DESIGN OF CONTROLLED ENVIRONMENT FOR TISSUE ENGINEERING

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Malcolm Lapera

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COMMITTEE MEMBERSHIP

TITLE:	Design of Controlled Environment for Tissue Engineering
AUTHOR:	Malcolm Lapera
DATE SUBMITTED:	February 14, 2014
COMMITTEE CHAIR:	Dr. Robert Crockett, Director, General Engineering Department Biomedical and General Engineering Department
COMMITTEE MEMBER:	Dr. Lily Laiho, Associate Professor Biomedical and General Engineering Department
COMMITTEE MEMBER:	Dr. David Clague, Associate Professor Biomedical and General Engineering Department

ABSTRACT

Design of Controlled Environment for Tissue Engineering

Malcolm Lapera

Tissue engineering aims at relieving the need for donor tissue and organs by developing a process of creating viable tissues in the laboratory setting. With over 120,000 people awaiting a transplant, the need for generating tissue engineered organs is very large [3]. In order for organs to be engineered, a few issues need to be overcome. A work space that both creates an environment which maintains cell viability over an extended period of time as well as accommodates the necessary fabrication equipment will be needed to further tissue engineering research. Therefore, a design for a "Tissue Engineering Hood," will be developed and evaluated. The goal of this design will provide an environment capable of providing 37°C, 95% humidity, and 5% CO_2, actively deter contamination, and provide the necessary support hardware for a 3D printer designed for tissue engineering. The design detailed in this paper was implemented successfully and evaluated. The current design has issues creating the proper environmental conditions, however does actively prevent contamination, and provides the necessary support hardware for a 3D printer. The current design was capable of reaching a temperature of 32°C, had issues increasing the humidity while incorporating the laminar air flow aspect of the design, and design flaws in the door allowed CO_2 to leak too rapidly. After remedying these and a few other minor issues described in the report, the tissue engineering hood will be a beneficial tool for use in tissue engineering.

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CHAPTER 1

Introduction

Tissue Engineering

Tissue engineering refers to the field of biomedical engineering aimed at the manufacturing of tissues for regenerative medicine. The general approach to developing a tissue is by creating a scaffold that mimics the extracellular matrix (ECM) of the tissue, then seeding the appropriate cell types onto the scaffold. The combination of cells and scaffold then create a tissue. Biodegradable materials are commonly used as scaffolding materials, so that the cells remodel the scaffold with ECM generated by the cells [1]. The generation of a tissue also often requires a cultivation step, where the scaffold and cell combinations are cultured in the proper conditions so that the cells can remodel the scaffold and form a tissue. This process is being developed and refined in order to create techniques for developing patient specific tissues for use in a clinical environment [2].

The generation of tissues and organs is aimed at combating the need for viable organs and tissues for organ transplants and skin grafts. Currently there are over 120,000 people waiting for an organ transplant, while only 24,131 transplants occurred between January and October of 2013[3]. This leaves a huge number of patients that go without the organs that are needed to save their lives. While organs are the end goal of tissue engineering, the generation of different tissues is also being explored and implemented. Tissue engineered skin has been used to treat severe burn victims, as approximately

50,000 burn victims are hospitalized yearly [4]. There are attempts to develop a tissue engineered solution for nearly every part of the body, as replacing damaged or diseased tissue with healthy tissue is an optimal solution but rarely an option.

As tissue engineering is an emerging field, there are still many issues to be resolved before it can reach its full potential. While there is a great range in success of different methods, a few key issues prevent the creation of larger constructs and producing them in an effective manner. The generation of larger tissues has yet to be achieved due to the difficulty in providing the necessary vascularization. The vasculature in tissue is responsible for nutrient delivery and waste removal, and without it the tissue cannot survive. Therefore without the ability to generate vasculature in the engineered tissues, it limits the size of constructs that can be made [5] [6]. The other issues are involved with quickly and efficiently producing a tissue engineered solution for a specific patient [7]. Currently the majority of the tissue engineering techniques require a large amount of time, manual labor and often require complex techniques. If a tissue engineered solution is to be effective in a clinical situation, it must be able to be generated in a timely fashion, be specific to the patient, and be highly reproducible in order to gain FDA approval [7]. There are many different techniques being examined to accomplish these goals; however they have not yet been achieved and new technology and techniques must be developed.

Cell Environment

To maintain cell viability, more than sterility is necessary. The proper environment, mimicking that of the body, must be simulated. Therefore, temperature must be kept at 37°C, humidity at approximately 95-99% and a CO_2 level of 5% for mammalian cells [8]. In a laboratory setting, this is simulated using a few different devices. The most common device used is an incubator. An incubator is a smaller cabinet that provides the proper temperature and CO_2 level for culturing cells in media. Humidity isn’t often controlled explicitly since cells are typically in a flask suspended in culturing media, thus creating its own humid environment. However humidity is often elevated by placing a water reservoir within the incubator or is explicitly controlled by the incubator. Sterility in these incubators can be compromised as there are no active measures for maintaining sterility, therefore anything that is placed in an incubator needs to be handled under sterile conditions.

Bioreactors are also often needed to provide any further stimuli to properly cultivate cells and tissues. Bioreactors are often custom devices that provide the necessary stimuli for their associated tissue. The stimuli varies based on the type of tissue, however typically compression, shear stress, repetitive elongation or electrical stimuli [2][9][10] are often applied. They are often used in combination with an incubator as the bioreactors don’t often control temperature, CO_2 or humidity, and focus primarily on providing mechanical stimulation. Therefore the combination of the two provides the proper conditions for cultivating a tissue. There are often some issues combining the two as they aren’t designed specifically for use with each other.

But all these methods still require the initial fabrication of the tissue. Engineered tissues are often created by first creating a scaffold then adding the cells to it, and cultivating the construct till it forms a viable tissue. This requires a sterile work space in which to assemble the constructs and fit it to a bioreactor. This is commonly accomplished using a laminar flow hood. A laminar flow hood provides an aseptic work environment within which a user can easily manipulate items without compromising sterility. This is accomplished by controlling the air flow and filtering any contaminates out of the air. However, as the user is allowed to reach in and work within the laminar flow hood, contamination can occur through surface transfer if any contaminated objects are brought into the hood. Therefore it is still required to use a proper aseptic handling technique to prevent contamination.

Fabrication Techniques for Tissue Engineering

The fabrication methods for tissue engineering are extremely varied; however there are a few common methods for creating scaffolds. When generating cylindrical constructs, electrospinning is often the go to method for fabrication. Electrospinning is a method of fabrication that involves extruding polymer solution through a narrow orifice to create a drop of the solution at the tip of the nozzle. A high voltage is then used to accelerate the droplet from the nozzle to a grounded target. The droplet dries while traveling through the air, forming a polymer fiber. This creates a nonwoven textile that can be used as a scaffold for tissue engineering [11]. The grounded target is often a rotating spindle which makes it easy to create a cylindrical construct without any seams. Not all materials can be used in electrospinning, however PGA, PLGA, PLC, collagen

and fibrinogen have been successfully used [11]. As generating a tissue engineered blood vessel is currently one of the most practical and profitable ventures for tissue engineering, a cylindrical construct can be of great use [12]. Beyond blood vessels, the tissue engineering of nerves will also benefit from a useful cylindrical scaffold [13].

Hydrogels are also a common material used for scaffolds in tissue engineering. Hydrogels are cross-linked polymers that form a porous gel, making them structurally similar to ECM. They are also typically polymers and polypeptides which makes them chemically similar as well. They are also easily fabricated, by adding a cross-linking agent to usable polymers [11]. One of their main allures is that they can be injected into a tissue and form a scaffold *In Situ* [11][14]. They can also be used in 3D printing by using the cross-linking agent to polymerize a scaffold out of solution [15].

Three dimensional printing is another fabrication method of promise for creating tissue engineering scaffolds. 3D printing is a fabrication method where a print head extrudes a building material that solidifies in a two dimensional pattern. Another layer is then printed on top of previous layers until a three dimensional object is formed. There are few different methods of printing a solid layer in 3D printing. The two most common are laser based sintering, where a laser is used to solidify a solution through cross-linking or sintering, and fused deposition modeling, where a material is extruded onto a platform [16]. Fused deposition modeling is primarily used for tissue engineering as a laser is damaging to any cells in use and breaks down many polypeptides that can be used as a scaffold. There are a few different deposition methods used in fused deposition modeling as well. The more common methods of deposition are ink jet printing, precision extruding

deposition and volumetric extrusion. Ink jet printing utilizes the printing technology used in ink jet printers to extrude a small amount of liquid in a highly precise manner. This method is also commonly used in a two component system, where one material printed is base material that is polymerized with the second material. Precision extruding deposition works much like a hot glue gun on two axis control system. A heating element liquefies a polymer and extrudes it where it re-solidifies to form a 3D object. Volumetric Deposition is the most common method used for tissue engineering as it is the most versatile and does not harm the materials being deposited. It deposits material by extruding it from a syringe through precision control. Pneumatic control over the deposition syringes is also the most common method of control [16]. There are many different methods and forms of 3D printing, making it a diverse method of fabrication and a useful resource for tissue engineering.

Three dimensional printing has the potential to generate extremely complex internal geometries to promote cell proliferation and vascularization. The ability to have an extremely high level control on the internal geometries is crucial for the generation of large tissues. The high level of control is also crucial for generating the structural complexity seen in many organs such as the kidney and heart. Another advantage of the high level of control in the complexity of the scaffold design granted by 3D printing is patient specificity. As each patient will need a tissue of a different geometry or organ of different size, the ability to easily tailor the generated tissue to the patient’s specific needs is also necessary for the success of tissue engineering [6]. Therefore the high level of

control over the internal and gross geometries of the scaffolds gives 3D printing a significant potential for tissue engineering [17][18].

Another advantage of 3D printing for the field of tissue engineering is that it can print multiple materials at the same time. Many different materials can be extruded based on the extrusion method being used, as well as a having more than one deposition head on a device. This allows for a large number of materials to be used in a 3D printer, including cells, providing a large number of design options for tissue engineering. This also allows for both cells and scaffold to be printed simultaneously, giving the possibility of generating tissues without the need of generating a scaffold and then seeding the cells onto it. This also removes the issue of cell proliferation through larger scaffolds, as the cells can be placed in their desired location rather than being seeded and traveling from the surface of the scaffold inwards [16][19]. Multiple cell types can be deposited as well, allowing for controlling the location of each type of cell. This can be extremely important for generating tissues with multiple cell types. This is necessary for any large tissues or organs, as at minimum the vascularization needed requires multiple cell types. All these advantages of 3D printing for tissue engineering make it a prime choice as a fabrication method for furthering tissue engineering research.

Goals of Tissue Engineering Hood

In order to develop a device that will aid in the generation of larger tissues through various fabrication techniques, the “tissue engineering hood” will have the following requirements. It will have to provide the proper environment to maintain cell viability and promote proper cellular activity. This requires providing a work space

which actively maintains the sterility of the environment. Bacterial and fungal contamination can kill of all the cells used in any sort of tissue engineering, therefore providing an aseptic environment at minimum is necessary for creating any construct that is intended to survive longer than 24 hours. Beyond maintaining sterility, the proper temperature, humidity, and CO_2 concentration must be able to be controlled. As described previously, a temperature of 37°C, humidity of 95-99%, and a CO_2 concentration of 5% are necessary for mammalian cells, therefore those conditions are required at minimum. Beyond providing the proper environment for cells, the work space must also provide the proper hardware for supporting possible fabrication equipment. Due to the advantages presented by 3D printing for tissue engineering, this design will focus on providing the support hardware necessary to operate the more common commercial 3D printers designed for tissue engineering. By achieving these goals, the fabricated device should provide a work space optimized for fabricating larger tissues and organs.

CHAPTER 2

Design

Design Requirements

With the previously described goal of developing an aseptic work space that provides the proper environment for cells to thrive in and can accommodate devices for tissue construction, the first step in the design is to properly define the necessary design requirements. For this design, the proper environment must be defined as well as provide the necessary support functions for common devices used in tissue engineering. This design will focus on accommodating 3D printers currently on the market used for tissue engineering. Also by providing the necessary support for a 3D printer, most other devices will have sufficient support as well.

Environment Requirements

To provide the proper environment, an aseptic environment must be maintained, and temperature, humidity and percentage of CO_2 be controlled. Along with providing an aseptic environment, one must be able to reach into the work area and manipulate items being used without contaminating the environment. As for temperature, in the case of tissue engineering, standard body temperature must be achieved for proper growth. Therefore the workspace must be able to reach 37 ° C, with little variance throughout the workspace and to be stable over time, preferably varying +/- 0.5 ° C. However, for the sake of versatility the work space should be able to be heated to a range of temperatures.

Therefore, the work space should be able to reach temperatures of 45 ° C, starting from room temperature.

While ph is commonly stabilized via media solutions for the cells and constructs, humidity and percent CO_2 control are necessary for extended periods of time. Humidity should be kept in the range of 95-99% relative humidity, therefore the workspace should be able to reach 99% relative humidity from the humidity in the room. The humidity should also be kept constant, varying by +/- 2% relative humidity. The percentage of CO_2 should be kept at 5%, varying by +/-0.5%, but should also be set as high as 10% to accommodate different experiments and cell types.

Table 1 – Environment Design Requirements

	Range	Accuracy
Temperature	25°C (RT) - 45°C	±0.5°C
Humidity	Up to 99%	±2%
CO2 %	0.04 - 10%	±0.5%

Printer Accommodation Requirements

The most common commercial 3D printer used for tissue engineering is the 3D-Bioplotter by EnvisionTEC. Another common printer is the BAT (Bio-Assembly Tool) by Sciperio, however many of the 3D printers used in research are custom built. While the size, function, and necessary support may vary greatly from printer to printer, nearly all run off 120 VAC. Therefore there should be access to a 120 VAC plug within the

work space. As the 3D-Bioplotter is the most common commercial printer, its requirements will be used as standard. The 3D-Bioplotter requires 10 Amps, therefore the outlet must provide 120 VAC and 10 Amps minimum [20]. The 3D-Bioplotter as well as the BAT uses pneumatic actuators to control its deposition method [20][21]. Therefore a hook up to a compressed inert gas must also be provided in order to operate these printers. This is a common actuation method for controlling direct deposit 3D printing devices. The 3D-Bioplotter requires 6-8 bar (85-115 psi) for operation, therefore 115 psi should be able to be provided at minimum. Many research facilities are outfitted with a 100 psi line, therefore many devices are built to take advantage of this. Another less common requirement is controlling the temperature of the materials to be deposited. This is necessary for such things as collagen as it polymerizes above 7 ° C [22]. Therefore a circulating water coolant system needs to be provided to control the temperature of the materials. The last thing that needs to be considered for accommodating a 3D printer is the size of the work space. The overall dimensions of the 3D-Bioplotter are 38.425”(W)x24.527”(D)x30.433"(H), therefore the work space must be a bit larger to easily accommodate the printer [20].

Table 2 – 3D Printer Support Design Requirements

	Range	Accuracy
Air Pressure	85-115 psi	±15 psi
Deposition Pen Temperature	4-40°C	± 1°C
Power	120 VAC, 10 Amps	
Working Volume	42"(W)x30"(D)x36"(H) min.	

Overall Goals

The overall goal of the hood is to provide an aseptic environment which cells thrive in and accommodate the use of a 3D printer. Therefore beyond the previously mentioned designed requirements, there is also the goal of maintaining cell viability for an extended period of time. Currently 3D printers can print the largest viable tissue engineered constructs within 4-6 hours. However with the potential of 3D printing to incorporate vascularization and thus increasing the viable tissue construct size, keeping the cells healthy for a longer period of time is necessary. Therefore the cells need to be kept healthy for 8 – 10 hours, potentially longer. This would mean that there is 65-75% cell viability and reproduction of cells in the culture after the extended period of time, which is the level of cell viability seen in cultures housed in an incubator. It is also important to prevent contamination of the cell cultures while housed in the hood. Minimizing the overall footprint of the tissue engineering hood is also a goal of the design.

Preliminary Design Decisions

Humidity Control

In order to control the humidity in the hood accurately, a method of increasing the humidity and sensing the humidity is necessary to provide accurate control. The method of adding humidity must be able to fit within the workings of the tissue engineering hood, while not taking up space in the work space set aside to accommodate a 3D printer. The method of increasing humidity must be able to be controlled electronically, to provide control via the on-board microcontroller. The sensing method must be able to interface with the on-board microcontroller to act as feedback for control of the method of increasing humidity.

An electronic humidifier is the obvious choice for increasing the humidity of the tissue engineering hood. There are two types of humidifiers, evaporative and ultrasonic. Evaporative humidifiers work by blowing air over a wetted material to cause water to evaporate and increase humidity. This method is beneficial as it will prevent any particulates or ions in the water to be spread around the device. Ultrasonic humidifiers create a mist of water using ultrasonic vibrations to add humidity into the air. This method has the possibility of adding contaminates into the air as it actually puts water into the air [22]. Therefore to decrease the chances of contamination and corrosion, an evaporative humidifier with proper treatments to the water supply should be selected. Based on the size of the necessary working volume (30 cubic feet) and accounting added volume of the hood to circulate air and house equipment, a humidifier that can accommodate at least 50 cubic feet is necessary. A commercially available option would

also be preferred to limit the potential for fabrication error and save time. Through a cursory and extensive web search, one option remained. The Cigar Oasis II XL is an evaporative humidifier which is rated to provide control over humidity for up to 60 cubic feet. It is electronically controlled, requiring 12 VAC and 600 mA, and has the dimensions of 6.5”x5.3”x13”. The compact size, electronic control, and effective size rating match the necessary design requirements for our system. This was selected over a custom system in order to remove the issues involved with designing and implementing a custom design.

Figure 1 – Humidity Control

For sensing the humidity, a humidity sensor needed to be able to communicate with the microcontroller in a compatible manner (Serial or I2C), be able to read 0-100% humidity, be relatively accurate (+/- 1%), be diffusive read type, and not need a reference to sense the humidity. Low cost, low voltage and a large amount of reference materials for interfacing would be highly preferred. From these requirements, Sparkfun’s HH10D humidity sensor was used. It is inexpensive, runs off 3.3V, making it low voltage, communicates via I2C and has extensive documentation on proper utilization. It runs off

150 µA, operates between -10 and 60 °C, and has ±3% accuracy. The board it's mounted on has the dimensions of 8 mm wide and 24 mm long.

Temperature Control

Temperature control will need a method of heating as well as a method of sensing the temperature to provide proper control. An electronic method of heating will be necessary for it to be controlled via a microcontroller. The temperature must also be electronically sensed in order to interface with the control scheme. Resistance heating is a very common method for heating air when there is a fan to pump air over the heated element. With the combined goal of providing laminar flow within the hood, resistance heating will be used to heat the air being circulated. Therefore a resistive heating element should be able to be easily adhered to a metal heat sink, have significant wattage output, be run off at most 120 VAC, and operate over the range of 20 ° C – 100 ° C. To accomplish this Omega's Kapton resistance heaters were used. They feature a pressure sensitive adhesive and a wide range of sizes, voltage requirements and wattage. For this project, four 1"x4", 120 VAC, 20 Watt heaters were selected.

The temperature sensors should run off 5V, be accurate to at most 1°C, read temperatures ranging from 4°C – 50°C, and have multiple sensors be easily interfaced with the microcontroller. To accommodate these requirements, Sparkfun's TMP36 temperature sensors were selected. They run off 5V and provide an analog signal calibrated by the manufacturer. They do not require any amplification or calibration making them easily interfaced with the tissue engineering hood and do not require any

further equipment. The sensors have an accuracy and resolution of ±1°C and operate between -40-125°C.

CO2 Control

To provide control of the concentration of CO_2, a method of infusing the work space with CO_2 evenly and monitoring the concentration is necessary. The air flow from the laminar flow aspect can be taken advantage of to evenly distribute the CO_2, while being a gas, it will naturally evenly distribute in the workspace regardless. However the release of pressurized gas causes cooling which will cause unwanted temperature fluctuations if released within the work space. Therefore releasing it into the airflow before entering the work space will prevent these fluctuations. Using a tank of CO_2 and an electronic solenoid to control the inlet of gas will provide the necessary infusion of CO_2 required. The solenoid will have to be able to be controlled electronically, preferably from a 12VDC source, be of a normally closed design, and be able to accommodate at least 20 psi of CO_2. A regulator to control the pressure released from CO_2 tank will also be required. It must be calibrated for CO_2, and be able to regulate the pressure from 0-50 psi at minimum. The solenoid chosen was an ASCO two-way valve, of normally closed design, with an electronic solenoid that operates using 12VDC. The inlet and outlet have ¼" NPT female fittings. The regulator chosen is capable of regulating up to 1500 psi, which greatly exceeds its intended use. An air hose compatible with both the regulator outlet fitting and inlet of the solenoid valve was custom made and purchased locally at Contractor's Maintenance. Brass fittings rated to withstand up to 100 psi of pressure were used to mount and connect the solenoid to the tissue engineer hood and channel the air

flow to the appropriate location. These parts consisted of a through wall connection, threaded pipe and a female x male 90° elbow and a male x male coupling, all with 1/4" NPT connections.

An electronic CO_2 sensor is required to provide proper control over the concentration of CO_2 in the tissue engineering hood. It must be a diffusive sensor type, not require any reference gas, be able to read a range of concentrations from 0-10% at minimum, easily interface with a microcontroller, and be affordable. After a cursory web search, there was only one affordable option that met all the design requirements. The COZIR CO_2 meter reads a range of 0-20% CO_2 through a diffusive sensor, has an accuracy of 70 ppm, runs off of 3.3VDC and 33mA, and communicates via a serial port. It also has a warm up time of less than 10 seconds and can take measurements every 500 milliseconds. All other comparable options were far outside the acceptable price range, exceeding $1000.

Water Coolant System

The water coolant system for controlling the temperature of the deposition materials requires three main aspects: the heating and cooling system, the water pump, and the water tank and hardware. This is due to needing to control the temperature of the water, circulate the water and to be properly housed.

The water pump needs to be able to circulate water at decent rate and be electronically controlled. Pumps designed for water coolant systems used in cooling computers, are especially applicable to this situation. A Swiftech MCP355 water pump

was selected. It runs off 12VDC and 1.46 Amps, accommodates 3/8 ID tubing, has an output of approximately 120 gallons per hour, and operates with water temperatures up to 60°C.

The heating and cooling system needs to be electronic and consolidated. Peltier devices, also known as thermoelectric coolers, are optimal for this application as they can both heat and cool within the same device. The device needs to be outfitted with a heat sink and cooling fan and be designed to transfer the heat directly to the water tank. A preassembled peltier system was purchased from Digikey that meets the necessary requirements. The chosen assembly was designed for direct contact to the desired surface, has a built in heat sink and fan for dissipating unwanted heat and operates off 12VDC with a nominal voltage of 2.6 Amps. It has a max surface temperature of 80°C and has a range of -10 to 50°C.

The water tank needs to be able to easily reach thermal equilibrium with the peltier device and the water it houses. Aluminum provides a corrosion-resistant container and is relatively good at conducting heat. A foot of 2 ½" square tubing provides for approximately 0.26 gallons of water to be housed. The water will be channeled through 3/8" ID PVC tubing, using brass fittings to connect the tubing through the sheet metal. These will lead to an outlet and inlet designed to hook up to an existing cooling system via quick-connect universal hose sockets.

Aseptic Environment

The tissue engineering hood must also provided an aseptic environment that a user can reach into, take things in and out of with ease and manipulate items in the hood. Mimicking a laminar flow hood design can accommodate these design requirements. Laminar flow hoods are designed to prevent contamination of the work space through controlled air flow and filtration, while still allowing the user to bring things in and out of the hood, and work inside it without contamination, provided one uses a proper aseptic technique and the use of sterile products. Laminar flow hoods require a blower motor that has a high enough output to produce an air speed of 0.5 m/s as well as using the proper HEPA filters to evenly distribute the air flow and filter any particulates. The HEPA filters must filter out anything larger than 0.2 microns to provide the aseptic environment. A pre-filter is also required to remove any large particulates that might damage the more fragile HEPA filters. The HEPA filters are also designed to provide the proper air flow given the proper conditions. Charts given by the manufacturers are used to discern the correct filter.

To accommodate the necessary requirement of filtration, two 24”x30”x3” standard volume HEPA filters were purchased from HEPAfilters.com. The size of the HEPA filters was chosen because it was the only standard size that could be used to accommodate the design requirements of the working volume. Using them did however cause an increase in the size of the working volume to a width of 48”. Having a custom size HEPA filter created would have significantly increased the price of the filters as well as the lead time to receive it. The HEPA filters chosen filter particulates greater than 0.2

microns and can accommodate humidity up to 99.99%. For the prefilters, the same supplier suggested the ScoatFoam filter media, as it is very inexpensive and could be cut to the necessary dimensions easily. Therefore two pieces of 24”x30”x1” ScoatFoam filter was purchased to function as the prefilters.

The blower motor required must have a large enough output to provide an average air speed of 0.5 m/s through an area of 48”x30”. Blower motor output is rated in CFM (Cubic Feet per Minute), therefore a volumetric air speed must be calculated as follows.

$$Volumetric\ Air\ Speed\ [CFM] = \left(0.5\frac{m}{sec} x60\ \frac{sec}{min} x3.28\frac{feet}{m}\right) x\ (4'\ x\ 2.5')$$

$$=\ 984\ CFM$$

Therefore the blower motor selected for the system must be able to output approximately 984 CFM. The blower motor must also be able to be run off 120VAC and be able to be housed within the unit. A two speed motor would also be ideal for circulating the air at a lower speed when the hood is closed, so as to reduce the energy used and put less stress on the system while continuing to circulate the air sealed within the hood. To meet these requirements, a FASCO two speed 120VAC blower motor was purchased. At the high speed, it outputs 1000 CFM and has integral circuitry for controlling motor speed, making it easily integrated into the command scheme.

A common addition to laminar flow hoods is a germicidal UV lamp. As laminar flow hoods need the air flow to be constantly circulating to maintain their level of sterility, some laminar flow hoods use germicidal UV lamps to allow turning off the air flow without causing contamination. The germicidal UV lamps are used to kill any

organic contamination that could occurred while the air flow is inactive, therefore adding an increase in contamination prevention. The UV rays can however be harmful to the user as well; therefore the UV lamps are only for use while the laminar flow hood is not in use. To provide this system, a germicidal UV bulb and UV digital ballast must be selected. The germicidal UV bulbs are rated by their length and wattage. A UV ballast is then selected based off of the bulb to provide the proper current and voltage to operate the bulb. For this project, a 30”, 37 Watt germicidal UV bulb was selected, as well as the corresponding UV ballast. The mounting fixtures and shield to direct the light inward were to be fabricated.

Air Pressure

To provide the necessary air pressure to operate any pneumatic actuators present on any 3D printers or devices to be used in the tissue engineering hood, a supply of pressured gas and regulation system must be present. Upon recommendation by a sales representative at Airgas, nitrogen gas was selected. This is due to it being relatively inexpensive, inert, and commonly used to operate pneumatic systems. The system should also be able to be altered to use a supply of compressed air if available from the laboratory the device is used in. But to allow the device to be a stand alone system, a separate supply must be available. Therefore a 20 gallon nitrogen tank was selected to be incorporated into the device. This size was selected to be nearly equivalent in size to the CO_2 tank selected and provide at least enough gas to operate a device for at least one period of use. An inert gas regulator compatible with the tanks was also purchased to regulate the pressure released into the system.

A two way ball valve was selected to control the inlet of nitrogen to a universal quick connect hose socket. This was selected upon the assumption that the pneumatic actuators present would control when air was needed for the actuation as long as the pressure was present. Therefore the tissue engineering hood does not need to provide electronic control of the air pressure. Adequate brass pipe and fittings were also selected to allow for the nitrogen to be passed from the back exterior of the hood into the work space. A custom air hose was purchased from Contractor's Maintenance to connect the regulator with the two-way ball valve.

Electronics

To provide power for a 3D printer, a power outlet mounted within the workspace is required. The plug must be rated for at least 120 VAC and 10 amps. A round single plug outlet was selected, and is rated for 120 VAC and 20 amps. A matching face plate for plug was also selected.

The tissue engineering hood requires an onboard microcontroller in order to control all the actuaries and sensors in order to maintain the proper environment to maintain cell viability. Based on the previously selected sensors, the microcontroller must have multiple analog to digital converter pins, at least three serial ports, an I2C communication bus, a large number of digital input and output pins, as well as a decent amount of memory. It also must be powered using 12 VDC and have onboard regulation for 5 V output. Based off these requirements, as well as cost and familiarity, an Arduino Mega 2560 was selected. The Arduino Mega 2560 runs off 7-12 VDC, has internal regulators to output 3.3 and 5 VDC, has 54 digital pins, 16 analog pins, 4 serial ports, one

I2C port, 256KB of flash memory and a clock speed of 16MHz. These capabilities will provide the necessary control over all the necessary electronics for the device.

The sensor input as well as necessary user input must be able to be displayed electronically. Therefore, an LCD display is necessary. The LCD display must, at minimum, be able to display two rows of sixteen characters and have a built in LED for illumination. A monochrome sixteen by two character LCD display was chosen to match these requirements as well as the desired aesthetic. The display requires a 5 V source, the use of one serial port, and six other digital I/O pins.

The user must be able to control when each system is implemented. Therefore, a system of user input is required. To match the desired aesthetic and for intuitive use, toggle switches were chosen to provide on/off control for each system. This requires seven total toggle switches, four of which must be able to withstand at least 5 VDC and 0.2 amps. The remaining three must able to withstand 120 VAC and 10 amps. The lower-rated toggles will be used for control over the hood temperature, humidity, CO2 concentration, and water coolant systems. The higher-rated toggles will be used to provide an overall on/off for the device and on/off control for the blower motor and UV lights. To indicate to the user that a system in on and functioning, LEDs will be incorporated into the display. Three millimeter green LEDs were chosen to match the green monochrome LCD display. In order for the user to input the desired settings of the environment within the tissue engineering hood, linear sliding potentiometers were chosen to match the desired aesthetic. The hood temperature, humidity, CO2

concentration and water coolant systems each require their own linear sliding potentiometer for control.

In order to provide electronic control via the microcontroller, MOSFETs and relays are required. MOSFETs are commonly used to provide on/off control via a microcontroller, as they can be operated using a 5VDC signal with low amperage, which can be easily provided by any of the digital output pins of a microcontroller. Relays are used when controlling higher voltages or currents is necessary, or when a signal needs to be switched from one line to another. Controlling a relay via a microcontroller also normally requires a MOSFET, because microcontrollers typically cannot produce enough current to excite the induction coil that operates the relay. Therefore using a MOSFET to control an independent source is necessary for controlling the relay. The MOSFETs must be N-channel MOSFETs and have a gate voltage of 5VDC and be able to control at least 12VDC. The system requires two relays that are rated for 120 VAC and 15 Amps, with at most a 12VDC coil. The other relays will need to be rated for at least 12 VDC and 5 Amps with at most a 12VDC coil. The MOSFETs selected were purchased from Sparkfun and were rated to control 60VDC and 30A, with a gate voltage of 5VDC. One of the relays chosen was rated to control 120VAC/150VAC, or 30VDC, 5A with a 5VDC coil. The other relay was rated to control 125VAC, 15A, and had a 12VDC coil. Diodes are necessary to protect the circuit from back EMF generated around the motors being used and the relay’s coil. Resistors of various ohms will also be necessary for many different areas of the circuitry.

Overall Materials

The overall structure of the tissue engineering hood needs to be fabricated using a metal that is corrosion resistant and relatively machine-able. The two main options would be aluminum or stainless steel. Aluminum has the advantage of being less expensive and lighter, while stainless steel is slightly more resistant to corrosion and is easier to weld. Since the structure was to be bolted together instead of being welded, and aluminum has comparable corrosion resistance, aluminum was used. Being lighter and less expensive are more important factors as the structure was to be quite large and thus require a lot of material. This saved on cost on both raw materials and shipping, as well as made the entire device lighter. In order to bolt the pieces of sheet metal together, pieces of angle aluminum were necessary to bolt them together. Square tubing was necessary to reinforce certain aspects of the design. To bolt everything together 10-32 Phillips button head machine screws and nuts were used. 10-32 machine screws were chosen because they were the largest bolts that could be used with ¾" angle aluminum.

In order to provide an air tight seal, gaskets were needed for all the joints. This requires many different shapes and lengths. Therefore gasket tape provides an optimum solution. Gasket tape of ½" wide and 0.20" thick was purchased from McMaster-Carr.

Multiple different gauges of wire were necessary for wiring all the circuitry. The blower motor and power outlet require 12 gauge wire, the UV system requires 16 gauge wire, while the remaining circuitry would be sufficiently wired with 22 gauge wire. Through hole protoboards were necessary to solder and mount all the electrical components. Various crimp connectors were highly useful when installing all the

circuitry. Terminal blocks were used to provide parallel connections for 120 VAC and 12 VDC.

To provide a see through surface that can be used to house the work space, acrylic sheeting was chosen. This was chosen for it being relatively inexpensive, machine-able and that it filters approximately 60% of UV rays. Glass sheets of the necessary size would be much heavier, more expensive and more difficult to machine. Acrylic will also be used to build the door.

Final Design

Overall Structure

The overall structure’s design was driven by the design requirements and the necessary equipment. With attempting to minimize the footprint of the overall hood, having to accommodate two 24”x30” HEPA filters placed side by side, and having sheet metal typically 48”, the hood was designed to be 48.5” across. The extra ½” comes from using angled aluminum to connect the sheet metal, as well as providing enough space for the HEPA filters to fit within hood. There are also points that extend beyond the 48.5”, these being the water coolant system and the humidifier fill spout. The depth of the hood was also attempted to be minimized, however again was constrained by the size of the HEPA filters and necessary work space volume. Ducting for the airflow as well as space to house equipment such as the humidifier and blower motor, the overall depth of the hood comes to 36.5”. There are points on the hood that extend beyond the 36.5”, these

being the display box in the front and CO_2 solenoid valve in the back. This brings the overall clearance to 44.5”.

The overall metallic structure resembles a C shape surrounding the workspace, and stands on 4 legs. This is illustrated in figure 2 below. The overall height of the structure atop the legs comes to 81.5”. The hood itself has an uneven bottom, this is to accommodate the user sitting at the hood as well as accommodating the size of the blower motor.

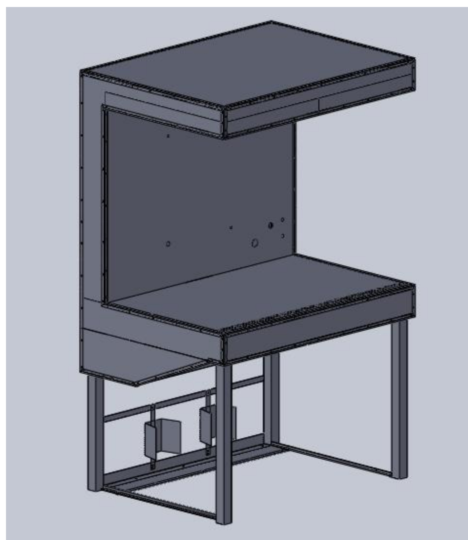


Figure 2 –Solid Model of Overall Structure minus Acrylic Housing

The front legs are 30” long while the back legs are 22” in order to accommodate the unevenness of the hood itself. The legs are set atop static dissipating caster wheels and the front leg of each side is connected to the back leg using aluminum strap and angled pieces to provide added stability. The back legs are also connected together with straps and angled pieces, but they also serve to provide support for a rack to house the

CO_2 and nitrogen tanks. The overall design of the leg and rack system can be seen in the image below.

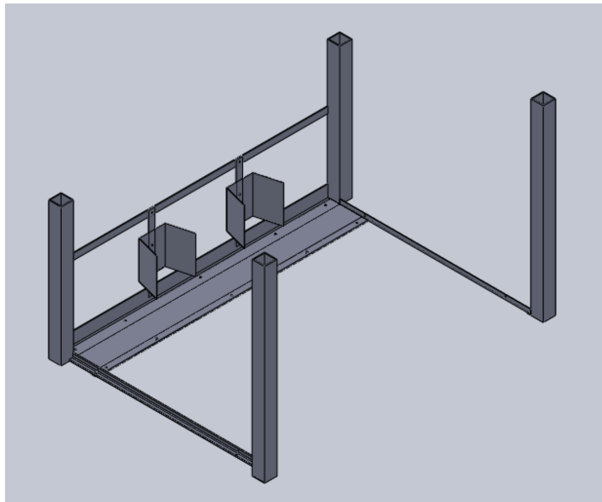


Figure 3 – Solid Model of Legs and Tank Rack

The workspace is designed to have base and back to be made of aluminum sheet metal, the top to be the HEPA filters and the sides and front to be constructed from acrylic sheeting. The front also features a door to allow for the user to interact with materials with the work space. The base of the workspace features a grate drilled into, located at the very front of it. There is also a square cut into the back of it where the blower motor can mount to it. There are also holes drilled into it to mount it to angled aluminum. See Appendix F for specific details on the work space base. The back of the workspace has the dimensions of 48"x36", and is to be outfitted with holes for mounting the humidity and CO_2 sensors, as well as holes for mounting a power outlet, nitrogen hook up and inlet and outlet for the water coolant system. The power outlet hole requires a diameter of 1 3/8". The nitrogen hook-up requires a 1" diameter hole, while the water

inlet and outlet require a 5/8” diameter hole. See Appendix F for specific details for the back work space panel. The HEPA filters require a surface to be set upon and for tension to be applied for the foam gaskets on the HEPA filters to provide an adequate seal. Angled aluminum, strips of sheet aluminum, and strap aluminum were used to provide the appropriate support. The HEPA filters are supported along the exterior edges as well as having a support run through the center of the workspace, since we are using two HEPA filters side by side. The door is built of acrylic sheet and slides within two pieces of aluminum u-channel. Rubber strips were used to provide a seal and enough friction to keep the door in place. A magnet is incased at the base at on the right side of the door, which interacts with a reed switch housed in the u-channel to indicate to the microcontroller when the door is closed.

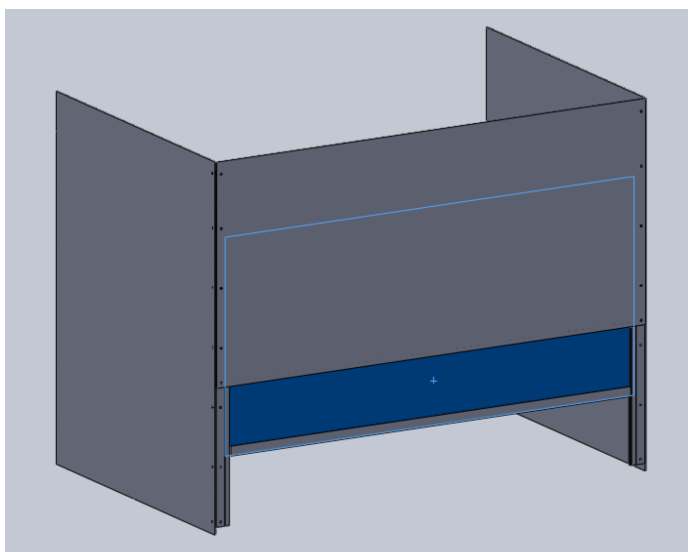


Figure 4 – Solid Model of Acrylic Sides and Door

To provide the proper aseptic environment using the laminar flow design, controlling the direction of air flow is imperative. To accomplish this, certain structural

aspects are necessary. The blower motor housed beneath the workspace needs to be sectioned off from the rest of the air ducting in order to provide air to be drawn down through the grate in the workspace. This prevents any airborne particulates from entering the work space, and draws them into the air ducting, causing them to be filtered out before entering the workspace. The diagram below illustrates the desired air flow path.

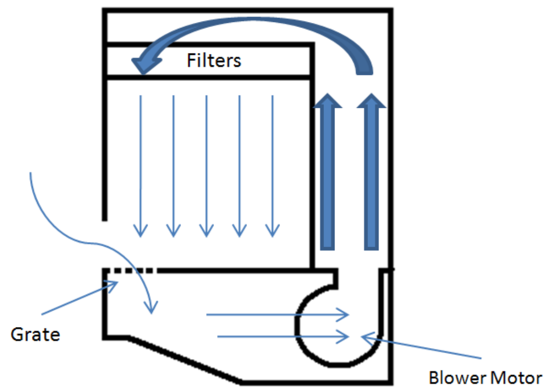


Figure 5 – Illustration of intended air flow path

While most of the assembly will be bolted together with machine screws and hex nuts, in order to properly assemble and disassemble the hood, some connections must be made without access to both sides of the surface, which is necessary to use machine screws with hex nuts. In order to accommodate this, PEM nuts will be pressed into the sheet metal in specific locations. PEM nuts are nuts that can be pressed into a piece of sheet metal, keeping the nut in place and thus essentially acting as a threaded hole. The graph below illustrates the edges of the sheet metal that required PEM nuts by the red color, which can also be seen in the engineering drawings for each piece.

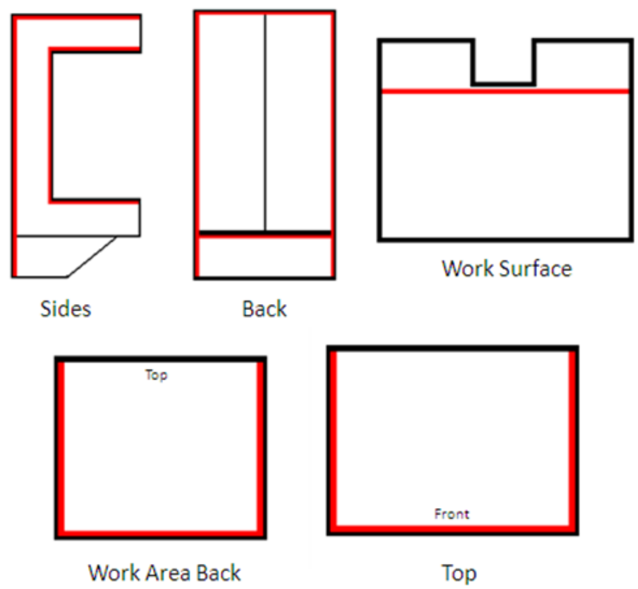


Figure 6 – Illustration of PEM nut locations

Environmental Control

To get an accurate air temperature reading, an array of temperature sensors was implemented. Eight sensors were implemented within the hood. Two were attached to the bottom of the work surface, four to the back of the work area back, and two were attached to the heating element. The sensors were mounted to the sheet metal and incased in a thermally conductive epoxy to promote an accurate and steady reading. By encasing them in a block of the thermally conductive epoxy, the temperature sensor reads a value from the center of a mass that is thermally equivalent throughout its mass. To accomplish this, 1" aluminum square tubing was cut into a number of 1" segments. A hole was drilled into the side of the square tubing, the temperature sensor ran through the hole and then the square tube was mounted using silicon to the sheet metal. The sheet metal was placed on a level surface, and then filled with the thermally conductive epoxy till the

epoxy set. Another temperature sensor was mounted in the same fashion to the water tank, in order to read the temperature of the water.

The heating element was made of pieces of aluminum sheet metal, and mounted together with ¾" L-brackets, and assembled as seen in the following figures. The structure has the overall dimensions of 8" wide, 5 ¾" deep, and 4" tall. This aluminum structure acts as a heat sink for the resistant heating elements, which the blower motor blows across, raising the air temperature in the hood. Four resistance heating elements are adhered to the center of the large slats. This provides for a total of 80 Watts being produced by the heating elements. The heating element is mounted 4 inches above the output of the blower motor. The figure below illustrates the structure of the heating element.

The humidifier is mounted atop the work surface, yet behind the work area back panel, being located to the left of blower motor outlet. The humidifier had to have its width trimmed by ¼" on each side in order to fit in the ducting. The output of the humidifier is faced toward the blower motor outlet, using its output to aid in transmitting the humidity throughout the tissue engineering hood. The fill hole is connected to the exterior of the hood via 3/8" ID PVC tubing and the corresponding fixtures. A 5/8" diameter hole in the sheet metal is necessary for the necessary fixtures to be mounted through it. Two brass couplings with a 3/8" ID hose coupling on one side and a ¼" NPT male fitting on the other are joined together through the sheet metal using another brass coupling with female ¼" NPT connections on both sides.

Two humidity sensors are mounted on the work area back panel; one towards the top and one towards the bottom, equidistant from the center. The two are used to get an average reading for the whole of the hood, in order to accommodate any gradients in humidity. The sensor head enters the work space area by poking through a hole drilled in the work space. This allows the sensor to read the humidity in the work area while keeping all the wires and circuitry in the ducting behind the work area. The sensor itself is adhered to the aluminum using silicone caulk. The two sensors were placed 8” up and 16” to the right and 28” up and 32” to the right of the bottom right hand corner of the back of the work space, respectively.

To infuse the system with CO_2, a CO_2 tank was housed beneath the tissue engineering hood, with an air house running up the back on the exterior to a 2-way normally closed electronic solenoid, which releases the gas into the back of tissue engineering hood, near the output of the blower motor. This requires a through wall brass fitting that accepts ¼” NPT fitting and an elbow connector with two male ¼” NPT fittings. A 2”-1/4” pipe with NPT attaches on the inside of the hood releasing the CO_2 into the air duct. The solenoid is regulated by the readings from the CO_2 sensors mounted on the back of the of the work space back panel. The CO_2 sensors are mounted in the same manner as the humidity sensors. The two sensors were placed 8” up and 32” to the right and 28” up and 16” to the right of the bottom right hand corner of the back of the work space, respectively.

Laminar Flow and UV System

The blower motor is mounted on the base of the tissue engineering hood, centered at the rear. It was mounted using 1” aluminum square tubing. The blower motor comes with holes drilled so that it can be mounted. The square tubing is fitted with threaded holes so that the holes on the blower motor line up with the square tubing. The blower motor must be mounted so that the output of the blower motor fits into the back of the base of the work space panel. One inch L-brackets were attached to the top of the 1” square tubing, so that the square tubing could be attached to the base panel. PEM nuts had to be fitted to these L-brackets in order to properly assemble the hood.

The HEPA filters were placed at the top of the work space and kept in place through tension wires. They fit very snugly due to physical constraint from the dimensions of the hood, however the tension wires used hold down the pre-filters on top of the HEPA filters and provide a tight seal. A tight seal is necessary in order to have the air flow through the HEPA filters and not around them and leak unfiltered air into the work space. Two wires run across the width of the hood and four along the depth. Care was taken to not crush the filter media or to touch it with contaminated hands.

The UV bulb and shield are mounted at the front of the tissue engineering hood just below the HEPA filters. The shield houses the terminals for plugging in the bulb as well as directs the UV light into the hood. The figure below illustrates the shape of the shield necessary. The wiring runs down the right side against the 1” square tubing supporting the front of the tissue engineering hood. The UV ballast is connected to the

wiring and mounted with the protoboards and power converter underneath the work space.

3D Printer Considerations

The power outlet is mounted on the back panel of the work space, near the bottom right side. It requires a 1 3/8” diameter hole and to be wired to 120 VAC. It is mounted 4” up and 10” from the bottom right quarter of the back panel of the work space.

The water coolant system consists of a one foot 2 ½” aluminum square tube, capped on each end with plastic end caps and sealed with silicon. The bottom cap is fitted with a coupling with a 3/8” ID hose fitting on one end and male ¼” NPT fitting on the other. This is to connect PVC hose to the inlet of the water pump, mounted below the water tank. PVC hose then connects the outlet of the water pump to another brass fitting as described above to transmit water through the exterior of the hood. This was done in the same fashion as for the fill hole of the humidifier. More hose is then connected to another brass fitting that fits through the back panel of the work space to a quick connect universal hose socket. The water is then carried back to the water tank if the first hose socket is connected to another, and the same method for bringing water from the pump will be used to bring it back to the water tank. The tank needs a ¼” NPT threaded hole for the brass fitting to screw into. The whole system is mounted on to the right side of the tissue engineering hood on the exterior.

A direct contact peltier device with built in cooling fan is mounted onto the aluminum water tank. This requires two thread 4-40 holes with thread locker on the bolts

to mount it and prevent leaks. Thermal grease is also necessary between the peltier and water tank to properly transmit the heat. The peltier device will provide cooling or heating depending on the direction of current through the device.

The nitrogen system has a tank mounted on the rack beneath the tissue engineering hood and has an air hose running from the regulator to a two-way ball valve. The ball valve is then connected through an elbow joint with two male 3/8” NPT fittings to a through wall brass fitting with female 3/8” NPT fittings. A 5” – 3/8” threaded pipe connects that through wall fitting to another that comes through the back panel of the work space. This through wall fitting connects the pipe to a quick connect universal hose socket. A coupling with male 3/8” NPT fittings on both sides connects the through wall connector to the universal hose socket.

Electronics

The Arduino Mega 2560 is mounted within the display box, mounted on the front right corner of the tissue engineering hood. The pinout table for the arduino can be found in Appendix A. It is mounted to the bottom of the display box using three 3/8” nylon stand-offs, threaded for 4-40 machine screws. The smaller protoboard is mounted next to it using 4 of the same stand offs. A 13/32” hole is drilled in the back of the display box as well as into the tissue engineering hood to allow for wires to pass through and connect to the arduino and toggle switches. Just inside the hood, at the top of the downward slant on the right side of the base, a sheet of aluminum is mounted via 4 metal stand-offs to mount the remaining electronics to. Two terminal blocks, one for 120VAC and one for 12VDC, are mounted there with two protoboards and the 12VDC 6A converter.

The display features the LCD display, 5 LEDs, 7 toggle switches, and 4 linear slide pots to provide the necessary user input. Each toggle switch controls one of the systems of the tissue engineering hood, these being the hood temperature, humidity control, CO_2 concentration, water coolant system, blower motor, UV lights and the hood power. The on/off control for the hood only disconnects the power to the 12VDC converter, disabling all systems besides the blower motor and UV lights. As these will often be run for an extended period of time, the electronics will last longer if not being constantly run as well. The toggle for the blower motor turns the motor on to its HI setting, being the normal setting. The control over the motor speed requires the electronics to be turned on. The power outlet inside the hood is also functional whenever the device is plugged in.

The control systems are mostly on/off control. The blower motor is switched from its high motor speed to the low motor speed when the reed switch is excited by the magnet in the door. The water coolant system's peltier device is controlled via two relays by controlling the direction current is run though the device, while constantly running the cooling fan. The direction is based on whether the water needs to be heated or cooled to the desired temperature set. The temperature can be set between 4°C-50°C. The water pump is turned on once the desired temperature is reached and remains on till the system is turned off with the toggle switch. The electronic solenoid controlling the CO_2 infusion is opened when its toggle is flipped to the on position and the concentration is lower than that which is set by the linear slide potentiometers. The concentration can be set between 0.2% and 10%. The heating element is turned on if the hood temperature system is

activated with the toggle and the set temperature is below the current air temperature. The hood temperature can be set between room temperature and 50°C. The humidifier is controlled the same way, being able to be set between 20%-99%. The humidity sensors require their frequency output to be switched to a pin on the Arduino via a relay due to having the same address programmed into its firmware. The toggle switches are pull down switches, meaning that if they are set to their ON position the Arduino will read 0V. Circuit diagrams and pinout diagrams are all found in the Appendix C.

Bill of Materials

Table 3 – Bill of Materials for Constructing Tissue Engineering Hood

Bill of Materials					
Quantitiy	Description	Product #	Supplier	Unit Price	Subtotal
**************************Electronics**************************					
2	Humidity sensor - HH10D	SEN-10239	Sparkfun	$9.95	$19.90
12	N-Channel MOSFET 60V 30A	COM-10213	Sparkfun	$0.86	$10.32
2	ProtoBoard - Wombat (PTH)	PRT-08619	Sparkfun	$9.95	$19.90
1	Reed Switch – Insulated	COM-10601	Sparkfun	$1.95	$1.95
6	Relay SPDT Sealed - 5A	COM-00100	Sparkfun	$1.76	$10.56
4	Toggle Switch	COM-09276	Sparkfun	$1.95	$7.80
4	Slide Pot - Medium (10k Linear Taper)	COM-11621	Sparkfun	$2.50	$10.00
5	LED - Basic Green 3mm	COM-09650	Sparkfun	$0.32	$1.60
1	Arduino Mega 2560 R3	DEV-11061	Sparkfun	$58.95	$58.95
2	20% Cozir CO2 Sensor	GC-0006	CO2Meter.com	$209.00	$418.00
1	2 Pin - Double Ended - Precision Lighting GPH793T5L	AU-LGPH793T5L	1000Bulbs.com	$14.47	$14.47
1	Atlantic Ultraviolet 10-0054C	AU-B100054C	1000Bulbs.com	$95.00	$95.00
1	Peltier-Fan Assembly	926-1070-ND	Digikey	$179.55	$179.55
4	Kapton® (Polyimide Film) Insulated Flexible Heaters	KH-104/5-P	Omega	$36.00	$144.00
1	Conductive Epoxy	473-1089-ND	Digikey	$52.99	$52.99
1	Swiftech MCP355 3/8in Water Pump	20721	xoxide.com	$74.99	$74.99
1	NC Gas Solenoid valve 1/4" NPT - CO2	21996	ASCO Valves	$57.00	$57.00
1	Centrifugal Blower Motor 1000 CFM	T9FB187594	Global Industrial	$282.51	$282.51
1	Cigar Oasis II XL	OA2-1300	Cigar Oasis	$199.00	$199.00

10	Temperature Sensor	SEN-10988	Sparkfun	$1.35	$13.50
2	Logic Level Translators	BOB-08745	Sparkfun	$1.95	$3.90
1	Break Away Headers	PRT-00116	Sparkfun	$1.50	$1.50
1	Heat Shrink Kit	PRT-09353	Sparkfun	$7.95	$7.95
4	1/4", 4-40, 10 Pack Phillips Head Screws	PRT-10453	Sparkfun	$1.50	$6.00
2	Nylon Stand offs, 10 Pack	PRT-10927	Sparkfun	$2.95	$5.90
6	1/8"x1/8"x1/2" Block, N42 Magnet	B228	K&J Magnetics, Inc.	$0.52	$3.12
1	12V 6A converter	285-1825-ND	Digikey	25.08	$25.08
1	5V 0.8A regulator	NOPB-ND	Digikey	1.49	$1.49
2	100' 22 gauge wire solid	2781215	Radioshack	$8.54	$17.08
1	Extension Cord, 12 gauge, 25 feet	34083	Miners	$27.99	$27.99
1	12 gauge winged quick connects	34926	Miners	$2.59	$2.59
2	12V coil/125VAC 15A Relay	2750031	Radioshack	$4.49	$8.98
3	90' 22 gauge wire solid	2781221	Radioshack	$8.49	$25.47
1	Two Prong Connectors	2761388	Radioshack	$3.59	$3.59
3	Toggle Switch	314999	Miners	$2.99	$8.97
1	10 gauge Ring Crimp Connectors	34544	Miners	$3.59	$3.59
1	Single Plug 20A	3201639	Miners	$7.99	$7.99
1	Plug Cover White	3220787	Miners	$0.59	$0.59
1	Thermal Grease	2801098	Radioshack	$7.19	$7.19
1	Metal Stand off 4 pack	2760195	Radioshack	$1.79	$1.79
1	Desoldering Braid	6402090	Radioshack	$4.04	$4.04
1	Protoboard	2760158	Radioshack	$3.14	$3.14
1	Solder	6400005	Radioshack	$5.39	$5.39
2	Two Prong Connectors 4 pack	2761388	Radioshack	$3.60	$7.20
2	Butt Connectors 22-18 gauge 10pack	34558	Miners	$2.99	$5.98
1	10 gauge Ring Crimp Connectors	34548	Miners	$3.59	$3.59
1	Butt Connectors 22-18 gauge 100pack	34559	Miners	$14.99	$14.99
15	16 gauge wire red	89748	Miners	$0.39	$5.85
15	16 gauge wire blue	83183	Miners	$0.39	$5.85
1	Ring Crimp Connectors 22-18 gauge	34537	Miners	$3.59	$3.59
1	3' UV Lamp		Home Depot	$23.86	$23.86
2	Fuses		Miners	$4.66	$9.32
2	8 Circuit Terminal Block		Home Depot	$7.74	$15.48
2	Female to Female Jumper Wires	2760144	Radioshack	$5.39	$10.78
**************************Hardware*************************					
3	Plexiglass 48x48x.125"		Eplastics	$49.02	$147.06
1	6061 Aluminum Strap (1" Wide x 1/8" thick) 3'		OnlineMetals.com	$1.86	$1.86
1	6061 Aluminum Strap (1" Wide x 1/8" thick) 6'		OnlineMetals.com	$3.06	$3.06
1	6061 Aluminum Strap (1" Wide x 1/8" thick) 8'		OnlineMetals.com	$3.86	$3.86

3	6061 Aluminum Square Tube 8' (1" Wide x 1/8" Thick)		OnlineMetals.com	$16.53	$49.59
11	6061 Aluminum Angle 8' (3/4" Wide x 1/8" Thick)		OnlineMetals.com	$5.63	$61.93
2	6061 Aluminum Sheet 24x48" (1/16" Thick)		OnlineMetals.com	$45.75	$91.50
7	6061 Aluminum Sheet 36x48" (1/16" Thick)		OnlineMetals.com	$65.44	$458.08
2	24x30x3" Standard Volume HEPA Filter	HC240300X4A7	HEPAfilters.com	$211.85	$423.70
1	Scott-Foam Prefilter		HEPAfilters.com	$25.00	$25.00
4	Static Control Caster Wheels	2358T63	McMaster-Carr	$8.08	$32.32
1	10 pack Eye Hooks	9489T17	McMaster-Carr	$2.99	$2.99
2	S Hooks	6043T5	McMaster-Carr	$3.75	$7.50
1	10' PVC Tubing	5231K196	McMaster-Carr	$7.20	$7.20
1	Hose Clamp	5388K14	McMaster-Carr	$5.87	$5.87
8	Barbed Hose Straight for 3/8" Tube ID x 1/4 Male Pipe Size	44555K133	McMaster-Carr	$2.17	$17.36
2	Unversal Hose Socket 1/4" NPTF Female, 1/4 Coupling Size	53475K21	McMaster-Carr	$9.30	$18.60
5	18-8 Stainless Steel Round Head Phillips Machine Screw	91773A827	McMaster-Carr	$6.90	$34.50
5	18-8 Stainless Steel Machine Screw Hex Nut	91841A195	McMaster-Carr	$4.30	$21.50
4	Gasket Tape 1/2" wide 0.02" thick 50 ft long	9477K21	McMaster-Carr	$41.08	$164.32
1	3/8 90 degree female x male elbow	4429K152	McMaster-Carr	$9.08	$9.08
1	1/4 90 degree female x male elbow	4429K151	McMaster-Carr	$9.08	$9.08
2	3/8 Pipe Locknut	4429K123	McMaster-Carr	$2.00	$4.00
4	1/4 Pipe Locknut	4429K122	McMaster-Carr	$1.53	$6.12
1	8 feet 1/8" thick 1/2" Width Silicon Rubber	2614T18	McMaster-Carr	$1.50	$1.50
1	3/8" Universal Hose Socket	53475K23	McMaster-Carr	$10.18	$10.18
1	3/8" Brass Ball Valve Male x Female	47865K42	McMaster-Carr	$9.67	$9.67
2	Air Hose Plug, 3/8" Hose ID, 1/4 Coupling Size	1077T26	McMaster-Carr	$2.58	$5.16
2	Brass Hex Nipple, 3/8"	5485K23	McMaster-Carr	$3.28	$6.56
1	2 1/2" square tube, 1 ft length, aluminum	88875K791	McMaster-Carr	$12.72	$12.72
1	10 pack, Square Tube Caps	9565K92	McMaster-Carr	$7.80	$7.80
1	12 feet, silicon rubber 3/32" thick x 1/2" Width	2614T39	McMaster-Carr	$1.21	$1.21
1	1/4" Through Wall Pipe Fitting	8682T22	McMaster-Carr	$10.25	$10.25
2	3/8" Through Wall Pipe Fitting	8682T23	McMaster-Carr	$13.62	$27.24
1	10 pack, 3/4" Hose coupling	5345K11	McMaster-Carr	$5.74	$5.74
1	10 pack, 1" Hose coupling	5345K12	McMaster-Carr	$5.95	$5.95
1	2" 1/4" Brass Pipe, threaded	4568K133	McMaster-Carr	$2.17	$2.17
3	3/8" Hose ID, 1/4" coupling size, Air Hose Plug	1077T26	McMaster-Carr	$2.58	$7.74
7	PEM nuts 10-32 for 0.06" minimum	95117A466	McMaster-Carr	8.07	$56.49
2	1/4" Pipe Coupling	50785K92	McMaster-Carr	1.5	$3.00
1	10-32 Philips Head x 3/8" packs of 100	91773A827	McMaster-Carr	6.9	$6.90
1	2-56 Philips Head x 3/8" packs of 100	91773A079	McMaster-Carr	4.33	$4.33
1	2-56 Nuts packs of 100	91841A003	McMaster-Carr	2.53	$2.53

1	Funnel	1479T83	McMaster-Carr	2.43	$2.43
1	3/8" Pipe Threaded 5"	4568K159	McMaster-Carr	4.92	$4.92
1	CO2 Pressure Regulator		Airgas	$67.00	$67.00
1	5lb Aluminum CO2 Tank		Airgas	$12.50	$12.50
1	20 Gal Nitrogen Tank		Airgas	$13.00	$13.00
1	Nitrogen Regulator		Airgas	$135.00	$135.00
1	CO2 Gas - 5lb		Airgas	$95.00	$95.00
1	Nitrogen - 20 Gallons		Airgas	$79.19	$79.19
10	2"x2"x.125 Alum. Sq. Tube 24'		McCarthy Steel	$5.85	$58.50
2.205	1/8" x 1" Alum. Flat Bar 12'		McCarthy Steel	$5.10	$11.25
2.9	1/8" x 2"x2" Alum. Angle 25'		McCarthy Steel	$5.10	$14.79
0.888	1/2"x1/2"x1/32" Alum Channel 16'		McCarthy Steel	$5.10	$4.53
1	Air Hose, 3/8" Male Fitting, 3 Feet		Contractors Mainenance	$17.20	$17.20
1	Air Hose, 1/4" Male Fitting, 3 Feet		Contractors Mainenance	$17.25	$17.25
2	1/4" NPT Male x Male Couplings	13096	Ace Hardware	$2.99	$5.98
1	90' 22 gauge wire solid	2781221	Radioshack	$8.49	$8.49
2	Lock Washer #10	30699326013	Home Depot	$1.18	$2.36
1	Washer #10		Home Depot	$1.18	$1.18
2	1" Corner Brace 20 pack		Home Depot	$7.48	$14.96
2	1.5" Corner Brace 4 pack		Home Depot	$2.67	$5.34
9	3/4" Corner Brace 4 pack		Home Depot	$1.97	$17.73
5	1' rope 1/4" white		Home Depot	$0.22	$1.10
1	10-32 Hex Nuts	H140024	Miners	$3.59	$3.59
2	Philips 10-32x1/2"	H92196	Miners	$4.79	$9.58
1	Sheet Metal Screw #4x3/8"		Home Depot	$1.18	$1.18
2	Aluminum Bar 1/8"x3/4"x4'	5117973	Miners	$6.99	$13.98
2	Handles	5384136	Miners	$2.99	$5.98
1	Superglue	13003	Miners	$2.59	$2.59
1	Distilled Water 1 gallon	9215419	Miners	$1.79	$1.79
1	Thread Locker	18615	Miners	$3.99	$3.99
1	White Silicon Caulk	11315	Miners	$4.99	$4.99
Subtotal					$4,392.39
Taxes					$351.39
Total					$4,743.79

Expenses

While the total for the bill of materials comes to $4743.79, the cost of developing the tissue engineering hood came to $5418.31. The added costs came from shipping and handling costs, replacement and back-up parts. The shipping and handling accounted for $140.70, while $533.82 was spent on replacement and back-up parts. The majority of those costs come from extra aluminum, hardware and electronics.

CHAPTER 3

Fabrication

Manufacturing

Hood Fabrication

The structure of the tissue engineering hood was constructed out of basic structural shapes of aluminum, featuring primarily sheet metal, square tubing, and lengths of strap and angled aluminum. These were cut and shaped using common machinery. A band saw was used to cut all the square tubing and angle pieces. The band saw also provided all the angled cuts necessary. A drill press was used to drill all the holes in the angle pieces and the majority of those in the square tubing. A handheld drill was used when pieces needed to be assembled before the correct location of the hole could be determined. This was done primarily in the fabrication of the legs and tank rack assembly, and to transfer the location of the holes from the angle pieces to the sheet metal they were to be bolted to. The pieces of sheet metal were cut on a sheet metal shear, or by hand with handheld shears. When handheld shears were used, an angle grinder was used to clean up the edges and to square up the interior corners. The bolts used to assemble everything were 10-32 bolts, requiring that all the through holes be drilled using a #7 drill bit and all the holes to be threaded drilled with a #21 drill bit. Further description of the individual pieces being fabricated can be found in the engineering drawings in Appendix F.

The first portion of the tissue engineering hood to be fabricated was the legs and rack for the tanks. The was done by first connecting the two back legs with the necessary supports to keep them squared and straight up and down as well as providing the basis for the tank rack. The front legs were then attached to the back legs using structural aluminum running from front to back. The tank rack was then fabricated on top of the supports and designed to hold two tanks. The wheels were then attached to the bottom of each leg.

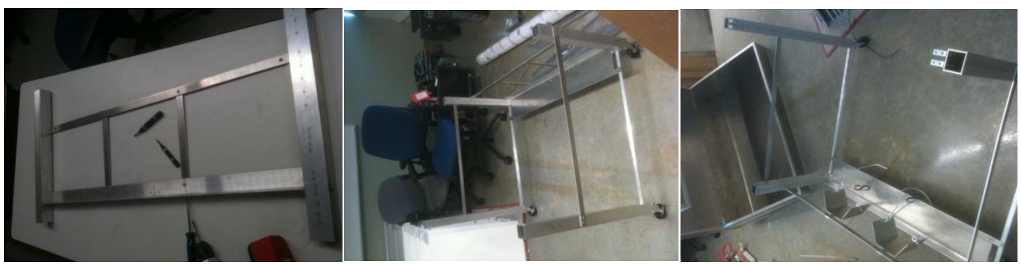


Figure 7 - Images from leg and tank rack construction

After completing the legs, the base of the tissue engineering hood was fabricated. This was fabricated using sheet metal and angled aluminum. The base was slanted to accommodate the size of the blower motor while still allowing a person to sit at the front of it. The base was then attached to the legs using L-brackets.

Figure 8 – Images from base of Tissue engineering hood construction

After the base was completed, the rest of the aluminum siding was fabricated. Each piece was cut to shape then fitted together using angled aluminum. This was done separately from the overall structure before all the holes were drilled in each piece. Once each piece was fitted together the overall structure was added to the legs. While attempting to piece the entire structure together, it was made clear that it would be impossible to bolt the whole thing together with basic nut and bolts, as both sides of the of the hole are not available. To solve this, PEM nuts were pressed into the sheet metal to provide a stationary threaded hole to bolt down the angled aluminum.

Figure 9 – Images from construction of overall hood structure fabrication

After the overall structure was assembled, the individual actuators were assembled and tested before being mounted to the overall device. This entailed developing a mount for the blower motor, fabricating a heating element, and constructing the water pump assembly. The electronics assembly was also mounted to a sheet of aluminum, and then mounted to the base of the tissue engineering hood and grounded to the chassis. The blower motor was mounted to the base as well, and then the display box was fabricated.

Figure 10 – Images of heater, water pump, and blower motor construction

Figure 11 – Image of display and user controls

After the display box was mounted on the front bottom right side of the tissue engineering hood and everything else below the main work space was completed, the main work surface was fabricated and fitted. This required drilling approximately 400 holes to create a grate at the front of the surface and a square hole for the outlet of the blower motor in the back. It also required drilling a 7/8” hole in the back right for wiring purposes. Once that was fabricated, and set in place, all the remaining sensors and actuators were mounted.

Figure 12 – Image of Sensor and Actuator Implementation

After all the actuators and back of the work space was added, the HEPA filters were fitted to the top of the device. The pre-filters were then laid on top and then secured using bailing wire. After the filters were added, the pieces of acrylic were fitted on each side. Then the UV system was mounted at the front of the top of the work space, facing inwards. Then the acrylic for the front of the tissue engineering hood and the door was mounted. A piece of strap aluminum bent inwards was added across the seam of the front piece of acrylic and the door to close the gap between the two.

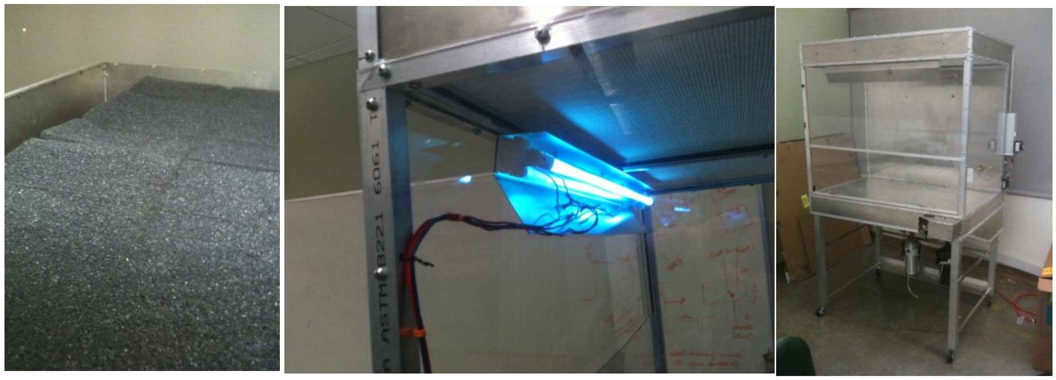


Figure 13 – Images of filters, UV system, and overall assembly

Electronics

The electronic components were wired together and soldered on three protoboards. Two of the protoboards were housed inside the hood, while the other was mounted in the display box. The 12VDC converter, 120 VAC and 12VDC terminal blocks and two protoboards were all mounted to a piece of aluminum sheet metal and mounted via metal standoffs inside the hood. Most of the actuators required a basic on/off control schemed that was controlled via a MOSFET relay combination. Detailed circuit diagrams can be found in Appendix C. The humidity sensors had a slightly more complicated wiring system, as the frequency output of each sensor had to take turns being read by the same pin on the Arduino. This required the use of relay to switch these lines periodically to gain accurate readings. The electronics are explained in much greater detail in the senior project report, “Laminar Flow Hood System Design” by Sophie Schneider that was done in collaboration with this project [23].

Programming

The program used to control the Arduino Mega 2560 was written using the Arduino IDE (Integrated Development Environment). The IDE uses the C sharp language and associated libraries written for the Arduino. The goal of the program is to provide control over the actuators based on sensor and user input. It featured a basic cascade programming scheme, going through one subroutine at a time then repeating. It first reads all the sensors, updates the display with these values, checks to see if any inputs have changed, then updates the actuators based on the sensor inputs and inputs from the user. It takes approximately 1.25 seconds to run through the program once, which can give some visible delays on the screen at times when updating the input values using the slide potentiometers. The flow chart found in Appendix D further illustrates the control scheme.

Validation

Bench Testing

Before the sensor and actuators were mounted onto the structure of the Tissue Engineering Hood, each one was tested to verify their function. The temperature sensors were wired to 7 feet of wire and compared to a sensor plugged directly into a bread board. This was done to see if there was a significant change in accuracy of the sensors over the length of transmission of the analog signal. The testing showed that the wires needed to be twisted to prevent a decrease in accuracy. The twisting of the signal and ground wires act to protect the signal from added noise. The CO_2 sensors required

calibration before being implemented. This was achieved by grounding a pin when placed in the appropriate environment. The sensors were placed in nitrogen to displace all the CO_2 present, resulting in a reading of 0 ppm. Alternatively the sensors could be calibrated in open air, with the assumption that there is a CO_2 concentration of 450 ppm. The open air method was used, as there were difficulties in obtaining a proper 0 ppm reading in the nitrogen. The humidity sensors were tested to confirm their accuracy and function by comparing the readings to a hygrometer. The solenoid, resistance heaters, water pump, UV system, and blower motor functionality were confirmed by applying the appropriate voltage and amperage.

Program Validation

After the tissue engineering hood was fabricated, sensors and actuators connected and all the electronics hooked up, the functionality of the sensors and actuators were confirmed. This was accomplished by writing individual programs and functions to test all the functional aspects of the tissue engineering hood. This ensured that all the MOSFETs and relays used to control the actuators were correctly installed, that the sensors were functioning correctly, and that the individual functions of the program worked appropriately.

CHAPTER 4

Results

The tissue engineering hood was successfully completed according to the final design described above. The dimensional requirements were met and thus can successfully house the 3D-Bioplotter and other devices. The laminar flow aspect of the design was successfully carried out and found to be successful. A dry ice fog was used to visually confirm the airflow in the device. There is significant airflow drawn through the grate at the opening, keeping contaminates from entering the workspace and instead traveling through the blower motor and being filtered out by the HEPA filters before entering the workspace. There were also no leaks around the HEPA filters, showing that the airflow was not bypassing the HEPA filters. Also smooth air flow was seen and felt coming through the filters. The control of the blower motor through the reed switch and magnet housed in the door was also confirmed.

The UV system was implemented successfully as well, providing and increased measure of sterility. The UV shield properly directs the light into the system while preventing loss out the front. The reflective nature of the polished aluminum also aids in reflecting the UV light through the system. The combination of the laminar flow system and UV lights provide an aseptic environment for the work space as long proper aseptic techniques are used when working within the hood.

Temperature

In order to characterize the efficiency of the temperature control, data was collected during the heating cycle. The heating rate, cooling rate, range of temperatures and accuracy of maintaining the set temperature was analyzed. The results however were less than desired. The highest air temperature reached was 32 ° C (89.6 ° F) after approximately 2 hours. This is 5 ° C (8.4 ° F) short of the design requirements and what is necessary to keep cells viable. It was also found that a significant amount of the heating was the produced from blower motor. Running the blower motor without activating the heating element, raised the temperature in the work space to 28 ° C (82.4 ° F) with the door closed and to 27 ° C (80.6 ° F) with the door open. Based off these results, the heating element is only raising the temperature 4 ° C (7.2 ° F) above what the blower motor is raising the temperature to. The heating rate was found to be 0.1223 ° C per minute, as seen in the graph below.

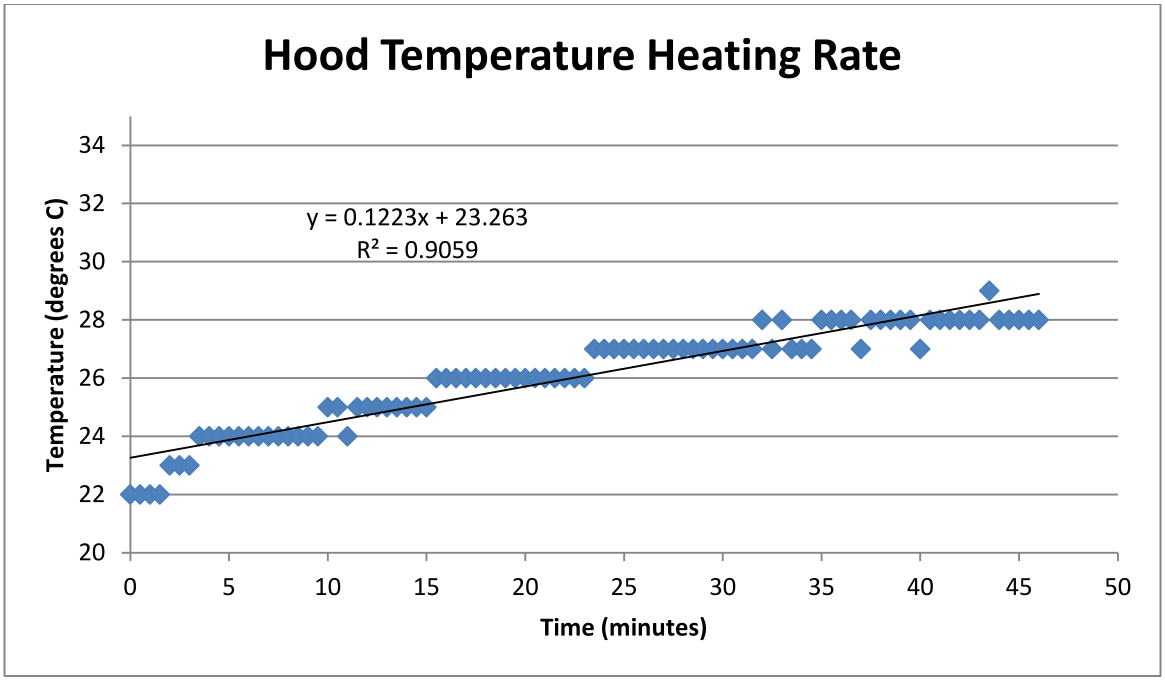


Figure 14 – Heating rate of tissue engineering hood temperature

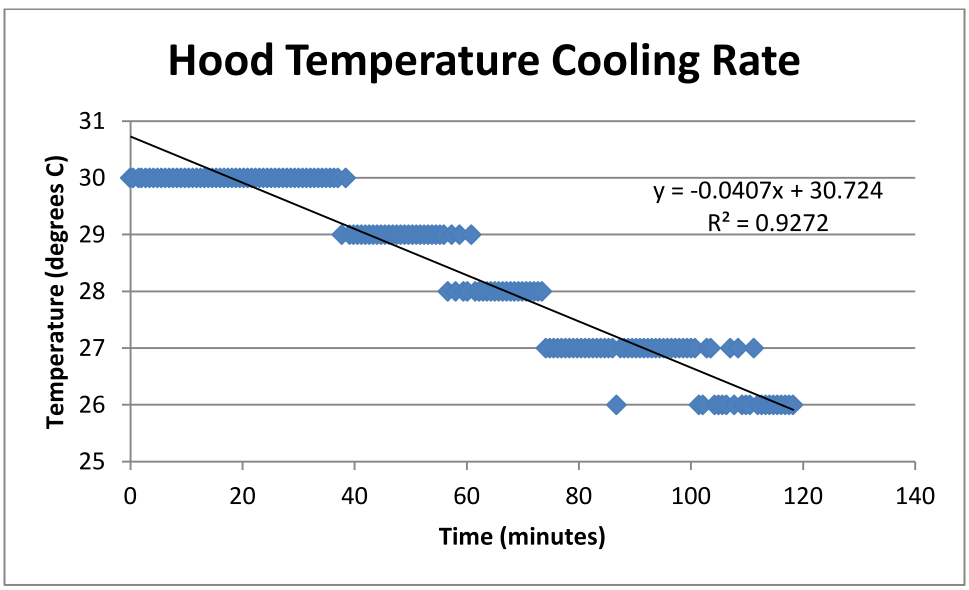


Figure 15 – Cooling Rate to room temperature of tissue engineering hood

The cooling rate of the tissue engineering hood was found to be decreasing at a rate of 0.04 ° C per minute, as seen in the graph above. This data was collected with the

door open and blower off, as the blower produces significant amount of heat and the hood temperature decreased very slowly with the door closed.

The accuracy in maintaining a set temperature was fairly effective. When set at 31 ° C, there was a standard deviation of 0.51 ° C, which matches the design requirements. The temperature sensors also had a degree of variance which suggests that the actual hood temperature was more stable. An air temperature gauge was also placed inside the hood during testing, which was completely stable during the testing.

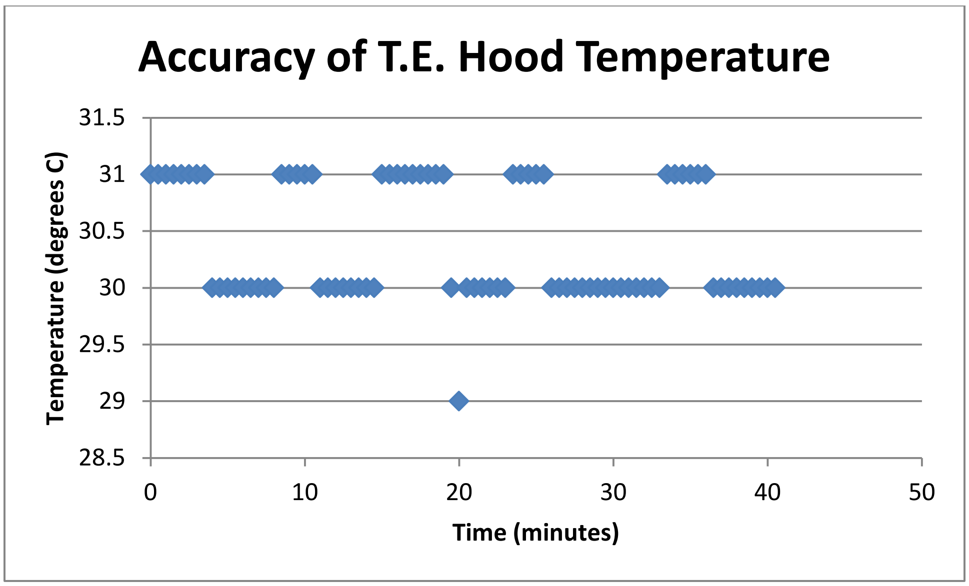


Figure 16 – Accuracy of maintaining a constant temperature in the tissue engineering hood

Humidity

The humidifier had poor results as well. While the humidifier was able to increase the humidity within the tissue engineering hood while the blower motor was off, running the blower motor decreased the humidity. While running both, the humidity would remain constant with the initial humidity. The humidifier was designed to accommodate

up 60 cubic feet, which is greater than the 47 cubic feet of the hood, however it doesn't seem to output enough humidity. While the humidity in the hood was not able to be sufficiently controlled, data on the accuracy of the humidity sensors was gathered. The sensors were found to have an accuracy of +/- 0.34% when the two sensors were averaged together. The sensors did appear to lose accuracy while CO_2 was being pumped into the hood. This is most likely due to the inlet being too close to one of the sensors, and the cold caused by the release of the pressurized CO_2 causes inaccurate readings.

CO2

The system was capable of raising the CO_2 percentage up to 10%, however there were significant leaks in the system. This caused the 5 lb CO_2 tank to become empty after two hours of maintaining the CO_2 percentage at 5%. The rate of raising the CO_2 percentage, rate of leaking and accuracy of maintaining a certain percentage was also analyzed. The rate of raising the CO_2 percentage with the regulator set at 10 psi was found to be 1.16% per minute. This could be adjusted based on the pressure set by the regulator however. The dissipation rate was found to be 0.58% per minute when the initial concentration was 5% CO_2. Some leaks were found and patched, decreasing the leakage rate to 0.36% per minute. The accuracy of maintaining 5% CO_2 was found to be +/- 0.27%. There was however an over-shoot of approximately 0.5% due to time delay due to the distance from the CO_2 inlet to the CO_2 sensor.

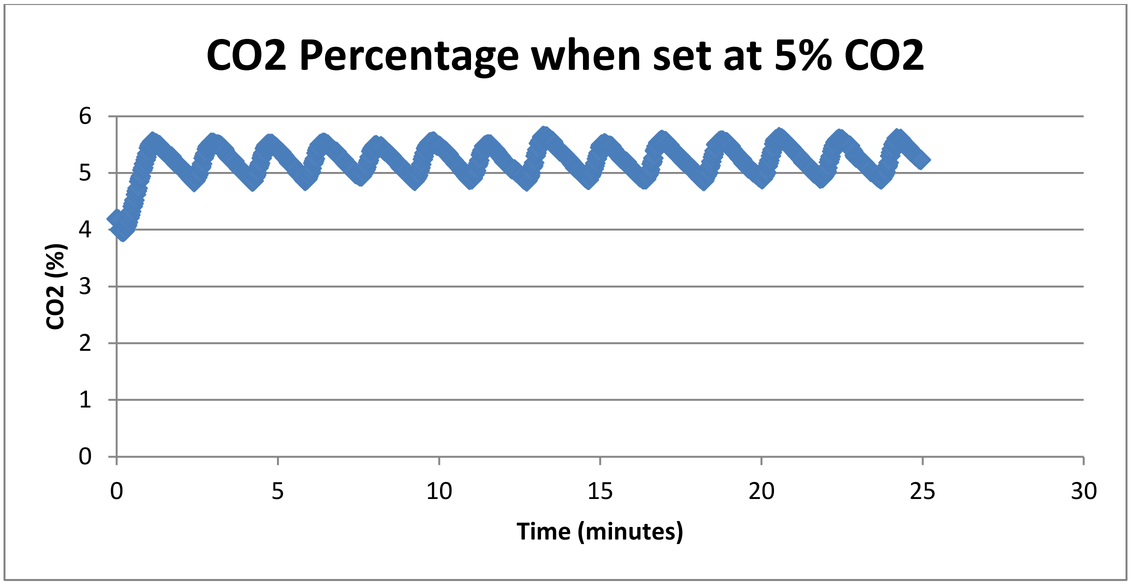


Figure 17 – Accuracy of maintaining a constant CO_2 percentage

3D Printing Requirements

Providing the necessary support to accommodate a 3D printer was provided with the final design. A plug capable of providing 120 VAC and 20 Amps was provided as well as a universal socket feeding compressed nitrogen in order to operate any pneumatic actuators. The regulator can easily provide the necessary pressure, however the brass pipe and fittings are rated for up to 200 psi. The system did not have any apparent leaks.

The water coolant system was functional, however its efficiency could be increased when using room temperature water. The cooling rate, heat rate, and accuracy of maintaining a set temperature was analyzed. The system was not efficient enough to heat and cool room temperature water through the full range of desired temperature, however if chilled or heated water is used, it reaches these goals. The cooling rate was found to decrease the water temperature by 0.33 ° C per minute. The heating rate was

found to increase the water temperature by 0.49 ° C per minute. The accuracy of the system was shown to be +/- 0.87 ° C, and there was an initial change of 1 ° C when the pump began circulating water.

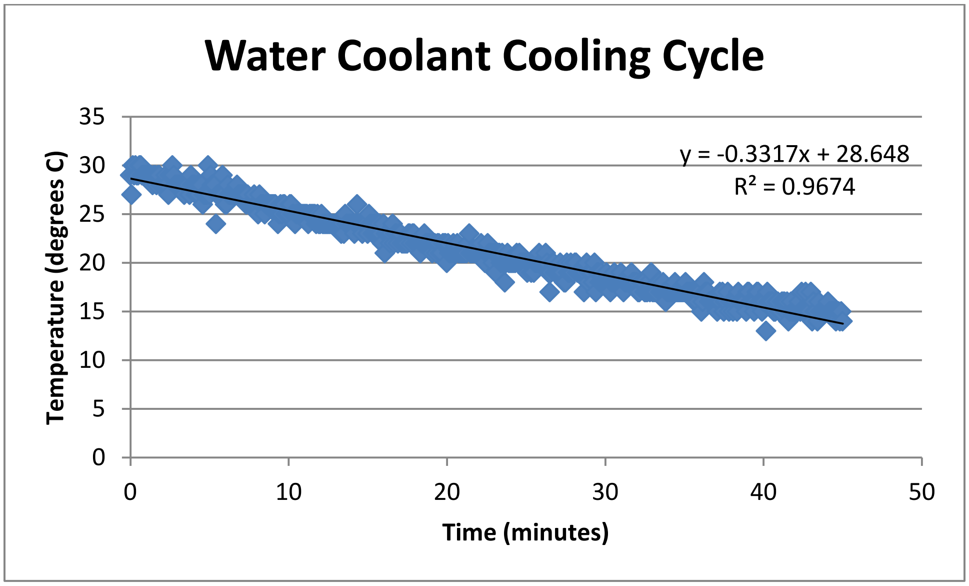


Figure 18 – Cooling cycle of water cooling system

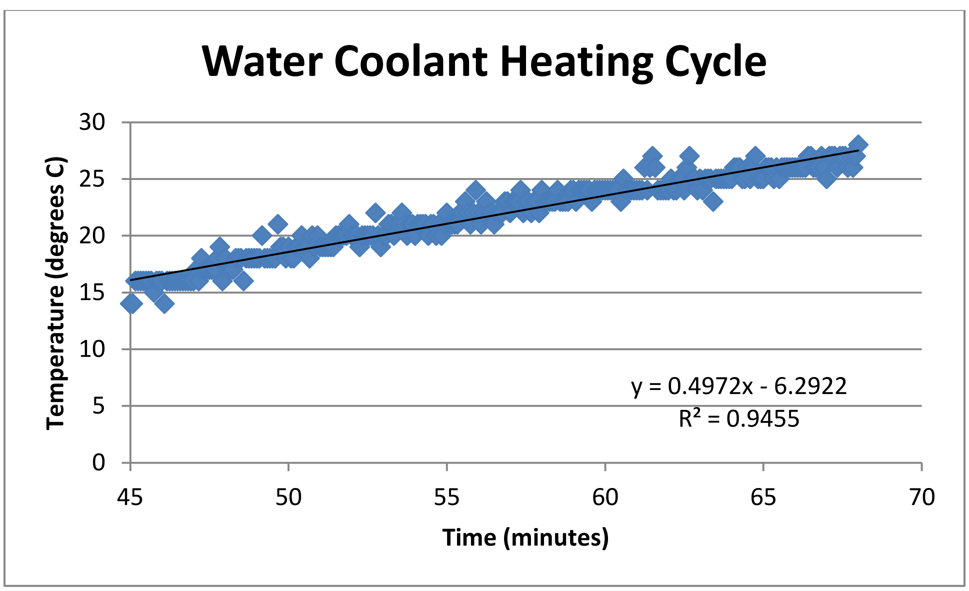


Figure 19 – Heating cycle of water coolant system

Cell Testing

To analyze the effectiveness of the tissue engineering hood at keeping cells alive, an experiment using 3T3 fibroblast cells was conducted. The goal of the experiment was to compare the percent of cell viability of the tissue engineering hood to a cell culture incubator and being kept on a work bench being exposed to normal room conditions. The conditions for the bench top control were 25 ° C, 40% humidity and 0.05% CO_2. The incubator provides the proper environment for cells to survive and grow, being 37 ° C, 95% humidity and 5% CO_2. The hood was able to reach 32 ° C, 30% humidity and 5% CO_2 for the first two hours, then dropping to 0.05% CO_2 for the rest of the experiment. A T75 flask was placed in each condition for an extended period of time to examine the viability over time. Each flask was placed under a microscope to examine the health of the cells every two hours for 10 hours. The experiment was run for 10 hours because at that time point, nearly all the cells in the bench top control appeared to have died. At the end of 10 hours, a Trypan Blue assay was performed on each flask to assess the percent viability of the cells and the total number of cells present. See Appendix G for the protocol used for the experiment.

The results of the experiment and typan blue assay are as stated below in Table 4. It was found that there was 42.4% difference of the T.E. Hood and the incubator. The percent viability was also 2.87 times greater in the T.E. Hood compared to the incubator having a percent viability 4.99 times greater than the bench top. This shows that while the T.E. Hood does not provide the adequate environment for cells to thrive, it does provide a better environment than the bench top. This also suggests that if the design requirements

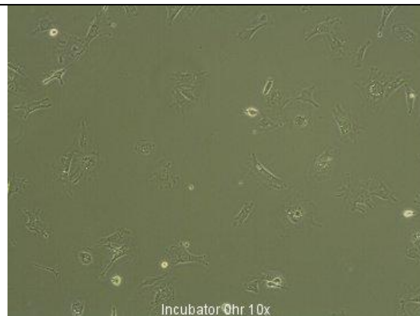
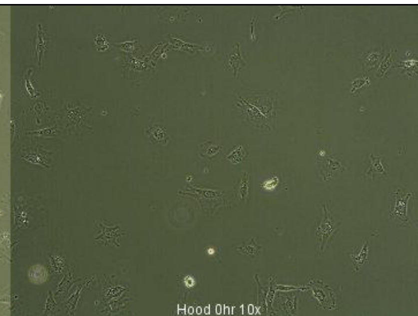
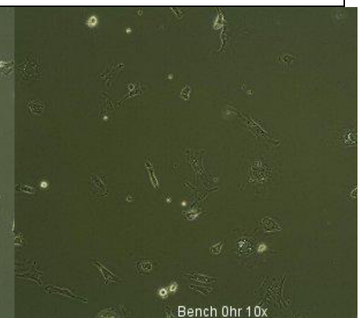
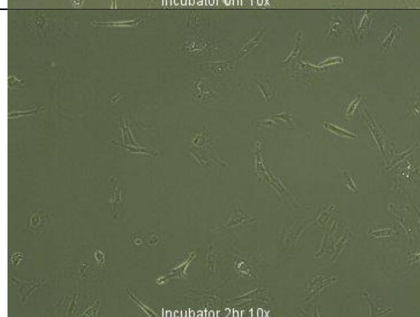
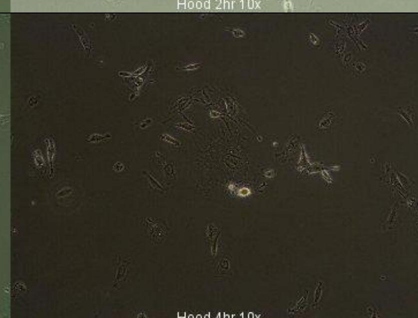
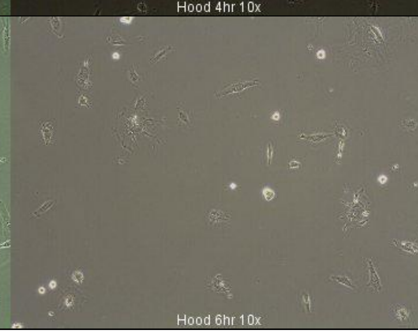
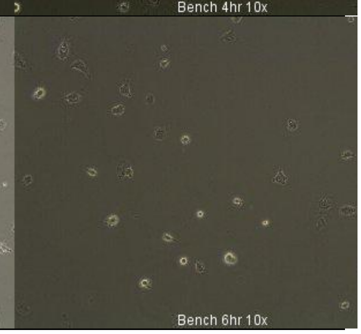
were met, the cells would be healthy and thrive. The results also showed that there were a higher number of cells in the flask housed in the incubator than the T.E. Hood and the bench top. This suggests that the incubator provided a more suitable environment for cells to duplicate than the T.E. Hood and bench top.

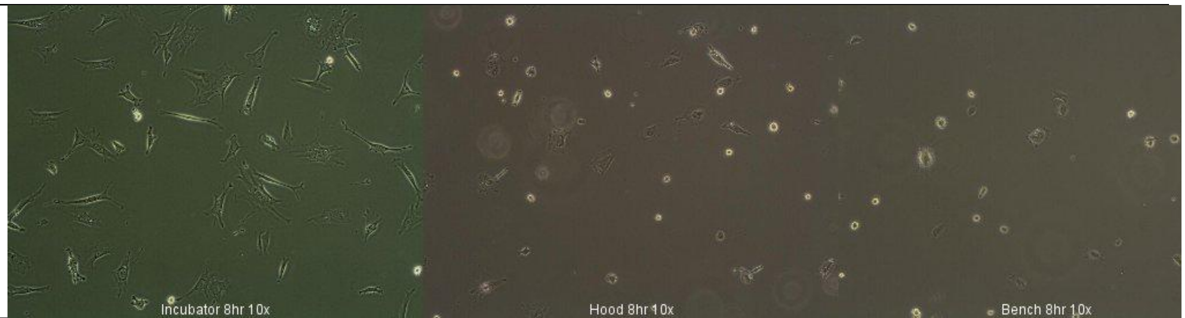
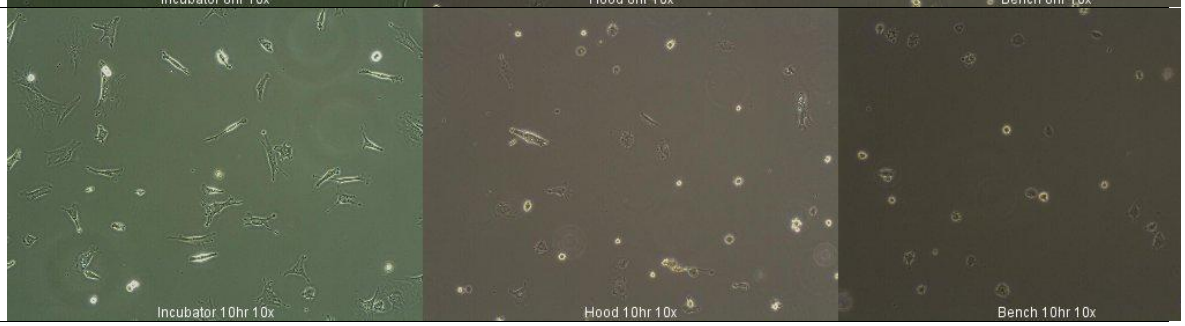
Table 4 – Summary of Tyrpan Blue Assay Results

	# Live	# Dead	# Total	Total # of Cells	% Viability
Incubator	44	21	65	520000	67.69
Bench	8	51	59	472000	13.55932
T.E. Hood	24	36	60	476000	40

Images at each time point were also captured and show the progression of cell health throughout the experiment. It shows that the incubator keeps the cells healthy, as they are properly adhered and begin to duplicate. The degradation of the cells can be seen in the T.E. Hood and bench top flasks. The bench top cells degrade much quicker however, showing that the environment provided in the T.E. Hood is helping to keep the cells alive.

Table 5 – Images of each test sample at two hour intervals

Time Point	Image of Cells Under Microscope (Incubator/Hood/Bench)		
0 hr			
2 hr			
4 hr			
6 hr			

8 hr		
10 hr		

Issues

Heating

There were some issues with the temperature control within the tissue engineering hood. These are important to remedy as temperature plays the most important role in maintaining cell viability during the tissue engineering process. The main issue seen was that the hood was not capable of reaching the desired temperature of 37 ° C. This is due most likely to two features of the design. The first issue could be the wattage of the heating element not being sufficient for the size of the tissue engineering hood. The other potential issue would be heat dissipation of the hood. The hood is made nearly entirely of aluminum, which dissipates heat fairly easily. Therefore the hood appears to be acting like a heat sink for itself.

Another issue that presented itself was the heat produced by the blower motor. With the blower motor generating such significant heat, it prevents the use of the tissue engineering hood at room temperature and temperatures below 28 ° C.

Humidity

The humidifier was found to not be efficient enough to properly control the humidity in the tissue engineering hood when the blower motor was running or when the door was open. The blower motor decreases the humidity in the hood when being run, which acts counter to the desired effects of the hood. Therefore this would have to be remedied in order to provide efficient control over the humidity within the tissue engineering hood.

CO2

The CO_2 control was effective at increasing the percentage of CO_2 within the tissue engineering hood, however there were significant leaks, causing the CO_2 percentage to vary too greatly. To counteract the leaks, too much CO_2 is used to keep the percentage constant. This caused the tank to empty after only 2 hours which is 8 hrs short of the minimum time necessary. While no significant leaks were found in the seams of the hood, the CO_2 percentage in the hood is approximately 100 times the normal air concentration, creating a large gradient to drive diffusion. Therefore even small leaks would have large effects. The door also did not seal very efficiently which would be necessary for proper control over the CO_2 concentration.

Leaks

To identify the leaks in the system, a dry ice fog was used to visually examine the air flow. One significant leak was located near the front right corner of the work surface. The leak draws air into the hood, which doesn't compromise sterility due to its location, however it would affect CO_2 concentration. By drawing air in at a lower concentration than that in the hood, the concentration in the hood decreases. Also, while the air flow was inwards, CO_2 would still be exiting due to the large concentration gradient. The door didn't seal properly, however doesn't draw a large amount of air into the work area when closed. Sealing the significant leak decreased the rate at which CO_2 decreased inside the tissue engineering. However it still decreased at a rate too significant for practical use.

CHAPTER 5

Next Steps

Heating

In order to remedy the insufficient heating, there are two obvious next steps. The first would be to increase the wattage of the heating element, and the other would be to insulate the exterior surfaces of the hood. Increasing the wattage will increase the amount of heat that is able to be added to the environment, while the insulation will help prevent heat loss. The insulation would be the more efficient first step, as a significant amount of heat is already being added to the environment. The insulation should also be kept to the exterior metal surfaces, as to still allow heat to radiate into the work area as well as increase the air temperature while preventing it from escaping into its surroundings. If the insulation proves to be insufficient in reaching the desired temperature, it proves that the heating system is inadequate and thus the wattage must be increased. Based on observations during testing, it appears that heat dissipation is the issue. Since the tissue engineering hood is intended to circulate the same air when the hood is closed, the hood should eventually be able to reach its intended temperature after enough time has passed. During testing however, once it reached its maximum temperature after approximately 2 hours, it was still at the same temperature more than 10 hours later. Therefore this suggests that the heating output is at its maximum while the heat dissipation prevents the temperature from continuing to rise. Foam insulation would most likely be the best option in terms of insulation, as the high amount of air flow could potentially pick up fiberglass and cause it to circulate. Foam insulation would also be easier to install due to its ability

to match any irregular contours of the hood as well as effectively fill any corners. The high humidity would also not mix well with fiberglass, potentially causing condensation which can lead to mold growth and thus contamination of the hood. These corrections should hopefully increase the heating efficiency to the appropriate level.

There is also the issue of the blower motor raising the air temperature in the hood above room temperature over time. Since the goal of the hood is to operate at 37 ° C, this is not a major issue; however it prevents the use of the hood below 28 ° C, limiting its potential uses. While this does not affect the intended use, the hood was designed to accommodate multiple uses. A potential remedy for preventing this would be to add a method of cooling to the air temperature control. Insulating the motor has a potential for remedying the issue, however due to the extended period time the motor is in use, the heat would eventually dissipate into the hood. Adding a sufficient heat sink to translate the heat build up to the exterior of the tissue engineering hood will be necessary to allow the hood to operate at room temperature.

Humidity

Increasing the humidity output will also be necessary to provide the intended function of the tissue engineering hood. While the most efficient commercial humidifier that could fit into the dimensions of the hood was used, the output still needs to be increased. In order to do this, the issue of the blower motor reducing the humidity must be reversed to increase the humidity. The current humidifier functions by blowing air over a water reservoir, causing evaporation and raising humidity. Therefore the blower motor can be used to produce more humidity in the same fashion. By adding another

water reservoir into the hood, the current air flow produced by the blower motor can be used to increase the humidity in the hood. The reservoir will need fungicidal treatment to prevent the water reservoir from causing contamination in the hood. This system would require a bit of trial and error and refinement as it is a custom design.

CO2

The issue with controlling the CO_2 concentration was the leaking of CO_2 from the system. Therefore the issue is obviously remedied by eliminating these leaks. To fix this, different fabrication techniques would be necessary as well as new design for a better sealing door. While gasket tape and silicon were used as an attempt to seal any leaks, they apparently were not effective enough. Therefore welding all the seams together would provide a much better seal. This would require TIG welding due to the use of aluminum. Welding all the seams would prevent the access to the inner workings of the hood, which would cause problems during the prototyping phase, however would be the best choice for the final design. As for improving the seal of the door, a latching mechanism should be added to apply pressure to the seal created by the rubber gasket.

Other Improvements

There are other improvements that can be made beyond addressing the previously identified issues. A custom circuit board should be created to consolidate the control circuits. This would provide for more reliable connections and consolidate the size of the circuits. Better wiring management should also be considered. The custom circuit board would provide the opportunity to consolidate the wires into buses giving a much cleaner

appearance and allow for easier management of the wires. Shielded wires should also be used to protect the analog signals of the temperature sensors for degrading. Improving the seals of the wires that pass through the exterior of the tissue engineering hood is also necessary to prevent any sort of leakage. This can be accomplished through using wiring buses and connectors mounted in the sheet metal to connect the inside to the exterior. Conduits should also be used to manage the wires and protect them from the moist and corrosive environment of the hood. More sensitive temperature sensors should also be considered, as well as more reliable humidity sensors. The humidity sensors can vary greatly, as well as possessing and addressing issues, requiring the use of a relay to switch between each sensor to gather readings. Insulating the sensors against the environment should also be considered in order to protect their circuits from corrosion over time.

A better water tank should also be designed. The seals on the current tank can fail at times due to thermal expansion and contraction from the changing temperatures. Also limiting the amount of water in the system will increase its efficiency. The overall dimensions should also be considered to be changed, as it will currently not fit through a standard door while assembled. The depth of the system needs to be restricted to less than 35” in order to allow it to easily pass through a standard door while assembled. This would require the obtainment of HEPA filters with custom dimensions, a new design of the overall structure as well as a new location for the display.

Commercialization

Once the issues of the tissue engineering hood have been resolved and the device functions as it should, there is a chance for it to be sold as a commercial product. The

current market for the tissue engineering hood would be research laboratories focusing in tissue engineering and biologics. While this market is fairly small and commonly already outfitted with a multitude of devices to meet the functionality achieved by the tissue engineering hood, it is a growing field and there are increased benefits from the tissue engineering hood. It may be difficult to introduce the device into the market, however if presented at a reasonable price and with the added benefits of the tissue engineering hood there should be a reasonable market size. Also as the device is a combination of systems, it will be potentially difficult to properly protect the intellectual property with a patent. Therefore providing a tissue engineering hood customized to a client’s needs would provide the most successful business model.

A small business venture featuring the tissue engineering hood would require the following set-up. Estimating the cost per unit being $5000, and the amount of time to fabricate one unit after refining the process to be at most 100 man hours, a single person could produce approximately 20 units in a year. A reasonable number of units sold each year would be 10-15 units. Therefore to make it viable enterprise for an individual without considering the necessary start-up capital, each unit would need to sell at a price of $11,000 to $12,000 for a standard device. Having a single product to support a business makes it a risky venture, therefore expanding the business to provide custom bioreactors or other support devices would reduce some of the risk.

CHAPTER 6

Conclusion

The tissue engineering hood is designed to provide the optimum work space for tissue engineering. Its current design focuses on providing the proper environmental conditions as well as the necessary faculties needed for 3D printing. The tissue engineering hood was designed to benefit the tissue engineering field by providing an environment optimal for long duration fabrication methods and the maintenance of cell viability during any process. While the current design had some difficulties providing the proper environment, it clearly demonstrates what changes must occur to achieve the desired functionality. Incorporating the necessary support hardware for 3D printing was successful and demonstrates that the hood could be modified for other similar functions. After implementing the previously mentioned methods for achieving the desired outcomes, the tissue engineering hood will be a beneficial addition to the equipment available to a tissue engineer.

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APPENDIX A

Arduino Pin Designations

ATMEGA Pin	Designation	ATMEGA Pin	Designation	ATMEGA Pin	Designation
IOREF	N/C	AREF	N/C	5V	N/C
RESET	N/C	GND	N/C	5V	N/C
3.3V	N/C	13	N/C	22	SCRN11
5V	5V Pots/Toggles	12	SCRN4	23	SCRN12
GND	Reed Switch Ground	11	SCRN6	24	SCRN13
GND	Arduino Power Ground	10	N/C	25	SCRN14
VIN	12V Arduino Power	9	N/C	26	HUM CTRL
A0	TEMP0	8	N/C	27	N/C
A1	TEMP1	7	N/C	28	HUM SEL
A2	TEMP2	6	N/C	29	PELTIER FAN
A3	TEMP3	5	N/C	30	PELTIER CTRL1
A4	TEMP4	4	N/C	31	PELTIER CTRL2
A5	TEMP5	3	N/C	32	H20 ON/OFF
A6	TEMP6	2	TOG0	33	HEATER ON/OFF
A7	TEMP7	1	TX	34	SOL ON/OFF
A8	TEMP8	0	N/C	35	BLOWER HI/LO
A9	POT0	14	TX2	36	REED
A10	POT1	15	N/C	37	LED4
A11	POT2	16	N/C	38	LED0
A12	POT3	17	N/C	39	LED1
A13	N/C	19	N/C	40	LED2
A14	N/C	19	N/C	41	LED3
A15	N/C	20	SDA	42	N/C
		21	SCL	43	TOG1
				44	TOG2
				45	TOG3
				46	N/C
				47	FOUT
				48	N/C
Toggle/LED/Potentiometer Legend				49	N/C
Number	**Control Panel**			50	RX2

	Function				
0	**Temperature**			51	N/C
1	**Humidity**			52	RX
2	**CO2 Concentration**			53	N/C
3	**Water Pump**			GND	LED Ground
4	**AC-DC Converter**			GND	Toggles & Potentiometers Ground

APPENDIX B

Final Program

```
//Tissue Engineering Control Program for the Arduino Mega 2560
//By Malcolm Lapera and Sophie Schneider
//Last Revised Date: 12/4/13
// Declare Libraries Here
#include <Wire.h>
#include <FreqCount.h>
#include <LiquidCrystal.h>
#include <SoftwareSerial.h>
#include <Average.h>
#include <Math.h>
#include <Timer.h>

// ******Pinouts*****
LiquidCrystal lcd(12, 11, 22, 23, 24, 25);      //LCD Pinouts
int potPin[] = {A9, A10, A11, A12};             //Slide Pot Pinouts
//Heater Pinout
int tempPin[] = {A0, A1, A2, A6, A7, A8};  //Temp Sensors
int heaterCTRL = 33;                            //Heater Relay
int heatTog = 2;                                //Heater Toggle
int heatLED = 38;                               //Heater LED
//Humidifier Pinout
int humSel = 28;            //Humidity Sensor Relay
int humCTRL = 26;            //Humidifier Relay
int humTog = 43;            //Humidity Toggle
int humLED = 39;            //Humidity LED
//CO2 Pinout
int CO2CTRL = 34;              //CO2 Solenoid Relay
int CO2Tog = 44;              //CO2 Toggle
int CO2LED = 40;              //CO2 LED
//H2O Heater Pinout
int tempH2OPin = A4;           //Temp Sensor for H2O
int H2OCTRL1 = 30;             //Peltier Hot
int H2OCTRL2 = 31;             //Peltier Cold
int H2OTog = 45;              //Water Coolant Toggle
int H2OLED = 41;              //Water Coolant LED
int H2OFan = 29;              //Peltier Fan
int H2OPump = 32;              //Water Pump
//Blower Pinout
int reedSW = 36;              //Reed Switch
int blowCTRL = 35;             //Blower Control Relay
//Converter Pinout
int convertLED = 37;           //ON/OFF LED
// ******************* Global Variables:**********************
float potSensor[4]; // temperature, humidity, CO2, H2O
float potCur[4];    //array for checking change in slide pots
float potPrev[4];
int action[4];
```

```
int hum_pot = 0;          //Global int variable for humidity slide pot
int temp_pot = 0;         //Global int variable for temperature slide pot
int water_pot = 0;        //Global int variable for water temp slide pot
// Flags
int Pump_Flag = 0; int Heat_Flag = 0; int Hum_Flag = 0; int CO2_Flag = 0; int H2O_Flag = 0;  //
Flags for controlling actuators
//Global Temp Variables
int tempInC[6]; // stores temp sensor values (in C)
//Global Humidity Sensor Variables
int sens;
int offset;
int enHum=0;
//Global CO2 Variables
SoftwareSerial mySerial(50, 14); //Rx,Tx
String val= ""; //holds the string of the value
double co2 =0; // holds the actual value
double multiplier = 10;
uint8_t buffer[25];
uint8_t ind =0;
float co2percent = 0.0;    //Global CO2 value
//Global H20 Variables
int tempInH2OC = 0;        //Global Water Temp value
int hoodTemp = 0;          //Global Hood Temp
int RHAVG = 0;             //Global Humidity average
int RH0 = 0;               //Global Humidity one
int RH1 = 0;               //Global Humidity two

//Counterrr
unsigned long count1=0;      //Counter for delaying humidity sensors
unsigned long count2=0;

// Any One-Time Operations Here
void setup(){
  //Pin declarations
  pinMode(heaterCTRL, OUTPUT); pinMode(heatTog, INPUT_PULLUP); pinMode(heatLED,
OUTPUT);
  pinMode(humSel, OUTPUT); pinMode(humCTRL, OUTPUT); pinMode(humTog,
INPUT_PULLUP);
  pinMode(humLED, OUTPUT); pinMode(CO2CTRL, OUTPUT); pinMode(CO2Tog,
INPUT_PULLUP);
  pinMode(CO2LED, OUTPUT); pinMode(H2OCTRL1, OUTPUT); pinMode(H2OCTRL2,
OUTPUT);
  pinMode(H2OFan, OUTPUT); pinMode(H2OTog, INPUT_PULLUP); pinMode(H2OLED,
OUTPUT);
  pinMode(reedSW, INPUT_PULLUP); pinMode(blowCTRL, OUTPUT); pinMode(H2OPump,
OUTPUT);
  pinMode(convertLED, OUTPUT);

  Serial.begin(9600);  //Serial Monitor Setup
  lcd.begin(16,2);      //LCD Setup
  //Temp Setup
  initSet_Temp();
  //Hum Setup
  Wire.begin();
```

```
  FreqCount.begin(1000);
  sens   =  i2cRead2bytes(81, 10); //Calibration for hum sensor
  offset =  i2cRead2bytes(81, 12); //Calibration for hum sensor
  initSet_Hum();
  //CO2 Setup
  mySerial.begin(9600); //Start Serial connection with CO2 Sensor
  initSet_CO2();
  //H20 Temp Setup
  initSet_H2O();
  digitalWrite(convertLED, HIGH);
  actuator_low();
  //Initial LCD Display
  lcd.clear();
  lcd.print("Tissue Engr Hood");
  lcd.setCursor(0,1);
  lcd.print("Initialized");
}

// MAsterMind Function
void loop(){
  count1++;                  //Increment humidity sensor counter
  sensor_read();             //read sensors
  Standard_Display();        //displays sensor values
  check_pots();              //displays change in slide pots for setting values
  check_toggles();           //checks if toggles have been switched
  update_actuators();        //Updates actuators based on sensors and if toggles are on
  if(count1 > 6){
    count1 = 0;
  }
}


//************** Initialization Functions ***************

//Initializes Previous/Current Pot Values
void initSet_Temp(){
  int temp = analogRead(potPin[0]);
  potSensor[0] = int(temp*30/1024+20);
  potPrev[0] = int(potSensor[0]);
  potCur[0] = int(potSensor[0]);
}

//Sets Intial Desired Humidity Level
void initSet_Hum(){
  int hum = analogRead(potPin[1]);
  potSensor[1] = int(hum*29/1020 + 70);
  potPrev[1] = int(potSensor[1]);
  potCur[1] = int(potSensor[1]);
}

//Sets Initial Desired CO2 Level
void initSet_CO2(){
  int CO_2 = analogRead(potPin[2]);
  potSensor[2] = (CO_2*0.0096 + 0.2);
```

```
  potPrev[2] = int(potSensor[2]*10);
  potCur[2] = int(potSensor[2]*10);
}

//Sets Initial Desired H2O Level
void initSet_H2O(){
  int temp2 = analogRead(potPin[3]);
  potSensor[3] = int(temp2*0.04505387+4);
  potPrev[3] = int(potSensor[3]);
  potCur[3] = int(potSensor[3]);
}

//Set Actuators Low
void actuator_low(){
  digitalWrite(heaterCTRL, LOW);
  digitalWrite(humCTRL, LOW);
  digitalWrite(CO2CTRL, LOW);
  digitalWrite(H2OCTRL1, LOW);
  digitalWrite(H2OCTRL2, LOW);
  digitalWrite(H2OFan, LOW);
  digitalWrite(H2OPump, LOW);
}

//**************************** Heater Functions ********************************//
// Returns Laminar Flow Hood Temperature
int Get_Temp(){
  int tempV[6]; // raw temp sensor values
  int i=0;
  for(i=0; i<6; i++){
     tempV[i] =  analogRead(tempPin[i]);
     tempInC[i] = ((tempV[i]*(4.8685)-500)/10)+5;
//*************************************************************************************
*************************
     delay(50);
  }
  hoodTemp = mean(tempInC, 6);
  return hoodTemp;
}

// Sets Temperature Via Pot Sensor Value
int Set_Temp(){
  int temp = analogRead(potPin[0]);
  potSensor[0] = int(temp*30/1020+20);
  potPrev[0] = int(potCur[0]);
  potCur[0] = int(potSensor[0]);
  temp_pot = int(potSensor[0]);
  return potSensor[0];
}

// Displays Potentiometer Set Temperature
void Display_Update_Temp(){
    lcd.clear();
    lcd.print("Set Temp:");
    lcd.setCursor(0,1);
```

```
  lcd.print(temp_pot);
  lcd.print(" C");
}

// Heater Control
void Adjust_Temp(){
  if(hoodTemp < temp_pot){
    digitalWrite(heaterCTRL, HIGH);
  }
  else{
  digitalWrite(heaterCTRL, LOW);
  }
}


//*************************** CO2 Functions **********************************//

// Returns Average of Two CO2 Sensor Readings
float Get_CO2(){
  //Cozir sensors ship from the factory in streaming mode
//So we read incoming bytes into a buffer until we get '0x0A' which is the ASCII value for new-
line
  float CO2_1;
  //float CO2_2;

  while(buffer[ind-1] != 0x0A)
  {
    if(mySerial.available())
    {
      buffer[ind] = mySerial.read();
      ind++;
    }
  }
  CO2_1 = report(); //Once we get the '0x0A' we will report what is in the buffer
  return CO2_1;
}

// Returns CO2 Sensor Reading in Percent
float report()
{
//Cycle through the buffer and send out each byte including the final linefeed
/*
each packet in the stream looks like "Z 00400 z 00360"
'Z' lets us know its a co2 reading. the first number is the filtered value and the number after the 'z'
is the raw value.
We are really only interested in the filtered value
*/
  for(int i=0; i < ind+1; i++)
  {
    if(buffer[i] == 'z') //once we hit the 'z' we can stop
    break;
    if((buffer[i] != 0x5A)&&(buffer[i] != 0x20)) //ignore 'Z' and white space
      {
        val += buffer[i]-48; //because we break at 'z' the only bytes getting added are the numbers
```

```
        // we subtract 48 to get to the actual numerical value
        // example the character '9' has an ASCII value of 57. [57-48=9]
       }
    }
    co2 = (multiplier * val.toInt()); //now we multiply the value by a factor specific ot the sensor. see
the Cozir software guide
    co2percent = co2/10000;
    ind=0; //Reset the buffer index to overwrite the previous packet
    val=""; //Reset the value string
    return co2percent;
   }

   // Sets Desired CO2 Level
   float Set_CO2(){
    int CO_2 = analogRead(potPin[2]);
    potSensor[2] = (CO_2*0.0096 + 0.2);
    potPrev[2] = int(potCur[2]);
    potCur[2] = int(potSensor[2]*10);
    potSensor[2] = int(potSensor[2]*10);
    potSensor[2] = float(potSensor[2]/10);
    return potSensor[2];
   }

   //Updates display with slide pot value
   void Display_Update_CO2(){
    lcd.clear();
    lcd.print("Set CO2 Percent:");
    lcd.setCursor(0,1);
    lcd.print(potSensor[2]);
    lcd.print("%");
   }

   //Controls solenoid to adjust CO2 level
   void Adjust_CO2(){
    if(co2percent < potSensor[2]){
      digitalWrite(CO2CTRL, HIGH);
    }
     else digitalWrite(CO2CTRL, LOW);
   }

   //**************************** H2O Pump Functions ******************************//
   //Reads Temperature sensor on water tank
   int Get_H2O(){
    int tempV; // raw temp sensor values
    tempV =  analogRead(tempH2OPin);
    tempInH2OC = ((tempV*(4.8685)-500)/10)+6;
//*******************************************************************************
return tempInH2OC;
   }

   //Reads slide pot for setting water tank temperature
   int Set_H2O(){
    int temp2 = analogRead(potPin[3]);
    potSensor[3] = int(temp2*0.04505387+4);
```

```
  potPrev[3] = int(potCur[3]);
  potCur[3] = int(potSensor[3]);
  water_pot = int(potSensor[3]);
  return potSensor[3];
}

//Updates display with slide pot value for water tank
void Display_Update_H2O(){
    lcd.clear();
    lcd.print("Set H2O Temp:");
    lcd.setCursor(0,1);
    lcd.print(water_pot);
    lcd.print(" C");
}

//Adjusts peltier to control water tank temperature and controls water pump
void Adjust_H2O(){
  if(tempInH2OC < water_pot){
    digitalWrite(H2OCTRL1, HIGH);
    digitalWrite(H2OCTRL2, LOW);
    digitalWrite(H2OFan, HIGH);
  }
  else if (tempInH2OC > water_pot){
    digitalWrite(H2OCTRL1, LOW);
    digitalWrite(H2OCTRL2, HIGH);
    digitalWrite(H2OFan, HIGH);
  }
  else if (tempInH2OC == water_pot){
    if (Pump_Flag == 0){
      digitalWrite(H2OPump, HIGH);
      Pump_Flag = 1;
    }
  }
  else{
    digitalWrite(H2OCTRL1, LOW);
    digitalWrite(H2OCTRL2, LOW);
    digitalWrite(H2OFan, LOW);
    digitalWrite(H2OPump, LOW);
  }
}

//**************************** Humidity Functions ******************************//
// Function for reading from humidity sensors
int i2cRead2bytes(int deviceaddress, byte address)  {
 // SET ADDRESS
 Wire.beginTransmission(deviceaddress);
 Wire.write(address); // address for sensitivity
 Wire.endTransmission();
 // REQUEST RETURN VALUE
 Wire.requestFrom(deviceaddress, 2);
 // COLLECT RETURN VALUE
 int rv = 0;
 for (int c = 0; c < 2; c++ )
 if (Wire.available()) rv = rv * 256 + Wire.read();
```

```
 return rv;
}

//Read Humidity Sensors and Return Average
float Get_Hum(){
if(count1 > 5){
  digitalWrite(humSel, LOW);
  delay(200);
  if (FreqCount.available()) {
    unsigned long count = FreqCount.read();
    RH0 =  (offset-count)*sens/4096;
  }
  digitalWrite(humSel, HIGH);
  delay(200);
  if (FreqCount.available()) {
    unsigned long count1 = FreqCount.read();
    RH1 =  (offset-count1)*sens/4096;
  }
    RHAVG = ((RH0+RH1)/2)-4;
    return RHAVG;
}
}

//Reads humidity value from slide pot
int Set_Hum(){
  int hum = analogRead(potPin[1]);
  potSensor[1] = hum*0.0785 + 20;
  potPrev[1] = int(potCur[1]);
  potCur[1] = int(potSensor[1]);
  hum_pot = int(potSensor[1]);
  return potSensor[1];
}

//Updates display with humidity value from slide pot
void Display_Update_Hum(){
  lcd.clear();
  lcd.print("Set Humidity:");
  lcd.setCursor(0,1);
  lcd.print(hum_pot);
  lcd.print("%");
}

//Adjusts Humidity by turining on humidifier
void Adjust_Hum(){
  if(RHAVG < potSensor[1]){
      digitalWrite(humCTRL, HIGH);
  }
  else {digitalWrite(humCTRL, LOW);}
}

//***************************** Blower Control ****************************//
//Adjusts blower output depending on position of door
void Adjust_Blower(){
    int reedVal = digitalRead(reedSW);
```

```
  if(reedVal == HIGH){
    digitalWrite(blowCTRL, LOW);
  }
  else if(reedVal == LOW){
    digitalWrite(blowCTRL, HIGH);
  }
  else digitalWrite(blowCTRL, LOW);
}

//***************************** Display
******************************************//
//Displays sensor values
void Standard_Display(){
  lcd.clear();
  lcd.print("Temp:");
  lcd.print(hoodTemp);
  lcd.print("C ");
  lcd.print("Hum:");
  lcd.print(RHAVG);
  lcd.print("%");
  lcd.setCursor(0,1);
  lcd.print("CO2:");
  lcd.print(co2percent);
  lcd.print("%");
  lcd.print("H2O:");
  lcd.print(tempInH2OC);
  lcd.print("C");
}


//***************************** Functions for MasterMind ********************//
//Reads Sensor values and Slide pots
void sensor_read(){
  Get_Temp();
  Get_Hum();
  Get_CO2();
  Get_H2O();
  Set_Temp();
  Set_Hum();
  Set_CO2();
  Set_H2O();
}

//Checks if toggles have been flipped
void check_toggles(){
  int heatOnOff = digitalRead(heatTog);
  int humOnOff = digitalRead(humTog);
  int CO2OnOff = digitalRead(CO2Tog);
  int H2OOnOff = digitalRead(H2OTog);

  if(heatOnOff == LOW){
    digitalWrite(heatLED, HIGH);
    Heat_Flag = 1;
  }
```

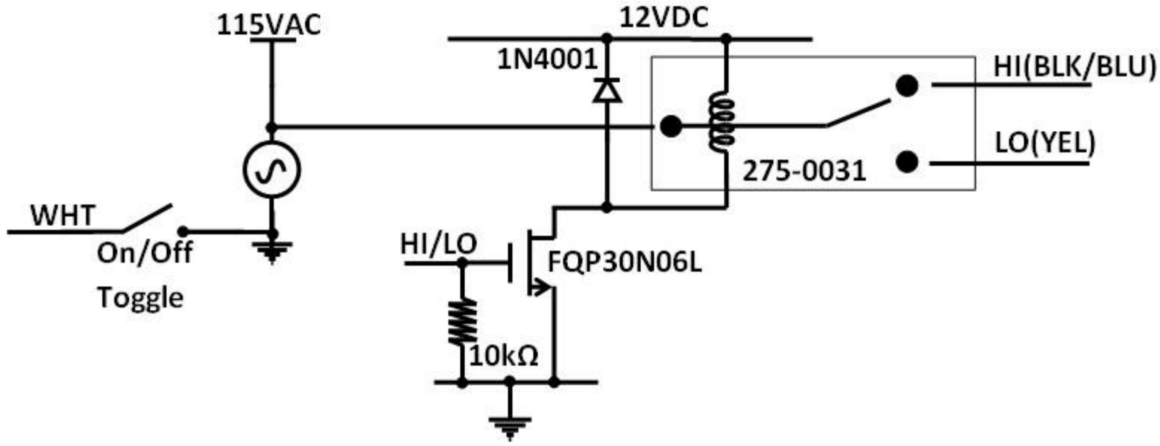
```
  else if(heatOnOff == HIGH) {
    digitalWrite(heatLED, LOW);
    digitalWrite(heaterCTRL, LOW);
    Heat_Flag = 0;
  }
  if(humOnOff == LOW){
    digitalWrite(humLED, HIGH);
    Hum_Flag = 1;
  }
  else if(humOnOff == HIGH){
    digitalWrite(humLED, LOW);
    digitalWrite(humCTRL, LOW);
    Hum_Flag = 0;
  }
  if(CO2OnOff == LOW){
    digitalWrite(CO2LED, HIGH);
    CO2_Flag = 1;
  }
  else if(CO2OnOff == HIGH){
    digitalWrite(CO2LED, LOW);
    digitalWrite(CO2CTRL, LOW);
    CO2_Flag = 0;
  }
  if(H2OOnOff == LOW){
    digitalWrite(H2OLED, HIGH);
    H2O_Flag = 1;
  }
  else if(H2OOnOff == HIGH){
   digitalWrite(H2OLED, LOW);
   digitalWrite(H2OCTRL1, LOW);
   digitalWrite(H2OCTRL2, LOW);
   digitalWrite(H2OFan, LOW);
   digitalWrite(H2OPump, LOW);
   H2O_Flag = 0;
   Pump_Flag = 0;
  }
}

//Checks if slide pots have changed
void check_pots(){
    int i;
  for(i=0; i<4; i++){
    if((potCur[i] != potPrev[i])) action[i] = 1;
    else action[i] = 0;
  }

  if(action[0] == 1){
    Display_Update_Temp();
    delay(100);
  }
  if(action[1] == 1){
    Display_Update_Hum();
    delay(100);
  }
```

```
  if(action[2] == 1){
   Display_Update_CO2();
   delay(100);
  }
  if(action[3] == 1){
   Display_Update_H2O();
   delay(100);
  }
}

//Updates actuators based on slide pot values and sensor values
void update_actuators(){
  //heater
  if(Heat_Flag == 1){
    Adjust_Temp();
  }
  //Humidity
  if(Hum_Flag == 1){
    Adjust_Hum();
  }
  //CO2
  if(CO2_Flag == 1){
    Adjust_CO2();
  }
  //Water Pump
  if(H2O_Flag == 1){
    Adjust_H2O();
  }
  //Blower
  Adjust_Blower();

}
```

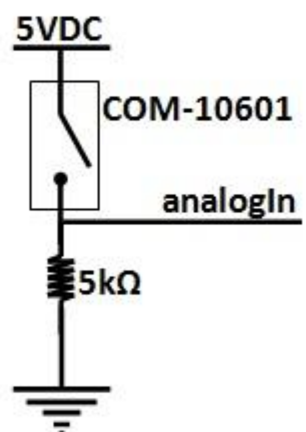
APPENDIX C

Circuit Diagrams

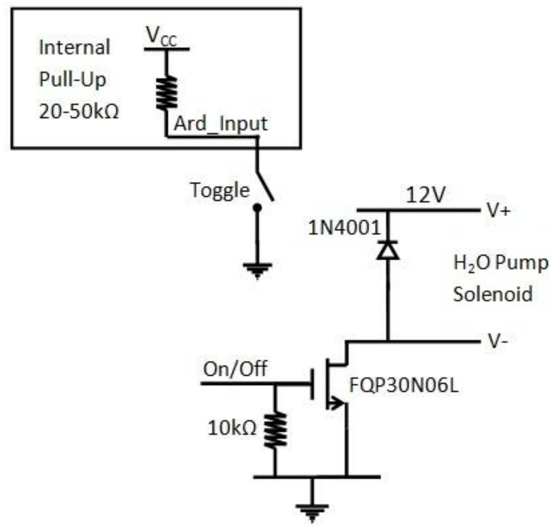
Blower Motor Control Circuit



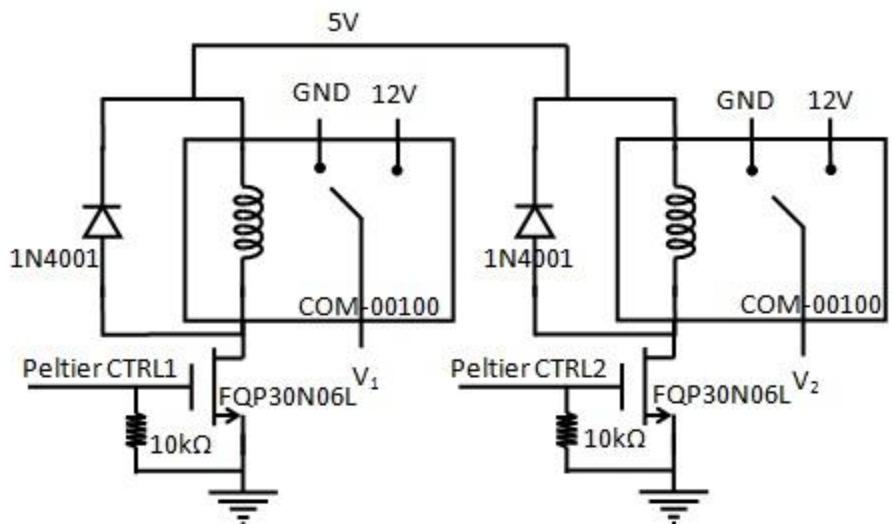
Toggle Switch Circuit



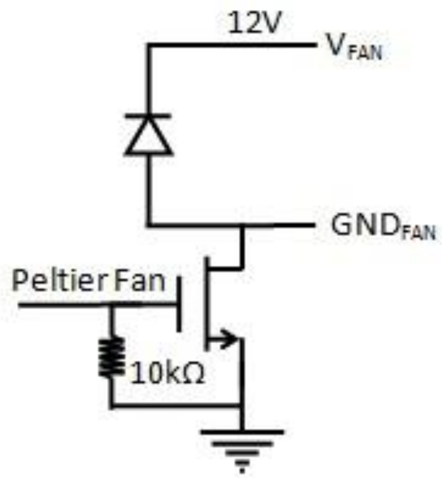
Water Pump Control Circuit



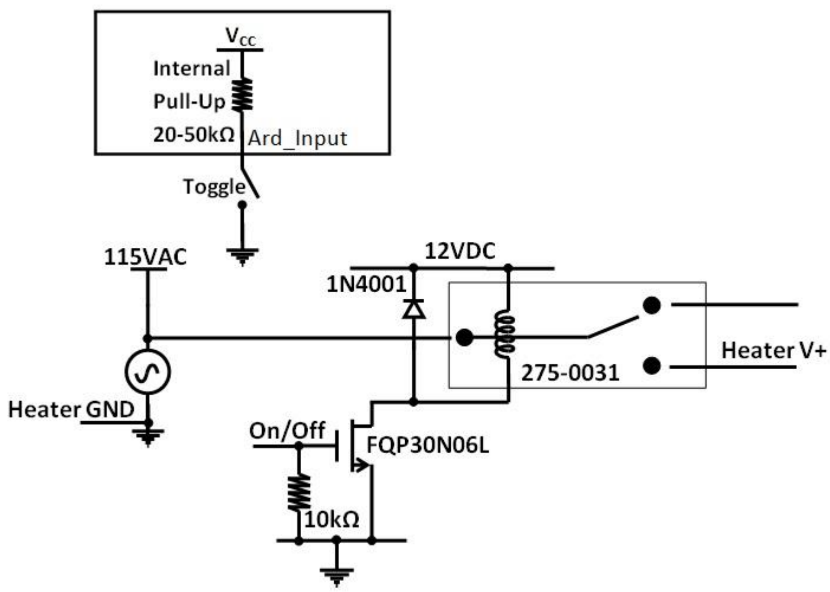
Peltier Control Circuit



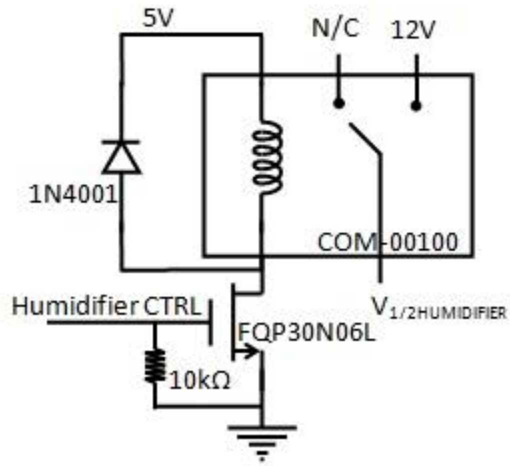
Peltier Fan Control Circuit



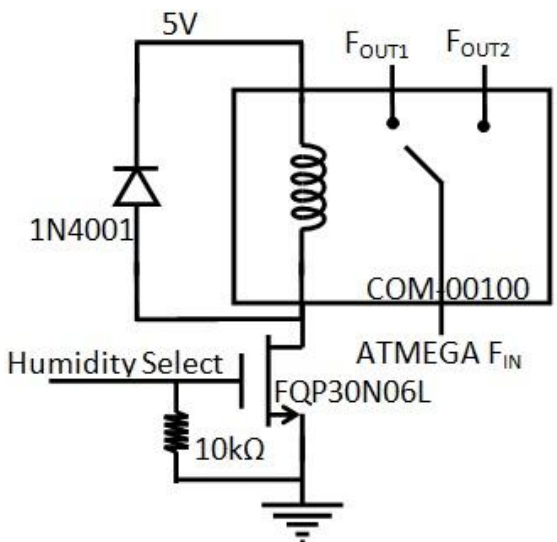
Heater Control Circuit



Humidifier Control Circuit

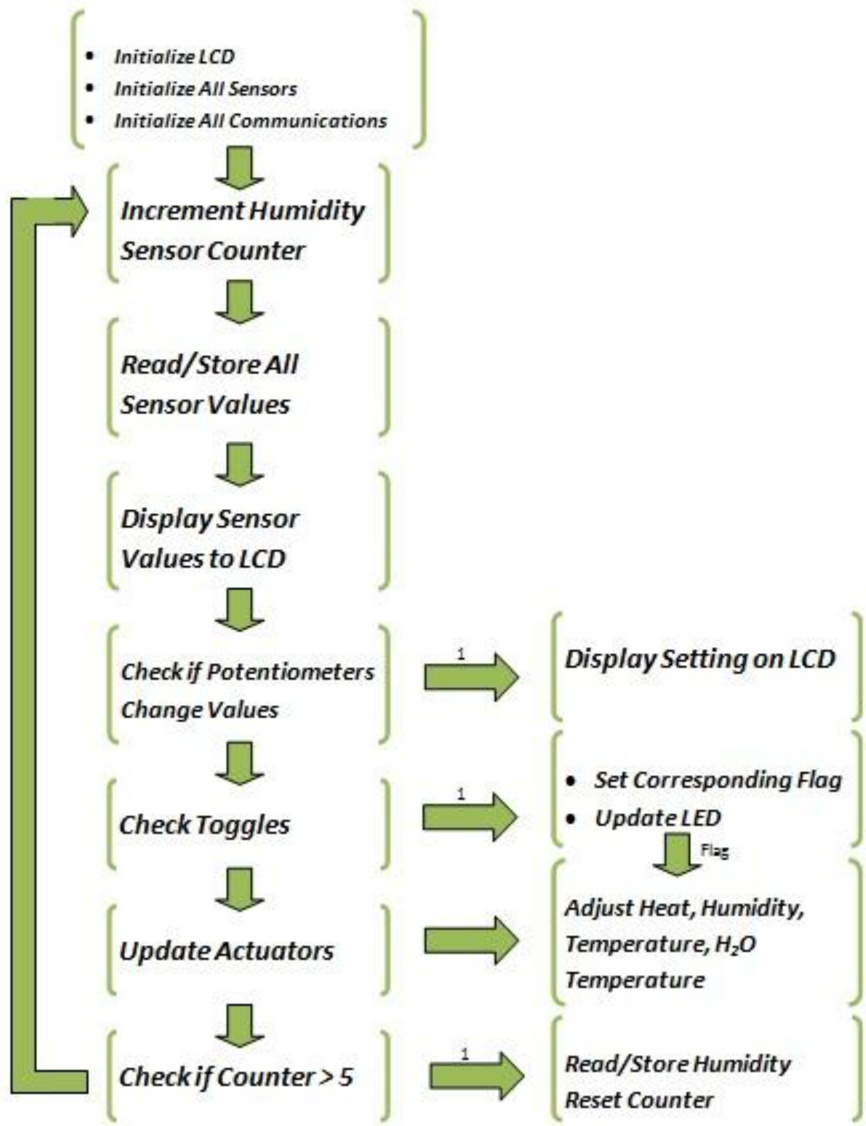


Humidity Sensor Read Circuit



APPENDIX D

Program Flowchart

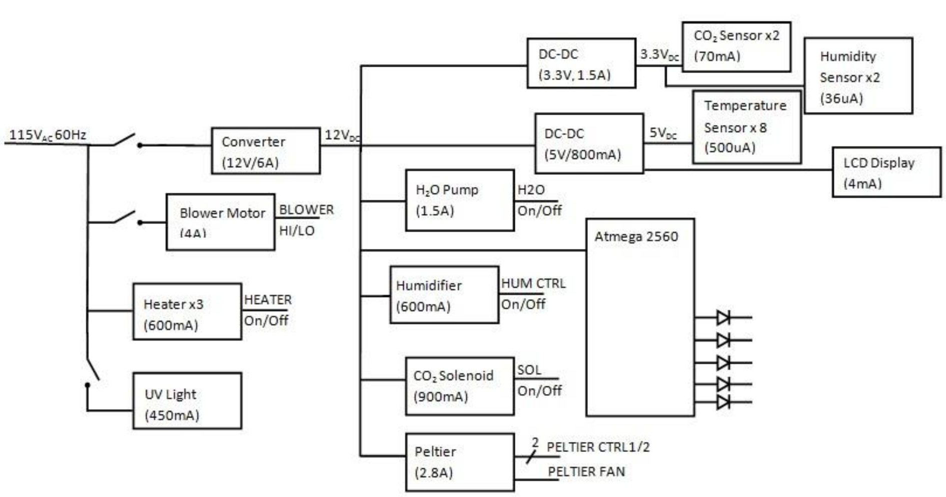


APPENDIX E

Power Considerations

AC or DC	Input/Output	Qty (#)	Vin (V)	Iin (A)	Power (W)	Itot (A)	Ptot (A)
DC	Humidity Sensor	2	3.3	0.000018	0.0000594	0.000036	0.000119
DC	CO2 Sensor	2	3.3	0.033	0.0035	0.066	0.007
DC	Temp Sensor	10	5	0.00005	0.00025	0.0005	0.0025
DC	Water Pump	1	12	1.46	18	1.46	18
DC	Humidifier	1	12	0.6	7.2	0.6	7.2
DC	CO2 Solenoid	1	12	0.883333	10.6	0.883333	10.6
DC	ATMEGA 2560	1	12	0.002	0.024	0.002	0.024
DC	Peltier	1	12	2.8	33.6	2.8	33.6
AC	Heater	3	115	0.173913	20	0.521739	60
AC	Blower Motor	1	115	4	460	4	460
AC	UV Ballast	1	120	0.45	38	0.45	38
Summary:							
Power Source (V)		**Total Current (A)**			**Total Power (W)**		
DC	3.3	0.066036			0.0071188		
DC	5	0.0005			0.0025		
DC	12	5.745333333			69.424		
AC	115/120	4.97173913			558		

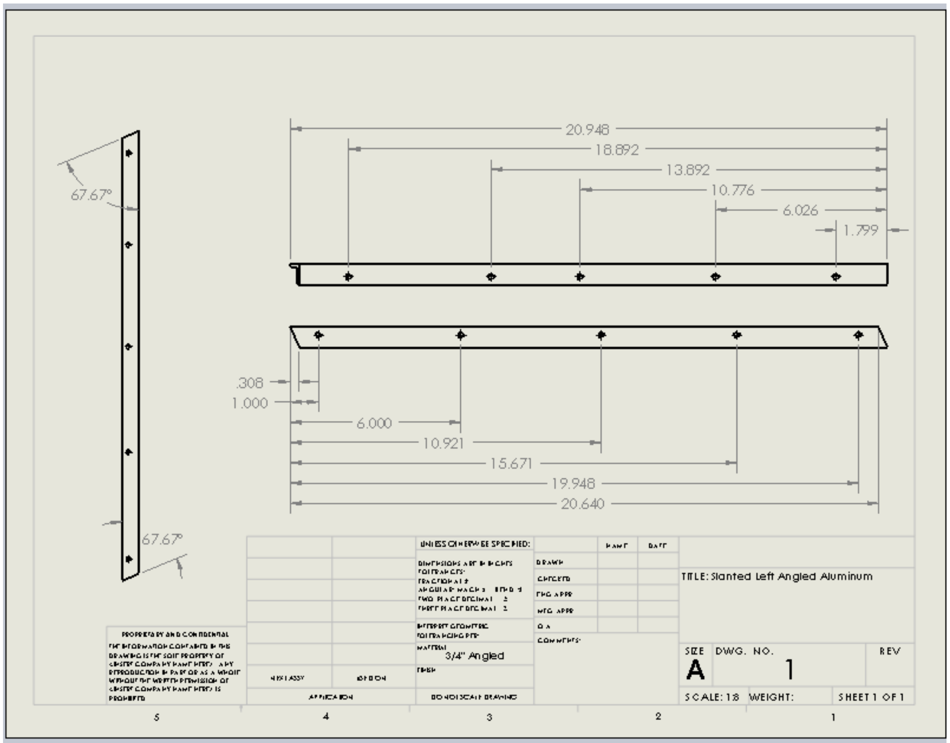
Power Flow Breakdown



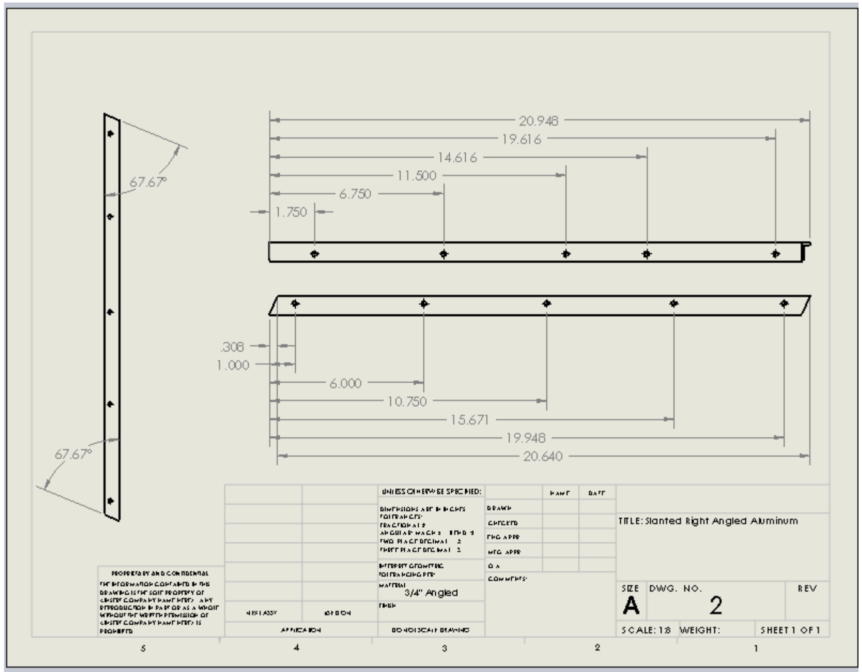
APPENDIX F

Engineering Drawings

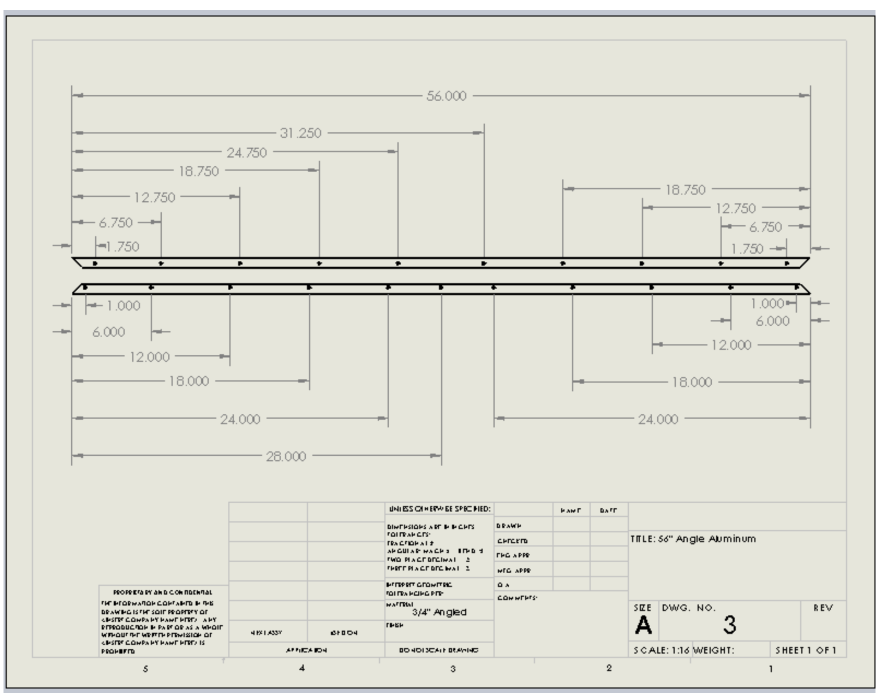
Slanted Left Angle



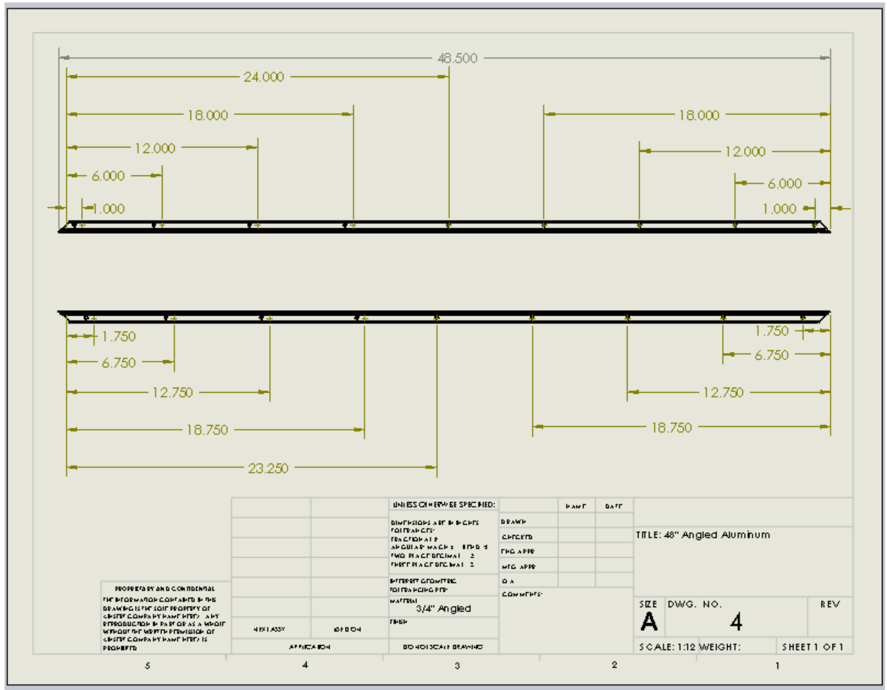
Slanted Right Angle



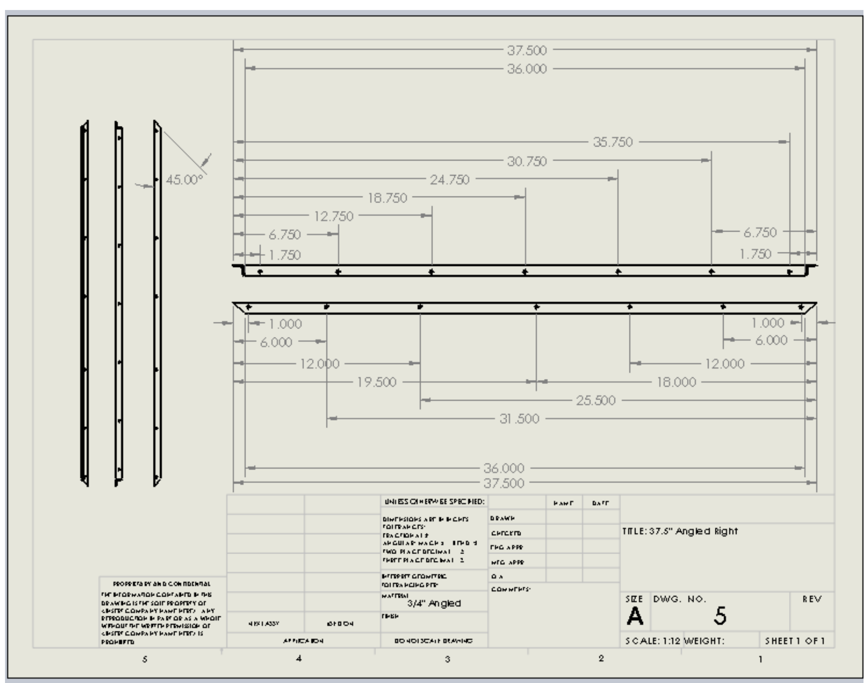
56” Angle



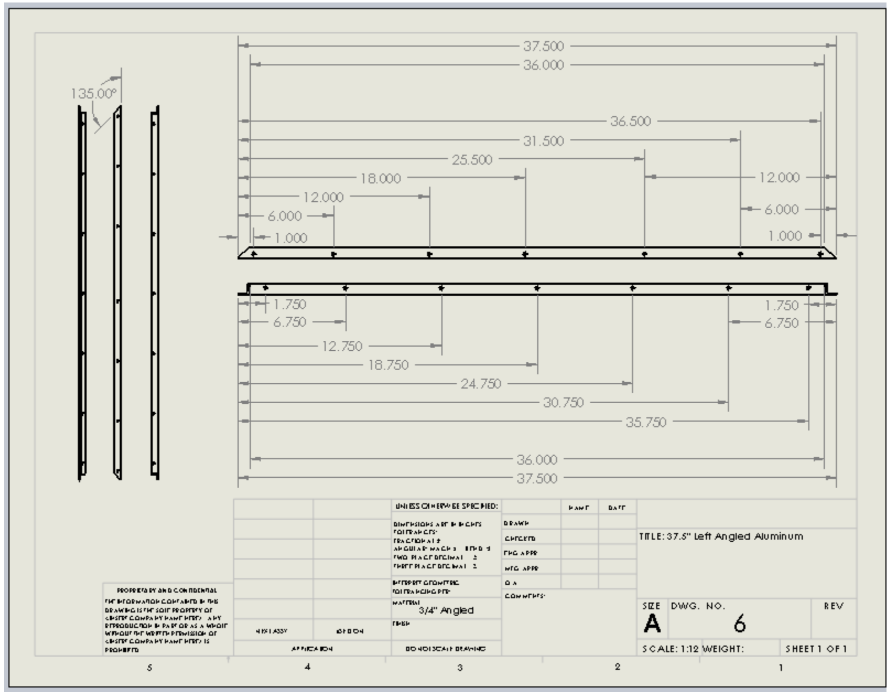
48” Angled Aluminum



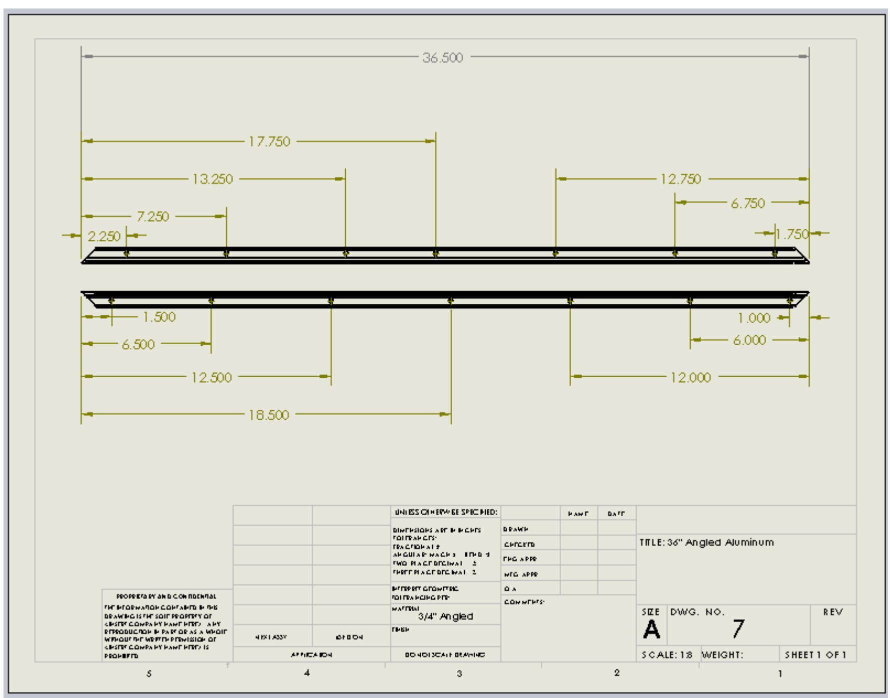
37.5” Right Angled Aluminum



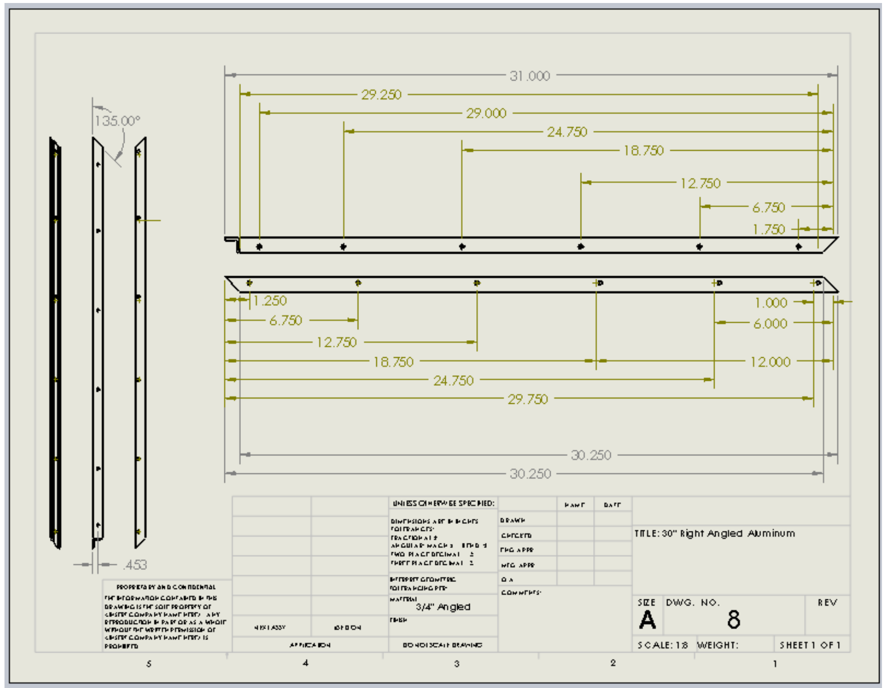
37.5" Left Angled Aluminum



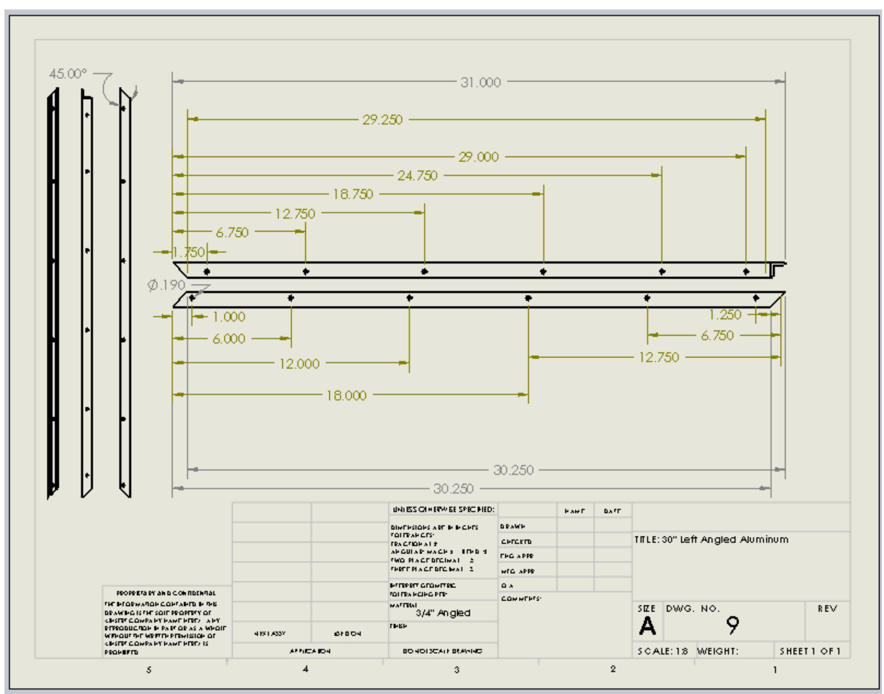
36" Angled Aluminum



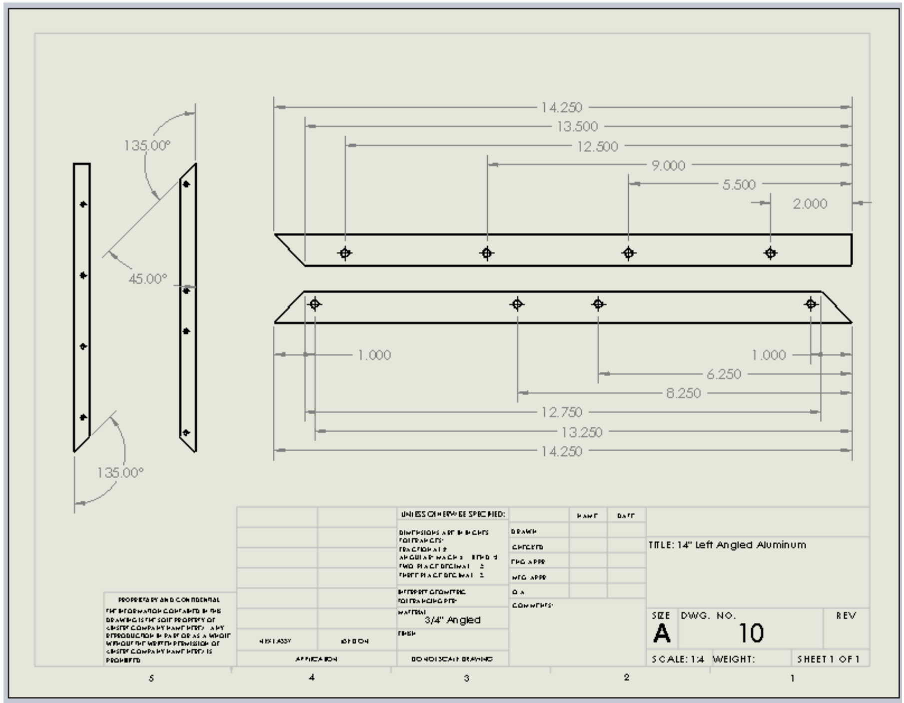
30” Right Angled Aluminum



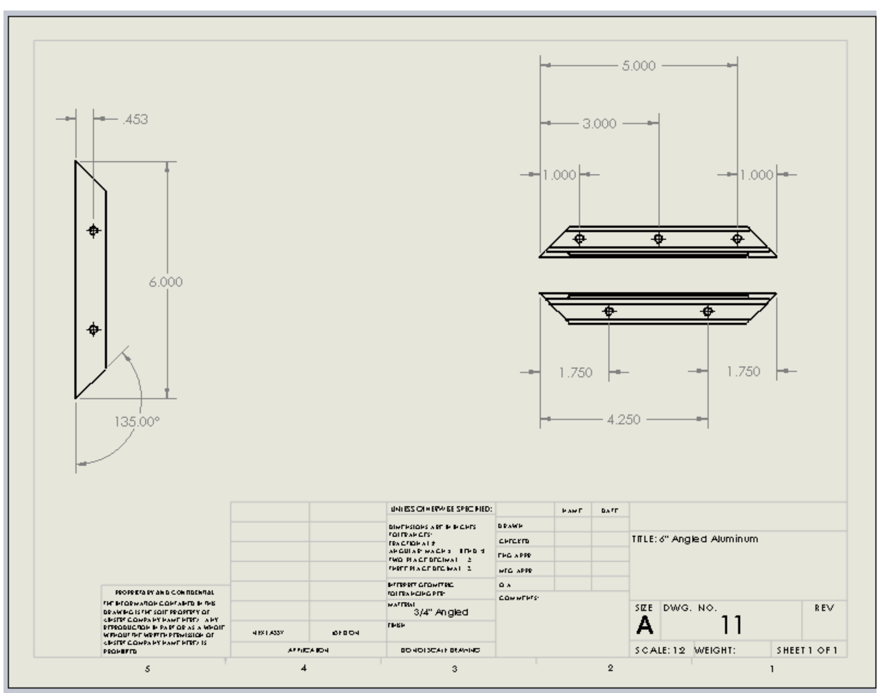
30” Left Angled Aluminum



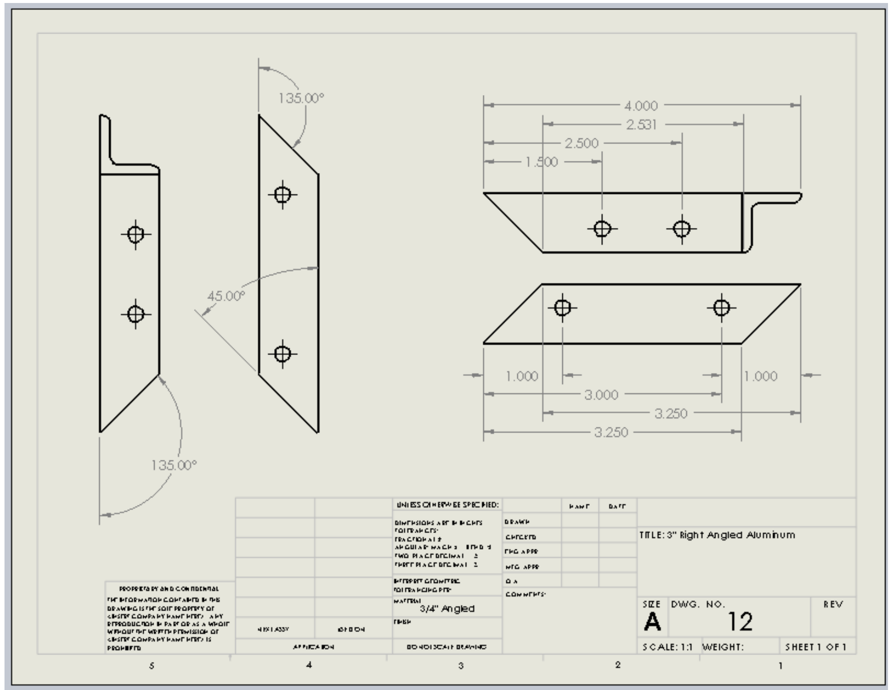
14” Left Angled Aluminum



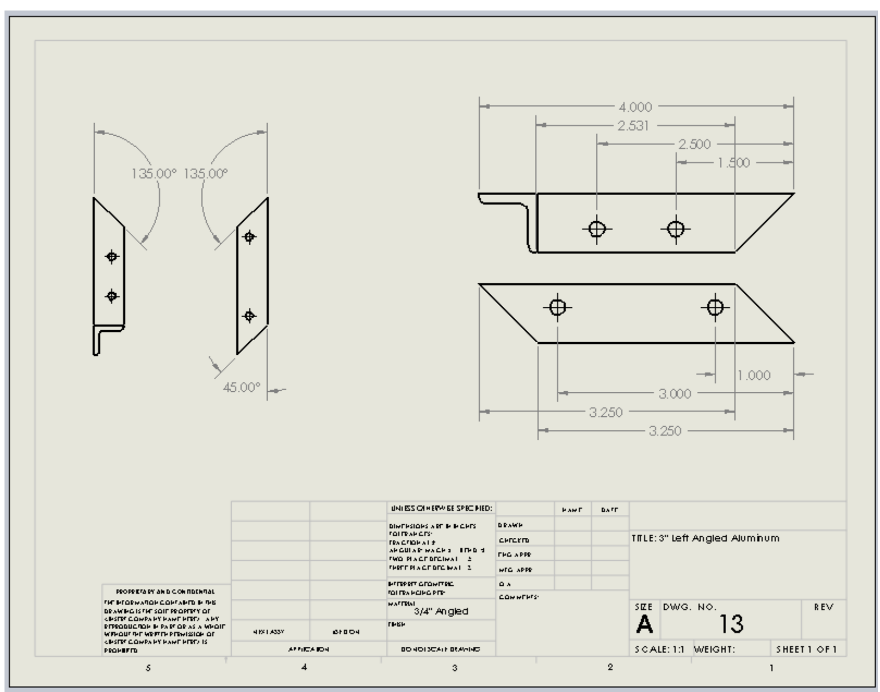
6” Angled Aluminum



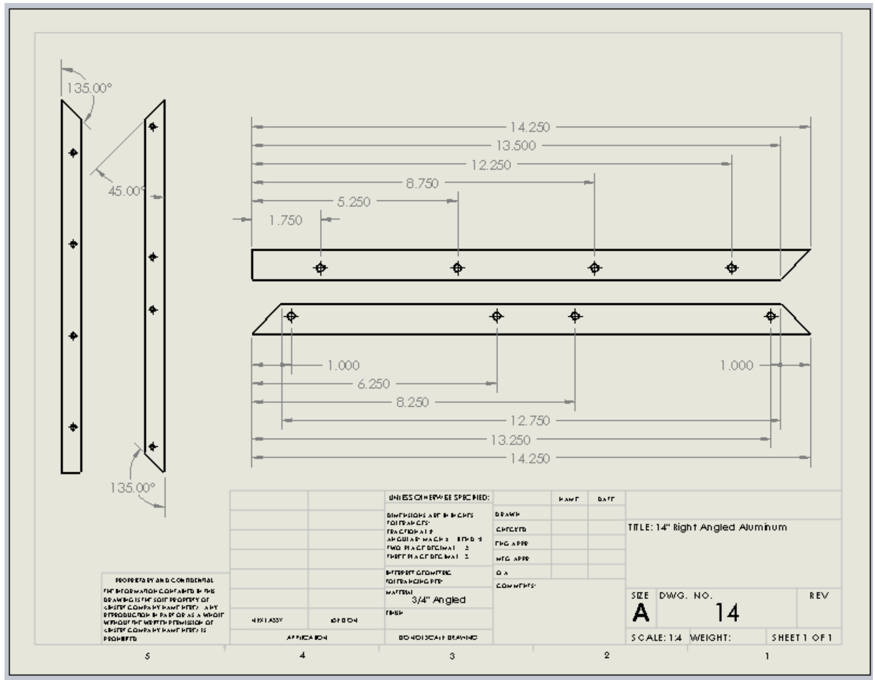
3” Right Angled Aluminum



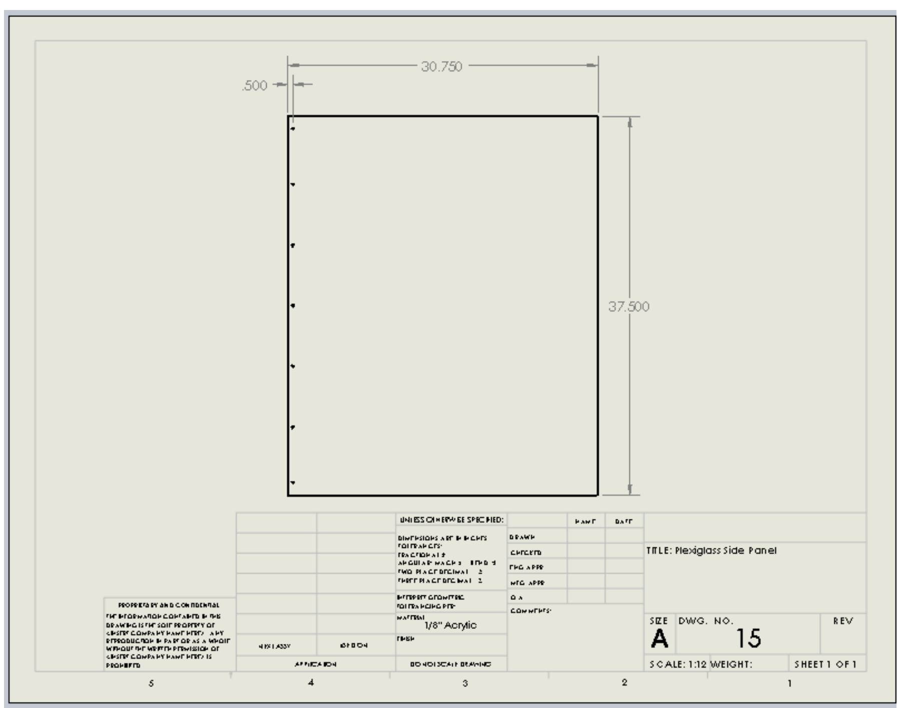
3” Left Angled Aluminum



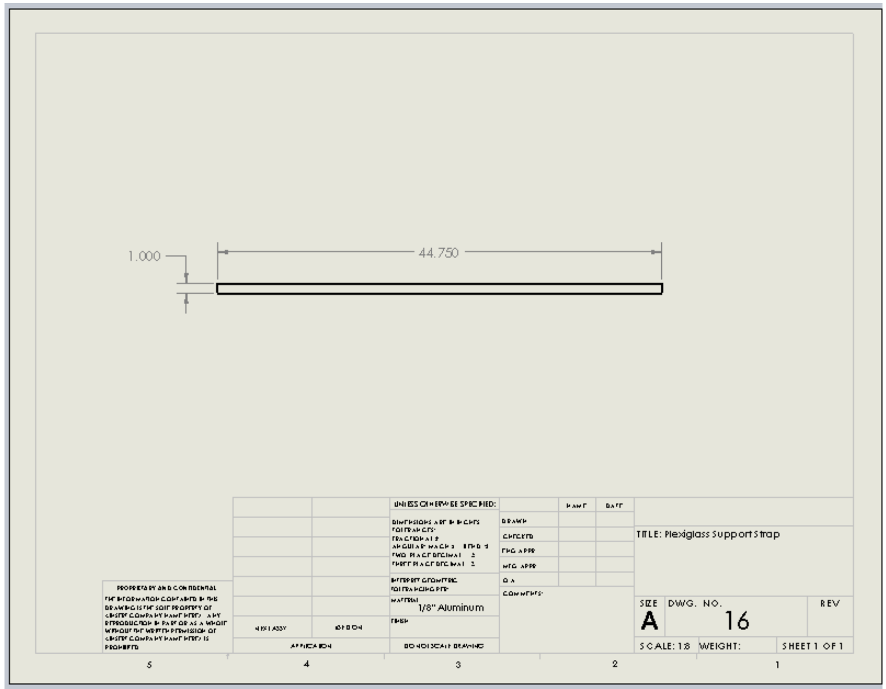
14” Right Angled Aluminum



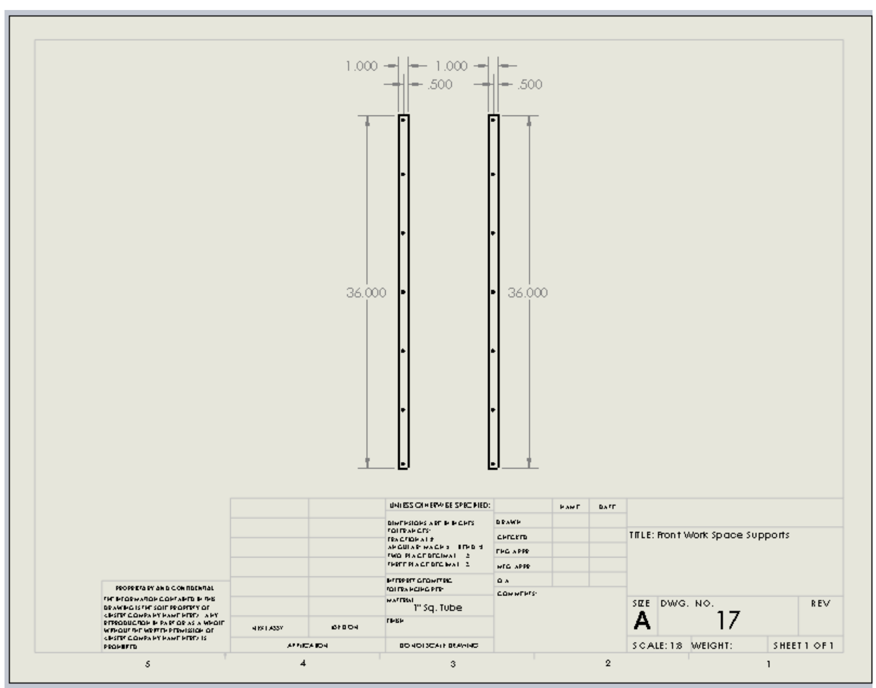
Acrylic Side Panel



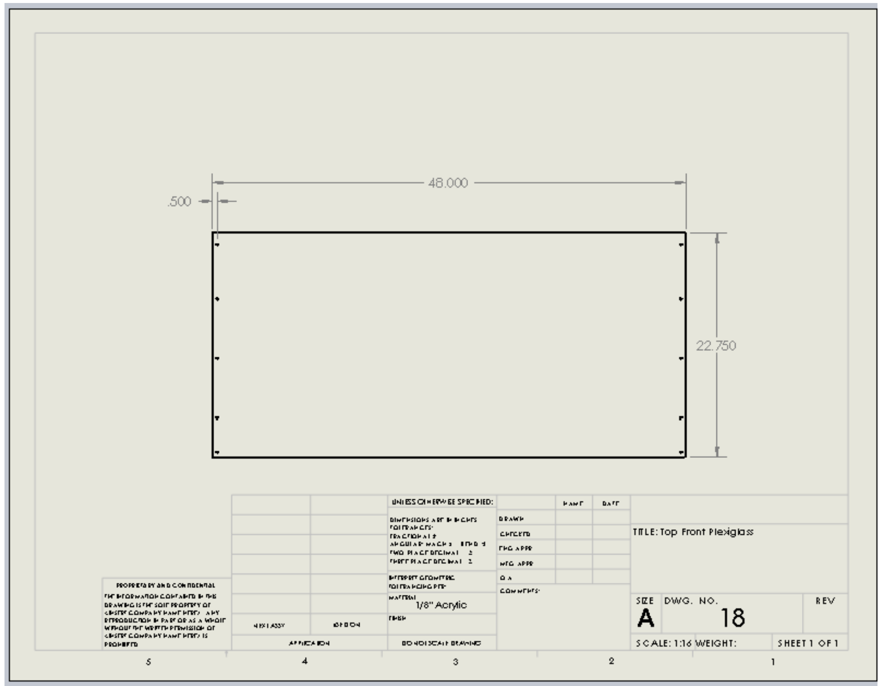
Acrylic Support Strap



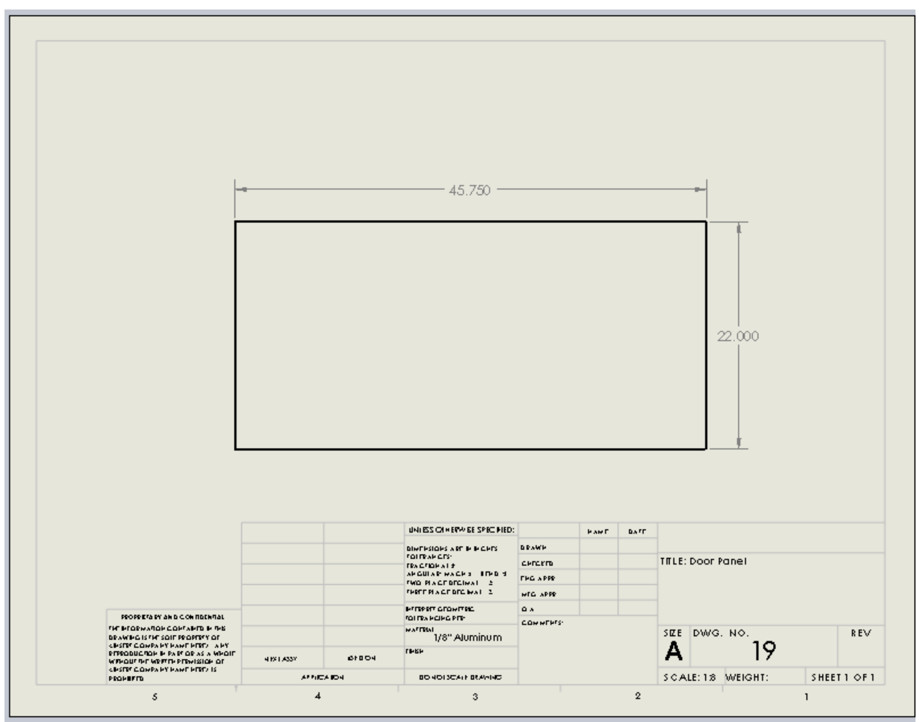
Front Work Space Supports



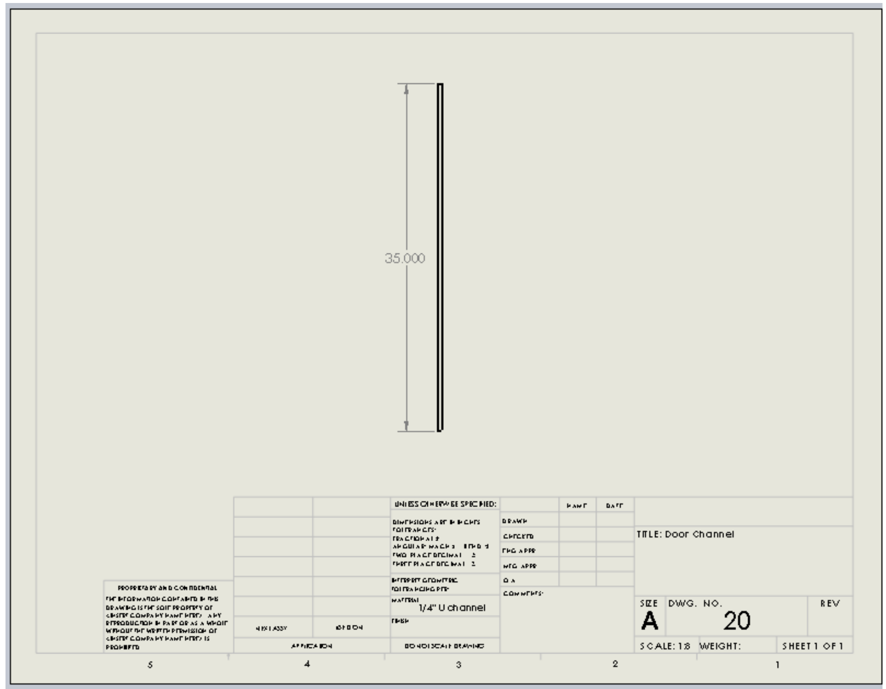
Top Front Acrylic Panel



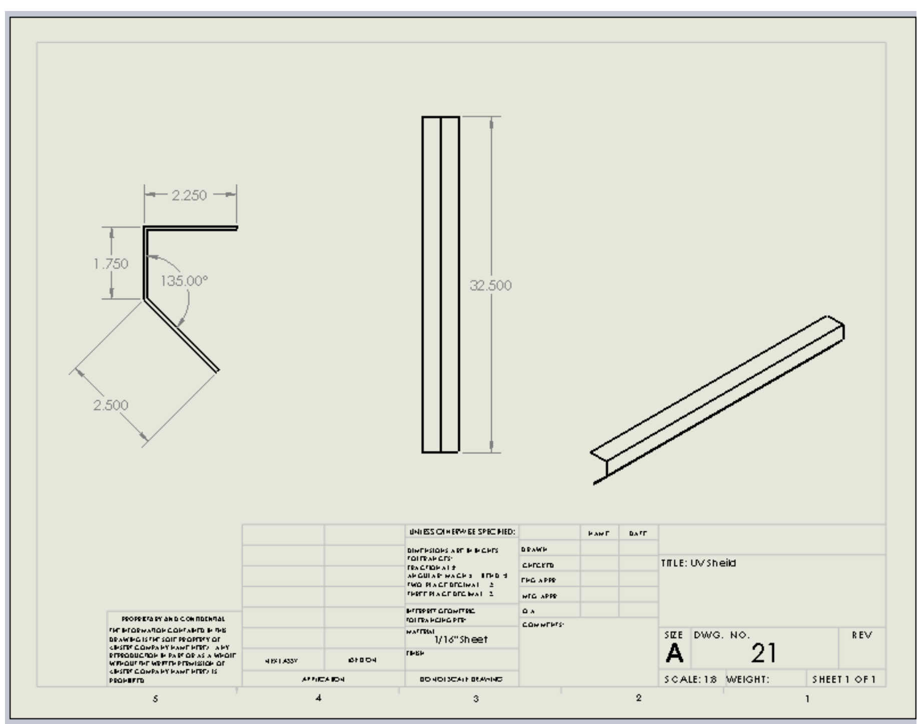
Acrylic Door Panel



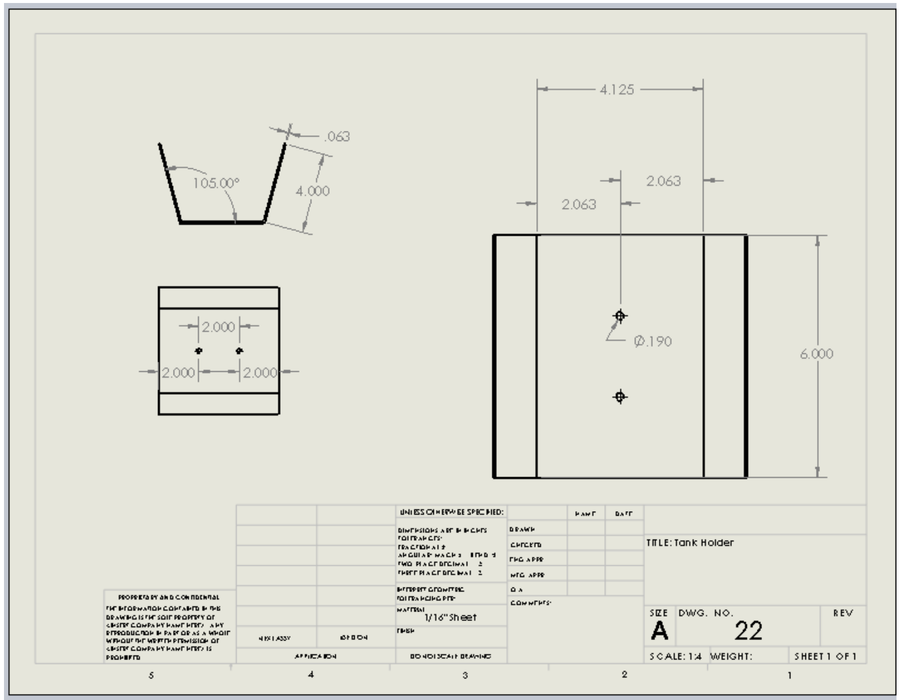
Door Channel



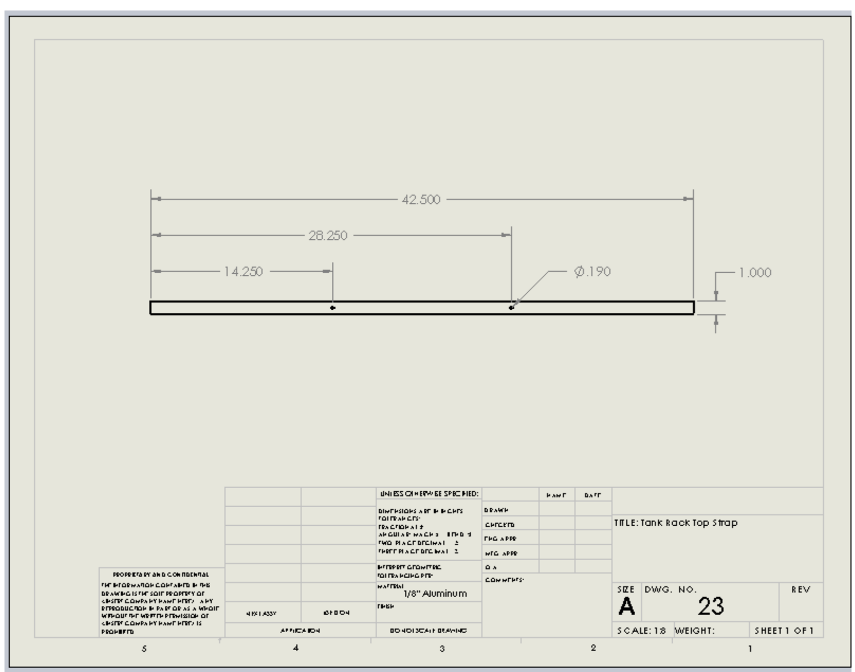
UV Shield



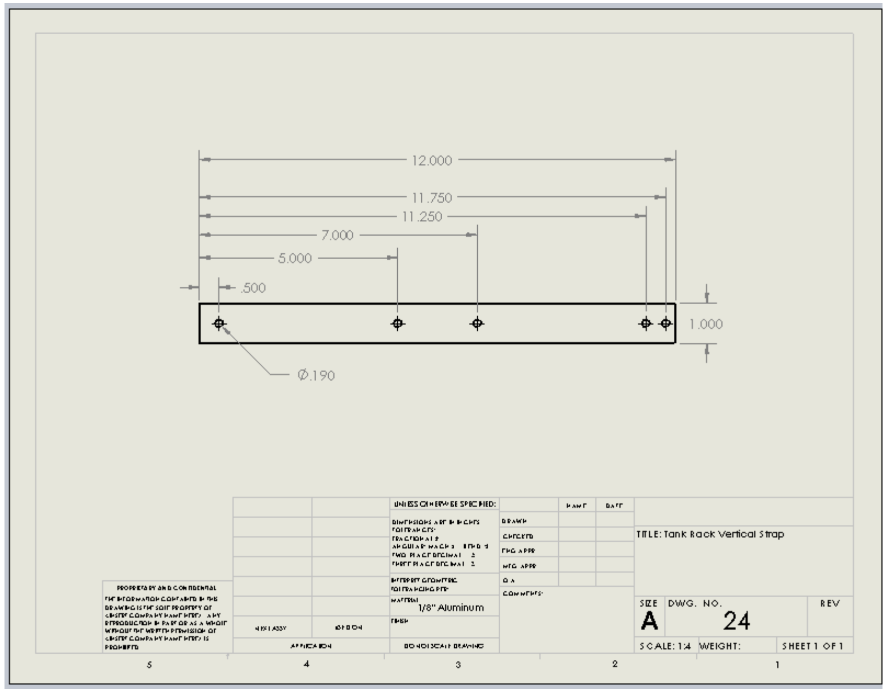
Tank Holder



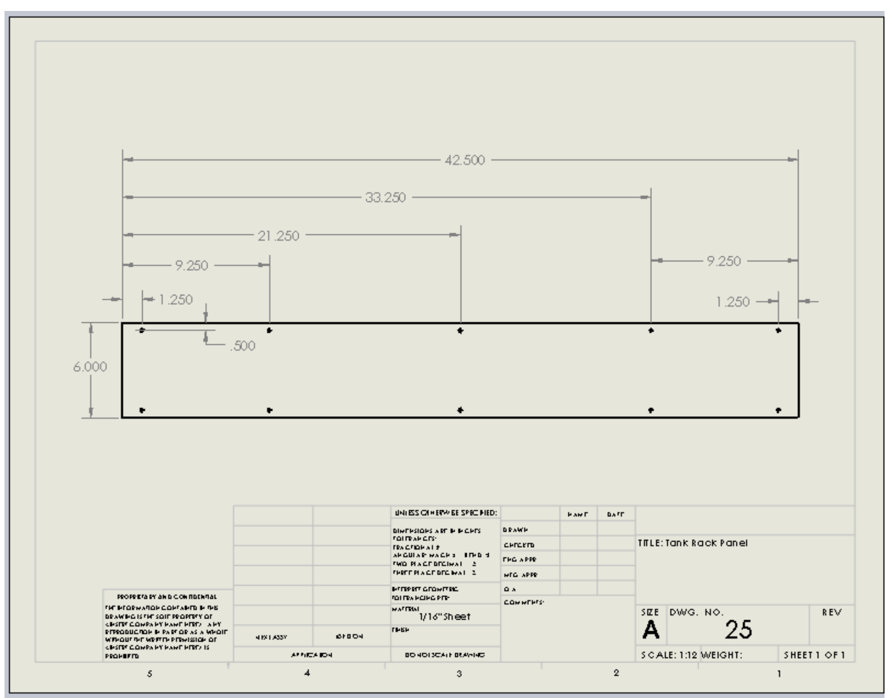
Tank Rack Top Strap



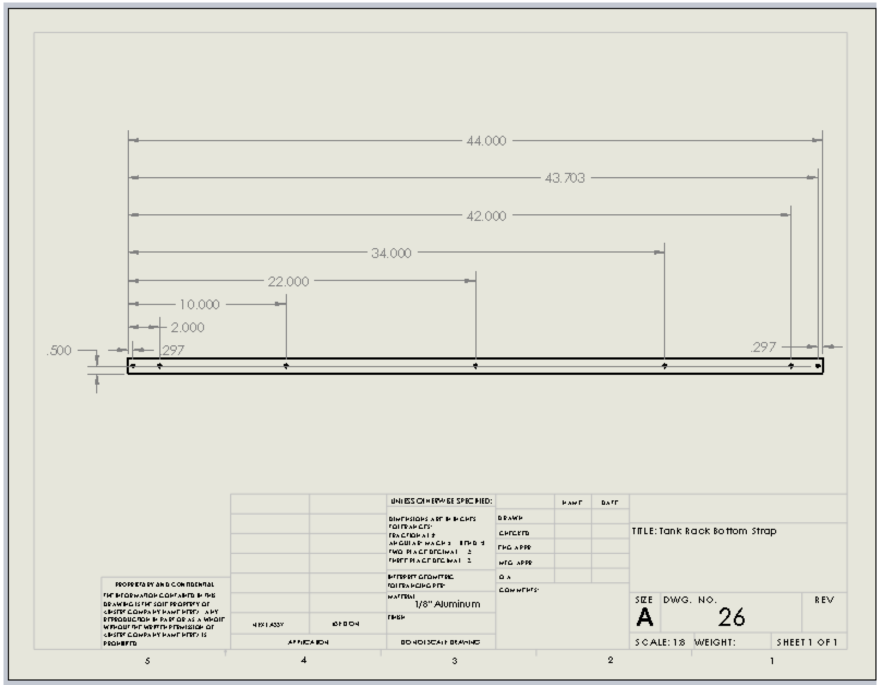
Tank Rack Vertical Strap



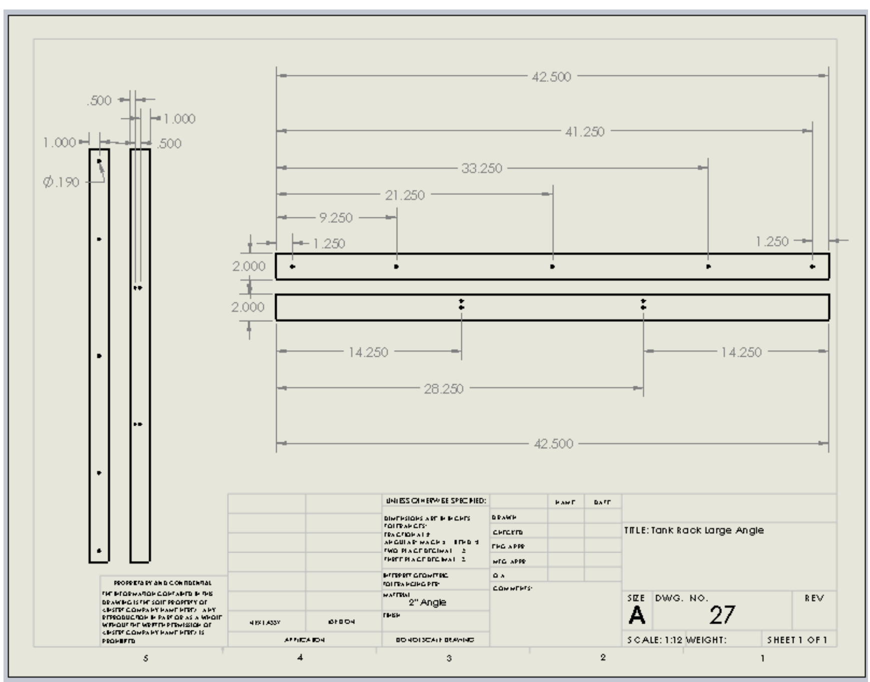
Tank Rack Panel



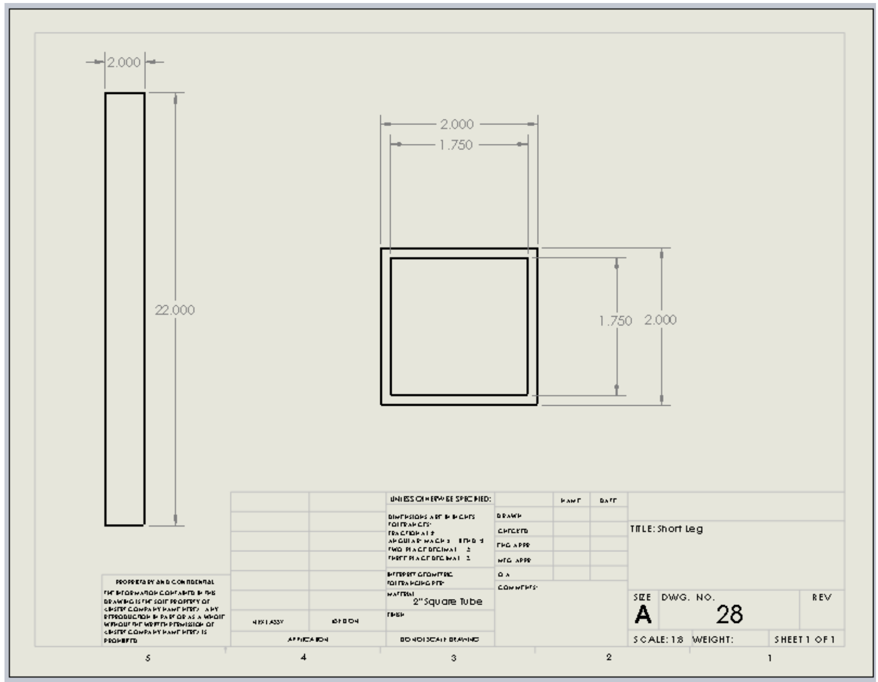
Tank Rack Bottom Strap



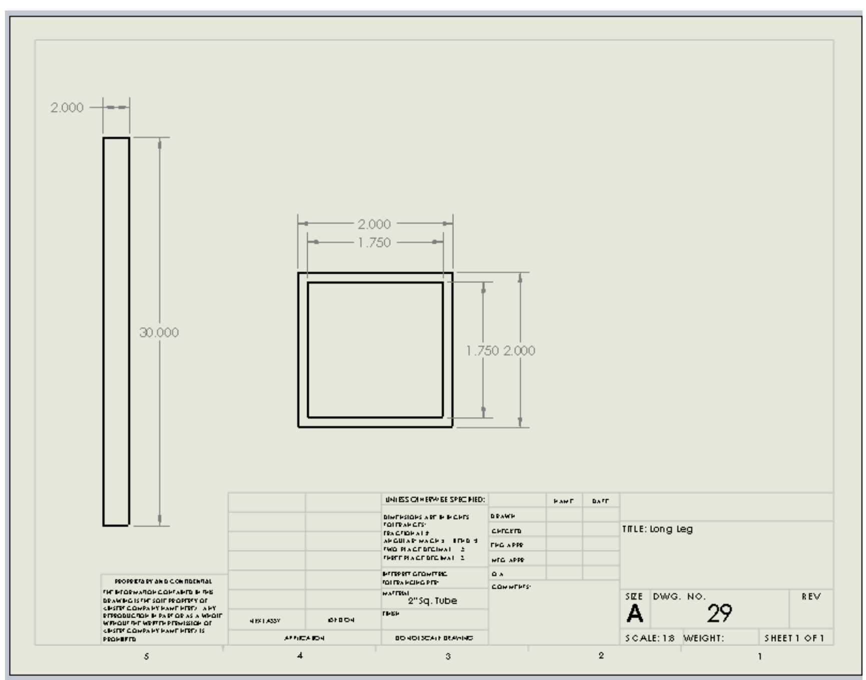
Tank Rack Large Angle Support



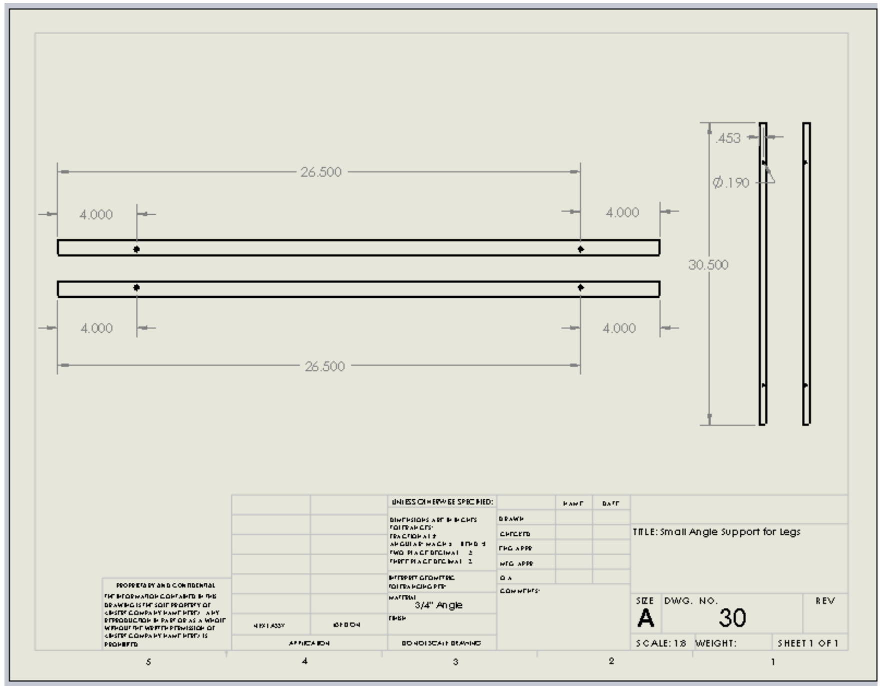
Short Leg



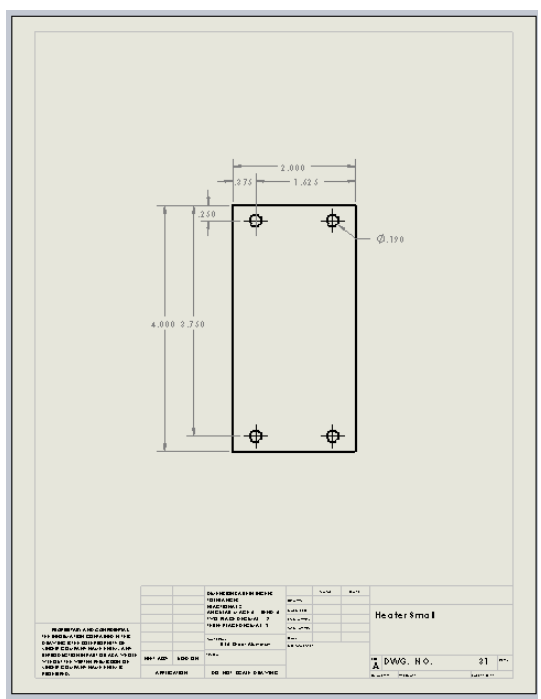
Long Leg



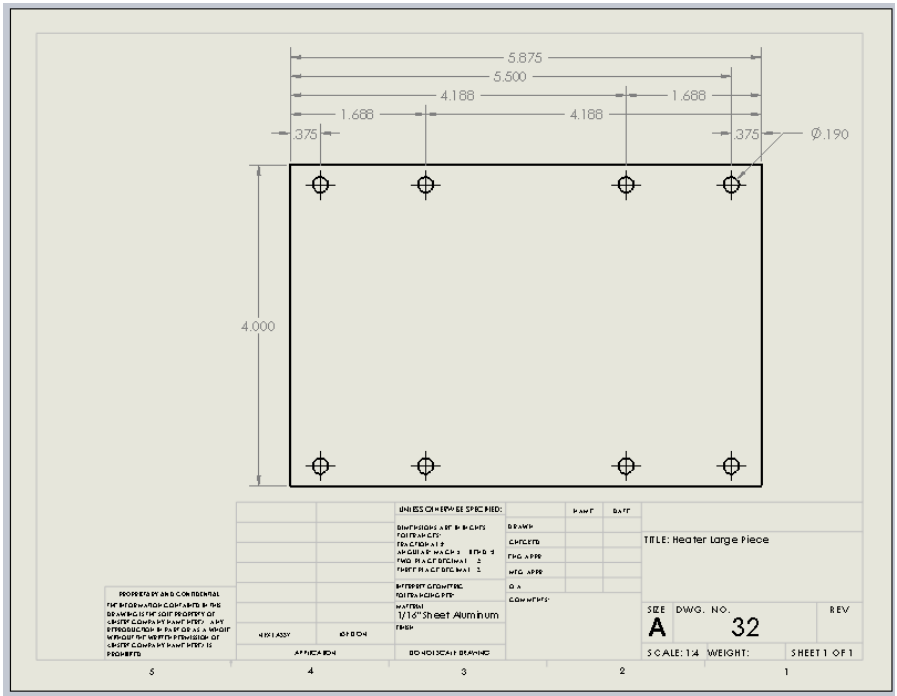
Small Angle Support for Legs



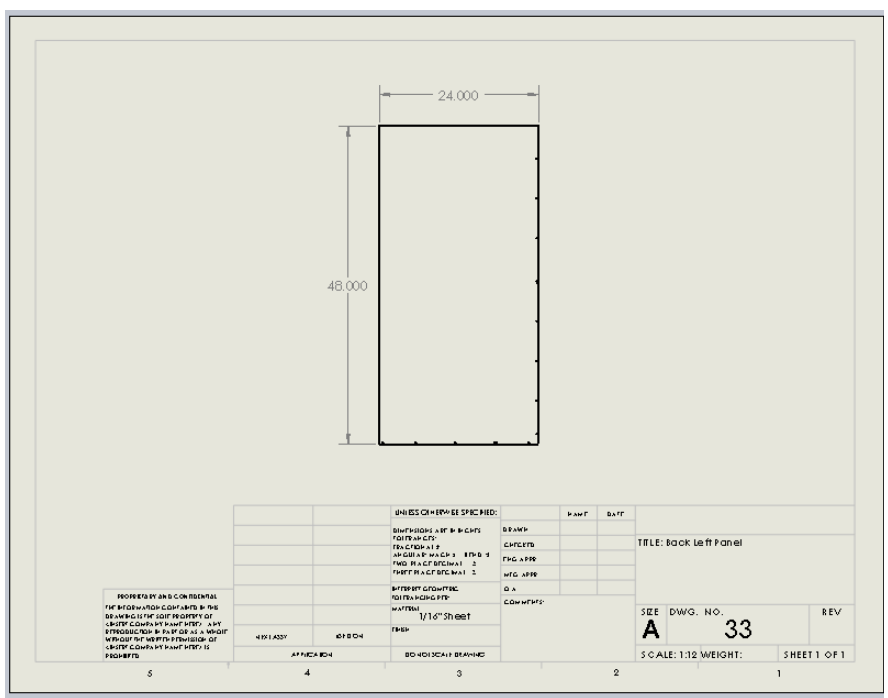
Heater Small Piece



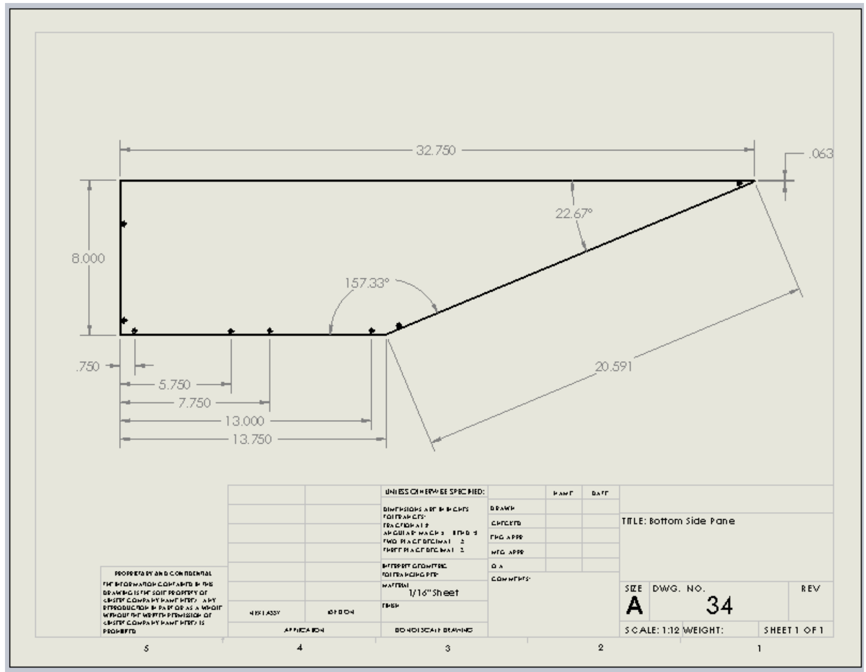
Heater Large Piece



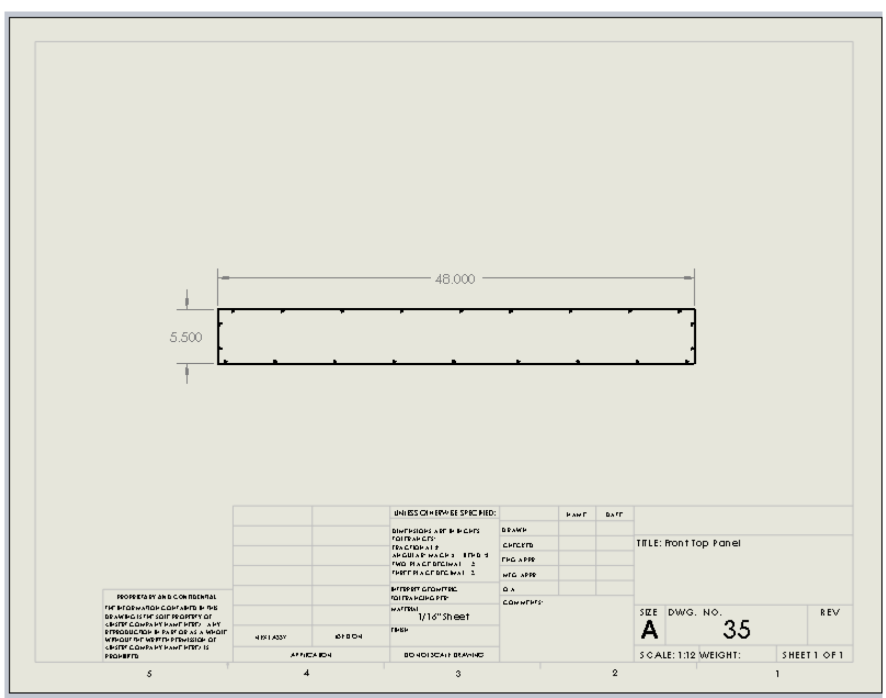
Back Left Panel



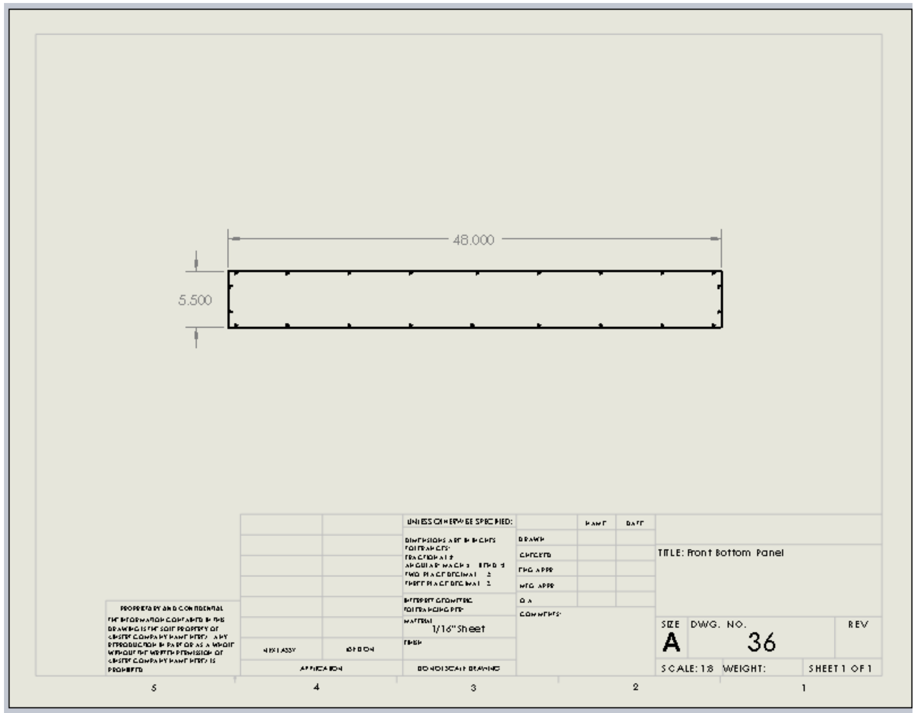
Bottom Side Panel



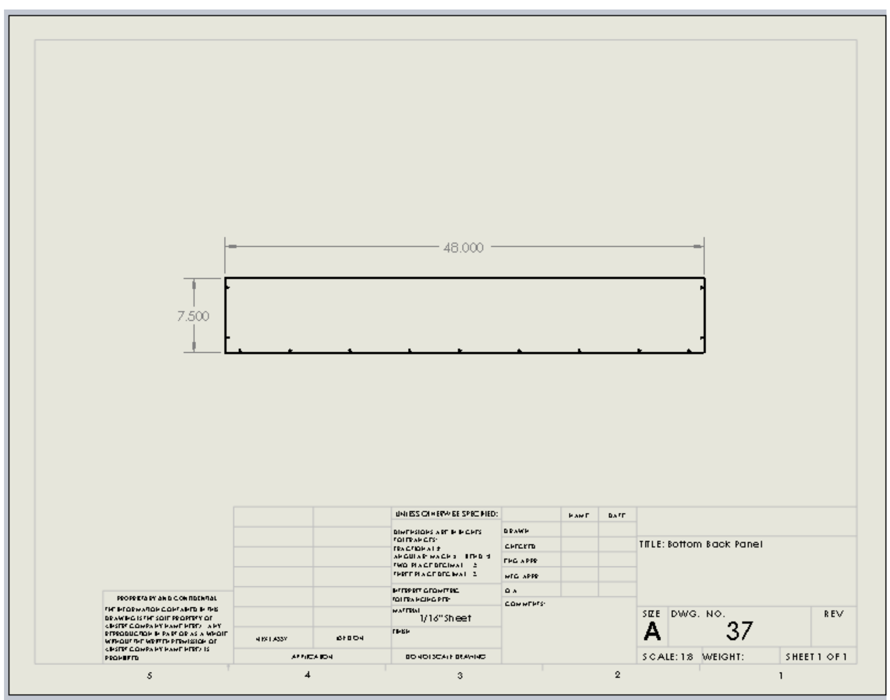
Front Top Panel



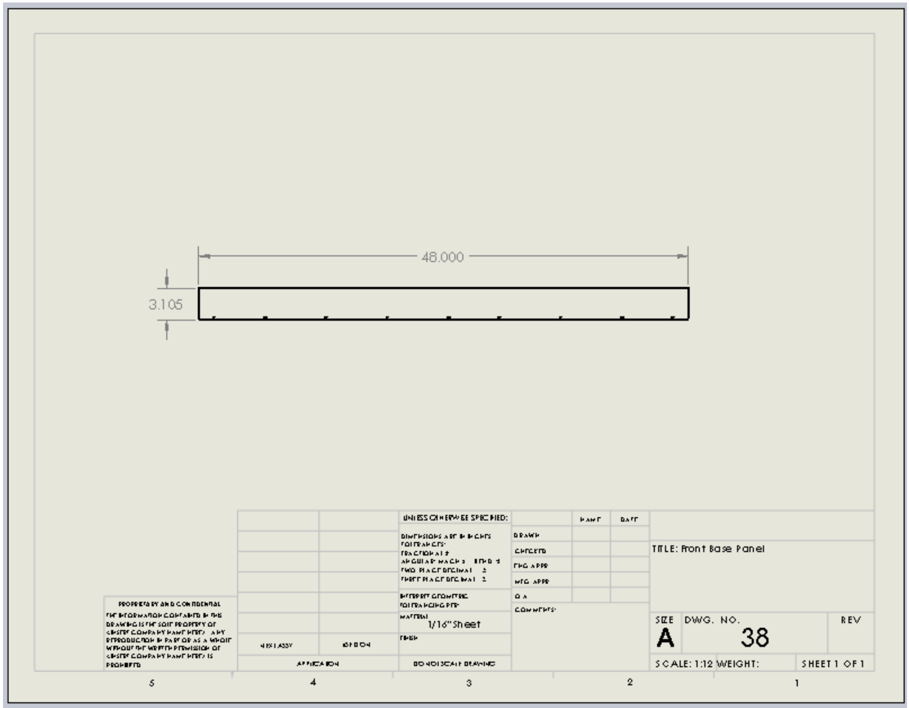
Front Bottom Panel



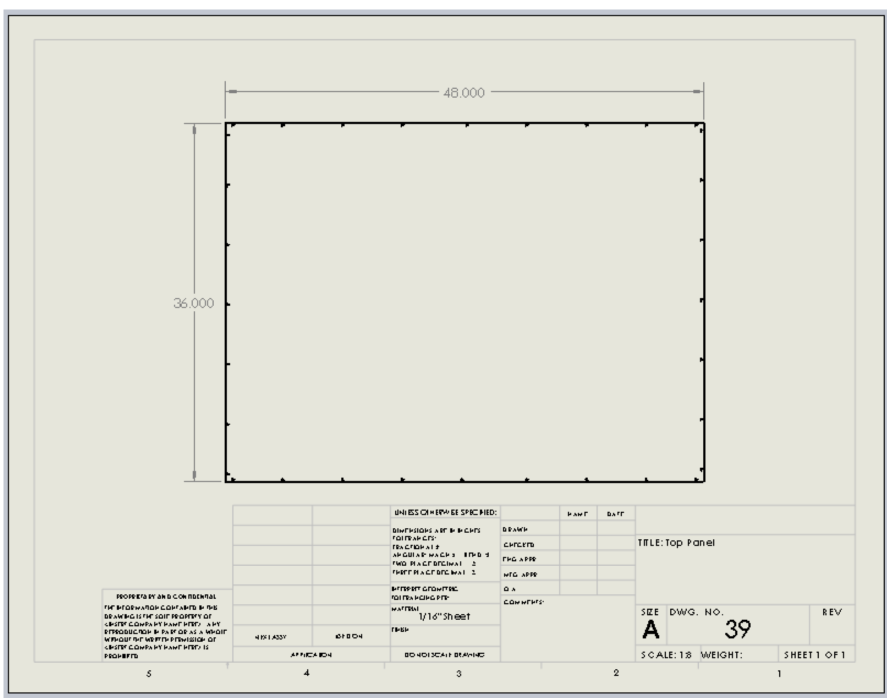
Bottom Back Panel



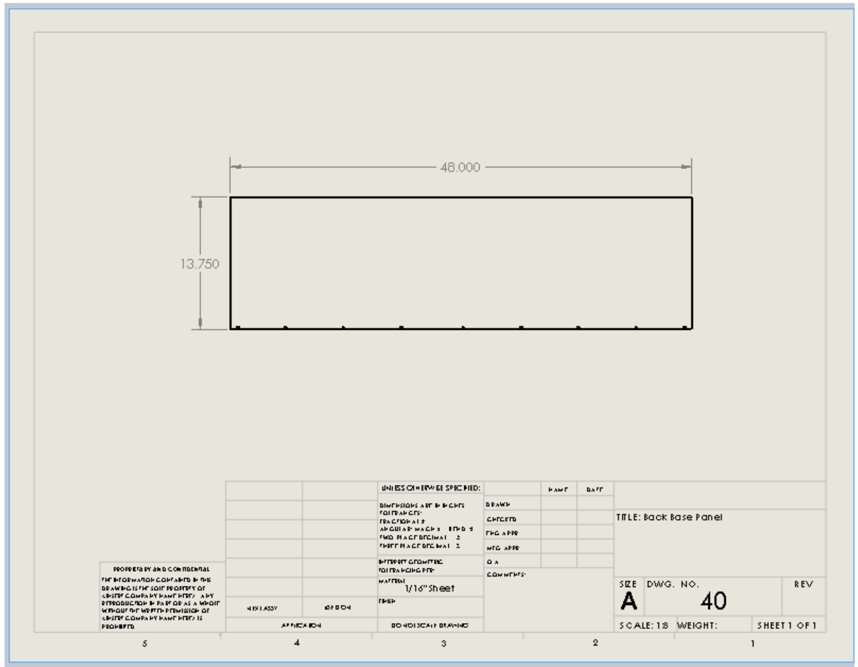
Front Base Panel



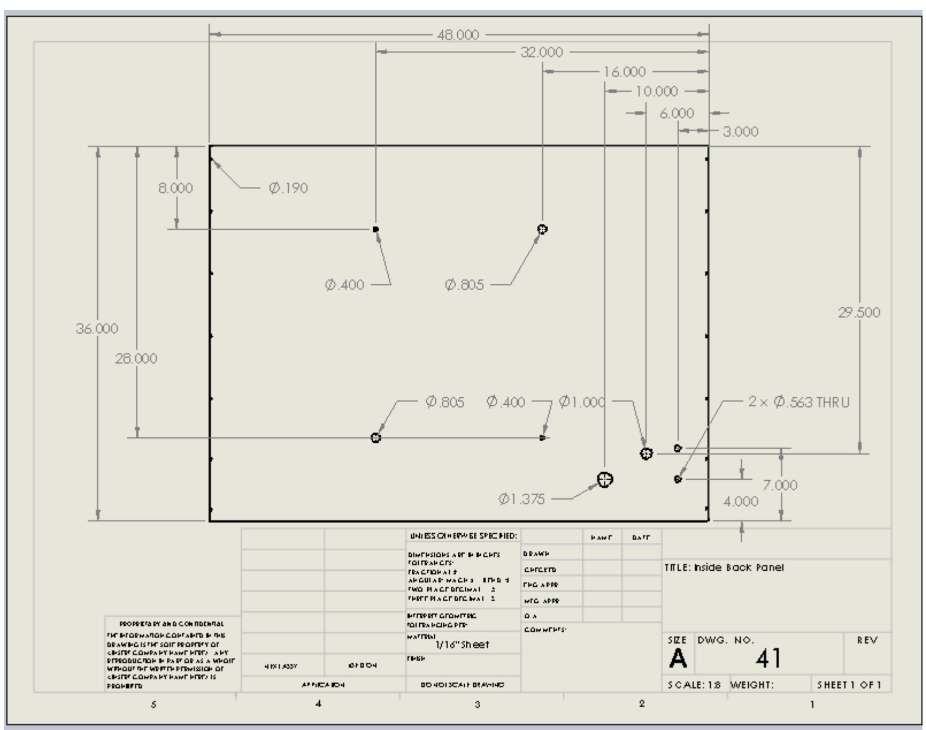
Top Panel



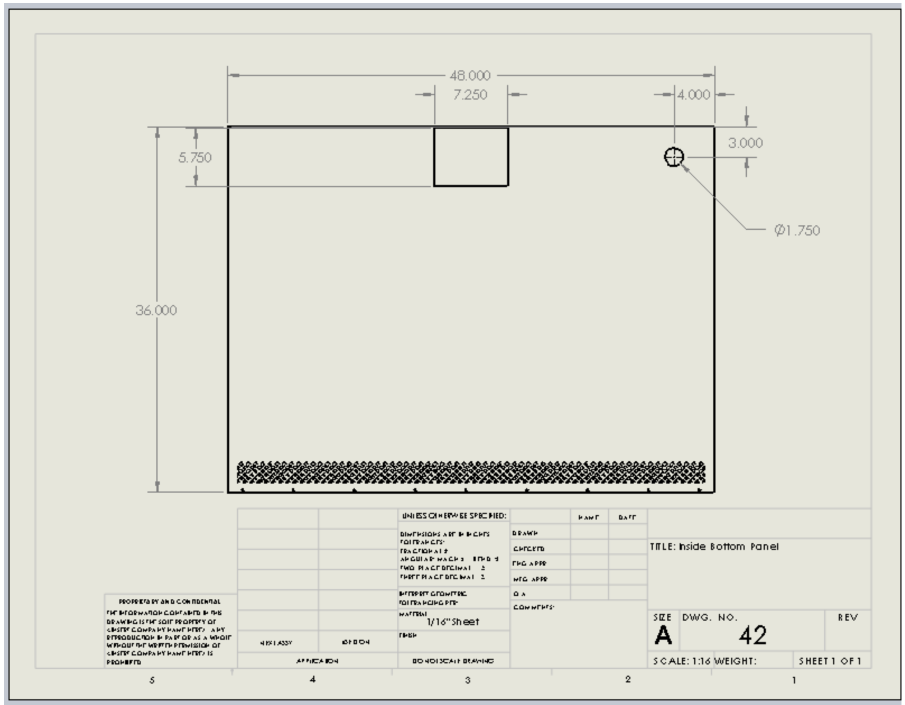
Back Base Panel



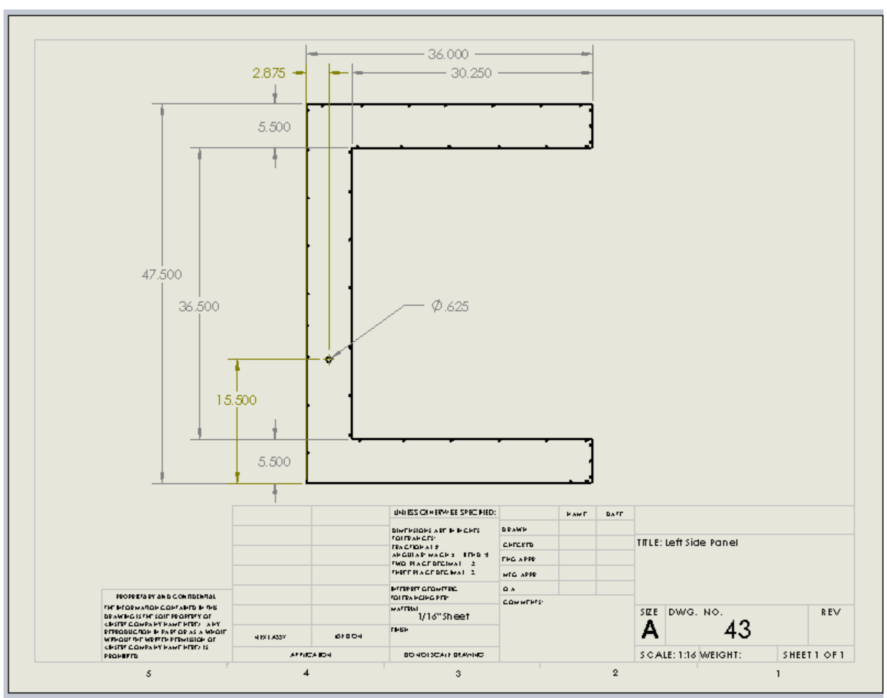
Back Work Space Panel



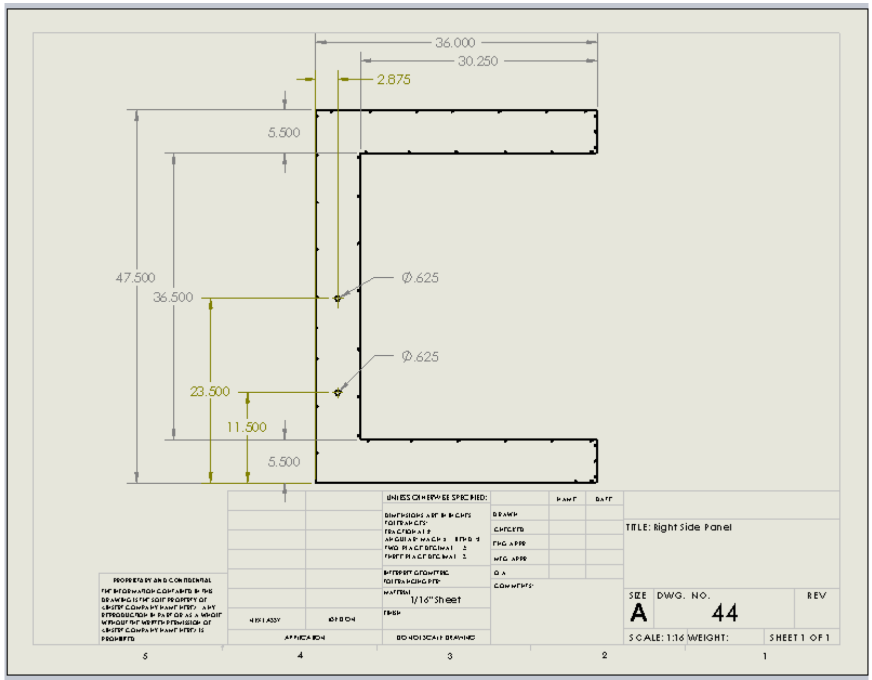
Work Surface Panel



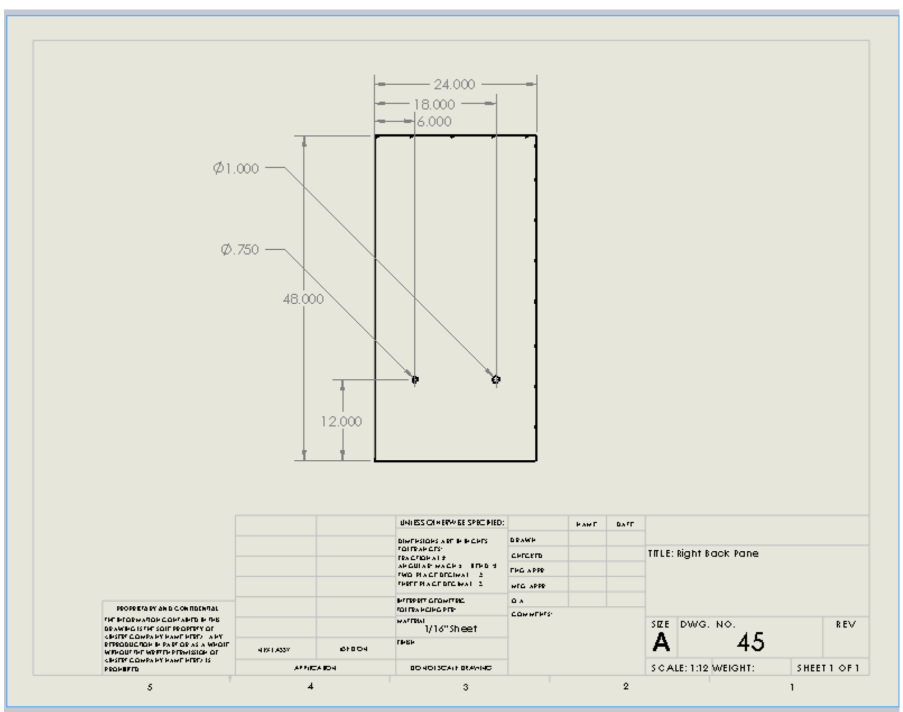
Left Side Panel



Right Side Panel



Right Back Panel



APPENDIX G

Cell Testing Protocol

Cell Viability Assessment of Tissue Engineering Hood

Goal: Compare the viability of cells housed in the Tissue Engineering Hood over a period of time to cells exposed to an uncontrolled environment and the standard of a cell culture incubator.

Equipment:

- 3 – T75 Flasks of 3T3 Fibroblast cells, approx. 20% confluent
- 1 – Inverted microscope w/ Camera
- Gloves
- 70% IPA
- Paper Towels
- Pipet-Aid
- 10 mL glass pipets
- 50 mL DCF-PBS
- 10 mL Trypsin
- 40 mL Media
- 3 – Hemocytometer
- Micropipet and tips

Protocol:

1. Receive 3 T75 flasks with containing 3T3 Fibroblasts that have been thawed and suspended in media and have had time to adhere to the flask. The flasks will be in the incubator.

2. Leave one flask in the incubator. Get a new pair of gloves and bring two flasks to room 331. Clean one flask with IPA and place into Tissue Engineering Hood. Place the other flask on the table, in the clear labeled area, marked biohazard, cleaned with IPA.

<u>Testing</u>

3. Every 2 hours, examine each flask under the inverted microscope and take a picture. Be sure to clean the stage and flask before examining.

4. Repeat until for a total duration of 48 hours. This can be amended based on results. End this phase of testing when cells kept on the bench top appear to all be dead.

<u>Trypan Blue Assesment</u>

5. Bring all flasks back to room 328. On bench top, repeat the steps 12 through 19 for each flask.

6. Aspirate of media, save for later.

7. Rinse with DCF-PBS.

8. Add 3 mL of trypsin, and wait for cells to detach.

9. Deactivate with 6 mL of media that was set aside and mix cell solution with pipet.

10. Remove 150 µL of cell solution and place in microcentrifuge tube.

11. Add 50 µL of Trypan Blue to the centrifuge tube. Cap tightly and mix by flicking.

12. Remove 10 µL and inject them into a hemocytometer. Place Hemocytometer on cleaned inverted microscope.

13. Count the number of cells, the number live cells (clear), and the number of dead (blue) in each of the square regions. Record these numbers as well as images of each area.

Clean up

14. Discard anything that touched cells in the Biohazard waste. This being, all pipet tips, flasks, hemocytometers, microcentrifuge tubes, and centrifuge tube.

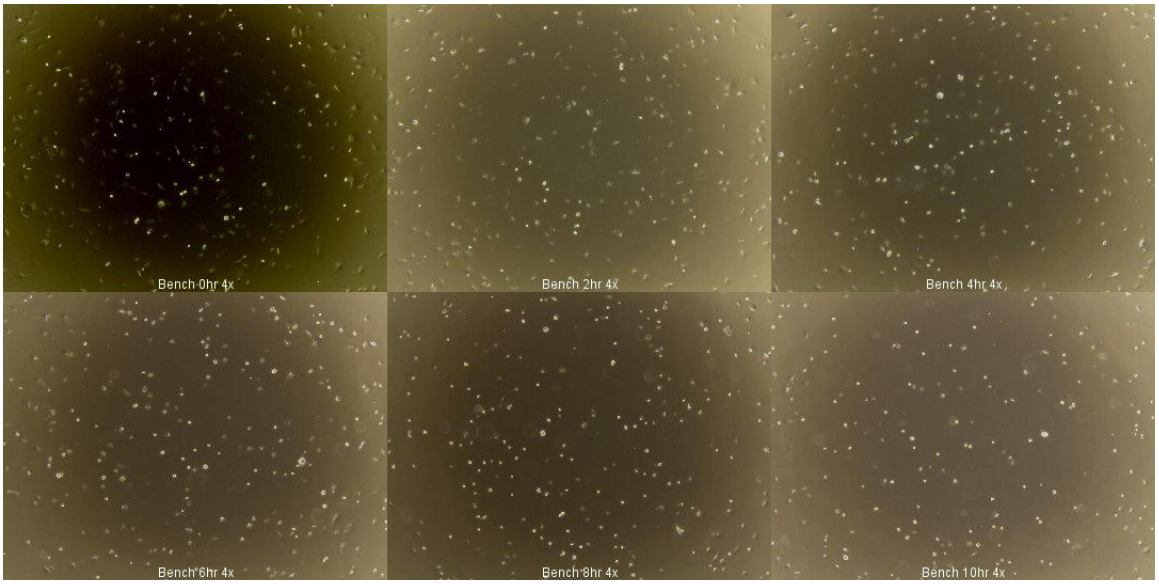
15. Clean all bench top work areas with IPA as well as the microscope stage.

16. Throw all other trash in the garbage. No liquids should go down the sink.

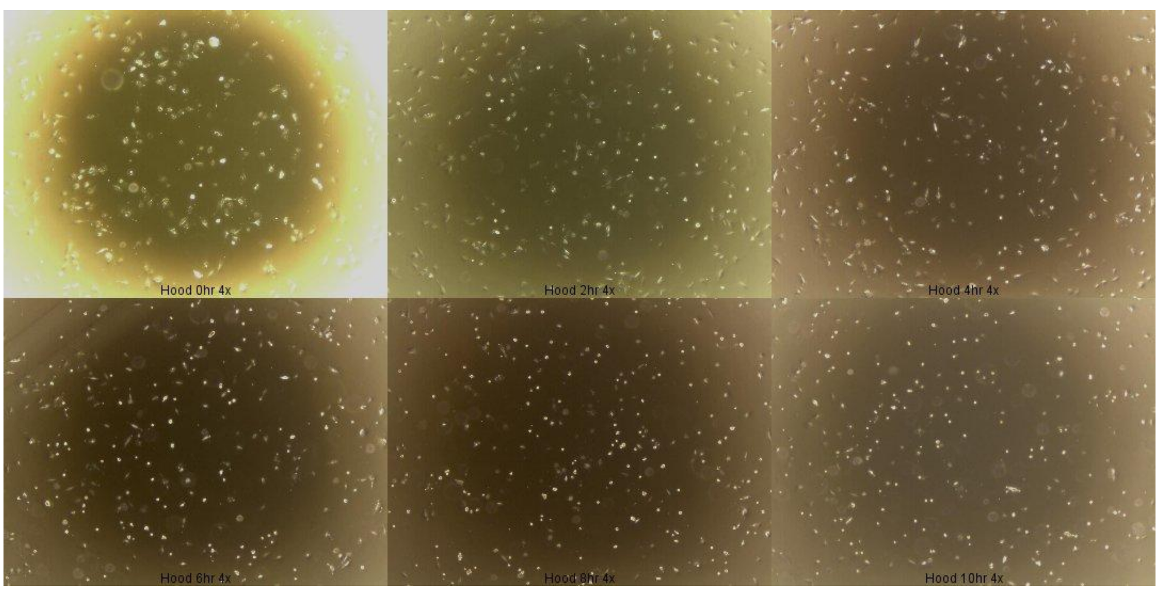
APPENDIX H

Cell Testing Images

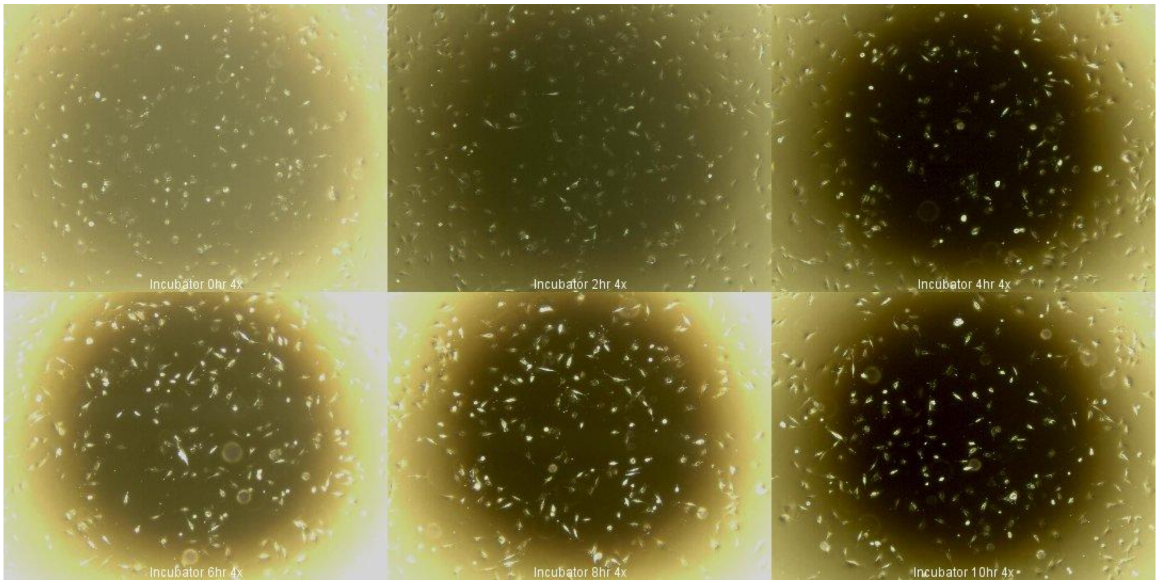
Bench Top Group Viability over Time Montage



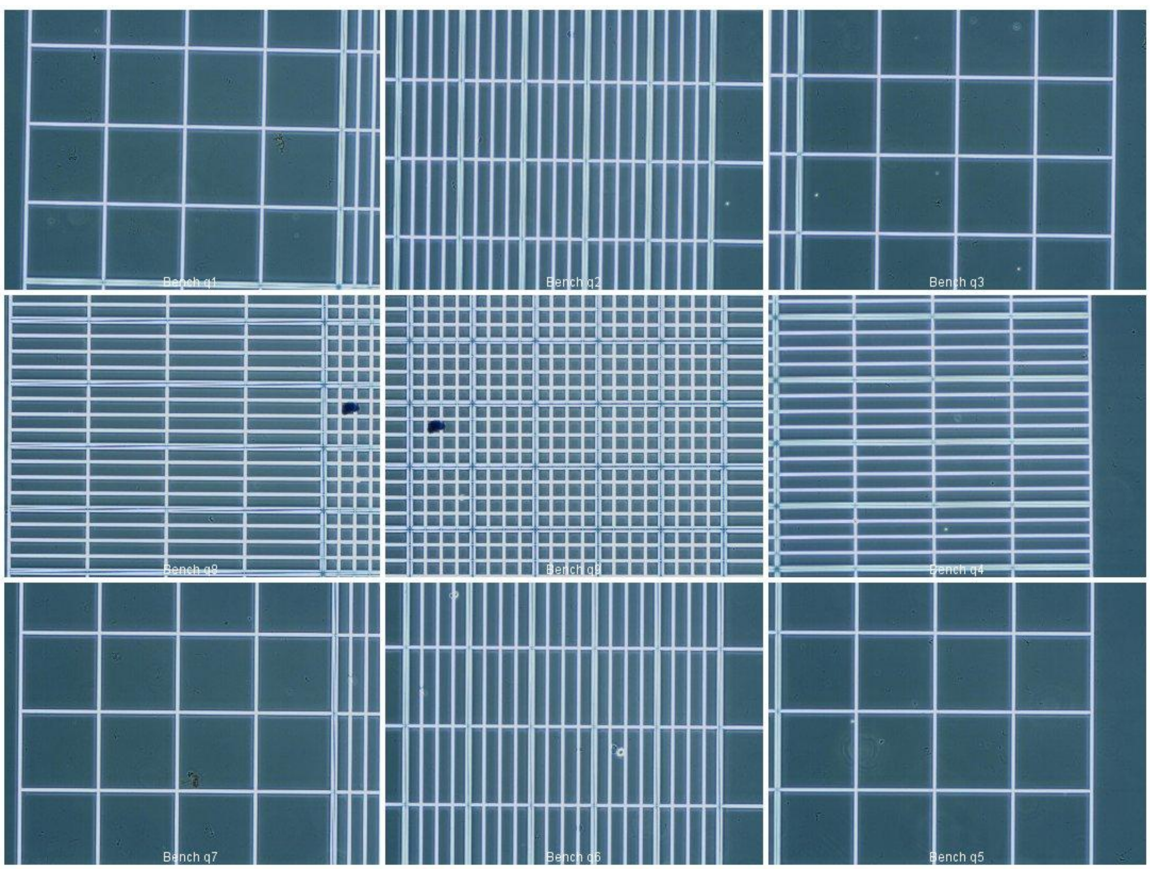
Tissue Engineering Hood Group Viability over Time Montage



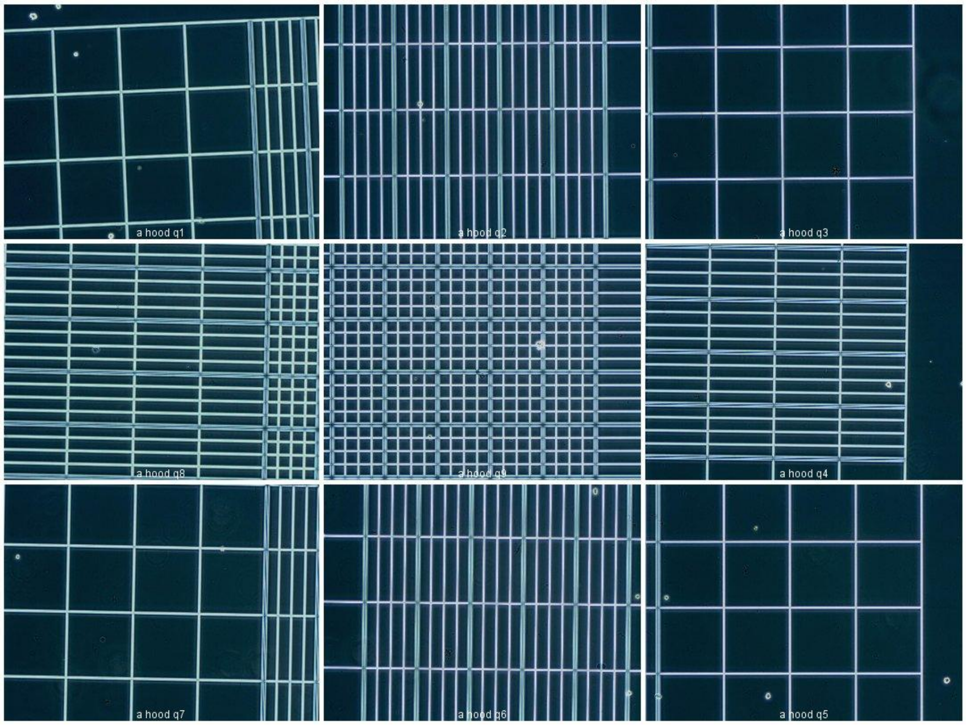
Incubator Group Viability over Time Montage



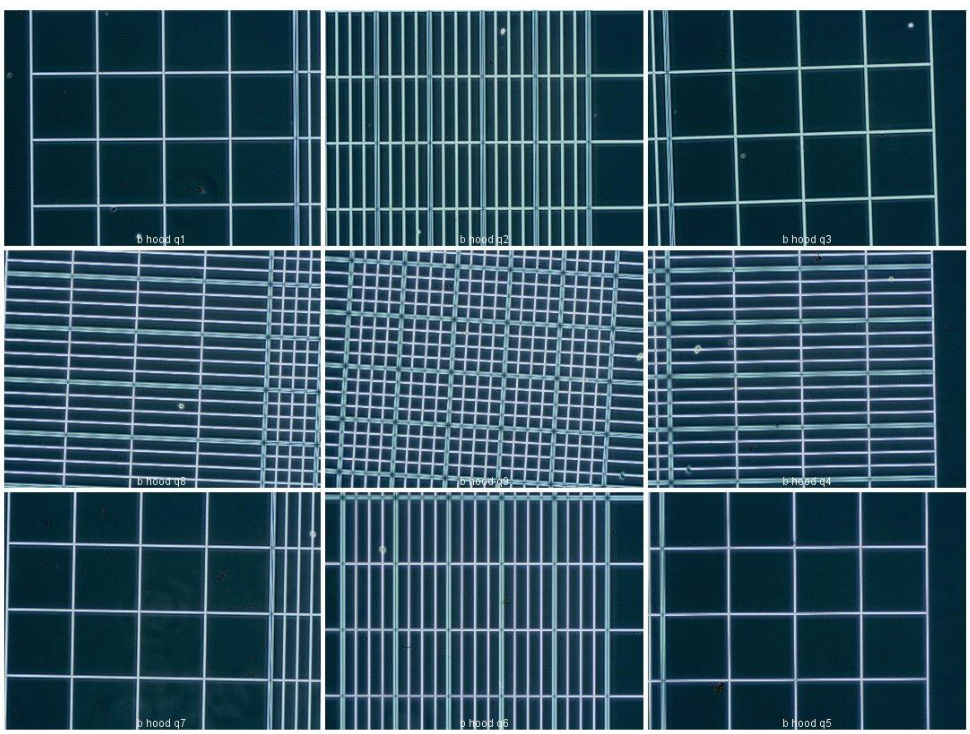
Trypan Blue Assessment of Bench Top Group Montage



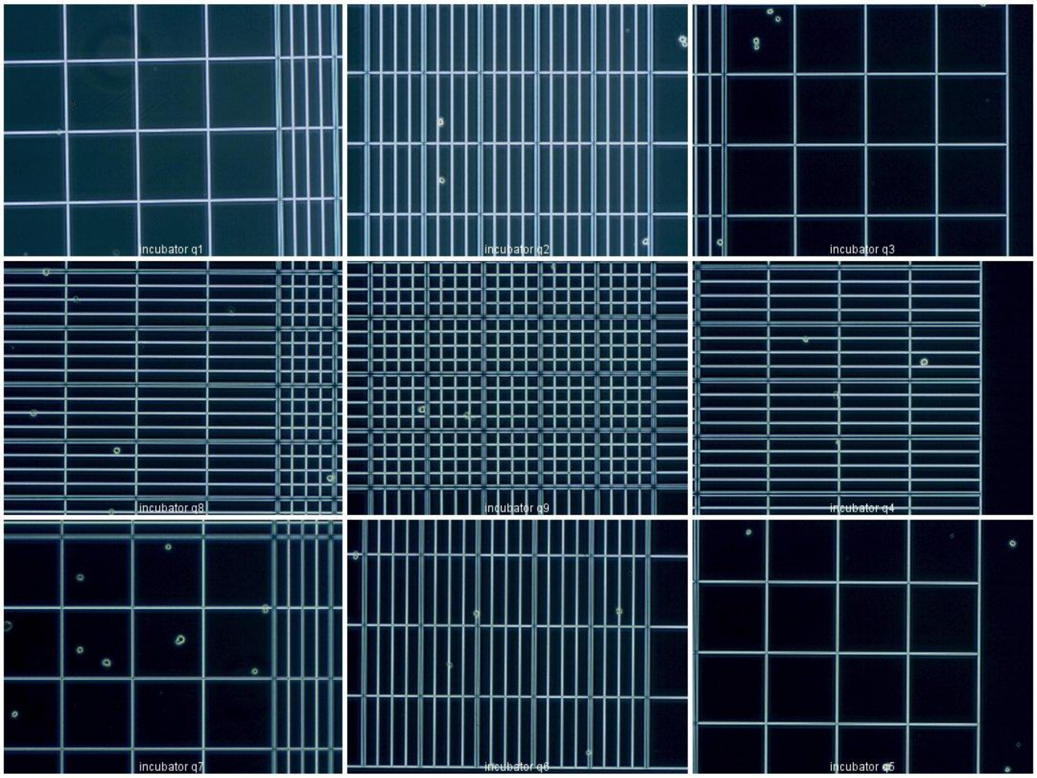
Trypan Blue Assessment of Tissue Engineering Hood Group A Montage



Trypan Blue Assessment of Tissue Engineering Hood Group B Montage



Trypan Blue Assessment of Incubator Group Montage



APPENDIX I

Data Sheets

Temp sensor

Low Voltage Temperature Sensors

TMP35/TMP36/TMP37

FEATURES

Low voltage operation (2.7 V to 5.5 V)
Calibrated directly in °C
10 mV/°C scale factor (20 mV/°C on TMP37)
±2°C accuracy over temperature (typ)
±0.5°C linearity (typ)
Stable with large capacitive loads
Specified −40°C to +125°C, operation to +150°C
Less than 50 μA quiescent current
Shutdown current 0.5 μA max
Low self-heating
Qualified for automotive applications

APPLICATIONS

Environmental control systems
Thermal protection
Industrial process control
Fire alarms
Power system monitors
CPU thermal management

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/ TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.

The low output impedance of the TMP35/TMP36/TMP37 and its linear output and precise calibration simplify interfacing to temperature control circuitry and ADCs. All three devices are intended for single-supply operation from 2.7 V to 5.5 V maximum. The supply current runs well below 50 μA, providing very low self-heating—less than 0.1°C in still air. In addition, a shutdown function is provided to cut the supply current to less than 0.5 μA.

The TMP35 is functionally compatible with the LM35/LM45 and provides a 250 mV output at 25°C. The TMP35 reads temperatures from 10°C to 125°C. The TMP36 is specified from −40°C to +125°C, provides a 750 mV output at 25°C, and operates to 125°C from a single 2.7 V supply. The TMP36 is functionally compatible with the LM50. Both the TMP35 and TMP36 have an output scale factor of 10 mV/°C.

FUNCTIONAL BLOCK DIAGRAM

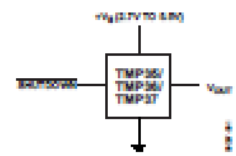


Figure 1.

PIN CONFIGURATIONS

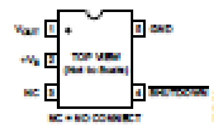


Figure 2. RJ-5 (SOT-23)

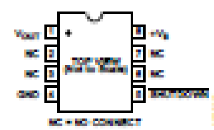


Figure 3. R-8 (SOIC_N)

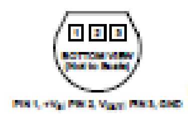


Figure 4. T-3 (TO-92)

The TMP37 is intended for applications over the range of 5°C to 100°C and provides an output scale factor of 20 mV/°C. The TMP37 provides a 500 mV output at 25°C. Operation extends to 150°C with reduced accuracy for all devices when operating from a 5 V supply.

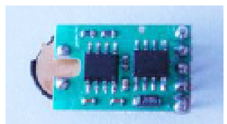
The TMP35/TMP36/TMP37 are available in low cost 3-lead TO-92, 8-lead SOIC_N, and 5-lead SOT-23 surface-mount packages.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113

Hope RF **HH10D**

HUMIDITY SENSOR MODULE

2010-5-31 PRELIMINARY Version: 2.0



- Relative humidity sensor
- Two point calibrated with capacitor type sensor, excellent performance
- Frequency output type, can be easily integrated with user application system
- Very low power consumption
- No extra components needed

Summary

The HH10D relative humidity sensor module is comprised with a capacitive type humidity sensor, a CMOS capacitor to frequency converter and an EEPROM used to holding the calibration factors. Due to the characteristics of capacitor type humidity sensor, the system can respond to humidity change very fast. Each sensor is calibrated twice at two different accurate humidity chambers, two unique sensor related coefficients are stored onto the EEPROM on the module. The data is used for humidity calculation.

FEATURES

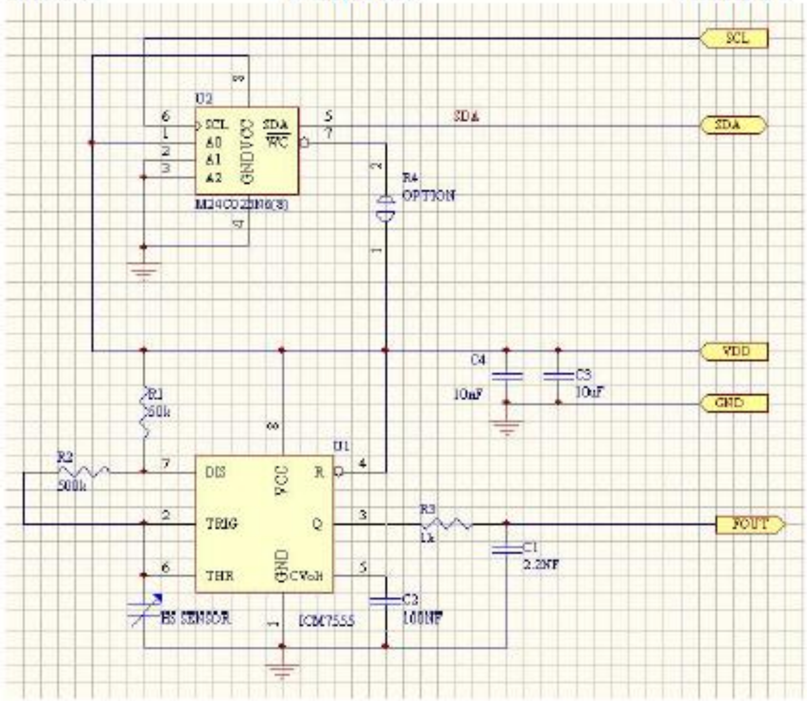
- Relative humidity sensor
- Two point calibrated with capacitor type sensor, excellent performance
- Frequency output type, can be easily integrated with user application system
- Very low power consumption
- No extra components needed

Applications

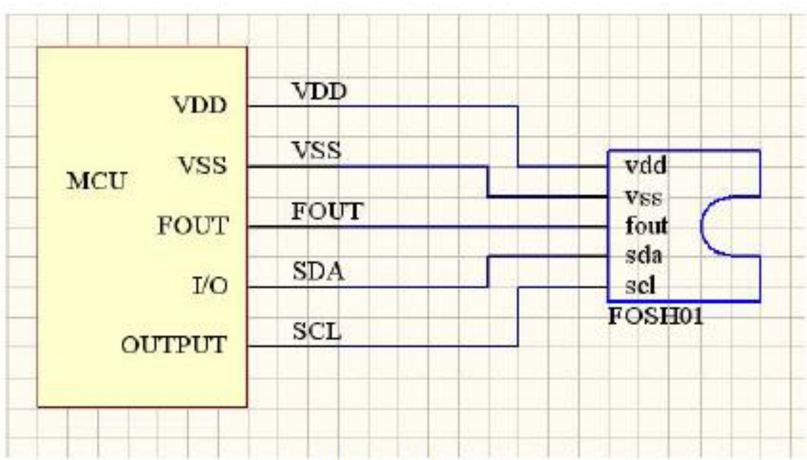
- HVAC
- Consumer Goods
- Dehumidifiers
- Test & measurement
- Automation
- Automotive
- Weather Stations
- Humidifiers
- Data Logging
- White Goods- Medical

Tel: +86-755-82973805 Fax: +86-755-82973550 E-mail: sales@hoperf.com http://www.hoperf.com

HUMIDITY SENSOR MODULE



Circuit Diagram



Application Circuit

Tel: +86-755-82973805 Fax: +86-755-82973550 E-mail: sales@hoperf.com http://www.hoperf.com

HUMIDITY SENSOR MODULE

2010-5-31 PRELIMINARY Version: 2.0

Sensor Performance Specification

Parameters	Conditions	Min	Typ	Max	Units
Resolution		0. 3	0. 08	0. 05	%
Accuracy			3		%
Repeatability		-0. 3		0. 3	%
Uncertainty			2		%
Range		0		99	%
Response Time			8		S
Hysteris			1		%
Long Term Stability		-0. 5		0. 5	%
Interchangeability		Fully Interchangeable			

HH10D Humidity Module Characteristic

Parameter	min	nominal	max	unit
humidity range	1		99	%
accuraccy	-3		+3	%
temperature range	-10		+60	C
working voltage	2. 7	3	3. 3	V
stability versus time		1%		per year
power consumption	120	150	180	uA
Output Frequency Range	5. 0	6. 5	10	KHZ

Calculation

In order to read out the correct humidity, 4 calibration factors need to be read out from the EEPROM at address of 10 and 11,12 and 13 for sensitivity, offset.

Once the frequency output from the sensor is measured, then the correct humidity value can be calculated in the following method:

HH10D Humidity Calculation Algorithm

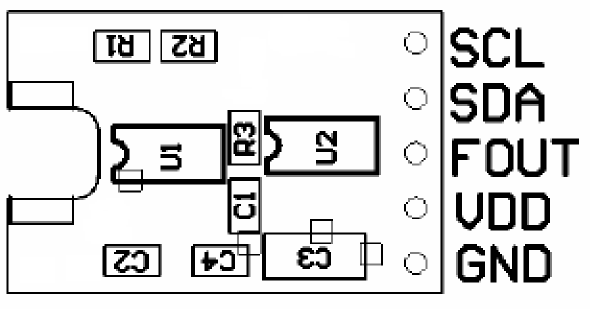
Data Definition		eeprom address
sensitivity	Sens(2byte value)	10
Offset	2 byte value	12
RH(%)=	(offset-Soh)*sens/2^12	

* RH(%) linear humidity value
* RH_corr temperature compensated humidity value
* Soh is the measured frequency value at Fout port

- the eeprom physical address is fixed to 01.

Tel: +86-755-82973805 Fax: +86-755-82973550 E-mail: sales@hoperf.com http://www.hoperf.com

Module PCB Layout:



L：24mm
W：8mm
Pin Pitch：2.54mm

HOPE MICROELECTRONICS CO.,LTD
Add:4/F, Block B3, East Industrial Area, Huaqiaocheng, Shenzhen, Guangdong, China
Tel: 86-755-82973805
Fax: 86-755-82973550
Email: sales@hoperf.com
trade@hoperf.com
Website: http://www.hoperf.com
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COZIR™

Ultra Low Power Carbon Dioxide Sensor

COZIR is an ultra low power (3.5mW[4]), high performance CO_2 sensor, ideally suited for battery operation, portable instruments and HVAC. Based on GSS IR LED and Detector technology, and innovative optical designs, the *COZIR* offers the lowest power NDIR sensor available. Optional temperature, humidity and light sensing are available. *COZIR* is a third generation product from GSS – leaders in IR LED CO2 sensing.

- Ultra-low Power 3.5mW
- Measurement ranges from 5% to 100%
- 3.3V supply.
- Peak current only 33mA.
- Optional Temperature and Humidity Output

CO2Meter.com
Indoor Air Quality Products

131 Business Center Drive, Suite A-3
Ormond Beach, FL 32174
877.678.4259 Toll Free
866.422.2356 Fax
www.co2meter.com
info@co2meter.com

Specifications

General Performance

Warm-up Time

•< 10s

Operating Conditions

• 0°C to 50°C (standard)
• -25°C to 55°C (extended range)
• 0 to 95% RH, non-condensing

Recommended Storage

• -30°C to +70°C

CO2 Measurement

Sensing Method

• Non-dispersive infrared (NDIR) absorption
• Patented Gold-plated optics
• Patented Solid-state source and detector

Sample Method

• Diffusion

Measurement Range

• 0-5%,0-20%,0-65%,0-100%

Accuracy

• ±70 ppm +/- 3% of reading[1]

Non Linearity

• < 1% of FS

Pressure Dependence

• 0.13% of reading per mm Hg

Operating Pressure Range

- 950 to 40 bar[2]

Response Time

- 4 secs to 2 mins (user Configurable)[3]
- Reading refreshed twice per second.[3]

Electrical/Mechanical

Power Input

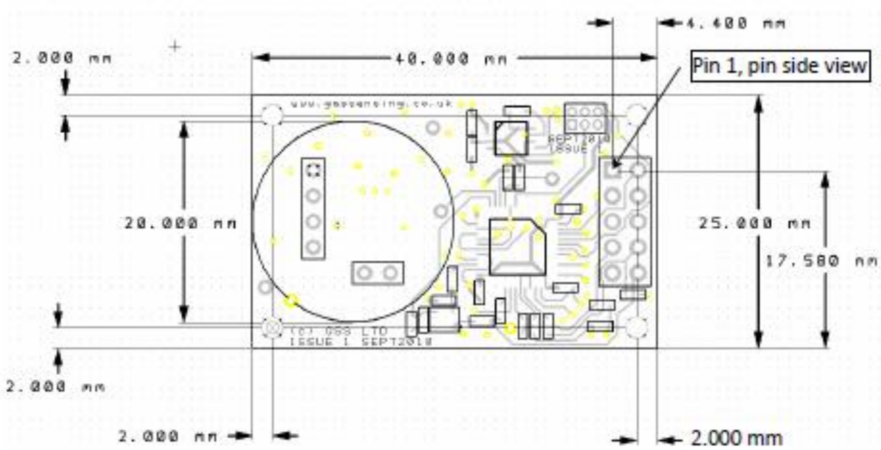
- 3.2 to 5V. (3.3V recommended).
- Peak Current 33mA[4].
- Average Current <1.5mA[4].

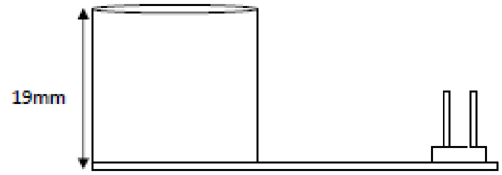
Power Consumption

- 3.5 mW[4]

Dimensions and Wiring Connections

- 2x5 0.1" header. Pin 1 is identified on the dimensional drawing.





Function	Pin #	Pin #	Function
0V	1	2	N/C
+3.3V	3	4	0V
Sensor Rx (in)	5	6	0V
Sensor Tx (out)	7	8	Zero N
Analogue O/P	9	10	Zero Air

Pin 2 should not be connected. Pins 4 and 6 do not require connection and are internally connected to GND.

The zeroing options are for hardware zeroing (both active low). These functions can also be implemented by sending a serial command (recommended).

Typical connections for digital interface are GND, 3.3V, Rx and Tx. Note that the Vh for the serial Tx line will be 3V regardless of the supply voltage.

The analog (voltage) output is available only when specified. Otherwise, N/C.

Temperature & Humidity Measurement[5]

Optional Temperature and Humidity sensor (only available as digital output)

Sensing Method

Humidity: Capacitive
Temperature: Bandgap

Measurement Range

- -25 to +55 °C
- 0 to 95% RH

Resolution

- 0.08 °C
- 0.08% RH

CO2Meter.com
Indoor Air Quality Products
131 Business Center Drive, Suite A-3
Ormond Beach, FL 32174
877.678.4259 Toll Free
866.422.2356 Fax
www.co2meter.com
info@co2meter.com

Absolute Accuracy[5]

- +/- 1 °C   0°C to 55°C.
- +/- 3% RH   20°C to 55°C.
- +/- 2 °C   over the full temperature range.
- +/- 5% RH   over the full temperature range.

Repeatability

- +/- 0.1 °C
- +/- 0.1 % RH

Note 1: All measurements are at STP unless otherwise stated.
Note 2: External Pressure calibration required to eliminate pressure dependence.
Note 3: User Configurable Filter Response.
Note 4: Power measurements for standard CO2 sensor with 2 readings per second. Temperature and humidity measurements increase the power consumption.
Note 5: Temperature and Humidity derived from Sensirion SHT21 chip. See Sensirion data sheet for full details.

131 Business Center Drive, Suite A-3
Ormond Beach, FL 32174
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TDK·Lambda **LS Series**

Single Output General Purpose Power Supplies

Features

- Very low cost
- 25W to 150W
- Small size
- 115VAC or 230VAC input
- Withstands 300VAC surges (5s)
- Three year warranty

Key Market Segments & Applications

RoHS

Specifications

Model		LS25	LS35	LS50	LS75	LS100	LS150
AC Input Voltage (300VAC for 5s)	VAC	88 - 264VAC (See note (2) for LS100)					88-132/176-264VAC(1)
Input Frequency	Hz	47 - 63Hz					
DC Input Voltage	VDC	125 - 373VDC					248 - 273VDC
Inrush Current (230VAC, cold start)	A	30	40	40	40	60	40
Power Factor	-	Meets EN61000-3-2, -3					
Input Current (115/230VAC)	A	0.7 / 0.4	0.8 / 0.55	1.3 / 0.8	1.6 / 1.0	2.2 / 1.2	3.5 / 2
Temperature Coefficient	-	<0.02%/°C					
Overcurrent Protection	-	> 110%					
Overvoltage Protection	V	3.3V: 3.8-4.45V, 5V: 5.75-6.75V, 12V: 13.8-16.2V, 15V: 17.25-20.25V, 24V: 27.6-32.4V, 36V: 41.4-48.6V, 48V: 55.2-64.8V					
Hold Up Time (115 / 230V input)	ms	14 / 80	12 / 80	14 / 60	14 / 60	25 / 150	20 / 28
Leakage Current (230VAC 60Hz)	mA	<1mA					
Remote Sense	-	No					
LED Indicator	-	Green LED = On					
Operating Temperature	°C	-25 to +70°C. Derate linearly to 50% load from +50 to +70°C (2)					
Storage Temperature	°C	-40 to +85°C					
Operating Humidity	-	20 - 90% RH (non condensing)					
Storage Humidity	-	10 - 95% RH (non condensing)					
Cooling	-	Convection					
Withstand Voltage	-	Input to Ground 1.5kVAC, Input to Output 3kVAC, Output to Ground 500VAC for 1 min.					
Isolation Resistance	-	>100M at 25C & 70%RH, Output to Ground 500VDC					
Vibration (non operating)	-	10 - 55Hz: 19.6m/s² constant sweep 1 min X, Y, Z for 1 hour					
Shock	-	< 196.1 m/s² (20G)					
Immunity	-	IEC61000-4-2, -3, -4, -5, -6, -8, -11					
Safety Agency Approvals	-	UL60950-1, EN60950-1, IEC60950-1, CE Mark					
Conducted & Radiated EMI	-	EN55011/EN55022-B, FCC-B					
MTBF (MIL-HDBK-217F)	hrs	906,997	706,464	712,890	648,786	545,375	505,393
Weight (Typ)	g	170	270	350	410	600	700
Size (LxWxH)	in	3.1 x 2.0 x 1.1	3.9 x 3.2 x 1.4	3.9 x 3.8 x 1.4	5.1 x 3.8 x 1.5	6.3 x 3.8 x 1.5	7.8 x 3.9 x 1.5
Warranty	yrs	Three Years					

Notes:

(1) Switch selectable for 115 or 230VAC

(2)
LS25-3	Derate linearly to 60% load from +40 to +70°C.
LS50, LS75-3 & -5	Derate linearly to 70% load from +50 to +70°C.
LS25-5 to 48, LS75-12 to 48	Derate linearly to 60% load from +50 to +70°C.
LS100-3 & -5	Derate linearly to 60% load from +45 to +70°C. Derate linearly to 80% load from 115V to 88VAC Input.
LS100-12, -15, -24, -36, -48	Derate linearly to 60% load from +50 to +70°C. Derate linearly to 80% load from 115V to 88VAC Input.
LS150-3 & -5,	Derate linearly to 50% load from +40 to +70°C.
LS150-12, -15, -24, -36, -48	Derate linearly to 70% load from +50 to +70°C.

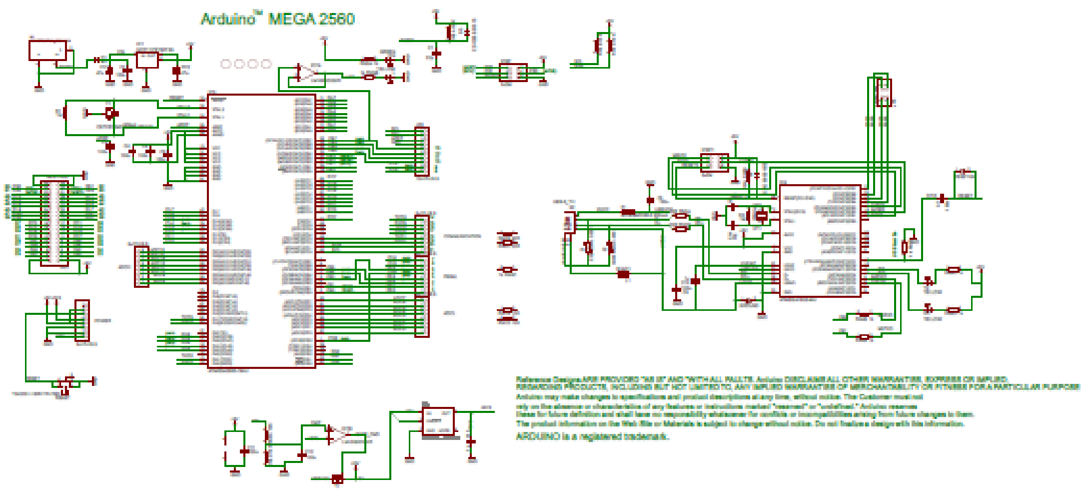
1-800-526-2324 • www.us.tdk-lambda.com/lp/ 73 Disclaimer: us.tdk-lambda.com/lp/legal.htm

Output Ratings

Model	Voltage	Adjust Range (V)	Max Current (A)	Load Reg (mV)	Line Reg (mV)	Ripple Noise (mV)	Efficiency (typ) %
LS25-3.3	3.3V	2.85 - 3.6	6.0	40	20	80	75
LS25-5	5V	4.5 - 5.5	5.0	40	20	80	79
LS25-12	12V	10.8 - 13.2	2.1	96	48	120	83
LS25-15	15V	13.5 - 16.5	1.7	120	60	120	83
LS25-24	24V	22 - 27.6	1.1	192	96	120	84
LS25-36	36V	32 - 40	0.75	288	144	150	84
LS25-48	48V	42 - 54	0.57	384	192	200	85
LS35-3.3	3.3V	2.85 - 3.6	7.0	40	20	80	75
LS35-5	5V	4.5 - 5.5	7.0	40	20	80	78
LS35-12	12V	10.8 - 13.2	3.0	96	48	120	82
LS35-15	15V	13.5 - 16.5	2.4	120	60	120	83
LS35-24	24V	22 - 27.6	1.5	192	96	120	84
LS35-36	36V	32 - 40	1.0	288	144	150	84
LS35-48	48V	42 - 54	0.8	384	192	200	84
LS50-3.3	3.3V	3.0 - 3.6	10.0	40	20	80	75
LS50-5	5V	4.75 - 5.5	10.0	40	20	80	80
LS50-12	12V	10.8 - 13.2	4.2	96	48	120	84
LS50-15	15V	13.5 - 16.5	3.4	120	60	120	85
LS50-24	24V	22 - 27.2	2.2	192	96	120	86
LS50-36	36V	32 - 40	1.4	288	144	150	86
LS50-48	48V	42 - 54	1.1	384	192	200	86
LS75-3.3	3.3V	3.0 - 3.6	15.0	40	20	80	75
LS75-5	5V	4.75 - 5.5	12.0	40	20	80	79
LS75-12	12V	10.8 - 13.2	6.0	96	48	120	84
LS75-15	15V	13.5 - 16.5	5.0	120	60	120	85
LS75-24	24V	22 - 27.2	3.2	192	96	120	86
LS75-36	36V	32 - 40	2.1	288	144	150	86
LS75-48	48V	42 - 54	1.6	384	192	200	87
LS100-3.3	3.3V	3.0 - 3.6	20.0	40	20	80	75
LS100-5	5V	4.75 - 5.5	16.0	40	25	80	79
LS100-12	12V	10.8 - 13.2	8.5	96	48	120	82
LS100-15	15V	13.5 - 16.5	7.0	120	60	120	84
LS100-24	24V	22 - 27.2	4.5	192	96	120	86
LS100-36	36V	32 - 40	3.0	288	144	150	86
LS100-48	48V	42 - 54	2.3	384	192	200	86
LS150-3.3	3.3V	3.0 - 3.6	30.0	40	20	80	75
LS150-5	5V	4.75 - 5.5	26.0	40	20	80	79
LS150-12	12V	10.8 - 13.2	12.5	96	48	120	83
LS150-15	15V	13.5 - 16.5	10.0	120	60	120	85
LS150-24	24V	22 - 27.2	6.5	192	96	120	86
LS150-36	36V	32 - 40	4.3	288	144	150	87
LS150-48	48V	42 - 54	3.3	384	192	200	87

For Additional Information, please visit
us.tdk-lambda.com/lp/products/ls-series.htm

Arduino Mega 2560 R3



UV Bulb

Specifications

Stock Code:	AU-LGPH793T5L	**Brand:**	Precision Lighting
Part No.:	GPH793T5L	**Wattage:**	37 Watt
Amperage:	425 mA	**Bulb Shape:**	T5
Length:	31.22 in.	**Life Hours:**	10,000

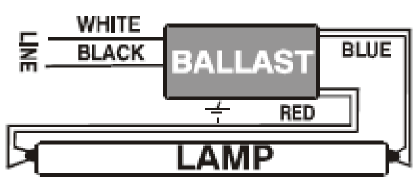
ATLANTIC ULTRAVIOLET CORPORATION

Surelite™ ELECTRONIC BALLAST

SPECIFICATIONS FOR ELECTRONIC BALLAST

Model No.	10-0054C
Lamp type:	Preheat Lamps GPH212T5L through GPH810T5L (Germicidal) and GPH212T5L through GPH810T5VH & VH/4 (Ozone producing lamps), including 'U'-bend Lamps.
Starting method:	Instant Start lamp voltage after 2 second ballast switch-on delay.
Input Line Voltage:	120 v.a.c.
Line Frequency:	50 - 60 Hz.
Fuse:	Internal 2 Ampere.
Input Watts:	10-38 Watts, depending on lamp used.
Output Current:	420 milliamperes. nominal.
Open-Circuit Volts:	850 volts
Short-Circuit Current:	450 milliamperes, approx.
Output Frequency:	45 kHz.
Operating Temperature:	-6° to 40° C (20° -105° F).
Wiring Method:	See diagram below
Maximum Distance:	6 ft. maximum between lamp and ballast.
Lead Lengths:	Line Power Leads 10". Lamp Leads 36".
Wire specifications:	18 Gauge, 1000v, Solid. Black & White:- AC in. Red & Blue:- Lamp Connections
Housing:	Extruded Aluminum alloy, with Aluminum alloy end-plates.
Size:	6 1/4" (Max) x 2 1/2" x 1 3/4".
Weight:	11 oz.
Mounting:	2 screws through slotted mounting tabs.

Specifications may be subject to change without notice.



375 Marcus Boulevard, Hauppauge, NY 11788

Phone: 631-273-0500 Fax: 631-273-0500

100054C

14/06

POLYIMIDE FILM INSULATED FLEXIBLE HEATERS

- Rated Up to 200°C (392°F)
- Etched Foil Design
- 0.010" Max Thickness
- 2.5, 5, or 10 Watts/in²
- 115, 230† and 28V
- Optional Pressure-Sensitive Adhesive (PSA)

Polyimide film insulated heaters are available in a variety of shapes, sizes, and wattages. Wattage ratings are 2.5, 5, or 10 W/in² at 115, 230† or 28V. Polyimide film offers a high degree of resistance to chemicals, and has excellent outgasing properties in high vacuum environments.

Typical construction consists of an etched foil element of 0.0005" or 0.0001" thickness which is encapsulated between two layers of 0.002" Polyimide film and 0.001" FEP adhesive.

† Most sizes available in 230V. Consult heaters sales and engineering.

Lead wires exit from the upper right hand corner of width (W) side of heater. For ½ and 1" wide heaters only, leads exit centrally from width (W) side. Leads exit round heaters radially.

Pressure sensitive adhesive (PSA) is available as an option on heaters rated at 2.5 or 5 W/in². The heaters can also be mechanically clamped or epoxy mounted by the user.

SPECIFICATIONS

Operating Temperature: -200 to 200°C (-328 to 392°F) for heaters without pressure sensitive adhesive (PSA). Maximum operating temperature for heaters with pressure sensitive adhesive is 120°C (248°F)
Maximum Thickness: 0.010" except at lead wire exit
Wattage: 2.5, 5 or 10 W/in²
Leads: FEP insulated (MIL-W-16878), 305 mm (12") long (wire gauge varies with heater)
Dielectric Strength: 1250 Vac
Minimum Bending Radius: 0.032"

KHR Series, Round, 115 Volts

To Order

Dia. cm (")	Total Wattage for Watt Density 2.5 W/in²	5 W/in²	10 W/in²	Without PSA Model No.	With PSA Model No.
5 (2)	—	—	31.4	KHR-2/(*)	KHR-2/(*)-P
7.6 (3)	17.7	35.3	70.7	KHR-3/(*)	KHR-3/(*)P
10 (4)	31.4	62.8	126	KHR-4/(*)	KHR-4/(*)-P
13 (5)	49.1	98.2	196	KHR-5/(*)	KHR-5/(*)-P
15 (6)	70.7	141	283	KHR-6/(*)	KHR-6/(*)-P
18 (7)	96.2	192	385	KHR-7/(*)	KHR-7/(*)-P
20 (8)	126	251	503	KHR-8/(*)	KHR-8/(*)-P
23 (9)	159	318	636	KHR-9/(*)	KHR-9/(*)-P
25 (10)	196	393	785	KHR-10/(*)	KHR-10/(*)-P
28 (11)	238	475	950	KHR-11/(*)	KHR-11/(*)-P
30 (12)	283	565	1131	KHR-12/(*)	KHR-12/(*)-P

Comes complete with operator's manual.
** Insert watt density: "2" for 2.5 W/in², "5" for 5 W/in² or "10" for 10 W/in².*
***Ordering Example:** KHLV-104/5-P, 2.5 x 10 cm (1 x 4"), 28V, 5 W/in² Polyimide film heater with PSA.*
***Note:** Heaters are available in only the watt densities where total wattage is indicated.*

KHLV Series, Rectangular, 28 Volts

Width, cm (")	Length, cm (")	Total Wattage for Watt Density 2.5W/in²	5W/in²	10W/in²	Without PSA Model No.	With PSA Model No.
1 (0.5)	5 (2)	—	5	10	KHLV-0502/(*)	KHLV-0502/(*)-P
1 (0.5)	10 (4)	5	10	20	KHLV-0504/(*)	KHLV-0504/(*)-P
2.5 (1)	2.5 (1)	—	5	10	KHLV-101/(*)	KHLV-101/(*)-P
2.5 (1)	5 (2)	5	10	20	KHLV-102/(*)	KHLV-102/(*)-P
2.5 (1)	7.6 (3)	7.5	15	30	KHLV-103/(*)	KHLV-103/(*)-P
2.5 (1)	10 (4)	10	20	40	KHLV-104/(*)	KHLV-104/(*)-P
2.5 (1)	13 (5)	12.5	25	50	KHLV-105/(*)	KHLV-105/(*)-P
5 (2)	5 (2)	10	20	40	KHLV-202/(*)	KHLV-202/(*)-P

POLYIMIDE FILM INSULATED FLEXIBLE HEATERS

KH Series, Rectangular, 115 Volts

To Order *Visit omega.com/khr_khlv_kh for Pricing and Details*

Width, cm (")	Length, cm (")	Total Wattage for Watt Density			Without PSA	With PSA
		2.5W/in²	5W/in²	10W/in²	Model No.	Model No.
2.5 (1)	7.6 (3)	—	—	30	KH-103/(*)	KH-103/(*)-P
2.5 (1)	10 (4)	—	20	40	KH-104/(*)	KH-104/(*)-P
2.5 (1)	13 (5)	—	25	50	KH-105/(*)	KH-105/(*)-P
2.5 (1)	15 (6)	15	30	60	KH-106/(*)	KH-106/(*)-P
2.5 (1)	20 (8)	20	40	80	KH-108/(*)	KH-108/(*)-P
2.5 (1)	25 (10)	25	50	100	KH-110/(*)	KH-110/(*)-P
2.5 (1)	30 (12)	30	60	120	KH-112/(*)	KH-112/(*)-P
5 (2)	5 (2)	—	20	40	KH-202/(*)	KH-202/(*)-P
5 (2)	7.6 (3)	15	30	60	KH-203/(*)	KH-203/(*)-P
5 (2)	10 (4)	20	40	80	KH-204/(*)	KH-204/(*)-P
5 (2)	13 (5)	25	50	100	KH-205/(*)	KH-205/(*)-P
5 (2)	15 (6)	30	60	120	KH-206/(*)	KH-206/(*)-P
5 (2)	20 (8)	40	80	160	KH-208/(*)	KH-208/(*)-P
5 (2)	25 (10)	50	100	200	KH-210/(*)	KH-210/(*)-P
5 (2)	30 (12)	60	120	240	KH-212/(*)	KH-212/(*)-P
7.6 (3)	7.6 (3)	22.5	45	90	KH-303/(*)	KH-303/(*)-P
7.6 (3)	10 (4)	30	60	120	KH-304/(*)	KH-304/(*)-P
7.6 (3)	13 (5)	37.5	75	150	KH-305/(*)	KH-305/(*)-P
7.6 (3)	15 (6)	45	90	180	KH-306/(*)	KH-306/(*)-P
7.6 (3)	20 (8)	60	120	240	KH-308/(*)	KH-308/(*)-P
7.6 (3)	25 (10)	75	150	300	KH-310/(*)	KH-310/(*)-P
7.6 (3)	30 (12)	90	180	360	KH-312/(*)	KH-312/(*)-P
10 (4)	10 (4)	40	80	160	KH-404/(*)	KH-404/(*)-P
10 (4)	13 (5)	50	100	200	KH-405/(*)	KH-405/(*)-P
10 (4)	15 (6)	60	120	240	KH-406/(*)	KH-406/(*)-P
10 (4)	20 (8)	80	160	320	KH-408/(*)	KH-408/(*)-P
10 (4)	25 (10)	100	200	400	KH-410/(*)	KH-410/(*)-P
10 (4)	30 (12)	120	240	480	KH-412/(*)	KH-412/(*)-P
13 (5)	13 (5)	62.5	125	250	KH-505/(*)	KH-505/(*)-P
13 (5)	15 (6)	75	150	300	KH-506/(*)	KH-506/(*)-P
13 (5)	20 (8)	100	200	400	KH-508/(*)	KH-508/(*)-P
13 (5)	25 (10)	125	250	500	KH-510/(*)	KH-510/(*)-P
13 (5)	30 (12)	150	300	600	KH-512/(*)	KH-512/(*)-P
15 (6)	15 (6)	90	180	360	KH-606/(*)	KH-606/(*)-P
15 (6)	20 (8)	120	240	480	KH-608/(*)	KH-608/(*)-P
15 (6)	25 (10)	150	300	600	KH-610/(*)	KH-610/(*)-P
15 (6)	30 (12)	180	360	720	KH-612/(*)	KH-612/(*)-P
20 (8)	20 (8)	160	320	640	KH-808/(*)	KH-808/(*)-P
20 (8)	25 (10)	200	400	800	KH-810/(*)	KH-810/(*)-P
20 (8)	30 (12)	240	480	960	KH-812/(*)	KH-812/(*)-P
25 (10)	25 (10)	250	500	1000	KH-1010/(*)	KH-1010/(*)-P
25 (10)	30 (12)	300	600	1200	KH-1012/(*)	KH-1012/(*)-P
30 (12)	30 (12)	360	720	1440	KH-1212/(*)	KH-1212/(*)-P

n/a – not available with PSA.
Comes complete with operator's manual.
** Insert watt density: "2" for 2.5 W/in², "5" for 5 W/in², "10" for 10 W/in².*
***Ordering Example:** KH-310/2, 7.6 x 25 cm (3 x 10"), 115 Vac, 2.5 W/in², Polyimide film heater.*
***Note:** Heaters are available in only the watt densities where total wattage is indicated.*

Water pump

PRODUCT DESCRIPTION

Introducing the latest Swiftech offering in watercooling pumps: The MCP355 Industrial Pump. This incredibly strong pump features a remarkably small footprint for its astounding 20 feet of head!

The MCP355 is able to deliver extreme reliability in today's most complex liquid cooled systems with minimal space through the use of a unique single moving part pump design. If you are running some serious hardware or a system with many and multiple waterblocks and watercooled components, this is the pump you have been waiting for!

Features:

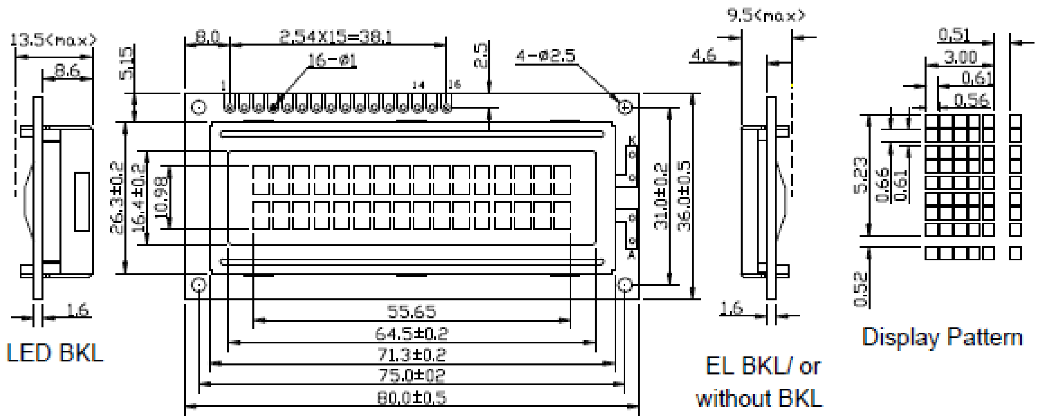
- Small footprint for easy system integration
- 50,000 hours MTBF equivalent to 5+ years lifetime
- Superior 12VDC convenience plugs directly into the computer power supply
- Can be used in full confidence in any MP servers and high-end workstations
- Superior real world performance thanks to its high pressure characteristics (20ft of head)
- Particularly well adapted to the proliferation of daisy-chained liquid cooling devices in a single circuit, such as multiple processors, chipset, graphics, and hard drives
- Native 3/8" barb fittings
- No maintenance required when used with de-mineralized water with anti-fungal additives
- Quick installation with adhesive neoprene pad, or permanent installation with screws and grommets
- RPM sensor plugs to 3-pin motherboard fan connectors and reports impeller rotational speed

Specifications:

- Normal Operating Voltage: 12VDC
- Operating Voltage: 8~13.2VDC
- Minimal Starting Voltage: 9VDC
- Power Consumption: 18W
- Current: 1.46A
- Head: 20.2ft
- Discharge: 120GPH
- Connection: 3/8" Barbs
- Pressure: 22PSI
- Electrical Connector: 4-pin Molex (with 3-pin RPM only connector)
- Weight: 7.3oz
- Noise: 30~32dBA
- Motor Type: Electronically Commutated, Brushless DC, Spherical Motor
- MTBF: 50,000 Hours

NOTE: The MCP355 is intended for high performance applications where a powerful pump is a necessity, but space is an issue. Because of this, it generates a higher audible noise then the MCP350 and MCP655 pumps and is not recommended for users seeking a silent system.

XIAMEN OCULAR **GDM1602K**



Feature

1. *5X8 dots with cursor*
2. *Built-in controller (KS0066U or Equivalent)*
3. *+5V power supply(Also available for +3.0V)*
4. *1/16 duty*
5. *BKL to be driven by pin1,pin2,or pin15,pin16,or A,K*
6. *N.V.optional*

PIN NO	Symbol	Fuction
1	VSS	GND
2	VDD	+5V
3	V0	Contrast adjustment
4	RS	H/L Register select signal
5	R/W	H/L Read/Write signal
6	E	H/L Enable signal
7	DB0	H/L Data bus line
8	DB1	H/L Data bus line
9	DB2	H/L Data bus line
10	DB3	H/L Data bus line
11	DB4	H/L Data bus line
12	DB5	H/L Data bus line
13	DB6	H/L Data bus line
14	DB7	H/L Data bus line
15	A	+4.2V for LED
16	K	Power supply for BKL(0V)

Mechanical Data

Item	Standard	Unit
Module dimension	80.0x36.0	mm
Viewing area	64.5x16.4	mm
Dot size	0.56x0.61	mm
Character size	3.00x5.23	mm

Absolute Maximum Rating

Item	Symbol	Standard			Unit
		Min	Typ	Max	
Power supply	VDD-VSS	-0.3	——	5.5	V
Input voltage	VI	-0.3	——	VDD	

Electronical characteristics

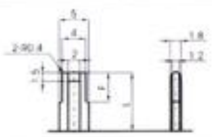
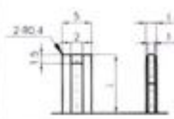
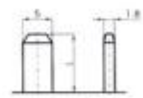
Item	Symbol	Condition	Standard			Unit
			Min	Typ	Max	
Input voltage	VDD	+5V	4.7	5.0	5.5	V
		+3.3V	2.7	3.0	5.3	V
Supply current	IDD	VDD=5V	——	1.5	4	mA
Recommended LCD riling voltage for normal temp version module	VDD-V0	-20°C	——	——	——	V
		0 °C	4.7	5.0	5.5	
		25°C	4.3	4.5	4.7	
		50°C	4.1	4.3	4.5	
		70°C	——	——	——	
LED forward voltage	VF	25°C	——	4.2	4.6	V
LED forward current	IF	25°C	——	120	160	mA
EL power supply current	IEL	Vel=110V AC 400Hz	——	——	——	mA

Display character address code:

Display position

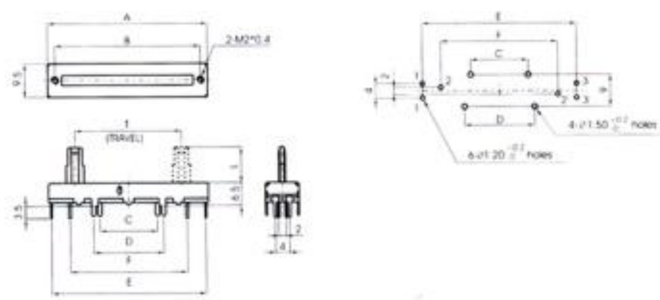
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DDRAM address	00	01	02	---	---	---	---	---								0FH
DDRAM address	40	41	42	---	---	---	---	---								4FH

LEVER TYPE

MATERIAL	Insulated lever			
LEVER TYPE	C	CA	B	
DIMENSIONS				

LENGTH(L)									
C	X	1	2	3	5	6	7		
	L	10	12.5	15	18	20	0		
	F	5	5	5	5	5	5		
CA	X	4	8						
	L	5	10						
B	X	9							
	L	10							

P.C.B. MOUNTING HOLE DETAIL



MODEL	T	A	B	C	D	E	F
C1531	15	30	26			28.5	18
C2031	20	35	31	6.2	9.8	33.5	23
C3031	30	45	41	16.2	19.8	43.5	33
C4531	45	60	56			58.5	48

Electrical characteristics:電氣的性能 ：

Total resistance 總阻值	5K Ω ~2M Ω
Total resistance tolerance 總阻偏差	± 20% more than 1M Ω ± 30%
Resistance taper 阻值規律	A, B, C, D, K, W, RD
Insulation resistance 絶緣電阻	100M Ω min. at 250V DC.
Withstand voltage 耐電壓	AC 300V (1 minute)

	Taper \ Travel		15 mm	20 mm	30 mm	45 mm
Rated power 額定功率 (W)	B	Single	0.05	0.1	0.2	0.25
		Dual	0.025	0.05	0.1	0.125
	Except B (B 以外)	Single	0.025	0.05	0.1	0.125
		Dual	0.012	0.025	0.05	0.06
Max. operating voltage(AC V) 最高使用電壓	B	Single	100	200	200	200
	Except B (B 以外)	Dual	50	150	150	150

Residual resistance 殘留阻值	Total resistance 總阻值	10K Ω	50K Ω	100K Ω	200K Ω	500K Ω	1M Ω
	Between terminals 1-2 端子 1-2 間	10 Ω	10 Ω	10 Ω	20 Ω	20 Ω	20 Ω
	Between terminals 2-3 端子 2-3 間	10 Ω	10 Ω	20 Ω	20 Ω	50 Ω	50 Ω

深 圳 市 昱 申 科 技 有 限 公 司
CHINA YOUNG SUN LED TECHNOLOGY CO., LTD.
TEL: (86) 755-28079401 28079402 28079403 28079404 28079405
FAX: (86) 755-28079407 E-mail: info@100LED.com Web: www.100LED.com

Model No.: YSL-R341K3D-D2

Applications:

- Decorations
- Bill Insperctor
- Inceticidal Lights
- Medical Appliance

Absolute Maximum Ratings: (Ta=25 ℃) .

ITEMS	Symbol	Absolute Maximum Rating	Unit
Forward Current	I_F	20	mA
Peak Forward Current	I_{FP}	30	mA
Suggestion Using Current	I_{SU}	16-18	mA
Reverse Current (VR=5V)	I_R	10	uA
Power Dissipation	P_D	65	mW
Operation Temperature	T_{OPR}	-40 ~ 85	℃
Storage Temperature	T_{STG}	-40 ~ 100	℃
Lead Soldering Temperature	T_{SOL}	Max. 260℃ for 3 Sec. Max. (3mm from the base of the expoxy bulb)	

Absolute Maximum Ratings: (Ta=25 ℃)

ITEMS	Symbol	Test condition	Min.	Typ.	Max.	Unit
Forward Voltage	V_F	I_F=20mA	2.0	---	2.4	V
Wavelength (nm) or TC(k)	Δ λ	I_F=20mA	590	---	595	nm
*Luminous intensity	I_V	I_F=20mA	40	---	100	mcd
50% Viewing Angle	2 θ 1/2	I_F=20mA	30	---	40	deg

Address: 5/F, Building B, Anzhilong Indl., Qinghua East Road., Longhua Town, Shenzhen CHINA. 518109

FAIRCHILD SEMICONDUCTOR®

May 2001

QFET™

FQP30N06L

FQP30N06L

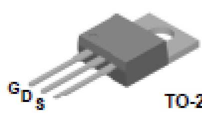
60V LOGIC N-Channel MOSFET

General Description

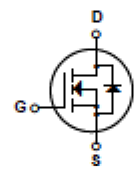
These N-Channel enhancement mode power field effect transistors are produced using Fairchild's proprietary, planar stripe, DMOS technology.
This advanced technology has been especially tailored to minimize on-state resistance, provide superior switching performance, and withstand high energy pulse in the avalanche and commutation mode. These devices are well suited for low voltage applications such as automotive, DC/DC converters, and high efficiency switching for power management in portable and battery operated products.

Features

- 32A, 60V, $R_{DS(on)}$ = 0.035Ω @V_{GS} = 10 V
- Low gate charge (typical 15 nC)
- Low Crss (typical 50 pF)
- Fast switching
- 100% avalanche tested
- Improved dv/dt capability
- 175°C maximum junction temperature rating



TO-220
FQP Series



Absolute Maximum Ratings T_C = 25°C unless otherwise noted

Symbol	Parameter		FQP30N06L	Units
V_{DSS}	Drain-Source Voltage		60	V
I_D	Drain Current - Continuous (T_C = 25°C)		32	A
	- Continuous (T_C = 100°C)		22.6	A
I_{DM}	Drain Current - Pulsed	(Note 1)	128	A
V_{GSS}	Gate-Source Voltage		± 20	V
E_{AS}	Single Pulsed Avalanche Energy	(Note 2)	350	mJ
I_{AR}	Avalanche Current	(Note 1)	32	A
E_{AR}	Repetitive Avalanche Energy	(Note 1)	7.9	mJ
dv/dt	Peak Diode Recovery dv/dt	(Note 3)	7.0	V/ns
P_D	Power Dissipation (T_C = 25°C)		79	W
	- Derate above 25°C		0.53	W/°C
T_J, T_{STG}	Operating and Storage Temperature Range		-55 to +175	°C
T_L	Maximum lead temperature for soldering purposes, 1/8" from case for 5 seconds		300	°C

Thermal Characteristics

Symbol	Parameter	Typ	Max	Units
$R_{\theta JC}$	Thermal Resistance, Junction-to-Case	--	1.90	°C/W
$R_{\theta CS}$	Thermal Resistance, Case-to-Sink	0.5	--	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient	--	62.5	°C/W

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Electrical Characteristics

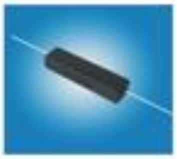
T_C = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
Off Characteristics						
BV_{DSS}	Drain-Source Breakdown Voltage	V_{GS} = 0 V, I_D = 250 μA	60	--	--	V
ΔBV_{DSS} / ΔT_J	Breakdown Voltage Temperature Coefficient	I_D = 250 μA, Referenced to 25°C	--	0.06	--	V/°C
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS} = 60 V, V_{GS} = 0 V	--	--	1	μA
		V_{DS} = 48 V, T_C = 150°C	--	--	10	μA
I_{GSSF}	Gate-Body Leakage Current, Forward	V_{GS} = 20 V, V_{DS} = 0 V	--	--	100	nA
I_{GSSR}	Gate-Body Leakage Current, Reverse	V_{GS} = -20 V, V_{DS} = 0 V	--	--	-100	nA
On Characteristics						
$V_{GS(th)}$	Gate Threshold Voltage	V_{DS} = V_{GS}, I_D = 250 μA	1.0	--	2.5	V
$R_{DS(on)}$	Static Drain-Source On-Resistance	V_{GS} = 10 V, I_D = 16 A	--	0.027	0.035	Ω
		V_{GS} = 5 V, I_D = 16 A	--	0.035	0.045	
g_{FS}	Forward Transconductance	V_{DS} = 25 V, I_D = 16 A (Note 4)	--	24	--	S
Dynamic Characteristics						
C_{iss}	Input Capacitance	V_{DS} = 25 V, V_{GS} = 0 V, f = 1.0 MHz	--	800	1040	pF
C_{oss}	Output Capacitance		--	270	350	pF
C_{rss}	Reverse Transfer Capacitance		--	50	65	pF
Switching Characteristics						
$t_{d(on)}$	Turn-On Delay Time	V_{DD} = 30 V, I_D = 16 A, R_G = 25 Ω (Note 4, 5)	--	15	40	ns
t_r	Turn-On Rise Time		--	210	430	ns
$t_{d(off)}$	Turn-Off Delay Time		--	60	130	ns
t_f	Turn-Off Fall Time		--	110	230	ns
Q_g	Total Gate Charge	V_{DS} = 48 V, I_D = 32 A, V_{GS} = 5 V (Note 4, 5)	--	15	20	nC
Q_{gs}	Gate-Source Charge		--	3.5	--	nC
Q_{gd}	Gate-Drain Charge		--	8.5	--	nC
Drain-Source Diode Characteristics and Maximum Ratings						
I_S	Maximum Continuous Drain-Source Diode Forward Current		--	--	32	A
I_{SM}	Maximum Pulsed Drain-Source Diode Forward Current		--	--	128	A
V_{SD}	Drain-Source Diode Forward Voltage	V_{GS} = 0 V, I_S = 32 A	--	--	1.5	V
t_{rr}	Reverse Recovery Time	V_{GS} = 0 V, I_S = 32 A, dI_F / dt = 100 A/μs (Note 4)	--	60	--	ns
Q_{rr}	Reverse Recovery Charge		--	90	--	nC

Notes:
1. Repetitive Rating : Pulse width limited by maximum junction temperature
2. L = 400μH, I_{AS} = 32A, V_{DD} = 25V, R_G = 25 Ω, Starting T_J = 25°C
3. I_{SD} ≤ 32A, di/dt ≤ 300A/μs, V_{DD} ≤ BV_{DSS}, Starting T_J = 25°C
4. Pulse Test : Pulse width ≤ 300μs, Duty cycle ≤ 2%
5. Essentially independent of operating temperature

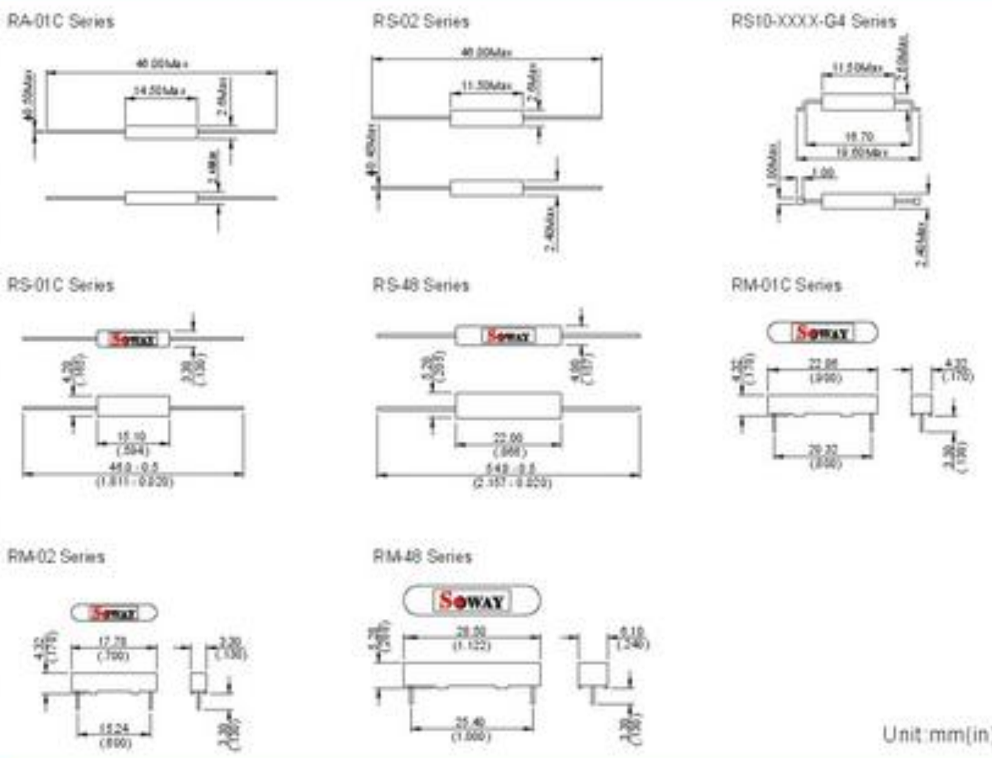
SOWAY www.sowaytech.cn

PCB 磁簧开关 PCB Mount Swithes



- 可直接安装于线路板上。
- 常开，常闭可选择。
- 无待机功率消耗。
- 客户可自定义灵敏度。
- 密封设计，可工作于恶劣环境。性能稳定，寿命增长。
- 底部凸脚设计，方便线路板的清洗。

- Be mounted directly into PCB
- Choice of normal open or normal close
- No standby power requirement
- Customer defined sensitivity
- Hermetically sealed, suit to tough environment and long life
- Moulded stand-offs to allow board washing



Electrical Characteristics 电气特性	RS、RM&RA-01C	RM&RS-02 and RS10-XXXX-G4	RS&RM-48
Switched Power (max) 最大开关功率	10W	10W	70W
Switched Voltage (max) 最大开关电压	DC180V AC130V	DC200V AC140V	DC200V AC250V
Breakdown Voltage (min) 最小击穿电压	200V	200V	400V
Switched Current (max) 最大开关电流	0.25A	0.5A	1.0A
Carry Current (max) 最大负载电流	1.0A	0.5A	1.75A
Contact Resistance (initial max) 最大接触阻抗	0.2Ω	0.2Ω	0.2Ω
Insulation Resistance (min) 最小绝缘阻抗	10^8	10^8	10^8
Operating Temperature 工作温度范围	-40 to +125℃	-40 to +125℃	-40 to +125℃

*Consult SOWAY for Customized Product 以上电气参数可按客户要求定制

SOWAY TECH LIMITED Tel: 86-755-88367005 Fax: 86-755-88366005 Email: soway@sowaytech.cn