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Project Omoverhi : low-cost, neonatal incubator

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Project Omoverhi

LOW-COST, NEONATAL INCUBATOR

by

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SENIOR DESIGN PROJECT REPORT

Submitted in partial fulfillment of the requirements
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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED

Project Omoverhi: Low-Cost, Neonatal Incubator

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Abstract

Project Omoverhi, since its beginning in 2010-2011, has been focused on creating an incubator that has the capability of operating completely off grid. This year the project has been focused on redesigning the original system to reduce the cost to approximately $1000. In addition to this we have designed and implemented a control system that enables the user to set a desired temperature which can be maintained to within 1 degree Celsius. Before the project is able to be completed further work must be done. The thermal storage system that was initially proposed by the original team still needs to be completed. Additionally the current prototype needs to be further tested and worked into a product that can easily be manufactured. Once the project is completed, hopefully it can be taken up by a non-profit organization to allow this product to be distributed to those in need of it.

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Chapter 1: Introduction

1.1 Project Background

Project Omoverhi aims to design and produce an incubation system that is capable of being operated on or off grid. The name Omoverhi was chosen by the founding team because it means lucky child in Urahobo, a native language of Nigeria. The idea behind this name is that one does not need to be lucky to survive; every infant has the right to survive and grow up. This system is going to help make this dream a reality.

An incubator is an advanced medical device. Intensive care units are for preterm and premature infants as well as for any infant with a low birth weight. Premature infants require specialized treatment due to the lack of maturity in their vital organs. Preterm infants are infants who are born before 37 weeks of gestation. While hospital grade incubators are capable of treating both premature and preterm infants, an Omoverhi Incubator is primarally intended for use by preterm infants. According to the World Health Organization, 15 million preterm infants are born annually around the world. Deaths predominantly occur in remote locations in developing countries such as Nigeria, India and Indonesia. 75% of the preterm deaths are due to inadequate care and complications that can be avoided by using cost effective interventions such as a simple incubator.

Preterm infants are at risk because their skin and fat layers have not developed to the appropriate thickness. These layers of skin and fat allow the infant to absorb and maintain body heat. These infants need a constant temperature environment of 37 degrees Celsius because of the inability of the infant to retain heat (Staff). Along with the ability of the incubator to provide a constant temperature environment, the incubator would ideally have the ability to run off grid, free from electricity. Most countries have some form of electrical system; however, many are insufficiently reliable to provide consistent power all day, and large areas of the world have no electrical connection at all. Having the ability to run off-grid means the incubator can always have a constant power supply. In time of off grid use, photovoltaic (PV) panels and thermal collectors provide the electricity and heated water to the system, giving the infant a suitable environment in which to develop.

Omoverhi’s inexpensive, easily maintained and capable of running off grid design is ideal for operating in small scale clinics in areas where electricity is not readily available. Refugee camps are another location where the Omoverhi incubator would be useful.

1.2 Project Motivation

According to the World Health Organization (WHO), an estimated 15 million infants worldwide are born preterm every year. Of these, more than 1 million die, often due to complications that could be avoided by use of simple intervewntions, such as keeping the infnat warm for the first several weeks of life. The five countries with the highest number of preterm births are as follows in ascending order: Indonesia, Pakistan, Nigeria, China, and India with the most at over 3 million in 2010 (Preterm Birth). Although these countries have well developed medical systems, not everyone has access to them, many people are too poor to afford the care, and others live in locations far removed from any form of medical facility. In these cases preterm birth can be a death sentence, unless an alternative method of care is available.

1.3 Overview of Field

Currently there are incubators and methods of infant care that can be employed in locations with limited to no medical infrastructure available. There are already many designs for infant incubators for use in regions where medical care is hard to come by. The Neonurture incubator has gathered attention lately because of the parts being from a 1986 Toyota 4Runner. It is designed to be very effective as well as easy to repair and maintain by using car parts as the operating machinery of the system. These systems works very well but are expensive, making them difficult to sell to the countries that need but cannot afford them, unless otherwise donated. Another incubation system, designed to be as inexpensive as possible, is known as the HEBI. This system incorporates a simple wood structure with a large incandescent light bulb which provides the heat to the infant. It provides the infant with the necessary heat but has very limited temperature control since the only way to adjust the temperature is with an on-off switch. In desperate situations where none of the aforementioned incubation systems are present, a method known as kangaroo care must be employed to ensure the infant survives. This method involves the infant's mother carrying the infant at her breasts constantly for weeks, until the infant is strong enough to survive on its own. This method is often the only way that mother's can keep their infants alive. However, since it involves constant care on the mothers part they are unable to do anything except tend to the infant around the clock. In situations where the mother must work, on a form or other job, the whole family or even village can suffer if she is unable to work for up to several weeks.

1.4 Project Objectives

The overall objective of Project Omoverhi is to provide an inexpensive incubation system that is capable of operating both on and off grid. Our system is designed to be a simple, affordable incubation system with the capability of running completely off grid, using only a solar thermal system and a small photovoltaic panel for the necessary power. The charter Omoverhi team in 2010-2011 set out to validate their conceptual design by proving that an incubation system can work using a water-based heat exchanger as the heat source. The 2011-2012 team worked to design a thermal energy energy storage system; this energy would enable the system to work when there is little or no sunlight. The 2011-2012 team was unable to design a thermal storage system that worked efficiently enough for use in the incubation system due to unforeseen issues with the solidification of the PCM (Phase Change Material) that they employed. The goal for our team was to redesign the 2010-2011 system to be easily assembled, inexpensive (under $1000), and outfitted with an integrated control system. The incubator needed to be able to meet the requirements vital for preterm infant care as well as be assembled with environmentally responsible materials.

Chapter 2: Customer Needs

2.1 Industrial Standards

Medical devices have very stringent sets of standards to ensure a high level of quality for all devices that are to be used in a medical capacity. The United States Food and Drug Administration (FDA), is the primary government agency that guarantees the safety and effectiveness of any food or medical product used in the U.S. The agency's approval is required in order to get any medical device into use in a United States hospital. More specialized agencies such as the Association for the Advancement of Medical Instruments (AAMI), provide detailed guidelines and specifications for the manufacture of medical devices. When these standards were attempted to be retrieved, it was discovered that they needed to be purchased as is the case for many industrial standards. Since we were operating on a limited budget, the decision was made to ask United States medical professionals involved in neonatal infant care what the needs of an incubation system are. We received a very detailed and helpful response from Dr. David Campbell, the head Bio-Engineer for medical equipment at San Joaquin General Hospital. He informed us, among many things, that the most vital part of any incubation device is temperature regulation. Dr. Campbell also told us that airflow is very important. If the airflow is too low, the air stagnates, and if too high, increased convection over the infant's underdeveloped skin lowers the infant's internal temperature. He provided us with an upper limit to airspeed over the infant of 8 cm/sec. He also described how the humidity level has a significant impact on the infant's internal temperature. In order to control the humidity level, many systems, even high end models, use methods such as swamping, which if improperly maintained, present a significant risk of bacterial colonization. Based on this and additional information provided to us by David Campbell, which can be seen in Appendix B, we were able to create requirements for our own design. Limits such as: (1) a maximum airspeed of 8 cm/s over the infant, (2) the transient response of the system to return to equilibrium to be under 15 minutes, (3) and the ability for the incubator's internal temperature to be adjusted by a caretaker. These were very helpful in the design process, giving us goals that our incubator would need to achieve.

2.2 Customer Report

The 2010-2011 Omoverhi team contacted Dr. Amina Bello and Dr. Olukemi Tongo, both of whom work in Nigerian hospitals. Our team also contacted them and asked asking for specific information on what they believe to be the most essential parts of an incubation device. These two doctors expressed a definite need for a solar powered incubation system. One of the doctors, Dr. Bello, works in a university hospital and said that their hospital experiences power outages of several hours on a daily basis. Dr. Tongo who works in a more remote hospital said that the majority of their power comes from generators and that they are lucky to receive a few hours of power from the national grid per day. The exact information recieved from these contacts can be found in Appendix B for additional reference.

2.3 User Scenario

The system is intended to use a small amount of energy which can be provided by two medium efficiency solar panels and a thermal collector. The excess energy gained from the solar panels would charge the energy backup system, a 35 Ah battery; while heat would be provided by the solar thermal collector. This system is also be capable of working on grid with an energy backup system to account for the often frequent power outages that are a problem for hospitals in countries such as Nigeria. The on grid system would operate with basic grid power reduced to 12 volts to power the control system and additional power for a water heater. This heat could ideally be stored in a PCM which would maintain a constant temperature of water being input to the system.

The actual operational interface of the system needed to remain as simple as possible to ensure that the end user will be able to operate the system even with limited technical expertise. A doctor would be able to specify a temperature for the infant to mature properly and set it on the interface panel without need to constantly check on the infant’s temperature. A reliable temperature control system would allow the doctor to more easily attend to multiple patients.

Chapter 3: Goals and Restrictions

3.1 System Goals

The goals that we had going into this project were: (1) to reduce the cost of the finished product from $3000 to approximately $1000 (which did include the cost of energy sources) and (2) to improve the existing design by making it simpler to operate by adding a control system. We attempted to accomplish these goals by redesigning the existing system. We set operational goals to guide our design of the system, with the primary of these being the ability of the system to maintain the needed 37 degrees Celsius as governed by the medical needs of the infant. Medical devices engineered according to the United States medical standards are capable of maintaining this temperature to within +/- 0.5 degrees Celsius. Our system however will not be able to maintain the temperature this precisely. In order to set a realistic goal with respect to temperature control while maintaining our goal of keeping the cost below $1000, we proceeded with a realistic goal of maintaining the temperature within +/- 2 degrees Celsius. In addition to the goals of maintaining the temperature and keeping the cost of the system low, the electrical draw of the system needs to be as low as possible to allow for off-grid operation of the system.

3.2 Medical Concerns

3.2.1 Ventilation

Ventilation is necessary to provide the patient with fresh air and sufficient oxygen. Flowing air is also necessary to provide sufficient transfer of heat from the heat source to the shell environment and the patient (Campbell). The ventilation needs to be carefully managed so that there is enough fresh air and convective heat transfer over the heat exchanger, but the flow is not so fast that it makes the patient uncomfortable and causes an increase in heat loss of the incubation system to the outside environment.

3.2.2 Humidity

The humidity of the shell environment can negatively affect the patient if it is not at a healthy level. Infants can lose moisture and heat by evaporation if humidity is too low, while higher levels of humidity increase the likelihood for germs and bacteria to be present (Campbell). The ability to control or at least monitor humidity is beneficial.

3.2.3 Infant Reflux

Infants sometimes suffer from infant reflux, or infant acid reflux, a condition in which contents of the stomach are pushed back through the esophagus. Infants are prone to this because the lower esophageal sphincter (LES), a ring of muscle between the esophagus and the stomach, is not fully developed. The LES should only open when swallowing, to allow food to pass into the stomach, but in infants it may open at other times and allow food and acid to flow back out. A liquid diet and lying flat for extended periods of time contribute to a greater likelihood of infant reflux. A liquid diet is unavoidable, but positioning an infant at an inclined position can reduce symptoms ("Infant Reflux").

3.2.4 Noise

Exposure of infants to excessive noise is a concern which has more recently been realized. Newborns are sensitive to noise and excessively loud and prolonged noise can potentially cause adverse impacts on hearing, brain development, and sleep (Liu). Standards from organizations including the American Academy of Pediatrics and the World Health Organization state that the sound pressure level to a patient in a neonatal care unit should not exceed 45 dBA (A-weighted decibels, which are decibels adjusted to account for the way the human ear perceives loudness). However, this can be difficult to achieve in practice even with modern incubators under normal hospital conditions (Kakehashi, et al.).

3.3 Limitations

Any project will have limitations under which it will operate, as well as limitations upon the design and manufacture of the project. The main limitation that we are operating under is the limitation of the equipment available to us, primarily the manufacturing equipment the manufacturing equipment in the machine shop. This limits the type of parts we are able to make on our own. Several of the metal sheets we designed as part of the enclosure had large holes in the central area of the sheet, and the sheet was too large to fit in the equipment that we have in the shop. To make these parts, we had an external shop use a plasma cutter capable of cutting the aluminum that we had for our parts.

Another limitation that we had on our project is our testing capability. We were able to purchase all the thermal monitoring equipment that the system needs in order to operate well within our budget; however, in order to conduct longer, more thorough tests, more advanced equipment was needed. We were able to get the equipment from School of Engineering faculty, however in planning these additional tests we ran into another limitation, that of time.

Throughout the whole project we have been pressed for time. Even though we were able to finish the project as desired, there are still many further tests that could be conducted. However, in order to perform these tests, access to a system that can monitor and record data from multiple. It was possible to get data from the sensor within the control system, but this was insufficient to get a thorough sense of exactly how the system behaves.

Chapter 4: System Design

4.1 Biological System Requirements

The incubator is broken up into the shell of the incubator, where the infant resides, as well as the structure that the shell sits on. The structure was designed and implemented with a maximum allowed load at 150 pounds, more than enough support for a physically stable structure and the infant. The opening hatch to the shell is located on the front face, allowing the hatch to rest on the inclined acrylic that sits adjacent to the front face of the shell. The inclined acrylic allows the hatch to rest on the shell of the incubator at an angle that does not allow the hatch to fall back down possible harming the infant.

As stated in the goals section, temperature control of the air inside the shell was a major concern. The optimal temperature of the air inside the shell is 37 degrees Celsius. Control of the temperature inside the shell is also critical to the safety of the infant. The control system needs to be capable of being adjusted by a doctor while still being maintained to the desired accuracy of +/- 2 degrees Celsius.

4.2 Functional Decomposition

- Shell
  - Prevent heat loss
    - High thermal resistance
    - Tight seals to reduce air loss in and out
  - Infant safe
    - Rigid shell to keep infant safe from external harm
    - Use material that is biocompatible with the infant
    - Maintain the filtered air from the inlet
- Tight seals to prevent unwanted airflow in
  - Allow for visibility or monitoring
    - Acrylic siding, a transparent material
- Thermal System
- Air Temperature control
  - Control system
    - Adjust speed of airflow based on actual temperature
    - Adjust temperature of heat source
    - Airflow monitors, fan speed

        - Air temp monitors
- Infant temperature monitoring
- Airflow
    - Inlet filtration system
        - Basic air filter
        - Inlet fan

4.3 Key System level constraints and tradeoffs

The first major goal of our system is the temperature maintenance within the shell of the incubator. The second primary goal is to keep the cost of the incubator below $1000. The third constraint is the ability to run the incubator off-grid, or operate in an environment that experiences frequent blackouts. With this in mind, the amount of electricity used needs to be kept at a minimum, putting importance on the efficiency of the system. These goals constrain the design and provide a foundation upon which the design can be shaped.

The goal of temperature maintenance impacts many other factors because of its importance to the system. The temperature control has to be accurate enough to satisfy the health and safety needs of the infant while simultaneously being as inexpensive and energy efficient as possible. The ability of the temperature control system to maintain, adjust and respond to a temperature disturbance is of vital importance to any incubation system due to its vital importance to the infant's survival.

Dr. Campbell mentioned the importance of humidity system maintenance to the health of an infant in early stages of development. However he also mentioned the difficulty of maintenance of systems such as these and the potential health risks that they can cause. Dr. Tongo and Dr. Bello also mentioned the importance of a humidity control system, but also ranked its importance below the ability for the incubator to maintain the internal temperature of the infant. It was decided to not include a humidification system because of the additional cost it would add to the overall system, the complexity it would add to the operation and maintenance of the system and the potential for infection.

4.4 System Layout

The system works using a combination of electrical power and thermal power; a system sketch of the components that are powered with the electrical and thermal power can be found in Figure 1. An Omoverhi Incubator is setup with the capability to run off-grid using solar thermal collectors and PV panels to gather the electricity necessary. All of the heat that will eventually be provided to the infant would come from the solar thermal panels, and the PV power is used to run the control system, pump and fans. The hot water comes from the thermal storage system or a hot water source and the control system is controlled by a 12 V battery. The hot water is then pumped through a heat exchanging system as air is blown across the heat exchanger by fans. If the temperature inside the incubation chamber is not warm enough for the infant, the fans pull cool air over the heat exchanger and into the shell. If the incubation chamber is too hot, another fan activates, pulling the hot air from the system out to the exterior environment. The floor of the incubator has slates in order to promote airflow from the heat exchanger to the inside of the incubator. While small gaps between shell components exist, it is carefully assembled, durable, and the amount of air loss from the gaps is negligible.

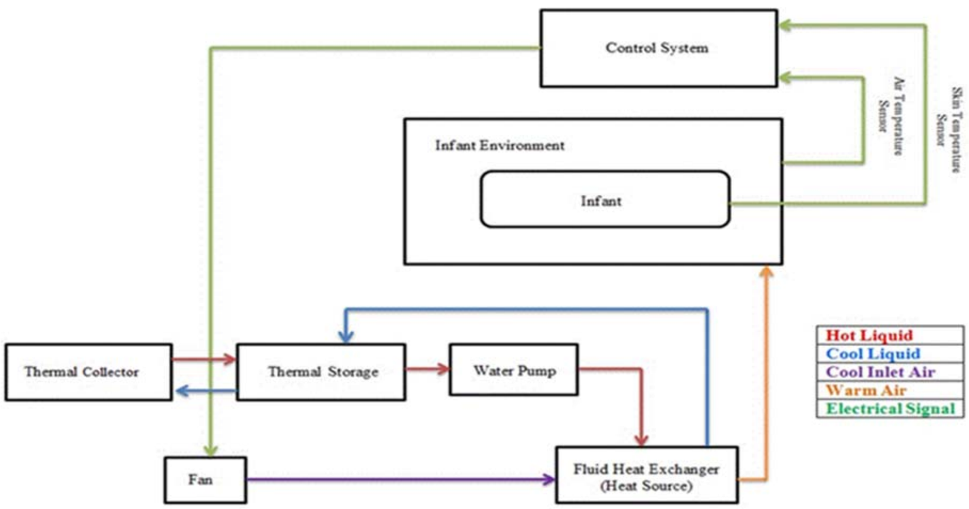


Figure 1: System sketch of the Omoverhi incubator.

Chapter 5: Mechanical System

5.1 Mechanical System Overview

The mechanical system is responsible for transferring heat to and from the incubator and for the incubator's structural integrity. Although the incubator was designed with the idea of it being able to operate on or off grid, for the purpose of this project, the prototype was built as being on grid. As a result, the system relies on a water heater and a standard 12V AC power source. For further clarification as to how the system works on grid refer to Figure 2; to see how the system works off grid refer to Figure 3.

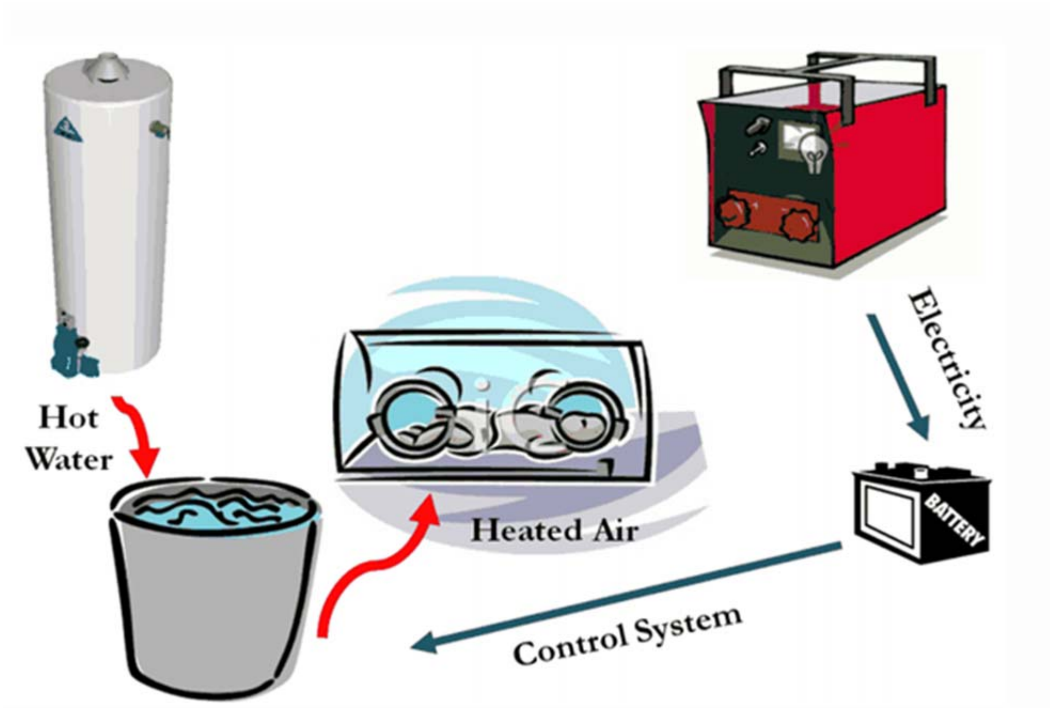


Figure 2: A representation of how the system would work if it were connected on grid.

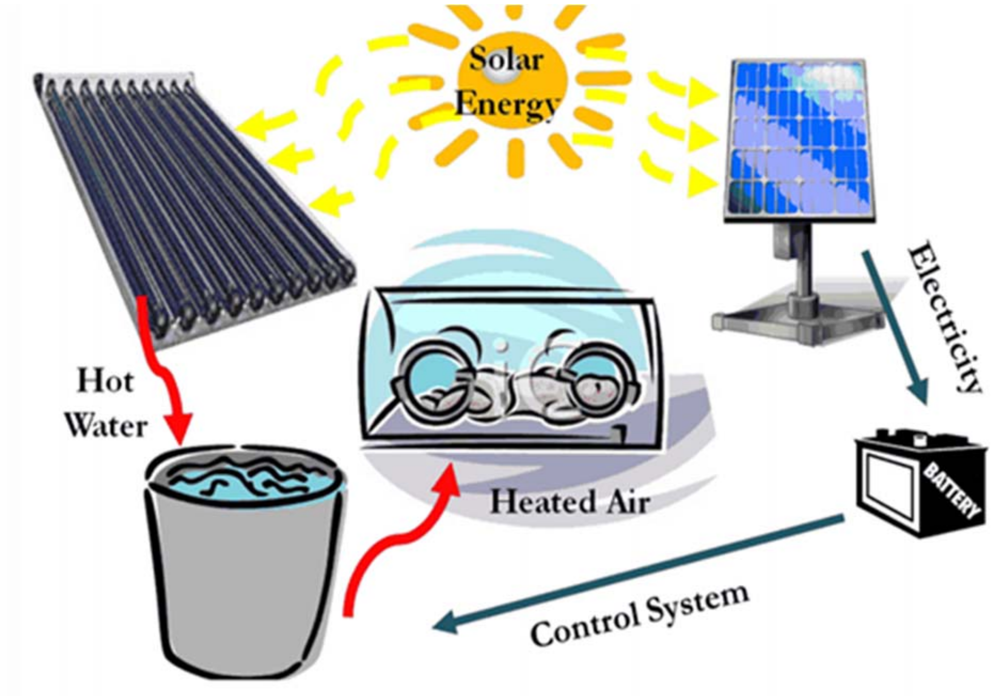


Figure 3: A representation of how the system would work if it were off grid.

From these diagrams it is evident that the system relies on three subsystems to provide the desired heat to the infant: the water heater/thermal collector, a thermal storage tank, and the incubator. As previously stated, the prototype used a water heater to attain its hot water. Using the water heater, a predetermined outlet temperature for the water was chosen at approximately 55°C, which is the same temperature achieved in an off-grid thermal storage system utilizing a PCM explored by the 2011-2012 Omoverhi Project. The water heater outlet temperature fluctuated by approximately ± 4°C. With a thermal collector, thermal energy is captured from the sun and transferred to water flowing through the thermal collector's tubes. The heated water then moves to a storage tank which is surrounded by insulation to reduce heat losses since condensation can exacerbate heat losses. Heat from the water is then transferred to a PCM, which fixes the temperature of the storage tank, but allows heat to be stored as latent heat. In conjunction with a thermal collector, the storage tank would act as a battery, in which thermal energy is stored when the sun is out and used when it is not visible. A separate water supply passes through the storage tank and is used for the incubator's heat exchanger. The heat exchanger in the incubator consists of copper pipes and a radiator connected to a fan. The actual process of transferring the thermal energy from the water to the air inside the incubator is described in Section 5.3.

5.2 Incubator Design

The incubator design can be divided into four subsystems: structural support, enclosure, shell, and bed. A 3-D rendering of the described incubator can be found in Figure 4. The structural support is the device that holds the other subsystems and the preterm infant. The enclosure is responsible for enclosing the heat exchanger and the electrical components needed for the incubator to work. The shell is responsible for retaining the heated air, preventing airborne infections from reaching the preterm infant, and venting the stagnant air. The bed is intended to have an adjustable inclination from 0 to 20 degrees, reduce the noise exposure to the infant, and keep the preterm infant in place.

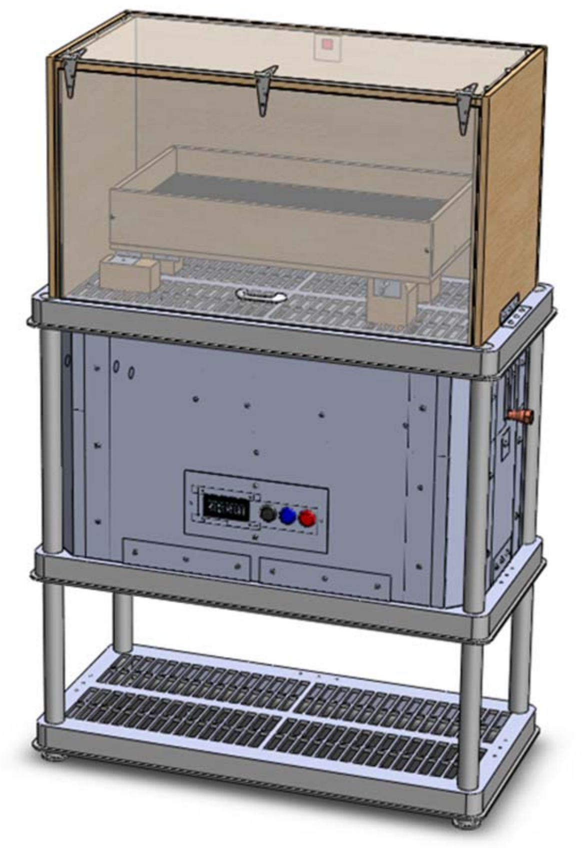


Figure 4: 3-D rendering of the incubator with all of its components.

5.2.1 Structural Support

The structural support is what sustains the weight of the incubator's subsystems and the infant. It has an engineering factor of safety of approximately three, which means that not only can it withstand the weight of the subsystems and infant, it can support close to three times that weight on each shelf; each shelf is rated to hold up to 150 pounds. The weight of each component and what subsystem they correspond to can be found in Table 1. As noted in Table 1, the middle shelf would need to support 51 pounds. By adding the total weight of the bed and shell, the top shelf would need to support 44 pounds. The weight each shelf has to support is substantially lower than 150 pounds.

Table 1: Breakdown of the components that make up each subsystem and their corresponding weight.

Mechanical System	Component	Weight in lbs.
Enclosure	Electrical Components	5
	Battery	15
	Pump	7
	Foam Insulation	1
	Copper Pipe	8
	Radiator	1
	Plastic Tubing	4
	Sheet Metal	8
	Sheet Metal Screws	2
	N/A	Total: 51
Shell	Wood	15
	Acrylic	5
	Hinges	2
	N/A	Total: 22

Bed	Brackets	3
	Foam	2
	Pins	3
	Wood	10
	Preterm Infant	4
	N/A	Total: 22

Details of the structure design were not critical in the creation of the prototype. Instead, the structural support was chosen on the constraints we set and by the dimensions of the system components and the weight each shelf would need to hold. For the prototype, the structural support was bought at Home Depot for approximately $35; the 3-D rendering can be found in Figure 5. Not only did it satisfy our constraints, but it was simple to assemble, and the holes in the shelves allow for the heated air to travel upwards. Another support structure with the same or similar features could be used, and this flexibility will allow the user to replace the structural support at a local hardware store.

Figure 5: A 3-D rendering of the structural support of the incubator.

5.2.2 Enclosure

The enclosure is the subsystem that houses the electrical components, battery, pump, copper piping, and radiator. Internally the enclosure is broken into two parts, the bottom and top portion. The bottom portion is where the electrical components, battery, and pump are located, while the top houses the heat exchanger components, the copper piping, radiator, and fans. Although, it would be ideal to have the electrical components on the top compartment and heat exchanger components on the bottom to prevent the possibility of water leaking from the radiator or copper pipes onto the electrical system, doing so would mean that electrical components would be heated from the heated air. By heating the electrical components there is the possibility of getting inaccurate readings, and even over-heating the microcontroller (Arduino). As a result, the electrical components had to be housed in the bottom compartment, while the heat exchanger components were placed in the top compartment. Another benefit of having the heat exchanger components on the top compartment is that the heated air does not have to travel as far, which results in less heat loss. For safety reasons, the battery is kept in the bottom compartment to protect the preterm infant in the rare event of a leaking battery. By being underneath the insulation and having the heat exchanger components in the top compartment the chemicals can be contained in the bottom compartment. Alternatively, the battery can be placed outside the incubator if the user desires.

The exterior is comprised of Aluminum 5022, sheet metal screws, an LCD screen and arcade buttons; a visual representation of the exterior of the enclosure can be found in Figure 6. Aluminum 5022 was chosen for its ease in machining and repair, low cost, low density, resistance to corrosion, and availability (Sheet metal materials). In a developing country it is not easy to attain all of the required components to create an incubator. However, by using Aluminum 5022 we increase the likelihood for an individual in a developing country to have access to these materials and possibly make repairs in a prompt manner. However, the amount of repairs the aluminum would need would be minimal due to aluminum's resistance to corrosion and durability (Properties of Aluminum). Besides the material property benefits of aluminum, it aesthetically resembles a hospital device. Even though, the presentation of the incubator is not relevant towards its performance, it is important to the parents of the preterm infants.

The aluminum components are held together with sheet metal screws to reduce the total number of parts required. If bolts were used there would be a need for nuts and washers; this would not only result in the overall system weighing more, but make the assembly of the incubator more complex and time consuming. The other components found on the exterior of the enclosure are the LCD screen and arcade buttons; these components make up the user interface. They allow the caretaker to set the desired temperature. The user interface provides real-time information, and it frees up the caretaker’s time. The caretaker is able to set the temperature and take care of other patients or focus their time on another task. The incubator also displays actual temperature and humidity so that the caretaker may monitor the infant's environment. The simplicity of the user interface allows for any caretaker to operate the incubator.

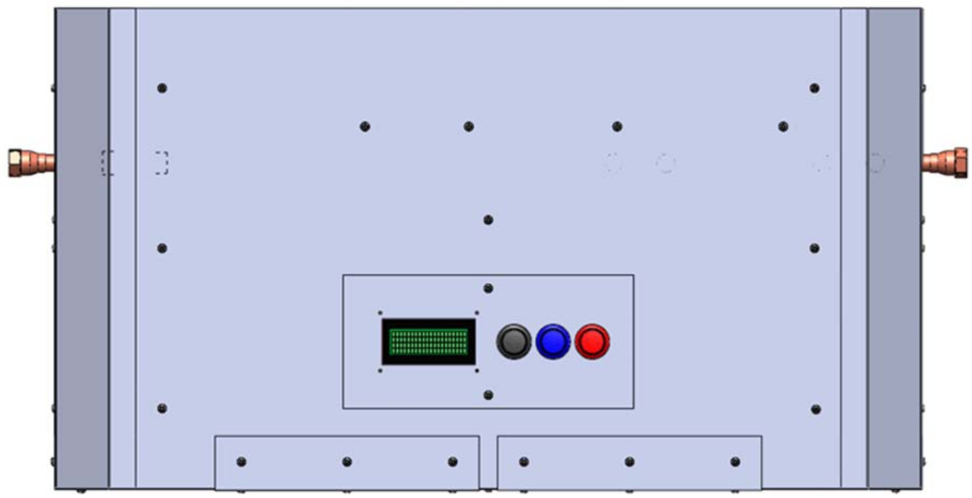


Figure 6: A 2-D projection of the front view of the enclosure.

5.2.3 Shell

The shell is the section that the patient is housed in. It needs to maintain a safe and controlled environment for the patient and enable monitoring and access by medical workers. The shell was designed in the shape of a simple rectangular box with the side and back faces made from untreated fir plywood and the top and front faces made from transparent acrylic plastic; the shell can be found in Figure 7. These materials were used because they have sufficient thermal insulating properties for the application and are relatively low in cost.

The wood panels for the shell were cut from boards using circular and band saws and the shape was finished using a belt grinder. Each wood panel was coated with two layers of a polyurethane water-based varnish. The polyurethane coating strengthens the surface of the wood and helps to protect it from degrading from insects, exposure to moisture, and physical wear. This increases the lifespan of the wood and makes the surface easy to maintain and keep sanitary. The panels were fixed to each other with wood screws, and pilot and clearance holes for the screws were made using a drill press and handheld power drills.

The acrylic panels were cut out using a laser cutter. These panels included holes for screws and bolts. The top acrylic panel, the ceiling, was fixed to the wooden side panels with screws and held flush against the back panel. A small wood block was attached to the back panel to provide additional structural support for the ceiling and to serve as a mount for a temperature and humidity sensor for monitoring the environment. The front acrylic panel functions as a door which opens upwards. The door is attached to and hinged at the ceiling with metal hinges attached to both panels by nuts and bolts. A small gap between the ceiling and the door allows for some ventilation and provides clearance for the hinge action. Strips of foam were used to seal all other gaps to reduce heat loss and lower the noise level in the shell. An acrylic plastic handle was attached to the door with adhesive glue.

The transparent acrylic door and ceiling allow the patient to be monitored from the outside. Modern, standard incubators often have all transparent shells and use more complex geometry, but using plywood for part of the shell and keeping the design simple makes the prototype Omoverhi incubator much more robust and resistant to accidental damage, reduces cost, and simplifies the construction of the design while only partially limiting operator visibility, a good tradeoff given the objectives for this product.

Figure 7: A 3-D rendering of the shell used in the incubator.

5.2.4 Bed

The purpose of the bed is to not only house the preterm infant, but to reduce the amount of noise the infant is exposed to. To ensure that the infant would not fall out or be able to roll out of the bed, the bed was designed as a box with relatively high walls. In addition to the noise reduction achieved by the bed's wood, a foam layer that is rated to reduce noise by up to 65% is placed on the base of the bed. The actual safe noise levels, along with an explanation to the importance of low noise can be found in Section 3.2.4.

The inclination of the bed is another medical constraint that had to be taken into account. The caretaker or doctor should be able to adjust the inclination of the bed from 0-20 degrees to reduce acid reflux in the preterm infant. The importance of reducing acid reflux can be found in the Section 3.2.3. Taking into the account the geometry of the structural support used, the legs of the bed were manufactured to fit into the holes of the structural support. Brackets and safety pins were added to allow for movement in the legs. The head of the bed, the side that is raised, also contains another block in order to equally distribute the weight of the bed. This added block will be referred to as block 1 and its visual representation can be found in Figure 8. As a result, the legs on the front side as well as block 1 are able to rotate. When block 1 is rotated 90 degrees; i.e., when it is perpendicular to front legs, it allows the bed to be set to a maximum inclination of 20 degrees. The legs in the back have limited movement in order to prevent too much movement of the bed, the combined adjustability of the front and back legs enable the bed inclination to be set from 0 to 20 degrees, while keeping the bed stable. A 3-D rendering of the bed at its maximum inclination can be found in Figure 8. By using manually adjustable legs instead of a motorized device, noise, energy, and cost are significantly reduced.

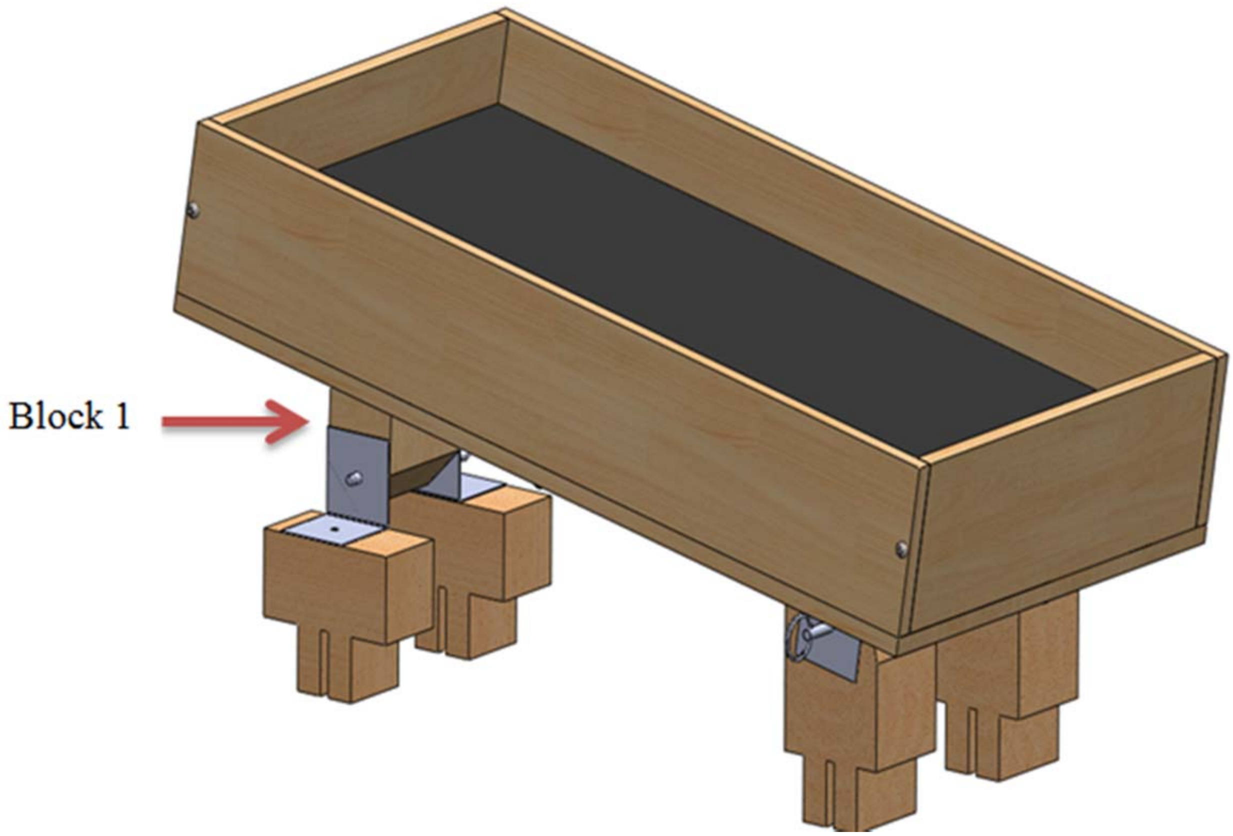


Figure 8: A 3-D rendering of the bed used in the incubator.

5.3 Thermal

The purpose of the thermal system is to heat the air entering the incubator shell to maintain the infant at the desired temperature. The thermal system consists of a heat exchanger, a way to direct air over the heat exchanger, as well as a way to make the water flow through the heat exchanger. Calculations were performed to aid in the design of the thermal system such that it would heat the air to 40 degrees Celsius. These calculations were based on assumptions derived from a theoretical system. The theoretical system consisted of a chamber, thin in depth, but that would lie flat in the incubator enclosure. This system was designed to optimize efficiency with a simple tube in chamber design. The NTU method (as detailed in Appendix B) for heat exchanger calculation was used to determine the minimum length of copper tubing required in order to heat the air from ambient of 20 degrees to 40 degrees Celsius. 40 degrees was chosen to ensure that the air sufficiently heats the shell environment. After calculations, it was determined that 2.5 meters of copper tubing would be sufficient, and would heat the air in the system to 42 degrees Celsius. Once the physical system was constructed and tested, it was discovered that the heat exchanger only heated the air to roughly 35 degrees which is obviously not adequate to heat the incubator to the desired 37 degrees. This problem was solved by adding a radiator at the air inlet which heated the air further. The radiator that was chosen was a small and inexpensive CPU radiator which heated the air at the outlet of the radiator to 52 degrees when the water was approx. 60 degrees. This design change increased the efficiency of the overall system much more than initially planned. The combination of the copper piping and the radiator made maintaining the incubator at 37 degrees possible.

Before the control system could be designed, the manner in which the outlet temperature would be adjusted needed to be specified. Early on in the design stage of the control system we debated whether to adjust the airspeed over the heat exchanger or the flow of water through the heat exchanger to control the outlet air temperature. The problem with controlling the air temperature by adjusting the volume of airflow is that the fans would need to be set so high that the airflow over the infant exceed the maximum of 8cm/s (Campbell). Additionally the opposite may happen that the external temperature is so hot that the fans must stop completely to keep from blowing hot air into the system. However it was decided that the benefit of having a quicker response time by having the system depend upon the airspeed was more important. The problem of the fans operating outside of the intended limits was solved by implementing a fan that cannot provide more airflow than our maximum 8cm/s limit, while the minimum airflow was solved by creating a simple method of reducing the air-temperature by reversing the airflow to pull the hot air out from the system.

Chapter 6: Control System

6.1 List of Requirements

After analyzing a professional Dräeger incubator model 8000IC and taking into consideration the conditions in which our incubator is going to be used, we have determined that the following requirements must be met:

Functional Requirements

1. The system will allow users to view and manipulate the temperature.
2. The system will appropriately regulate the water pump and the ventilation fans to automatically control the temperature chosen by the user.

Non-functional requirements:

1. The system will be simple, user-friendly and intuitive for new users to operate.
2. The system will be reliable.
3. The system will be energy efficient.

6.2 Use Cases

The use cases shown below outline the different features that were implemented in our system. In order to minimize the extent of human errors, the user will have limited control of the incubator. Only the basic functions are available for the user.

Case 1:

Actor: User

Goal: View humidity inside incubator

Pre-condition: Control system must be turned on

Post-condition: User able to check humidity

Scenario:

1. Press and hold black button
2. View display panel.

Case 2:

Actor: User

Goal: Change Temperature

Pre-condition: Control system must be turned on

Post-condition: Can vary the inside temperature

Scenario:

1. Display panel
2. Press button red/blue to raise/lower temperature

6.3 Control System Diagram

Figure 9 illustrates the control system and the relation between its components. The Arduino board acts like a CPU, controlling every other component, and is powered by the 12V battery which also powers the fans and the water pump.

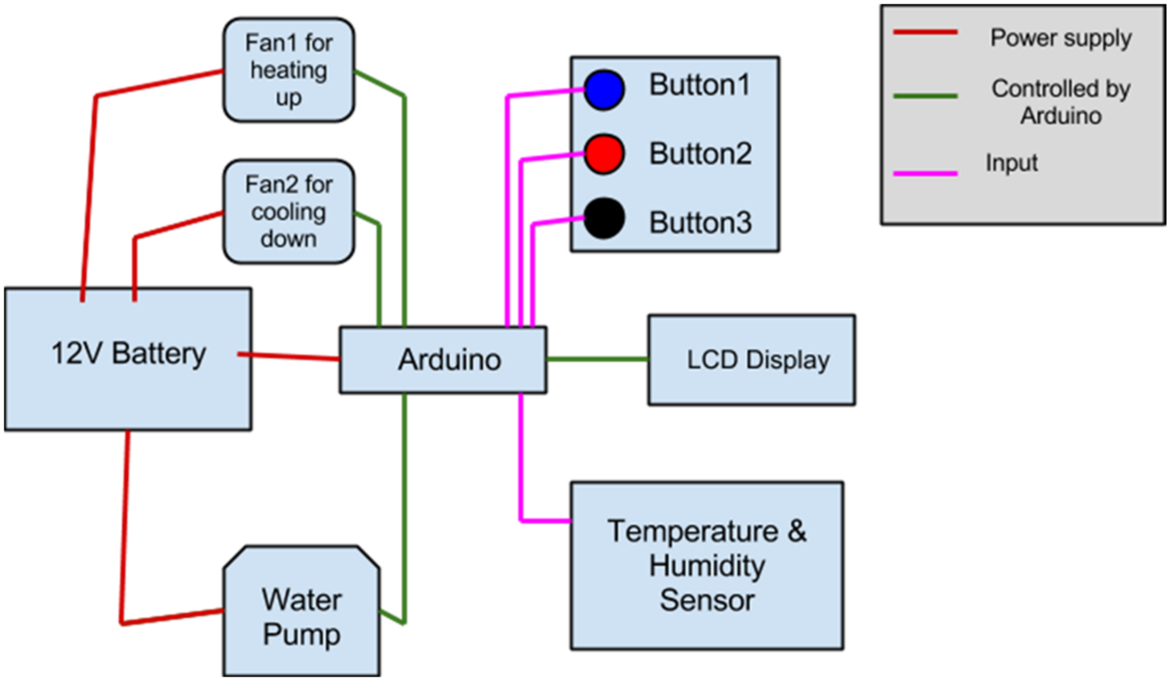


Figure 9: Control System Diagram

6.4 Temperature Control Flow Diagram

The following figure 10 shows the logic behind the control system and how it manages to control the temperature inside the incubator. This loop runs every half a second and uses ranges of +- degrees Fahrenheit which will manipulate the fans depending on the case. Appendix D contains the code used to run the program of the control system.

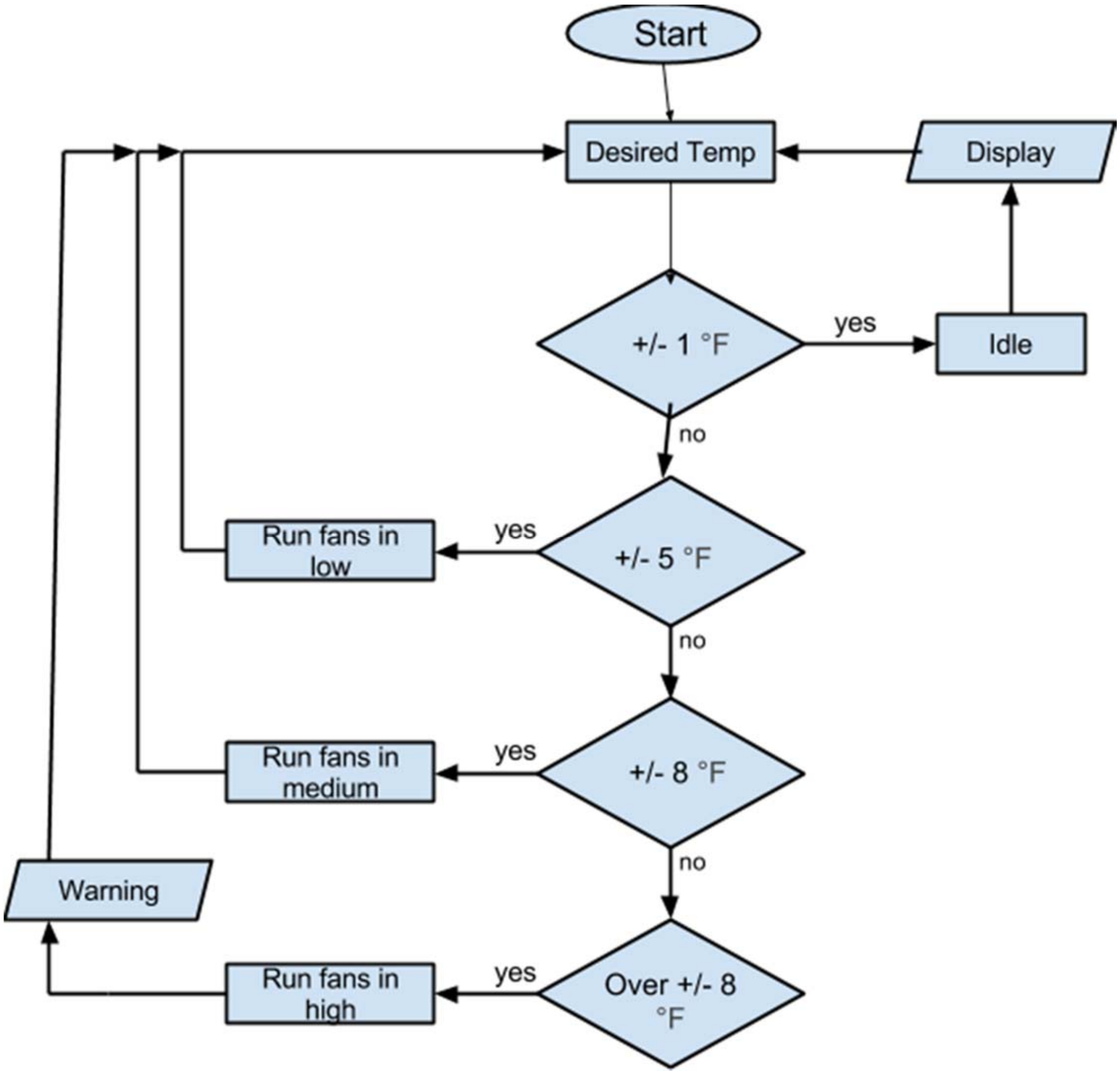


Figure 10: Temperature Control Flow Diagram

6.5 Technologies Used

- **Arduino Mega 2560:** Its performance, cost and size made this technology adequate for our system. Was chosen over the Arduino Uno because the Mega 2560 has more pins in which to connect and control other components.
- **C Programming language:** Main programming language for Arduino which facilitated the coding because of the previous knowledge in this programming language.

- **Humidity and Temperature sensor SHT15:** The sensor, ordered from sparkfun.com, is used to monitor the temperature and humidity inside the incubator. It has an accuracy of +/- 0.3°C and it is the sensor used by the Arduino to track the temperature and adjust the other components to maintain the desired temperature.
- **Water pump:** The 12VDC, 3.0GPM, 55PSI pump was perfect for the amount of water we needed to flow through the copper pipes. Even though it can handle up to 7.5 amps, we only needed to run it at 2.86 amps to reach our desired water flow. Another advantage is that the pump can run dry, which was really helpful when doing testing.
- **Fans:** The fans are 92mm in diameter and run from a 12V power source. They are used to help transfer the heat into the incubator, or in the other case, blow the heated air out to help the incubator cool down. The fans are also speed adjustable, which gave more flexibility to the system when trying to maintain the desired temperature.
- **LCD display:** The LCD display, also ordered from sparkfun.com, has a 20x4 character display and it is used to display the information the user needs to know such as desired temperature, inside temperature and humidity.
- **Buttons:** The three arcade buttons (blue, red and black) can handle up to 3 amps and are used for changing the desired temperature by the user and also for checking the humidity inside the incubator.

6.6 Design Rationale

The main goal of the control system is to be simple and user friendly. Limiting the user's options will help prevent human mistakes that can lead to serious or even fatal accidents.

The control system is implemented using an Arduino Mega 2560 because it is a suitable microcontroller to fulfill our requirements. The coding was done in C which is the main programming language for the Arduino board. The Arduino Mega 2560 is connected to a display panel and 3 arcade buttons which are the interface between the system and the user. From the interface the user will be able to manipulate the basic functions such as changing the desired temperature and also checking the humidity.

The humidity and temperature sensor SHT15 was chosen because of its accuracy and low price. Given that the control system relies strongly on the correctness of the temperature data, we needed a sensor that would give the system a low error margin. The fans chosen were based on low price and the fact that they have adjustable speed; this way we assure that they would not get damaged when using variable current to reach different airflow speeds.

Lastly the water pump was adequate because it can be used dry, which means that it can run without having any water flowing through it, and it will not get damaged. This feature was really helpful when testing the electric system because we would continuously turn it on and off and it simplified our job by not having to connect the pipes with running water.

6.7 Testing

Testing throughout the process of assembling the control system was crucial. When working with embedded systems, problems can not only be caused by the software but also by the hardware, which can make the debugging process extremely difficult. The following test methods were used for the system:

- **Unit testing:** Each individual component was tested separately before assembling the entire system. For example, to test the LCD with the arcade buttons we created a program that simulated the temperature inside the incubator and then we were able to change the desired temperature on the display. For the fans we wrote different functions to run them at different speeds and tested them each individually to make sure we were achieving the desired airflow. All of the components were connected to the Arduino during every test to make sure the Arduino was capable of controlling them.

- **System Testing:** After the unit testing was complete, all of the individual components were assembled together to see how they interacted with each other. For example, the value read from the temperature sensor was now displayed on the LCD, and used in the code as a parameter to determine the fan speed. Once everything was put together there was an extensive test period of the system as a whole to make sure it worked properly.

6.8 Electrical and Power

The Omoverhi incubator requires the electrical system to provide the electrical power to facilitate thermal regulation. This system was designed based on one of our main goals: to be energy efficient by minimizing power consumption. The main power source is the 12V, 35Ah battery which can be connected to an external power source but can also provide up to 10 hours of electricity without external power. Table 2 shows all the components used for the electrical system.

Table 2: Electrical components and specifications

TY	Product	Specifications
	Capacitor	10 Nanofarads
	Resistor	1 kOhm -¼ Watt
	Resistor	10 kOhm -¼ Watt
	MOSFET	N-Channel 60V 30A
	Voltage Regulator	12V IO=1.5 A
	Voltage Regulator	9V IO=1 A
	Battery	12V 35Ah
	Arcade Buttons	3A max
	Arduino	Mega 2560
	LCD-00256	20 x 4 Parallel Interface
	Temperature Sensor SHT15	Resolution +/- 0.3°C @ 25°C
	Fans	92mm 12V
	Pump	12 VDC, 3.0 GPM, 55 PSI, and 7.5 Amps

Figure 11 shows a detailed schematic of the electrical system. The components that have to be turned on and off (the pump and the fans) are controlled through the Arduino microcontroller by using a MOSFET. The arcade buttons are each connected to their own resistor and capacitor which helps clean up the signal so it is easier to detect when the button is pressed. The temperature and humidity sensor is connected to ground and the 3.3V provided by the Arduino, and also requires two pins in the Arduino board. The LCD display is connected to 5V and ground, and uses seven pins from the Arduino board.

We used a 12V voltage regulator to avoid voltage spikes in case a problem arose with the battery. Also, by using the voltage regulator we are able to limit the amount of current the devices or components are able to get from the battery. The 12V regulator enables a maximum current output of 1.5A. Although the Arduino is designed to accept 12V inputs, a 9V voltage regulator was used to reduce the voltage and protect against any unanticipated voltage spikes; this regulator gave out a maximum current output of 1A.

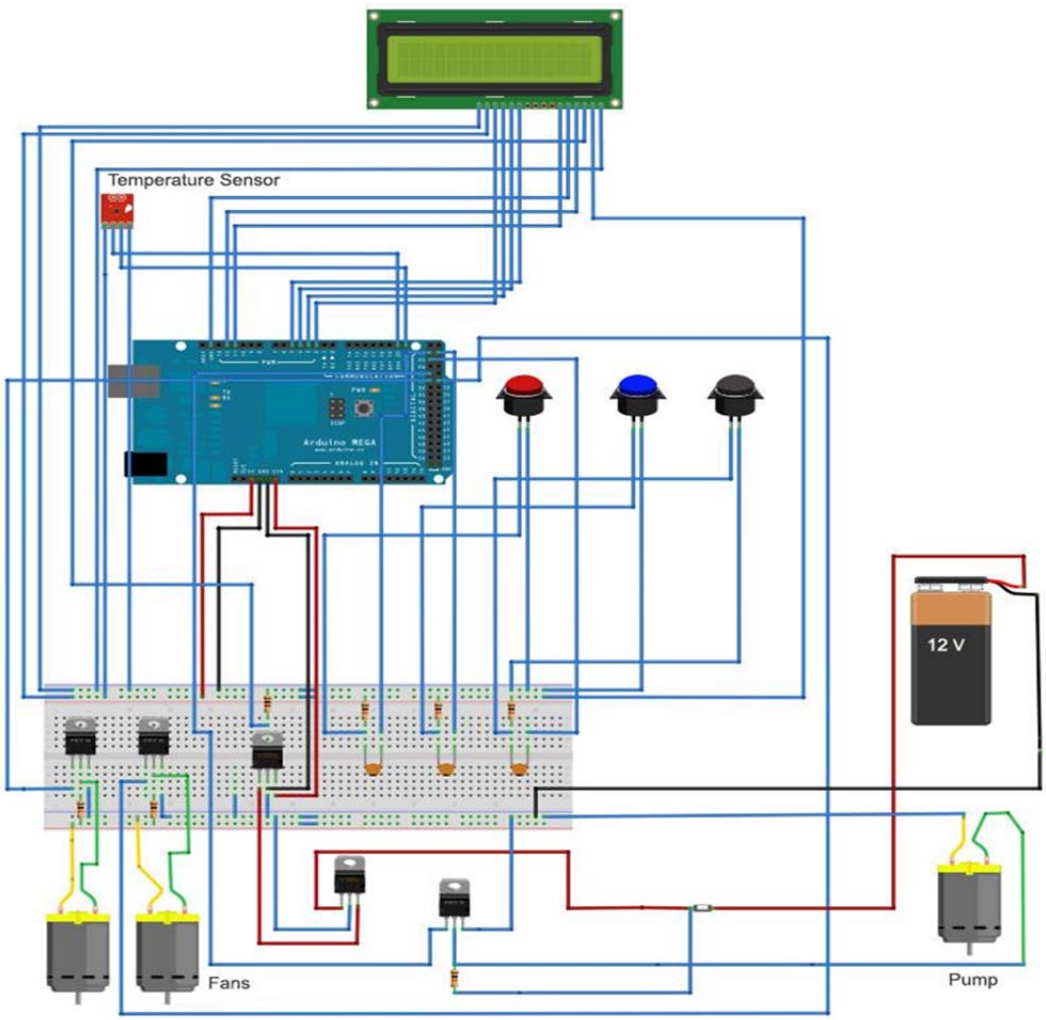


Figure 11: Electrical System Schematic

Chapter 7: Testing and Results

7.1 Testing Procedure

Figure 12 illustrates the assembled prototype of the incubator as configured for testing inside our laboratory workspace. A variety of tests were conducted to verify the operational capabilities of the system. The capabilities of the system that needed to be verified were: the heat exchanger performance, the control system's capabilities and the transient response of the system. The performance of the heat exchanger was verified by assembling the heat exchanger without the shell on top of it and running hot water through it with air flowing over the top of it and measuring the temperature of the air coming through the outlets. The next thing to be verified was the effect of the airspeed on the outlet air temperature. This test was conducted in a similar manner by measuring the outlet air temperatures for various fan speeds.

After the initial two tests were completed, which verified the assumptions made for the design of the control system, then the control system could be tested. The testing of the control system involved setting up the complete system and running it as it would be operated in the field. The same temperature sensor was used for all of the initial tests as well as for the testing of the control system. A USB connection was made to the Arduino inside the incubator itself, which was able to record the temperature data that was being fed back into the control system. This data gives us a good general sense of the operation of the system as a whole, but does not give us a sense of any variations in temperature distribution throughout the enclosure which could impact the infant.

7.2 Testing Results

7.2.1 Heat Exchanger Performance

The initial test, testing the effectiveness of the heat exchanger itself, proved that the copper heat exchanger as designed was not sufficient to heat the air to the desired temperature. Consequently, a change to the heat exchanger had to be made. Initially we attempted reducing the depth of the heat exchanger, which was only effective to an extent and did not get the outlet air temperature to the desired 40 degrees Celsius. Once we put the radiator in place and ran the system, we were able to achieve 45 degrees at the outlet. This excess temperature is very good for our design, since our control system was designed to cool the system as well as heat it up.

7.2.2 Effect of Airspeed

The radiator was added to allow the heat exchanger system to perform as necessary, the test to verify the effects of fan speed was performed. The outlet temperatures with the inlet fan set to high and low were recorded and can be seen in Figure 12.

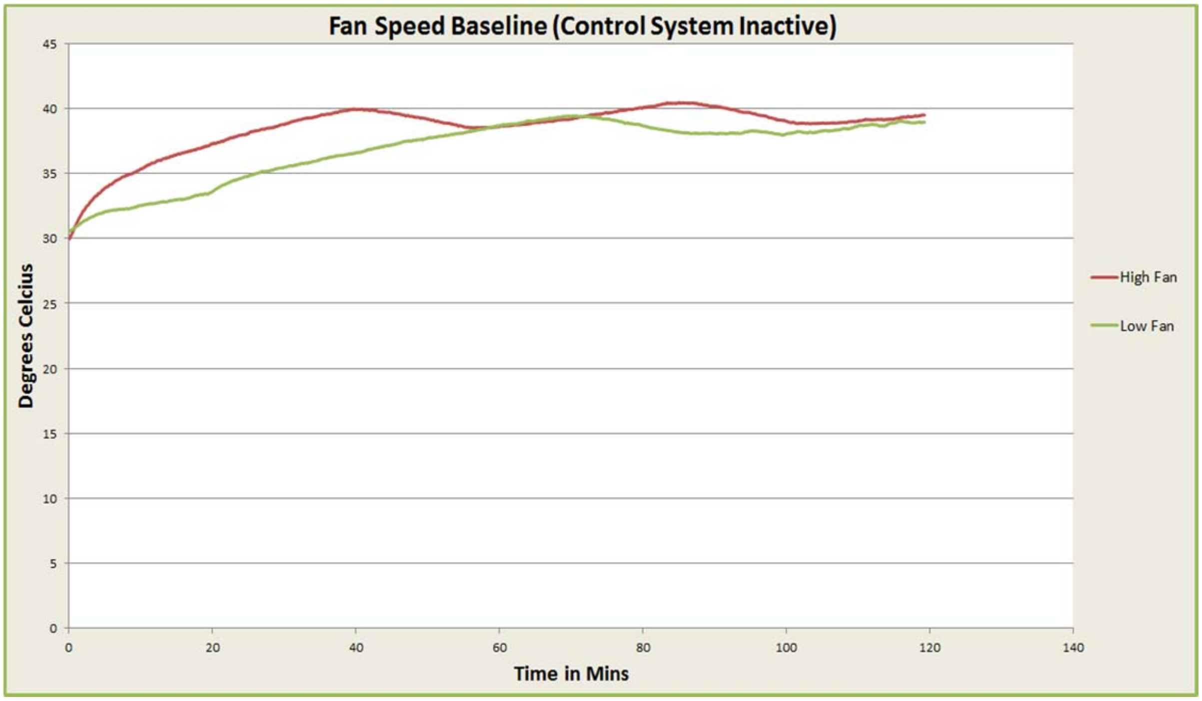


Figure 12: Graph of heat exchanger outlet temperature for two different fan settings

We are able to tell from this graph that our hypothesis of more volume flow resulting in a higher outlet temperature was indeed confirmed. The fluctuations in the temperature were from fluctuations in the water temperature due to the heating cycle of the water heater used for testing. The water temperature was observed, *via* thermocouples within the water stream, to be cycling between 57 degrees and 67 degrees Celsius. This fluctuation caused at most a 2 degree Celsius fluctuation in the air outlet temperature.

7.2.3 Control System Performance

The next test was executed to verify that the control system performed as desired. The data was collected as explained earlier, by connecting a laptop to the Arduino's USB port. The test was limited in length due to the software that was being used to record the data. The code was pulling the temperature values being input into the control system and recording them in a display window. These values were then transferred into Excel to be processed. The limiting factor on the lengths of the tests was the capacity to transfer the data into Excel. When performing the earlier test without the control system implemented, the data points could be taken once every ten seconds. While running the control system the data was being taken twice every second in order for the control system to operate as desired. A test was performed for 4 hours, but when the data was transferred to Excel, large quantities of the data were lost and the whole test needed to be repeated, but for a more manageable duration. Due to the limited length of the test performed, only the short-term steady state of the system was verified. Figure 13 is a graph of the temperature of the shell's internal temperature with the control system implemented.

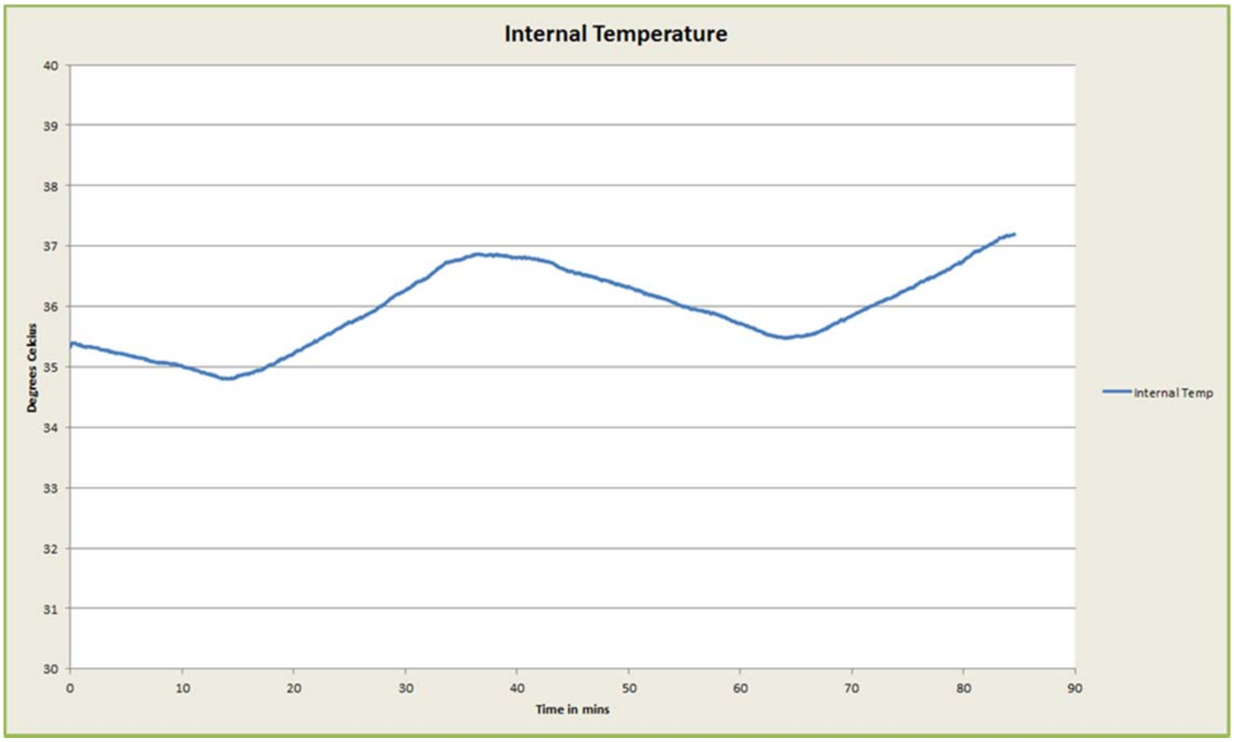


Figure 13: Graph of internal temperature of system operating with control system activated.

The air temperature still fluctuates in response to the fluctuations in the water temperature which is to be expected. The control system was set to 97 degrees Fahrenheit (36.2 degrees Celsius) and was able to maintain this temperature to within a +/- 1 degree Celsius. This margin is in fact below our set goal margin of +/- 2 degrees Celsius. These results only represent the short-term performance of the system. Additional testing of the long-term performance of the system is necessary before it can be said that the system will work in practice. One factor that our tests were unable to verify was the magnitude of impact a fluctuation in ambient temperature. Additionally the exact relation between the water temperature and the air temperature needs to be determined.

7.2.4 Transient Response

Before the system could be said to work properly the transient response of the system needed to be verified. Standards for medical incubators are that the system needs to be able to achieve the desired steady state within 15 minutes after having the door open for 5 minutes. The way in which the transient response of the system was verified was: first, the entire system was allowed to cool, second, once the control system is activated, the temperature sensor is turned on to record data. To test how quickly the system achieves steady state, the system was brought to steady state and then the main door was opened for 1 minute or for 5 minutes, then closed, and the response of the system was measured and graphed in Figure 14.

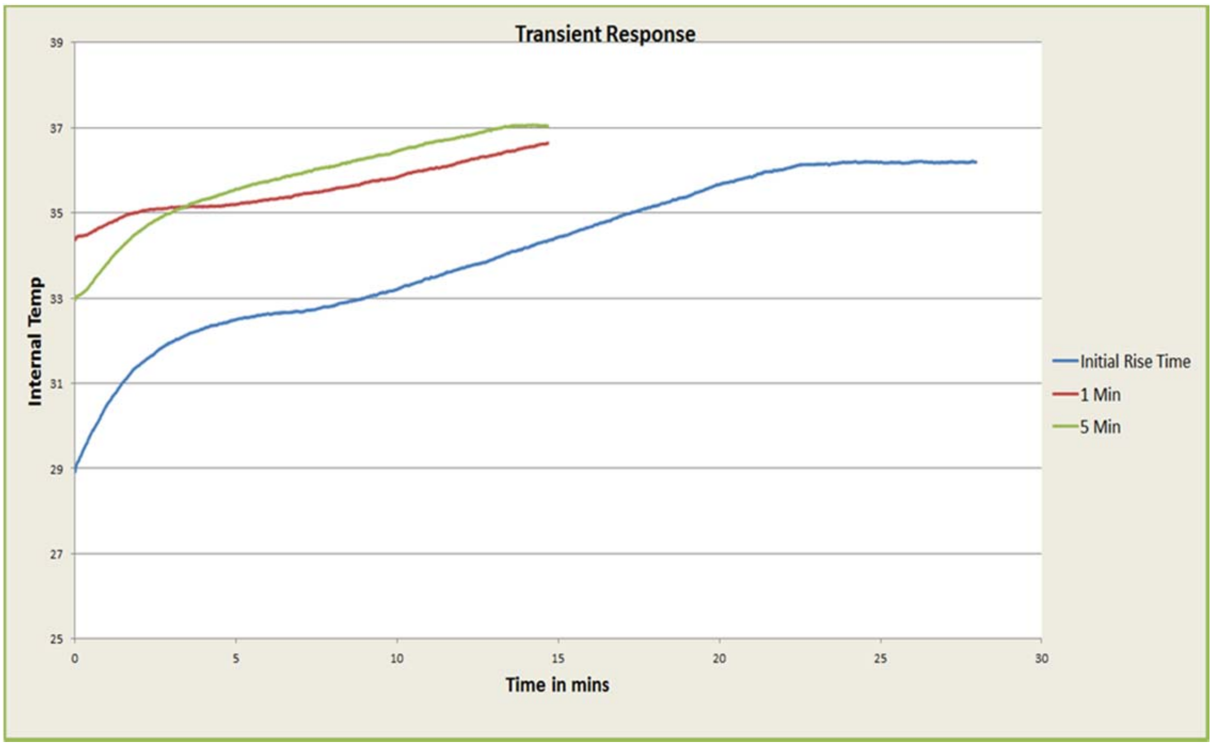


Figure 14: Graph of transient response of the system for different situations

From the graph, it is evident that the system was able to recover within the desired time of 15 minutes. The test was performed twice, once with the door open for one minute, and again with the door open for five minutes.

7.3 Further Testing Possibilities

The testing results obtained so far are promising and clearly do not reveal any shortcomings of the system. However they do not confirm the long-term response of the system nor the specifics of the relations between external factors and the internal temperature. The system's ability to maintain the temperature set by the control system as well as its ability to respond when the system is forced out of equilibrium shows that the incubation system is performing as desired. However the tests performed only verify the *short term* performance of the system and do not provide a detailed relationship between the internal temperature and the multiple external factors that impact it. Additionally, the temperature distribution throughout the bed would need to be verified to confirm that the temperature the infant is exposed to is within the desired boundaries. Further testing should be executed and used to extract an upper and lower operating limit for the water temperature being used for the system. Unfortunately time constraints prevented these tests from being performed. These tests would constitute a thorough confirmation before the system could begin to be mass produced and distributed to those in need of it.

Chapter 8: Project Economics and Management

8.1 Cost Analysis

As one of the main goals of the project, the cost was of vital importance. Below is a rough breakdown of the expenses for the project by subsystem as well as an estimation for the cost of a mass produced end product. The cost estimate performed did not account for the power source for the system. Since the system is capable of running off of multiple power sources, grid power or solar power, the cost of the power provided to the system would vary depending on the end usage.

Table 3: Basic cost breakdown of fabrication

Subsystem	Prototype Cost	Production Cost
Structure	$265	$130
Thermal System	$150	$100
Control System	$270	$200
Bed	$60	$50
Shell	$80	$50
Total	$825	$530

It is possible to tell from this table that the control system was the most significant expense of the prototype and is estimated to be the largest expense for the final production cost. This is to be expected because of the electrical hardware and circuitry required, even when an affordable option is chosen. The other large expense, at least for the prototype, was the structure. This consisted of the shelving frame, which was only $35, but also included the aluminum sheet metal walls of the enclosure. The material itself did not constitute the majority of the expense. Instead, most of the cost was associated with fabrication. Despite the fact that we managed to get a very inexpensive offer for the fabrication of our prototype pieces, it still was more than it would cost to get the pieces made in sets of 100. An inquiry was made to a large scale machine shop as to what the cost to machine 100 sheet metal parts would be; they returned an estimate of $7 per part. This means that all of the pieces of the enclosure assembly could be manufactured for around $50.

Despite these relatively large expenses the end product is estimated to cost only $530. This is nearly half of the initial goal for cost. However, this cost estimate only represents the material and manufacturing costs, not the end price of a unit. A detailed budgetary spreadsheet is located in Appendix E, however many of the expenses listed in that spreadsheet, such as testing equipment, would not be necessary for the production model. As stated in the market analysis section, the HEBI incubator costs $500 plus shipping, our product may cost $530 to manufacture, but the price would need to be higher even if it was being made and distributed by a non-profit organization. It would most likely cost approximately $700 to be purchased and shipped to a location that needs it.

Additionally, if the system is intended to be used in the off-grid setup with the solar panels implemented, the cost per unit would increase. Solar panels suitable for our application can cost anywhere from $300 to $600. This could potentially account for the majority of the cost of the end system. In addition to this, a solar thermal system can be anything from a system that heats water to its boiling point ($500), black water tank, which would absorb heat and could be made from local materials (<$100). The goal of our project was to reduce the cost of the incubator itself to below $1000. That does not mean that the end system will cost less than $1000.

8.2 Timeline

Throughout the year the work done could be broken down into three major sections: a theoretical design and planning section during the Fall quarter, a fabrication and assembly section for the Winter quarter, and testing and troubleshooting during the Spring quarter.

8.3 Design Process

The design process began with a brainstorming session to come up with ideas of the problems that must be addressed. The main issues that these sessions attempted to address were the goals and design restrictions as explained in the goals and limitations section, primarily that of the temperature management. From there, basic calculations were performed to determine specific dimensions and specifications. After the basic specifications and design were determined, technical drawings were made to allow for the fabrication and assembly of the system. The few major parts that were too large or difficult to manufacture were sent out to a local shop that was willing to give a discount for the manufacturing of the parts. Then once the parts were assembled and the basic performance tests were conducted, further design changes had to be made to ensure that the system performs as desired. After this was done the system was tested again to ensure that, as a whole, it performs as necessary.

8.4 Product Deployment and Organization Development Plan

8.4.1 Goal

The goal of Project Omoverhi as a nonprofit enterprise is to be able to produce and deploy as many of our incubators as possible to places where they can be effectively used to make a difference. The deployment of the incubators will be primarily limited by the funding that can be obtained.

8.4.2 Market

The market for the Omoverhi incubator will primarily be developing nations. There are 15 million preterm births each year and the majority of them occur in such countries. This market has the greatest ability to take advantage of the type of incubator that we have designed. In these places, there is a need for incubators and there is access to enough electricity to run models of our system, and there are also tools and materials to provide repairs for them. The demand for incubators in these locations has remained much higher than the supply because modern incubators are priced far beyond the affordable range for them. Donated incubators have been able to fulfill some of this need but there are far too few units and they are not optimally designed for use and maintenance outside of industrialized countries and can break down and become useless in this market. Given the state of this market, potentially thousands of units of our product could find guaranteed use if delivered to the right people. The only realistic limit for the deployment of Omoverhi incubators is obtaining funding to manufacture them and developing connections to find out where to send them.

8.4.3. Competition

There are several other low-cost incubation technologies from other nonprofit organizations but these are not viewed as competitors because all parties are operating as charitable organizations and each product has its own advantages and disadvantages in specific areas of the market. The Omoverhi incubator is not intended to be a product that will fulfill the needs for all preterm infants or that will necessarily replace other products, but is designed to provide an additional solution that some may decide is best suited for their needs.

The Hemel Baby Incubator (HEBI) is most similar in appearance to our incubator. The HEBI has certain similarities such as materials used but differs most significantly in its heat source. The HEBI generates heat from incandescent light bulbs. The HEBI is lower in cost than the predicted large scale production price of the Omoverhi incubator but does not have certain features such as an adjustable angle bed and a battery for operating without a constant power source. Performance of the HEBI is also subject to variation depending on the rated output of the light bulbs used and how far through their life cycles they are. The type of incandescent lights used in the HEBI usually run for 1200 hours before burning out, but operating times will be shortened by greater numbers of on and off cycles. The lights in the HEBI will need to be replaced periodically, and doing so may become more difficult in the future following the trend of incandescent lights being replaced by more efficient ones, which are not suitable for this application because they generate less heat. The HEBI runs completely off electrical power while the Omoverhi incubator needs electricity (whether from an on-grid or off-grid source) and a hot water source.

The NeoNurture incubator design is based on automobile parts. Like the HEBI, the NeoNurture incubator provides heat from lights and requires only electricity to operate but it uses automobile headlamps rather than household light bulbs. The NeoNurture incubator has the potential to be manufactured for little to no material costs if parts from retired vehicles are readily available. However, expertise may be needed to extract the parts from automobiles, the parts are not guaranteed to be in good condition, and there is difficulty maintaining a standard product across different part sources (parts from different vehicles). There are also safety concerns with using old automobile parts in a medical device, if the parts are not adequately cleaned and prepared for this type of repurposing, a patient could potentially be exposed to harmful substances.

8.4.4 Marketing Strategy

While Project Omoverhi has made contact with a few potential users, it does not have the extensive resources to build additional connections on the scale so desired. We believe that we can have a greater impact by working with larger aid organizations rather than independently. These organizations already have well-established networks and infrastructure, which will make it easier to find potential users and deliver incubators to them. Funding will be dependent on money allocated from these and other aid organizations and outside donations. The Omoverhi incubator will be marketed to donors as an important product to fund because it fulfills the need for a low-cost incubator that has the ability to run only partially on electrical power or completely off grid.

Marketing points to use will be:

- High utilization rate; product is in demand and needed by many, donations for this product are guaranteed to have a positive impact
- Can be partially manufactured in target use locations
    - Potential to help local businesses
    - Able to make replacement parts locally
- Simple to operate; does not require extensive training, closed-loop control system automatically maintains temperature
    - Features not included in other low-cost incubators
    - Adjustable tilt bed
    - Flexible heat source: able to use gas or electric water heaters, solar water heaters, or water heated by any means such as over a fire
    - Battery for uninterrupted usage when power is not constantly available and ability to run electronics off solar panels

8.4.5 Manufacturing

Our prototype incubator was made from consumer available parts and materials that were manufactured into parts with a minimal amount of complex machinery. The main materials used to make original parts included wood, acrylic plastic, aluminum sheet metal, copper pipes, and polystyrene foam. The most complex machine needed to form these materials was a laser cutter for the acrylic plastic. The tools and machinery needed for manufacturing the other materials into parts were band saws, mills, sheet metal cutters, sheet metal benders, tube cutters, welding torches, soldering irons, and utility knives. Final products used as parts could be integrated with common hand tools. With all the parts collected and manufactured, the incubator is delivered unassembled as a kit that requires only hand tools to assemble.

It is possible for many of the parts to be made or bought in some of the target places of use. When this is the case, arrangements may be made to have the parts bought or manufactured in the target locale which will save on shipping costs and provide business in the local economy. Otherwise, manufacturing will happen primarily in the United States where Project Omoverhi is based.

The cost of the prototype incubator in parts, materials, and labor not conducted by Project Omoverhi team members was $825. However, if produced on a large scale, the material and outside labor costs of a single Omoverhi incubator can be reduced to an estimated $530. Manufacturing of most parts will be contracted to machining shops in quantities of parts for at least 100 incubators to reduce costs to this level. Final product parts will be bought in large quantities when lower prices are offered for bulk orders.

8.4.6 Service

Most service and repair is to be conducted by product owners or through local services. Some parts, such as screws and hinges, are standard hardware components that can be bought where the incubator is deployed. Blueprints of parts will be provided so that certain ones, such as those made from wood or aluminum can be made by local services. Other parts that may be difficult to obtain and work with in the areas of use, such as acrylic plastic and certain mechanical and electronic parts will need to be shipped from the United States or other countries where they are readily available. Service manuals will be included and the Omoverhi incubator's simple design will allow the replacement of parts to be a manageable task by users.

8.4.7 Deployment

Before proceeding to large scale production a final design for the Omoverhi incubator will be selected to move out of the prototype phase. When funding and users for at least 100 incubators is available, parts will be ordered and manufactured. Inventory can be kept in rented storage containers or a warehouse for about $4000-$5000 per year. Shipping costs will vary depending on the methods of affiliate aid organizations in sending aid products to target locations. Given the estimated large scale production costs and factoring in other costs, the funding necessary for each wave of deployment will likely be between $65,000 and $90,000.

While working to acquire funding for production of bulk sets of incubators thereafter, Project Omoverhi will maintain contact with the first set of users to gain feedback of the product's actual performance. If the Omoverhi incubator is working adequately and as intended then production will continue in this fashion. Some funds will also be reserved for buying and fabricating replacement parts to be sent on request.

Chapter 9: Societal and Environmental Impact

9.1 Project Overview

Project Omoverhi aims to design and produce an incubation system that is capable of being operated on and off grid. This would be done by the use of solar panels and thermal collectors, to provide the electricity and to provide the heated water, respectively. According to the World Health Organization (WHO), 15 million infants around the world are born preterm. Of the 15 million preterm births, one million die due to complications. These deaths predominantly take place in remote locations in developing countries such as Nigeria, India and Indonesia. The WHO goes on to say that of this 1 million who die, three-fourths could be saved through the use of cost effective interventions, such as inexpensive incubators. These cost effective interventions do not include urgent care facilities such as hospitals. Omoverhi's inexpensive, easily maintained, and capable of running off grid design would be ideal for operating in small scale clinics in areas where electricity is not readily available. Refugee camps are also locations that the Omoverhi incubator would lend itself because of inadequate electricity availability.

We designed the incubator with the user in mind. The temperature control system allows for the doctors to attend to other needs while the infant is kept safe, with the assumption that the doctors would need to care for a group of patients rather than a single infant. The Omoverhi incubator was designed for times when a doctor is not present or the caretaker in the small town is responsible for the life of the infant. We do not expect the user to be technologically savvy; in turn the control system is intuitive and simple. This assumption was kept in mind throughout the design process and can be seen in all of the major aspects of the system. Similarly, the structure and shell were designed to have the capability to be easily assembled and disassembled. The simple design allows for any lay person to assemble the incubator. The simplicity is three-fold, allowing for easy assembly and disassembly, operation, and maintenance and repair.

9.2 Social

Not only would the family of an infant in need benefit from having an incubator in a local town, the area as a whole would benefit (Design that Matters). If the family is able to have the preterm infant placed in an inexpensive incubator chances are that the treatment would cost less. Allowing the family to save money would in return allow them to, "invest more in the health, education and the future of their children, enabling families to be more sustainable"

(NeoNurture). At the same time, if the clinic has an incubator it would be perceived as a "good" rural clinic with staff that are capable of delivering infants. Consequently, it would "create a magnet for clinical deliveries, as opposed to home births" (NeoNurture). By having the infant delivered in a clinic, rather than at home, the chances of the mother or infant being exposed to harmful bacteria or germs is greatly reduced and they can receive immediate medical attention in case of emergency. Through implementation of Omoverhi incubators in areas where there is a high rate of preterm births, the reduction of deaths due to inadequate care can greatly increase the moral of the town or city.

9.3 Ethical Framework

Our motivation is to save lives. Luck should not play a role in preterm infant mortality. Team Omoverhi, "lucky child", aims to spread the use of low-cost, sustainable, and effective incubators so that infants do not need to be lucky in order to survive. In developing nations, not only is there disparity of electricity between urban centers and rural communities, but within the cities, electricity is a commodity, a commodity that often times cannot be afforded by those who need it, such as prematurely born infants who would otherwise die without it. With this in mind we came together to design, create and look for implementation of our incubator in areas of need around the world.

It is in our nature as students at a Jesuit University to incorporate the values, morals and decision making skills that reflect a Jesuit education. When coming up with our design idea, we kept the Santa Clara University ideals of Competence, Conscience, and Compassion in our mind. It started with having a genuine want to help others in need. To do the Jesuit way, be men for others, was our mentality. Potentially having the ability to save infants, who would not otherwise survive is all the motivation we needed. Next in our design process we had to make a conscience effort to produce an incubator where it would have the most impact. Making the incubator too expensive that developing countries cannot afford it does not help those preterm infants, regardless of the product quality. Making a profit is not a goal of Project Omoverhi. Another aspect besides cost was to make use of materials that would not be harmful to the infant or subject the infant to external factors such as noise from the fans and pumps. We were able to get the necessary requirements that allow us to create an incubator that would save preterm infants lives through calculations and computer simulations. This is where our engineering knowledge and a genuine need meet. Through our education at Santa Clara University we have developed the skills crucial to the design of the incubator.

9.4 Health & Safety

It is hard to quantify the impact of a medical device beyond the exact capabilities and performance of the device. We can say confidently that, when operated properly, our device is able to maintain a steady temperature of 36.5C with a fluctuation of +/- 1 degrees. This a crucial factor in the design of the incubator because of the infants inability to maintain body heat, however it is much harder to say how many infants our device has saved. It would take time before a thorough conclusion about the effectiveness of the Omoverhi project can be determined. The first step is what we have been doing, to design a system that is capable of maintaining an infant's body temperature and provide a safe environment in which it can mature. The next step will be getting the product in the field and seeing how it operates. According to the WHO, only 1 million of the 15 million premature infants die worldwide. However this rate would be significantly lower for infants born in locations in which the Omoverhi system would be implemented. Some of the infants placed in the Omoverhi device will die but the question is, is it because the device failed in its purpose or because the infant was unfortunately going to die anyway due to birth complications. In order to be sure, not only will the devices need to be monitored to ensure proper operation, but also a statistically significant number of infants need to use the system before a solid conclusion can be made about the saving potential the system has. Without implementation and time to hear feedback all we can provide is the information obtained from experiments, were our system was able to remain in the prescribed temperature range as well as meet the standards in the most essential aspects of a hospital incubator.

9.5 Location

The location of an Omoverhi incubator can be worldwide, ranging from large cities with unreliable grid power or to a small remote village where electricity is not accessible. Having the ability to assemble the incubator on site is one of the most important design features of the incubator. An Omoverhi incubator can be assembled locally to the patient, removing extended travel from the difficulty of giving birth offers a safe and local option to start a family.

9.6 Environmental and Sustainability

The Omoverhi incubator was designed to be a sustainable device and have a long lifecycle by using durable materials and making it easy to maintain and repair. The component of the incubator with the shortest life cycle would be the deep cycle battery, with an estimated life cycle of 4-8 years (Deep Cycle Battery FAQ). Once the battery no longer holds its charge, it would need to be recycled or disposed of properly according to each country's regulations. Other components of the incubator are expected to have a longer lifecycle than the battery, and can be reused in other applications once they have reached the end of their lifecycle. Such examples could be reusing the shelves, using the wood to build other products, or using the acrylic to house items.

The aluminum housing for the structure is resistant to rust and is not bearing loads that would cause it to eventually fail, so this should not need to be replaced. In the event that it is accidentally damaged such as by an impact, replacement parts could be manufactured by any metalworking shop. The acrylic plastic panels of the shell should also last throughout the entire product lifecycle. The acrylic would be somewhat more difficult to replace without having to ship in parts from other places, so we designed the incubator to minimize the amount needed. Both the aluminum sheet metal and acrylic plastic are recyclable but it is not likely that recycling facilities will be present in the areas that the incubator is needed in. In developing nations, a lot of people will find uses for things that we would never consider. The environmental impact of these materials is not a great concern because they are relatively durable and unlikely to become waste.

Parts of the shell and the bed are made from wood. Most of this wood cannot be disposed of without some negative environmental impact because of materials such as glue in the plywood that was used. However, the wooden components are made to last a long time by designing them with rigid construction and by the application of a polyurethane varnish to them. The polyurethane coating helps to make the wood resistant to damage from moisture. This makes the wooden parts worse for common disposal but much less likely to actually need to be replaced and disposed.

The Omoverhi incubator has the ability to run completely off of solar power and avoid causing air pollution if a solar water heater and photovoltaic panel are attached. This can be especially beneficial if it helps to avoid or reduce the use of a fossil fuel based generator in the vicinity of the medical facility where the incubator is being used.

These factors in our design minimize the potential negative impacts of the Omoverhi incubator on the environment and make it a more sustainable product that can continue to serve its purpose for a long time and not become waste.

Chapter 10: Conclusion

10.1 Future Work

Our team focused on providing the most important features of an incubator with the intention that less critical aspects would be improved in the future. Some work on Project Omoverhi has been continued outside of Santa Clara University by members from the first two senior design teams and the project is also available to be continued as a senior design project in the future.

One area that we hope to make improvements on is aesthetics. Aesthetics was less of a priority in our design because it does not directly impact the performance of the incubator. However, appearances can impact what hospital workers and patients' families perceive to be the capabilities of our device. Even if our incubator is capable for the application, if people do not have faith in it because of preconceptions based on its appearance compared to modern medical devices, they may be less likely to use it. Future work in this area should be done with the goal of designing it to look more like a high quality medical device.

Our team had also hoped to work on thermal collection and storage systems but we were not able to in the time we had for our project. Future work on this would build on the work that was done in the first and second year projects to improve their systems and integrate them with the prototype incubator we developed. An Omoverhi incubator equipped with these systems is a step closer to being able to operate without the need for power from an electrical grid.

Work needs to be done on the manufacturing process to improve consistency and to optimize the design for large scale production. Consistency is necessary to guarantee each model of the Omoverhi incubator performs to specifications; as a medical device entrusted with the care of a vulnerable infant, it is important that it operates properly and as expected. The design of the system should also be modified so that it is possible to do most of the manufacturing efficiently on a large scale. This will reduce individual unit costs and allow our product to be made and distributed in greater numbers.

Outside of engineering goals, Project Omoverhi needs to work on building connections with aid organizations and people in places where the Omoverhi incubator might be effectively used. Work also needs to be done to find donors to fund the production of incubators or provide other useful resources. Some work has been done on a website for Project Omoverhi that will eventually help to facilitate the development of a community for donors, recipients, and engineers around the project.

10.2 Summary

The system we have developed is one of the most practical solutions for addressing the lack of proper care for infants affected preterm and other complications in impoverished regions. It is practical for use in these locations because it is capable of providing the most crucial aspects of patient care at a cost low enough that each unit can be funded by donors for several hundred dollars. It was also designed to address unique challenges present in the places it is intended to be used. Our prototype incubator was constructed from consumer available parts and materials with a minimal amount of complex tools and machinery. This design makes replacements for many parts capable of being bought or fabricated in the target areas of use. Our prototype is capable of maintaining a proper environmental temperature for a patient, which is the primary function of an incubator. Once set, the temperature is maintained automatically with the closed-loop control system which makes the system easy to operate. The Omoverhi incubator's battery allows it to work through blackouts, which are common in some places where this technology is needed, and makes it ready for use with photovoltaic panels, with the required ability to store power for nighttime usage. Heat for its operation can be provided by any hot water source. With photovoltaic panels and a heat source such as a solar water heater the Omoverhi incubator has the ability to operate without needing electricity from a power grid.

This project was successful in designing and constructing a working neonatal infant incubator optimized for use in developing countries. With additional work and funding, Project Omoverhi has the ability to deploy incubators to places where they are needed to make a positive difference.

Appendix A: Bibliography and References

Bello, A., 2010, Pediatrician at Citizen Medical Centre, Lagos, Nigeria, private communication.

Campbell, David. E-mail Interview. 30 October 2012.

"Deep Cycle Battery FAQ." *Batteriesinaflash.com*. Batteriesinaflash.com, n.d. Web. 13 June 2013. <http://www.batteriesinaflash.com/deep-cycle-battery-faq>.

"Infant Reflux." *Mayo Clinic*. Mayo Foundation for Medical Education and Research, 28 Mar 2013. Web. 7 Jun 2013. <http://www.mayoclinic.com/health/infant-acid-reflux/DS00787>.

Liu, W. F. "The Impact Of A Noise Reduction Quality Improvement Project Upon Sound Levels In The Open-Unit-Design Neonatal Intensive Care Unit." *Journal Of Perinatology* 30.7 (2010):

489-496. *Academic Search Complete*. Web. 3 June 2013.

"Preterm Birth." *WHO*. World Health Organization, n.d. Web. 7 Apr. 2013.

"Properties of Aluminum." *Hydro.com*. Hydro.com, 6 Sept. 2012. Web. 10 June 2013.

<http://www.hydro.com/en/Subsites/NorthAmerica/Aluminum/Properties-of-Aluminum/>.

"Reproductive Health." *Centers for Disease Control and Prevention*. Centers for Disease Control and Prevention, 21 Mar. 2013. Web. 9 Mar. 2013.

Staff, Mayo Clinic. "Premature Birth: Complications." *Mayo Clinic*. Mayo Foundation for Medical Education and Research, 29 Dec. 2011. Web. 6 Apr. 2013.

"Sheet metal materials." Technical Reference. 2004. DSM Manufacturing Company. 09 June 2013 <http://www.precisionsheetmetal.com/home/materials.htm>.

Tereza Yoshiko Kakehashi, et al. "Noise At The Neonatal Intensive Care Unit And Inside The Incubator." *Revista Latino-Americana De Enfermagem (RLAE)* 19.5 (2011): 1214-1221. *Academic Search Complete*. Web. 3 June 2013

“Vote for DtM Neonurture Incubator in the 2010 People’s Design Award.” design that matters. 08 Oct. 2010 < http://designthatmatters.org/news/dtm-blog/2010/10/vote_for_dtms_n.php>

Appendix B: Medical Professional Correspondence

David Campbell

An incubator is designed to look at far more environmental parameters then temperature. Relative to temperature, monitoring is very sophisticated. There are four types of heat loss in an infant. Ideally the incubator mitigates all forms of heat loss as the goal is to reduce expended kilocals for mitigating temperature gradients from normathermia and shifting them to metabolic activities of building tissues that are premature to life sustaining function. The four types of heat loss are conductive, radiant, convective and transdermal. Conductive heat loss relates to surface contact either to foreign mass or atmosphere and is the most common perceived. Radiant Heat loss is much more profound as the infant radiates to the walls of a gradient temperature mean of the inside atmosphere and that of the outside. Think of standing in a warm shower next to a cold window and how cold it is outside of the water stream. Most incubators use a double wall design to insulate this type of loss with the inner wall at normothermic ambient to set point. Convective heat loss is also profound. Air must be constantly circulated thru the device to maintain proper O_2/CO_2 concentration and ambient set temp, resulting in heat loss due to air movement. Again, think of how fast your hair dries out in a wind or with a blow dryer. The ideal air movement is less than 8 cm per second across the skin surface, but at the same time the unit must respond to loss of atmospheric temp when opened and closed for clinical intervention. The rapid movement to these invasive demands can heat stress critical newborns. Rapid responses create overshoots and undershot corrections that are disguised by averaging algorithms to suppress alarms. Modern incubators use air channeling across inlet ports to provide an air curtain to retard atmosphere loss during intervention.

The final form of heat loss is transdermal. Generally this relates to humidity. Air water content is profound both above and below ideal set point. Think of a cold fog in San Francisco versus cold air in the mountains. Or, on the heat side, a warm day in Arizona versus Mississippi humidity. Insensible water loss is a big factor in heat mitigation in the newborn and humidity regulation is tricky. In Europe, incubators using swamping to keep high humidity that is finely controlled. Problem with this technique is bacterial colonization that can quickly occur.

There is no ideal set point for temperature. Many algorithms are in dispute that assign set point temp to gestational age and weight. 36 degrees C is normal in a newborn. Keep in mind a premie has no skin at is HIGHLY susceptible to heat loss and temp variations. Drager has a graphical calculator to depict appropriate temp based on gestational age and weight, but it is not multi center validated.

Incubators have more environmental concerns then temperature. Noise is a serious concern. Outside, to the mature ear they are very quite. Put your head in one. It is like a sound chamber. Sound levels should be below 45 decibels to be credible. Lower if possible. Any port openings should be designed to have a soft opening and closure sound Also ,temp recovery time when opened is a concern. To fast and you have overshoots. To slow and the infant suffers.

Finally, for now, temperature sensor placement on the infant for the servo feedback loop is important. This also is the subject of much debate. Fleshy areas well perfused are best and temp sensors should be disposable.

Dr. Amina Bello

1. What is your name?

    Dr Amina Bello

2. What hospital/facility do you practice in and what is your title?

    Citizen medical centre ikoyi, lagos/Private hospital. Pediatrician

3. What is your education?

    MB.,BS. FMCPaed

4. Do you have experience with medicine/medical devices in underdeveloped countries?

    Yes

5. With your experience in the medical field in Nigeria, do you find that there are many issues with incubators and premature infants?

    Yes. What are the main causes of premature deaths? Infections, Respiratory distress syndrome, Neonatal jaundice and anemia, Asphyxia and Birth defects

6. Do you have functional incubators in your hospitals? If so, how many?

    Yes, Two

7. Do you think a solar powered incubator would be ideal for underdeveloped locations where electricity is an issue? In your facility?

    Yes

8. Do you feel that there is a definite need for this kind of device in third world countries? Your hospital?

    Yes

9. When do you need an incubator?

    For preterm low birth weight babies and some very ill term babies.

10. How often do you use incubators?

    Frequently

11. What aspects of an incubator do you use?

Temperature control, Humidity.

12. What would make the incubators you use better?

Providing Cardiac and Respiratory monitors, and Alarms.

13. What is the biggest problem you find with incubators? If no problem, how would you suggest improvement of current market incubators?

(no response for this question)

14. What crucial aspects must an incubator address?

Temperature control, Humidity, Oxygenation, Protection(barrier) from infection

15. In what order would you rank the necessity of humidity, heat, oxygen, bed tilt? Why?

Heat, Oxygen, Humidity, Bed tilt

16. What data/ sensors do you need to operate the incubator?

(no response for this question)

17. What are the current power supplies for the incubators you currently use?

220V - 50HZ

18. What medical equipment do you have at your disposal that aide the use of an incubator?

19. What is your preferred way to access the baby?

Through the operating windows and sometimes the front door.

20. What is the average range of time babies at your hospital spend in an incubator?

For preterm low birth weight babies, one to four weeks, for term ill babies, 3 days to 2 weeks

21. How many incubators are used at one time?

Two

22. What percentage of all new babies at your hospital would you say need an incubator?

20 to 25%

23. What is the average age of babies in your incubators?

30weeks

24. How young can the babies be?

28weeks

25. What are other needs of a premature infant besides an incubator that you would need access to?

Parental nutrition, Surfactant.

26. Would a Solar Powered Incubator be a device you would want implemented in your hospital? [this would be free of charge – for initial observation/evaluation]

Yes

If Yes,

a. Do you believe your hospital could sustain a solar powered incubator?

Yes

b. Is the hospital air-conditioned?

Yes

c. On average, how often does your hospital have electricity?

Every day on generator supply, Few hours or no supply a day from national power supply

d. Do you have a backup generator? How often is it used?

Yes, Everyday

e. How tall is the building?

One story building

f. Would you say the hospital is in a shady region or a sunny region?

Sunny

RESOURCES?

- What resources does the hospital have? (capabilities, distilled water, compressed gas, roof space, un-purified water for tank) All of the above

- What is the building like? (picture of building?, size, location, # of stories, roof space, distance of roof to floor etc.) Its located at ikoyi south west, a suuny area, one story building, free roof pace.

- Does the building have AC? How hot/cold will the inside temperature be (not an average, but highs and lows)? Yes

Olukemi Tongo

1. What is your name? Olukemi Tongo

2. What hospital/facility do you practice in and what is your title? University College Hospital Ibadan, Nigeria

3. What is your education? MBChB, FWACP

4. Do you have experience with medicine/medical devices in underdeveloped countries? Yes

5. With your experience in the medical field in Nigeria, do you find that there are many issues with incubators and premature infants? What are the main causes of premature deaths? (main causes of death in preterm infants) Infection, thermal control, metabolic derangements

6. Do you have functional incubators in your hospitals? If so, how many? Yes, 10

7. Do you think a solar powered incubator would be ideal for underdeveloped locations where electricity is an issue? In your facility? Yes, because power supply is a major challenge in recent times. We currently experience several hours of power outage on a daily basis

8. Do you feel that there is a definite need for this kind of device in third world countries? Your hospital? Definitely Yes

9. When do you need an incubator? When there are small preterm babies or term babies who are ill and have need for good thermal control and for ease of observation

10. How often do you use incubators? Daily, we need as many as 12 – 14 at any given time

11. What aspects of an incubator do you use? Warmer, bed tilt, humidifier, temperature monitors, some with phototherapy

12. What would make the incubators you use better? Warming mattress, double walls to minimize heat loss during power outages and when opened

13. What is the biggest problem you find with incubators? If no problem, how would you suggest improvement of current market incubators? Battery back up, the need to use humidifier adds to the risk of infection and distilled water is not readily available, would prefer if it is not necessary as this environment has high relative humidity

14. What crucial aspects must an incubator address? Autoregulation of thermal control with too high or too low alarms and possibly apnea alarms

15. In what order would you rank the necessity of humidity, heat, oxygen, bed tilt? Why? Heat, bed tilt, humidity, oxygen

16. What data/sensors do you need to operate the incubator? Temperature probes – skin and air, thermoneutral settings, environmental temperature and humidity sensors

17. What are the current power supplies for the incubators you currently use? Electricity

18. What medical equipment do you have at your disposal that aide the use of an incubator?

19. What is your preferred way to access the baby? Through the incubator vents but sometimes the entire side has to be opened for procedures

20. What is the average range of time babies at your hospital spend in an incubator? Highly variable from few days to as long as 4 weeks depending on size on admission

21. How many incubators are used at one time? 8 – 10 (we sometimes require more)

22. What percentage of all new babies at your hospital would you say need an incubator? Roughly, 45% of admitted newborns

23. What is the average age of babies in your incubators? From birth till 4 weeks

24. How young can the babies be? Immediately after birth, gestational age 26 weeks

25. What are other needs of a premature infant besides an incubator that you would need access to? Phototherapy, multiparameter monitors, blood gas analysers, cutaneous jaundice meters

Hospital Environment

- What resources do you have? (capabilities, distilled water, compressed gas, roof space, un-purified water for tank)

- What is the building like? (size, location, # of stories, roof space, distance of roof to floor etc.) (maybe pick one building for now or have a list of possible buildings?)

-Do you have AC? How hot/cold will the inside temperature be (not an average, but highs and lows)?

- Capabilities; A 22 bed ward, we provide intensive neonatal care to all categories of newborns in our setting(inborn & outborn). We have another neonatal ward in the hospital for the outborn only as well.

- We do not have adequate/regular supply of distilled water as we do not have a distiller of our own, but we get it from the hospital pharmacy

- We use movable oxygen cylinders for oxygen by patient bedside or piped through a central line. We have an air compressor which is also piped centrally but currently not functioning

- We have some roof space as we are on the last floor

- We have purified water with overhead tank as reservoir for the ward

- We have AC on the side of the ward where incubators are used (the ward is divided into 2 units).

- How hot - 34 degrees Celcius

- How cold 26 degree Celcius

The only fear I expressed in my mail to Dr. Fawole is that I may not be able to get approval for any of our incubators to be dismantled otherwise every other aspect seems workable. I hope you will find this information useful and timely.

Cheers,

Kemi

Appendix C: Design Calculations

The NTU method is a method that uses the characteristics of a heat exchanger, such as length, diameter, speed of the flow and the fluids that are flowing through the heat exchanger.

$$E = \frac{q}{q_{max}} \qquad NTU = \frac{UA}{C_{min}} \qquad C_r = \frac{C_{min}}{C_{max}}$$

It is based on these three values in essence. The NTU for which the method is named, stands for number of transfer units. It is a relationship between: U the overall thermal resistance of the system, A the surface area over which the heat exchanging is taking place and Cmin the smaller of the two fluids' specific heats. The value E is the ratio between the actual heat transfer, q, and the maximum theoretical heat that could be transferred qmax. Then the value Cr is the ratio between the two specific heats of the fluids. If the two fluids are the same then the value of Cr is 1. These three values are determined the same way for any setup of heat exchanger. Where the specifics for the type of heat exchanger comes into play is the equations for the efficiency of the heat exchanger.

Shell-and-tube

One shell pass (2, 4, . . . tube passes)

$$\varepsilon_1 = 2\left\{1 + C_r + (1 + C_r^2)^{1/2} \times \frac{1 + \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}{1 - \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}\right\}^{-1}$$

n shell passes (2*n*, 4*n*, . . . tube passes)

$$\varepsilon = \left[\left(\frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - 1\right]\left[\left(\frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - C_r\right]^{-1}$$

One shell pass
(2, 4, . . . tube passes)

$$(\mathrm{NTU})_1 = -(1 + C_r^2)^{-1/2} \ln\left(\frac{E - 1}{E + 1}\right)$$

$$E = \frac{2/\varepsilon_1 - (1 + C_r)}{(1 + C_r^2)^{1/2}}$$

n shell passes
(2*n*, 4*n*, . . . tube passes)

Use Equations 11.30b and 11.30c with

$$\varepsilon_1 = \frac{F - 1}{F - C_r} \quad F = \left(\frac{\varepsilon C_r - 1}{\varepsilon - 1}\right)^{1/n} \quad \mathrm{NTU} = n(\mathrm{NTU})_1$$

These are the equations that relate the three NTU values to the physical layout of the system. These equations are specific for shell-and-tube heat exchangers, which was the type of heat exchanger that was being designed for when these equations were being used.

In order to use these equations, the convective coefficients for the system needed to be determined. This is because the value for the overall thermal resistance is based on the conductive resistances through the pipes in the system, as well as the convective coefficients for the fluids flowing over the tubes. In order to determine this coefficient, the Nussult number first needs to be found.

$$Nu = \frac{hx}{k} \tag{1}$$

This is a unitless number that relates the convective coefficient, conductive coefficient of the fluid, and a characteristic length of the system, in this case the diameter of the pipe. This value is determined different ways for different situations. In our case the equation to determine is the equation for water flowing through a pipe is:

$$Nu = 0.0265 Re^{\frac{4}{5}} Pr^{0.4} \tag{2}$$

While the equation for determining the Nussult number for air flowing over a tube is:

$$Nu = 0.3 + \left(\frac{0.62 Re^{\frac{1}{2}} Pr^{\frac{1}{3}}}{\left(1 + \left(\frac{0.4}{\mathrm{Pr}}\right)^{\frac{2}{3}}\right)^{\frac{1}{4}}} \right) \left(1 + \left(\frac{Re}{282000}\right)^{\frac{5}{8}}\right)^{\frac{4}{5}} \tag{3}$$

The Reynolds number had to be determined for this value which is simply:

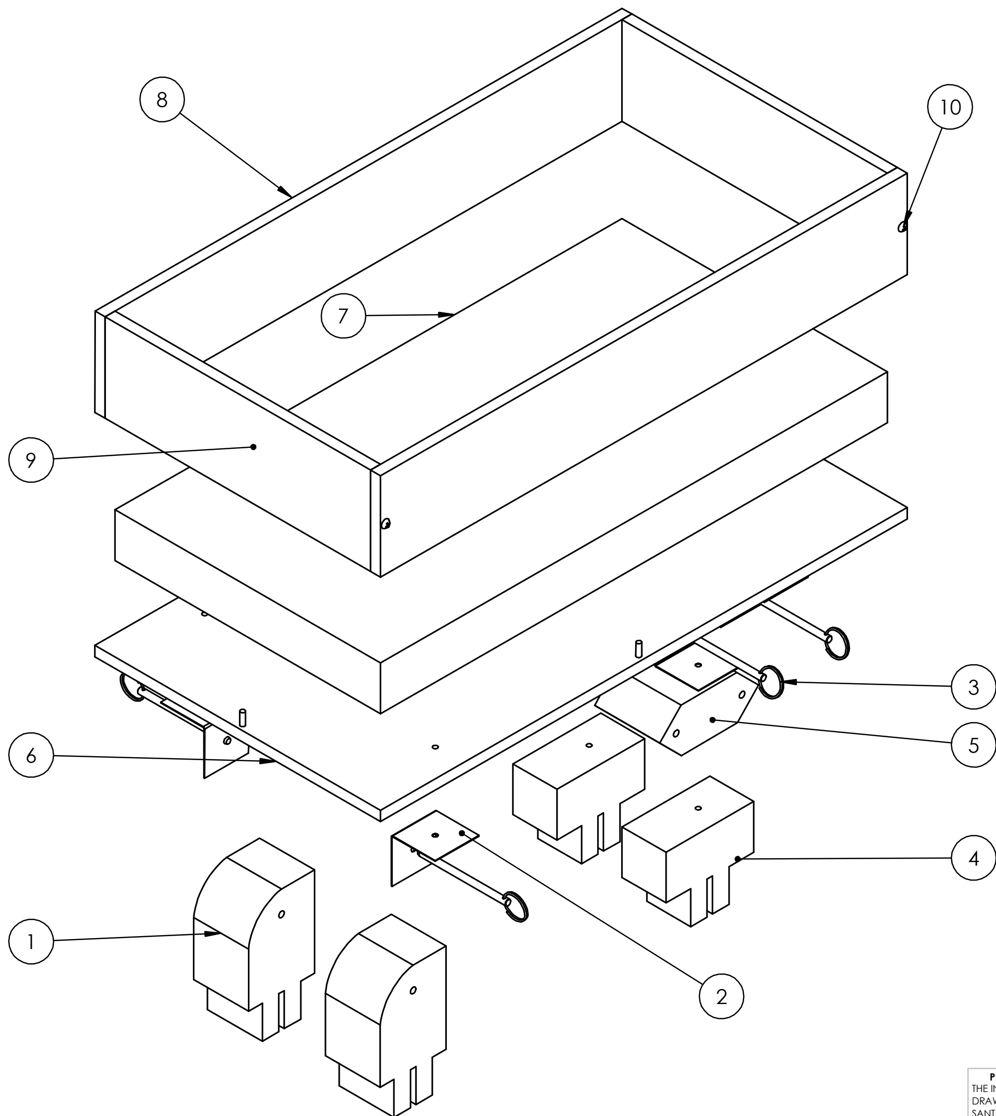
$$Re = \frac{Vd}{\nu} \tag{4}$$

The process for determining a proper length of copper to work for the design was first done by calculating a minimum length that would result in 36 degrees Celsius. The system that was created was 2.5 cm x 60cm x 90cm. This was a quick theoretical system that would be as efficient as possible. Using a maximum velocity of 0.72 meters per second, determined from the flow of 0.0108 cubic meters per second, which was in turn determined by the maximum speed of 8cm/s over the infant. The convective coefficients determined for the system were, h_{air} = 3.563. This value is so low that it is even below average values for natural convection. The water convective coefficient was determined by equation 2 and with a velocity determined by the pump that was implemented by the 2010-2011 team, was set at 2.354 meters per second. The coefficient was found to be 1.175×10^4. Seeing as the thermal resistance value is determined by the inverse of the convective coefficient, it can be noticed that the air speed would have a much stronger impact on an outlet temperature of the air than the flow of the water would. Once these values were implemented into the NTU method equations, a length was determined through the surface area part of the NTU value for a half inch diameter pipe at 5.639 meters. This value was determined to be far too much and a simple change to the system was proposed, that some baffles are added which would redirect the air, increasing the velocity without changing the volume of air flowing through the system. Once these baffles were added then the velocity of the air was increased to 3.6 meters per second, which correlated to a new required length of piping of only 0.44 meters.

These calculations were performed to get a sense of length of piping that would be required to heat the air to within the desired temperature range. The same equations were performed, only in reverse, with a set length of piping of 2 meters. This was to test if the current design of the heat exchanger would be effective. This length of piping, with the exact same setup was determined to heat the air to 43.7 degrees Celsius. These calculations led to the assumption that the designed length of piping would be sufficient to heat the air all the way to 43 degrees which should be enough to maintain the temperature of the incubator. However, the actual system as designed was not calculated, because the enclosure in which the heat exchanger was in was not infact 2.5 centimeters deep, and the baffle system could not be built as designed, nor could the inlet and flow of air be as designed. This resulted in the system not operating exactly as calculated.

After the dimensions of the piping were determined, further calculations were conducted to see how the system would respond to an increased airflow. The First Law of Thermodynamics would state that the more volume of cold air entering the system the colder the temperature of the outlet would be lower. However as the airspeed increases the convective coefficient increases. The relation to the increase of heat transferred due to this increased convective coefficient and the increased volume of flow was determined. The same calculations were conducted again and it was concluded that, at least theoretically, an increase of airflow, within our operating bounds, would correspond to an increase in outlet air temperature.

Appendix D: Detail and Assembly Drawings

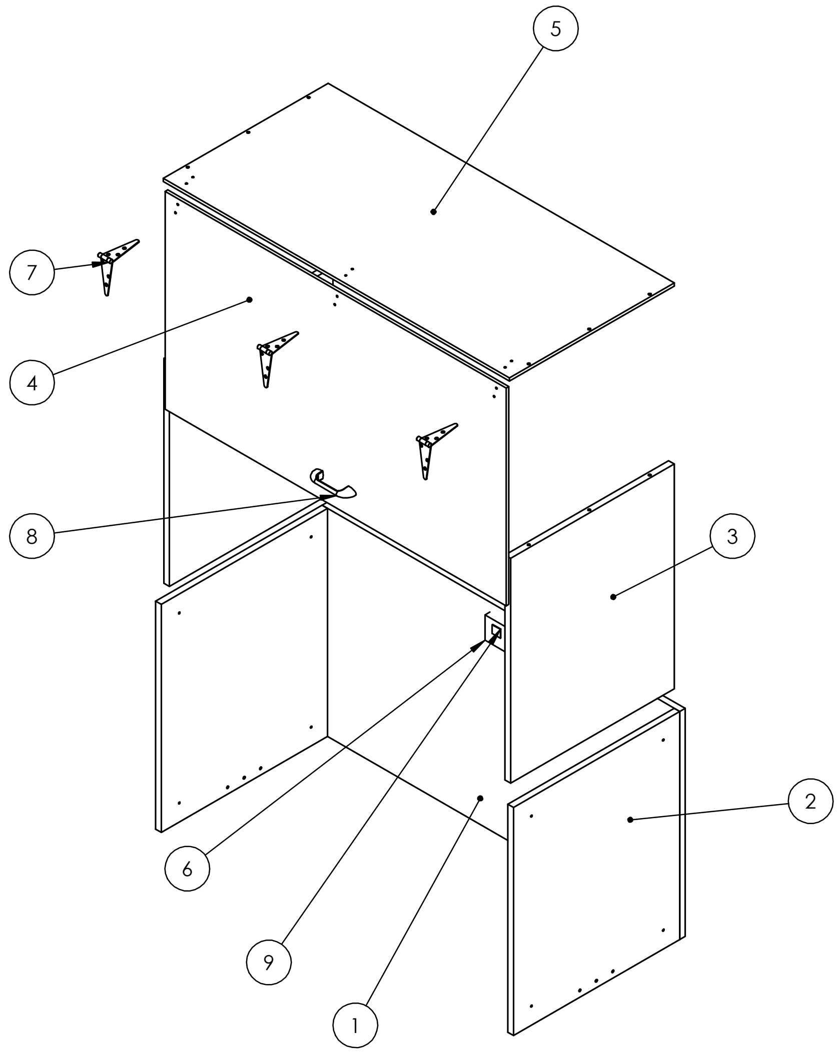


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6.5	Wood Bed Back Legs	2
2	6.4	Sheet Metal Bed Bracket	6
3	98404A155	Pins	4
4	6.6	Wood Bed Front Legs	2
5	6.7	Wood Bed Front Support	1
6	6.0	Wood Bed Base	1
7	6.3	Bed Noise Canceling Foam	1
8	6.1	Wood Bed Front and Back	2
9	6.2	Wood Bed Left and Right Side	2
10	CR-RHMS 0.19-32x1x1-N	Screws	8

SCALED 1:8

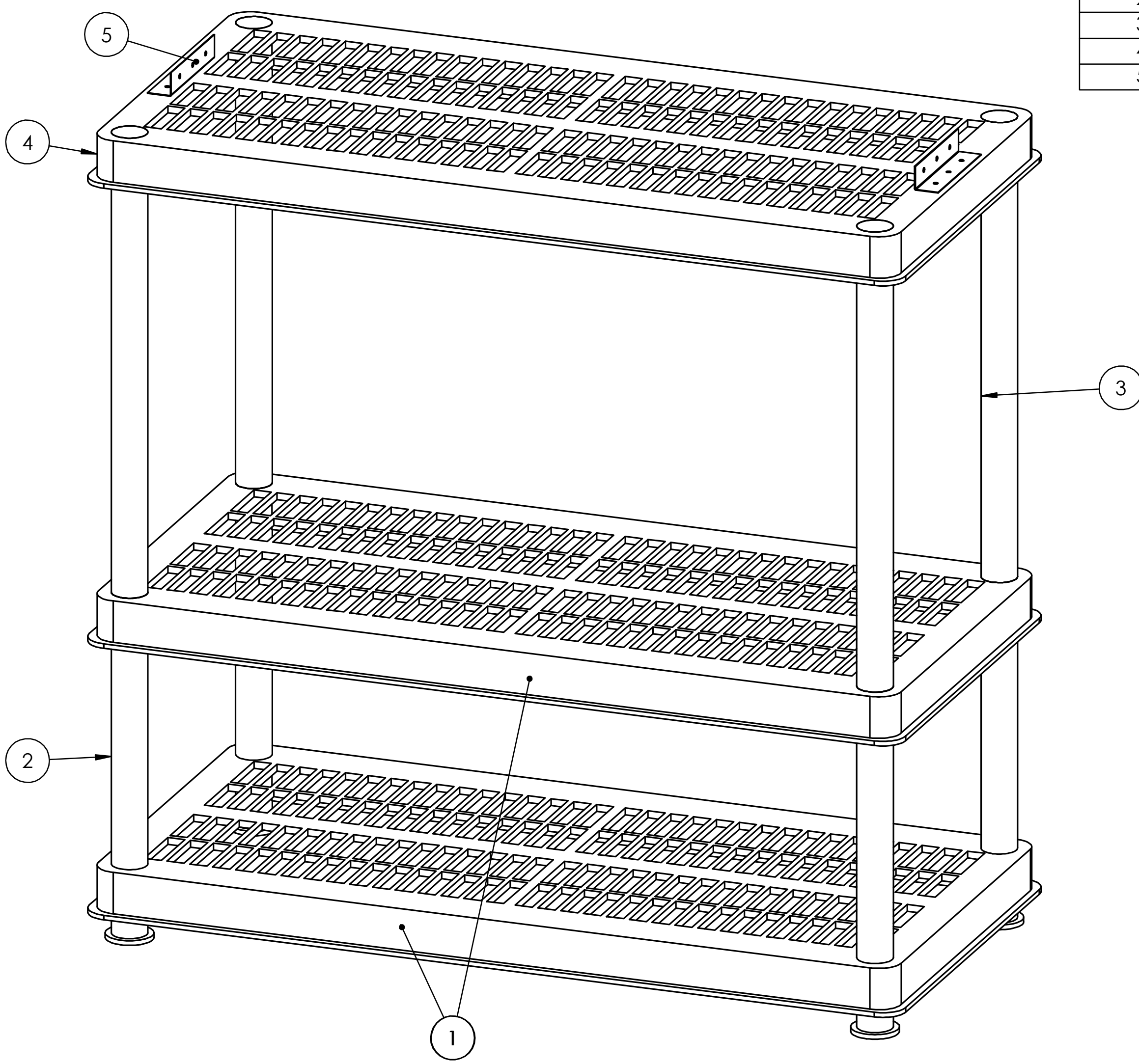
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Project Omoverhi
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/8/13	TITLE: Bed Assembly
MATERIAL	COMMENTS:			SIZE B DWG. NO. A1 REV 00
FINISH				SCALE: 1:4 WEIGHT: SHEET 1 OF 1
DO NOT SCALE DRAWING				

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1.2	Back of Shell Assembly-Wood	1
2	1.3	Outside SIde for Shell Assembly-Wood	2
3	1.4	Inside Side for Shell Assembly-Wood	2
4	1.0	Front Acrylic	1
5	1.1	Top Acrylic	1
6	1.5	Acrylic and Temperature Holder-Wood	1
7	1526A44	Strap Hinge	3
8	1815A52	McMaster-Carr Handle	1
9	SHT15 Breakout	Humidity and Temperature Sensor	1



SCALED 1:12

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Project Omoverhi
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/8/13	TITLE: Shell Assembly
MATERIAL	COMMENTS:			SIZE B · DWG. NO. A2 · REV 00
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:8 · WEIGHT: · SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	17601099	HDX Shelves	2
2	17601099	HDX Legs	4
3	2.1	Top Legs	4
4	2.0	Top Shelf	1
5	2.2	Structural Support Bracket	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/8/13

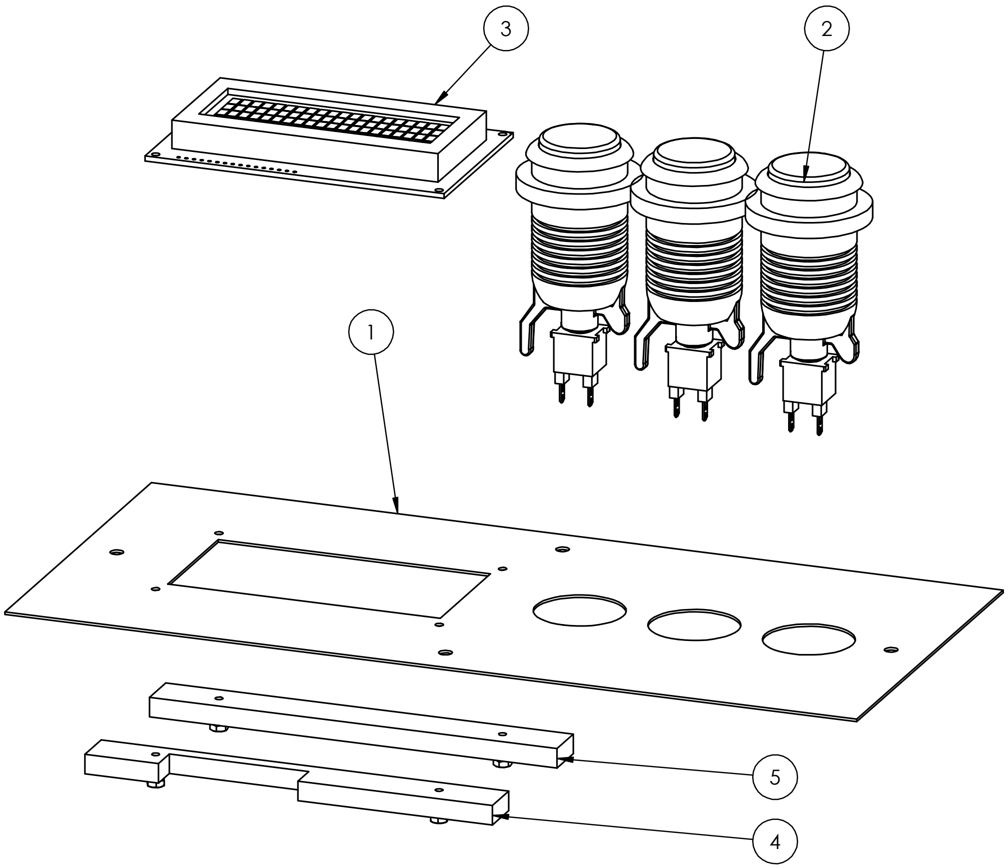
MATERIAL
FINISH
DO NOT SCALE DRAWING
COMMENTS:

Project Omoverhi

TITLE:
Structural Support Assembly

SIZE B | DWG. NO. A3 | REV 00
SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3.1	LCD Holder Enclosure	1
2	RTL-10432	Sparkfun Arcade Buttons	3
3	GDM2004D	Sparkfun LCD 20x4 Screen	1
4	5.3	Acrylic Top LCD Holder	1
5	5.4	Acrylic Bottom LCD Holder	1



SCALED 1:2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/8/13

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MATERIAL

FINISH

DO NOT SCALE DRAWING

COMMENTS:

Project Omoverhi

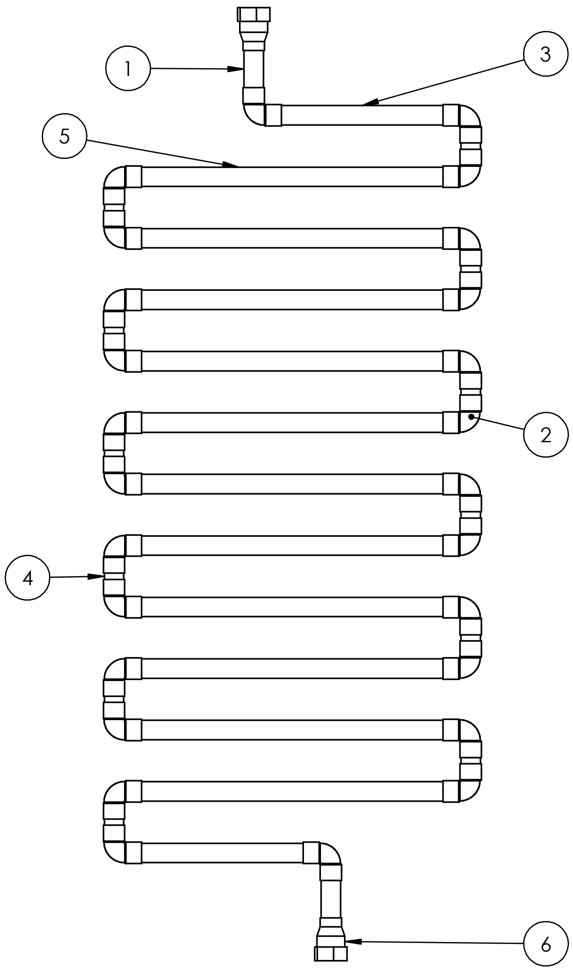
TITLE:

LCD Holder
Sub-Assembly

SIZE **B** DWG. NO. A4 REV 00

SCALE: 2:3 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4.5	Copper Entrance and Exit Pipe	2
2	5520K166	McMaster-Carr 90 Degree Copper Elbow	26
3	4.3	Small Length Copper Pipe	2
4	4.4	Fittings Copper Pipe	12
5	2.8.14.2	Long Length Copper Pipe	11
6	Solder-Joint Copper Tube Fitting	Solder-Joint Copper Tube Fitting	2



SCALED 1:8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/8/13

COMMENTS:

MATERIAL

FINISH

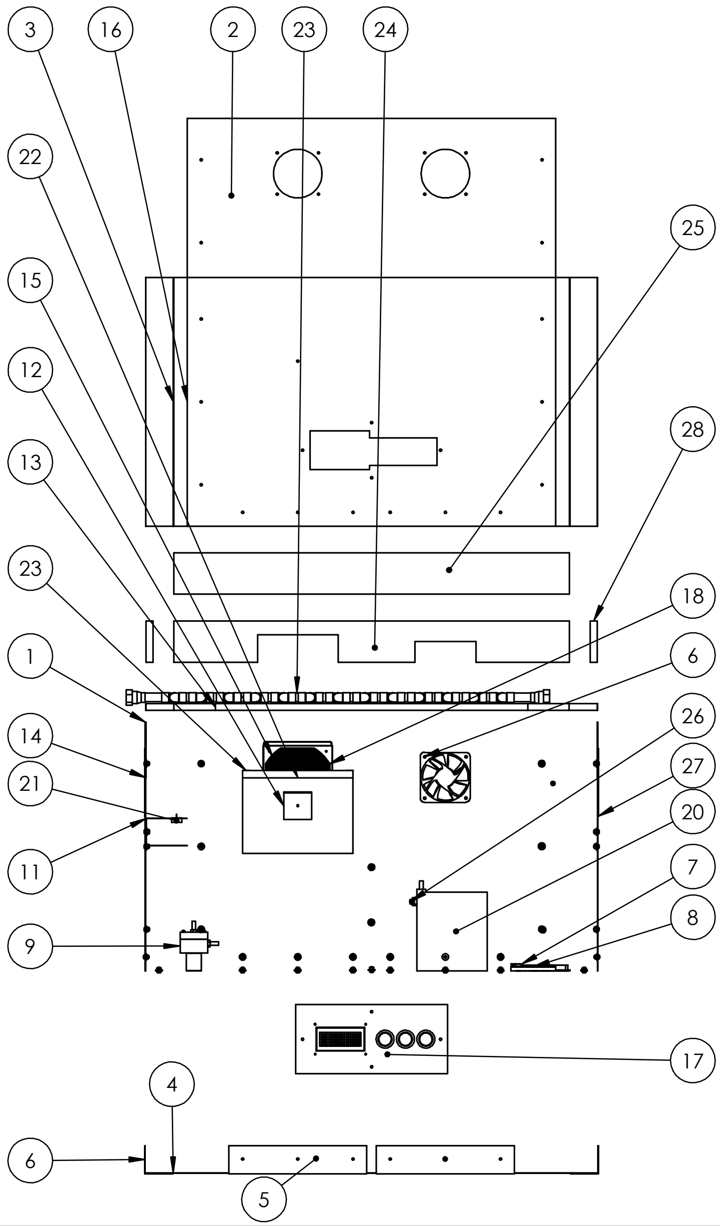
DO NOT SCALE DRAWING

Project Omoverhi

TITLE: Copper Pipe Configuration Sub-Assembly

SIZE B | DWG. NO. A5 | REV 00

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3.2	Outside Side Enclosure	2
2	3.0	Outside Back Enclosure	1
3	3.6	Outside Edge Enclosure	4
4	3.4	Outside Bottom Enclosure	1
5	3.5	Bracket Front Back Enclosure	4
6	3.7	Bracket Side Enclosure	2
7	ArduinoMega 2560	Micro-Controller	1
8	PRT-09567	Sparkfun MiniBreadboard	1
9	SHURflo 4008-101-E65	Shurflo Pump	1
10	A5	Copper Pipe Sub-Assembly	2
11	4.1	Inside Enclosure Voltage Reg. Bracket	1
12	4.0	Inside Enclosure Support Bracket	2
13	4.6	Bottom Base Insulation	1
14	3.9	Inside Pipe Cover Enclosure	2
15	0-761345-75002-8	Antec Fans	2
16	3.3	Outside Front Enclosure	1
17	A4	LCD Enclosure Sub-Assembly	1
18	XSPC EX120	Radiator	1
19	5.2	Radiator Holder	1
20	B008D5YG3G	35AH Battery	1
21	NTE970	12V Regulator	1
22	5.1	Directional Air Vent Ramp	1
23	5.0	Directional Air Vent Triangle	2
24	4.8	Insulation Back	1
25	4.7	Insulation Front	1
26	ST115	SPST 20A Switch	1
27	3.8	Outside Pipe Cover Enclosure	2
28	4.9	Side Insulation	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/8/13

MATERIAL

FINISH

DO NOT SCALE DRAWING

COMMENTS:

Project Omoverhi

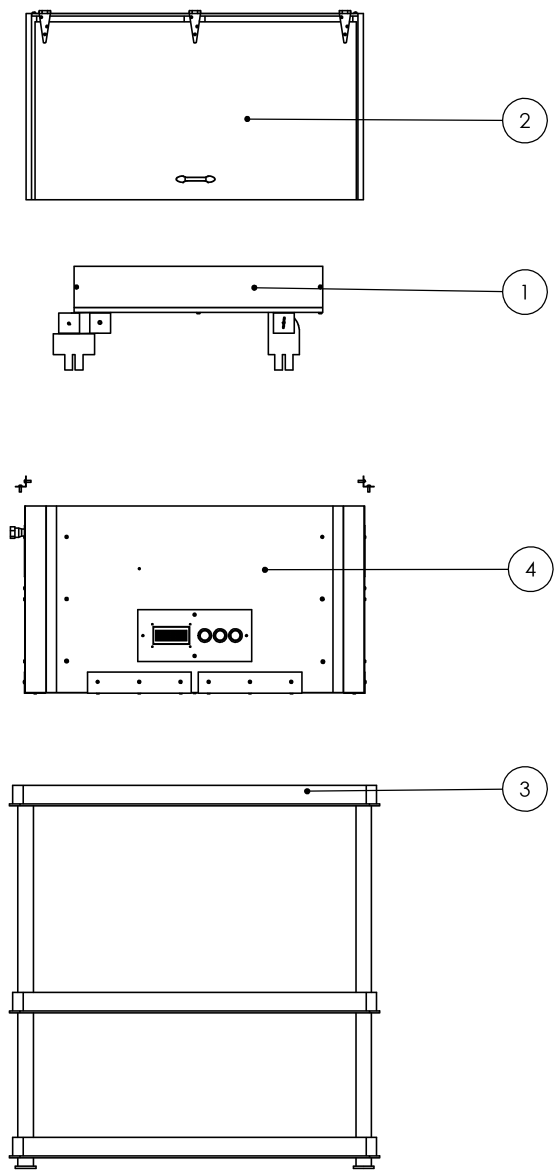
TITLE:

Enclosure Assembly

SIZE **B** DWG. NO. A6 REV 00

SCALE: 1:9 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A1	Bed Assembly	1
2	A2	Shell Assembly	1
3	A3	Structural Support Assembly	1
4	A6	Enclosure Assembly	1



SCALED 1:12

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/8/13

COMMENTS:

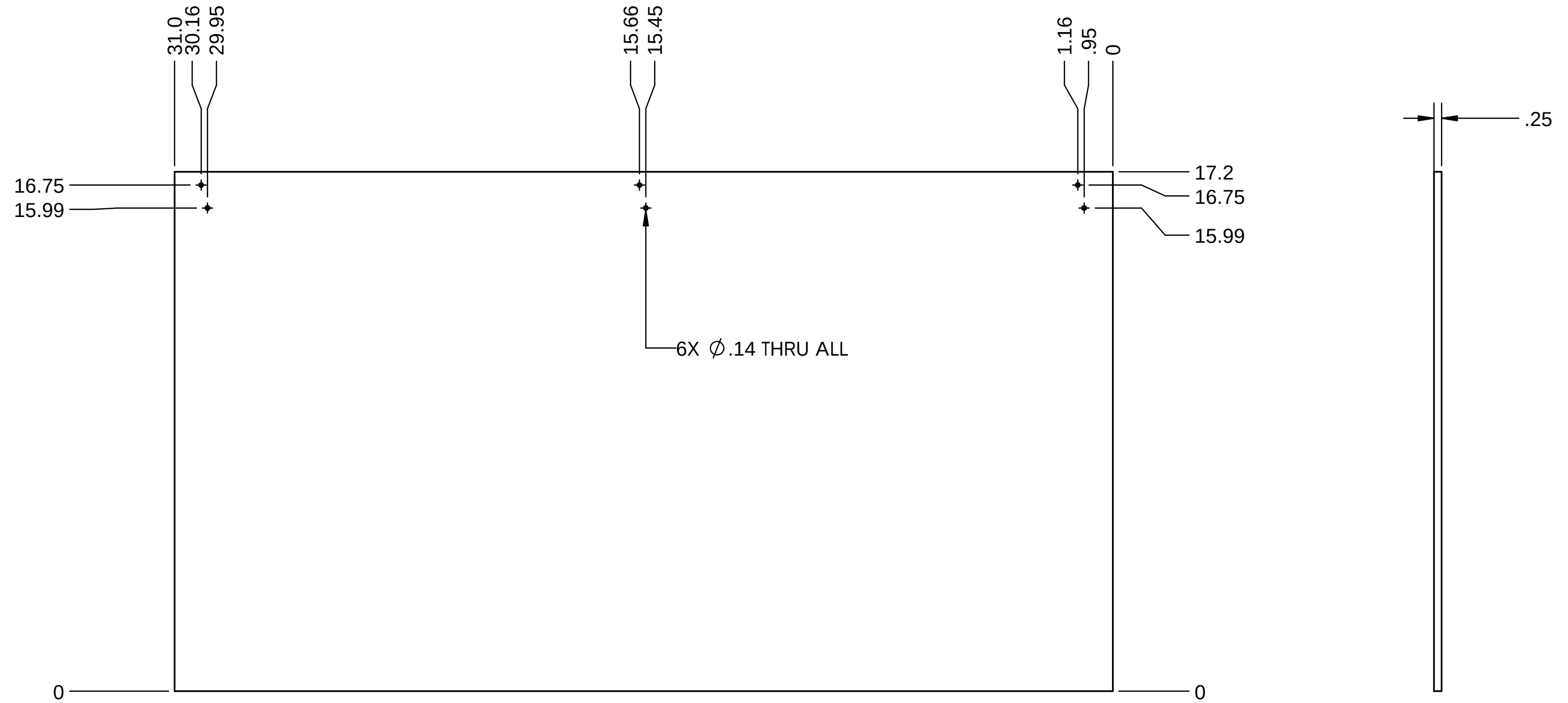
Project Omoverhi

TITLE:

System Assembly

SIZE B | DWG. NO. A7 | REV 00

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1



Actual thickness was set by manufacturer

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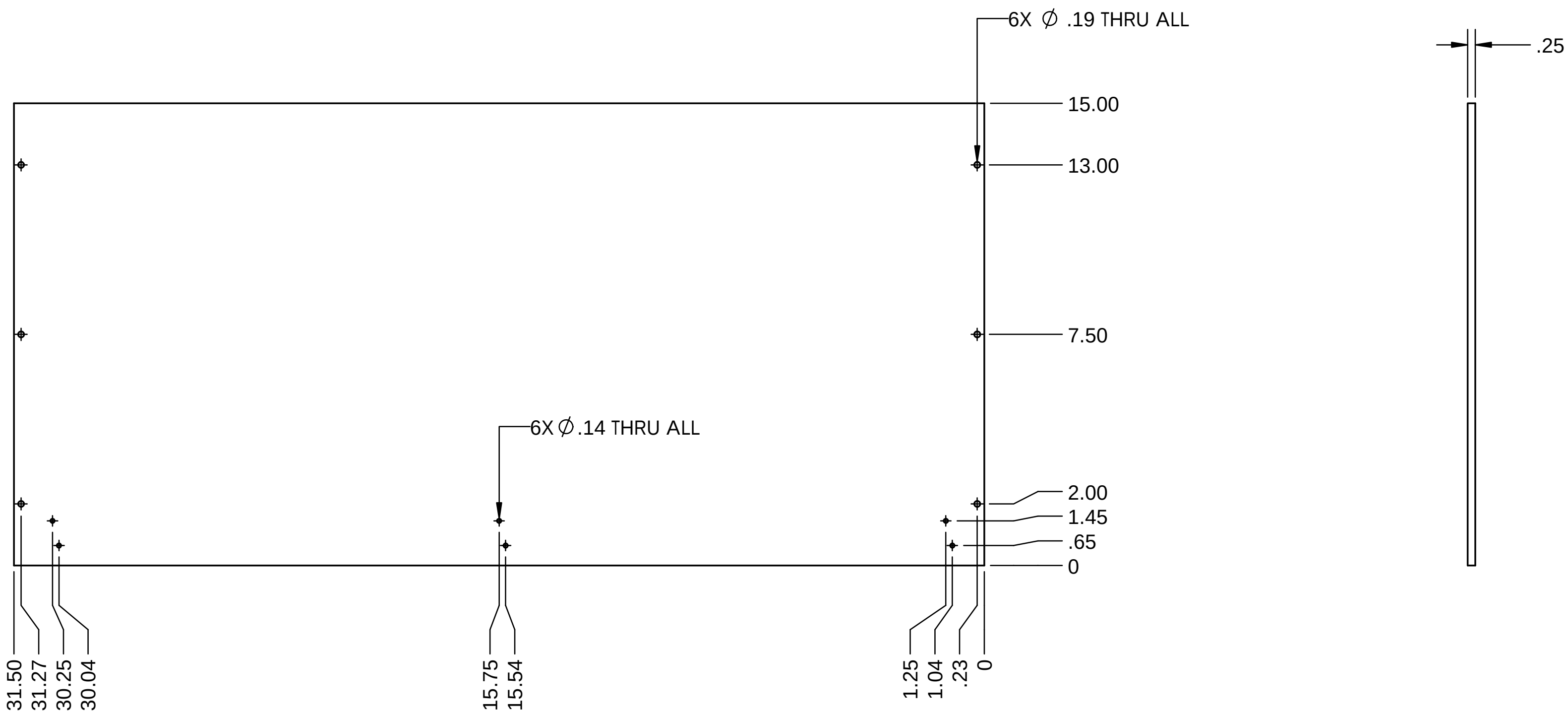
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/4/13
MATERIAL Acrylic	COMMENTS:		
FINISH No Finish			
DO NOT SCALE DRAWING			

Project Omoverhi

TITLE: Front Facing Door

SIZE	DWG. NO.	REV
B	1.0	00
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



Actual thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Acrylic
FINISH: None
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/4/13

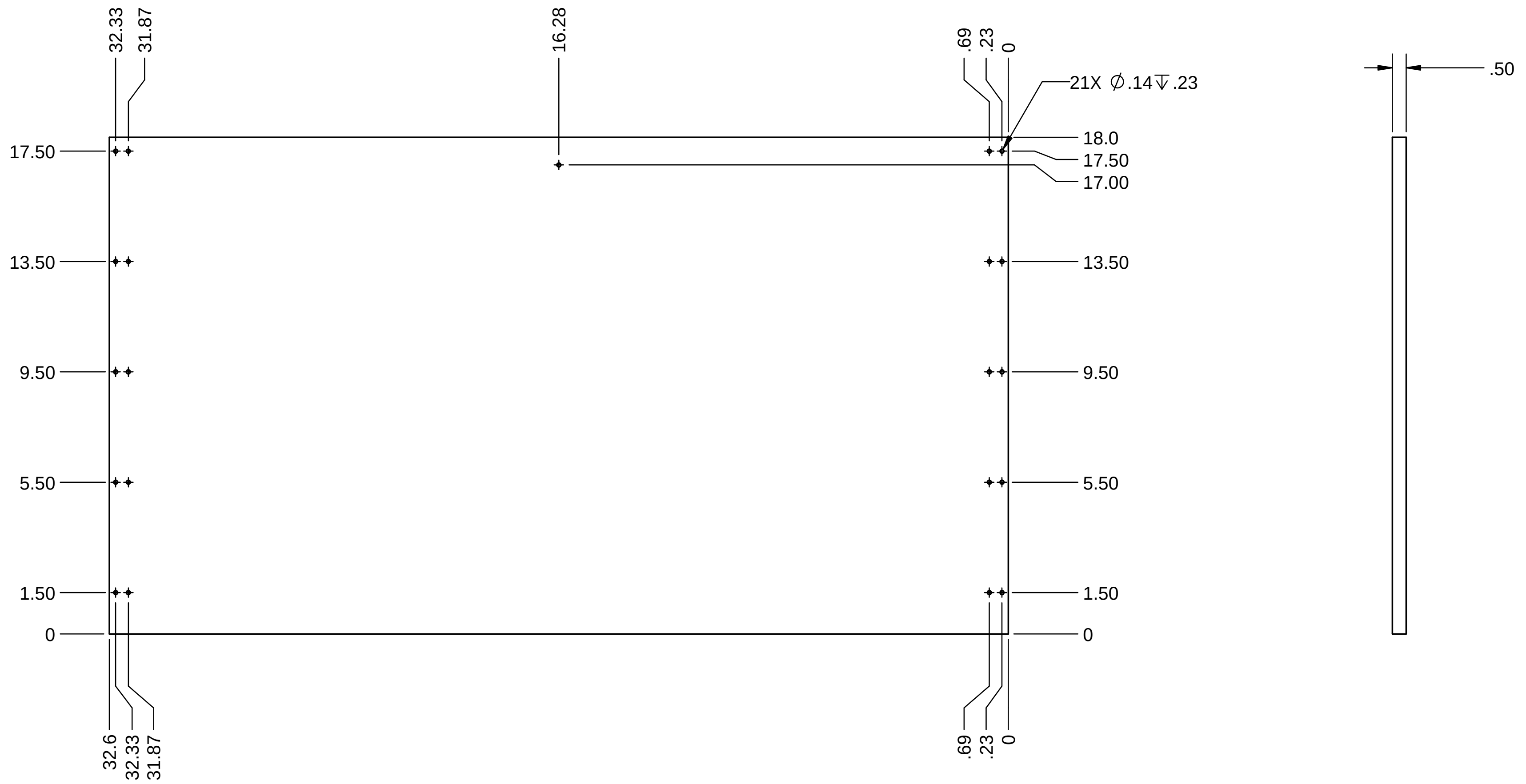
COMMENTS:

Project Omoverhi

TITLE: Top Piece of Acrylic for Shell

SIZE	DWG. NO.	REV
B	1.1	00

SCALE: 1:4 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Birch Plywood
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

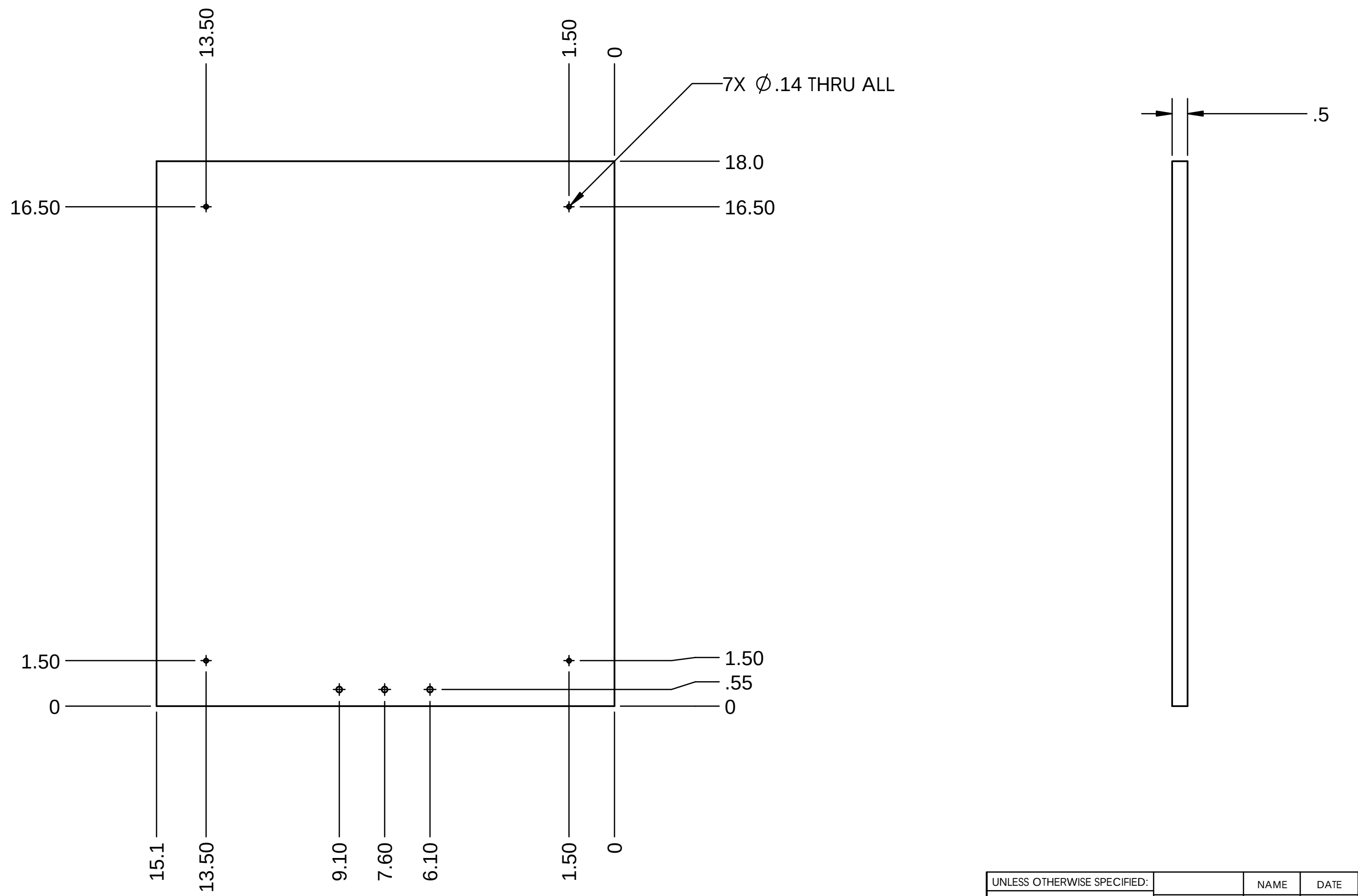
COMMENTS:

Project Omoverhi

TITLE: Back of the Shell Assembly-Wood

SIZE	DWG. NO.	REV
B	1.2	00

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



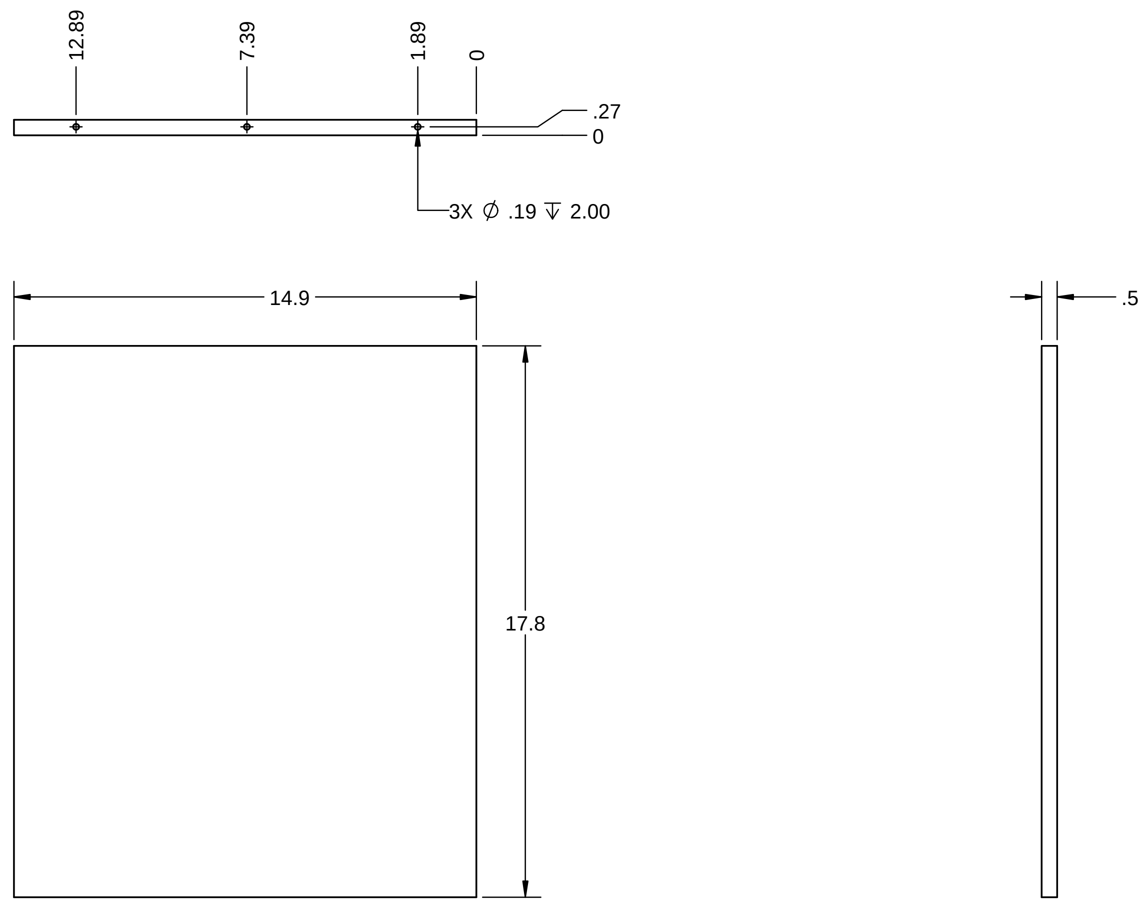
Project Omoverhi

TITLE: Outside Side for Shell Assembly

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/5/13
MATERIAL: Birch Plywood	COMMENTS:		
FINISH: Clear Lacquer Coat			
DO NOT SCALE DRAWING			

SIZE	DWG. NO.	REV
B	1.3	00
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

Thickness set by manufacturer



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Birch Plywood
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

COMMENTS:

Project Omoverhi

TITLE: Inside Side for Shell Assembly

SIZE: B | DWG. NO.: 1.4 | REV: 00

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

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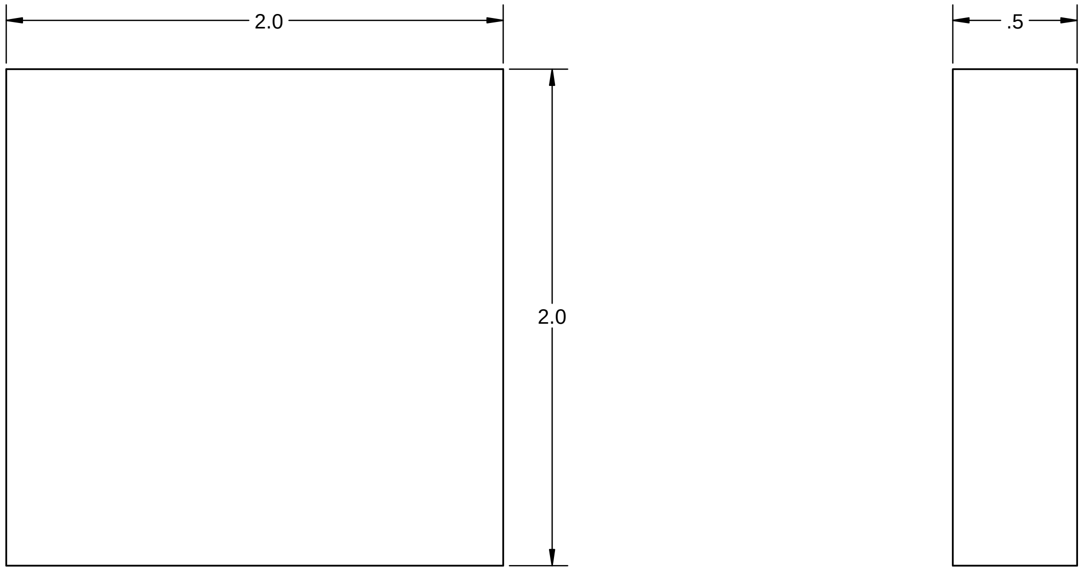

Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Birch Plywood
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

COMMENTS:

Project Omoverhi

TITLE: Temperature and Acrylic Holder

SIZE	DWG. NO.	REV
B	1.5	00

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

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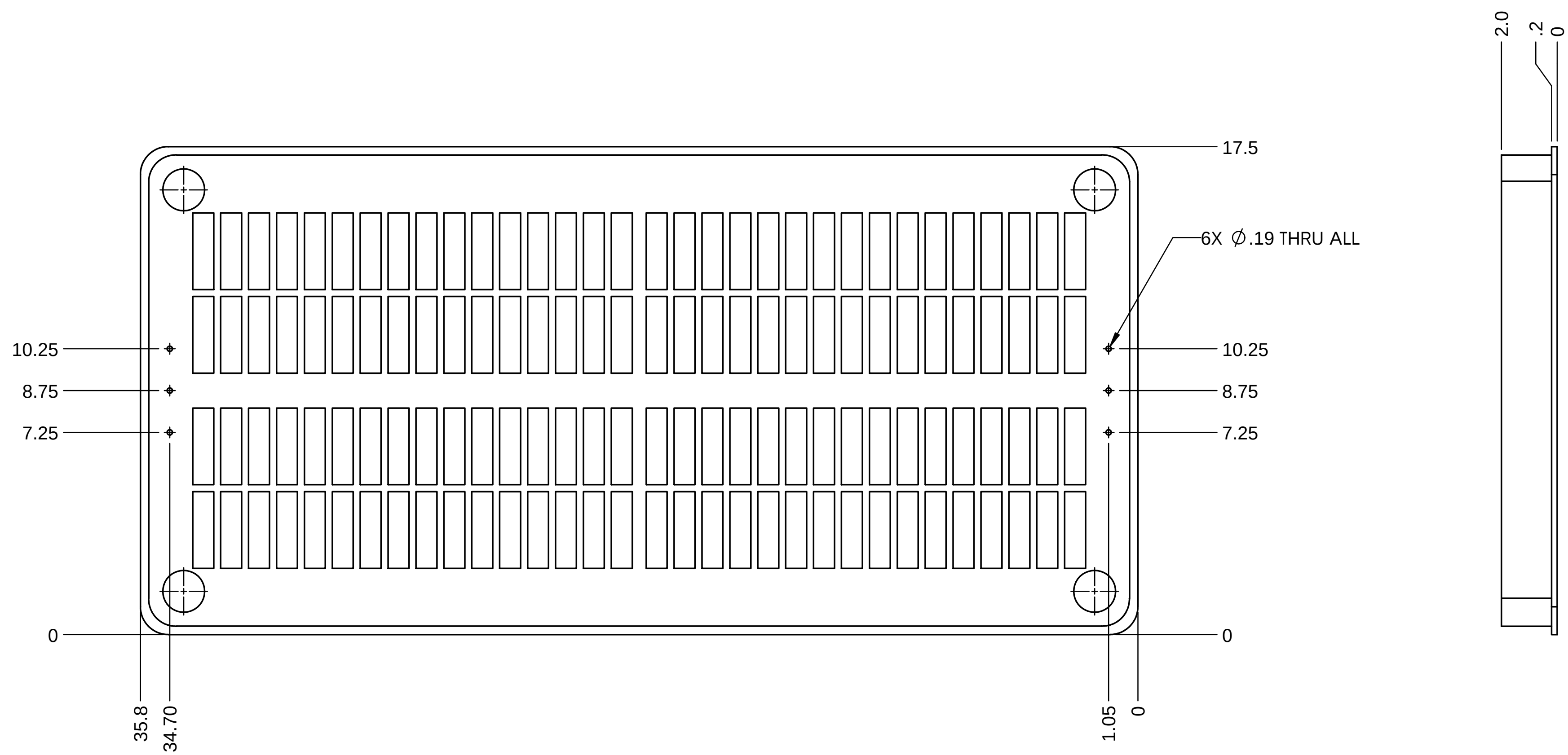

Only modification is holes. Thickness, width, length set by manufacturer.
Brand HDX
Purchased at Home Depot

UNLESS OTHERWISE SPECIFIED:	NAME	DATE
DRAWN	GG	6/5/13

DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

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MATERIAL N/A
FINISH None
DO NOT SCALE DRAWING

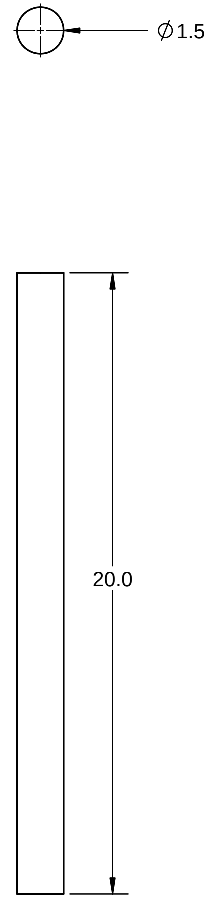
COMMENTS:

Project Omoverhi

TITLE: Top Shelf for Structural Support

SIZE B | DWG. NO. 2.0 | REV 00

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



Diameter is set by manufacturer
Brand HDX
Purchased at Home Depot

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UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Project Omoverhi
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/5/13	TITLE: Top Legs for Structural Support Assembly
MATERIAL Plastic	COMMENTS:			SIZE B
FINISH None				DWG. NO. 2.1
DO NOT SCALE DRAWING				REV 00
				SCALE: 1:4
				WEIGHT:
				SHEET 1 OF 1

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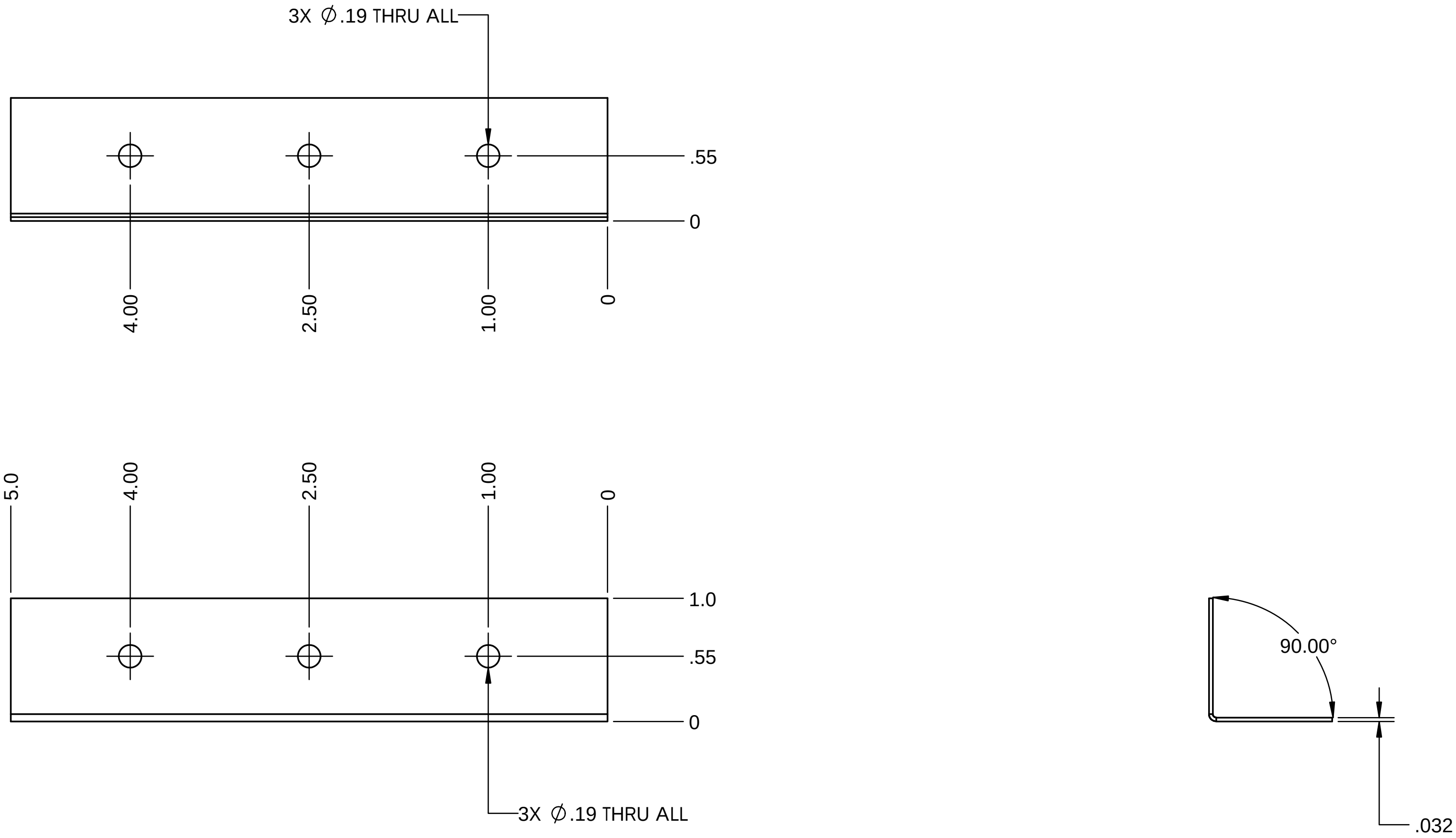

Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Aluminum 5052
FINISH: None
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

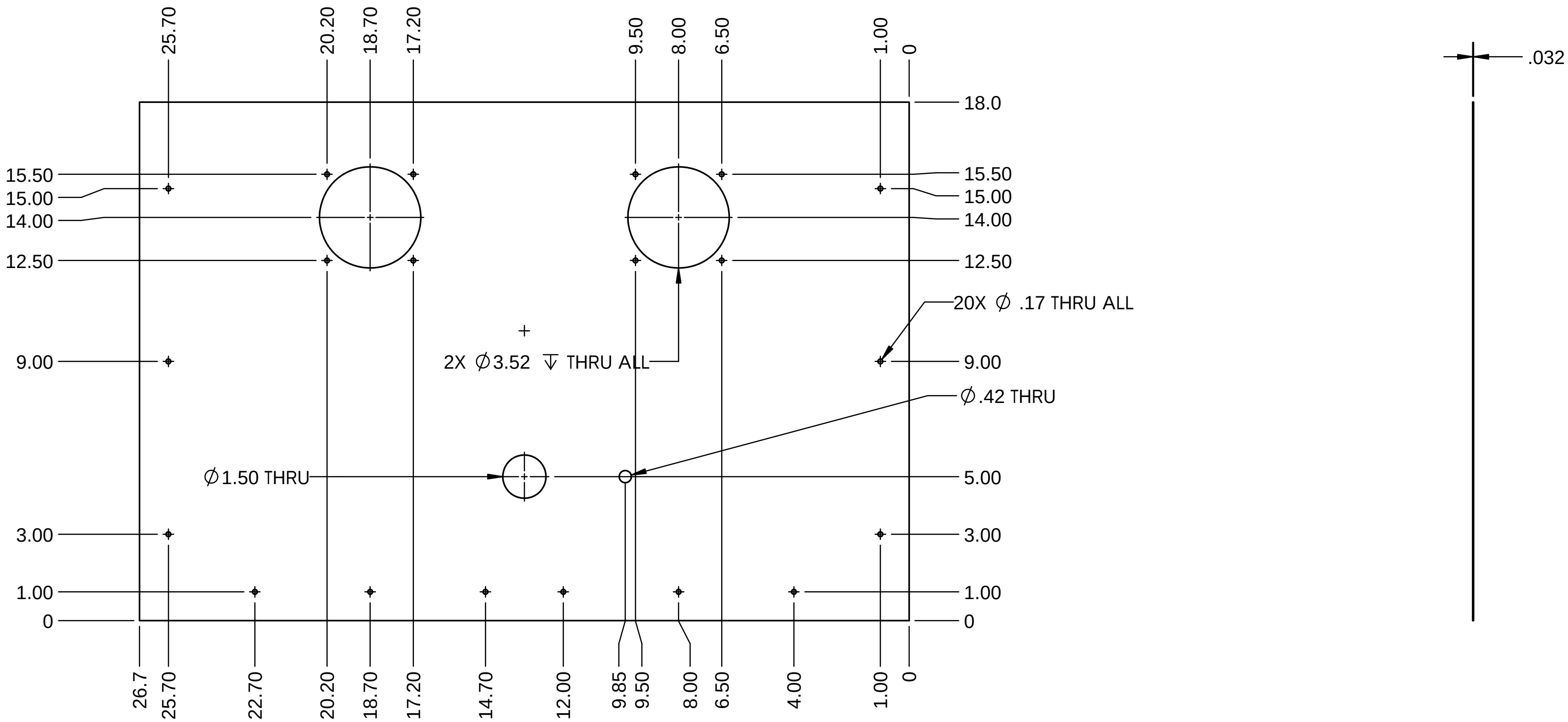
COMMENTS:

Project Omoverhi

TITLE: Structural Support Bracket

SIZE: B | DWG. NO. 2.2 | REV 00

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	2/4/13
	Revision	GG	6/5/13
MATERIAL: Aluminum 5052	COMMENTS:		
FINISH: None			

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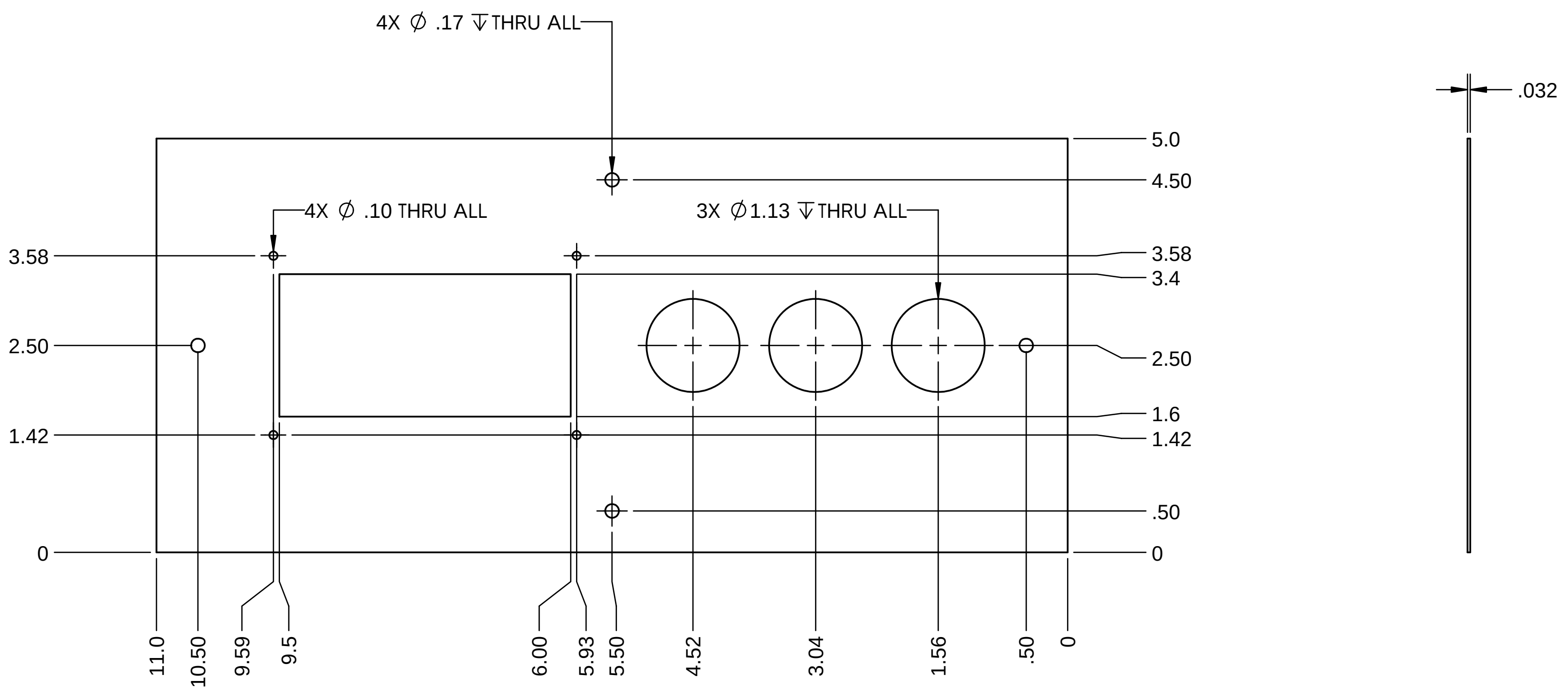
Project Omoverhi

TITLE: Outside Back Enclosure

SIZE	DWG. NO.	REV
B	3.0	00
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL Aluminum 5052
FINISH None

	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/5/13

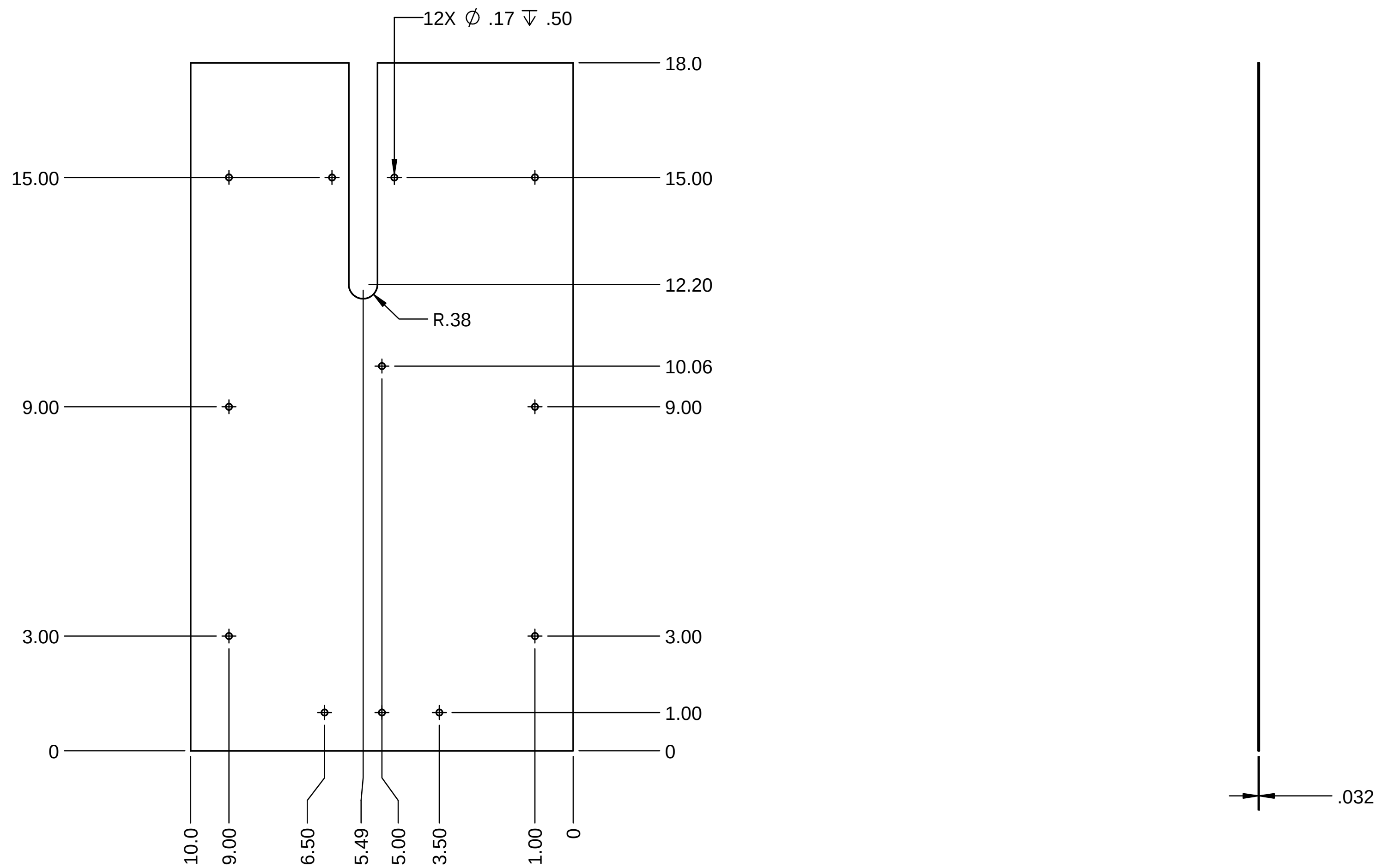
COMMENTS:

Project Omoverhi

TITLE: LCD Holder

SIZE B | DWG. NO. 3.1 | REV 01

SCALE: 2:3 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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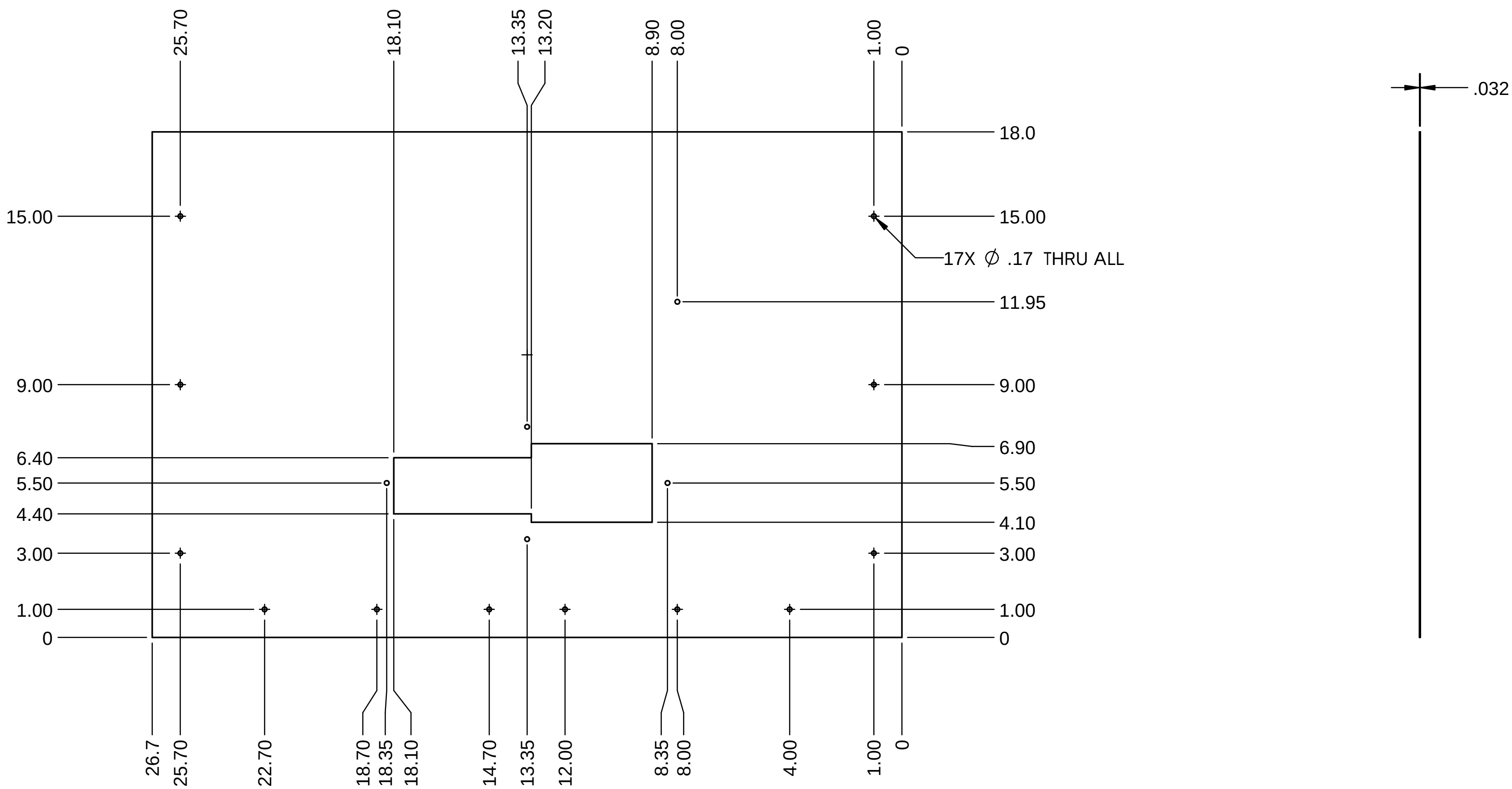
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/5/13

MATERIAL: Aluminum 5052
FINISH: None
COMMENTS:

Project Omoverhi
TITLE: Enclosure Side

SIZE: B | DWG. NO.: 3.2 | REV: 01
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL Aluminum 5052
FINISH None

	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/5/13

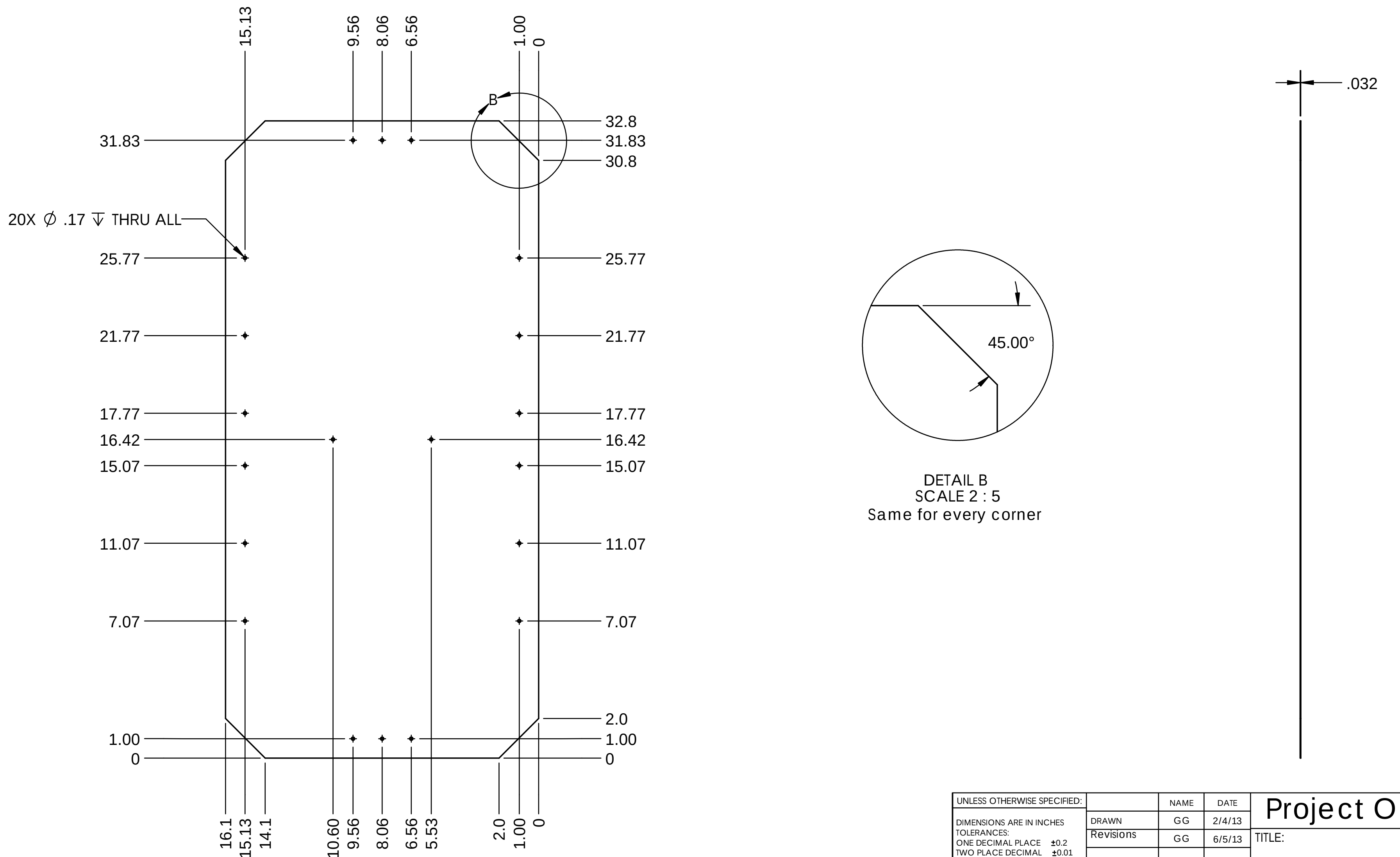
COMMENTS:

Project Omoverhi

TITLE: Outside Front Enclosure

SIZE B | DWG. NO. 3.3 | REV 01

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Aluminum 5052
FINISH: None

	NAME	DATE
DRAWN	GG	2/4/13
Revisions	GG	6/5/13

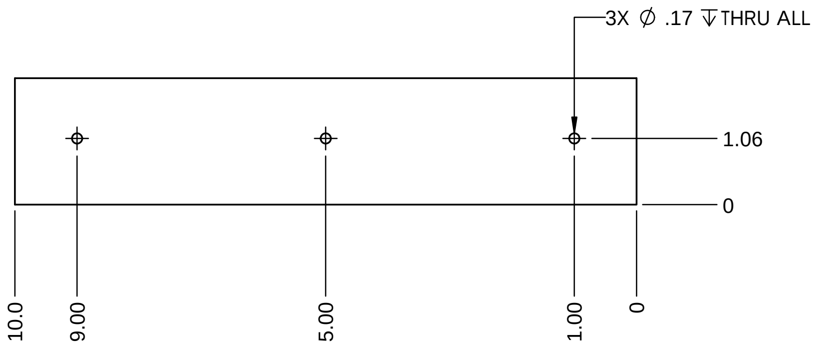
COMMENTS:

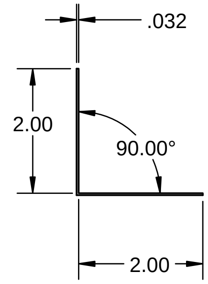
Project Omoverhi

TITLE: Outside Bottom Enclosure

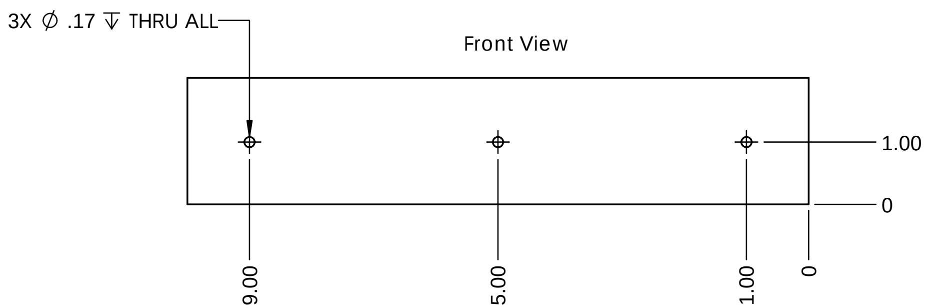
SIZE	DWG. NO.	REV
B	3.4	01

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1





Front View



Thickness Set by manufacturer

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DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

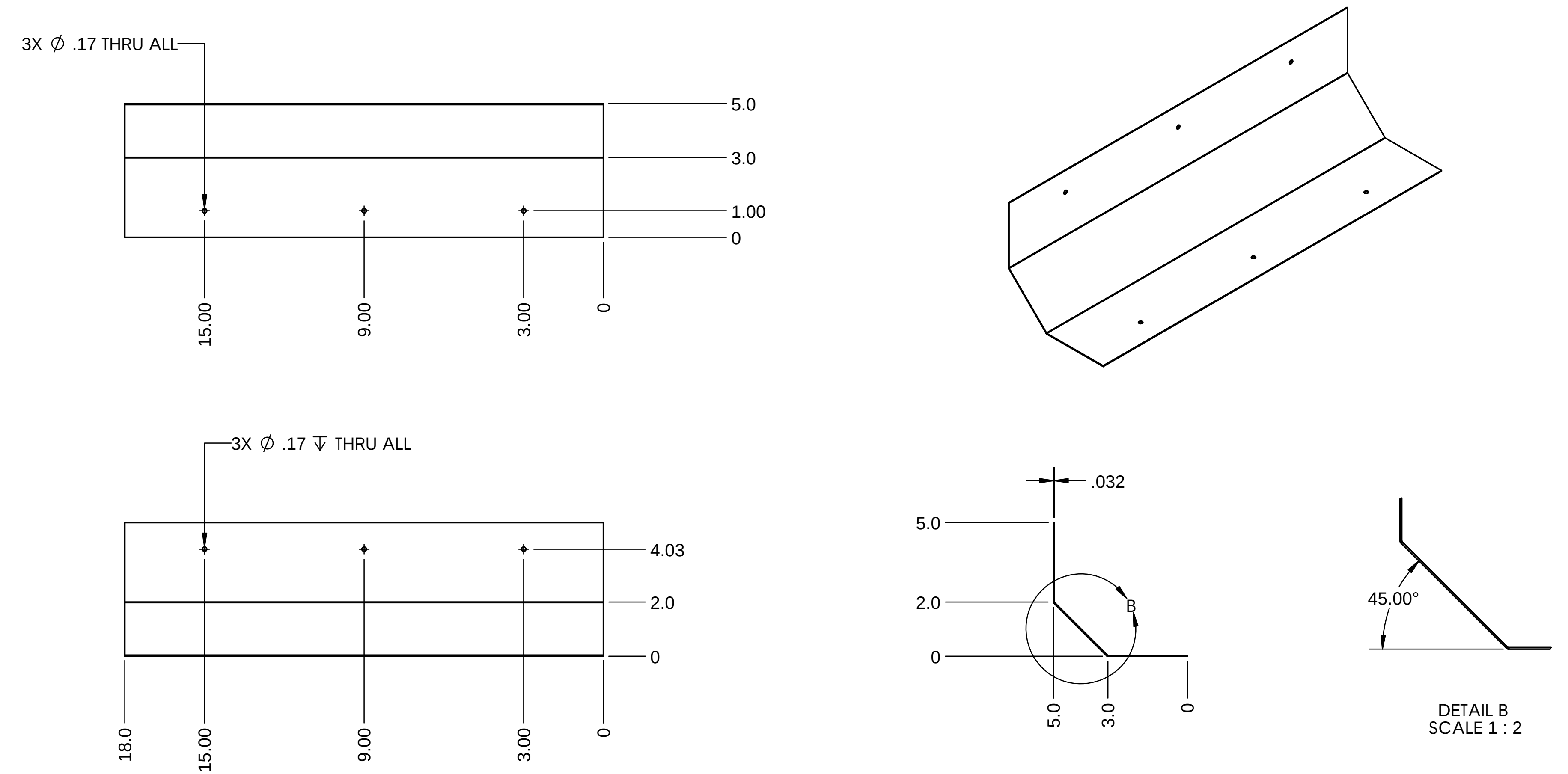
	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/5/13

MATERIAL: Aluminum 5052
FINISH: None
COMMENTS:

Project Omoverhi
TITLE: Front and Back Bracket Enclosure

SIZE	DWG. NO.	REV
B	3.5	01

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/5/13

COMMENTS:

MATERIAL Aluminum 5052

FINISH None

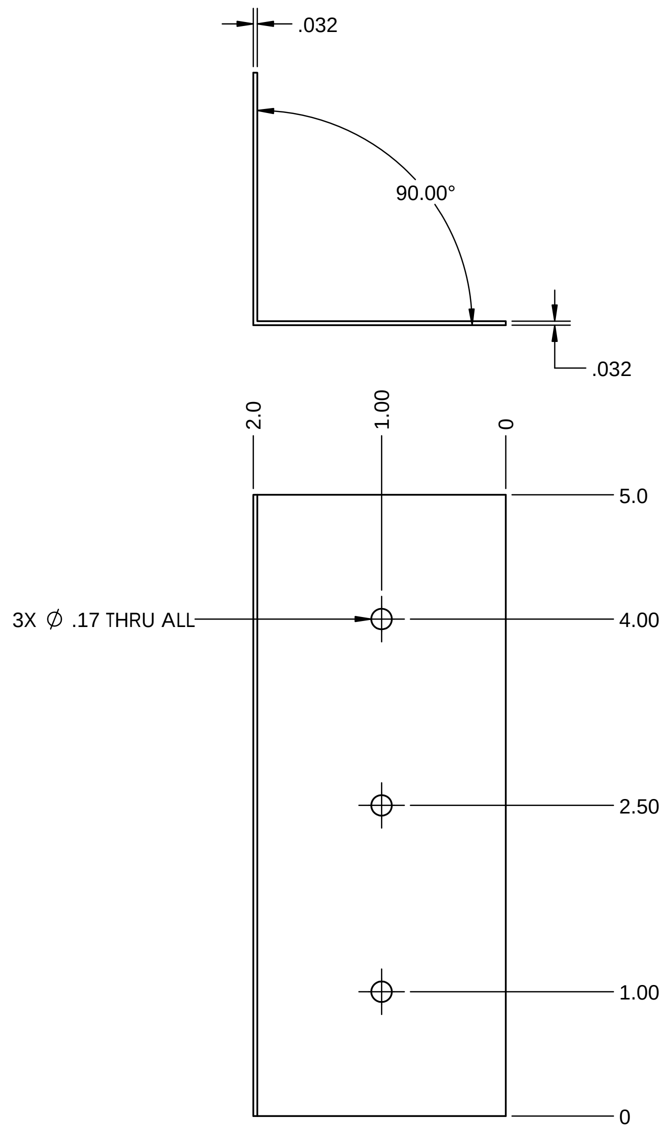
DO NOT SCALE DRAWING

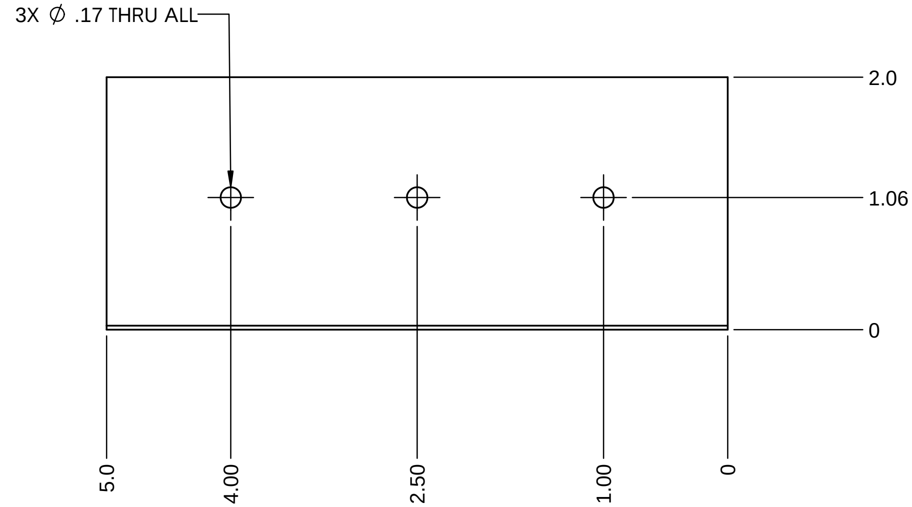
Project Omoverhi

TITLE: Outside Edge Enclosure

SIZE B | DWG. NO. 3.6 | REV 00

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1





Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	2/4/13
Revisions	GG	6/5/13

MATERIAL: Aluminum 5052
FINISH: None
DO NOT SCALE DRAWING

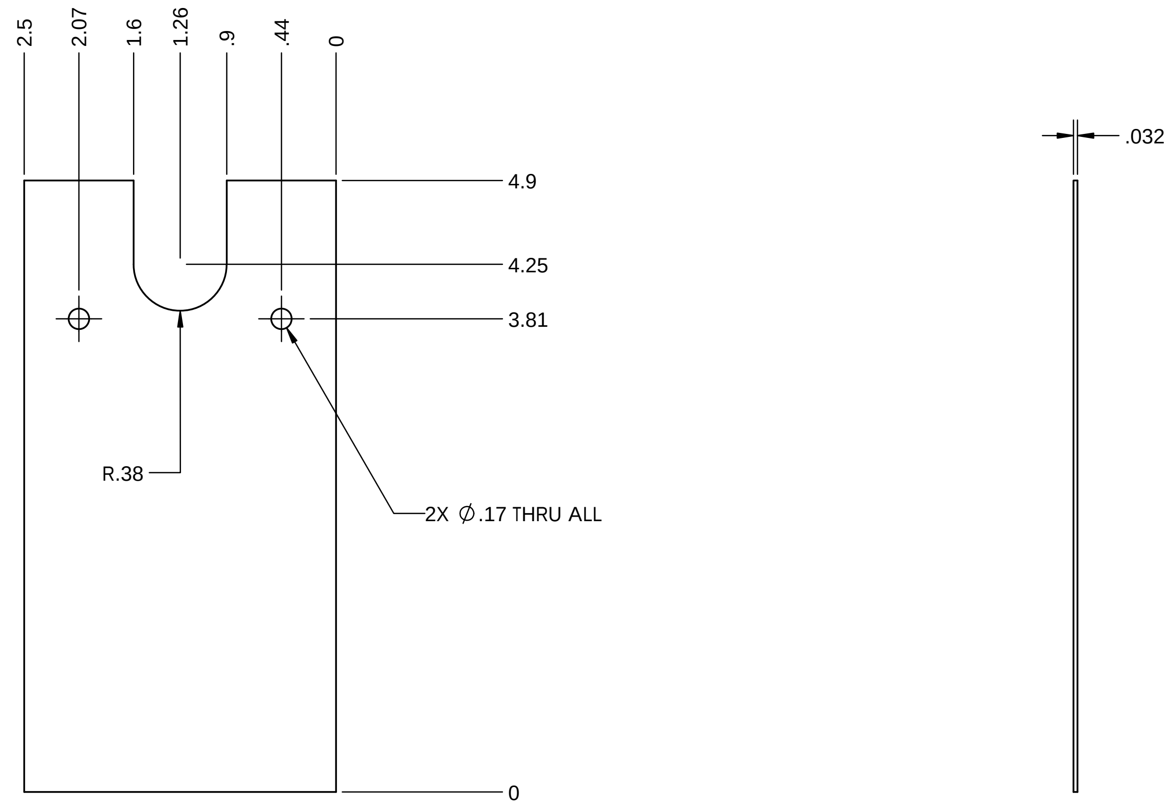
COMMENTS:

Project Omoverhi

TITLE:
Bracket Side Enclosure

SIZE: B | DWG. NO.: 3.7 | REV: 01

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL Aluminum 5052
FINISH None
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

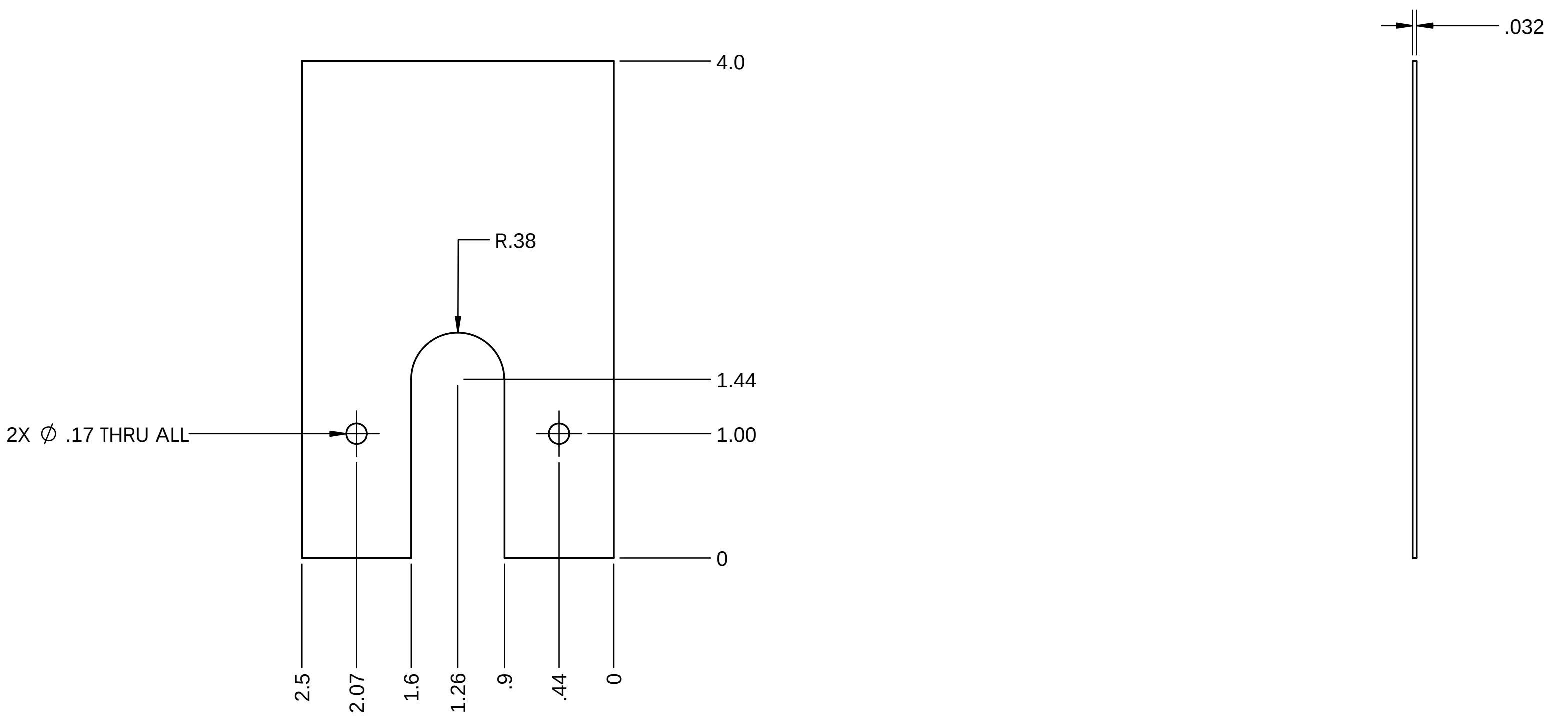
COMMENTS:

Project Omoverhi

TITLE: Outside Pipe Cover Enclosure

SIZE	DWG. NO.	REV
B	3.8	00

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

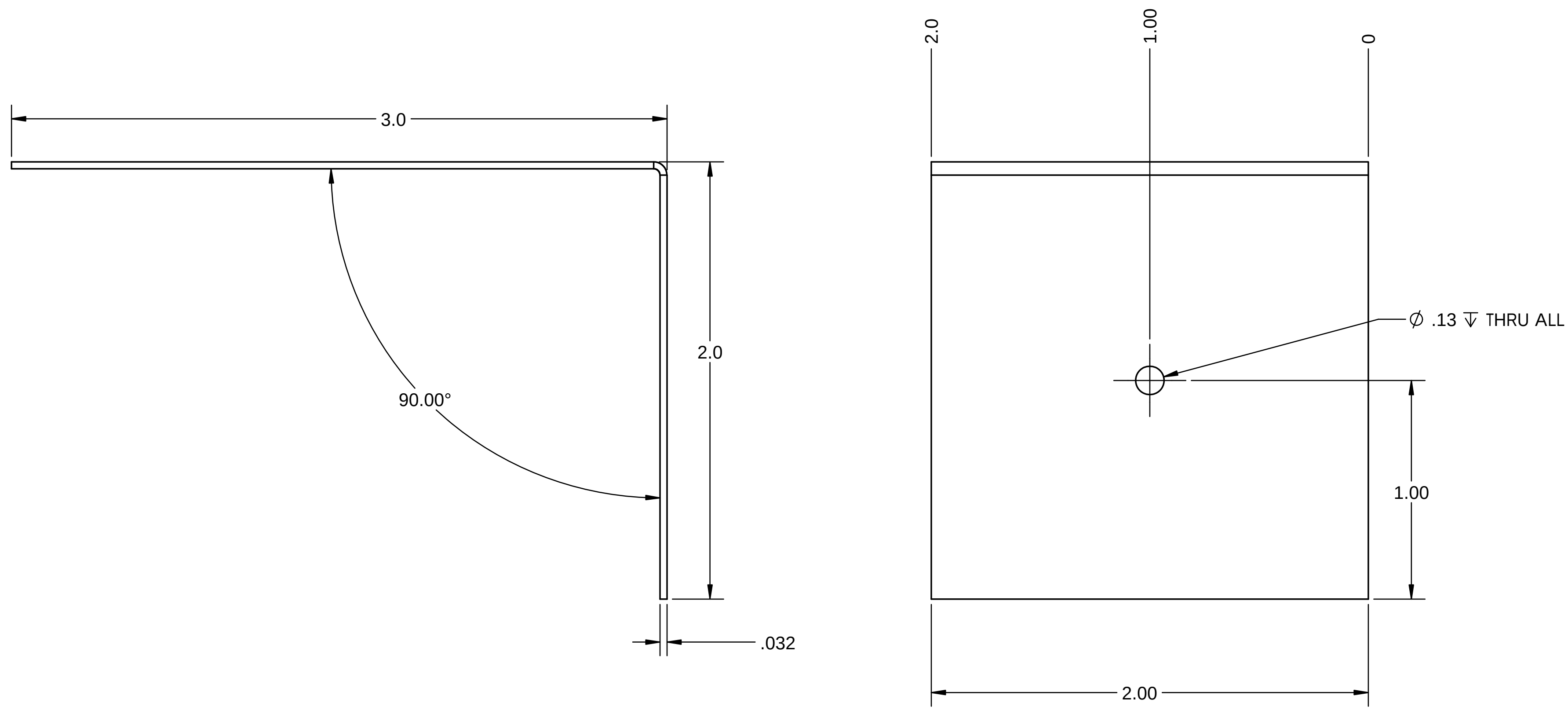
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/5/13
MATERIAL Aluminum 5052	COMMENTS:		
FINISH None			
DO NOT SCALE DRAWING			

Project Omoverhi

TITLE:

Inside Pipe Cover Enclosure

SIZE	DWG. NO.	REV
B	3.9	00
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



Thickness set by manufacturer

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	2/4/2013
	Revisions	GG	6/5/13
MATERIAL Aluminum 5052	COMMENTS:		
FINISH None			

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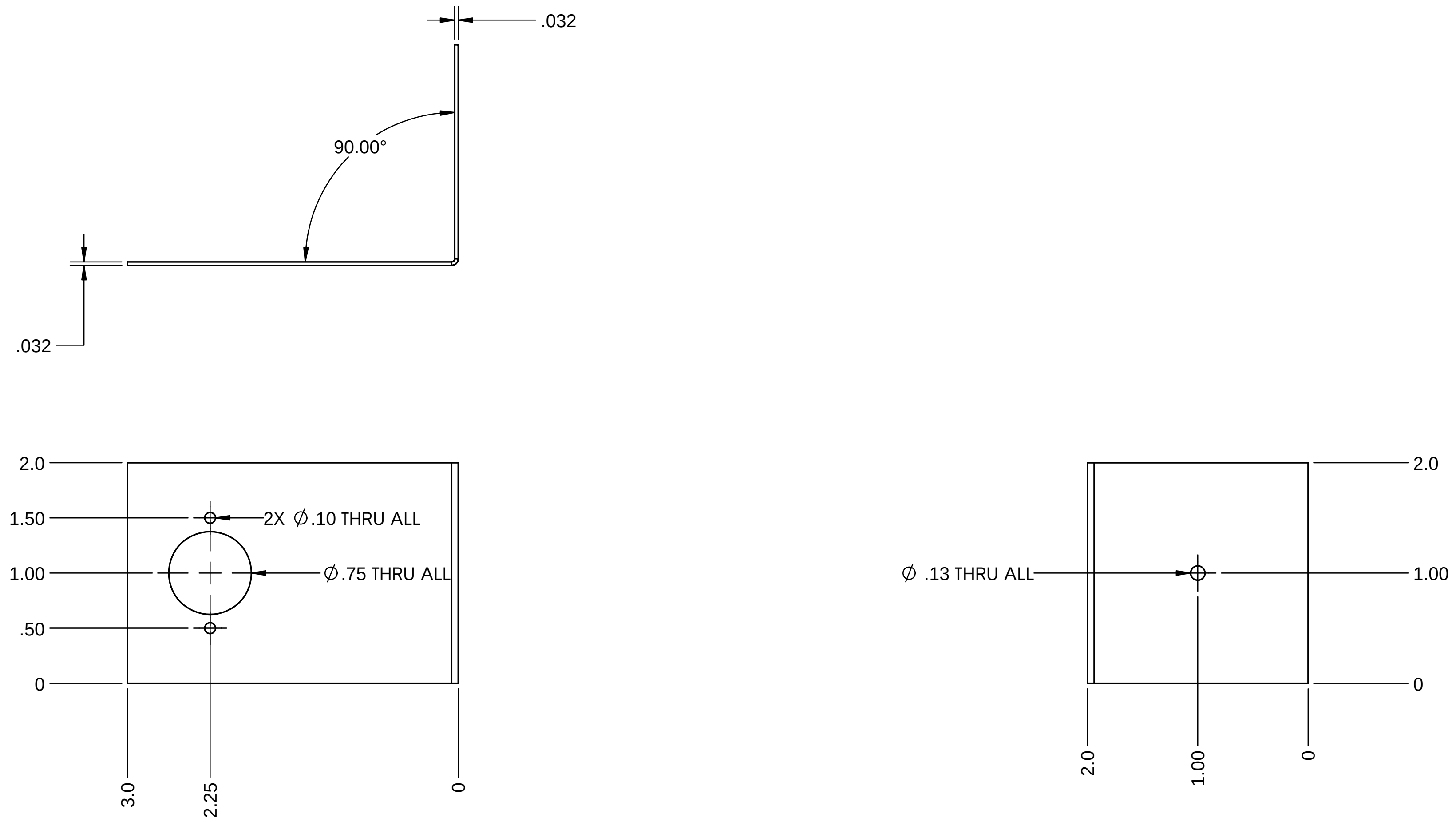
Project Omoverhi

TITLE: Inside Enclosure Support Bracket

SIZE B | DWG. NO. 4.0 | REV 01

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

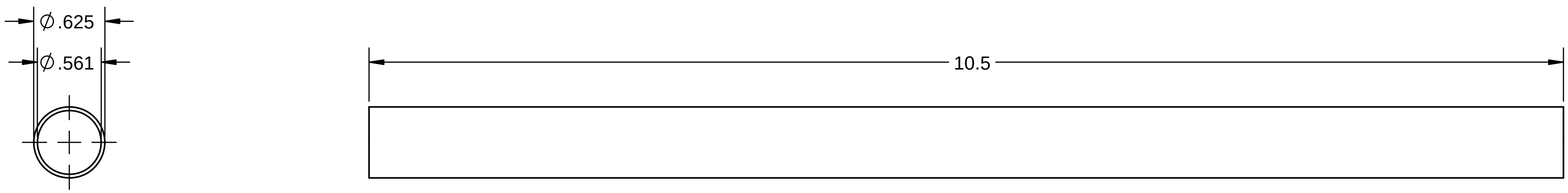
	NAME	DATE
DRAWN	GG	6/5/13

MATERIAL: Aluminum 5052
FINISH: None
DO NOT SCALE DRAWING
COMMENTS:

Project Omoverhi

TITLE: Inside Bracket Enclosure Holder Voltage Reg.

SIZE: B | DWG. NO.: 4.1 | REV: 00
SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Inside and Outside Diameters set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Copper
FINISH: Polished

	NAME	DATE
DRAWN	GG	2/4/2013

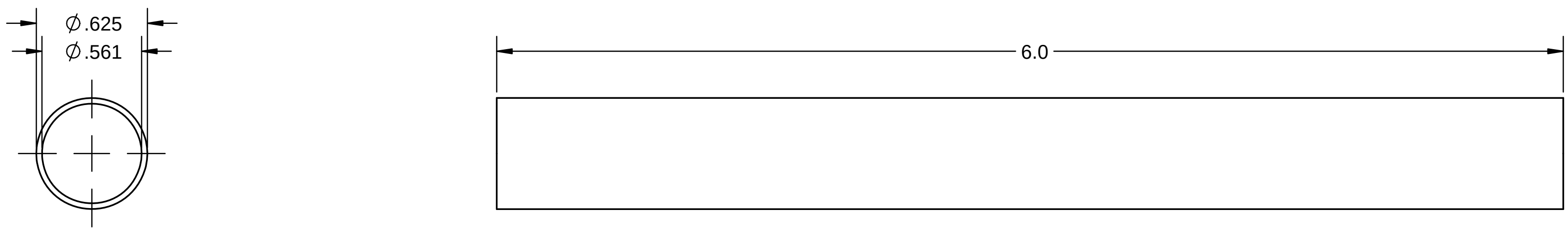
COMMENTS:

Project Omoverhi

TITLE: Long Length Copper Pipe

SIZE: B | DWG. NO.: 4.2 | REV: 00

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Inside and outside diameters set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Copper
FINISH: Polish

	NAME	DATE
DRAWN	GG	2/4/2013

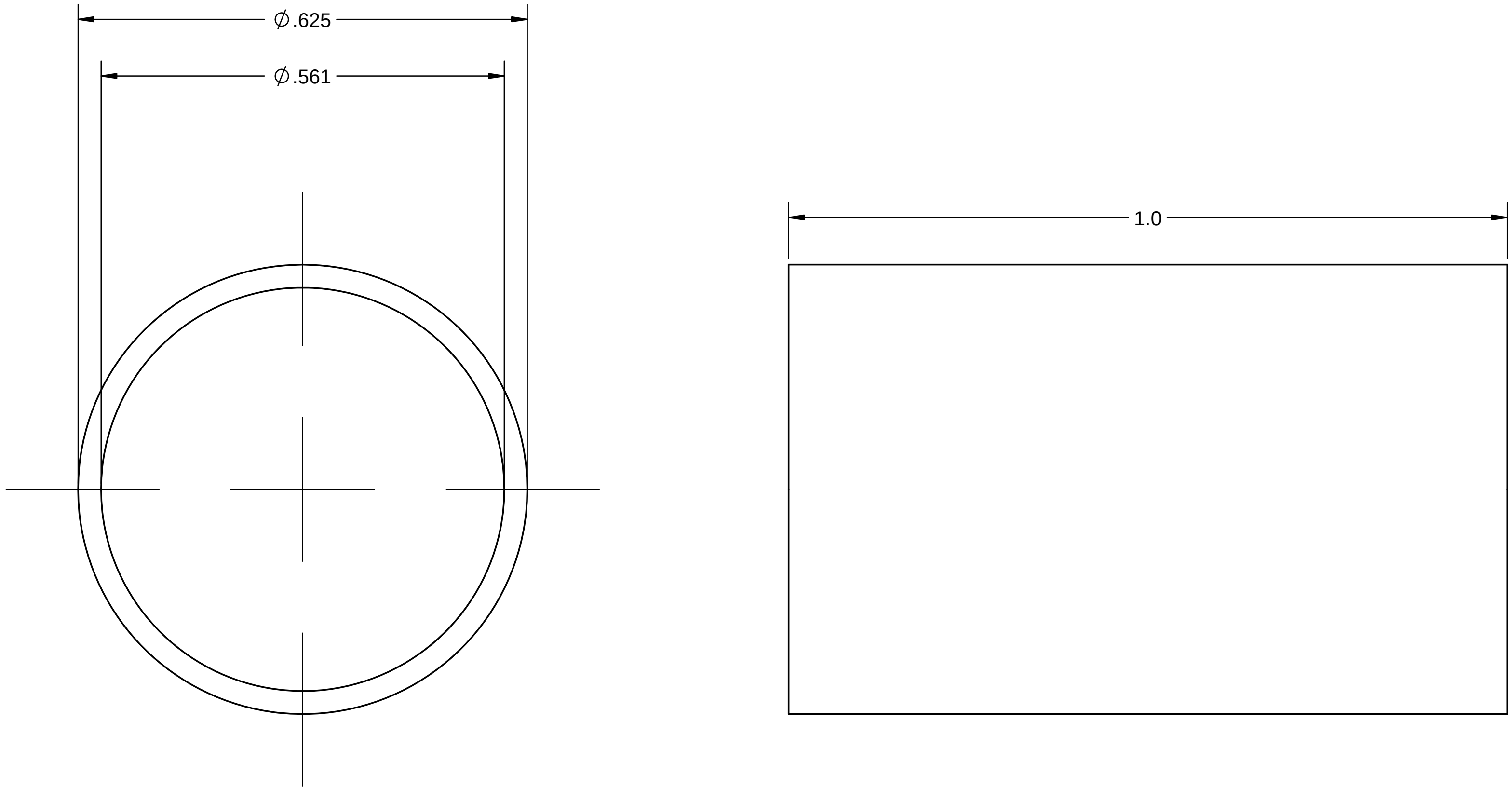
COMMENTS:

Project Omoverhi

TITLE: Small Length Copper Pipe

SIZE	DWG. NO.	REV
B	4.3	

SCALE: 3:2 WEIGHT: SHEET 1 OF 1



Inside and outside diameters set by manufacturer

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Copper
FINISH: Polish

	NAME	DATE
DRAWN	GG	2/4/2013

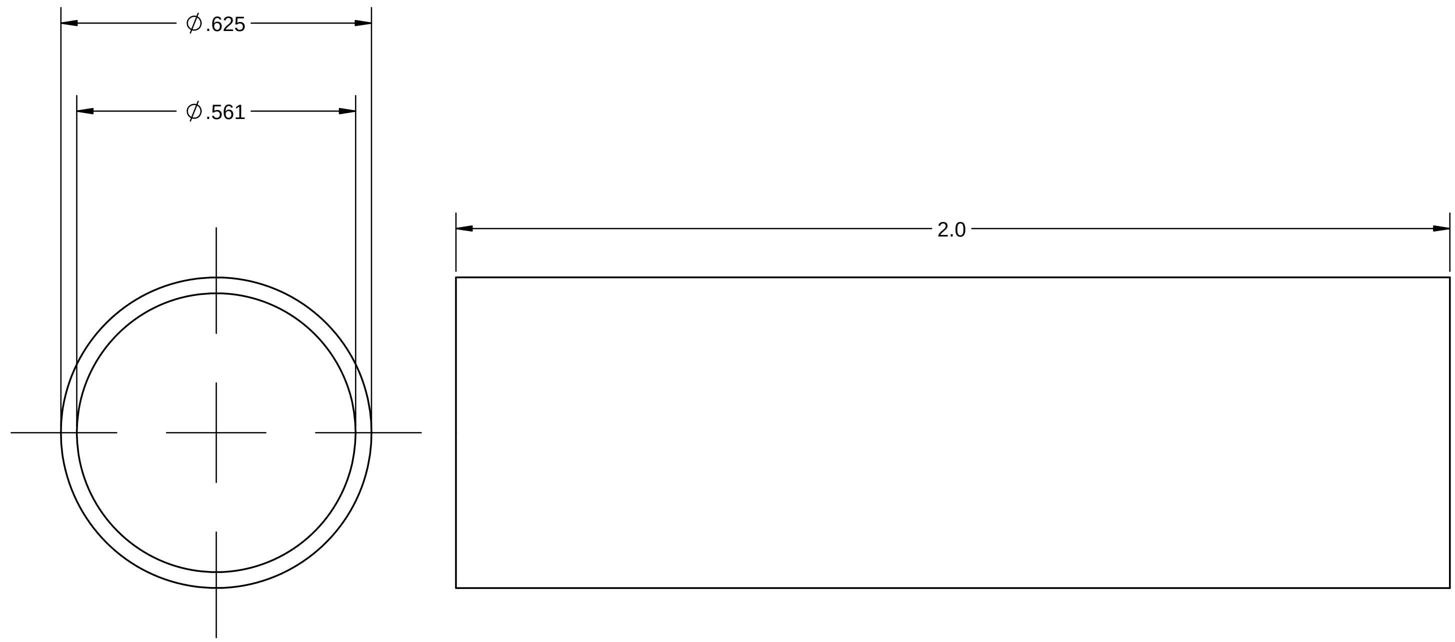
COMMENTS:

Project Omoverhi

TITLE:
Fittings
Copper Pipe

SIZE	DWG. NO.	REV
B	4.4	00

SCALE: 6:1 WEIGHT: SHEET 1 OF 1



Inside and outside diameters set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Copper
FINISH: Polish

	NAME	DATE
DRAWN	GG	2/4/2013

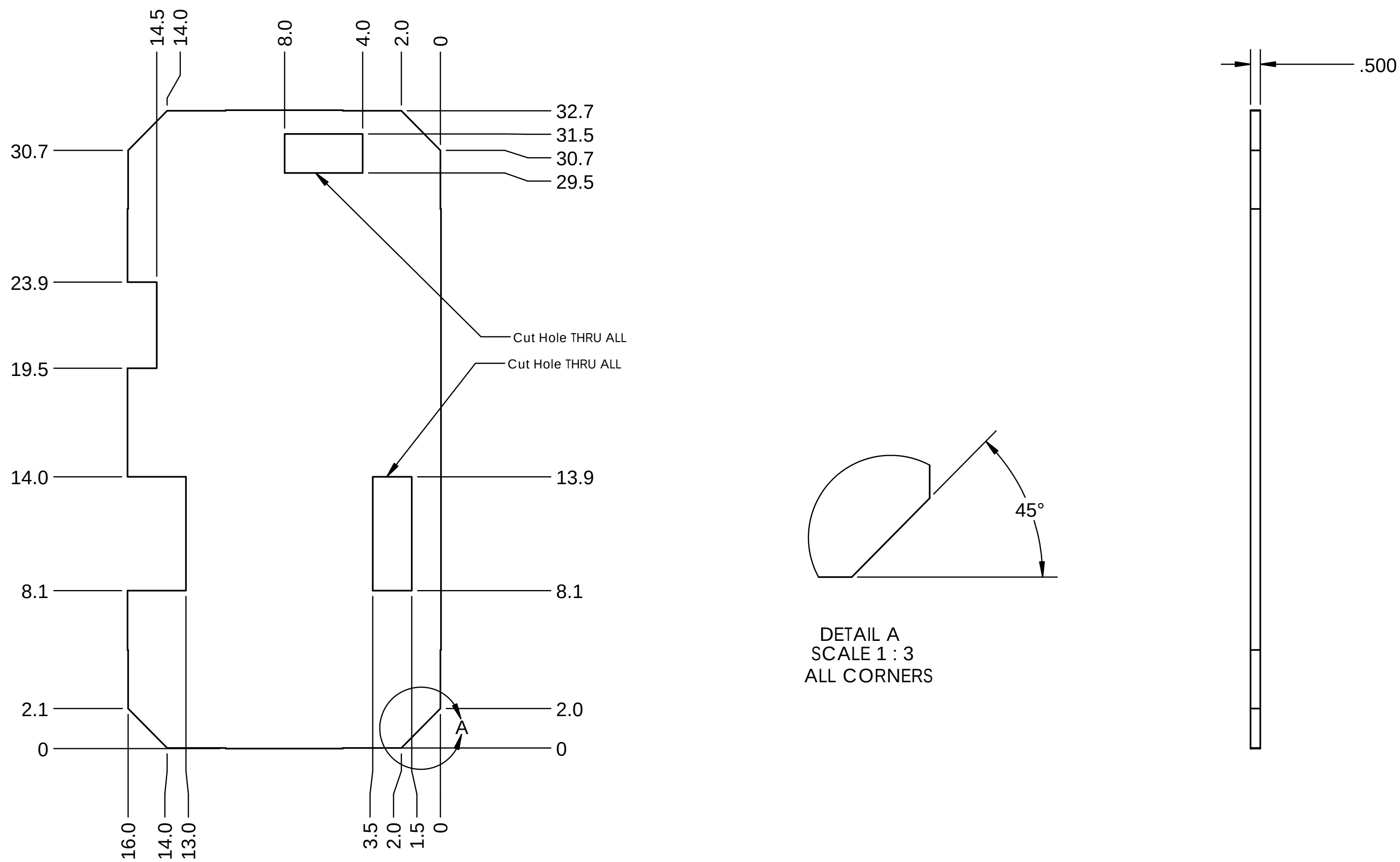
COMMENTS:

Project Omoverhi

TITLE: Entrance and Exit Copper Pipe

SIZE	DWG. NO.	REV
B	4.5	00

SCALE: 4:1 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/5/13
MATERIAL Foam Insulation	COMMENTS:		
FINISH N/A			
DO NOT SCALE DRAWING			

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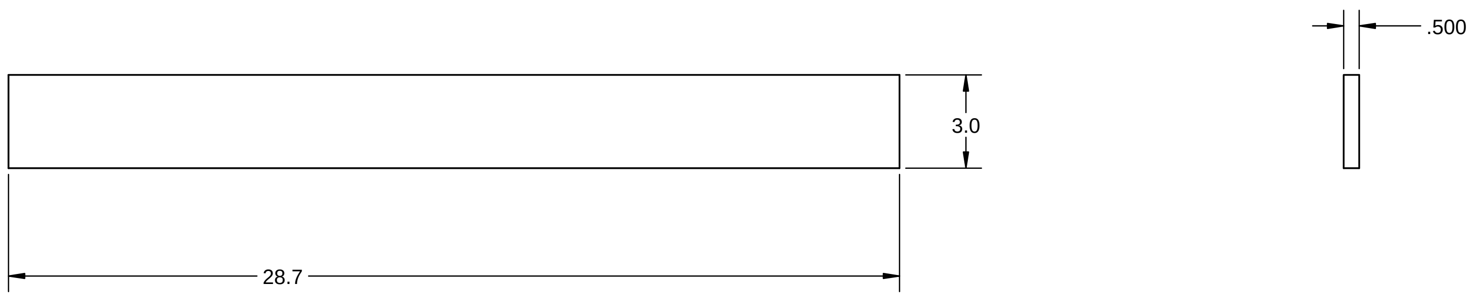
Project Omoverhi

TITLE:

Bottom Base Insulation

SIZE	DWG. NO.	REV
B	4.6	00

SCALE: 1:6 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
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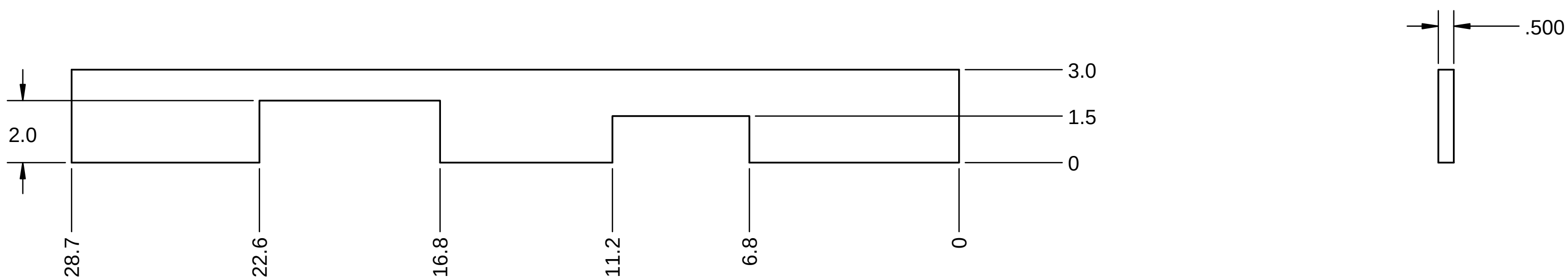
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/5/13

MATERIAL Foam Insulation
FINISH N/A
DO NOT SCALE DRAWING
COMMENTS:

Project Omoverhi
TITLE: Front Insulation

SIZE B | DWG. NO. 4.7 | REV 00
SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL Foam Insulation
FINISH N/A
DO NOT SCALE DRAWING

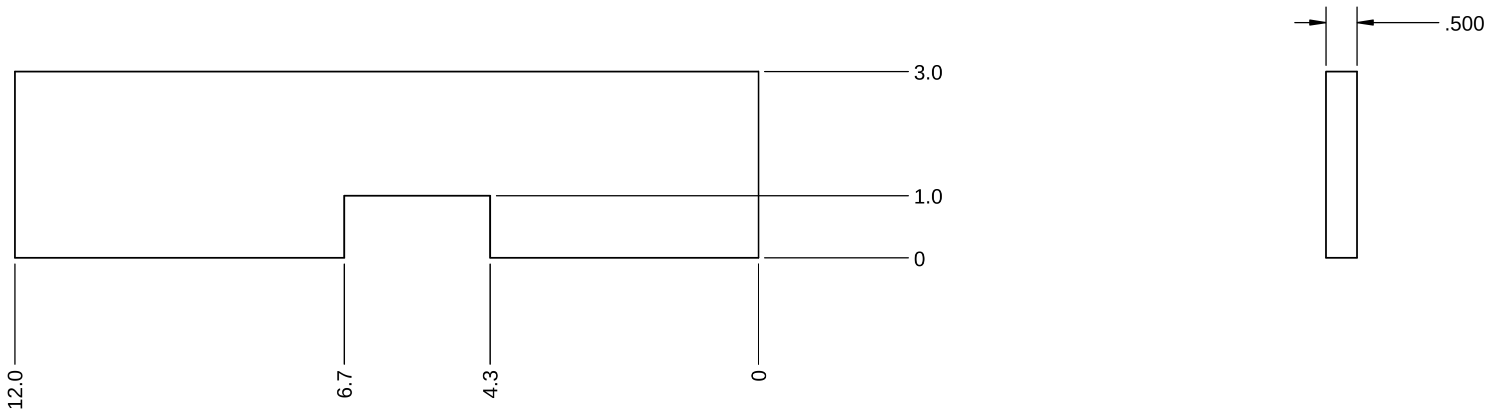
	NAME	DATE
DRAWN	GG	6/5/13

COMMENTS:

Project Omoverhi
TITLE: Back Insulation

SIZE	DWG. NO.	REV
B	4.8	00

SCALE: 1:4 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

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ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Foam Insulation
FINISH: N/A
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

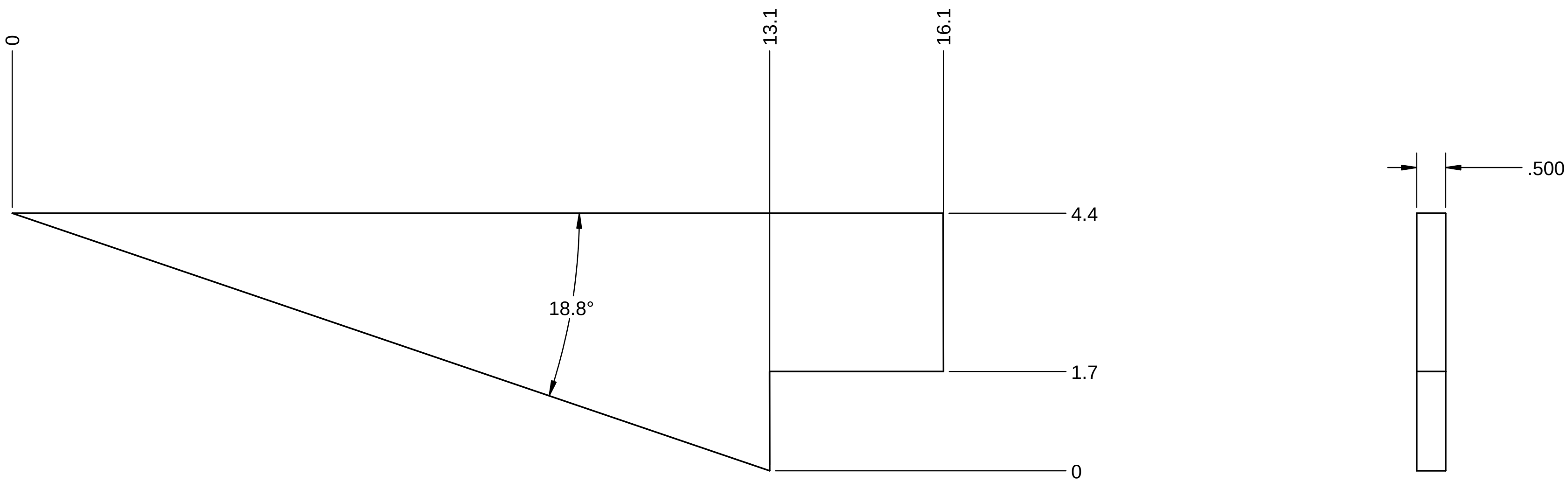
COMMENTS:

Project Omoverhi

TITLE: Side Insulation

SIZE: B | DWG. NO.: 4.9 | REV: 00

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Foam Insulation
FINISH: N/A
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

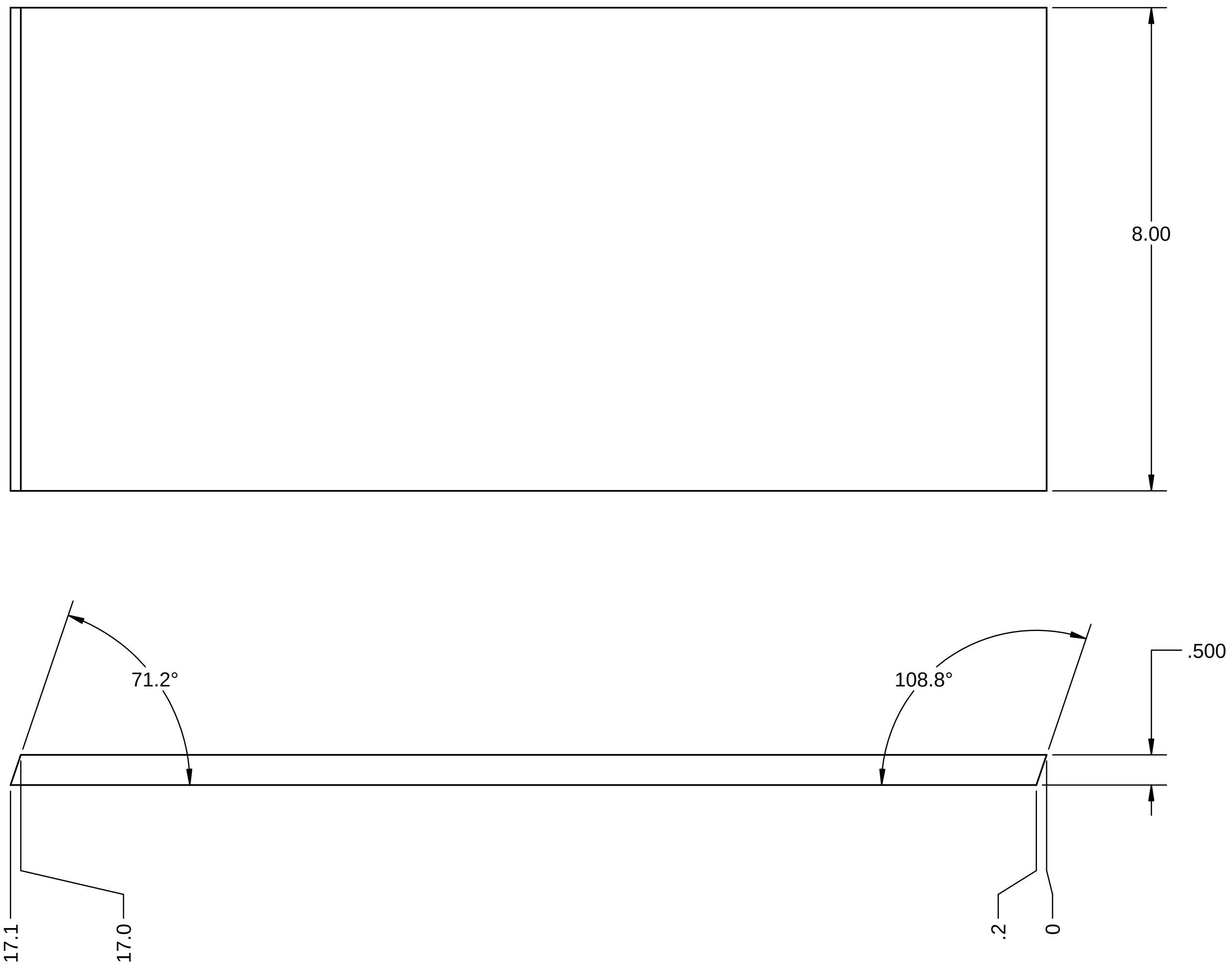
COMMENTS:

Project Omoverhi

TITLE: Triangle Insulation

SIZE	DWG. NO.	REV
B	5.0	00

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

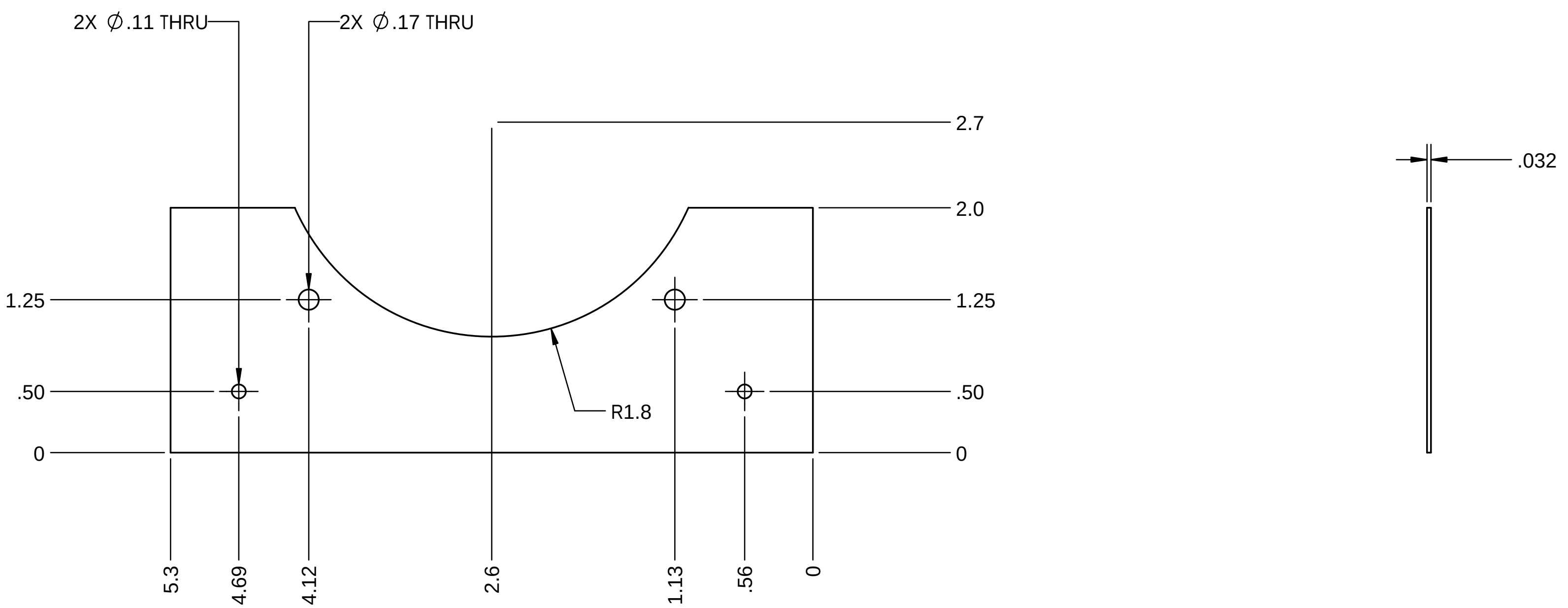
	NAME	DATE
DRAWN	GG	6/5/13

MATERIAL: Foam Insulation
FINISH: N/A
DO NOT SCALE DRAWING
COMMENTS:

Project Omoverhi
TITLE: Ramp Insulation

SIZE	DWG. NO.	REV
B	5.1	00

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/5/13

MATERIAL Aluminum 5052
FINISH None
DO NOT SCALE DRAWING

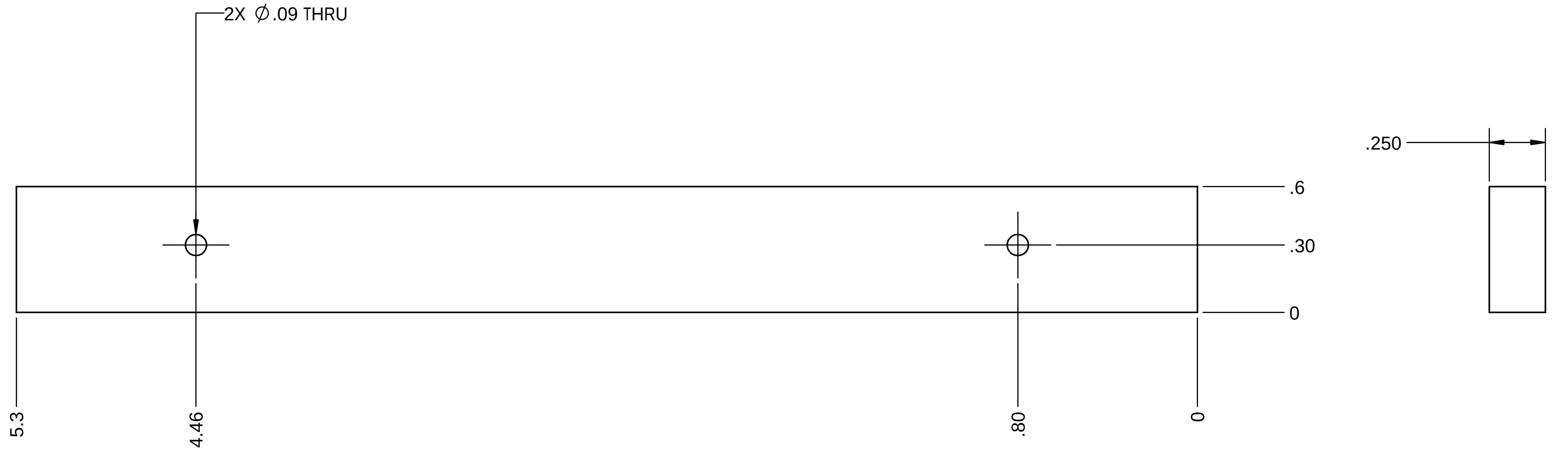
COMMENTS:

Project Omoverhi

TITLE: Radiator Holder Enclosure

SIZE B | DWG. NO. 5.2 | REV 00

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL
Acrylic

FINISH
Black Tint

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

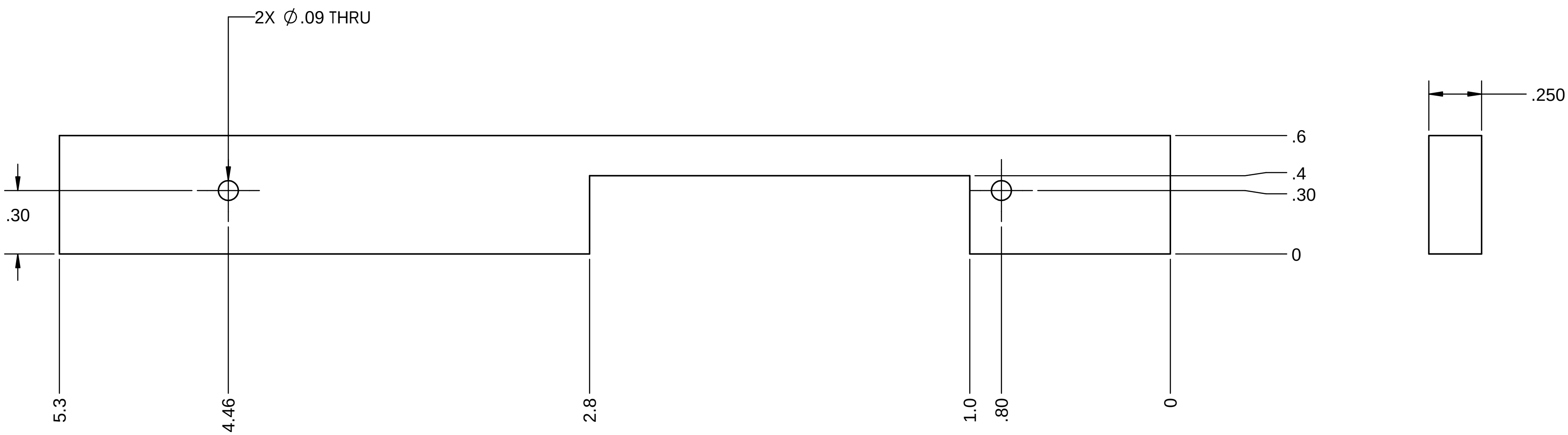
COMMENTS:

Project Omoverhi

TITLE:
Top
LCD Holder

SIZE B | DWG. NO. 5.3 | REV 00

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	6/5/13
MATERIAL: Acrylic	COMMENTS:		
FINISH: Black Tint			
DO NOT SCALE DRAWING			

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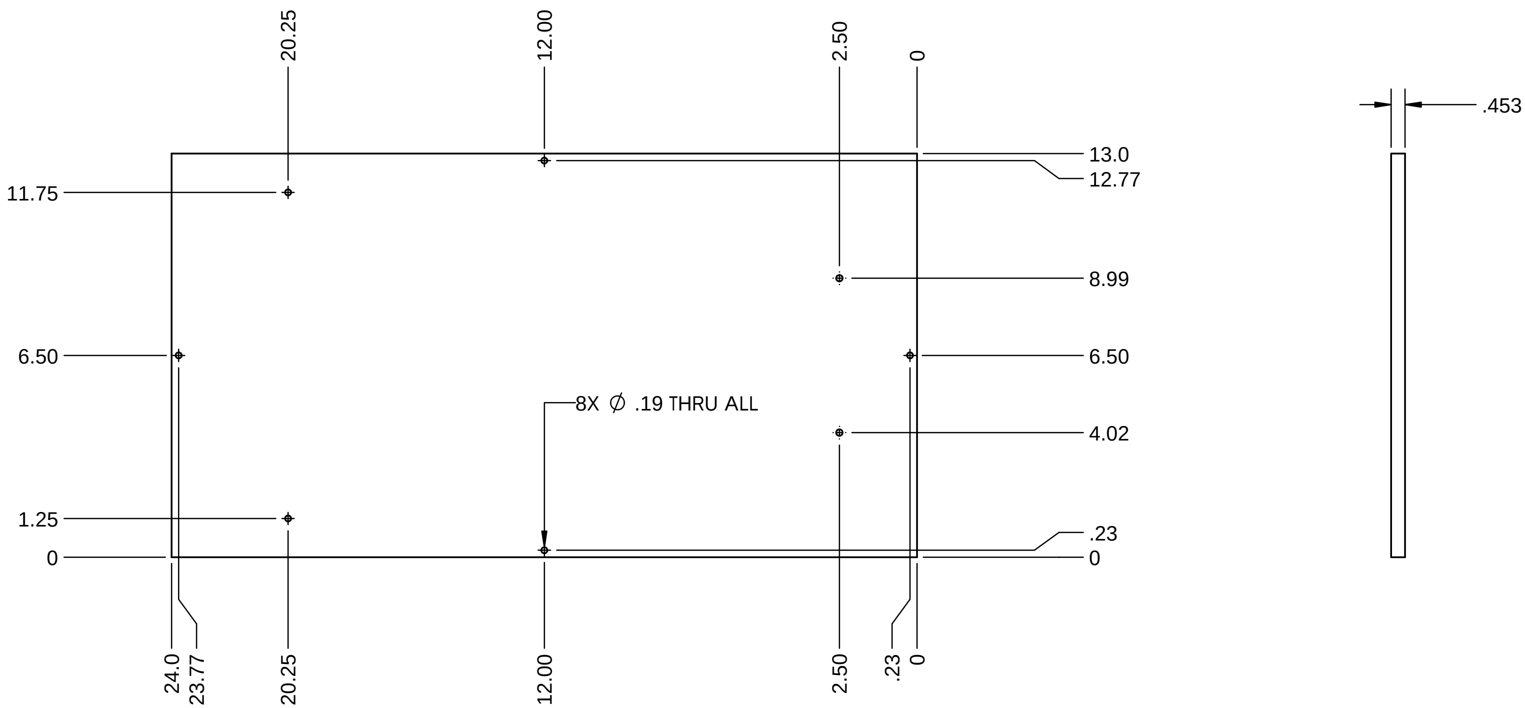
Project Omoverhi

TITLE:
Bottom
LCD Holder

SIZE	DWG. NO.	REV
B	5.4	00
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Birch Plywood

FINISH: Clear Lacquer Coat

	NAME	DATE
DRAWN	GG	2/4/2013

COMMENTS:

Project Omoverhi

TITLE: Wood Bed Base

SIZE	DWG. NO.	REV
B	6.0	00

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

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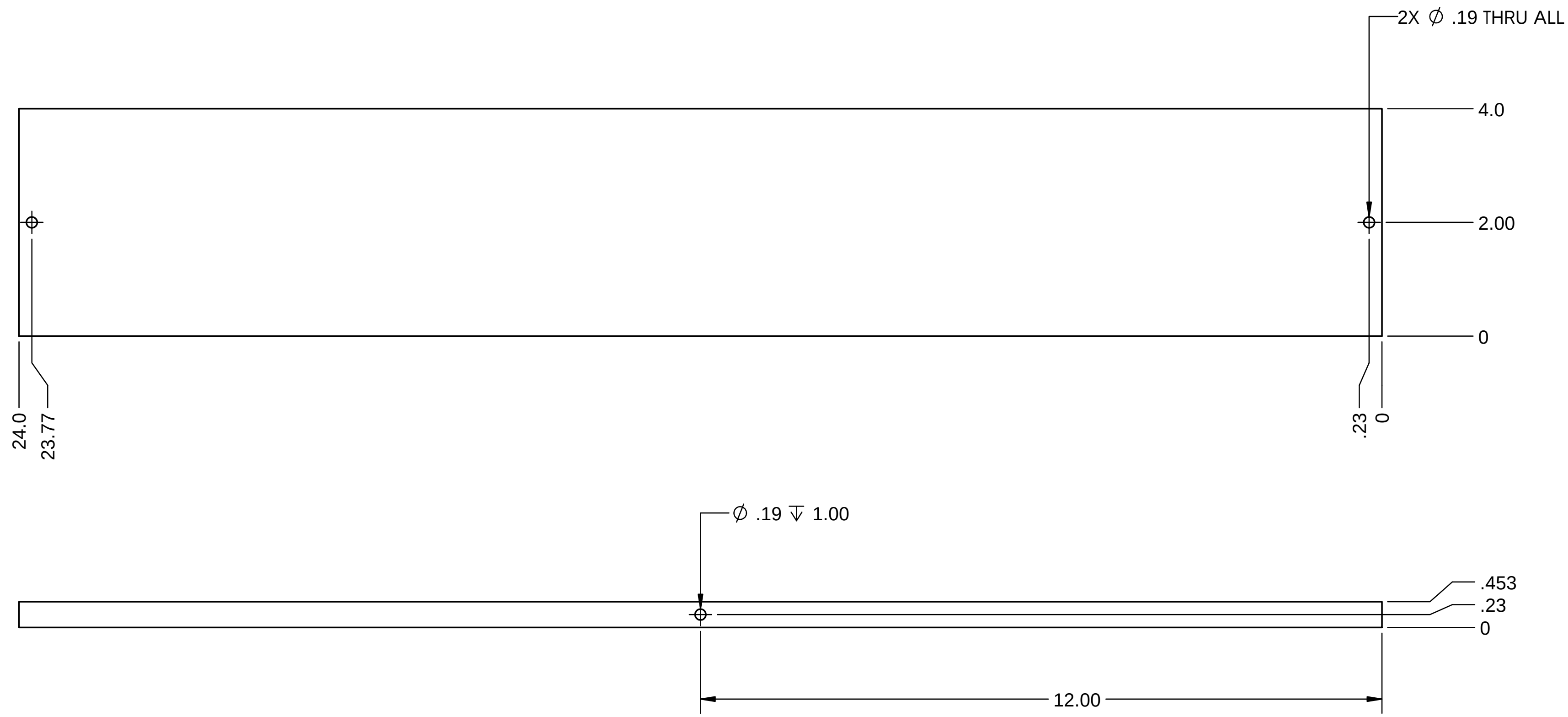

Thickness set by manufacturer

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DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL Birch Plywood
FINISH Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/5/13

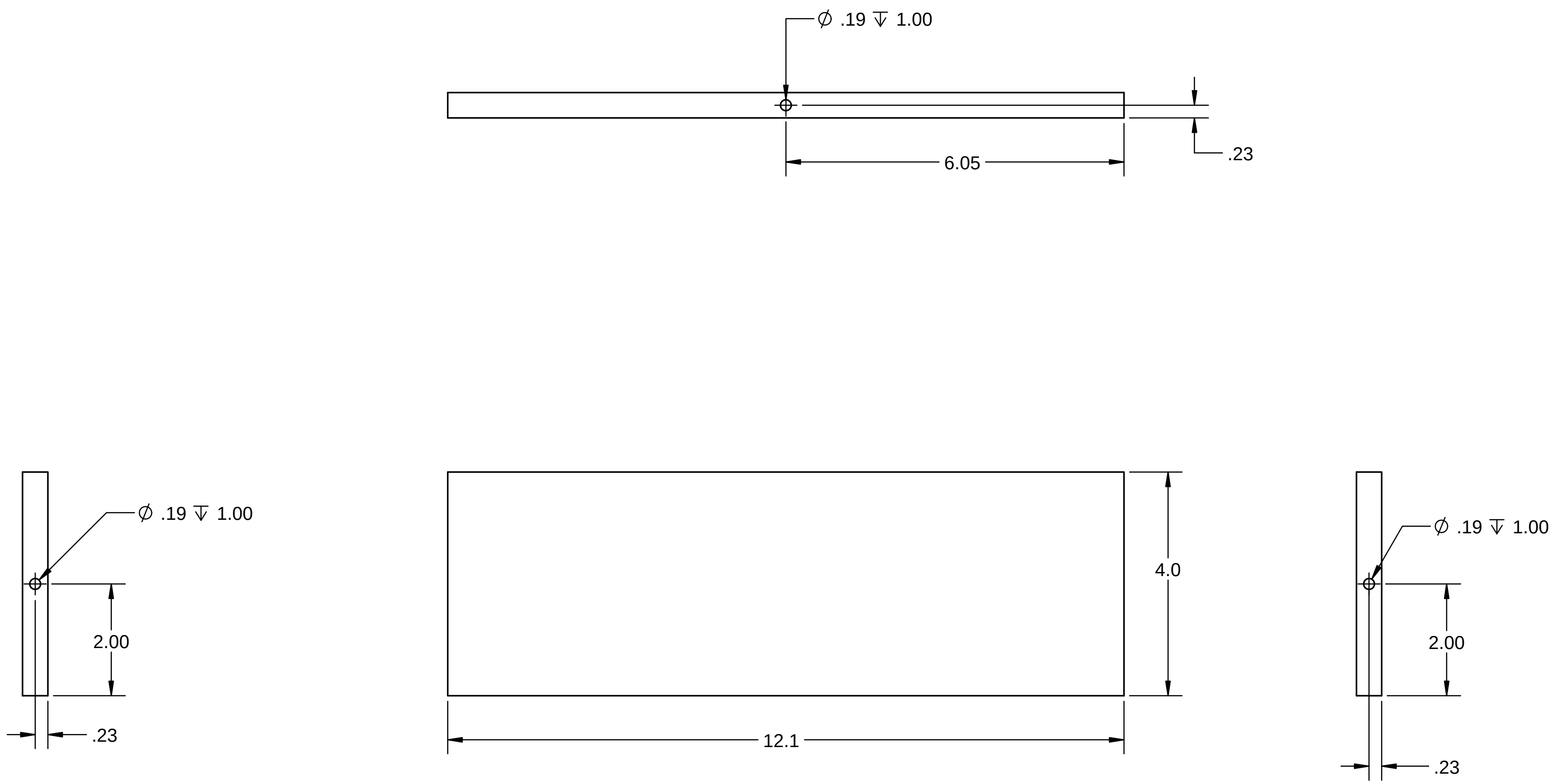
COMMENTS:

Project Omoverhi

TITLE:
Wood Bed
Front and Back Side

SIZE	DWG. NO.	REV
B	6.1	00

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



Thickness set by manufacturer

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TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	6/7/13

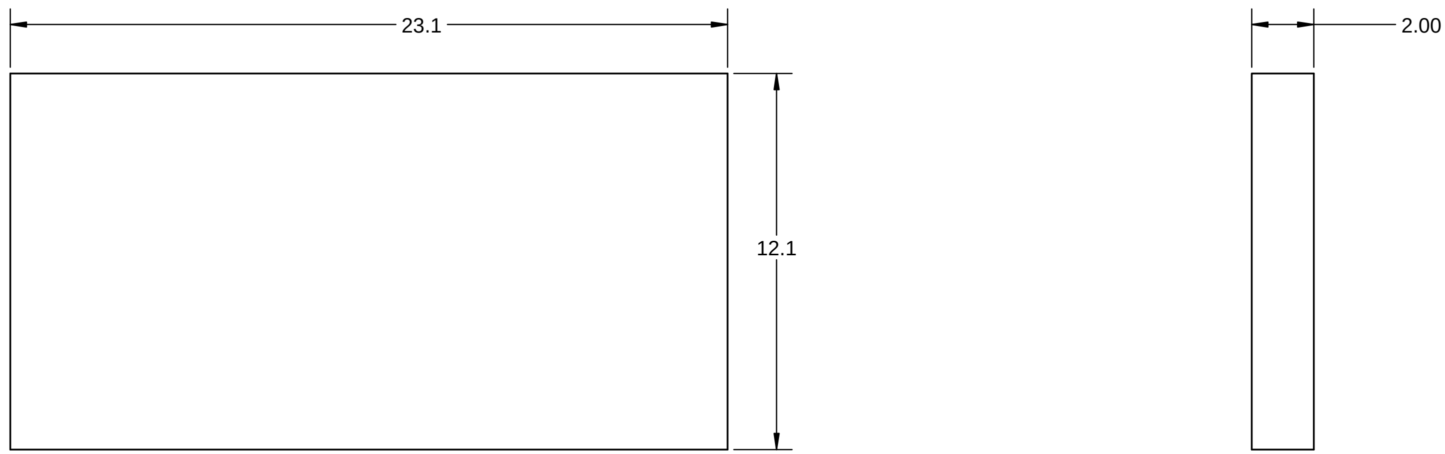
MATERIAL: Birch Plywood
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

COMMENTS:

Project Omoverhi

TITLE: Wood Bed Left and Right Side

SIZE: B | DWG. NO. 6.2 | REV 00
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



Thickness set by manufacturer
Rated sound absorption 65%
Purchased from McMaster-Carr

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL
Polyurethane Foam
FINISH
N/A
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/7/13

COMMENTS:

Project Omoverhi

TITLE:
Bed Noise
Canceling Foam

SIZE B | DWG. NO. 6.3 | REV 00
SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

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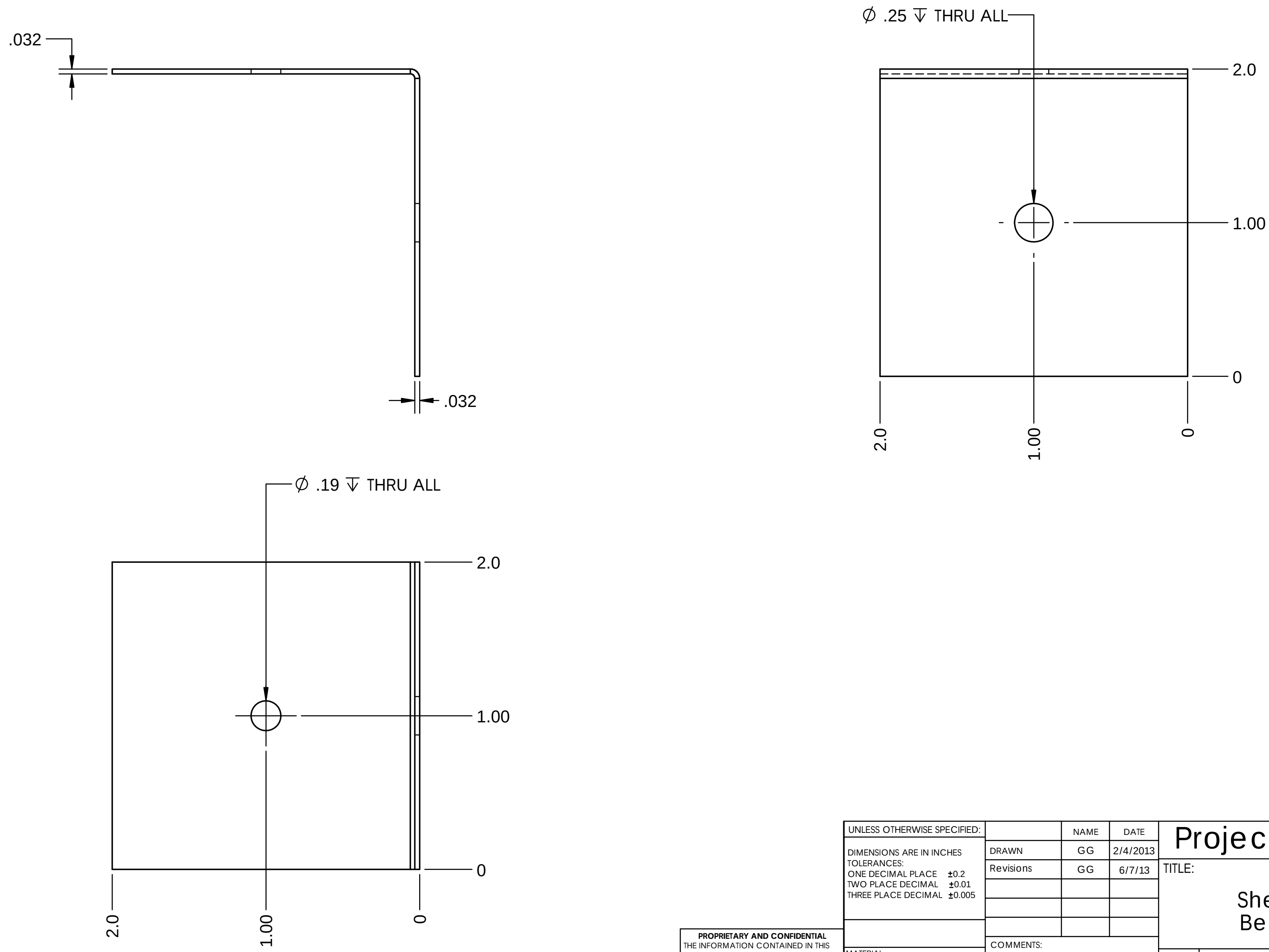

Thickness set by manufacturer

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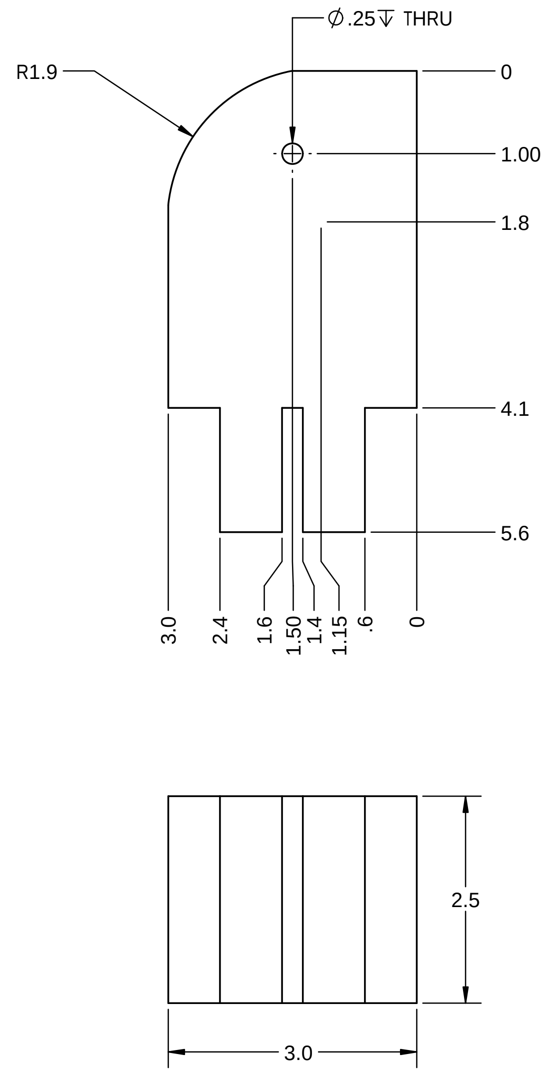
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Project Omoverhi
DIMENSIONS ARE IN INCHES TOLERANCES: ONE DECIMAL PLACE ±0.2 TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	GG	2/4/2013	TITLE:
	Revisions	GG	6/7/13	Sheet Metal Bed Bracket
MATERIAL Aluminum 5052	COMMENTS:			SIZE B · DWG. NO. 6.4 · REV 01
FINISH None				SCALE: 3:2 · WEIGHT: · SHEET 1 OF 1



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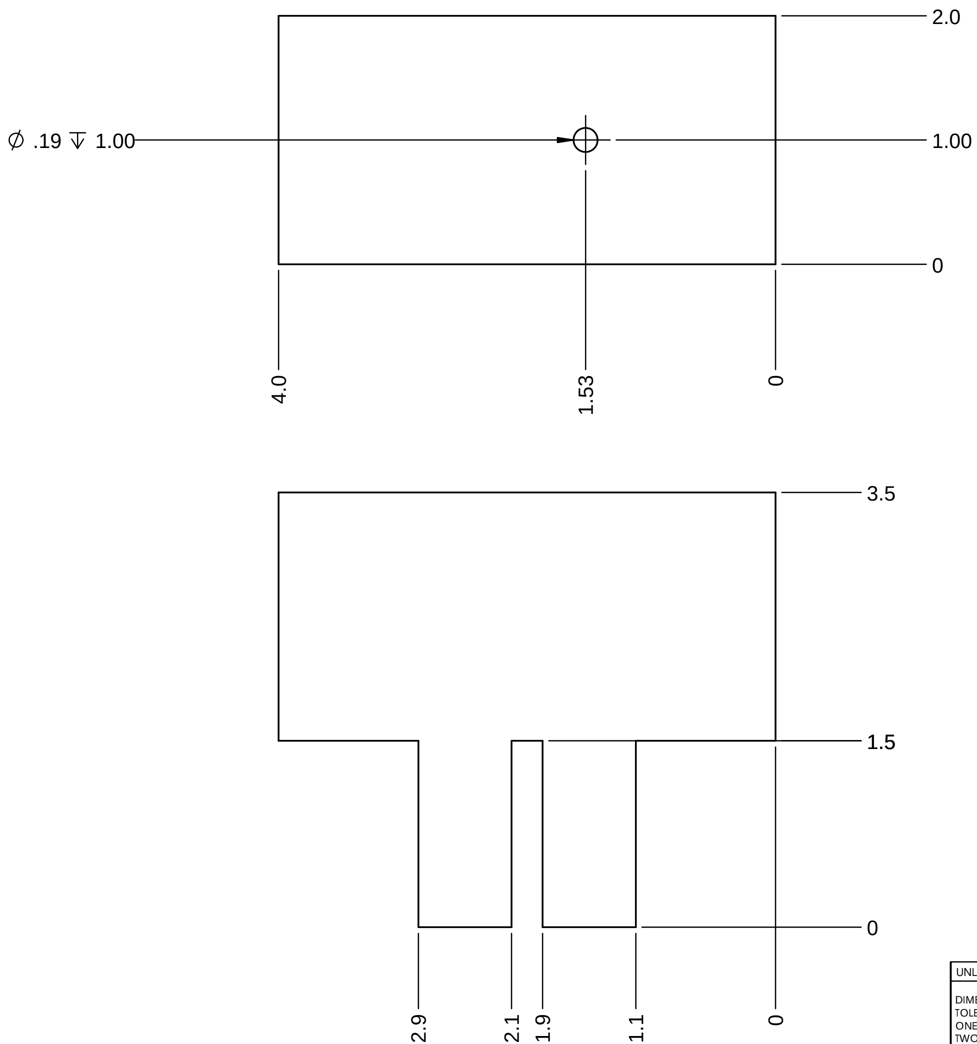
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/7/13

MATERIAL: Poppler
FINISH: Clear Lacquer Coat
COMMENTS:

Project Omoverhi
TITLE: Wood Back Leg

SIZE: B | DWG. NO.: 6.5 | REV: 01
SCALE: 2:3 | WEIGHT: | SHEET 1 OF 1



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DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Poppler
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	2/4/2013
Revisions	GG	6/7/13

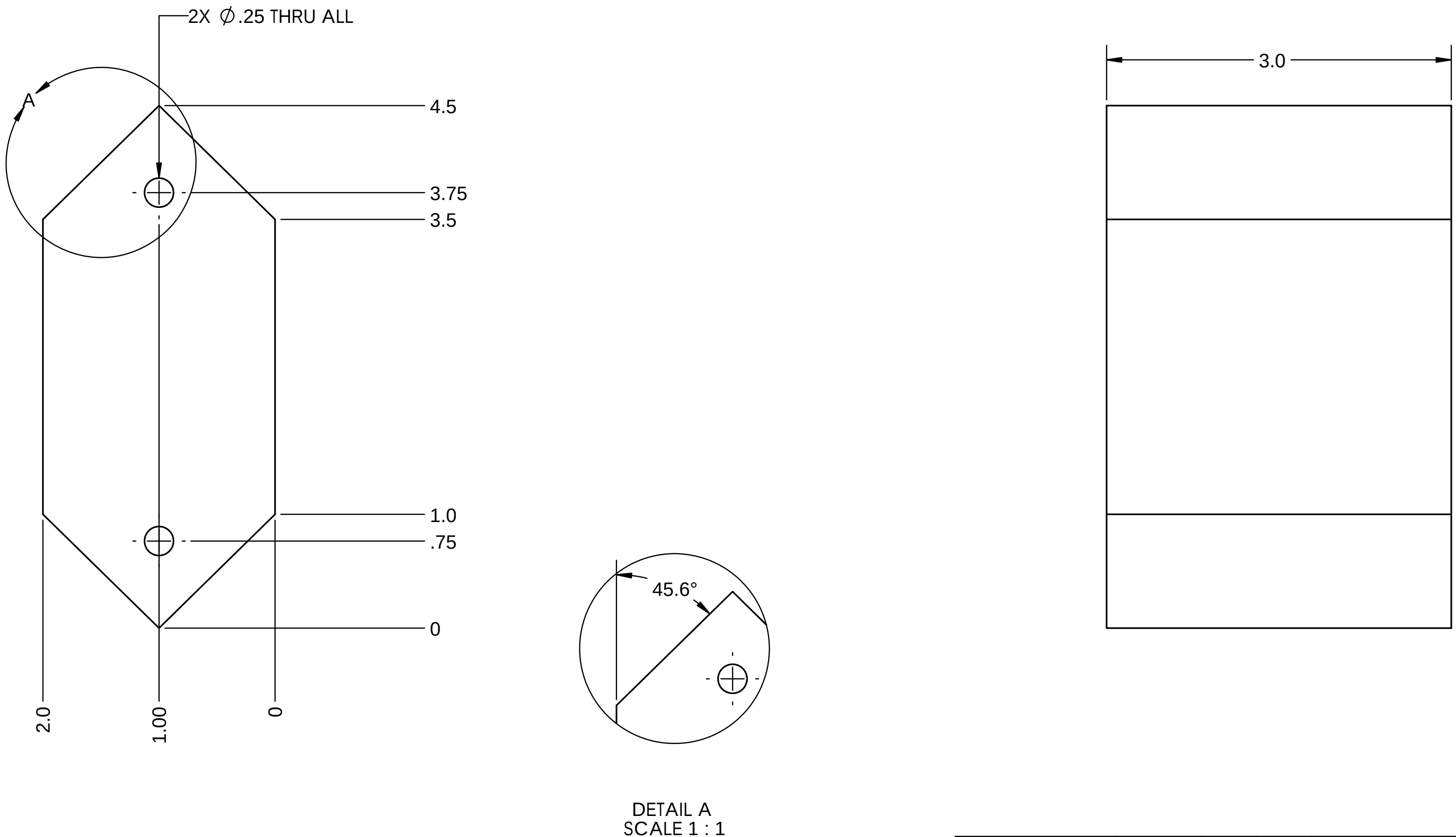
COMMENTS:

Project Omoverhi

TITLE: Bed Front Leg Support

SIZE: B | DWG. NO. 6.6 | REV 01

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



ALL CORNERS

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE DECIMAL PLACE ±0.2
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

MATERIAL: Poppler
FINISH: Clear Lacquer Coat
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GG	6/7/13

COMMENTS:

Project Omoverhi

TITLE: Wood Bed Front Support

SIZE	DWG. NO.	REV
B	6.7	00

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Appendix E: Arduino Code for the Control System

```
#include <LiquidCrystal.h>
//Mosfet Diagram refer to http://manualigratis.altervista.org/it/img51.png
/*
 The circuit:
 PIN 1--GND
 PIN 2--VCC (5V)
 PIN 3--VO (Connect 1K ohm resistor to ground)
 PIN 4--RS to pin 12
 PIN 5--RW to GND
 PIN 6--Enable to pin 11
 PIN 7--Not Connected
 PIN 8--Not Connected
 PIN 9--Not Connected
 PIN 10--Not Connected
 PIN 11--D4 to pin 5
 PIN 12--D5 to pin 4
 PIN 13--D6 to pin 3
 PIN 14--D7 to pin 2
 PIN 15--VCC Connect to Mosfet
 PIN 16--GND Connect to Mosfet
 */
//Based of the wiring code at
http://wiring.org.co/learning/basics/humiditytemperaturesht15.html
      //initialize the pins and variables for the fans
      int fanIn = 31;
      int fanOut = 30;
      int fanState = LOW;
      long previousMillis = 0;
      long interval = 0;
      long interval2 = 0;
      unsigned long currentMillis = 0;
      //end of fan section
      //initialize pump
      int pump = 28;
      int pumpState = LOW;
      //end---------------
      int SHT_clockPin = 8;  // pin used for clock
      int SHT_dataPin  = 9;  // pin used for data
      double desire_temp=98;
      // initialize the library with the numbers of the interface pins
      LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
      //int Light=43;// pin 43 will control the backlight
      //int lightState = LOW;
      double des=27.0;
      double ins=29.0;
      //Initialization for the buttons
      const int buttonPin1 = 22; //Red
      const int buttonPin2 = 23;  //Blue
      const int buttonPin3 = 24;  //Black
      int buttonState1 = 0; // variable for reading the pushbutton status
```

```
int buttonState2 = 0; // variable for reading the pushbutton status
int buttonState3 = 0; // variable for reading the pushbutton status
//Variables for differences in temperature
void setup(){
 Serial.begin(9600); // open serial at 9600 bps
 delay(500);
 pinMode(fanIn, OUTPUT);
 pinMode(fanOut, OUTPUT);
 pinMode(pump, OUTPUT);
 pinMode(buttonPin1, INPUT);
 pinMode(buttonPin2, INPUT);
 pinMode(buttonPin3, INPUT);
 lcd.begin(20, 4);
}
void loop(){
 buttonState1 = digitalRead(buttonPin1);
 buttonState2 = digitalRead(buttonPin2);
 buttonState3 = digitalRead(buttonPin3);
  // set the cursor to column 0, line 1
 // (note: line 1 is the second row, since counting begins with 0):
 lcd.setCursor(0, 1);
 //these can take a bit to get the values (100ms or so)
 float temperature=getTemperature();
 float humidity = getHumidity();
 double temptf = C_to_F(temperature);
 if (buttonState1 == HIGH) {
  desire_temp=desire_temp+1;
  Serial.println(desire_temp);
 lcd.print("     ");
 lcd.print(desire_temp);
 lcd.print(" ");
 lcd.print("     ");
 lcd.print(temptf);
 lcd.print(" ");
 lcd.print("Desired Temperature");
 lcd.print("Inside Temperature");
  Serial.print(temperature);
  Serial.print(" | ");
  Serial.print(temptf);
  Serial.print(" | ");
  Serial.println(humidity);
  delay(50);
 }
 else if (buttonState2 == HIGH) {
  desire_temp=desire_temp-1;
  Serial.println(desire_temp);
  lcd.print("   ");
 lcd.print(desire_temp);
 lcd.print(" ");
 lcd.print("     ");
 lcd.print(temptf);
 lcd.print(" ");
 lcd.print("Desired Temperature");
 lcd.print("Inside Temperature");
  Serial.print(temperature);
  Serial.print(" | ");
  Serial.print(temptf);
```

```
 Serial.print(" | ");
 Serial.println(humidity);
 delay(50);
}
else if (buttonState3 == HIGH) {
 lcd.clear();
 lcd.print(" Humidity %     ");
 lcd.print("    ");
 lcd.print(humidity);
 lcd.print("   ");
 Serial.println(humidity);
 delay(50);
}
else {
Serial.println(desire_temp);
 lcd.print("    ");
lcd.print(desire_temp);
lcd.print(" ");
lcd.print("     ");
lcd.print(temptf);
lcd.print(" ");
lcd.print("Desired Temperature");
lcd.print("Inside Temperature");
Serial.print(temperature);
Serial.print(" | ");
Serial.print(temptf);
Serial.print(" | ");
Serial.println(humidity);
delay(50);
}
if (temptf == desire_temp){
 fanOffIn();
 fanOffOut();
 pumpOff();
}
if (temptf <= (desire_temp-1) && temptf > (desire_temp-2)){
 fanLowIn();
 fanOffOut();
 pumpOff();
}
if (temptf <= (desire_temp-2) && temptf > (desire_temp-5)){
 fanMediumIn();
 fanOffOut();
 pumpOn();
}
if (temptf <= (desire_temp-5) && temptf > (desire_temp-8)){
 fanHighIn();
 fanOffOut();
 pumpOn();
}
if (temptf <= (desire_temp-8)){
 fanHighIn();
 fanOffOut();
 pumpOn();
}
if (temptf >= (desire_temp+1) && temptf < (desire_temp+2)){
 fanOffIn();
```

```
    fanLowOut();
    pumpOff();
   }
   if (temptf >= (desire_temp+2) && temptf < (desire_temp+5)){
    fanOffIn();
    fanMediumOut();
    pumpOff();
   }
   if (temptf >= (desire_temp+5) && temptf < (desire_temp+8)){
    fanOffIn();
    fanHighOut();
    pumpOff();
   }
   if (temptf >= (desire_temp+8)){
    fanOffIn();
    fanHighOut();
    pumpOff();
   }
  }
  float getTemperature(){
   //Return Temperature in Celsius
   SHT_sendCommand(B00000011, SHT_dataPin, SHT_clockPin);
   SHT_waitForResult(SHT_dataPin);
   int val = SHT_getData(SHT_dataPin, SHT_clockPin);
   SHT_skipCrc(SHT_dataPin, SHT_clockPin);
   return (float)val * 0.01 - 40; //convert to celsius
  }
  float getHumidity(){
   //Return  Relative Humidity
   SHT_sendCommand(B00000101, SHT_dataPin, SHT_clockPin);
   SHT_waitForResult(SHT_dataPin);
   int val = SHT_getData(SHT_dataPin, SHT_clockPin);
   SHT_skipCrc(SHT_dataPin, SHT_clockPin);
   return -4.0 + 0.0405 * val + -0.0000028 * val * val;
  }
  void SHT_sendCommand(int command, int dataPin, int clockPin){
   // send a command to the SHTx sensor
   // transmission start
   pinMode(dataPin, OUTPUT);
   pinMode(clockPin, OUTPUT);
   digitalWrite(dataPin, HIGH);
   digitalWrite(clockPin, HIGH);
   digitalWrite(dataPin, LOW);
   digitalWrite(clockPin, LOW);
   digitalWrite(clockPin, HIGH);
   digitalWrite(dataPin, HIGH);
   digitalWrite(clockPin, LOW);
   // shift out the command (the 3 MSB are address and must be 000, the
last 5 bits are the command)
   shiftOut(dataPin, clockPin, MSBFIRST, command);
   // verify we get the right ACK
   digitalWrite(clockPin, HIGH);
   pinMode(dataPin, INPUT);
   if (digitalRead(dataPin)) Serial.println("ACK error 0");
   digitalWrite(clockPin, LOW);
   if (!digitalRead(dataPin)) Serial.println("ACK error 1");
  }
```

```
void SHT_waitForResult(int dataPin){
 // wait for the SHTx answer
 pinMode(dataPin, INPUT);
 int ack; //acknowledgement
 //need to wait up to 2 seconds for the value
 for (int i = 0; i < 1000; ++i){
  delay(2);
  ack = digitalRead(dataPin);
  if (ack == LOW) break;
 }
 if (ack == HIGH) Serial.println("ACK error 2");
}
int SHT_getData(int dataPin, int clockPin){
 // get data from the SHTx sensor
 // get the MSB (most significant bits)
 pinMode(dataPin, INPUT);
 pinMode(clockPin, OUTPUT);
 byte MSB = shiftIn(dataPin, clockPin, MSBFIRST);
 // send the required ACK
 pinMode(dataPin, OUTPUT);
 digitalWrite(dataPin, HIGH);
 digitalWrite(dataPin, LOW);
 digitalWrite(clockPin, HIGH);
 digitalWrite(clockPin, LOW);
 // get the LSB (less significant bits)
 pinMode(dataPin, INPUT);
 byte LSB = shiftIn(dataPin, clockPin, MSBFIRST);
 return ((MSB << 8) | LSB); //combine bits
}
double C_to_F(float temperature){
double result;
result=(temperature*1.8)+32;
return result;
}
void SHT_skipCrc(int dataPin, int clockPin){
 // skip CRC data from the SHTx sensor
 pinMode(dataPin, OUTPUT);
 pinMode(clockPin, OUTPUT);
 digitalWrite(dataPin, HIGH);
 digitalWrite(clockPin, HIGH);
 digitalWrite(clockPin, LOW);
}
/*void backLight(){
 interval2 = 1000;
 currentMillis = millis();
 if(currentMillis - previousMillis > interval2) {
  previousMillis = currentMillis;
  // if the light is off turn it on and vice-versa:
  if (lightState == LOW)
  lightState = HIGH;
  else
  lightState = LOW;
  digitalWrite(light, lightState);
 }
}
*/
void fanHighIn(){
```

```
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = HIGH;
  digitalWrite(fanIn, fanState);
 }
void fanMediumIn(){
 interval = 5000;
 currentMillis = millis();
 if(currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
  // if the fan is off turn it on and vice-versa:
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = LOW;
  digitalWrite(fanIn, fanState);
 }
}
void fanLowIn(){
 interval = 50;
 currentMillis = millis();
 if(currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
  // if the fan is off turn it on and vice-versa:
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = LOW;
  digitalWrite(fanIn, fanState);
 }
}
void fanOffIn(){
  if (fanState == HIGH)
  fanState = LOW;
  else
  fanState = LOW;
  digitalWrite(fanIn, fanState);
 }
  void fanHighOut(){
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = HIGH;
  digitalWrite(fanOut, fanState);
 }
 void fanMediumOut(){
 interval = 500;
 currentMillis = millis();
 if(currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
  // if the fan is off turn it on and vice-versa:
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = LOW;
  digitalWrite(fanOut, fanState);
```

```
 }
}
void fanLowOut(){
 interval = 50;
 currentMillis = millis();
 if(currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
  // if the fan is off turn it on and vice-versa:
  if (fanState == LOW)
  fanState = HIGH;
  else
  fanState = LOW;
  digitalWrite(fanOut, fanState);
 }
}
void fanOffOut(){
  if (fanState == HIGH)
  fanState = LOW;
  else
  fanState = LOW;
  digitalWrite(fanOut, fanState);
}
void pumpOn(){
  if (pumpState == LOW)
  pumpState = HIGH;
  else
  pumpState = HIGH;
  digitalWrite(pump, pumpState);
}
void pumpOff(){
  if (pumpState == HIGH)
  pumpState = LOW;
  else
  pumpState = LOW;
  digitalWrite(pump, pumpState);
}
```

Appendix F: PDS

Datum description: Our current design (2012-2013 year) is compared to the prototype created in the 2010-2011 year

Parameter	Units	2012-2013 Design	2010-2011 Design
Performance			
Achievable steady state temperature range	ºC	30-37*	20-39
Temperature measurement accuracy	ºC	+/- 0.5	+/- 0.3
Temperature Variation from target	ºC	+/- 1.0	-
Temperature stabilization time	min	15	17
Maximum air speed over infant	cm/s	<8.0	-
Maximum noise level to patient during standard operation	dB	<80	-
Bed angle of inclination	º	0-20	0 or 12.5
Electrical consumption			
Fans	W	3.2-3.6	1-2
Pumps	W	34	60-67
Control system	W	6	<1
Total	W	43.2-43.6	62-70
Maximum operation time off battery	hr	11	-
Mattress thickness	cm	4.6	4
Cost	$	825	3293.22

*Specification is target, expected, or not known, and to be tested

Appendix G: Budgetary Spreadsheet

Budget Update

TEAM Omoverhi
Date 27-Jan-13

INCOME					
Category	**Source**	**Sought**	**Committed**	**Pending**	
Grant	Senior Design Fund	$ 4,000.00	$ 3,000.00		
Fundraising	N/A				***Provide details on***
					any pending funding
	TOTAL	**$ 4,000.00**	$ 3,000.00	$ -	$ 3,000.00

EXPENSES					Notes
Category	**Description**	**Estimated**	**Spent**	**Pending**	
Structure					
	Structural Frame	$ 40.00	$ 37.99	$ -	
	Exterior Sheet Metal	$ 85.00	$ 145.32	$ -	Was more expensive than initially predicted
	Manufactured off site		$ 50.00		Parts were too complicated to be made in our shop
	Insulation	$ 13.00	$ 10.00	$ -	
	Nuts & Bolts & Washers (se	$ 15.00	$ 22.00	$ -	Shipping expenses were unaccounted for and got a bulk pack, more than we needed as redundancy
Shell					
	Acrylic Sheeting	$ 160.00	$ -	$ -	Got the acrylic donated to us
	Plywood	$ 45.00	$ 53.80	$ -	The wood turned out to be much more expensive than initially predicted, but with the donation of the acrylic this subsystem is still well under budget
	Hinges	$ 5.00	$ 9.50	$ -	Used Metal ones rather than plastic
	Screws	$ 10.00	$ 10.00	$ -	
	Weld on Cement	$ 6.00	$ 6.00	$ -	
	Handle	$ 2.00	$ 2.00	$ -	
Thermal System					
	Piping	$ 40.00	$ 29.92	$ -	
	Soldering Kit	$ 30.00	$ -	$ -	Are able to use Don's
	Water Pump	$ 60.00	$ 70.00	$ -	
	Fan	$ 10.00	$ 18.00	$ -	Design changed to have 2 fans rather than 1
	Radiatiors		$ 40.00	$ -	Design was revised to include a radiator to make thermal system more efficient
Control System					
	Arduino	$ 50.00	$ 48.84	$ -	
	LCD Display	$ 25.00	$ 17.95	$ -	
	Wiring	$ 10.00	$ 33.00	$ -	
	Display Frame	$ 10.00	$ 25.00	$ -	Sent out to be made
	Buttons	$ 6.00	$ 3.85	$ -	
	Copper Wiring	$ 10.00	$ 9.97	$ -	
	Digital Temp Sensor	$ 50.00	$ 41.95	$ -	
	Soldering equipment	$ 20.00	$ 20.00	$ -	
	Breadboard	$ 8.00	$ 31.00	$ -	
	Resistors	$ 5.00	$ 7.95	$ -	Was only able to get a huge bulk pack of 500
	MOSFET		$ 8.60		Did not realise the need for this until recently
	Power Supply		$ 5.79		|
	Electronics Tool Box		$ 9.07		|
	Breadboard Jumper Wire		$ 5.85		|
Bed					
	Wooden Frame	$ 20.00	$ 20.00	$ -	
	Supports	$ 20.00	$ 20.00	$ -	
	Foam Bedding	$ 15.00	$ 13.00	$ -	
	Wood Glue	$ 5.00	$ -	$ -	Used Screws
	Screws & Washers		$ 7.00	$ -	
Assembly Equipment					
	Propane Soldering Torch	$ 50.00	$ -	$ -	Should have access to in Machine Lab,
	Electronics Soldering Gun	$ 30.00	$ 20.89	$ -	will only need if off campus work is required
	Caliper	$ 100.00	$ -	$ -	Don't need, can use Marks
Testing Equipment					
	Water Heater	$ 700.00	$ 237.00		Purchased a small tankless heater
	Thermal Sensors (x3)	$ 150.00	$ 20.00	$ 100.00	Used the one for the control system, and Dr. Mark's handheald thermocouples Intend to conduct more indepth tests, may need additional sensor equipment
	Multi-Meter	$ 20.00	$ -	$ -	Will only need if off campus work is required
	Airflow Sensors	$ 50.00	$ -	$ -	Didn't End up using this for the tests, may still want to in future tests
	Testing Plumbing				
Misc.					
	Balsawood for Model	$ 20.00	$ 20.00	$ -	
		Estimated	Spent	Pending	
	TOTAL	**$ 1,895.00**	$ 1,131.24	$ 100.00	$ 1,231.24
					Spent+Pending
	Net Reserve (Deficit)	**$ 1,105.00**	$ 1,868.76		$ 1,768.76
	Spent - Estimated cost	$ 663.76			

NOTE: Deficit in any area must be explained