136.56

7.3 Communication

Communication throughout this project was very efficient. The group members communicate with one another using a "group chat" on their cell phones. This makes it easy to keep the entire group updated as opposed to speaking with on another individually. The group used e-mail as a primary form of external communication. All e-mails that were sent or received by any member of the group were also copied or forwarded to the other members. Regular meetings were set up with various advisors, sponsors and others involved with the project in order to keep those involved updated. The only complication that occurs is setting up meeting times that are available for all members in the group as well as external personnel. When this conflict occurs, the group will send out a Doodle form in order to gain a better idea of everyone's availability. All group members are expected to check their e-mail multiple times every day so that any notifications or issues can be handled immediately. There have been no real concerns in the communication aspect of this project.

8. Conclusion

The Solar Sausage for Desalination is a unique project as it is both an engineering and entrepreneurial project. Since this project incorporated an entrepreneurial aspect, the engineering had to cater to the prospect of mass production and potential prospective consumers. This required an inexpensive product that satisfied the hydration needs of the consumer.

The design approach transitioned from heavily over-engineered designs using a heat exchanger to a simplistic design that could be easily understood by the general population. The simplicity of the design allows for easier repairs and operation. No additional specialized training would be required since the system is so simplistic. The simplicity also means less components that would have to be potentially replaced or repaired. Each component can also be substituted or replaced by items that would be easily obtained in developing countries worldwide (i.e. exchange the filter with a canvas bag). A modular design to produce clean drinking water for a small family rather than small community directly addressed the entrepreneurial side of this project as it added to the marketability of the Solar Sausage for Desalination.

The Solar Sausage for Desalination was produced using money from the generous $5,000.00 budget received from the College of Engineering. Upon reviewing final expenditures, the Solar Sausage for Desalination project used under 30% of the total budget, producing a product that costs approximately $855.26 per system as the price of a singularly produced Solar Sausage for Desalination system. When mass produced, the value will be greatly decreased since the purchases will be made in bulk and receive bulk pricing for the materials used. The system is easily constructed, deconstructed, and operated. It would require 30 minutes of daily maintenance in order to produce three gallons each day. Accounting for potential losses, this is still sufficient to meet the hydration needs of five adults in a single household. During the first year of operation, the water produced will cost approximately $0.61 per gallon. After ten years of operation, including minor repairs, the cost per gallon will reduce down to $0.16 per gallon.

In hindsight, minor changes could be made to the Solar Sausage for Desalination. During construction of the Solar Sausage, a Velcro material was used as the adhesive material. This material is significantly more expensive to adequate alternatives such as hot glue. Since this part of the system should remain attached, there is no need to use a material such as Velcro. Inexpensive hot glue would cost significantly less and work sufficiently for the requirements of the adhesive on the Solar Sausage.

Before this product is ready for introduction into the market against current competitors, some refinements should be made. This future work would directly contribute to refining the current product. Improvements can be made on the design of the condenser in order to maximize the condensation. This includes determining the most effective ways to keep the condenser cool and effective shapes that maximize results. The pressure pumping system could be improved by using different foot pumps or even other means to pump up the Solar Sausage. Ideally, another low-technology alternative, similar to the foot pumps will be used. Further testing would greatly benefit in determining ways to increase the water output such as experimenting with flash distillation or finding ways to decrease the cost. This would ultimately increase the efficiency of the Solar Sausage for Desalination. In order to better predict the outcome in various temperatures and atmospheres, further testing with varying ambient temperature and pressure could be conducted. Any additional information to specific temperatures or pressures could be included in an instruction manual specific to the region of deployment.

To advance the potential of this product, contacts with clean water organizations and humanitarian groups should be made. Also, investors should be contacted in order to refine and market this product so that it can begin introduction into the world market.

9. References

[1] Group Seven, Ian . Personal interview.

[2] "Direct Pumped Systems." *System Types*. The Florida Solar Energy Center. Web. 9 Oct. 2014.

[3] Gershenson, John. "MODULARITY IN PRODUCT DESIGN FOR MANUFACTURABILITY." *International Journal of Agile Manufacturing* 1.1 (1997). Web. 6 Nov. 2014. http://alvarestech.com/temp/PDP2011/CDAndrea/MODULARIDADE/PROJETO PARA MANUFATURA.pdf

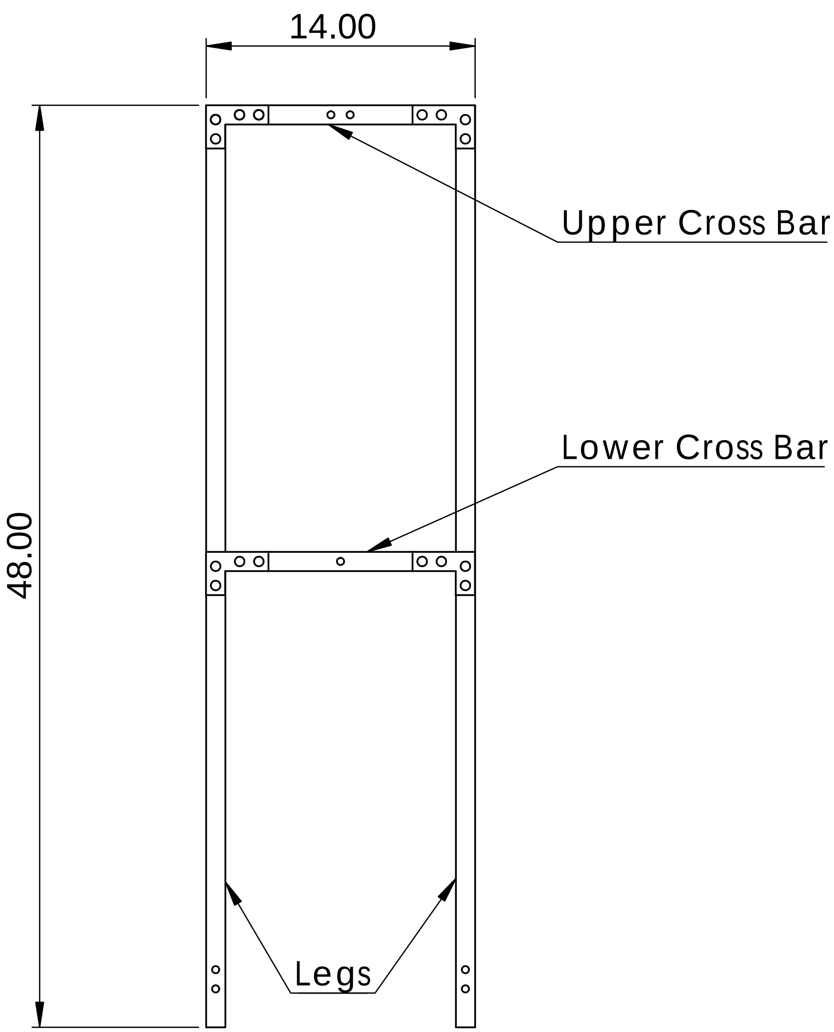
[4] "Aluminium." - *Element Information, Properties and Uses*. Royal Society of Chemistry. Web. 15 Mar. 2015. <http://www.rsc.org/periodic-table/element/13/aluminium>.

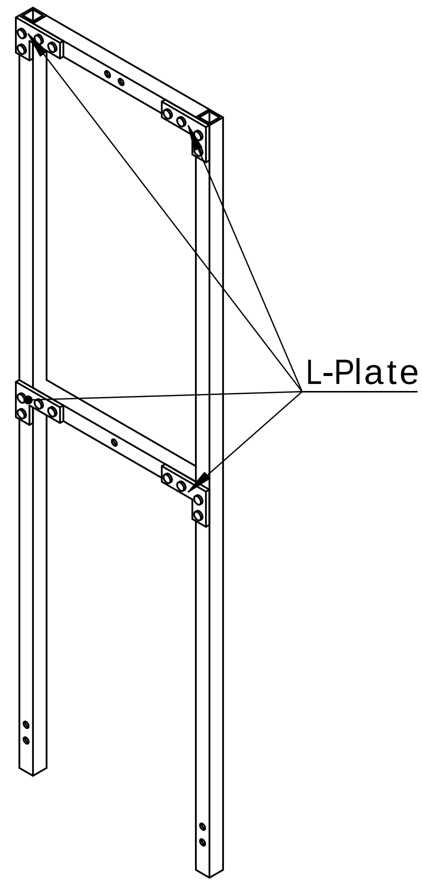
[5] Sinha, Sayontan. "Solar Insolation." Solar Insolation. Web. 21 Oct. 2014.

[6] Engel, Yunus A. Fundamentals of Thermal-fluid Sciences. 4th ed. Singapore: McGraw-Hill, 2012. Print.

Appendix A

Contents





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	FUNDING APPR.	Crystal Wells		
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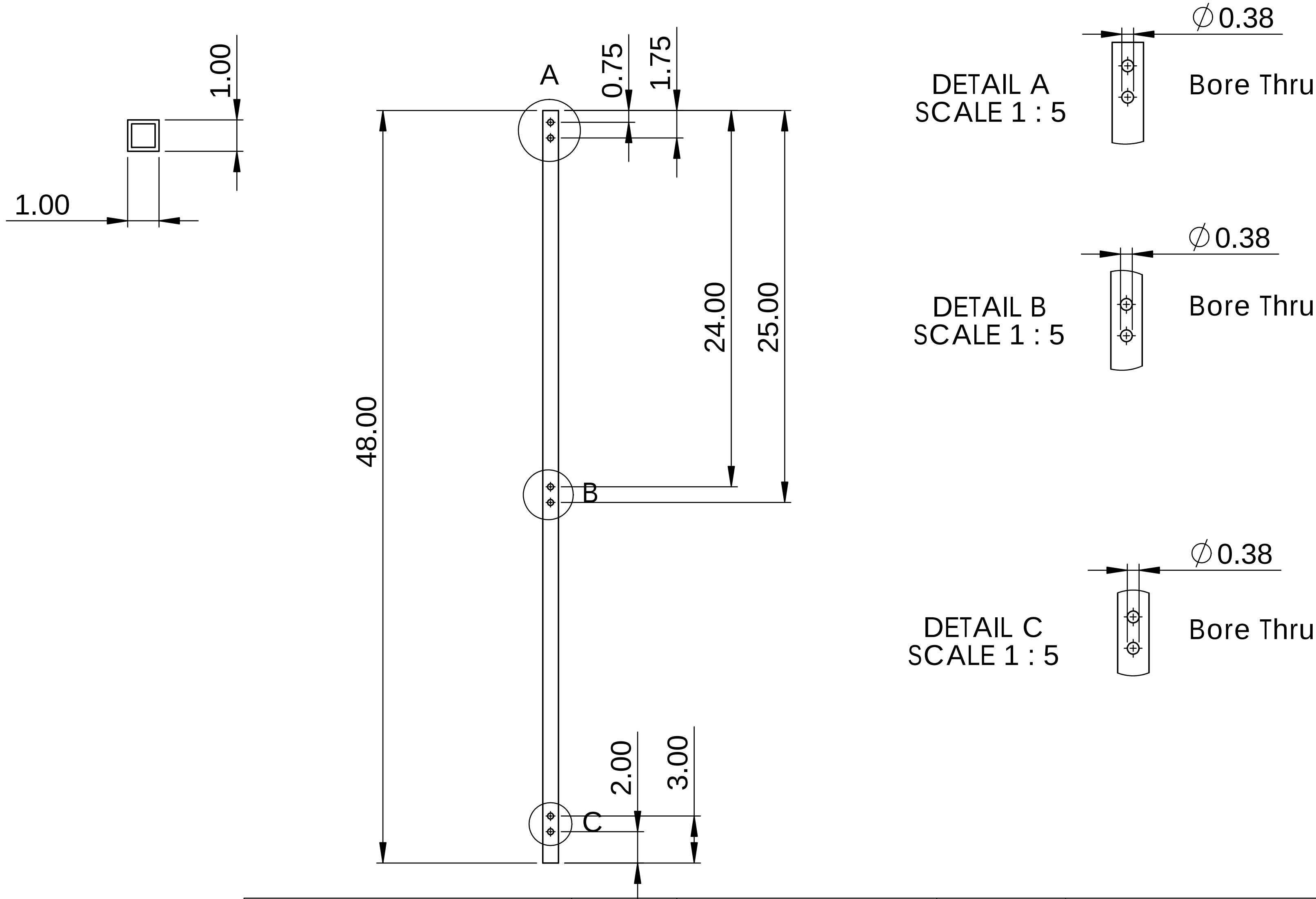

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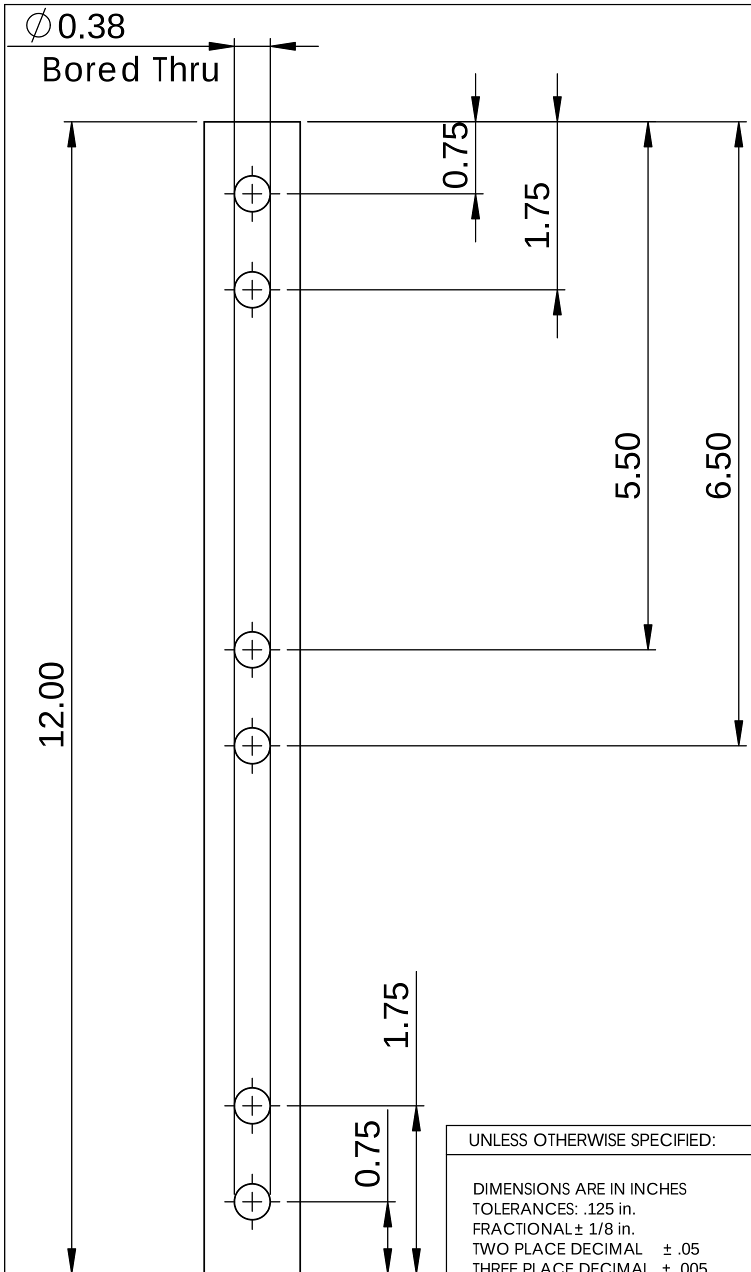

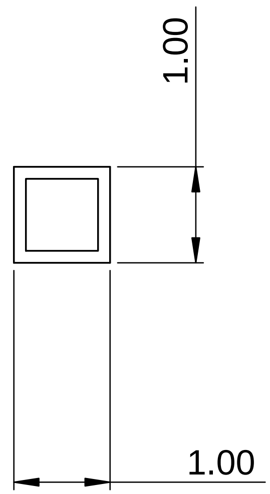

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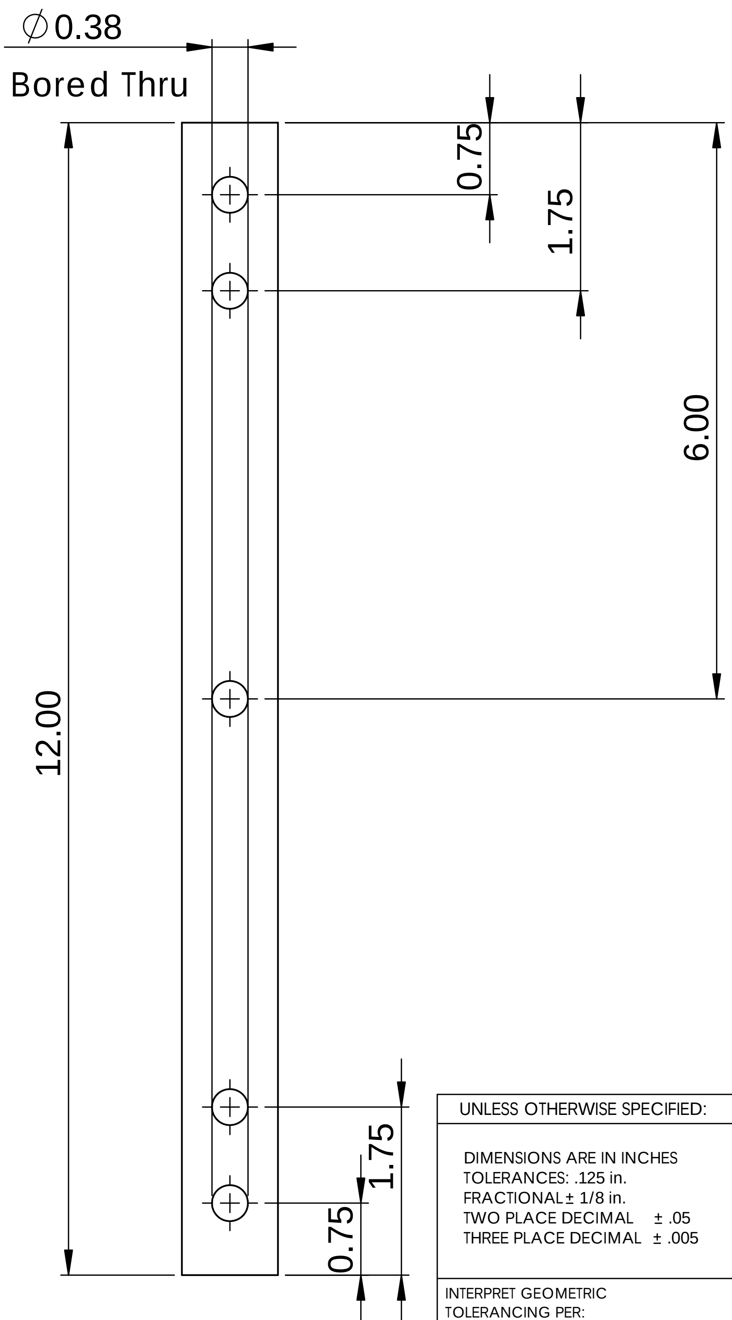

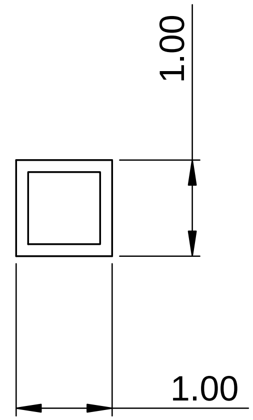

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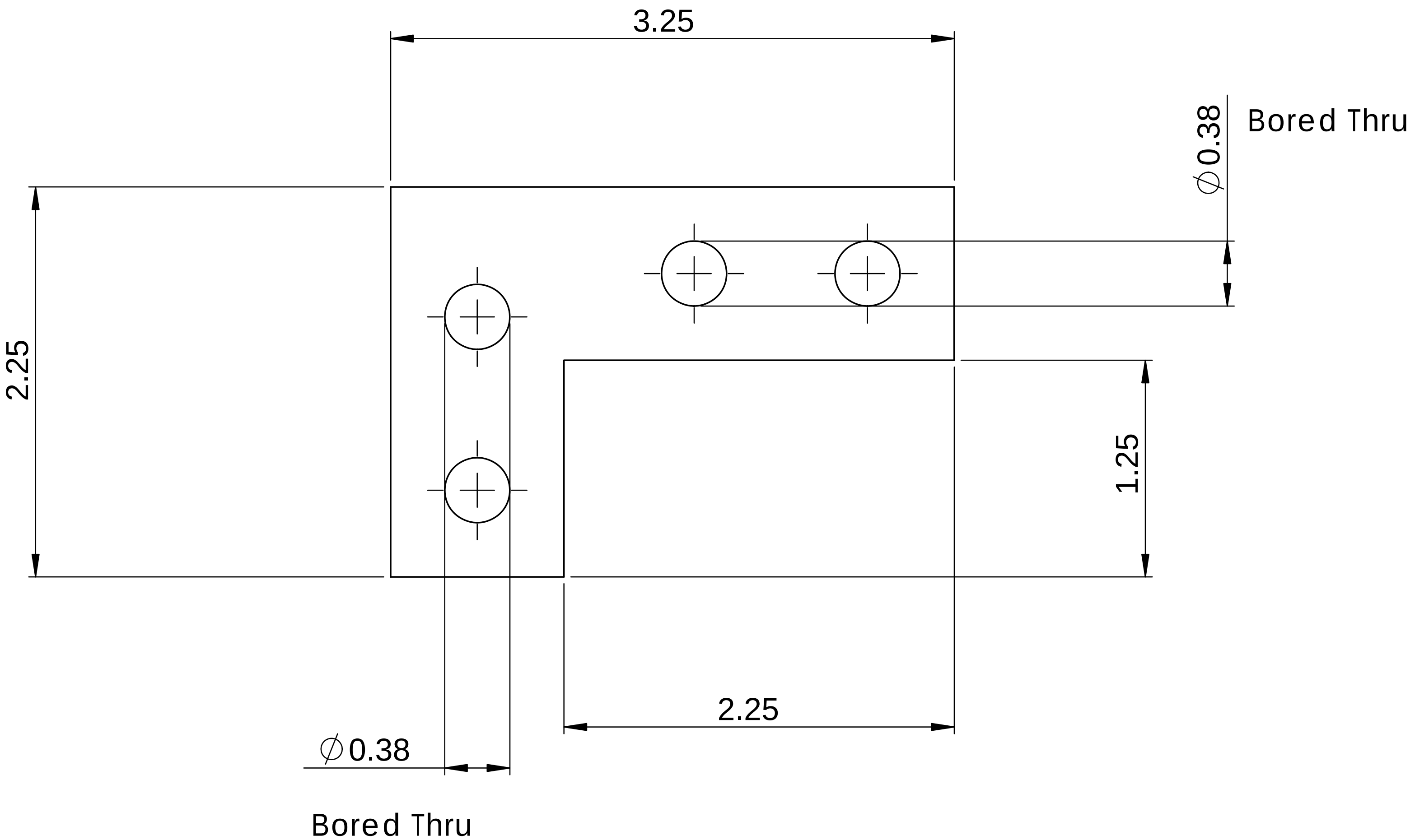

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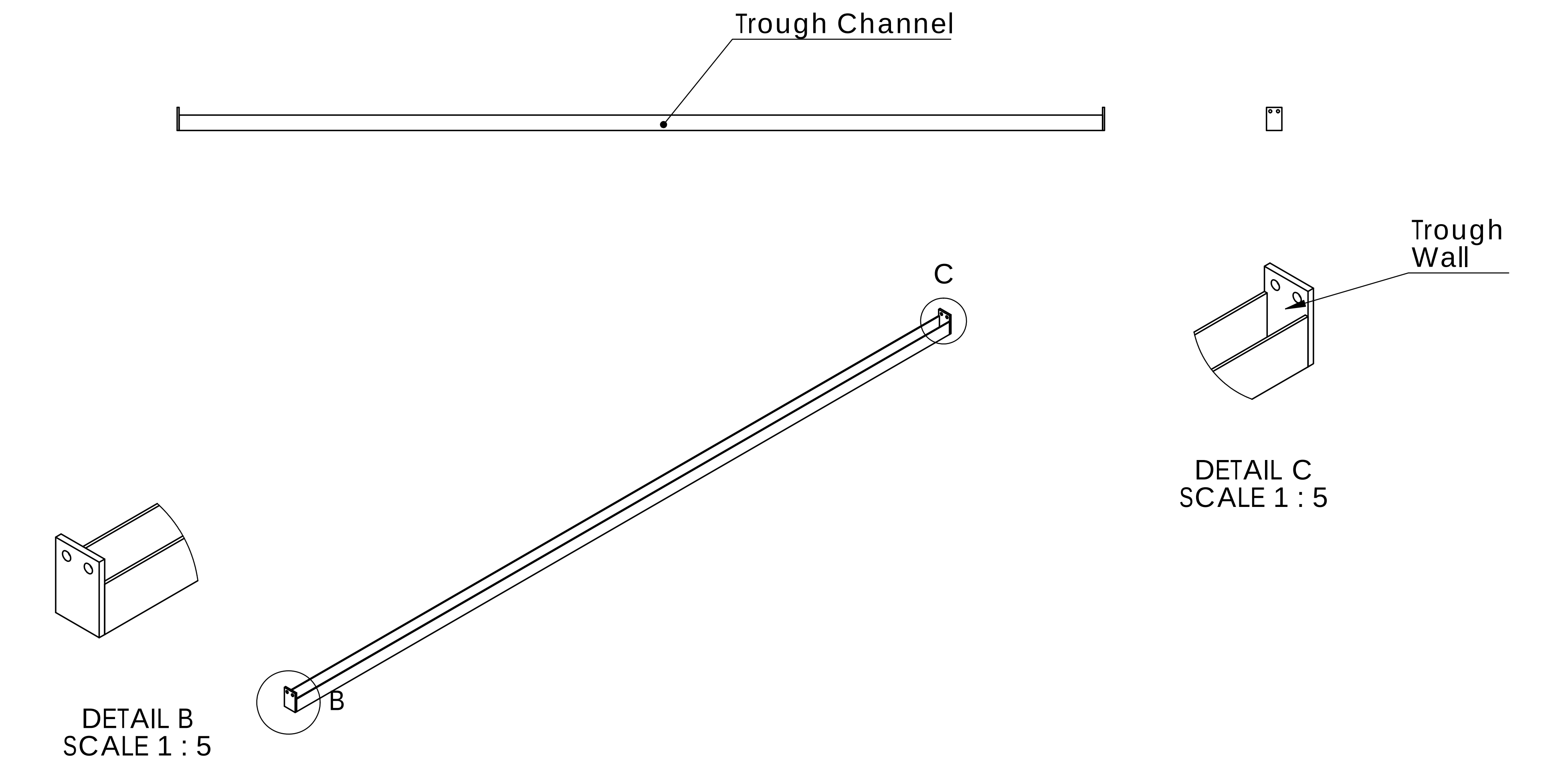

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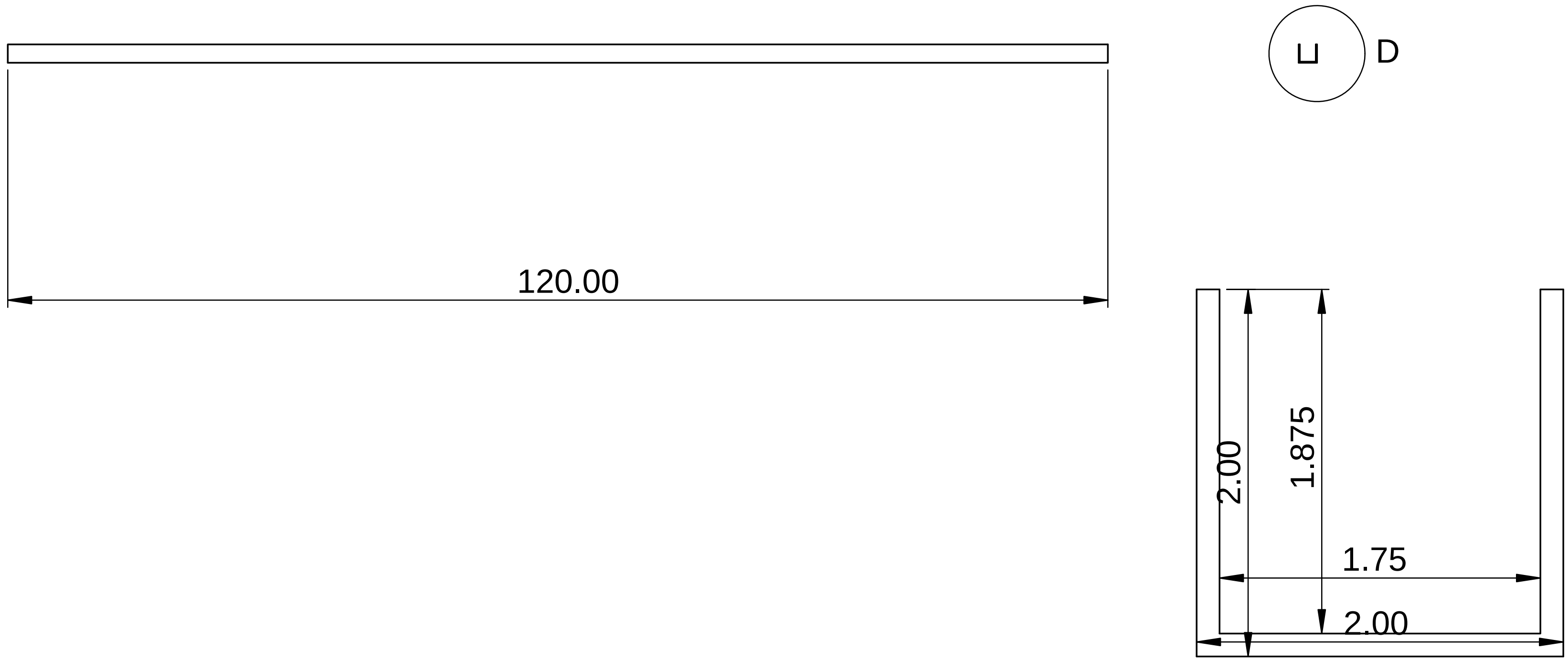

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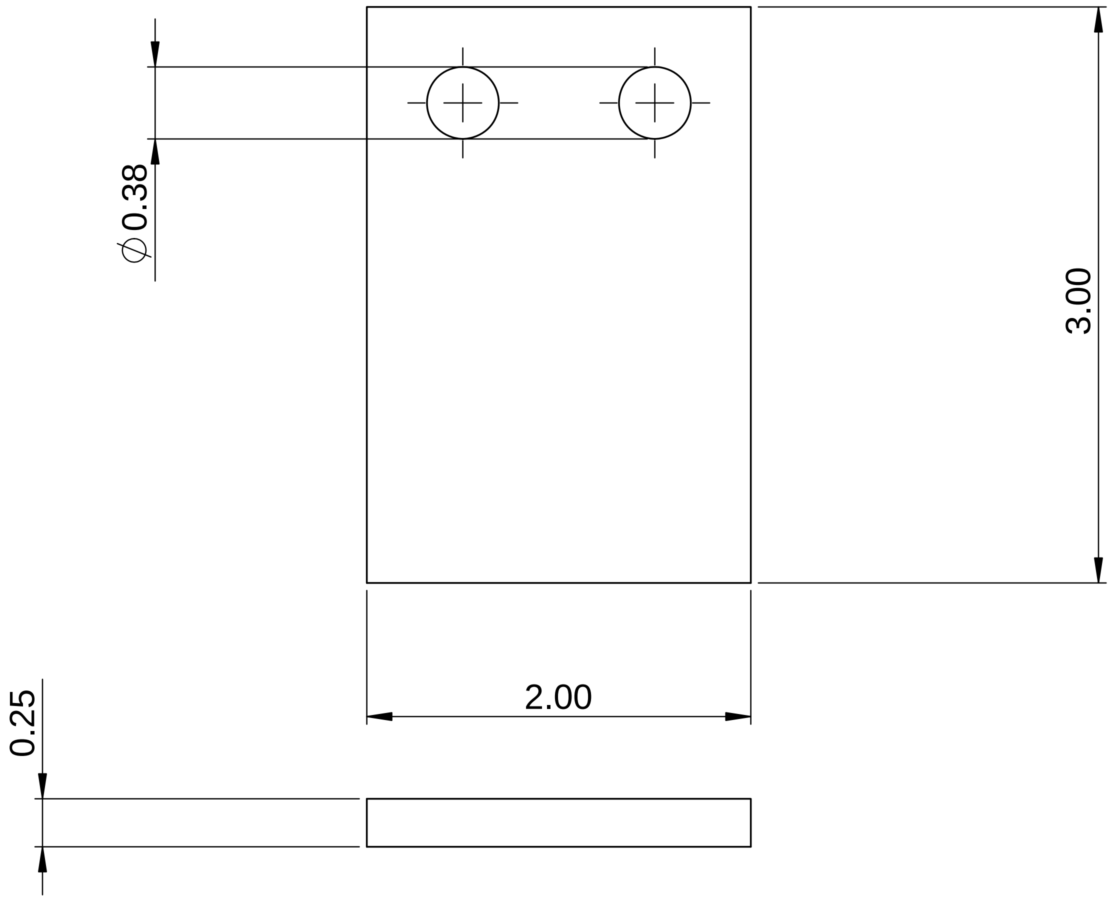

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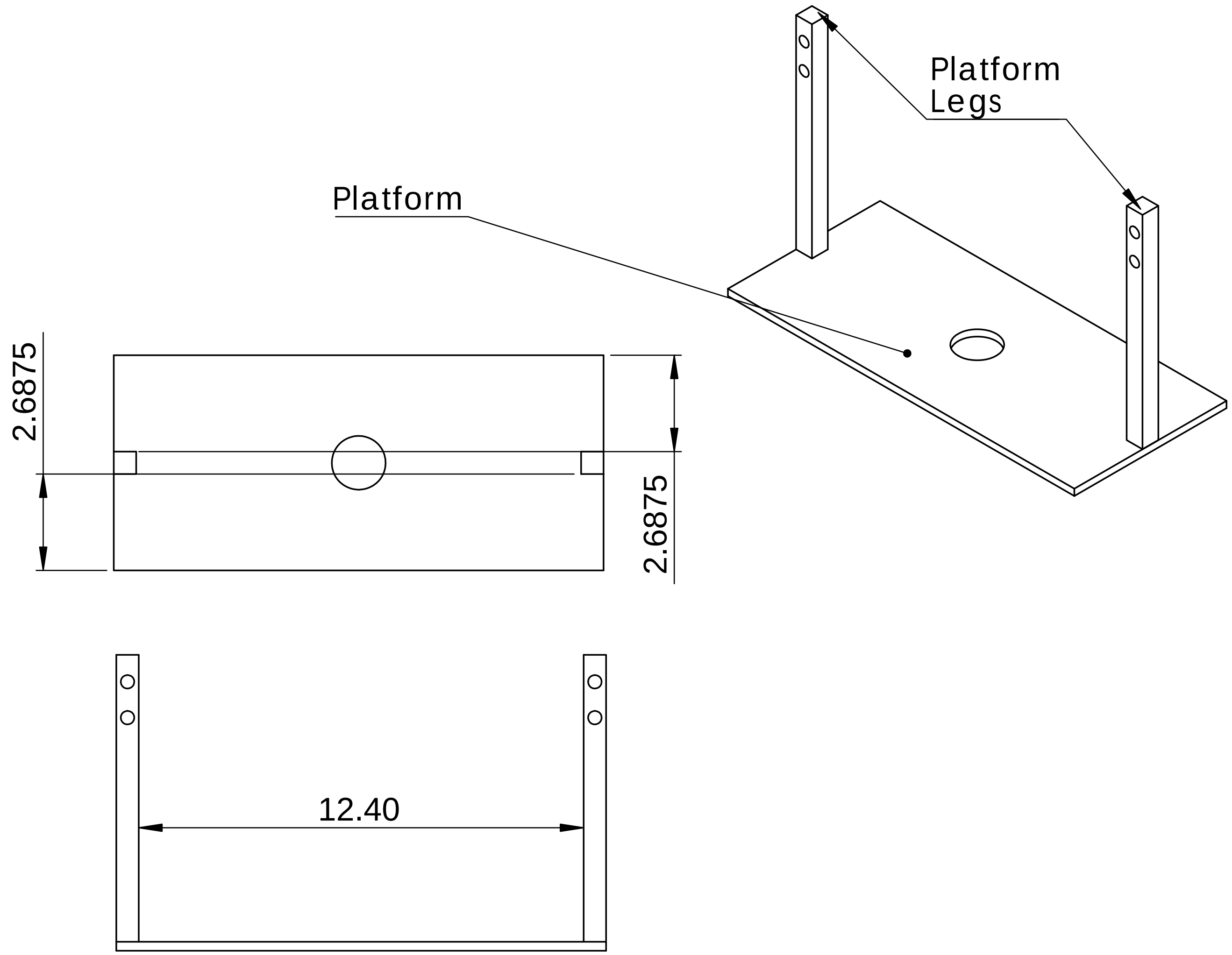

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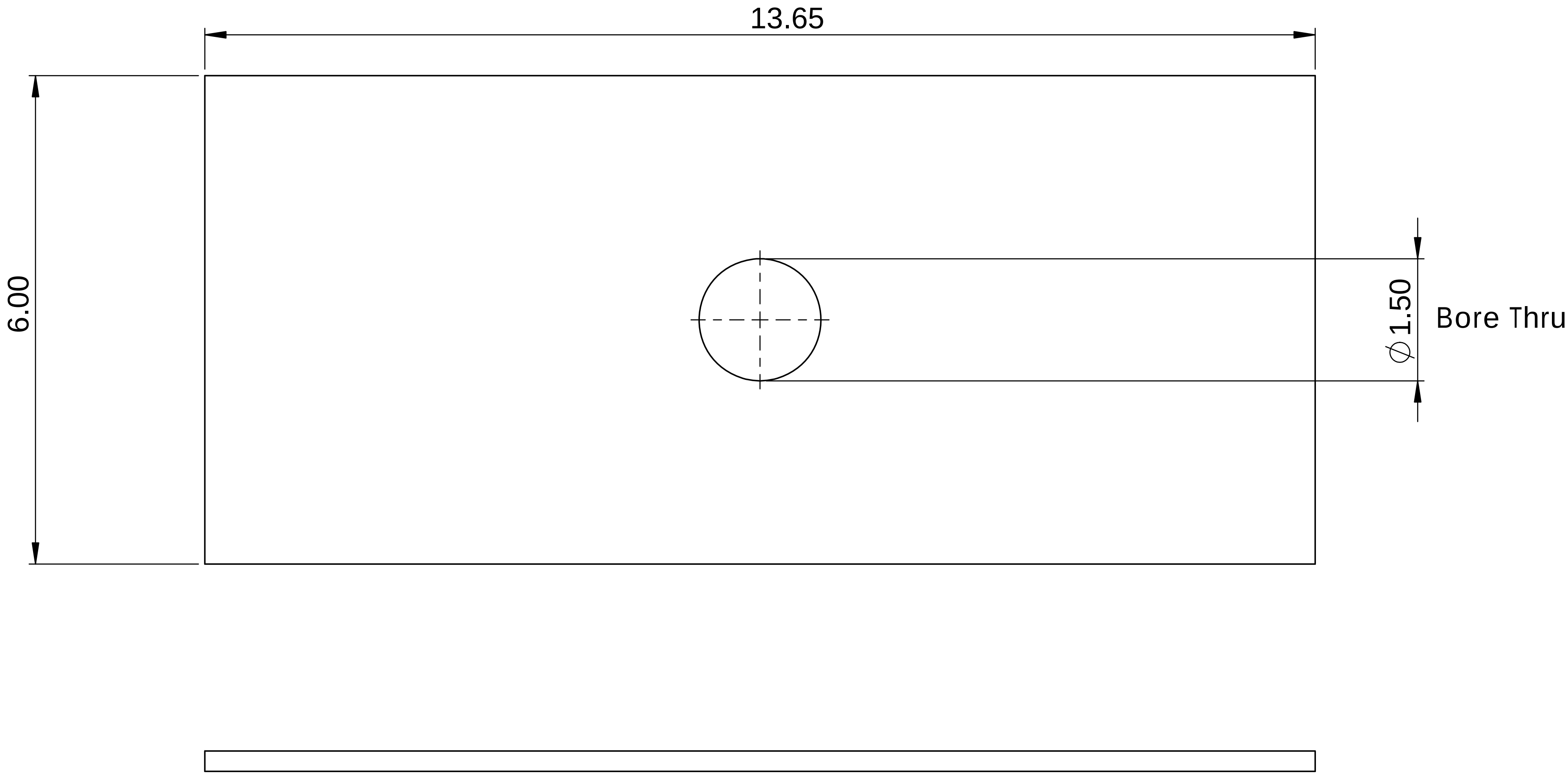

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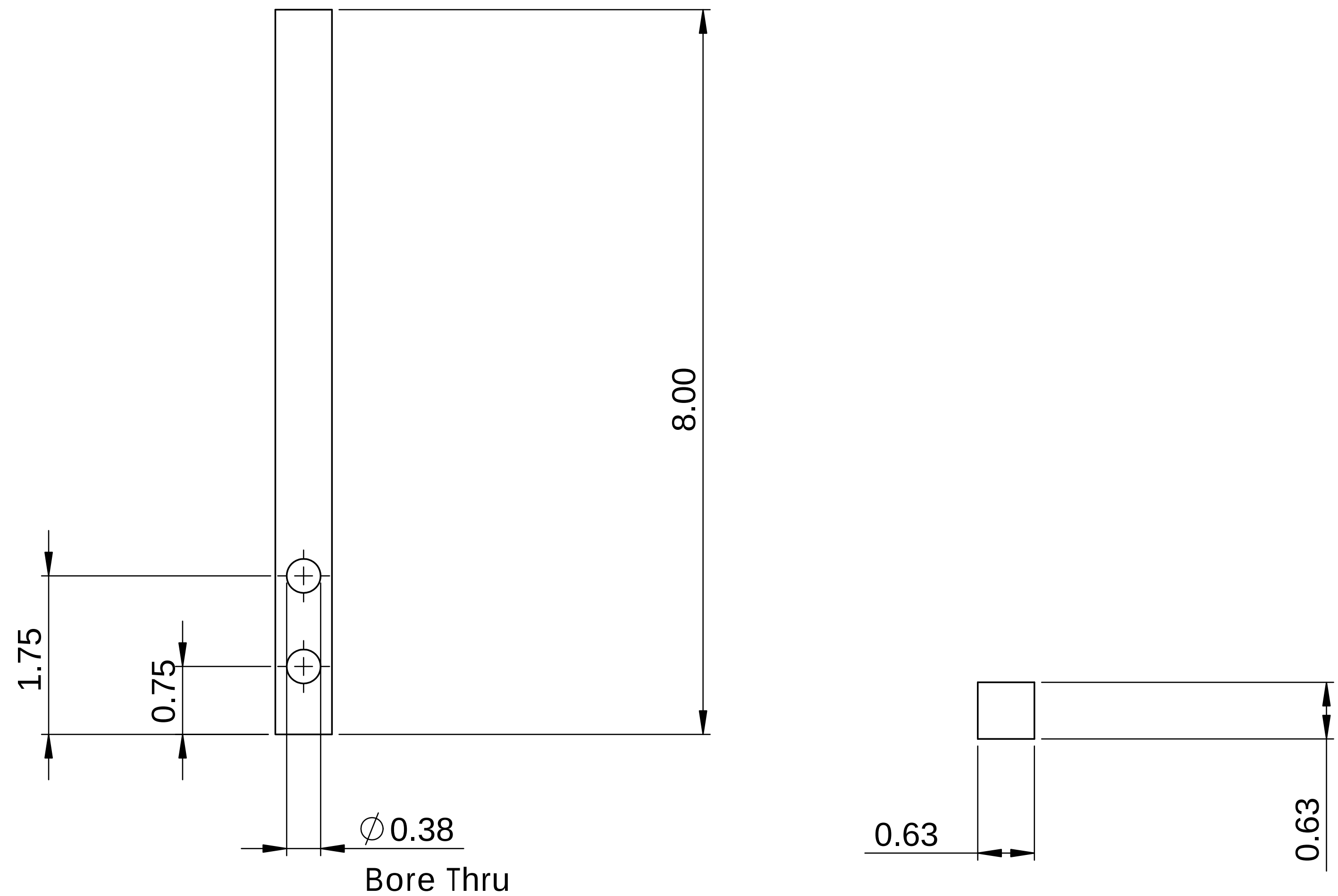
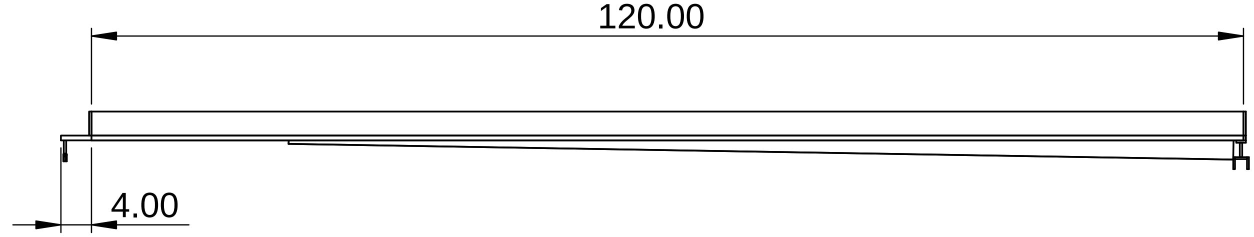
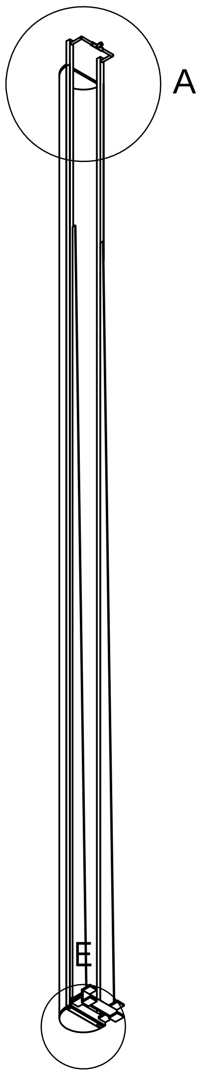
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A | DWG. NO. Platform | REV
FINISH				
DO NOT SCALE DRAWING				WEIGHT: | SHEET 2 OF 3

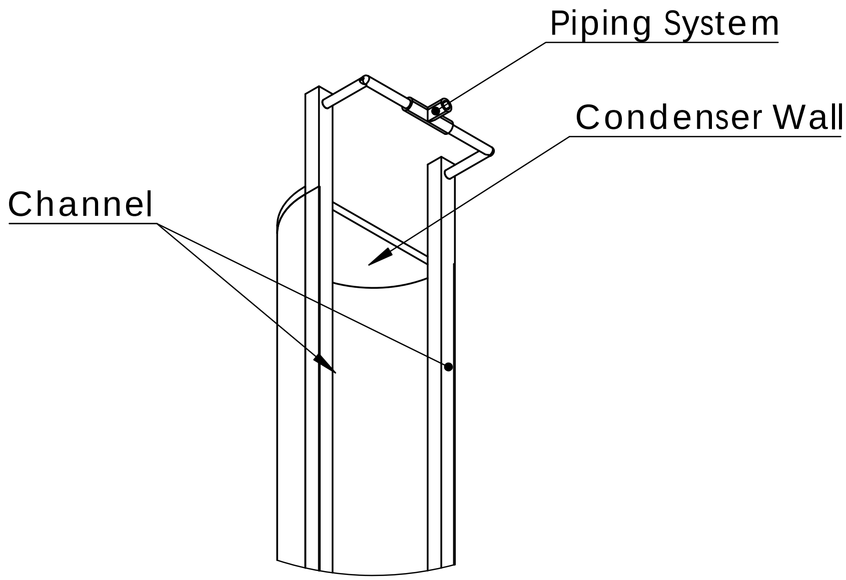


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A / DWG. NO. Platform Legs / REV
FINISH				
DO NOT SCALE DRAWING				WEIGHT: / SHEET 3 OF 3

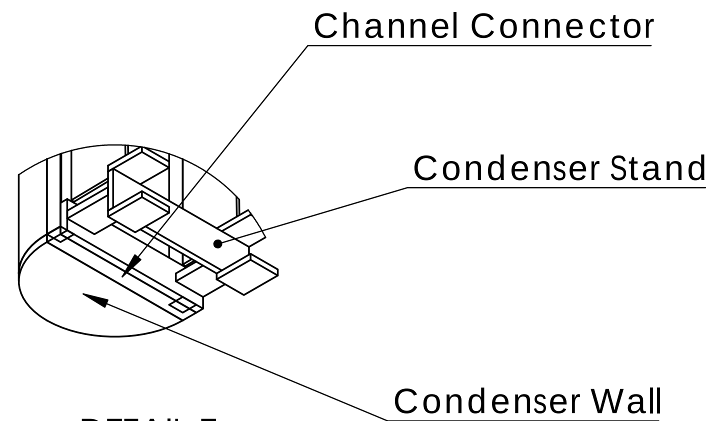
All Dimension in Inches
Needs Sheet metal







DETAIL A
SCALE 1 : 5

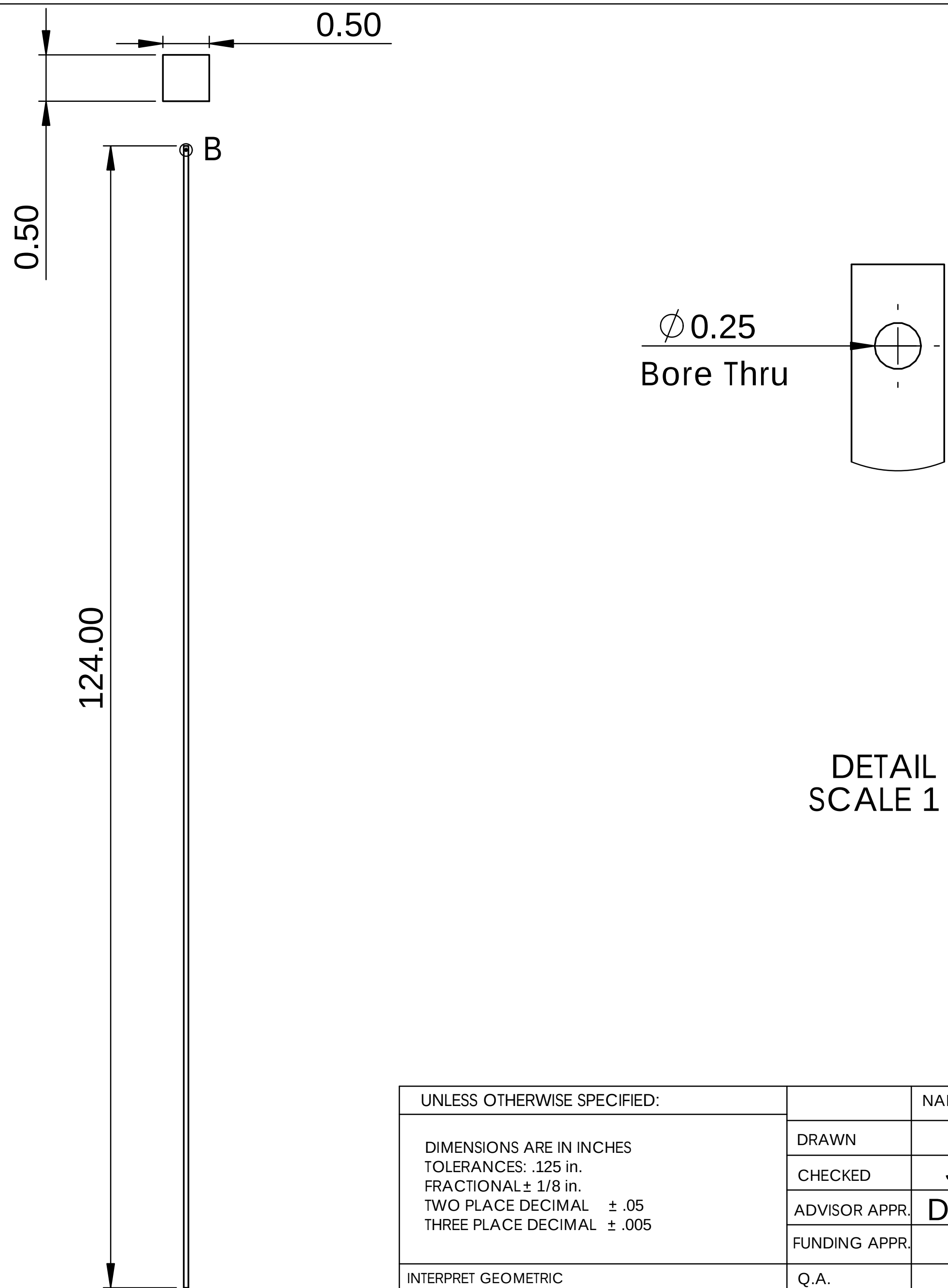


DETAIL E
SCALE 1 : 5

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer	
	CHECKED	Joseph Hamel	
	ADVISOR APPR.	Dr. Shangchao Lin	
	FUNDING APPR.	Crystal Wells	
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo	
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

Team 7		
TITLE:		
SIZE A	DWG. NO. Condenser	REV
	WEIGHT:	SHEET 1 OF 6

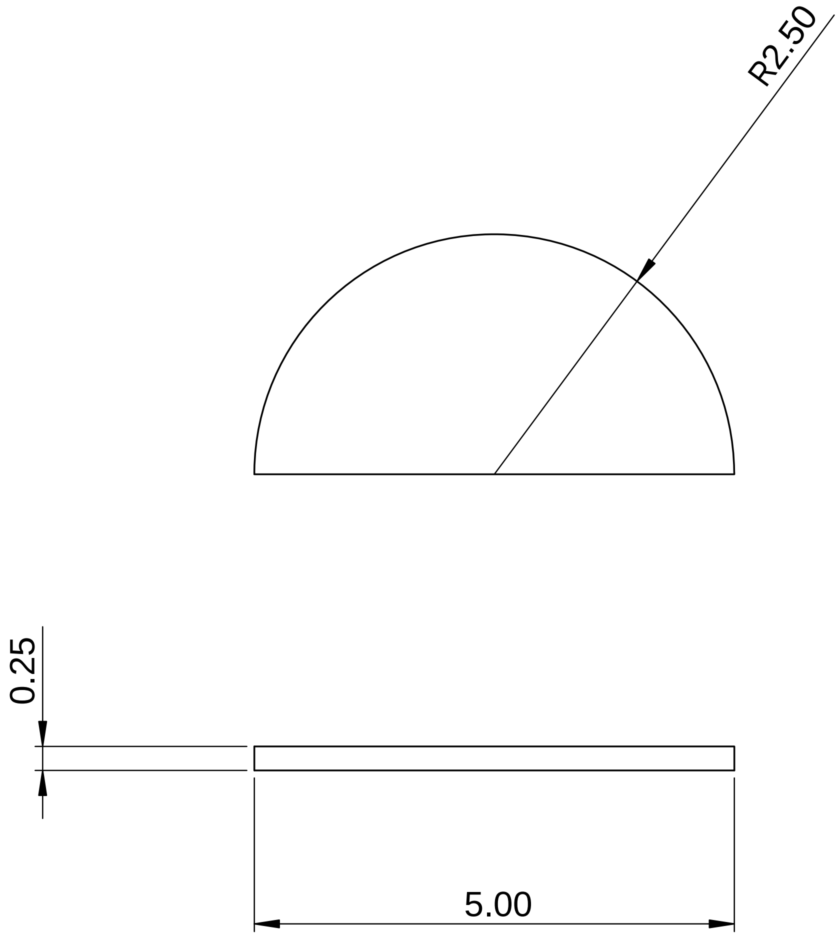
Material Suppled
Need 2



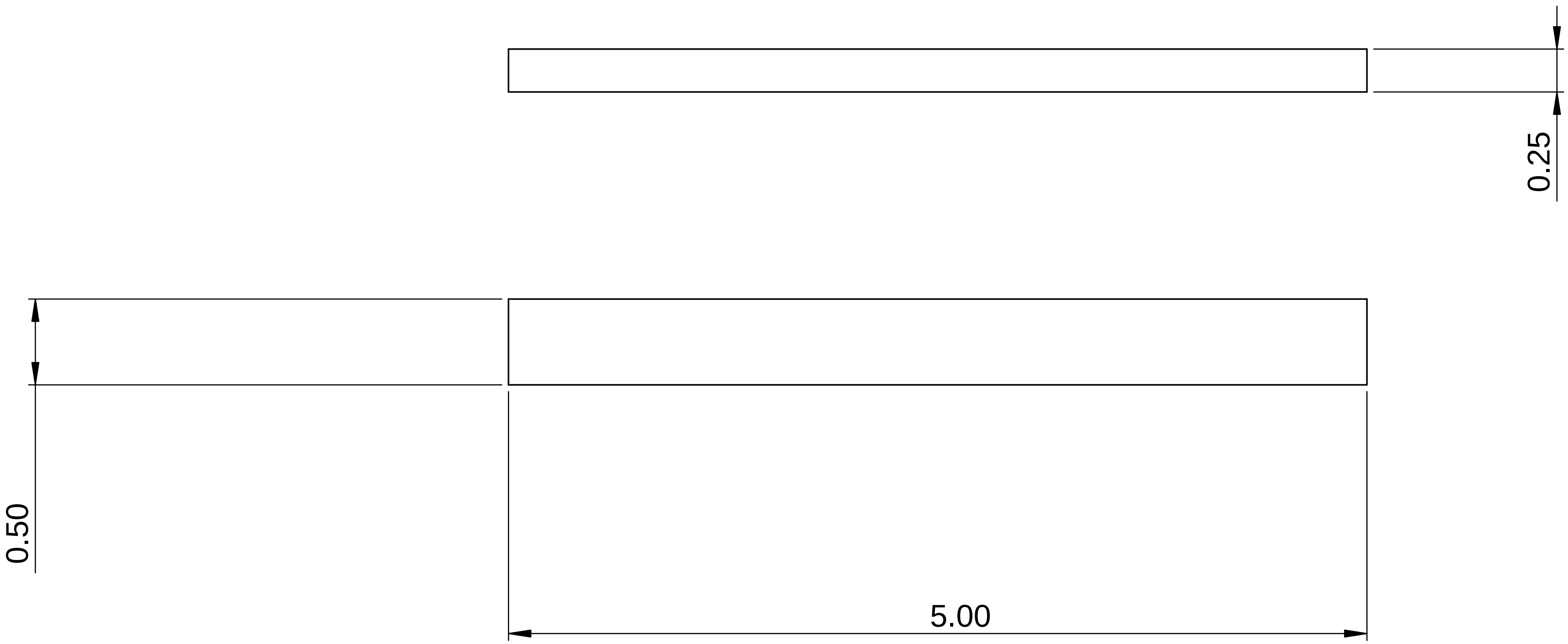
DETAIL B
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A — DWG. NO. Channel — REV
FINISH				WEIGHT: — SHEET 2 OF 6
DO NOT SCALE DRAWING				

Need 2



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A | DWG. NO. Condenser Wall | REV
FINISH				
DO NOT SCALE DRAWING				WEIGHT: | SHEET 3 OF 6



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: .125 in.
FRACTIONAL ± 1/8 in.
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Alex Stringer	
CHECKED	Joseph Hamel	
ADVISOR APPR.	Dr. Shangchao Lin	
FUNDING APPR.	Crystal Wells	
Q.A.	Alex Filardo	

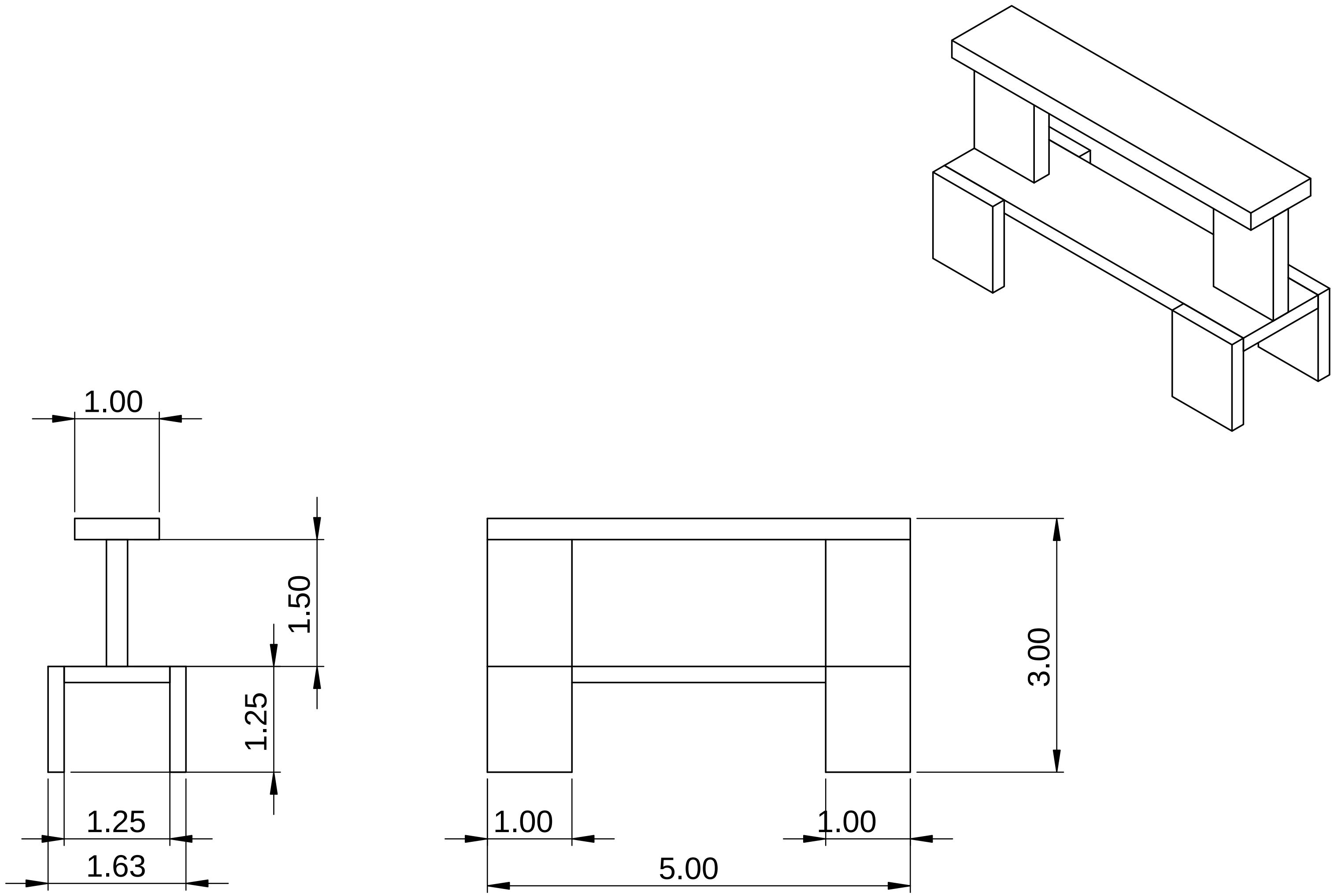
COMMENTS:

Team 7

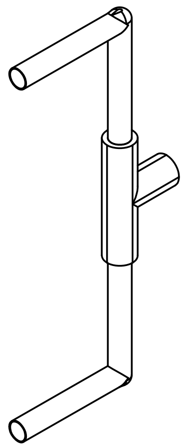
TITLE:

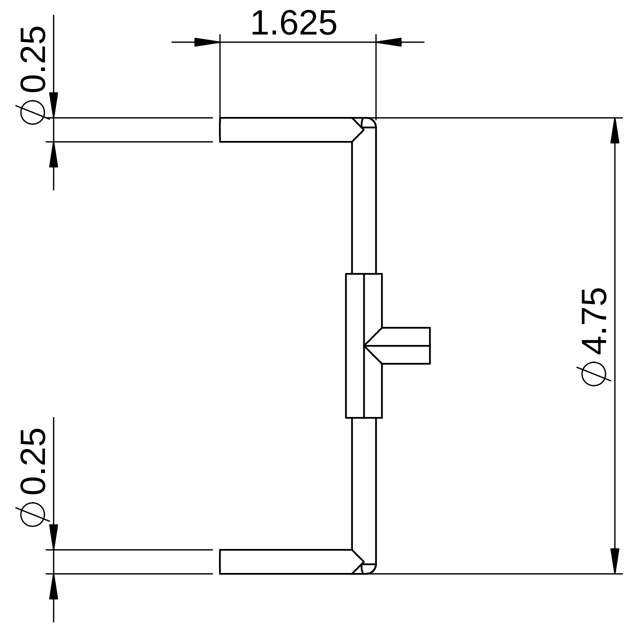
SIZE A | DWG. NO. Channel Connetor | REV

WEIGHT: | SHEET 4 OF 6



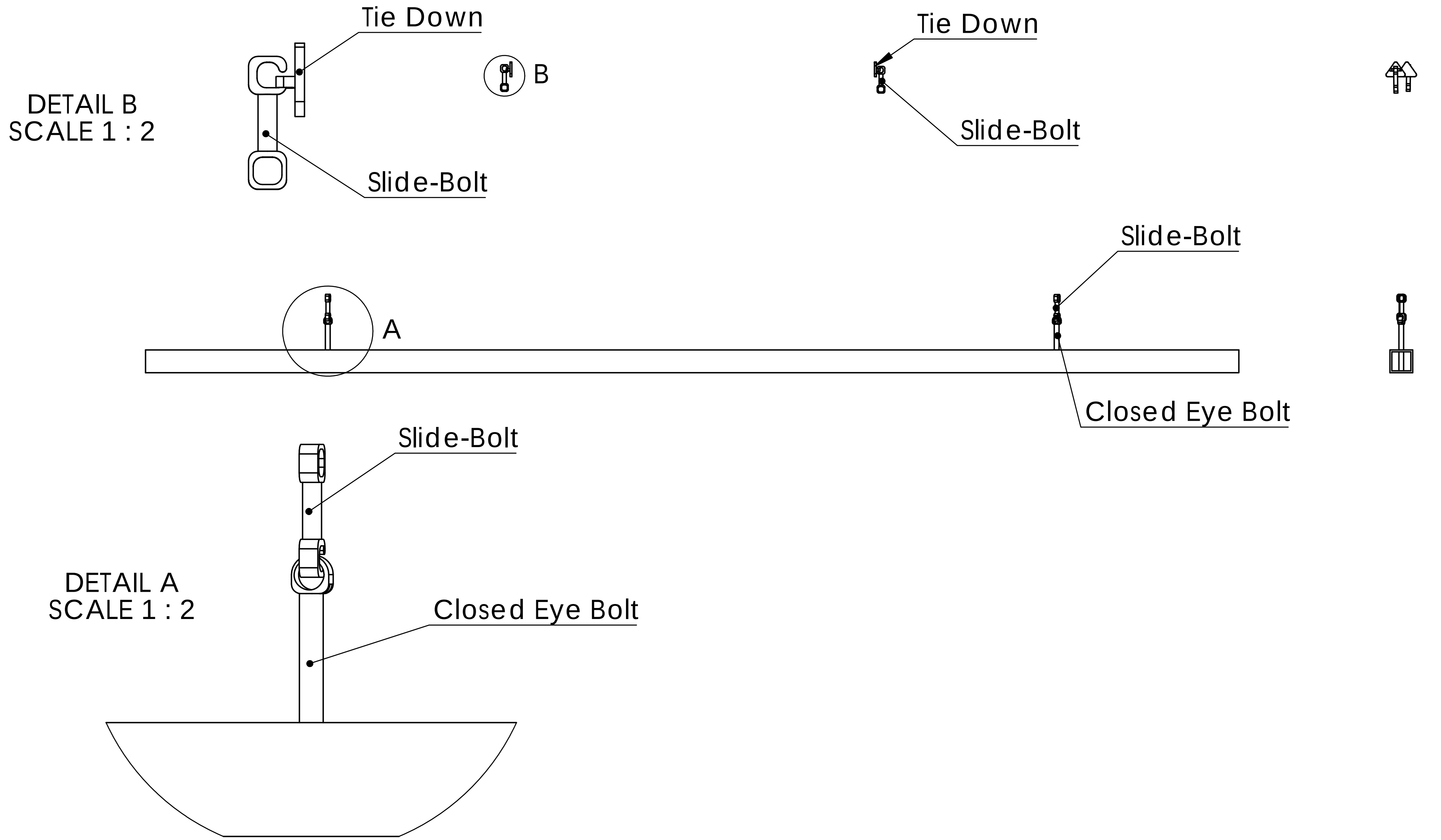
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A — DWG. NO. Condenser Stand — REV
FINISH				
DO NOT SCALE DRAWING				WEIGHT: — SHEET 5 OF 6



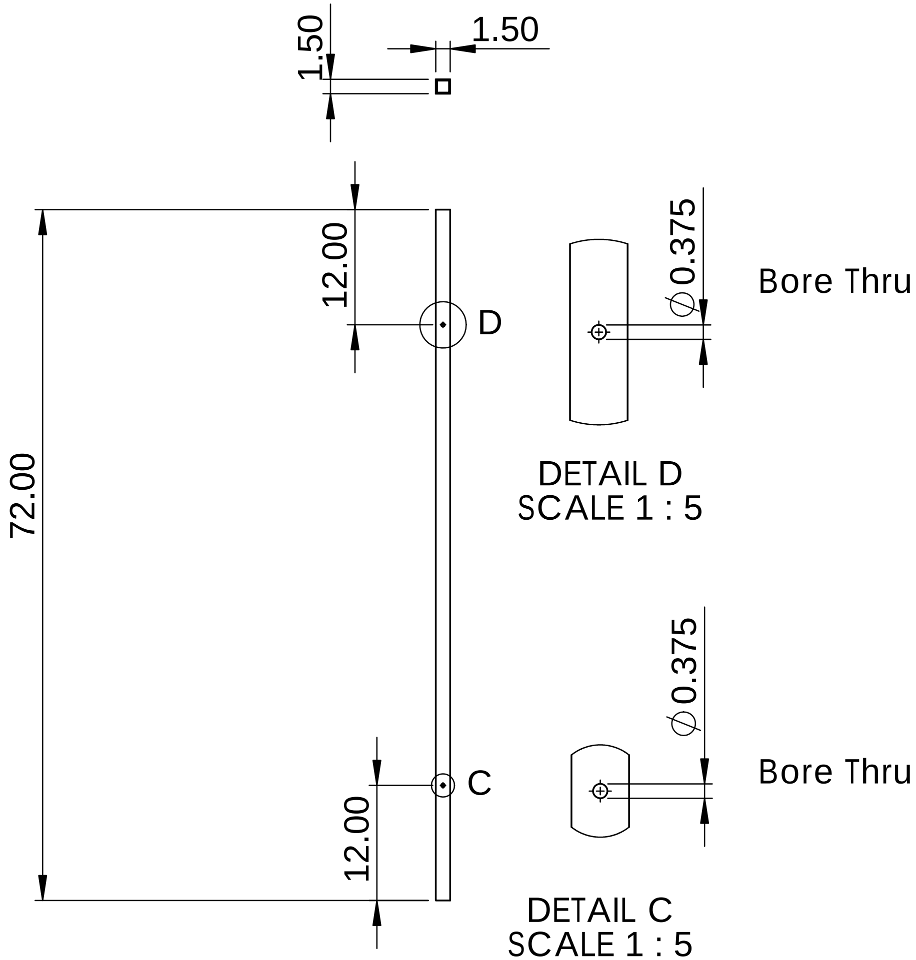


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer	
	CHECKED	Joseph Hamel	
	ADVISOR APPR.	Dr. Shangchao Lin	
	FUNDING APPR.	Crystal Wells	
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo	
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

Team 7			
TITLE:			
SIZE A	DWG. NO. Piping System		REV
	WEIGHT:	SHEET 6 OF 6	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A · DWG. NO. Sun Tracking · REV
FINISH				WEIGHT: · SHEET 1 OF 2
DO NOT SCALE DRAWING				



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Team 7
DIMENSIONS ARE IN INCHES TOLERANCES: .125 in. FRACTIONAL ± 1/8 in. TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	Alex Stringer		TITLE:
	CHECKED	Joseph Hamel		
	ADVISOR APPR.	Dr. Shangchao Lin		
	FUNDING APPR.	Crystal Wells		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	Alex Filardo		
MATERIAL	COMMENTS:			SIZE A · DWG. NO. Sun Tracking Bar · REV
FINISH				
DO NOT SCALE DRAWING				WEIGHT: · SHEET 2 OF 2

Appendix B Calculations

Solar Insulation

Before atmospheric affects: $S = 1347\frac{W}{m^2}$

After atmospheric affects at the equator: $S = 1000\frac{W}{m^2}$

The values changes with latitude (θ): $S_\theta = \left(1000\frac{W}{m^2}\right)cos\theta$

Local Solar Insulation for Tallahassee:

Latitude: $\theta = 30°$

$$S_\theta = 1000cos(30°)\frac{W}{m^2} = 866\frac{W}{m^2}$$

$$S_\theta = \left(866\frac{W}{m^2}\right)\left(\frac{0.3171\frac{Btu}{h*ft^2}}{1\frac{W}{m^2}}\right) = 274.6\frac{Btu}{h*ft^2}$$

$$S_\theta = 274.6\frac{Btu}{h*ft^2}$$

Reflective Surface Area

Solar Sausage dimensions:

Length: L = 10ft

Diameter: D = 3ft

- Unobstructed Reflective Surface Area:

$$A_{surface} = LD = (3ft)(10ft) = 30ft^2$$
$$A_{surface} = 30ft^2$$

- Obstructed Area:

The condenser obstructs the solar sausage bottom dimension:

Width: $w = \frac{5}{12}ft$

The maximum surface obstructed by the condenser is:

$$A_{obstructed} = (10ft)\left(\frac{5}{12}ft\right) = 4ft^2$$
$$A_{obstructed} = 4ft^2$$

- Total Reflective Surface Area:

$$A_{reflective} = A_{surface} - A_{obstructed} = 30ft - 4.17ft = 25.83ft^2$$

$$A_{reflective} = 25.83ft^2$$

Heat Delivered to Trough

The Solar Sausage has 3 points of loss

- ~16% loss when entering the project, $\eta_{entering}$
- ~10% reflective membrane, $\eta_{reflective}$
- ~12% loss when exiting the membrane, $\eta_{exiting}$

Therefor the heat delivered to the trough:

$$\dot{Q} = (S_\theta)(A_{reflective})(1 - \eta_{entering})(1 - \eta_{reflective})(1 - \eta_{exiting})$$

$$\dot{Q} = \left(274.6\frac{Btu}{h * ft^2}\right)(25.83ft^2)(1 - 0.16)(1 - 0.1)(1 - 0.12) = 4943.48\frac{Btu}{h}$$

$$\dot{Q} = 4943.48\frac{Btu}{h}$$

<u>Maximum Evaporation Rate</u>

We assume that water source provides saline water at temperature:

$$T_{source} = 77°\text{F} = 25°\text{C}$$

The maximum temperature the body of water will be allowed to achieve is:

$$T_{max} = 221°\text{F} = 105°\text{C}$$

The enthalpy of evaporation at 221°F:

$$h_{fg@105°\text{C}} = 2243.1\frac{kJ}{kg}$$

$$h_{fg@221°\text{F}} = \left(2243.1\frac{kJ}{kg}\right)\left(\frac{0.430\frac{Btu}{lbm}}{1\frac{kJ}{kg}}\right) = 964.533\frac{Btu}{lbm}$$

$$h_{fg@221°\text{F}} = 964.533\frac{Btu}{lbm}$$

The maximum evaporation rate can be calculated using the heat input to the trough and the enthalpy:

$$\dot{Q} = \dot{m}_{evap}h_{fg@221°\text{F}}$$

$$4943.48\frac{Btu}{h} = \dot{m}_{evap}(964.533\frac{Btu}{lbm})$$

$$\dot{m}_{evap} = \frac{4943.48\frac{Btu}{h}}{964.533\frac{Btu}{lbm}} = 5.125\frac{lbm}{h}$$

$$\dot{m}_{evap} = 5.125\frac{lbm}{h}$$

Appendix C Budget

Table 1: Stand cost per part breakdown

Stand Cost		
Part	# Needed	Cost
Leg	2	$ 26.40
Upper Cross Bar	1	$ 5.50
Lower Cross Bar	1	$ 5.50
Circle Hook	1	$ 1.98
L-Plate	4	$ 14.00
Nuts and Bolts	16	$ 5.12
	Total	$ 58.50

Table 2: Trough cost per part breakdown

Trough Cost		
Part	# Needed	Cost
Trough Channel	2	$ 54.78
Trough Wall	2	$ 7.00
Labor	45 min.	$ 60.00
	Total	$ 121.78

Table 3: Trough cost per part breakdown

Storage Tank Cost		
Part	# Needed	Cost
Bucket	1	$ 13.40
Ball Valve	1	$ 40.43
Platform	1	$ 38.66
	Total	$ 92.49

Table 4: Condenser cost per part breakdown

Condenser Cost		
Part	# Needed	Cost
Condenser Channel	2	$ 23.85
Condenser Wall	2	$ 8.38
Stand	1	$ 16.77
Channel Connector	2	$ 8.38
Condenser Hood	1	$ 20.00
Labor	150 min.	$ 120.00
	Total	$ 197.38

Table 5**:** Solar Sausage cost per part breakdown

Solar Sausage Cost		
Part	# Needed	Cost
Solar Sausage Cost	1	$ 10.00
Foot Pump	2	$ 21.98
Pressure Gauges	2	$ 120.00
Needle Valve	2	$ 40.60
Barstock Tee	2	$ 14.10
Sun Tracking Bar	1	$ 45.87
Adhesive-Backed	2	$ 22.00
Steel Wire Rope Clamps	4	$ 14.12
Closed-Eye Bolts	2	$ 3.92
Stainless Steel Wire Rope	1	$ 26.50
Slide-Bolt Spring	4	$ 7.52
	Total	$ 326.61

Table 6: Spending Overview

Spending Overview		
Category	Spent ($)	% of Budget*
Raw Materials	$ 464.85	9.30%
Accessories	$ 592.84	11.86%
Testing Supplies	$ 247.93	4.96%
Labor	$ 180.00	3.60%
Total	**$ 1,485.62**	**29.71%**
**Out of a budget of $5,000*		
Funds Available		$ 3,514.38

Table 7: Overall Component Cost Per Part

Cost Per Part			
Part	Cost/Part	# Needed	Total Cost
Stand	$ 58.50	2	$ 117.00
Trough	$ 121.78	1	$ 121.78
Storage Tank	$ 92.49	1	$ 92.49
Condenser	$ 197.38	1	$ 197.38
Solar Sausage	$ 326.61	1	$ 326.61
		Total	$ 855.26

Table 8**:** Cost of Raw Materials

Raw Materials				
Date	Item	Component	Quantity	Total Cost ($)
12/15/2014	Aluminum Angle 6063T5	Condenser	1	$ 7.22
12/15/2014	ALUMINUM SQUARE BAR 6061T6	Spike	4	$ 14.48
12/15/2014	ALUMINUM PLATE 3003H14	Stand/Trough	1	$ 84.07
12/15/2014	ALUMINUM CHANNEL 6063T5	Trough	2	$ 54.78
12/15/2014	ALUMINUM PLATE 6061T6	Condenser	1	$ 33.53
12/15/2014	ALUMINUM TUBE SQUARE 6061T6	Cross Bars	4	$ 21.99
12/15/2014	ALUMINUM TUBE SQUARE 6061T6	Legs	4	$ 52.79
12/15/2014	Aluminum Channel	Condenser	3	$ 23.85
12/15/2014	High-Strength Grade 8 Steel Cap Screw	Assembly	50	$ 9.66
12/15/2014	Zinc Aluminum Coated Steel Hex Nut	Assembly	50	$ 6.74
2/19/2015	Aluminum Round Bar 6061T6	Spike	4	$ 19.31
2/19/2015	Aluminum Plate 6061T6	Spike	4	$ 34.20
2/19/2015	ALUMINUM SQUARE BAR 6061T6	Storage Tank	2	$ 10.91
2/19/2015	ALUMINUM PLATE 6061T6	Storage Tank	1	$ 27.75
3/5/2015	1/2" Copper Pipe	Storage Tank	1	$ 4.73
3/5/2015	1/2" Copper Male Adapter	Storage Tank	1	$ 1.46
3/5/2015	1/2" Brass Pipe Nipple	Storage Tank	1	$ 4.17
3/5/2015	5/8" Flare Nut	Storage Tank	1	$ 3.64
3/5/2015	O-Ring	Storage Tank	10	$ 2.27
3/5/2015	1/2" 90 degree Elbow	Storage Tank	1	$ 1.43
3/25/2015	Rectangular Tubes—Unpolished,	Solar Sausage	1	$ 45.87
Raw Materials Total Cost $				**$ 464.85**

Table 9: Cost of Accessories

Accessories				
Date	Item	Component	Quantity	Total Cost ($)
12/15/2014	3M VHB Foam Tape	Solar Sausage	1	$ 190.60
2/19/2015	Black Rubber Hammer	Construction	1	$ 17.45
2/19/2015	High-Temperature Paint, Aerosol	Trough	1	$ 8.34
2/19/2015	NSF-Certified Brass Ball Valve	Storage Tank	1	$ 11.60
2/19/2015	Stainless Steel Coating, High Temp, Aerosal	Trough/Condenser	2	$ 35.34
3/5/2015	Easy-Set Polyester Needle Valve	Pressure Regulation	2	$ 40.60
3/5/2015	UN-Compliant Plastic Shipping Pail, 5 Gallon	Storage Tank	1	$ 13.40
3/5/2015	Wilmar W1638DB Foot Pump	Solar Sausage	2	$ 21.98
3/5/2015	Brass Hose Fitting, Adapter	Solar Sausage	2	$ 6.32
3/5/2015	1/8" ID Hose Barb Tee T Union	Solar Sausage	2	$ 10.12
3/5/2015	Brass Pipe Fitting, Barstock Tee	Solar Sausage	2	$ 14.20
3/5/2015	Low Pressure Gauge 3 PSI	Solar Sausage	2	$ 120.00
3/25/2015	Adhesive-Backed Tie-Down Rings	Solar Sausage	2	$ 22.00
3/25/2015	Low-Profile Stainless Steel Wire Rope Clamps One Bolt	Solar Sausage	4	$ 14.12
3/25/2015	Closed-Eye Routing Eyebolts	Solar Sausage	2	$ 3.92
3/25/2015	Plastic-Coated Stainless Steel Wire Rope Flexible 7 × 7—Strand Core .125" Diamter	Solar Sausage	1	$ 26.50
3/25/2015	Slide-Bolt Spring Snaps,	Solar Sausage	4	$ 7.52
3/25/2015	Thru-Wall Fitting for Drinking (Potable) Water	Storage Tank	1	$ 28.83
Accessories Total Cost ($)				**$ 592.84**

Table 10: Cost of Required Testing Supplies

Testing Supplies				
Date	Item	Component	Quantity	Total Cost ($)
2/11/2015	Pistol-Grip Infrared Thermometer	Trough	1	$ 97.88
2/19/2015	Heat-Resistant Glove	Trough	4	$ 15.64
3/5/2015	Graduated Plastic Beaker	Storage Tank	1	$ 19.88
3/5/2015	Salinity, Conductivity, TDS Meter	Water	1	$ 114.53
			Testing Supplies Total Cost ($)	**$ 247.93**

Table 11: Cost of Labor

Labor					
Date	Service	Company	Rate ($/hr)	Hours	Cost
2/11/2015	Welding	Tallahassee Welding	80	0.75	$ 60.00
4/7/2015	Welding	Tallahassee Welding	80	1.5	$ 120.00
				Labor Total Cost ($)	**$ 180.00**