Aeroponic/Hydroponic Growth Module

Final Design Report

Sponsor

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Statement of Disclaimer

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Chapter 1: Introduction

Sponsor Background and Needs

Aeroponic and hydroponic plant growers have problems controlling the conditions in which the plant grows. Currently when a growth system fails the user may be unaware of the problem and could lose the plant. Also, when a successful crop is grown users often have difficulty recreating the growth conditions needed to repeat the output. The goal of our project is to design and build a user-friendly system that allows for control and management of the plant's root zone environment along with a failsafe system that will back-up the primary system in case of failure.

This system is being designed for AliGroWorksUSA, Inc. with the target market ranging from the most experienced horticulturalist to beginner growers. We want our product to attract those individuals who want the ability to "pamper their plants." Most of the hydroponic and aeroponic systems currently in use are only for mass growing of plants. This product will be a stand-alone system designed to house a single plant. But for those interested in the product for investment purposes the system will be designed to have the ability to be implemented with other AliGroWorksUSA products that would allow for mass growing of plants.

The system will take the housing of a current self-watering design and implement all of the characteristics that would be needed to make the automated aeroponic/hydroponic plant pot. The system will have an aeroponic system to be the primary source of nutrient delivery to the root zone, with a hydroponic system to act as an emergency back-up system.

Modifications to the housing will need to be done in order to incorporate multiple tubes, including tubes for water inlet, a water outlet, along with tubing for any electronic wiring. There will also be a separate compartment that we would need to construct that would house the electronic components (microprocessor), to protect from water damage. Sensors will be utilized within the root zone area in a corner or side wall. For the atomization system, we will be using a centrifugal atomizer and a pump to get the desired droplet size. This will be placed in a location to optimize coverage of watering within the roots. The backup system will utilize a hydroponic system to water the roots without any atomization. The sensors will collect data for the microprocessor to communicate to the user the conditions of the root zone climate. These systems will improve the quality, production and ease of plant growing.

Objectives

The goal of our project is to design and build a user friendly system that allows for control and management of the plant's root zone environment along with a failsafe system that will act as a back-up to the primary system in case of failure. It was important that we translate the customer's needs and the needs of our sponsor into our engineering specifications. Our final device will allow the user to monitor nearly every aspect of the root zone environment, thus "pampering the plant."

After talking with our sponsor and brainstorming with each other, we determined that our device needs to:

- Be primarily aeroponic with a hydroponic backup system
- Monitor temperature, humidity, oxygen levels
- Monitor for failures in the system
- Be relatively easy to use

In analyzing what to incorporate into the design we utilized the Quality Function Deployment (QFD) method. The idea behind the QFD is to help us incorporate the customer's needs into engineering characteristics, and prioritize each of the characteristics while setting targets for development. The QFD we used can be seen in Appendix G. By using this approach we are able to gain a better understanding of the customer's needs and incorporate them into engineering specifications.

Table 1, below, lists the engineering specifications that we developed to best meet the customer's needs. It is a summary of values of our major design parameters. The requirement/target column lists values which we are trying to achieve in that specific design specification. The tolerance column lists values which the design parameter will be acceptable. The risk column denotes how difficult it will be to achieve that specific parameter, high (H) meaning it will be relatively difficult, and low (L) meaning it will be fairly easy to achieve. The last column, compliance, is to show how we will measure if we met the requirements or not. "A" denotes that it will be assessed by analysis, "T" denotes testing, "S" is for similarity to existing products, and "I" means it will be assessed by inspection.

Table 1: Formal Engineering Specifications

Spec #	Parameter Description	Requirement or target	Tolerance	Risk	Compliance
1	Temp control	60-70 °F	± 2 °F	M	S
2	Centrifugal Atomizer Motor Speed	3000 RPM*	Min	H	A, S
3	Centrifugal Atomizer Motor Life	2000 hours	Min	H	A,S
5	Cost	See Table 4	max	H	I
6	Size	10x10x15 in	max	M	I
7	Atomized Micron Size	50 microns	max	H	A,S,I
8	Temperature Sensing	Report Temperature	± 2 °F	L	S
9	Humidity Sensing	Report Humidity	± 2% RH	L	S
10	Airflow In	1 Minute Circulation	± 15 sec	L	A,T
11	Hydroponic Pump Head	15 inches	min	L	A,I
12	Hydroponic Pump Heat Generation	5 °F Rise in Water Reservoir	max	H	A,S,T
13	Hydroponic Pump Life	1000 hours	min	M	A,S

*Speed calculation based on equation derived for liquid metal. Water properties were used for calculation but estimates are on high side since equation takes into account only single stage atomization (no screen or distribution fan).

The "cost" requirement had a high risk because it is strongly dependent on the materials and equipment we use. The "size" requirement had a medium risk because it is dependent on the equipment we use as they could individually vary in size from different manufacturers. Temperature control is also medium as if may be somewhat difficult to maintain a constant temperature inside the root zone and is crucial to plant life. Pump and sensor requirements all had low risks; because we believe it will not be that difficult to meet those specific requirements.

Previously we had plant rotation as a design specification but after further discussion with our sponsor it was determined that rotation of the plant was no longer a priority of our project, as rotation is being implemented into another team's design and is part of light optimization. We will now be focusing our efforts on optimization of the root zone.

Chapter 2: Background

In our research we found many important issues that our product must address when it comes to general plant care. Our product will focus mainly on the root zone environment which will need to be controlled throughout plant growth stages. Other points to be considered will be the support of the maturing plant, the effect of growth media on the nutrient delivery system, and the current products available to the user.

The health of a plant relies intimately on the conditions held in the root zone environment. The primary contributing factors are temperature and oxygenation.

Temperature is of huge importance in the growth of the plant. The root zone should be kept within the range of 62-71 degrees Fahrenheit[1]. According to studies done at the Department of Biology, University of Turku, Finland[2] and the Department of Soil Science, University of Reading, UK[3] root temperature is directly related to nutrient absorption. These studies showed that the desired temperature ranges varied by plant type but generally agreed that 60-70 degrees Fahrenheit was desirable. This range led us to the conclusion that a variable temperature setting would be desirable to plant growers. This temperature control would likely require temperature sensors in the root zone and a heating element to raise temperature when it falls below a value that may be set by the user. The evaporative cooling effect of the aeroponic sprayers may be able to sufficiently cool the root zone when needed; the effectiveness would be increased by airflow through the root zone. The alternative would be to add components—such as thermoelectric cooling pads—but this would result in higher cost and added complexity.

Unlike temperature, oxygen intake in the root system is dependent on the growth stage of the plant. Knowledge of the plant's growth stages is very important. At the beginning of a plant's life, whether it be from seed or cutting, it is important that it is on a near constant watering schedule. Plants in this stage needless nutrients, but should be covered in order to keep the humidity from the aeroponic spray from escaping. During the rooting stage oxygen levels are of less priority. The next stage is vegetation for a period of about two weeks. This stage and all subsequent stages need periods of oxygenation between periods of watering. Oxygenation periods are those when the plant can intake oxygen through extremely fine hairs that branch off of the roots. The vegetative state should have an oxygenation to watering time ratio of about 2:1. Once the plant's leaves begin to grow larger they begin to cast shadow on the lower sections and less heat is transmitted to the root zone. The effect is that the watering can be reduced; typical oxygenation to watering is 3:1. The final and most important stage is the flowering stage. This stage needs significantly more oxygen; an oxygenation to watering ratio of 10:1 is recommended[4]. All of these ratios are general suggestions and the actual watering schedule should be controlled by the user.

Availability of oxygen to the plants is very important and could be realized through control of watering schedule timers. Oxygen and humidity sensors could also help to monitor the root zone environment, but should not be necessary for adequate control.

Plant height and size is an important factor in the design of the system. NASA's studies on the space shuttle Mir concluded that aeroponic systems produce plants with 80% more biomass weight per square meter[5]. Rapid plant growth can lead to thinner and weaker stems[6]. On top of that, during the flowering stages a plant can increase in size by a factor of three from its vegetative state. Though users can utilize methods to control the height of the plant—plant to light distance, using fans to stress-strengthen, topping—we as designers cannot control the actions of the user. Plant supports are used in many applications to keep plants from falling. Commonly used supports are stakes, cages, and tie downs.

Grow media is a passive material that contains no nutrients and serves only to hold the plant in place. In aeroponic systems grow medium is only used when starting a plant from a seedling or cutting. When choosing a medium for rooting seedlings or cuttings a sediment free medium is imperative, such as Rapid Rooters[7], so that any fallen medium will not clog the aeroponic system. When choosing grow medium for aeroponics, a water-repellent medium—such as a simple net basket—is desirable so that oxygen can reach the roots during oxygenation periods[8]. This tends to only be a problem with young rooting plants, as once the root systems are substantial the vast majority of the roots will hang freely allowing for adequate air. A water-repellent medium is also an advantage when it comes to the back-up hydroponic system. This allows for a constant drip system that will keep the roots moist while still allowing oxygenation, removing the need for a hydroponic watering schedule[9].

Currently most aeroponic systems on the market are built for mass growth of vegetables—our design will focus on a one plant one system approach. A patent search mirrored the current market findings. These systems are set up for the growth of multiple plants and have little to no ability to adjust the size of the system or focus on individual plant's needs[10]. These larger systems can cost the user thousands of dollars in start-up fees and thus push potential buyers out of the market. For those horticultural enthusiasts that want a small scale system, they must turn to home built systems that require a high level of commitment. The main problems with DIY projects (Do-It-Yourself) include: difficulty in system design, increase in system cost as most parts are bought separately from a variety of distributors, high level of maintenance, large time commitment to online forums/guides, and no guarantee of system performance. Our system will focus on alleviating some of these issues for the user.

The Competitors

When looking at other types of aeroponic systems and comparing, you get two different groups of systems. The first group consists of aeroponic systems designed for multiple plants in a single housing. The second group consists of systems advertised as “aeroponic”; which in actuality provide hydroponic nutrient delivery.

An example of the first group is the TreeFrog HP Aero[11] platform system shown in Figure 1, this system is a larger system that houses up to 26 plants and is upwards of 5 feet in length and width, and thus it is not likely it would be used in a home setting. It uses a high-pressure pump with multiple atomizers, but it does not monitor any of the root zone characteristics. It retails for over $750.

Figure 1: Treefrog HP Aero Platform System

An example of the second group of aeroponic systems is the Miracle-Gro AeroGarden 7[12] shown in Figure 2. This system has the capability of adjusting to accommodate a range of plant heights; the max dimensions are 20”x12.25”x21”. This system features a control panel that tells you when to add water and nutrients, and the lights automatically turn on and off. It claims to be an aeroponic system, but after further research this system has the roots in the water/nutrients and supplies oxygen through an air stone or other method. It does not actually have the roots in air nor does it atomize the nutrients, and thus it is not a true aeroponic system.

Figure 2: Miracle-Gro AeroGarden

Chapter 3: Design Developments

Concept Backgrounds

In the below sections relevant background information for proposed components and concepts is given.

Definition of atomization

Atomization occurs when the relative velocity between air and water is high enough to rip the water apart and into small particles—or droplets. In general, the higher this relative velocity the smaller the average droplet size will be. Because of the chaotic nature of atomization a single droplet size is not actually attainable; rather a range of droplet sizes are created and represented by an average droplet size.

Measuring Droplet Size

Droplet size is very difficult to determine empirically and is usually done in a laboratory. Some testing procedures include laser reflection and shadow photography analyzed with complex computer programs to determine the average droplet size. There are many correlations found empirically that calculate the projected droplet size for both high pressure atomizing nozzles and centrifugal atomization[13].

Centrifugal Atomizers

Centrifugal atomizers use centrifugal force to accelerate the water to a speed high enough for atomization. This system simply needs water to be introduced into the middle of a spinning disk for operation and does not rely on high pressures or flow rates. The droplet size off of the spinner is a function of speed and diameter of the disk.

These systems can be seen in use in centrifugal humidifiers, an example schematic can be found in Appendix G. These humidifiers are very cleverly constructed in that the centrifugal atomizer, water introduction pump, and mist distribution fan all run off of the same motor—this is a great way to decrease the number of components in the system that require electricity and space. Centrifugal humidifiers also use a filtering screen and a pre-mixing chamber to further break down water particles to smaller droplet sizes before being distributed to the surroundings. Though humidifier companies do not state droplet size there are reports from aeroponic DIY builders that droplets can get down to 20 microns. The equations available for determining droplet size are only for that coming directly off of the spinner and do not account for reduction in drop size due to the filtering screens or pre-mixing chambers.

These humidifiers are priced around $200-$300. Our system on the other hand would not need to be as expensive as the space we plan to operate in will be significantly smaller—about 6 cubic ft. as opposed to a 1,000 square foot house—and thus the motor (the most expensive component) will be much smaller. Humidifiers also are required to have filters and water circulation to prevent releasing bacteria into the air, both functions that in our system are dealt with elsewhere and would not be necessary for the atomizing system.

Though not seen often in the DIY community we believe that this system will work well for our root zone. At Harvard in 1976 an experiment was run using the centrifugal atomizing disk right out of a humidifier with great success. Below in Figure 3, is a schematic of the aeroponic module used, along with the development of pea plant roots after 3 weeks—seen in Figure 4. The plants grown in this system were of a wide range including: peas, fava beans, peanuts, soybeans, Australian evergreen trees, sweet fern trees, and sunflowers. All were successfully cultivated[14].

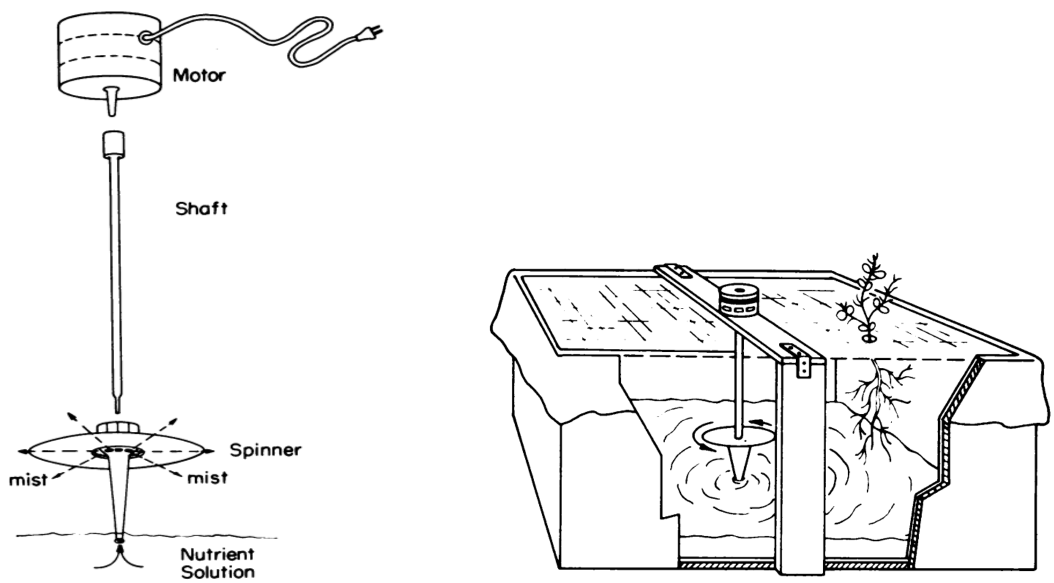


Figure 3: Left- Motor, Shaft, and Humidifier Spinner Schematic; Right- Aeroponic System Schematic

Figure 4: Pea Plant Roots after 3 Weeks of Growth

High Pressure Water Nozzle Atomization

High-pressure water nozzles are the standard in the aeroponic community. They work by producing a large pressure gradient that serves to accelerate water out of the atomizing nozzle at a high enough velocity to produce atomization. In order to achieve the pressure needed—80 to 100 psi at each nozzle—a piston or diaphragm pump is needed. In order to keep from fouling the system the pumps have filters that need to be washed or replaced monthly—though this would likely be reduced through the use of pre-filtering in a nutrient delivery system.

In Table 2, below, examples of atomization pumps are presented. The requirements for each pump depend on the amount of atomizing nozzles they would be serving. Each individual pot is assumed to have two nozzles. As an initial sizing parameter we assumed that each nozzle would require water flow ratings of about 30 GPH. It should be noted that the pump must be provide high pressure and not just high flow rate. The table extends to four pots in order to accommodate the use of a fully utilized Pivoting Lift Mechanism.

Table 2: Recommended Pumps

# Systems	# Nozzles	Pre	Recommended Pump	Type	Price	Dimensions (in)	Weight (lbs)
1	2	30	Aquatic 6800	In Line	$75	3 x 4 x 7	6
2	4	60	Aquatic 6800	In Line	$75	3 x 4 x 7	6
3	6	120	Aquatic 6880	In Line	$75	3 x 4 x 7	6
4	8	240	Aquatic 8800	In Line	$100	3.6 x 4 x 7.3	6.5

The atomizing nozzles are slightly more expensive than the typical nozzles because they must be able to accommodate the higher pressures and velocities. They are also designed differently in order to get the desired droplet sizes. The nozzles we will be using produce droplet sizes ranging from 5-50 microns in diameter.

Temperature Sensors

Thermistors use ceramic resistors whose electrical resistance changes with temperature. This relationship between resistance and temperature is known and can be used to accurately report the temperature of the thermistor and therefore the surroundings that the thermistor is in. Thermistors work very well in the range from -130°F to 260°F, our application fits comfortably in this range. Thermistors can be bought for very cheap (~$0.50 for a single thermistor), require only a single stabilizing resistor and can be controlled easily by a microcontroller.

Humidity Sensors

A capacitive type humidity sensor changes its capacitance based on the relative humidity (RH) of the surrounding air. As the relative humidity increases the capacitance also increase.

Capacitive type humidity sensors act linearly between 5% and 95% and measurement can be reported very accurately. Outside of this limit the reading becomes nonlinear and cannot be accurately reported without special materials or signal conditioning. Response time is dependent on the sensor bought and can be anywhere from about 5 to 60 seconds.

Oxygen Sensors

Many oxygen sensors are currently on the market, but none were found that were viable for our project. A quick overview of information found follows.

Soil testers are used to measure the oxygen content of soil but unfortunately these sensors cannot get wet and are very costly (~$200). Other options such as Oxygen Optodes only take measurements of dissolved oxygen in liquid water and thus will not give us the oxygen content of the root zone.

The Clark Electrode was developed in the automobile industry to analyze oxygen content of exhaust. These sensors use a galvanic cell—much like a battery—and produce an electrical voltage when exposed to oxygen. These sensors are the cheapest—the lowest found was $25—but also have the issue that they cannot get wet.

Because of the functional issues and cost we suggest that an oxygen sensor not be used. Instead we think that having outside air periodically added to the system would be a better approach for oxygen level management. Our concept for achieving this can be found in the Oxygen section of Design Development.

Resistive Heating Elements

A resistive heating element converts electricity into heat through the process of resistive or Joule heating. Electric current passing through the element encounters resistance, resulting in an increase in temperature. With airflow over the heating element heat will be transferred into the root zone to raise the temperature.

Design Development

Approach

Working through the concept design phase has pushed us to realize some of the best possible solutions to some of the issues of the task at hand. We began the process by making a list of every function needed in our final design. We then brainstormed as many possible solutions for each function and discussed them within the team. Initial concepts for the aeroponic system and hydroponic system can be found in Appendix G.

Following the brainstorming we utilized Pugh matrices to help us narrow down the amount of concepts we would consider. The Pugh matrix is used to evaluate alternative designs against a baseline. It utilizes a comparative scoring method to evaluate designs; using customer requirements you compare designs to the baseline and give scores according to whether the new design is better or worse than the baseline. This helps to weed out some of the weaker designs while also sparking ideas for new designs. Pugh Matrices can be found in Appendix G.

Following the Pugh matrices we moved on to developing decision matrices, to help us choose a final design. The decision matrices work by taking the remaining concept designs and giving them scores on how well they would perform in certain design criteria. This is different than the Pugh matrices in that you also assign the design criteria weighted values based on importance of the criteria. This helps to give the concept a better overall scoring taking into consideration all criteria. This protects against a biased top design; not allowing a winner based on a great performance in one area but poor performance in other areas. Decision matrices can be found in Appendix G.

From these decision matrices we found that either a centrifugal atomizer or the standard pump and atomizing nozzle were the best choices for the aeroponic system. We also found that the basic pump and hose drip system would be the optimal backup hydroponic system. In the following sections you will find more in depth descriptions of our concepts and why we chose them.

Concepts

Centrifugal Atomizer

We believe that this system would be the most appropriate for the scope of this project. The centrifugal atomizer does not require high pressures to atomize and can feed directly from the water reservoir. This means that it will work equally as well whether the reservoir is filled manually or through the use of water lines. Another benefit is that it can be made compactly and thus will give the root system ample room for growth.

Another major benefit to centrifugal atomizers is that droplet size is inversely proportional to motor speed. This means that if users are given a range of motor speeds to select from they can have some control over droplet size. This is a level of control that aeroponic systems do not currently provide. Though reporting exact droplet sizes will be difficult, there are a handful of equations available to us that will give us approximations. From experience in research on the DIY aeroponic community it is obvious that droplet size is very important and must be at least 50 microns. Our suggestion is that we determine the upper limit of the centrifugal system to be at 50 microns through the use of the equations in Appendix E and through visual inspection gauge the effect of filtering screens and pre-mixing.

Motors

When determining what type of motor to choose we considered both brushed motors and brushless motors. There are pros and cons to both types; first we will discuss the brushed motors. Some advantages to brushed motors are that you are able to replace the brushes when worn out, they operate in extreme environments, and they are relatively inexpensive. The negatives to brushed motors are that they do require periodic maintenance due to worn down brushes, they have lower speed range due to the mechanical limitations on the brushes, and poor heat dissipation. When looking at brushless motors and drawing comparisons, brushless motors require less maintenance, have higher electrical efficiencies, reduced sizes, and higher speed ranges. The drawback to brushless motors is that they are slightly more complicated and they also are more expensive.

Our design will require a higher speed range for the main system; and due to the size constraints of the root zone area that we have to design in, the smaller motors are desired. For these reasons we decided to go with a brushless motor[16].

High Pressure Water Nozzle

Our other option is to use a high-pressure water atomization nozzle. This system would require a pump such as those seen in Table 3, which because of size needs to be external to the pot. The main advantage of these systems is simply in their reliability. These systems are the most commonly used in the aeroponic community and thus are widely accepted as a means of atomization. For our project the effectiveness of such a system is questionable and dependent on the number of systems the user desires. For example if the user wishes to run four systems with the Pivoting Lift Mechanism, buying a single pump for $100 may be reasonable. On the other hand if the user only desires one system, a $75 pump may not be viable. Another thing to note is that this system does not necessarily need to be sold with an external pump and could be design to work with pumps that users already own—the part of the DIY community who already own pumps may find this appealing.

Conclusions on Atomization

Selecting between the centrifugal and high-pressure atomization systems is reliant on the direction we would like to go in terms of customer needs. If we would like to focus on customers that only want a few units the centrifugal atomizer would be the most cost effective choice. If we focus on customers desiring many systems, the high-pressure atomizer with external pump would be the best choice, as it is more cost effective for multiple units.

A third option would be to provide both atomization systems while leaving the pump as a separate item. What this means is that the system would be designed with the primary system being the centrifugal atomizer but would also include the tubing, hook-ups and nozzles for the high-pressure system. This way the user can decide which system they would like to run—possibly even both if they prefer. This system would have the most user options but would obviously come with an increase in price.

Rotation and Tomato Cage

Rotation was originally one of the key features that we were going to address, but as of recently it has been left as a responsibility of the Pivoting Lift Mechanism team. After this change we still wanted to investigate the benefits of rotating the plant independent of the pot body. The main advantage would be the rotation of the root system as it would allow for better coverage from the aeroponic and hydroponic systems. But issues arose when investigating the effects of rotating the root system and it was decided not to move forward with these designs. These issues included: possible root damage, conflicts with the tomato cage needing to rotate with the plant, and additional cost and complexity due to the need of an additional motor and bearings—which would have to be strong enough to rotate a large, fully grown plant.

Because we no longer are rotating the system we believe that the tomato cage provided in the manual self-watering pot would be sufficient. Using this tomato cage, we can increase the amount of shared tooling between the manual and automated pots, decreasing manufacturing costs. We came to the conclusion that it would not be necessary to automate the tomato cage because it does not need to move with the growth of the plant. Since the cage will only have to be raised if the plant needs support, we believe that the manual version is sufficient.

Hydroponic System

The hydroponic system that we have chosen is a simple drip system. Once triggered, a small submersible pump in the water reservoir will power a constant drip system. The pump required should be high flow and low pressure and would only need to provide two feet of head—the vertical distance the pump can push the water.

Aeroponic Failure Detection

In order to detect failure we have decided to focus on the detection of water leaving the atomizer. We chose this location as it is the end point of the aeroponic system and thus failure of any of the components will be represented here. We will be using a water sensing circuit to detect failure, if the sensor is not tripped after a set time period or number of watering cycles failure will be assumed. The sensor is very cheap, under $1 for prototyping, and should be able to easily connect with a microcontroller.

Other Systems/Functions

Temperature Monitoring

Temperature monitoring will be performed by placing thermistors in various locations in the root zone. By having sensors in various locations an average can be calculated and the temperature of the root zone can be better monitored.

Humidity Monitoring

Measuring the humidity of the system is of high importance as it gives us a quick look at the status of the root system—low humidity can alert the user that the roots may be drying out. We will be using a capacitive type hygrometer which can adjust to changes in relative humidity within a few seconds. Humidity sensors can be found for $4 to $8—but do require somewhat complex circuits. A combination sensor was found at Sparkfun.com that incorporates both humidity and temperature sensors. The humidity sensor works in the entire range of 0-100% relative humidity and has an accuracy of ±2%. The temperature sensor has an accuracy ±1 ° F. The sensor can be bought for $10 and is ready to be connected to a microcontroller; we believe this is the sensor we should use.

Oxygenation of Root Zone

A major concern to root development is the delivery of oxygen in between watering cycles. We deemed it ideal for the oxygen levels to be monitored—in parts per million for example—and adjusted with air inflow when necessary. A handful of sensors and methods are currently available on the market but each comes with its own disadvantages—the most common one being high price.

The most reasonably sensor available is the Clark Electrode. These sensors are the cheapest at $25; unfortunately we believe that this price is still too high for the scope of this project.

Our solution to this problem is to work around the need for oxygen sensors by setting up an oxygenation cycle in between watering cycles. This would be accomplished through the use of an inlet air fan that would be programmed to run during the time between watering cycles when the root system is taking in the majority of its oxygen. One issue presented by this approach is root dry-out. This can be managed with a combination of programmed settings and may include: monitoring the humidity levels, and having a fan shut-off level; setting a maximum fan run time; or through fan airflow control.

Cooling

We have decided to investigate the viability of using a thermoelectric cooling pad to lower the temperature of the system when needed. Because of the nature of the thermoelectric pads one side gets cold while the other gets hot. For effective use both sides of the pad need airflow over the surface—preferably in conjunction with heat transferring fins.

If this system proves to be too expensive for use, the other option adds no extra cost to the system. The effect of evaporative cooling will already take place in the root zone when airflow is introduced. As air flows over wet surfaces water will evaporate into the air and reduce the temperature. This could be relied on to reduce system temperature but may not be sufficient when large temperature decreases are needed.

Heating, Cooling, and Airflow

In order to accomplish airflow to the roots we plan on adding a fan that can circulate air inside of the root zone. This function can also be utilized to control the temperature of the root zone. By adding a simple resistive heating element to the fan's duct system, warm air can be circulated when the temperature drops below a minimum tolerable temperature; as a safety mechanism the fan must be set to run anytime the heating element is on to prevent component damage. When the system needs to be cooled the fan can be turned on to push out hot air or to circulate cool air if an active cooling system is to be used. Other concerns that must be addressed and possible solutions include: light penetration into the system, prevented by directing the air-flow through curved ducts; dirt contamination with in-flowing air, prevented with an air filter or screen; and root damage from direct heat, prevented by choosing an appropriate outlet direction for the fan duct.

Final Decision

For our top concept we will be using either a centrifugal atomizer and motor or the more widely used pump with at least two atomizing nozzle. The backup system will use a basic tube to be implemented with a submersible pump that will pump water up to the top of the roots and allow the water to trickle down—a hydroponic system design.

The outer structure of the design will be based off of an already existing self-watering pot. We will take this and remove some unnecessary components if any and integrate our aeroponic/hydroponic components. In the existing pot there is a lower section reserved for the water reservoir with a centralized opening into root zone area. In this opening is where we plan to have the main aeroponic atomization system, sending the atomized droplets upward into the root zone. The backup hydroponic system will be placed in a corner of the interior. This will include a small pump that is placed in the water reservoir, and a small water line from the pump up to the top of the root zone. We also plan to have multiple sensors located on the interior walls of the root zone area. A water-tight enclosure for the electronic components will also be necessary; this will be located below the reservoir.

The material of choice has already been decided upon since our project is a more sophisticated version of an already existing self-watering plant pot. We will be using the same design of the housing and the same materials in order to save costs on manufacturing. The material of choice would be ABS plastic.

For the aeroponic system we came up with the concepts presented and described in Appendix G. The final concepts were chosen to be the centrifugal atomizer and the high-pressure water atomizer. Represented in Figure 5, is a simplified schematic of our system.

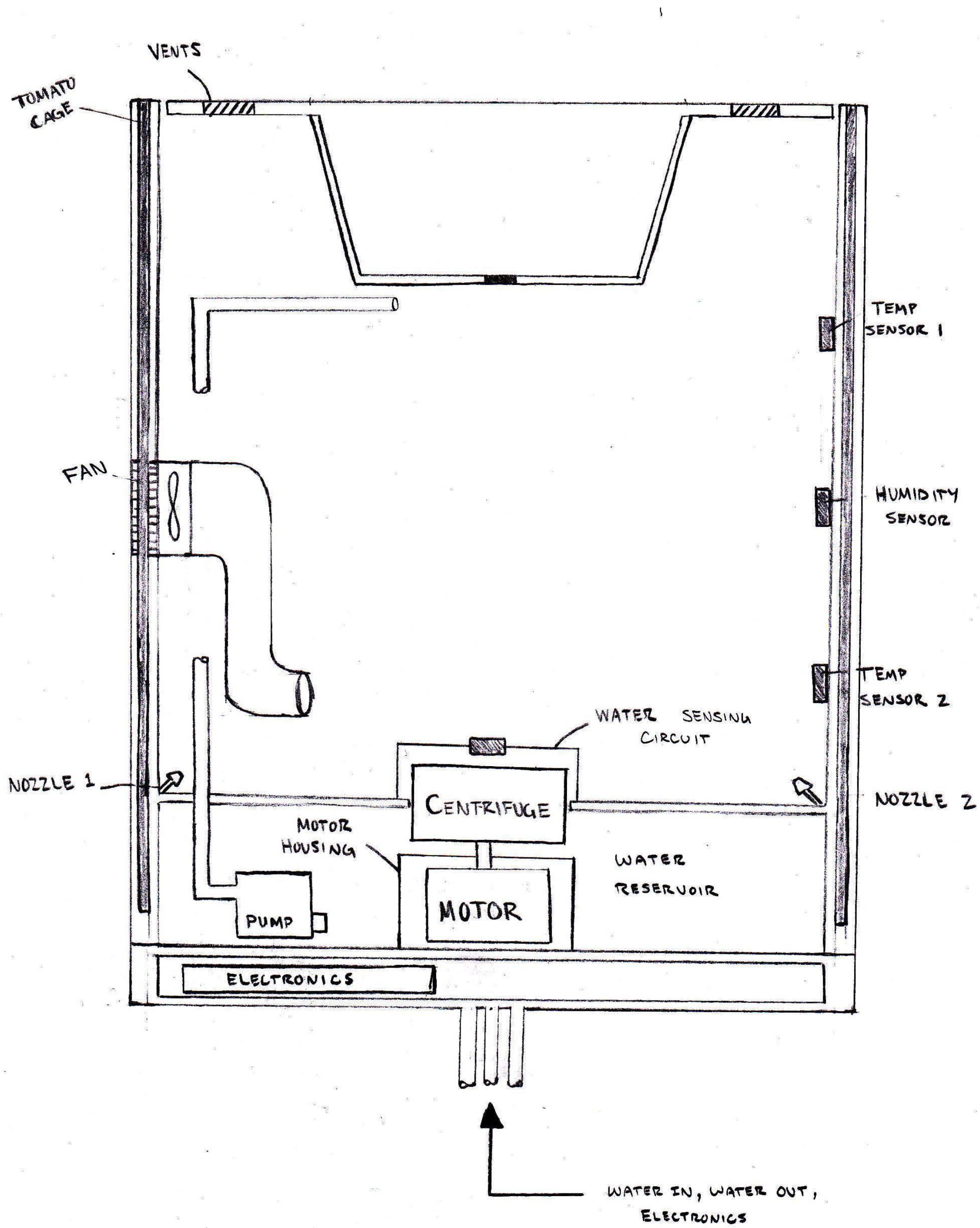


Figure 5: Simplified Schematic of System

Chapter 4: Description of Final Design

Overall System Description

For the final design we will be using a centrifugal atomizer as the driving unit of the Aeroponic System. This system will include the Archimedes Pump, Distribution Fan, and Atomizer running directly off of the shaft of a single motor. The Backup Hydroponic System will use a submersible pump that will pump water upward and out of a drip ring with nozzles directed radially inward around the top of the root zone. There will also be a series of sensors to work in conjunction with a microcontroller to provide the user with full control over the system. Figure 6 shows the general layout of the system and figure 7 shows the aeroponic atomization system.

The outer structure of the design will be based off of the already designed self-watering pot. In the existing pot there is a lower section reserved for the water reservoir, with a centralized opening into the root zone. This opening is where we plan to have the Aeroponic Atomization System, pumping the nutrients up and sending the atomized droplets upward into the root zone.

The backup hydroponic system will be placed in a corner of the reservoir. This will include a small pump that is placed in the water reservoir, and a small water line from the pump up to the top of the root zone.

The Air Flow Fan and Duct will be located on the side of the lower section of the root zone. Inside the duct a coiled Nichrome wire will act as the Heat Coil.

We will have multiple sensors located on the interior walls of the root zone and reservoir. Thermistors will be placed in the upper and lower root zone as well as one in the reservoir to measure temperature of the root zone air and reservoir water, respectively. A single Hygrometer will be placed in the mid-section of the root zone to monitor humidity. Three water-sensing circuits will be used: one at the outlet of the Atomization System to monitor for failure, and two in the reservoir to monitor water capacity/level. A water-tight enclosure for the electronic components will also be necessary; this is currently located above the Air Flow Fan.

System Layout

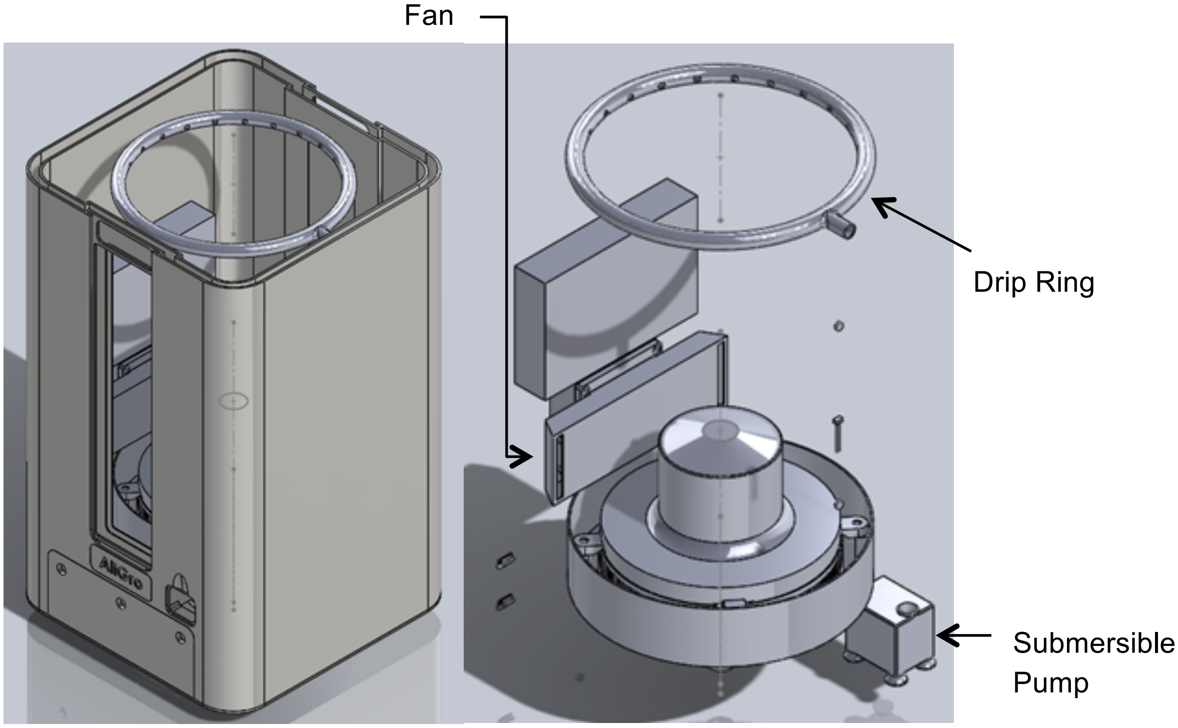


Figure 6: Overview of System Layout

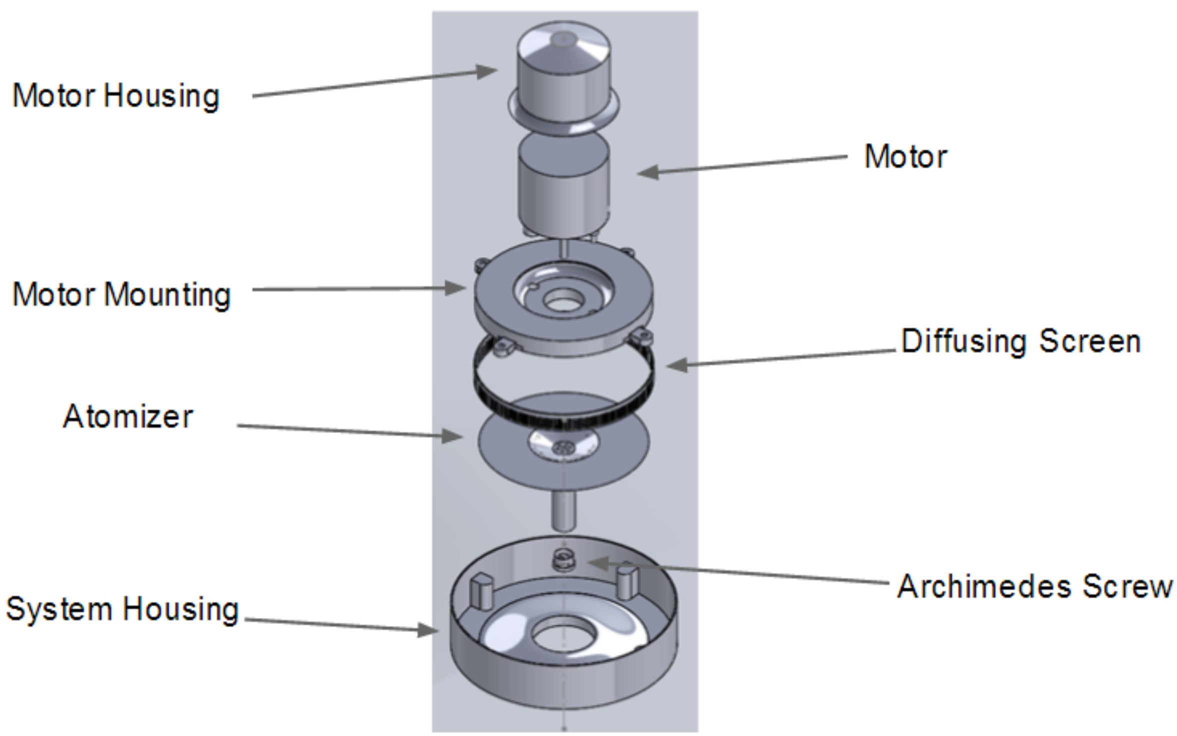


Figure 7: Aeroponic Atomizer System Layout

Detailed Design Description

Aeroponic System

After presenting two different designs for atomization, centrifugal and high-pressure atomizers, the decision was made to proceed with designing, building and testing the centrifugal atomizing system. A huge benefit of the centrifugal atomization system when compared to the high pressure pump system, is that the nutrients will be able to be pumped up to the atomizer, atomized and then delivered to the roots by only using a single motor. Similar to that of a home humidifying unit, this system will use an atomizing disk, in conjunction with a fan and a diffusing screen to provide the targeted droplet size of 50 microns. Figure 8 gives details on how the atomization process works.

As this is the most important design specification for the project, some components will require further testing before recommendations can be made. For instance, the final dimensions of the atomizing disk will not be determined until further testing and analysis is performed. Various designs of the atomizing disk will be tested to determine the best size of the disk, keeping in mind the volume of space that will be taken, the size of the droplets that each will produce, as well as the flow rate produced by the fan. Testing will done with varying disk size diameters as well as varying fan blade sizes.

For this reason the final specifications on the motor used in the Aeroponic system cannot be finalized until the final dimensions of the atomizing disk have been determined. This is because the different sizes of disks will require different operating speeds of the motor to achieve the desired droplet size and flow rate. Once the desired speed for a 50μm droplet size is determined, that will be the central point for the range of speed we want the motor to have, this will allow for the user to control the size of the droplet size if desired.

Hydroponic System

In the concept design we implemented a simple drip system as the backup system and this is what will be used in the final design. One alteration that was made was that the system will also use a radial dripper to provide a more even distribution of the nutrients to the roots. Once triggered, a small submersible pump in the water reservoir will power a constant drip system. The pump required should be high flow and low pressure and would only need to provide 15 inches of head—the vertical distance the pump can push the water. The pump we selected that would be appropriate is the Aquatop NP-302 which is a basic submersible pump that could provide more than the required head needed, is reliable, and is inexpensive. The pump has dimensions of 2.2in x 1.8in x 2in, and can provide a max head of 27 in and a max flow rate of 130 gph.

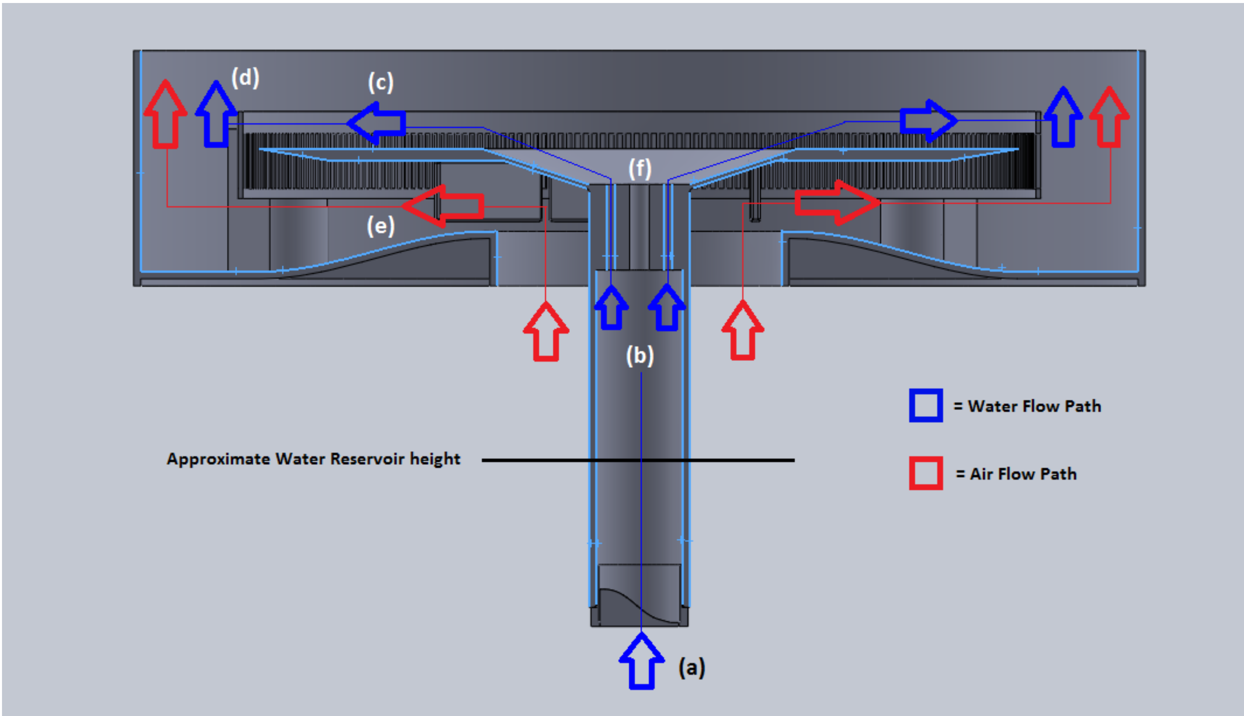


Figure 8: Atomizing Disk: (a) Water Inlet; (b) Entrance Pipe Exit/ Disk Inlet; (c) Water accelerates towards disk edge; (d) Atomized water exit; (e) Airflow through System Housing; (f) Motor Shaft mounting hole

Flow Path of Water and Air through the Atomizer System

a) The Archimedes Pump is fully submerged in the reservoir. When the system rotates it begins to pump water vertically.
b) Here the pumped water exits the entrance pipe through six holes, initially separating the flow.
c) On the spinning disk of the Atomizer, the water is pushed to the outside of the disk due to centrifugal force, accelerating its tangential speed.
d) At the edge of the disk water has reached atomization velocities. At this point the water flow is split: smaller droplets are ejected directly into the air while larger droplets impact the ribs of the Diffusing Screen. Of these larger droplets some are broken into smaller droplets and ejected into air, while the droplets that are still too large fall down into the system housing to return to the reservoir.
e) Air flow is pulled into the system housing, powered by the Distribution Fan blades on the bottom of the spinning disk. This Airflow is directed by the surface of the housing toward the edge of the disk and then upward, perpendicular to

the water exiting the diffusing screen. This airflow picks up small droplets and transports them into the root zone; droplets that are too large to be pulled into the airflow fall down into the system housing to return to the reservoir.

f) The shaft of the motor is mounted through this larger central hole and secured with a set screw.

Supporting Analysis

Centrifugal Atomizer

The main focus on the centrifugal atomization was the determination of the droplet size after atomization. Consultation with Dr. Shollenberger of the California Polytechnic University Mechanical Engineering Department, led to research on experimental correlations for drop size. Correlations for determining the mode of drop formation, and mean droplet sizes were found: detailed analysis can be found in Appendix E. The mode of droplet formation was determined to be film disintegration; which correlates to the largest flow rates. Knowing this the correct correlation was used and the mean droplet size for the centrifugal humidifier was determined to be very near to 50 microns, our target droplet size.

It should be noted that the correlations do not take into account the effect of the Diffusing Screen or the Distribution Fan, which both serve to decrease the droplet size distributed to the root zone.

Because of the high level of complexity and randomness seen in two-phase fluid flows, the calculated mean diameter can only be used as an estimation. In order to determine the correct droplet size for our system testing must be done.

There are two primary ways to influence the droplet diameter with centrifugal atomization: either adjust the diameter of the Atomizing disk or the speed at which it rotates. The general rule is that the larger the diameter or the higher rotational speed, the smaller the droplet diameter.

The first tests that will be performed will be to determine the disk diameter and rotational speed range for the prototype. The testing will involve purchasing multiple standard Atomizer Disks for the Trion Herrmidifier Centrifugal Humidifier. These disks will be laser cut to different diameters while all other dimensions and features will be kept the same. In this way we will be able to isolate the effect of changing disk diameters. The testing will also involve running each disk over the speed range of 3,000 RPM-8,000 RPM to investigate the effect of rotational speed. The minimum speed was chosen because it is the speed at which the Distribution Fan is rated. At speeds below this, the fan’s power will decrease, which subsequently will decrease the mass flow rate of water delivered to the root zone. The maximum speed was determine by inspection of the Figure 9, where it can be seen that at speeds increasing the speed above 8000 RPM has a less drastic effect on droplet diameter. Our goal is to determine a disk diameter and a range of rotational speeds that will provide a range of droplet diameters from 25-75 microns.

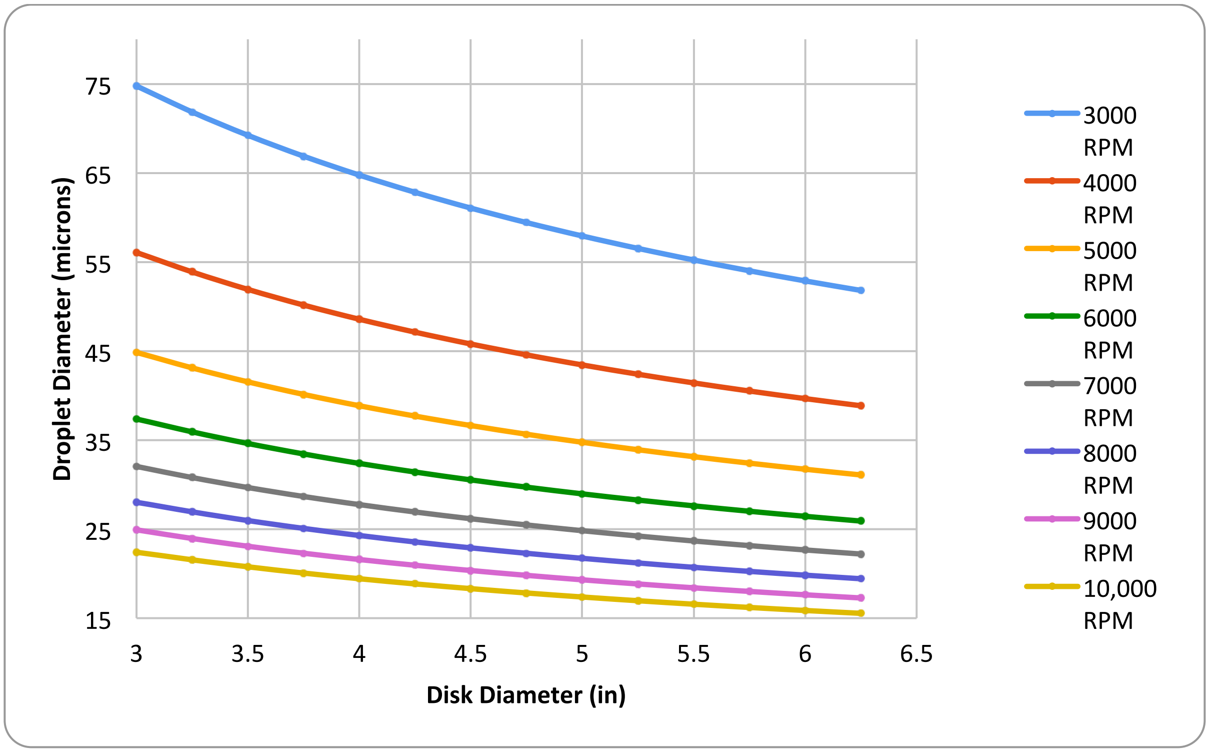


Figure 9: Droplet Size Variation with Disk Diameter and Speed

Fan Flow

To determine the fan needed an approximate flow rate was determined. Using the volume of the root zone and a one-minute time for full cycling of fresh air the flow rate needed was determined to be about 1 cfm, found in Appendix E. This is a very small flow rate, so the choice in fans was very broad. We decided to go with the Enermax Marathon, magnetic bearing cooling fan. This fan has a maximum flow rate of 26 cfm, much higher than we need for oxygenating flow between watering cycles. This range of flow rate is desirable for heating and cooling, as the flow rate would need to be higher for larger cooling or heating loads.

The fan provides many benefits, namely the magnetic bearing. This bearing is water resistant as it uses an induced magnetic field to hold the fan in place and provide rotation. These bearings last much longer than standard ball bearings, approximately 40,000 hours. Another benefit is that these bearings function at an extremely low sound output, about 14dB—lower than a whisper.

The fan will need to be provided power through a relay, as the voltage and amperage requirements are higher than a microcontroller can provide, but will still be controlled through the microcontroller.

System Heating

Heating of the root zone will be controlled through the use of a Nichrome Heating coil. In order to determine the heating load required by the system heat transfer analysis was performed, found in Appendix E. The result from this analysis is that heating load would be 50W. This value was determined using a 65°F root zone temperature and a 40°F ambient air temperature, considered a worst case scenario temperature differential. In the more likely case that the ambient temperature was in the range of 50-60°F, only 15-25W would be necessary.

Through communication with Gary Jacobs from Jacobs Online, our selected Nichrome wire distributor, the Nichrome-60 28 gauge heating coil was chosen.

Safety Considerations

There are no huge risks of injury with the system as all of the components will be enclosed in the system; the user will be operating the module remotely. There are two areas that may be of small concern, the fact that the electronics will be in very close proximity to the water reservoir and that the heating coil will have components surrounding it of a plastic material. The concern of the electronics will be addressed by ensuring the electronics housing is properly sealed and will also undergo testing to ensure no leakage. The issue with the heating coil was already addressed and will require the fan to be on anytime the heating coils are used. This will also be tested to ensure flow across the coils is enough to prevent any damage from the heat produced.

The root zone climate will be monitored by the numerous sensors and will be controlled by the user; therefore the only risk of damage to the plant could be due to the rotating disk. It is possible that roots can make their way into the Atomizer Housing, and thus be exposed to the spinning Atomizing Disk. Though we are unsure this will actually cause any damage to the roots, it is a good preventative measure to avoid the issue. To avoid this we may implement a mesh like screen to avoid roots from entering, yet still allowing for the atomized droplets to escape. This too will require testing to determine whether or not this will be an issue with the flow rate of nutrients to the plants.

Material Selection

The majority of the components of the Self Watering Pot design are going to be injected molded. Since our design is going to be easily implemented with the already existing module, the majority of the components of the prototype design are going to be made using the rapid prototype machine on the Cal Poly Campus. For this reason we are going with ABS-plastic for most of the parts that are not going to be outsourced. The motor housing and the fan duct are the only two components that are going to be made of another material, aluminum. Aluminum was chosen for these two components because they will be dealing with heat. This is critical for the motor housing as it is very important that the housing be moderately conductive with heat to prevent any damage to the motor.

Cost Analysis

The next phase in the project is to begin Atomizer Disk testing. The tables below display a cost breakdown for the testing procedure. The Diffuser Screens for Atomizing Disks B and C will be laser cut out of strips of ABS, detailed drawings can be found in Appendix D. Also supplied in the appendices are tables of the cost analysis for testing, as well as prototype costs, two rightmost columns of these tables are the distributors to be used for purchase of the prototype parts and the manufacturer that we could use for the large scale production of the product.

In appendix C, is a list of the components needed for testing. Originally, the plan was to 3-D print the atomizer disks, but now we plan to purchase five Trion 707u Impellers, the Atomizer Disk from the Centrifugal Humidifier. We will laser cut the disks to different configurations; this approach will decrease the cost of testing. The atomizing disks we will be using requires a ¼ inch shaft from the motor, while we will be using a motor with a 1/8-inch shaft, for this reason we also need a shaft coupler and a ¼ D-shaft. The diffusing screen will be laser cut specifically for each atomizing disk, so a large strip of ABS will be ordered. The motor to mount adapter will also be made from the ABS strip.

In Appendix A, receipts for the items that have already been purchased for the project; these expenses need to be reimbursed to Sean Marrs. The table in Appendix C lists the components that are required for the final prototype but ordering of these components will be postponed until testing is complete.

It should be noted that the Centrifugal Atomizer Motor is not currently selected for prototyping but for the testing of the atomizing disks. This motor will need a larger speed range than that of the prototype because the operating range of the prototype will be determined through testing.

Chapter 5: Product Realization

Laser Cutting

The majority of the prototype was made of acrylic and PETG. Components were cut from these materials using a laser cutter in order to get exact dimensions. Components were bonded together using acrylic cement—a solvent that melts mating surfaces to provide a solid connection.

Though laser cutting was used as the primary fabrication for the exactness of dimensions and production of complicated shapes, the nature of how laser cutting works provided some unexpected difficulties.

The primary issue was the production of flat edges for edge gluing. Because the laser needed multiple passes to cut through the material the distance between the laser and material increased over successive passes. This increase in distance affected the intensity of the laser and the width of the cut. This effect produced slanted edges instead of the flat surfaces needed for edge gluing.

To solve this problem we first adjusted the distance between the laser and the material after each pass. This was our attempt to keep said distance constant throughout the cutting process. This resulted in flatter edges, though not perfectly flat. From this point we used a combination of sanding and grinding to produce edges suitable for edge gluing. In addition to these methods we also adjusted the design of components to limit the use of edge gluing as well as organized the cutting templates to take advantage of the flat edges of the raw material.

Many components, while the same material as those laser cut, were cut out by hand. These components were primarily rectangular in shape and include but are not limited to the fan duct and electronics housing. The main tools for manufacturing were safety blades—for scoring and breaking along the score—and hacksaws. These components were assembled using the same acrylic cement methods.

Leakage Mitigation

After the majority of manufacturing was complete, preliminary testing of the prototype revealed what would be one of our largest problems— water leakage out of the system. While the majority of the system was designed to have vertically overlapping edges to keep water in the system, points of access for the motor, pump, and sensors were high-risk areas for leakage due to the wicking effect of water. The small gaps between the system housing and the wires exiting the system provided ample opportunity for water to make its way out of the system.

Most of these leakage points were temporary, as they would be sealed with silicon for the final prototype. But during the interim, leakage was mitigated with temporary barriers such as duct tape and were prevented from contact with any active electricity areas such as the microprocessor and relays.

For the final prototype the system housing exit for the motor's power cord was the only component not sealed with silicon. This was in order to maintain the ability to remove the motor from the system completely in order to gain access to the water reservoir and atomizing impeller. To prevent leakage this cord was routed under the fan duct's protective cover. Furthermore the cord was routed in a parabolic shape, the vertex being the lowest point, so that water on the cord would collect and drip back into the reservoir.

Humidity/Temperature Sensor

The combined humidity and temperature sensor placed in the root zone failed to produce correct readings. The humidity sensor while likely reporting the correct values some of the time, proved not valuable. The problem emerges from the fact that after a short period of time, the humidity sensor is completely saturated with water during the atomization process and thus would read nearly 100% humidity. This is not surprising due to the fact that during the atomization process the air in the root zone is saturated past its ability to hold moisture, this could be seen from the large amount of condensation and settling following the end of the atomization process.
The main issue with the humidity sensor is realized after the end of the atomization process. After this the sensor is completely covered in condensation and does not dry enough during the off time to read anything but 100%.

After verification of the system's ability to provide an adequate root zone environment for the growing of an actual plant, it was decided that keeping an adequate level of humidity was not problem. Due to the short duty cycles used for the system it has been determined that the humidity sensor, assuming that it provided accurate data, was not a valuable sensor for this system and would not be recommended in further iterations.

The temperature sensor included with the humidity sensor eventually failed due to constant exposure to water. The temperature of the root zone is the most important parameter to monitor for the root zone environment so it is highly recommended for future iterations to replace the humidity/temperature sensor with a water-proof temperature sensor like that used in the water reservoir.

Coding

A big portion of the project was the requirement of a control system. For the brains of the module we decided to go with the use of an Arduino microcontroller. Arduino is an open-source electronics platform based on easy to use hardware and software, which is used to develop interactive objects. In the case of our project, it takes inputs from different sensors and also controls a motor, pump, and fan.

Writing the code for the module required a lot of forum based research; since Arduino is an open-source platform, there is much available that people share for the benefit of others. The process involved taking small portions of previously written codes or codes that only did one single function. These would later be used and combined into one unique code for our project. For instance, we would write one code that would sense temperature and output the values, or we would write the code to control the fan for a specific timing schedule.

A big problem with the coding portion of the project was that nobody from team was a programmer. Nobody was great at coding, nor did anybody have very much experience with coding or using microcontrollers.

Issues began to arise when we began construction of the final code that would complete all the necessary functions of the module, together. It became apparent that the higher the functionality you want the project to be, the greater the difficulty of the code will need to be, at least for the less experienced programmers.

If further development of the project is to be considered, we would recommend that a professional programmer re-write the code. Although the module works well and completes all the necessary functions, it was written on a very inexperienced level. The code could more than likely be written in a more efficient way. This is important as it could cause the Arduino to freeze, like computers do sometimes. This is usually an issue for the more complex projects and should not be an issue here. There is also the possibility of a freeze due to the memory capacity. While the Arduino runs it is continuously storing data, so eventually all the onboard memory will be filled and this could cause problems with the program. This can be avoided by writing a much more complicated code that basically has a reset function built into the code—to clear the memory when it reaches near capacity, which can easily be done by a much more experienced programmer.

Changes from Final Design

The major changes from the final design implemented in the prototype were the relocation of the electronics bay and the ventilation fan, as well as the limiting of the fan's functionality.

The electronics bay was originally planned to be located in the root zone but was moved exterior to the system housing. This was done for two reasons: to provide better access to the electrical components during testing and iteration, and to provide a higher level of safety for the prototype by limiting the chance of contact between the electrical components and water.

For the original design the ventilation fan was located approximately at the vertical midpoint of the root zone and included heating coils to raise the temperature of the root zone if necessary. Before the fan was manufactured the system was tested to get an initial heat profile. It was found from this that cooling the system would be the main function of the fan and that if necessary the heat produced by the motor would be sufficient for maintaining an adequate root zone temperature.

The location of the fan was decided based on lengthening the life of the fan by reducing contact with water and saturated air. As the main function of the fan was now to remove heat from the system the most effective location would have been the top of the root zone so that it could pull out the higher temperature air, but this would have subjected the fan to direct contact with the saturated air leaving the system. To prevent this the ventilation fan was moved to the lowest point in the root zone so that the air moving through the fan would be the dry air from outside the system.

Electronics Bay Manufacturing

The main thing that was addressed in the manufacturing of the electronics bay was the isolation of the high voltage components. The relays that controlled power flow to the pump and motor provided 120V, standard wall power, and thus for safety considerations needed to be physically isolated. To accomplish this a removable cover was manufactured.

Chapter 6: Design Verification (Testing)

Motor Heat Profile

The first test to be conducted was the motor heat profile. In these tests two temperature sensors were used; one in the system's root zone and one in physical contact with the motor cover. In the first test the atomization system was run for the entirety of the time and the temperature data of the root zone and motor were plotted against time. This test provided us with the rate of temperature increase of the motor. The second test utilized a 25% duty cycle for the motor to reflect the cycle that would be used for an actual plant. The cycle times were: four minutes on and sixteen minutes off. This provided us with appropriate run times for the motor to limit heat transfer into the system.

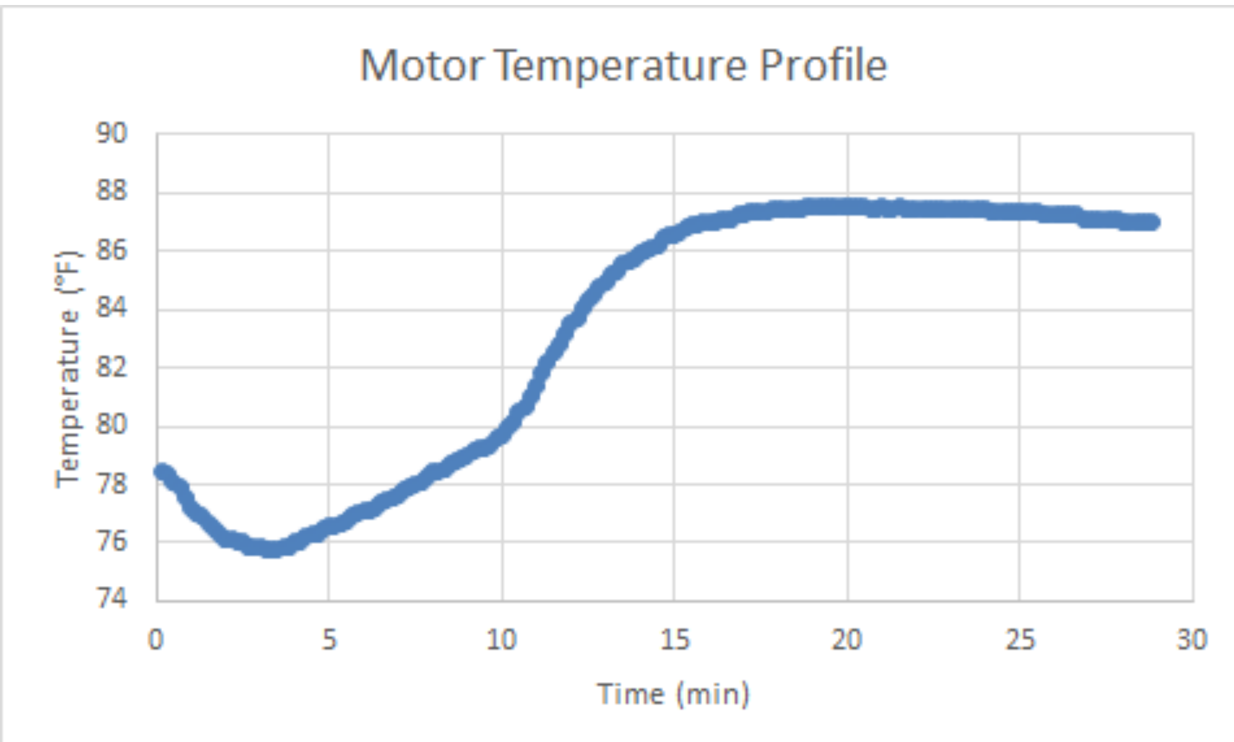


Figure 10: Motor Temperature Profile

Figure 10 shows the change in temperature of the motor after being run constantly for 20 minutes. It can be seen that initially the temperature drops due to the evaporative cooling effect from the atomized water-air flow.

Motor and Pump Heat Test

The next test was run with the addition of the hydroponic drip system as well as utilizing an on-off cycle for both components to reflect how the prototype would run when a plant was in the system. The temperature of the root zone and motor were collected. The schedule was as follows: four minutes of motor run time followed by two and a half minutes of pump run time and then a thirteen and half minutes of off time.

The concept behind using the hydroponic pump was to use the water provided by the hydroponic system to cool the motor cover and transfer heat into the water reservoir instead of the root zone. As it takes more energy to increase the temperature of water than air, the root zone temperature did not rise as significantly as the motor only tests.

Motor and Ventilation Fan Heat Tests

After studying the results of the previous tests it was determined that the maximum root zone temperature occurred near the end of each cycle. From this information we decided to run the ventilation fan for the last two minutes of the cycle, this would also allow time for any excess moisture in the air to settle before the air was removed from the system. The schedule was as follows: four minutes of motor run time, fourteen minutes of off time, and then two minutes of ventilation fan on time. The results of this test were that the temperature of the root zone was mitigated much more effectively than with just the pump. This made sense because the air being pulled into the system was much drier relative to the air in the system. The result of this was that water collected on the inside surface of the system housing would evaporate into the air, reducing its temperature, while the hot air collected at the top of the system would be removed.

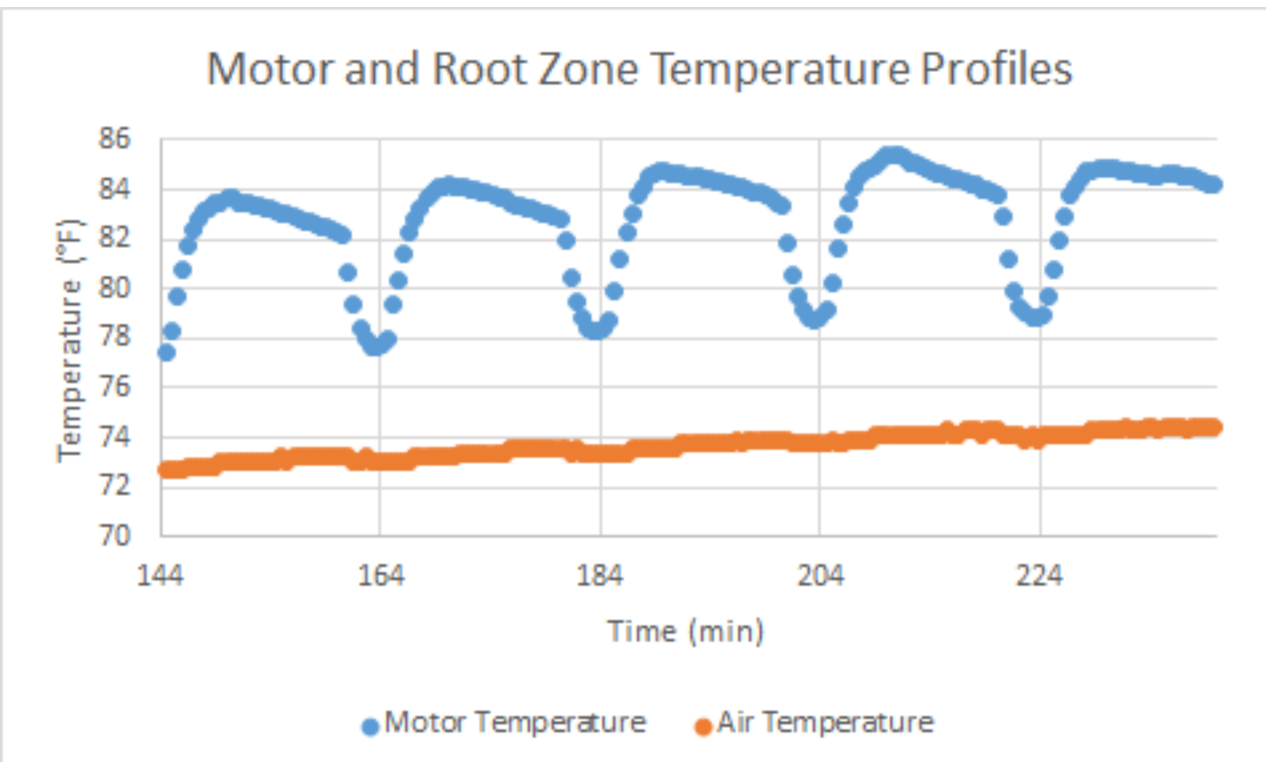


Figure 11: Motor and Root Zone Temperatures

Figure 11 shows that after three hours of run time the motor begins to reach a steady state temperature but the air in the root zone continues to climb with small fluctuations due to the ventilation fan. This test showed us that the percentage of the motor's run time in each cycle should be reduced while the ventilation fan's run time should be increased.

Motor, Pump, and Ventilation Fan Heat Test

The later cycles would include all three components to keep the root zone temperature as close to the ambient outside air temperature. Figure 12 shows that even though the motor has not yet reached steady-state, the root zone temperature is mitigated by the ventilation fan.

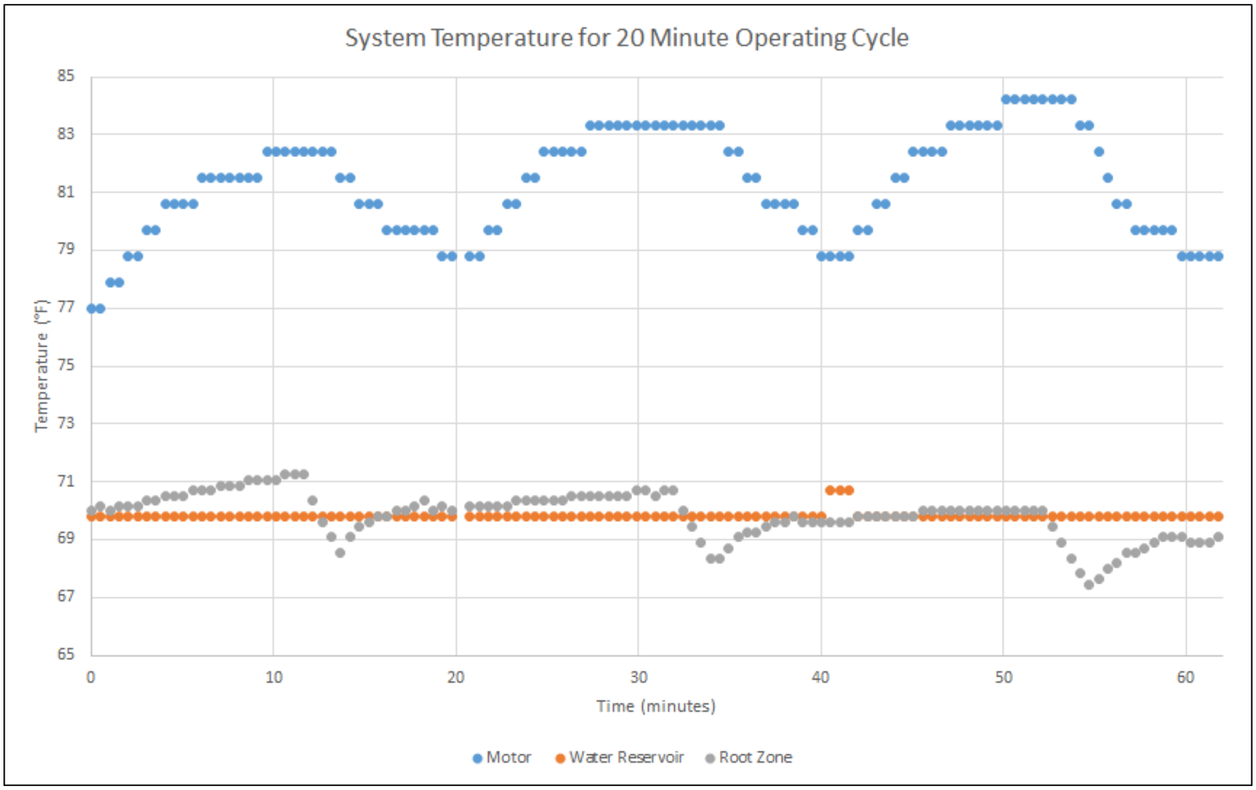


Figure 12: Temperature Profile for Motor, Root Zone, and Reservoir

At this point the construction of the prototype was complete and the cycle was run non-stop with an established tomato plant for a period of two weeks. Over the two weeks the duty cycles of the motor, pump, and fan, as well as the duration of the whole cycle were changed to observe the reaction of the plant. After many iterations it was found that the plant did well with a much shorter cycle, a total duration of three minutes and ten seconds. The schedule was as follows: thirty seconds of motor run time, ten seconds of pump run time, one minute off, ten seconds of pump run time, one minute off. For this cycle the fan ran for the entire time that the motor was off. The reason for this is that the fan used in the prototype, and its placement, was not as effective as the fan used for testing which was larger and located at the top of the root zone. The reason for the short bursts of the pump was to limit the use of the pump while still removing some heat from the motor and to keep the lower sections of the roots moist and cool as they were the closest to the motor.

Chapter 7: Conclusions and Other Recommendations

Near the end of testing the final design and code, deterioration of the plant's root health was noticed after the addition of more nutrient water solution. We observed a rapid change of the tips of the root ends from a nice healthy white to a black color. After further investigation, we found that the nutrient-water solution in the reservoir was much too concentrated. Normally the nutrient water solution is kept at a constant pH of 6 and a Total Dissolved Solid (TDS) content of 1200ppm, but the solution in the reservoir was at a TDS of 1700ppm. We expect that this happened because water evaporated out of the system, but left much of the nutrients behind, concentrating the solution. To prevent against this we would recommend the addition of a TDS meter and pH sensor to the design, as levels too high or too low of either could harm the plant.

The current water level sensor in the system is a very simple sensor. It is comprised of two probes that sense a small voltage that goes from one probe to the other through the nutrient-water solution. If there is no water then the circuit is not completed, and it displays an error message. It is a simple sensor that essentially says "yes" there is water, or "no" when the reservoir is empty. More modern sensors function in the same way, but utilize strips rather than probes. These would be a better choice because they can give more accurate readings of the water level and can display exactly how much is in the reservoir after it is calibrated.

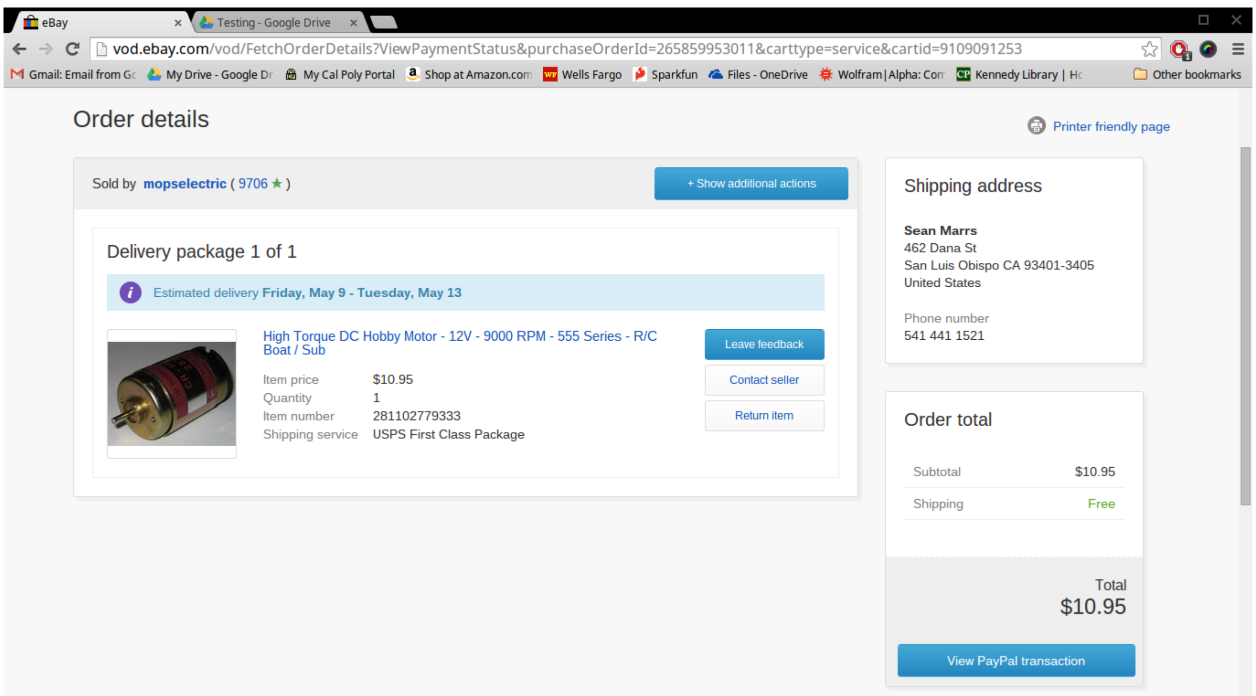
In the current design the fan location was already an improvement from the initial design. Currently, since the atomizing disk works very well, there is some fine nutrient mist that makes its way to the fan when the system is running. Although it wasn't an issue, ideally we don't want any of the nutrients to get onto the fan to protect from nutrient build up and electronic shortening. It would be a good idea to redesign the location or the shelter for the fan. Some ideas we had are to put a netting material that would allow for air to pass through but collect the small nutrients before they reach the fan. Another option is to design some louvers that would remain closed and open up as the fan turns on.

Another recommendation we have is to improve the exhaust outlets for the ventilation fan. Currently we have 6 small holes that were drilled to act as passageways for the exhaust air to escape. When the atomizer is on, the air flow is strong enough that air and a small amount of nutrients escapes through these exhaust ports. Ideally we wouldn't want any excess water to escape, just the warm air. So we would like to recommend that the same additions be added to that of the exhaust ports that we recommended for the fan as well, either a moisture collecting material or the opening and closing louvers.

Appendix A - Already Purchased Components

Already Purchased Components					
System Component	Name	Price	Quantity	Manufacturer	Distributor
Centrifugal Atomizer Motor	555 DC Motor	$10.95	1		Online Ebay Transaction
Motor Speed Control	AC-DC Hobby Transformer	$2.00	1	Tillman	GoodWill Industries
Microprocessor	Arduino Uno And Starter Kit	$59.95	1	Arduino	Sparkfun.com
Humidity Sensor, Jumper wires, Thermistor	(1) RHT03 Humidity Sensor, (1) 10K Thermistor, (10) Male-Male Jumper Cables	$19.66	1	Max Detect	Sparkfun.com
Total		**92.56**			

DC Motor for Atomizer Disks Tests



Arduino and Starter Kit

Gmail by Google

Sean Marrs <sbmarrs@gmail.com>

Amazon.com order of Arduino Uno Ultimate....

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Total Before Tax:	$54.99
Order Total:	**$54.99**

Humidity Sensor, Thermistor, and Jumpers

SparkFun Invoice

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Billing
Sean Marrs
462 Dana St
San Luis Obispo, California 93401
United States

Delivery
Sean Marrs
462 Dana St
San Luis Obispo, California 93401
United States
5414411521
sbmarrs@gmail.com

Shipping Method: USPS First Class Mail

Tracking Number: 9400110200881139586800
Payment Method: Tokenized Credit Card
Order Status: Shipped 2014-04-02

SKU	Product Name	Qty	Price	Total
PRT-11710	Jumper Wires Premium 6" F/F - 20 AWG (10 Pack)	1	$4.95	$4.95
SEN-00250	Thermistor 10K	1	$0.75	$0.75
SEN-10167	Humidity and Temperature Sensor - RHT03	1	$9.95	$9.95

SUPPLIER'S CERTIFICATION OF COMPLIANCE
It is hereby certified that the product(s) provided in this shipment conform to the requirements and the manufacturer's part number identified in the customer's purchase order and these parts have been received, stored and shipped by SparkFun Electronics.

Signature, SparkFun Customer Service Manager

Subtotal	$15.65
Shipping/Handling	$4.01
Grand Total	$19.66
Transactions:	
Apr-01 Credit Card 4275	$19.66
Order Balance:	**$0.00**

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Please direct any questions or concerns to customerservice@sparkfun.com or 303.284.0979.

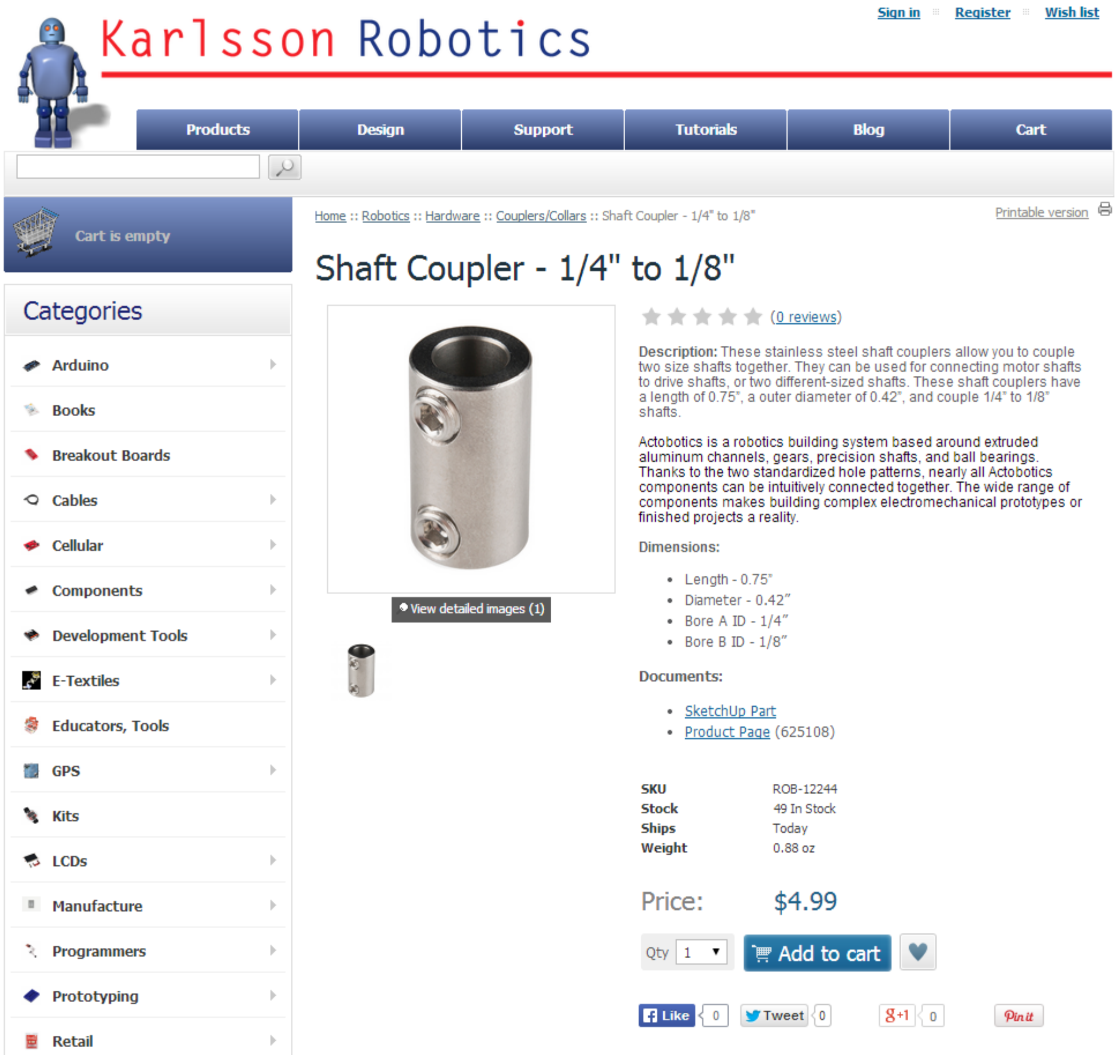
Page 1 of 1

Appendix B - Atomizer Testing Cost Breakdown

Components To Be Purchased For Testing				
System Component	Name	Price	Quantity	Distributor
Atomizing Disks	Trion 707u Impeller	$33.00	5	Bel-Aire
Shaft Coupler	1/8" to 1/4"	$4.99	1	Karlsson Robotics
D-Shaft	1/4" - D Shaft	$1.29	1	Karlsson Robotics
Diffusing Screen	3/64"x2"x5' ABS Strip	$7.15	1	McMaster-Carr
Test Motor Mount	3/64"x2"x5' ABS Strip	-	-	McMaster-Carr
Total		**$178.43**		

Trion 707u Impeller

Atomizer Testing 1/8" to 1/4" Coupler



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Home :: Robotics :: Hardware :: Couplers/Collars :: Shaft Coupler - 1/4" to 1/8"

Printable version

Shaft Coupler - 1/4" to 1/8"

View detailed images (1)

(0 reviews)

Description: These stainless steel shaft couplers allow you to couple two size shafts together. They can be used for connecting motor shafts to drive shafts, or two different-sized shafts. These shaft couplers have a length of 0.75", a outer diameter of 0.42", and couple 1/4" to 1/8" shafts.

Actobotics is a robotics building system based around extruded aluminum channels, gears, precision shafts, and ball bearings. Thanks to the two standardized hole patterns, nearly all Actobotics components can be intuitively connected together. The wide range of components makes building complex electromechanical prototypes or finished projects a reality.

Dimensions:

- Length - 0.75"
- Diameter - 0.42"
- Bore A ID - 1/4"
- Bore B ID - 1/8"

Documents:

- SketchUp Part
- Product Page (625108)

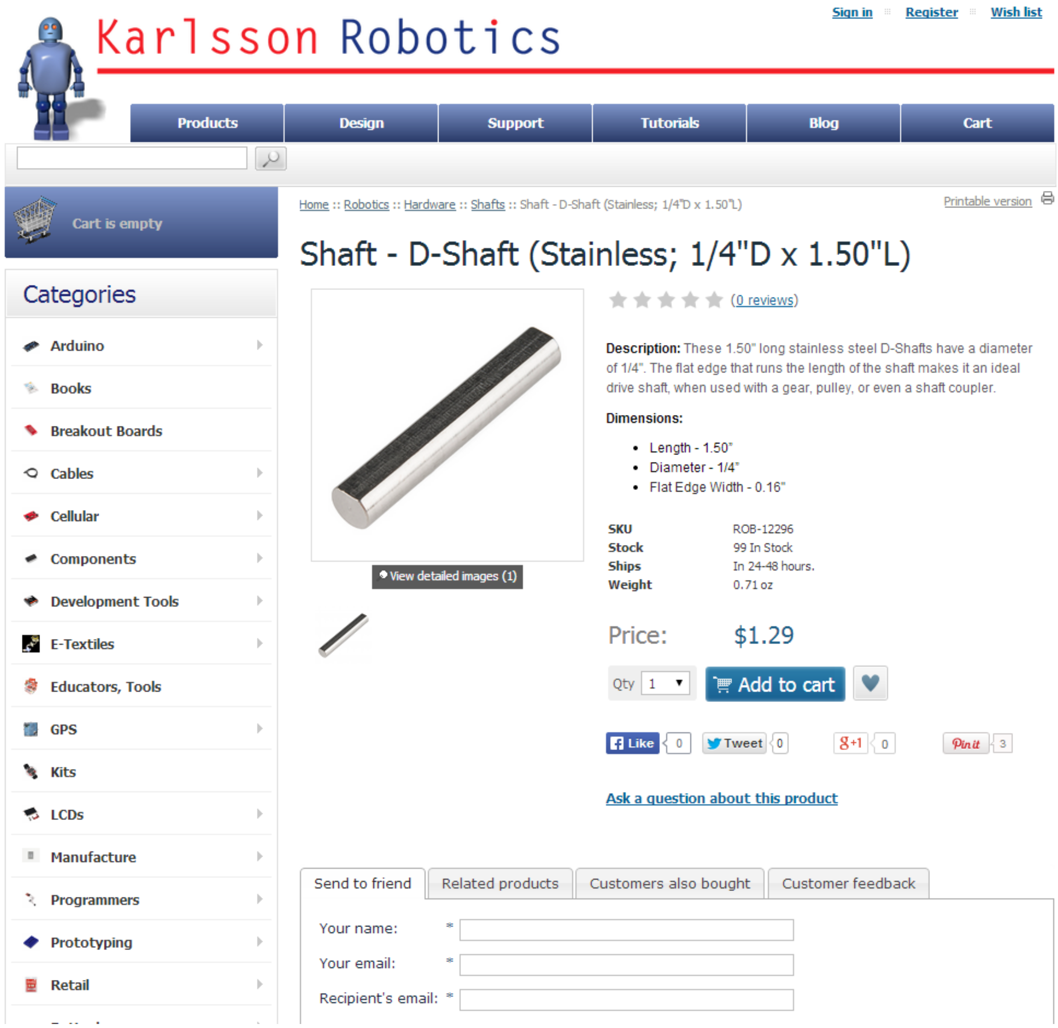
SKU	ROB-12244
Stock	49 In Stock
Ships	Today
Weight	0.88 oz

Price: $4.99

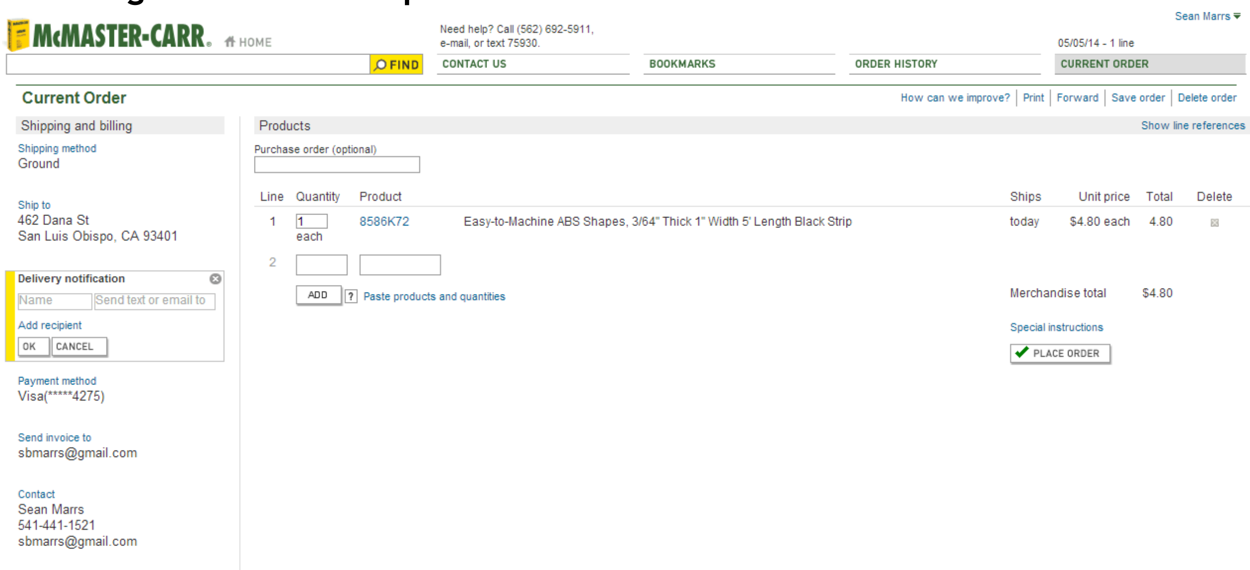
Qty 1 Add to cart

Like 0 Tweet 0 +1 0 Pin it

Atomizer Testing D-Shaft



Diffusing Screen ABS Strip



Sean Marrs

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Add recipient
OK | CANCEL

Payment method
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Send invoice to
sbmarrs@gmail.com

Contact
Sean Marrs
541-441-1521
sbmarrs@gmail.com

Products

Show line references

Purchase order (optional)

Line	Quantity	Product		Ships	Unit price	Total	Delete
1	1 each	8586K72	Easy-to-Machine ABS Shapes, 3/64" Thick 1" Width 5' Length Black Strip	today	$4.80 each	4.80	
2							

ADD | ? Paste products and quantities

Merchandise total $4.80

Special instructions

PLACE ORDER

Appendix C - Cost Breakdown for Prototype Components

Final Prototype Componenets					
System Component	Name	Price	Quantity	Manufacturer	Distributor
Hydroponic Pump	Aquatop NP-302	$12.99	1	Aquatop	TruAqua
Hydroponic Ring Dripper	Water Farm Drip Ring	$8.99	1	General Hydroponics	Rogue Hydro
Cooling Fan	Marathon Enlobal Fan 80mm UC-8EB	$7.95	1	Enermax	Coolerguys
Electrical Relay	SPDT 12V 5A	$0.59	3	American Zettler	FutureElectronics
Temperature Probe	Thermistor 10K	$0.75	4		Sparkfun.com
Nichrome Heating Coil	Nichrome 60- 28 gauge	$4.00	1		Jacobs Online
Hydroponic System tubing	Vinyl Tubing 1/2" ID	$2.99	1	Lee's Vinyl Tubing	Dr. Foster and Smith
Electrical Transistors	NPN (P2N2222A)	$0.50	3	On Semiconductor	Sparkfun.com
Final Prototype Manufactured Components					
System Component	**Material**	**Price**	**Method of Fabrication**	**Distributor**	
Motor Housing	4"x 24" 6061 Aluminum	$6.69	Machined	McMaster-Carr	
Diffusing Screen	3/64"x2"x5' ABS Strip	$7.15	Laser Cut	McMaster-Carr	
Fan Duct	4"x 24" 6061 Aluminum	$6.69	Machined	McMaster-Carr	
Total		**$63.72**			

Hydroponic Submersible Pump

WARRANTY INFORMATION

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PRODUCTS ARE WARRANTIED BY AQUATOP AQUATIC SUPPLIES TO THE ORIGINAL PURCHASER AGAINST DEFECTIVE MATERIAL AND WORKMANSHIP UNDER NORMAL USE FOR A PERIOD OF 180 DAYS FROM THE DATE OF THE ORIGINAL PURCHASE. AQUATOP ELITE PRODUCTS CARRY A WARRANTY OF ONE YEAR FROM THE DATE OF ORIGINAL PURCHASE. PRODUCTS HAVE NO WARRANTY IF: 1) THE PRODUCT HAS BEEN SERVICED, MODIFIED OR TAMPERED WITH BY ANYONE OTHER THAN AQUATOP AQUATIC SUPPLIES, 2) THE PRODUCT HAS BEEN ABUSED OR DAMAGED (INCLUDING BROKEN OR CRACKED BULBS), AND/OR 3) THE PRODUCT HAS BEEN TRANSPORTED WITHOUT PROPER PACKAGING.

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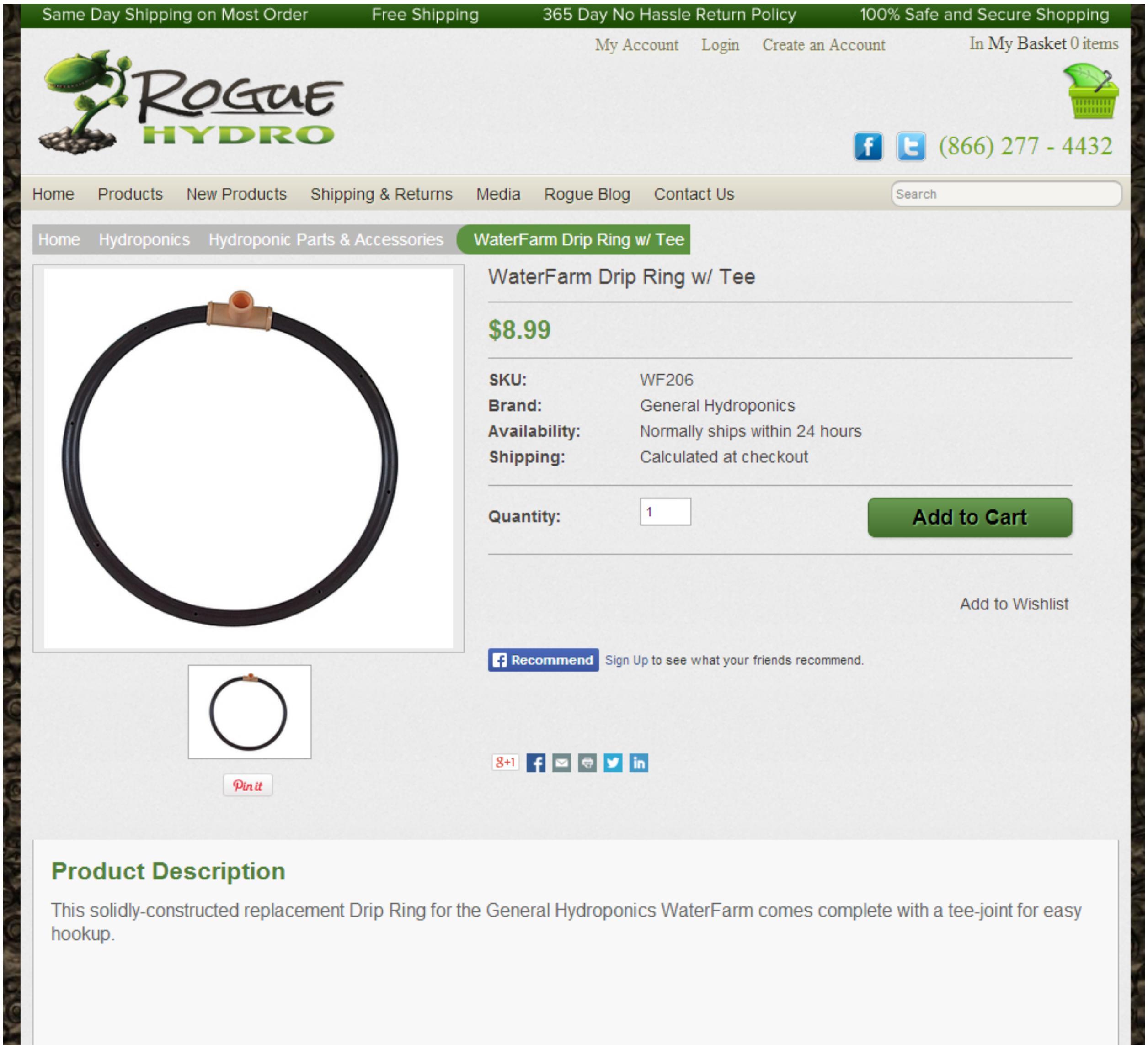
Hydroponic Drip Ring



Cooling Fan

MARATHON FAN

UC-8/12EB

Your satisfaction, Our priority

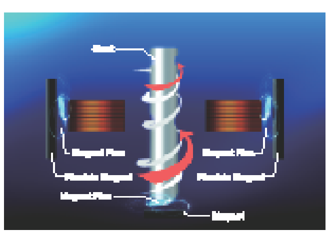
marathon keep running

- LOWER NOISE
- LONGER LIFE
- CLEANABLE

40,000 hours MTBF
higher than 2 Ball Bearing

Feature

- Exclusive ENLOBAL bearing with magnetic-barometric design to run friction-free and noiseless.
- Nano-technology for lowest abrasion and highest durability.
- Detachable fan blades for cleaning.
- Best wire management and 3 to 4 pin adaptor.



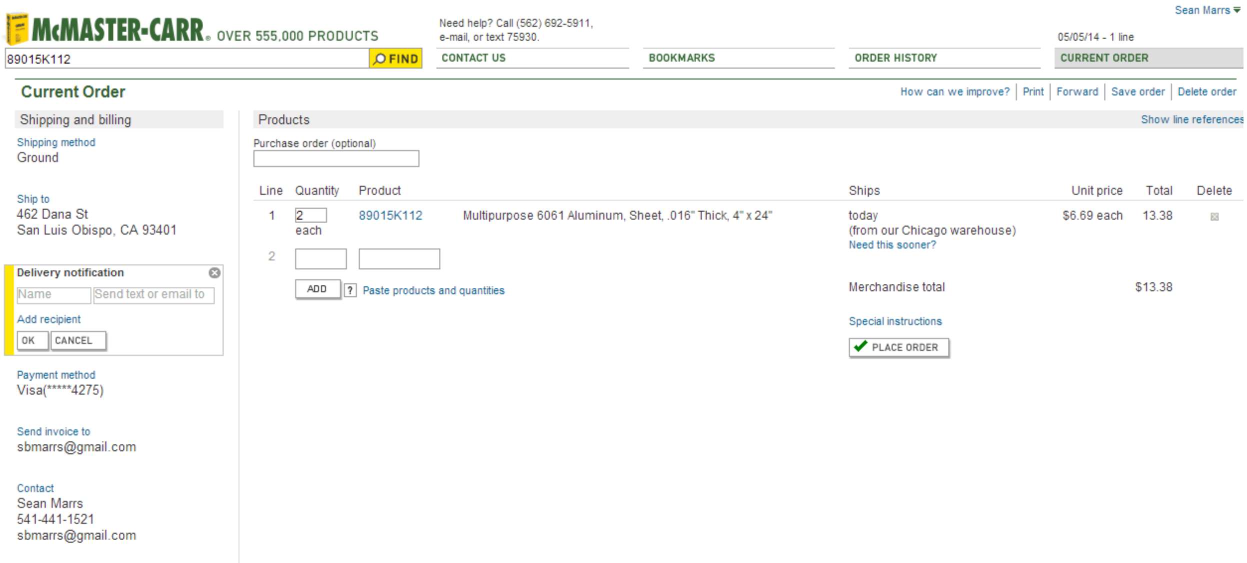
Specifications

Model	UC-12EB	UC-8EB
Size	12cm	8cm
Bearing type	Enlobal	Enlobal
Noise level (dBA)	17	14
Speed range (RPM)	1000 ± 10%	1500 ± 10%
Airflow (CFM)	44	24
Blades	7-fold	7-fold

ENERMAX

www.enermax.com

McMaster-Carr Shopping Cart for Motor Housing and Fan Duct



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Sean Marrs

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OK CANCEL

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Visa(*****4275)

Send invoice to
sbmarrs@gmail.com

Contact
Sean Marrs
541-441-1521
sbmarrs@gmail.com

Products

Show line references

Purchase order (optional)

Line	Quantity	Product		Ships	Unit price	Total	Delete
1	2 each	89015K112	Multipurpose 6061 Aluminum, Sheet, .016" Thick, 4" x 24"	today (from our Chicago warehouse) Need this sooner?	$6.69 each	13.38	
2							

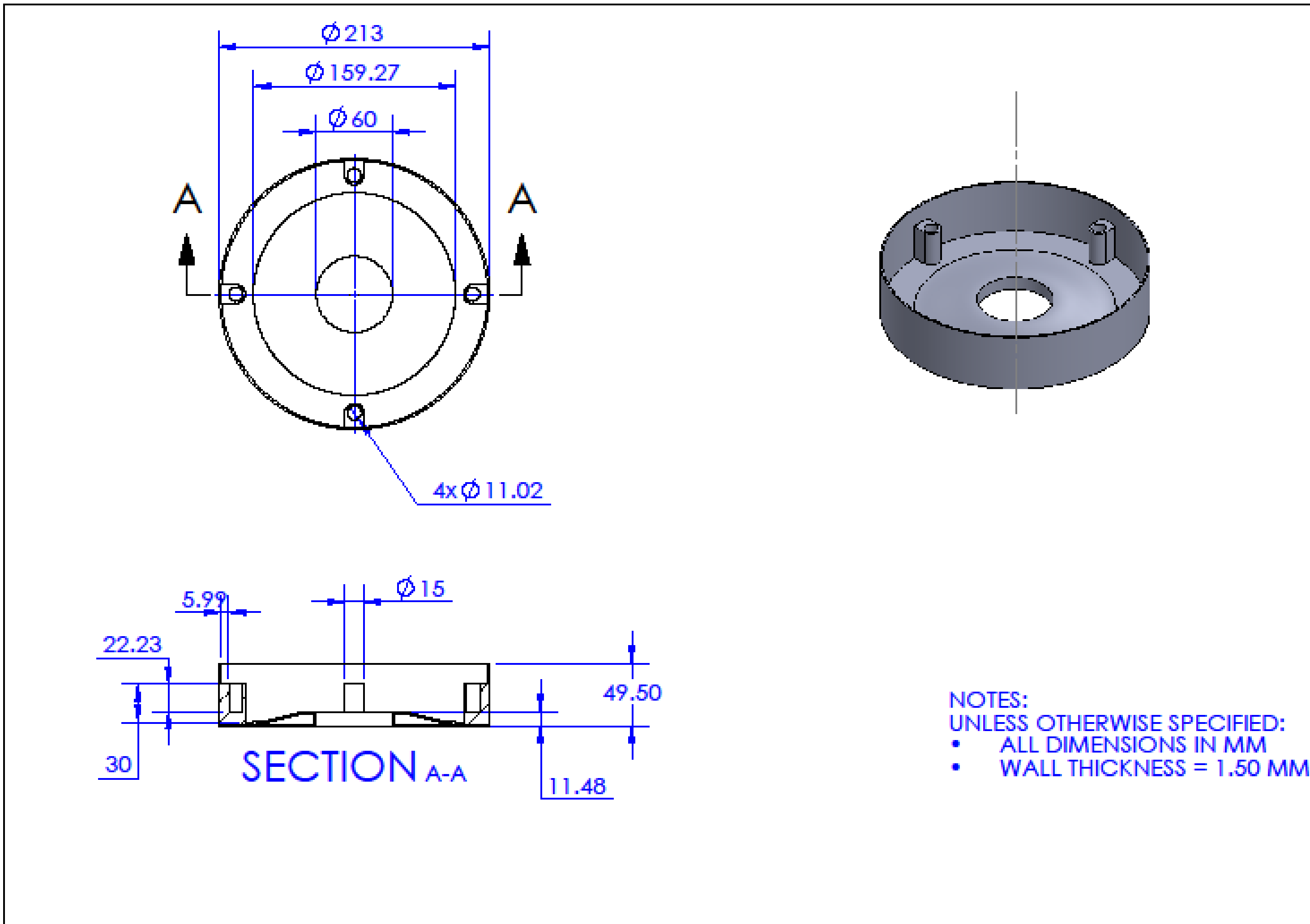
ADD ? Paste products and quantities

Merchandise total $13.38

Special instructions

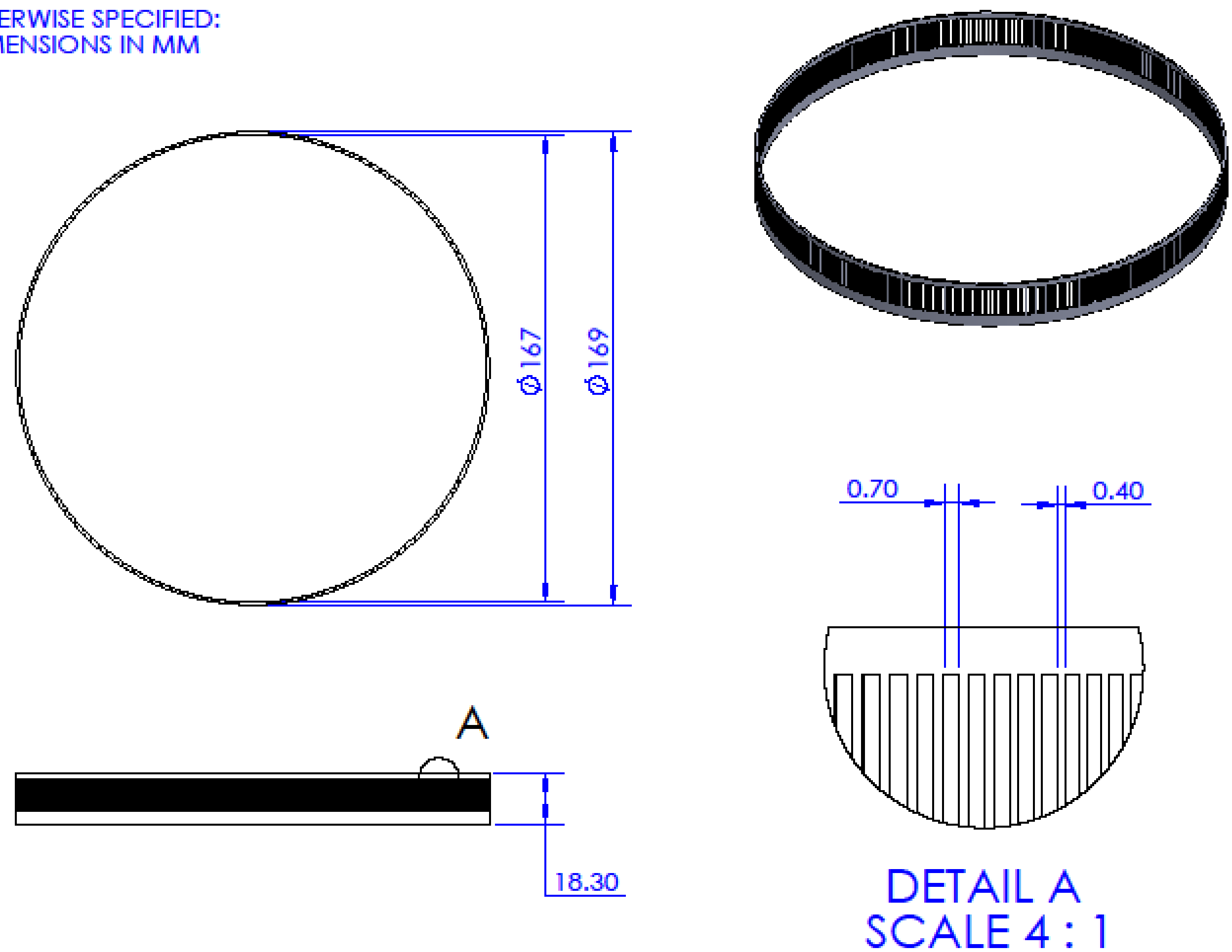
PLACE ORDER

Appendix D-Detailed Drawings

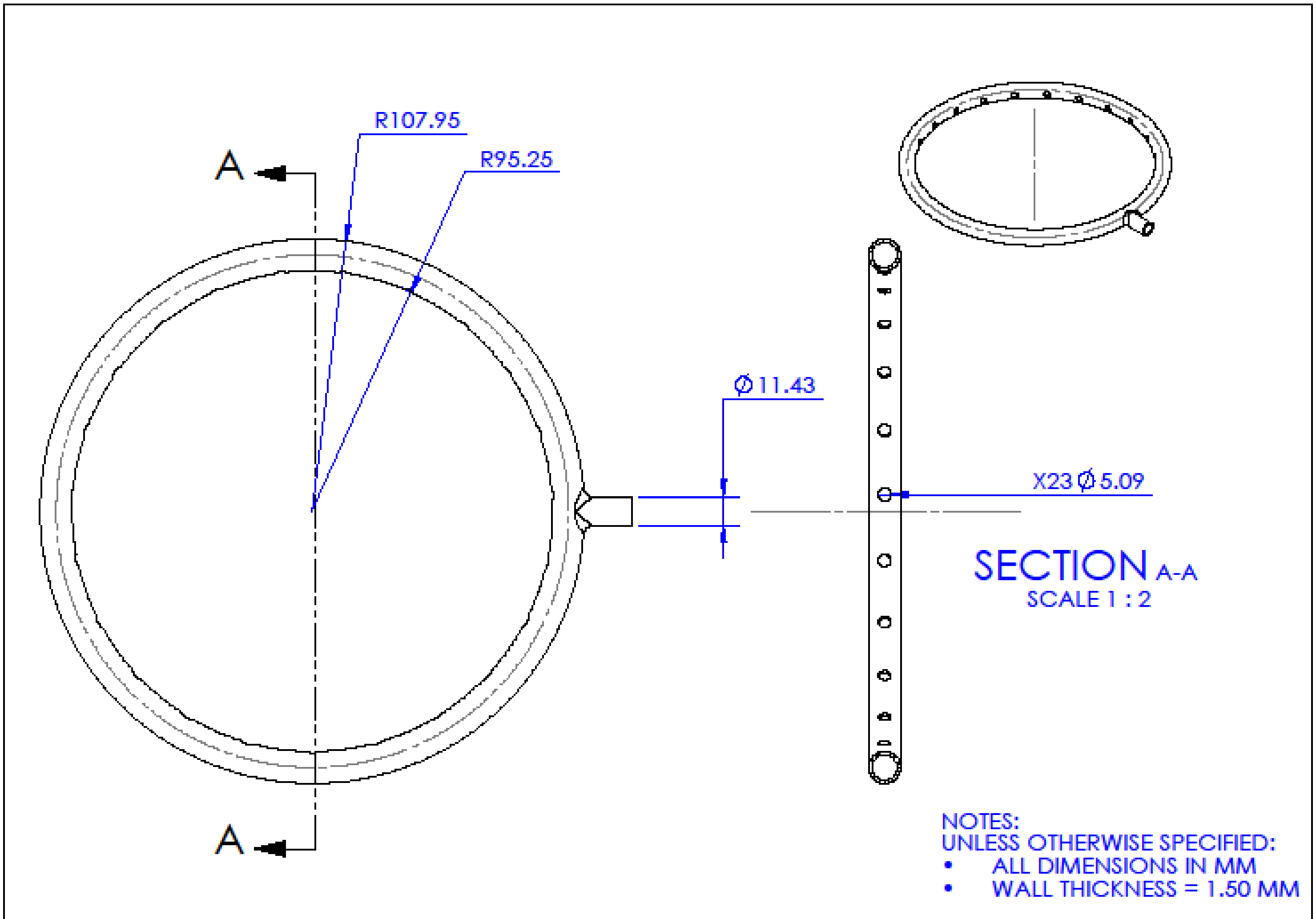


Team Two Guys	Dwg. #: TTG01	Title: ATOMIZER HOUSING		Drwn. By: JOSH MORENO
AliGroWorksUSA, Inc	CAL POLY SENIOR PROJECT ME 429	Date: 4/23/14	Scale: 1:4	Chkd. By:

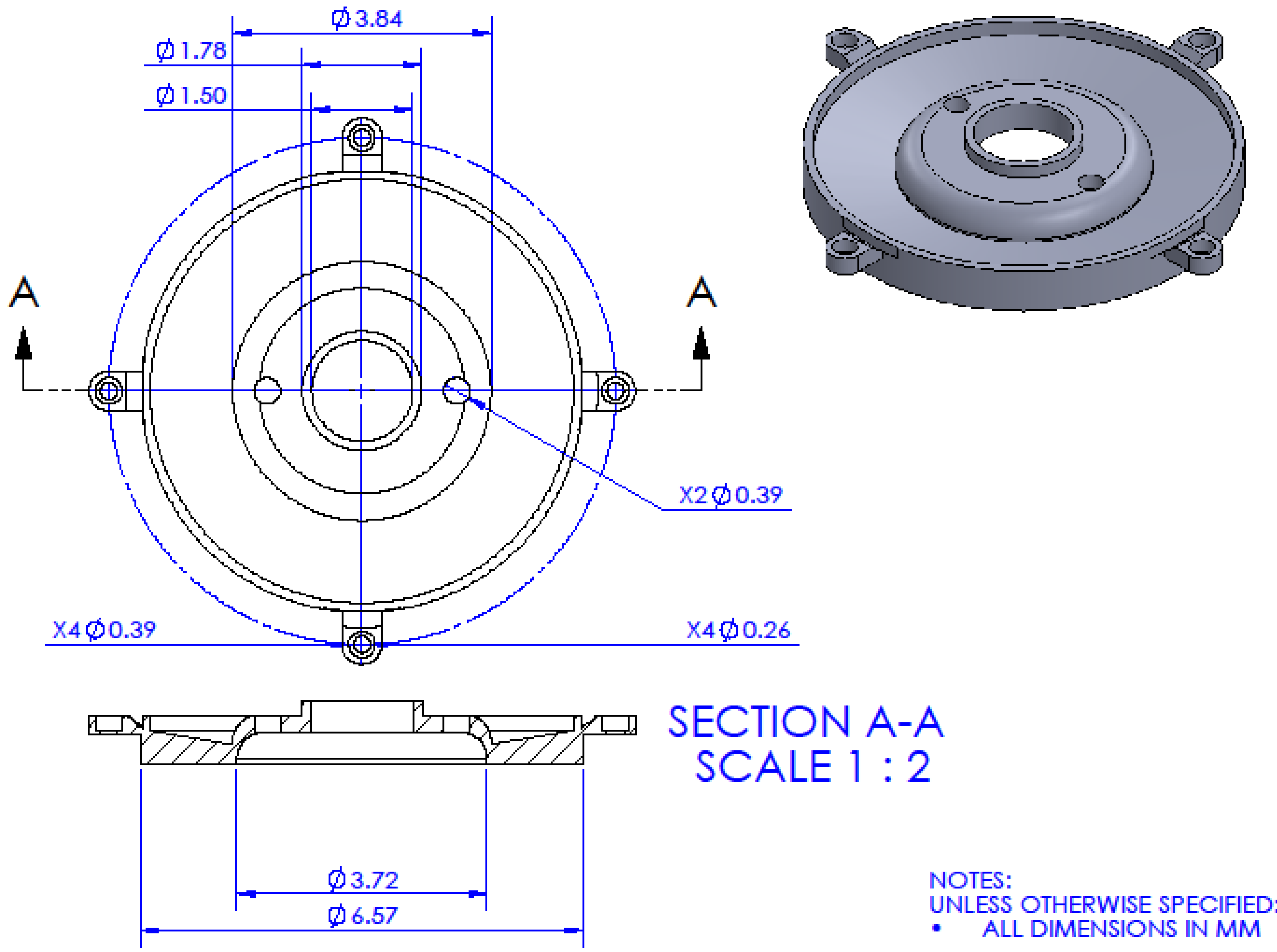
NOTES:
UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN MM



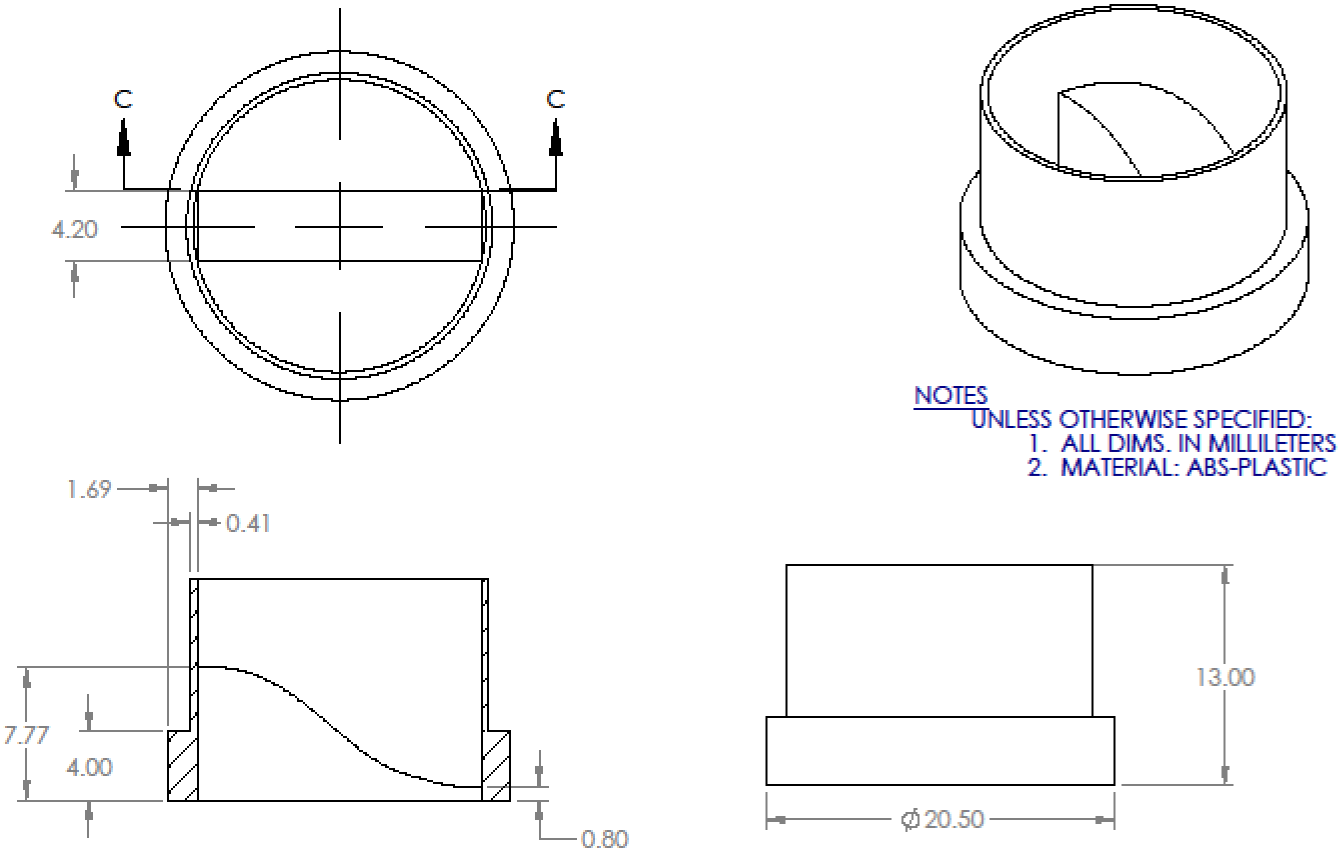
Team Two Guys	Dwg. #: TTG02	Title: DIFFUSING SCREEN		Drwn. By: SEAN MARRS
AliGroWorksUSA, Inc	CAL POLY SENIOR PROJECT ME 429	Date: 4/23/14	Scale: 1:2	Chkd. By:



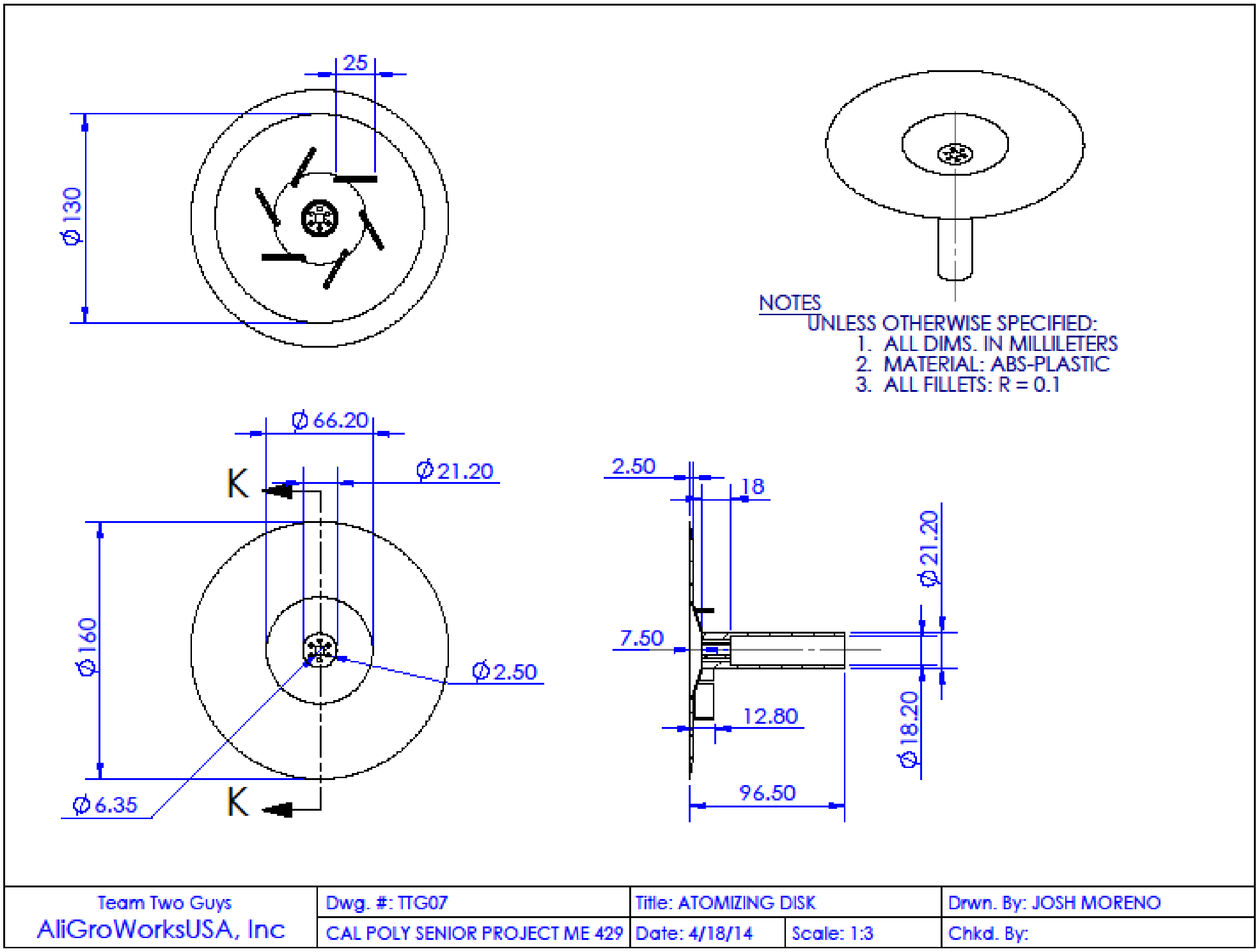
Team Two Guys AliGroWorksUSA, Inc	Dwg. #: TTG04	Title: HYDROPONIC SPRINKLER		Drwn. By: JOSH MORENO
	CAL POLY SENIOR PROJECT ME 429	Date: 4/24/14	Scale: 1:2	Chkd. By:



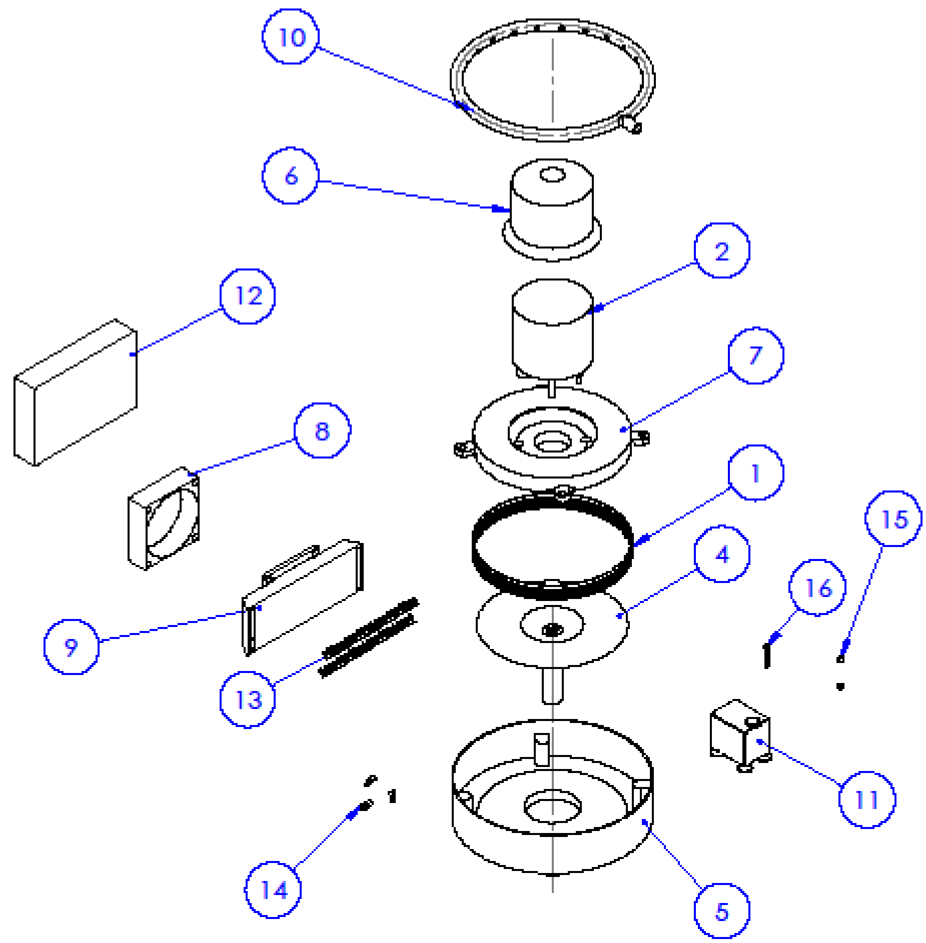
Team Two Guys AliGroWorksUSA, Inc	Dwg. #: TTG05	Title: MOTOR MOUNT		Drwn. By: JOSH MORENO
	CAL POLY SENIOR PROJECT ME 429	Date: 4/24/14	Scale: 1:2	Chkd. By:

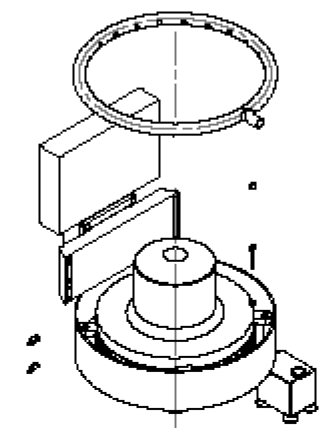


Team Two Guys AliGroWorksUSA, Inc	Dwg. #: TTG06	Title: ARCHIMIDES PUMP		Drwn. By:Josh Moreno
	CAL POLY SENIOR PROJECT ME 429	Date: 4/21/14	Scale: 3:1	Chkd. By:



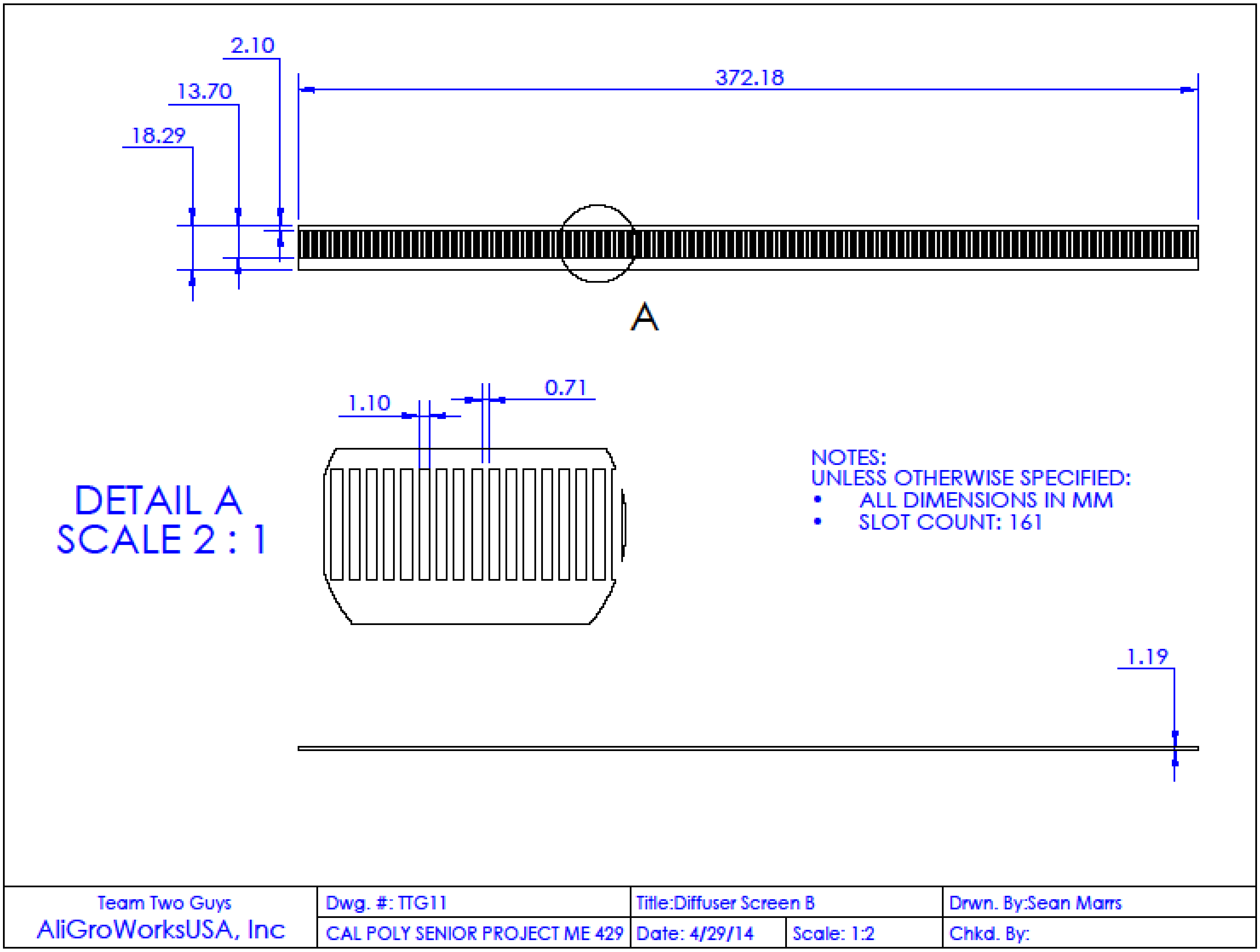
25
Ø130
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLILETERS
2. MATERIAL: ABS-PLASTIC
3. ALL FILLETS: R = 0.1
Ø66.20
Ø21.20
K
Ø160
Ø2.50
Ø6.35
K
2.50
18
Ø21.20
7.50
12.80
Ø18.20
96.50
Team Two Guys
AliGroWorksUSA, Inc
Dwg. #: TTG07
CAL POLY SENIOR PROJECT ME 429
Title: ATOMIZING DISK
Date: 4/18/14
Scale: 1:3
Drwn. By: JOSH MORENO
Chkd. By:





ITEM NO.	PART NUMBER	QTY.
1	DIFFUSER SCREEN	1
2	MOTOR	1
3	ARCHIMIDES PUMP	1
4	ATOMIZER	1
5	SYSTEM HOUSING	1
6	MOTOR HOUSING	1
7	MOTOR MOUNT	1
8	COOLING FAN	1
9	FAN DUCT	1
10	HYDRO SPRINKLER	1
11	SUBMERSIBLE PUMP	1
12	ELECTRONICS BAY HOUSING	1
13	HEATING COIL	2
14	WATER SENSOR	3
15	THERMISTER	2
16	HYGROMETER	1

Team Two Guys AliGroWorksUSA, Inc	Dwg. #: TTG08	Title: AEROPONIC ASSEMBLY		Drwn. By: JOSH MORENO
	CAL POLY SENIOR PROJECT ME 429	Date: 4/23/14	Scale: 1:6	Chkd. By:


2.10
13.70
18.29
372.18
A
1.10
0.71
DETAIL A
SCALE 2 : 1
NOTES:
UNLESS OTHERWISE SPECIFIED:
• ALL DIMENSIONS IN MM
• SLOT COUNT: 161
1.19
Team Two Guys
AliGroWorksUSA, Inc
Dwg. #: TTG11
CAL POLY SENIOR PROJECT ME 429
Title:Diffuser Screen B
Date: 4/29/14
Scale: 1:2
Drwn. By:Sean Marrs
Chkd. By:

Appendix E-Detailed Supporting Analysis

Atomizer Drop Formation Mode Calculation

Aeroponic System – Centrifugal Atomizer Droplet Size

Drop formation modes

$D \triangleq$ Disk diameter (cm)
$\rho \triangleq$ Density (g/cm^3)
$\sigma \triangleq$ Surface Tension (dyne/cm)
$n \triangleq$ Rotational Speed (rpm)
$D = 16$ cm
$\rho = 1\ g/cm^3$
$\mu = 72.8$ dyne/cm
$n = 3000$ rpm
$q = 16.1\ cm^3/s$

If $q \geq q_{transition}$ then Drop formation in film disintegration mode.

$$q_{transition} = 20 D^{1/2} \left(\frac{1}{n}\right)^{2/3} \left(\frac{\sigma}{\rho}\right)^{1/3} = 20(16cm)^{1/2}\left(\frac{1}{3000rpm}\right)^{2/3}\left(\frac{72.8\frac{dyne}{cm}}{1\ g/cm^3}\right)^{1/3}$$

$$q_{transition} = 1.608\ cm^3/s < 16.1\ cm^3/s$$

Film Disintegration

Equation for $q_{transition}$ given by Anders E.W. Jarfors, "On the design of a rotary spray former: experimental and theoretical background". [18]

Atomizer Droplet Size Calculation

Droplet Diameter of Film Disintegration

$$D = \frac{0.76}{N}\left(\frac{\sigma}{d\rho_L}\right)^{0.5}$$ [Fraser and Eisenklam] [19]

$N \triangleq$ rotational speed (rad/s)

$\sigma \triangleq$ Surface Tension (dyne/cm)

$d \triangleq$ Disk Diameter (cm)

$\rho_L \triangleq$ Fluid Density (g/cm^3)

$D \triangleq$ Droplet Diameter (cm)

$\sigma = 72.8$ dyne/cm

$d = 16$ cm

$\rho_L = 1$ g/cm^3

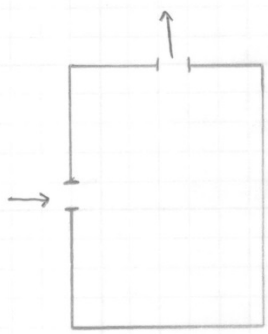
$$N = 3000 \text{ rpm}\left(\frac{2\pi \text{ rad}}{1 \text{ rev}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 314.16 \text{ rad/s}$$

$$D = \left(\frac{0.76}{314.16 \frac{\text{rad}}{\text{s}}}\right)\left(\frac{72.8 \frac{\text{dyne}}{\text{cm}} \cdot \frac{\text{g}\cdot\text{cm/s}^2}{1 \text{ dyne}}}{(16 \text{ cm})(1 \text{ g/cm}^3)}\right)^{0.5}$$

$$D = 0.00516 \text{ cm}\left(\frac{10000 \mu\text{m}}{1 \text{ cm}}\right) = \boxed{51.6 \mu\text{m}}$$

Cooling Fan Flow Rate Calculation

Air Flow Fan Flow Rate:



Assumptions:

1) Constant Air properties
2) Steady-State
3) Effect of Root System on system volume is negligible

Dimensions of Root Zone

14.806" × 9.937" × 9.937"

$$\forall = (14.806\,in)(9.937\,in)(9.937\,in)\left(\frac{1\,ft^3}{(12)^3\,in^3}\right)$$

$$\forall = 0.8457\,ft^3$$

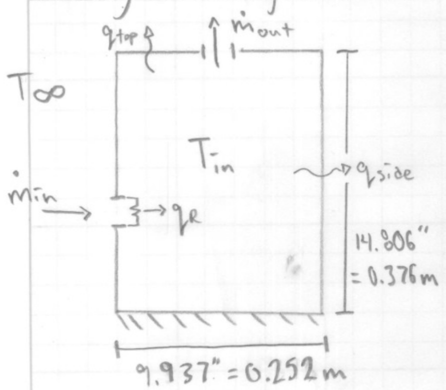
The time for the volume of the system to be totally replaced has been chosen to be 1 minute.

t = 1 minute

$$\dot{\forall} = \frac{\forall}{t} = \frac{0.8457\,ft^3}{1\,min}\left(\frac{1\,cfm}{1\,ft^3/min}\right)$$

$$\boxed{\dot{\forall} = 0.8460\,cfm}$$

Heating Coil - System Heat Transfer



Assumptions:

1) Heat transfer through mass flow, side walls and top considered.
2) Steady-State
3) Uniform inside temperature
4) Air Ideal Gas
5) No heat transfer from radiation due to grow lights.
6) Constant Air properties evaluated at T_{ave}
7) Uniform Wall temperature at T_{ave}

System Properties

$T_\infty = 40°F = 4.44°C$

$T_{in} = 65°F = 18.33°C$

$\dot{V} = 0.846 \text{ cfm} = 3.99 \times 10^{-4} \frac{m^3}{s}$

$t = 3.175 \times 10^{-3} m$

Fluid Properties evaluated at T_{ave}

$$T_{ave} = \frac{T_\infty + T_{in}}{2} = \frac{14.44°C + 18.33°C}{2} + 273.15 = 284.55 \text{ K}$$

$\rho = 1.2 \frac{kg}{m^3}$

$c_p = 1000 \frac{J}{kg \cdot K}$

$K_{ABS} = 0.17 \frac{W}{m \cdot K}$

$\nu = 1.4377 \times 10^{-5} \frac{m^2}{s}$

$Pr = 0.7114$

$g = 9.81 \text{ m/s}^2$

Conservation of mass

$$\dot{m}_{in} - \dot{m}_{out} = \frac{d m_{cv}}{dt}^{\nearrow 0}$$

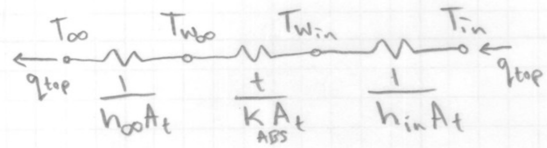
$$\dot{m}_{in} = \dot{m}_{out} = \dot{m}$$

1st Law

$$\dot{m} c_p (T_\infty - T_{in}) + q_R - q_{top} - q_{side} = \rho \forall c_p \frac{dT}{dt}^{\nearrow 0}$$

$$q_R = q_{top} + q_{side} + \dot{m} c_p (T_{in} - T_\infty)$$

q_{top}



h_∞

$$\overline{Nu}_L = 0.54\, Ra^{1/4}$$

$$Ra = Gr\, Pr$$

$$Gr = \frac{g \beta (T_w - T_\infty) L^3}{\nu^2}$$

where $\beta = \frac{1}{T_{ave}} = 0.00351\ K^{-1}$; $L = \frac{A_s}{P} = \frac{(0.252m)^2}{4(0.252m)} = 0.06309\ m$

$$Gr = \frac{(9.81 m/s^2)(0.00351 K^{-1})(284.55K - (14.44°C + 273.15))(0.06309m)^3}{(1.4377 \times 10^{-5} \frac{m^2}{s})}$$

$$Gr = 2.92 \times 10^7$$

$$Ra = (2.92 \times 10^5)(0.7114) = 2.07 \times 10^5$$

$$\overline{Nu}_L = 0.54 (2.07 \times 10^5)^{1/4} = 11.52$$

$$h_\infty = \frac{\overline{Nu}_L k}{L} = \frac{(11.52)(0.17 \frac{W}{m \cdot K})}{(0.06309m)} = \boxed{31.05 \frac{W}{m^2 \cdot K}}$$

3

h_{in}

$$Gr = \frac{g\beta(T_{in}-T_w)L^3}{\nu^2} = \frac{(9.81\,m/s^2)(0.00351\,K^{-1})((18.33^\circ C+273.15)-284.55K)(.06309m)^3}{(1.4377\times10^{-5}\,\frac{m^2}{s})}$$

$$Gr = 2.90\times10^5$$

$$Ra = (2.90\times10^5)(0.7114) = 2.07\times10^5$$

$$\overline{Nu}_L = 0.54\,(2.07\times10^5)^{1/4} = 11.51$$

$$h_{in} = \frac{(11.51)(0.17\,\frac{W}{m\cdot K})}{(0.06309m)} = 31.06\,\frac{W}{m^2\cdot K}$$

$$q_{top} = U_{top}A_t(T_{in}-T_\infty)$$

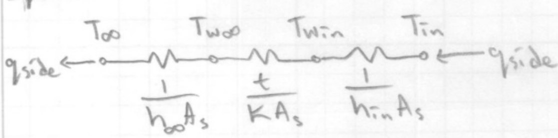
$$U_{top} = \left(\frac{1}{h_\infty}+\frac{t}{K}+\frac{1}{h_{in}}\right)^{-1} = \left(\frac{1}{31.05\,\frac{W}{m^2\cdot K}}+\frac{3.175\times10^{-3}\,m}{0.17\,\frac{W}{m\cdot K}}+\frac{1}{31.06\,\frac{W}{m^2\cdot K}}\right)^{-1}$$

$$= 12.03\,\frac{W}{m^2\cdot K}$$

$$A_t = (0.252\,m)^2 = 0.0635\,m^2$$

$$q_{top} = (12.03\,\frac{W}{m^2\cdot K})(0.0635\,m^2)(18.33-4.44)K = \boxed{10.61\ W}$$

q_{side}



h_∞

$$\overline{Nu}_L = 0.68 + \frac{0.67\,Ra^{1/4}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{4/9}}$$

$$Gr = \frac{g\beta(T_w-T_\infty)L^3}{\nu^2} = \frac{(9.81m/s^2)(0.00351\,K^{-1})(284.55K-(4.44+273.15)K)(0.376m)^3}{(1.4377\times10^{-5}\,\frac{m^2}{s})}$$

$$Gr = 6.17\times10^7$$

4

$$Ra = (6.17\times10^{7})(0.7114) = 4.39\times10^{7}$$

$$\overline{Nu}_L = 0.68 + \frac{0.67(4.39\times10^{7})^{1/4}}{\left[1+\left(\frac{0.492}{0.7114}\right)^{9/16}\right]^{4/9}} = 42.55$$

$$h_\infty = \frac{(42.55)(0.17\ \frac{W}{m\cdot K})}{(0.376\ m)} = 19.24\ \frac{W}{m^2\cdot K}$$

h_{in}

$$Gr = \frac{(9.81\ m/s^2)(0.00351\ K^{-1})((18.33+273.15)-284.55)K(0.376\ m)^3}{(1.4377\times10^{-5}\ \frac{m^2}{s})}$$

$$Gr = 6.15\times10^{7}$$

$$Ra = (6.15\times10^{7})(0.7114) = 4.37\times10^{7}$$

$$\overline{Nu}_L = 0.68 + \frac{0.67(4.37\times10^{7})^{1/4}}{\left[1+\left(\frac{0.492}{0.7114}\right)^{9/16}\right]^{4/9}} = 42.508$$

$$h_{in} = \frac{(42.508)(0.17\ \frac{W}{m\cdot K})}{(0.376\ m)} = 19.215\ \frac{W}{m^2\cdot K}$$

$$q_{side} = U_{side}A_s(T_{in} - T_\infty)$$

$$U_{side} = \left(\frac{1}{19.24\ \frac{W}{m^2\cdot K}} + \frac{3.175\times10^{-3}\ m}{0.17\ \frac{W}{m\cdot K}} + \frac{1}{19.215\ \frac{W}{m^2\cdot K}}\right)^{-1} = 8.150\ \frac{W}{m^2\cdot K}$$

$$A_s = 4(0.252\ m)(0.376\ m) = 0.379\ m^2$$

$$q_{side} = (8.150\ \frac{W}{m^2\cdot K})(0.379\ m^2)(18.33-4.44)K = \boxed{42.90\ W}$$

q_R

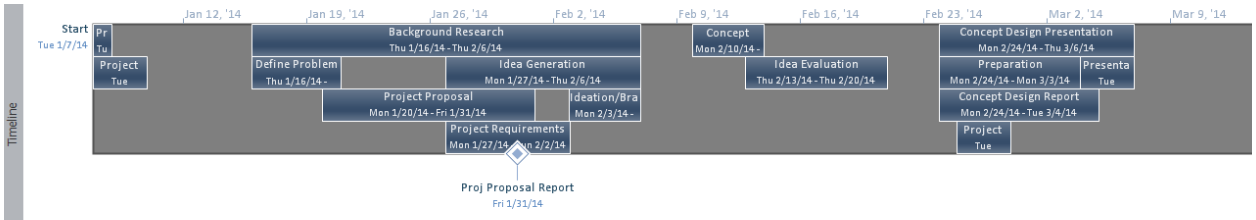
$$q_R = q_{top} + q_{side} + \dot{m}c_p(T_{in} - T_\infty)$$

$$= (10.61\ W) + (42.90\ W) + (1.2\ \frac{kg}{m^3})(3.99\times10^{-4}\ \frac{m^3}{s})(1000\ \frac{J}{kg\cdot K})(18.33-4.44)K$$

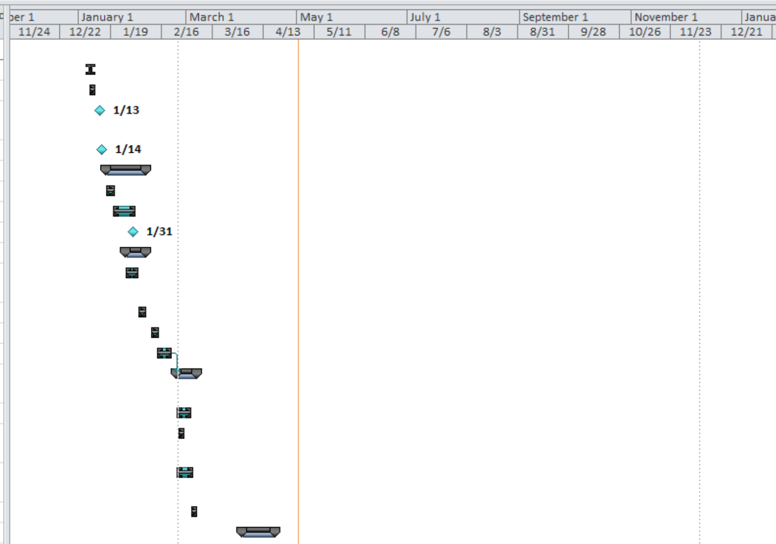
$$\boxed{q_R = 60.28\ W}$$

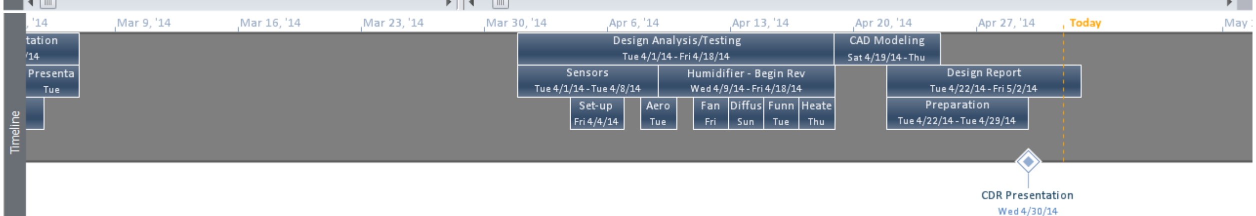
Conclusion: This will be set as the maximum heat transfer needed to maintain a 65°F root zone. It should be noted that heat loss through sides should be lower in the actual system as the insulating effect of the Tomato Cage storage void.

Appendix F- Gantt Chart

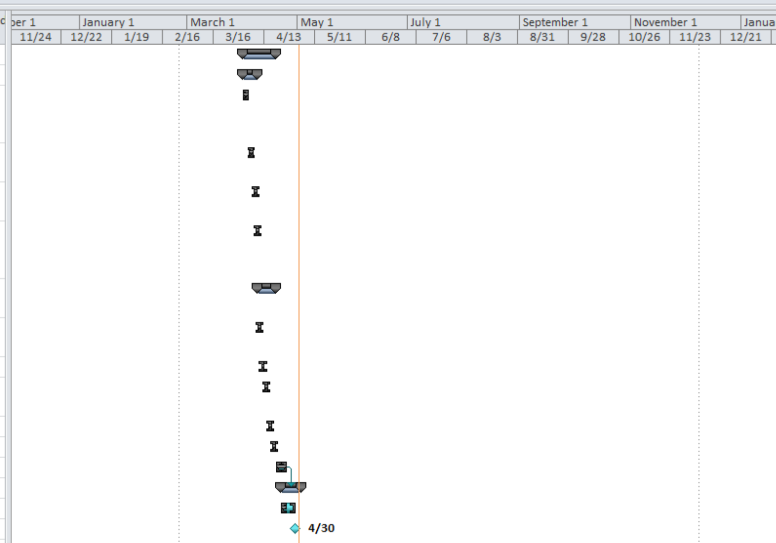


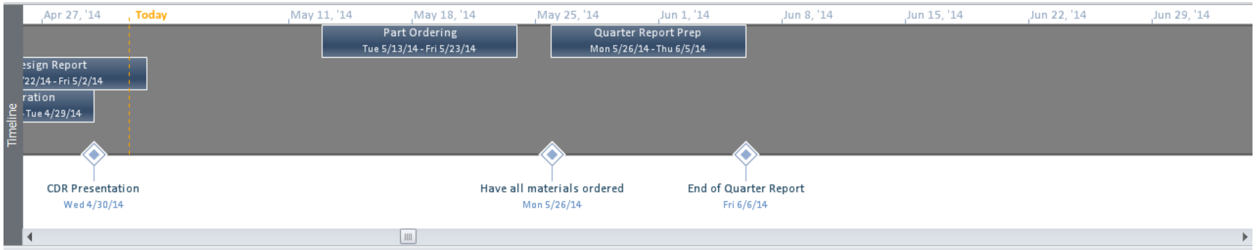
Task Name	Dura	Start	Finish	Prec
1 [redacted]				
2 Project Presentations	1 day	Tue 1/7/14	Tue 1/7/14	
3 Project Preferences	3 days	Tue 1/7/14	Thu 1/9/14	
4 Telleconference meeting - Adam	0 days	Mon 1/13/14	Mon 1/13/14	
5 Sponsor Visit	0 days	Tue 1/14/1	Tue 1/14/14	
6 **Background Research**	**16 day**	**Thu 1/16/1**	**Thu 2/6/14**	
7 Define Problem	3 days	Thu 1/16/1	Mon 1/20/1	
8 Project Proposal	10 day	Mon 1/20/1	Fri 1/31/14	
9 Proj Proposal Report	0 days	Fri 1/31/14	Fri 1/31/14	
10 **Idea Generation**	**9 days**	**Mon 1/27/**	**Thu 2/6/14**	
11 Project Requirements	6 days	Mon 1/27/14	Sun 2/2/14	
12 Ideation/Brainstorm	4 days	Mon 2/3/1	Thu 2/6/14	
13 Concept Models	4 days	Mon 2/10/1	Thu 2/13/14	
14 Idea Evaluation	6 days	Thu 2/13/1	Thu 2/20/14	
15 **Concept Design Presentation**	**9 days**	**Mon 2/24/14**	**Thu 3/6/14**	14
16 Preparation	6 days	Mon 2/24/1	Mon 3/3/14	
17 Project Planning/Budget	3 days	Tue 2/25/14	Thu 2/27/14	
18 Concept Design Report	7 days	Mon 2/24/14	Tue 3/4/14	
19 Presentations	3 days	Tue 3/4/14	Thu 3/6/14	
20 **Design Analysis/Testing**	**14 day**	**Tue 4/1/14**	**Fri 4/18/14**	



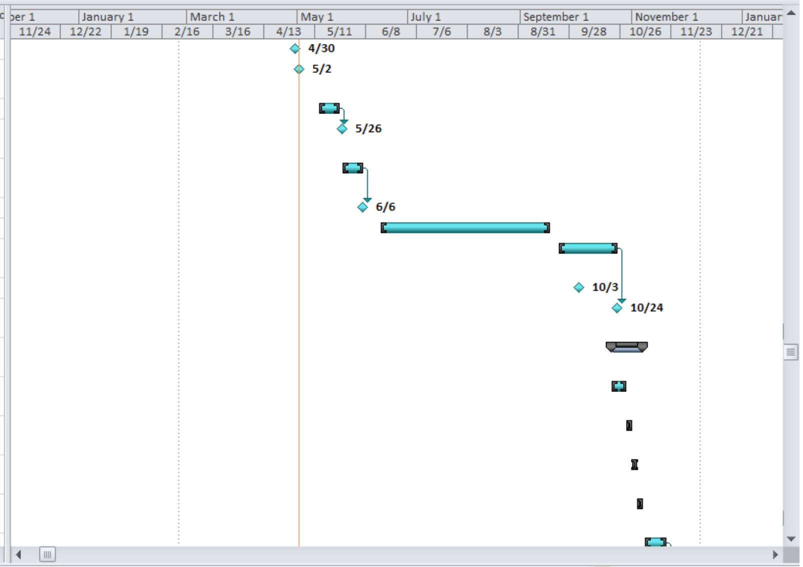


Task Name	Dura	Start	Finish	Prec
20 **Design Analysis/Testing**	**14 day**	**Tue 4/1/14**	**Fri 4/18/14**	
21 **Sensors**	**6 days**	**Tue 4/1/14**	**Tue 4/8/14**	
22 Microcontroller Research/ Purchasing	3 days	Tue 4/1/14	Thu 4/3/14	
23 Set-up Arduino Uno Microcontroller	2 days	Fri 4/4/14	Sun 4/6/14	
24 Thermistor/ Hygrometer Test	2 days	Mon 4/7/14	Tue 4/8/14	
25 Aero Droplet Size calcs/ Meet with Shollenberger	2 days	Tue 4/8/14	Wed 4/9/14	
26 **Humidifier - Begin Rev Engineering**	**8 days**	**Wed 4/9/14**	**Fri 4/18/14**	
27 Deconstruction/ Engr Plan	2 days	Wed 4/9/14	Thu 4/10/14	
28 Fan calcs/testing	2 days	Fri 4/11/14	Sat 4/12/14	
29 Diffusing Screen Effectiveness	2 days	Sun 4/13/14	Mon 4/14/14	
30 Funnel Pump	2 days	Tue 4/15/1	Wed 4/16/1	
31 Heater Test	2 days	Thu 4/17/1	Fri 4/18/14	
32 CAD Modeling	5 days	Sat 4/19/14	Thu 4/24/14	
33 **Design Report**	**9 days**	**Tue 4/22/1**	**Fri 5/2/14**	32
34 Preparation	6 days	Tue 4/22/1	Tue 4/29/14	
35 CDR Presentation	0 days	Wed 4/30/	Wed 4/30/1	
36 Final Design Report	0 days	Fri 5/2/14	Fri 5/2/14	

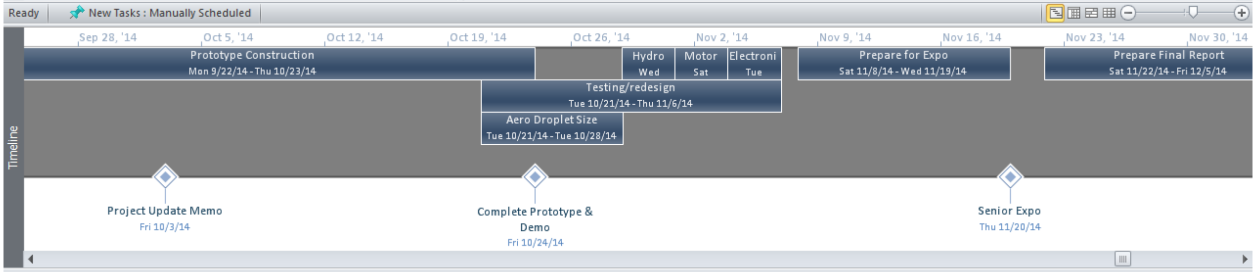




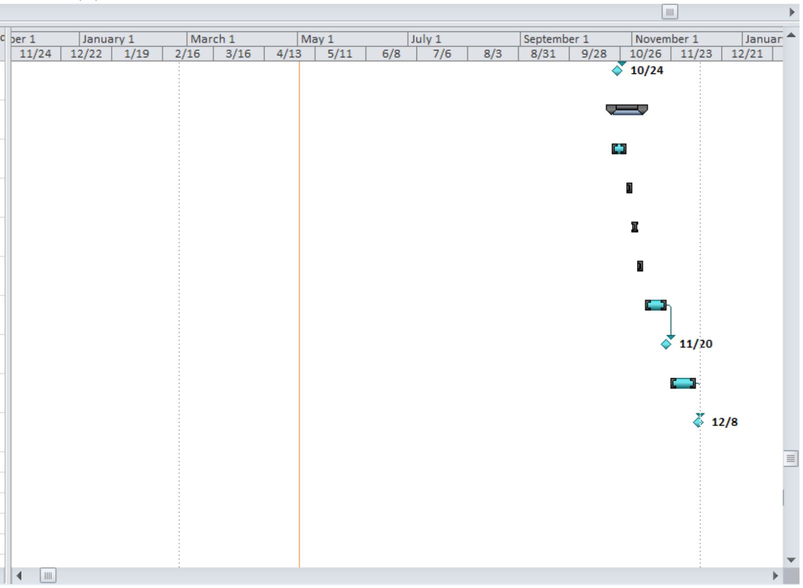
	Task Name	Dura	Start	Finish	Prec
35	CDR Presentation	0 days	Wed 4/30/1	Wed 4/30/14	
36	Final Design Report Due	0 days	Fri 5/2/14	Fri 5/2/14	
37	Part Ordering	9 days	Tue 5/13/14	Fri 5/23/14	
38	Have all materials ordered	0 days	Mon 5/26/14	Mon 5/26/14	37
39	Quarter Report Prep	9 days	Mon 5/26/14	Thu 6/5/14	
40	End of Quarter Report	0 days	Fri 6/6/14	Fri 6/6/14	39
41	Atomizer Disk Testing	67 day	Mon 6/16/1	Tue 9/16/14	
42	Prototype Construction	24 days	Mon 9/22/14	Thu 10/23/14	
43	Project Update Memo	0 days	Fri 10/3/14	Fri 10/3/14	
44	Complete Prototype & Demo	0 days	Fri 10/24/14	Fri 10/24/14	42
45	**Testing/redesign**	**13 days**	**Tue 10/21/14**	**Thu 11/6/14**	
46	Aero Droplet Size	6 days	Tue 10/21/14	Tue 10/28/14	
47	Hydro pump heat transfer	3 days	Wed 10/29/14	Fri 10/31/14	
48	Motor Housing Leakage	2 days	Sat 11/1/14	Mon 11/3/14	
49	Electronics Housing	3 days	Tue 11/4/14	Thu 11/6/14	
50	Prepare for Expo	9 days	Sat	Wed	



Ready | New Tasks : Manually Scheduled

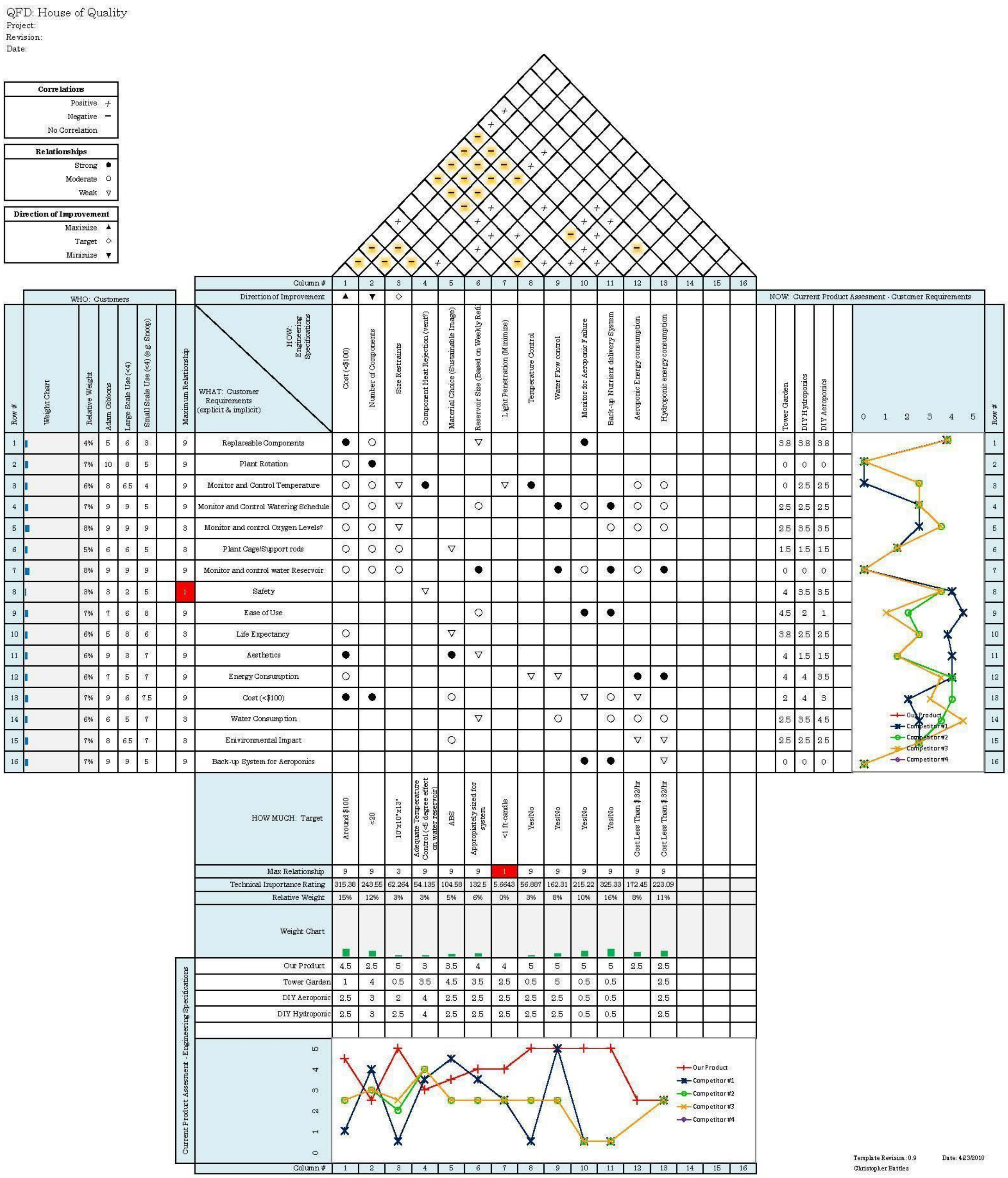


	Task Name	Dura	Start	Finish	Prec
44	Complete Prototype & Demo	0 days	Fri 10/24/14	Fri 10/24/14	42
45	**Testing/redesign**	**13 days**	**Tue 10/21/14**	**Thu 11/6/14**	
46	Aero Droplet Size	6 days	Tue 10/21/14	Tue 10/28/14	
47	Hydro pump heat transfer	3 days	Wed 10/29/14	Fri 10/31/14	
48	Motor Housing Leakage	2 days	Sat 11/1/14	Mon 11/3/14	
49	Electronics Housing	3 days	Tue 11/4/14	Thu 11/6/14	
50	Prepare for Expo	9 days	Sat 11/8/14	Wed 11/19/14	
51	Senior Expo	0 days	Thu 11/20/14	Thu 11/20/14	50
52	Prepare Final Report	11 days	Sat 11/22/14	Fri 12/5/14	
53	Final Report	0 days	Mon 12/8/14	Mon 12/8/14	52

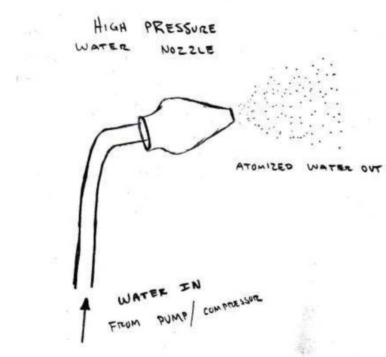
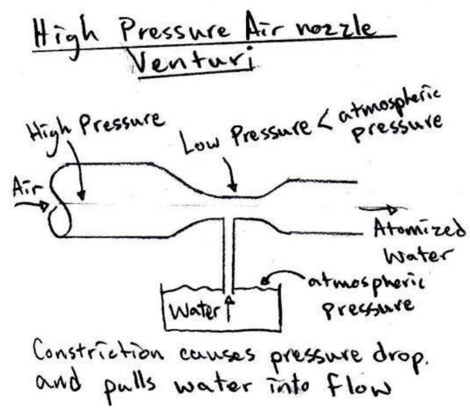
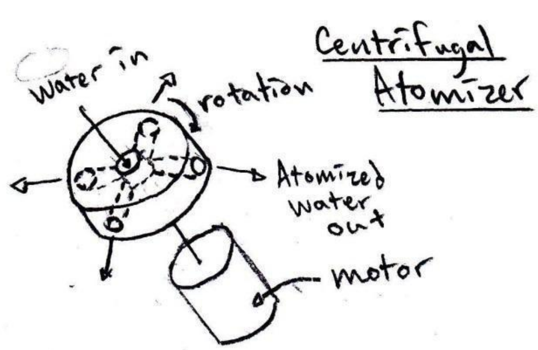


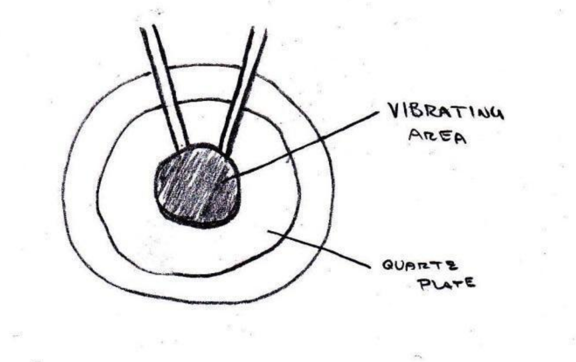
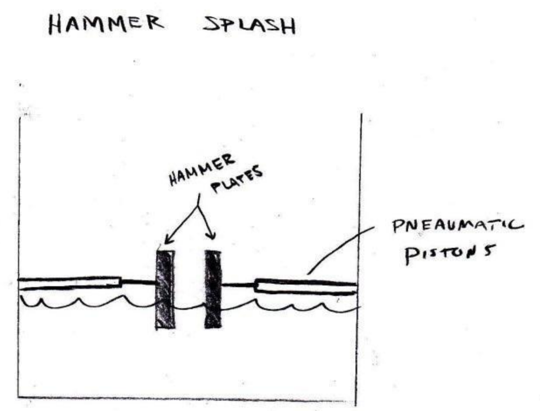
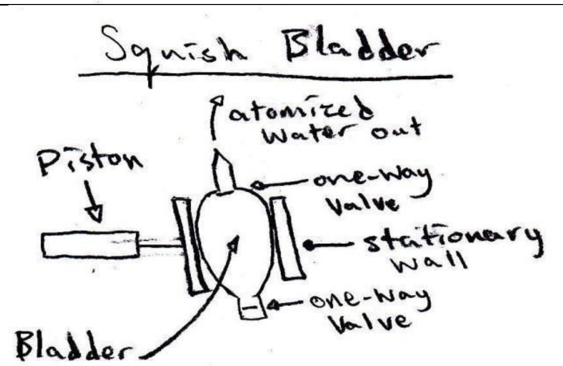
Appendix G-Concept Design Materials

Quality Functional Deployment Graphical Tool

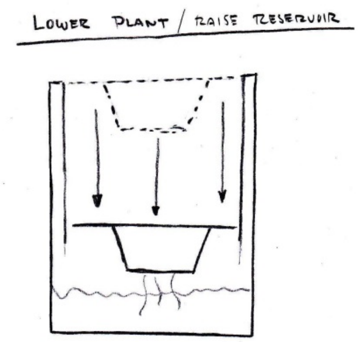
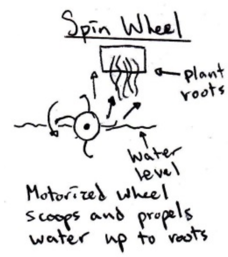
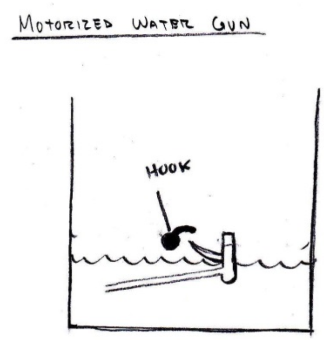


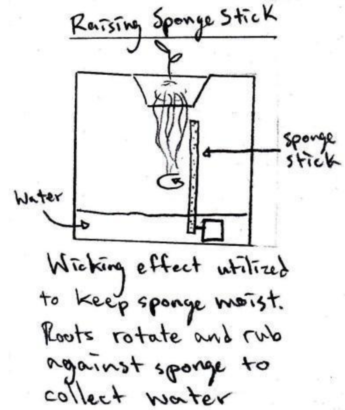
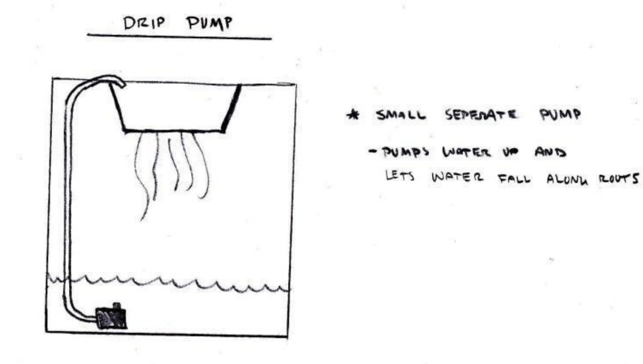
Aeroponic Concept Sketches

Aeroponic Atomizers		
High Pressure Water Nozzle	Using a high pressure pump water is moved through tubing and out an atomizing nozzle which atomizes the water through increased turbulence and a rapid constriction-thus increasing velocity. This concept was used as the standard or datum concept due to its common use in current systems.	
High Pressure Air Nozzle/Venturi	Using a high pressure air compressor air is moved through tubing and into a Venturi nozzle. At the constriction point a much smaller water line is attached. The constriction increases the velocity of the air flow and according the Bernoulli's equation a favorably pressure gradient is developed that pulls water into the flow.	
Centrifugal	The nozzle is circular with multiple outlets and a single inlet in the center. Water is introduced into the middle of the nozzle and centrifugal forces accelerate the water out of the side exits. Drop size is inversely proportional to speed and is controllable.	

Ultrasonic Oscillator	A circuit element called a crystal oscillator is used to transmit 1.6 MHz frequency to a transducer membrane. When exposed to water the transducer vibrates the water and the effect is atomized water of extremely small drop size (~5 microns).	
Hammer Splash	Pistons used to acceleration specially shaped plates toward each other. When coming together the water is propelled at a velocity high enough for atomization.	
Squish Bladder	A bladder with mono-directional valves at the inlet and outlet is squeezed; water is propelled at a velocity high enough for atomization.	

Hydroponic Back-up Concept Sketches

Hydroponic System		
Lower plant/raise reservoir	The plant is lowered until the roots are submerged, or the reservoir is raised for the same effect.	
Spin Wheel	A motored disk has fins along the circumference that splash water up toward the roots.	
Motorized water gun	A toothed motor drives a piston-cylinder setup akin to a spray bottle.	
Conveyor belt	A motored belt system that raises water cups out of the reservoir and dumps them at the top of the root zone.	

Hydroponic System		
Raising sponge stick	A sponge is raised into contact with the roots, with the other end still in contact with the water reservoir. Water is transported from the reservoir up into physical contact with the roots.	
secondary drip pump	A simple drip hydroponic system powered by a small back-up pump reserved solely for this purpose.	

Aeroponic Atomizer Pugh Matrix

Atomizer Pugh Matrix

Criteria	Design	High Pressure Water Nozzle	Venturi	High Pressure Air Nozzle	Centrifugal	Ultrasonic Oscillator	Hammer Splash	Squish Bladder
Replaceable Components		D	-	0	-	-	0	-
Plant Rotation			0	0	0	0	0	0
Monitor and Control Temperature			0	0	0	0	0	0
Monitor and Control Watering Schedule		A	0	0	+	+	+	0
Monitor and control Oxygen Levels?			0	0	0	0	0	0
Plant Cage/Support rods			0	0	+	0	+	0
Monitor and control water Reservoir			0	0	+	+	0	0
Safety		T	0	0	-	-	-	0
Ease of Use			0	0	0	0	0	0
Life Expectancy			+	-	+	-	+	-
Aesthetics			0	0	0	0	0	0
Energy Consumption			+	0	+	0	+	0
Cost (<$100)		U	+	0	+	+	0	+
Water Consumption			0	0	0	0	0	0
Environmental Impact			0	0	0	0	0	0
Back-up System for Aeroponics		M	0	0	0	0	0	0
	∑+		3	0	6	3	4	1
	∑-		1	1	2	3	1	2
	∑0		12	15	8	10	11	13

Hydroponic Back-up Pugh Matrix

CONCEPT CRITERIA	Switch Valve (Drip system with same pump as atomizer)	Lower Plant/Raise Reservoir	Spin Wheel	Motorized Water Gun	Conveyor Belt	Raising Sponge stick	Secondary Drip Pump
Replaceable Components	D	-	S	-	-	-	-
Plant Rotation		S	S	S	S	S	S
Safety to the plant	A	-	-	S	-	-	S
Ease of Use		-	S	S	S	-	S
Life Expectancy	T	+	+	+	+	+	+
Cost (<25%)		-	-	-	-	-	-
Water Delivery Rate	U	+	+	S	-	-	S
Oxidation		-	+	+	S	+	S
Reliance on main components	M	+	+	+	+	+	+
∑ +		3	4	3	2	3	2
∑ -		5	2	2	4	5	2
∑ S		1	3	4	3	1	5

Decision Matrices

Atomizer							
Design Criteria	# of Components/Complexity /Space	Effectiveness if Roots do not rotate	Maintenance (replaceable components)	Life Expectancy	Manufacturing Cost	Effectiveness of Single Watering Cycle	Summation
Weight	5	3	5	7	8.75	10	38.75
Weight Factor	0.13	0.08	0.13	0.18	0.23	0.26	1
Concepts							
High Pressure Water Nozzle	75	75	85	85	65	87	
	9.68	5.81	10.97	15.35	14.68	22.45	78.94
High Pressure Air Nozzle/Venturi	70	68	75	80	60	80	
	9.03	5.26	9.68	14.45	13.55	20.65	72.62
Centrifugal	65	60	70	80	60	93	
	8.39	4.65	9.03	14.45	13.55	24.00	74.06
Ultrasonic Oscillator	74	90	80	65	75	65	
	9.55	6.97	10.32	11.74	16.94	16.77	72.29
Hammer Splash	55	50	60	50	55	58	
	7.10	3.87	7.74	9.03	12.42	14.97	55.13
Squish Bladder	50	50	55	50	55	60	
	6.45	3.87	7.10	9.03	12.42	15.48	54.35

Hydroponic System							
Design Criteria	# of Components/Complexity /Space	Effectiveness if Roots dont rotate	Life Expectancy	Manufacturing Cost	Effectiveness of Watering	Water Oxidation	Summation
Weight	7	6	5	8	10	6	42
Weight Factor	0.17	0.14	0.12	0.19	0.24	0.14	1
Concepts							
Switch Valve (same pump as atomizer)	85	69	85	90	80	75	
	14.17	9.86	10.12	17.14	19.05	10.71	81.047619
Lower plant/raise reservoir	60	85	55	55	92	60	
	10.00	12.14	6.55	10.48	21.90	8.57	69.642857
Spin Wheel	85	78	75	71	87	90	
	14.17	11.14	8.93	13.52	20.71	12.86	81.333333
Motorized water gun	65	78	60	65	75	80	
	10.83	11.14	7.14	12.38	17.86	11.43	70.785714
Conveyor belt	60	69	55	55	70	70	
	10.00	9.86	6.55	10.48	16.67	10.00	63.547619
Raising spongestick	60	55	70	76	60	95	
	10.00	7.86	8.33	14.48	14.29	13.57	68.52381
secondary drip pump	85	69	90	82	80	75	
	14.17	9.86	10.71	15.62	19.05	10.71	80.119048

Failure Mode Effects Analysis

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results			
									Actions Taken	Sev	Occur	Crit
Aeroponics	Motor failure	Loss of atomization	8	Fatigued	6	48	Size appropriately, Fatigue calcs	4/17/2014		8	3	24
			8	water damage	3	24	Test motor housing	11/6/2014	Submerse in water/humidity sensor	3	3	9
	Atomizer Disk	Loss of atomization	7	cracking/breaking	2	14	Material Choice	4/17/2014		3	2	6
			7	corrosion	2	14	Material Choice	4/17/2014		3	2	6
	Distribution Fan	Loss of atomization	7	cracking/breaking	2	14	Material Choice	4/17/2014		3	2	6
Hydroponics	Pump	Possible plant death	9	Fatigued	7	63	Size appropriately, Fatigue calcs	4/17/2014		9	3	27
	hose	Possible plant death	7	cracking/breaking	2	14	Material Choice	4/17/2014		3	2	6
Electronics	Housing	Electrical System/Component Failure	9	Leakage	2	18	Test electronics housing	11/6/2014		3	2	6
	Humidty Sensor	Loss of Root Zone Control	5	Calibration Inaccuracies	3	15	Sensor Choice	4/17/2014		3	3	9
	Temp Sensor	Loss of Root Zone Control	5	Calibration Inaccuracies/ connections	2	10	Sensor placement/housing	4/17/2014		3	2	6
	Water Sensor	Loss of failure sensor/ water level sensor	7	Probes in contact or too far apart	4	28	Sensor placement/housing	4/17/2014		3	4	12
	Micro Controller	Eventual Plant Death	9	Overheating	3	27	Venting	4/17/2014		5	3	15
Air Fan	Fan	Loss of airflow	1	Fatigue	4	4	Size appropriately, Fatigue calcs	4/17/2014		1	2	2
			1	Impeller Damage	2	2	Mesh Screen	4/17/2014		1	1	1
	Heater	Loss of temp control	2	Overheating	4	8	Heating coil choice/ airflow	4/17/2014		2	2	4

Design Verification Plan and Report

ME428 DVP&R Format

Date: 12/5/2014 | Sponsor: AligroWorks - Adam Gibbons | Component/Assembly | LEAD ENGINEER: SEAN MARRS

TEST PLAN										TEST REPORT			
						SAMPLES TESTED		TIMING		TEST RESULTS			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	NOTES
1	Hydro Pump Life	Run 1 month with multiple inspections	No failure or damage to system or plant health	Sean	CV	1-2	A	3/10/2014	4/17/2014	Pass	1	0	
2	Humidity Sensor Test	Verify Accuracy, Response time	Within 2% tolerance, Response time under 10 sec	Sean	CV	1-2	A	4/1/2014	4/6/2014	Pass	1	0	
3	Temperature Sensor	Verify Accuracy, Response time	Within 2% tolerance, Response time under 10 sec	Sean	CV	1-2	A	4/1/2014	4/6/2014	Pass	1	0	
5	Aero Droplet Size	Visual inspection of humidifier atomizer	Reasonable droplet size/ mass flowrate	Sean/ Josh	CV	1-2	A	4/7/2014	4/8/2014	Pass	1	0	
6	Distribution fan effectiveness	Visual inspection of distribution of water/nutrients	Adequately/evenly distribute nutrients	Sean/ Josh	CV	1-2	A	4/9/2014	4/10/2014	Pass	1	0	Vastly improves mass flowrate delivery to plant
7	Diffusing screen Effectiveness	Visual Inspection of water when through screen	Decrease in droplet size	Sean/ Josh	CV	1-2	A	4/11/2014	4/12/2014	Pass	1	0	
8	Archimedes Screw	Test flow rate of funnel	Transports fluid	Josh	CV	1-2	A	4/13/2014	4/14/2014	Pass	1	0	
	Atomizer Disk Testing	Test disk designs over varying speeds	Optimum Droplet size/ mass flow	Sean	CV	3	A	6/16/2014	9/16/2014	Pass	3	0	Larger disk sizes produce smaller droplets
9	Aero Droplet Size	Visual inspection over range of motor	50 microns	Sean/ Josh	DV	1-2	B	10/21/2014	10/28/2014	Pass	1	0	

APPENDIX H- Operating Manual

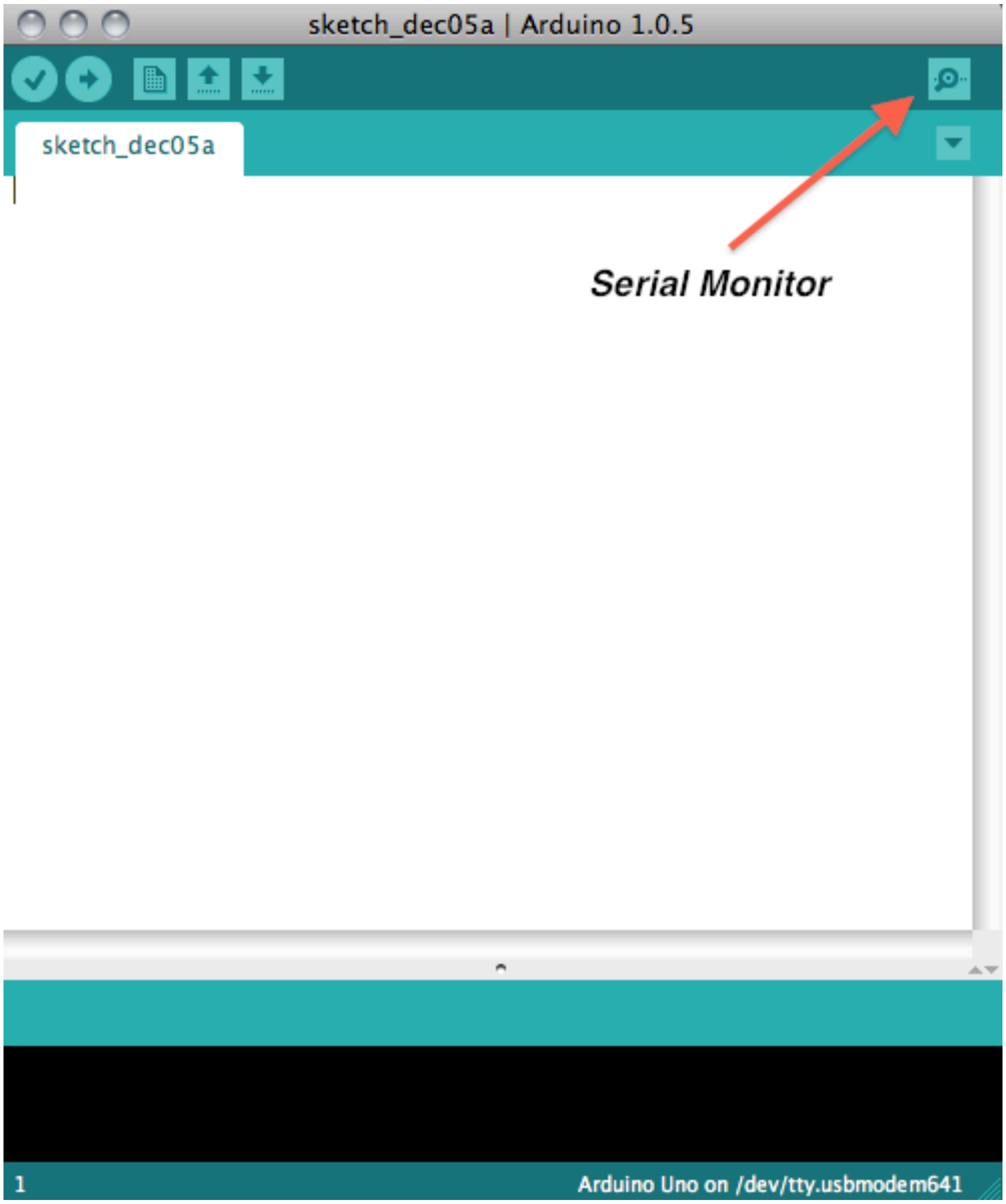
Running the System

1) Before running the system ensure that there is water in the reservoir, if the water level is too low the system will not start.
   a) As long as the water level is above the minimum the system will run normally.
   b) DO NOT fill the reservoir up to the bottom of the Motor Base, at least an inch of air below the Motor Base is required for air-flow.
   c) For one gallon of reservoir water fill to the bottom of the fan duct.
2) Plug in both the Arduino power cord (12V, 1A AC adapter) and the relay power cord (three prong, grounded). The system will begin running automatically on the preset watering cycle.

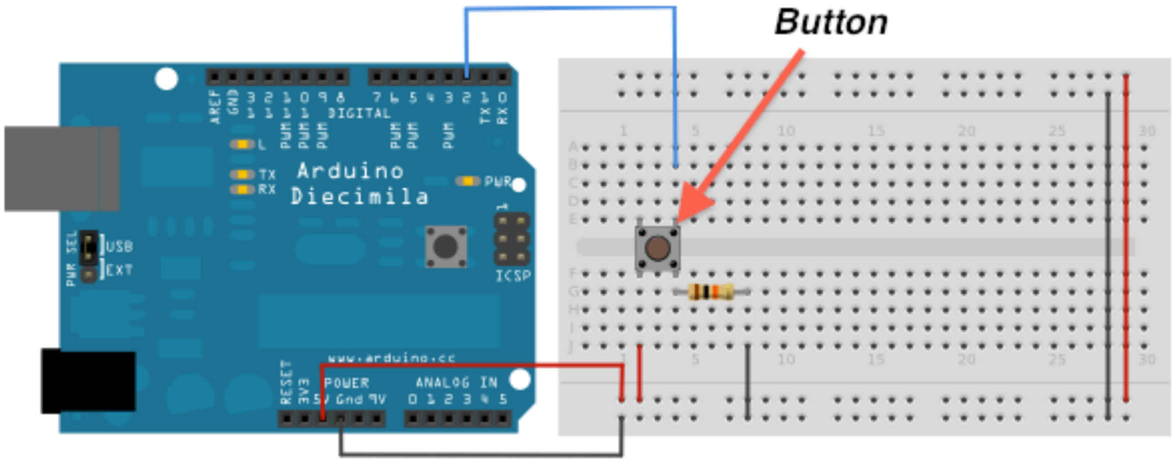
Displaying Temperature Values

Because there is no display on the system itself, the system needs to plugged into computer/ laptop with the Arduino code running to read the sensor values.

1) Open up the Arduino IDE program via the USB drive provided.
2) Connect the computer to the Arduino Uno board via the USB cable.
3) Open up the serial monitor (the magnifying glass icon) located in the upper right hand corner of the sketchpad
   a) Note-Opening the serial monitor will reset the code and return to the beginning of the watering cycle.



4) To display sensor values, simply push the small black button located on the breadboard next to the Arduino UNO board. When the button is pushed, the sensor values will appear in the serial monitor.



5) When you are finished simply disconnect USB and close the arduino program, the system will continue to function normally.

Disassembly for Access To Reservoir and Atomizing System

1) Remove root zone housing by raising vertically.
   a) To replace, lower root zone housing starting with the corner that has the ventilation fan hood
2) Lift the motor base (platform that atomizer system is attached to) from the edge opposite the electronics bay, raise a few inches, and slide the motor's power cord out of the slot in the motor base. Return motor base to original position.
3) Lift Atomizing System and remove, rest the Atomizing System on the motor mount with the impeller pointing up. For Atomizing System disassembly see below.
4) Remove the Motor Base.

Atomizer System Disassembly

1) Remove the Archimedes Screw— a flat head screw driver or other small prying device may be necessary if an excess of mineral deposits are present.
2) Remove the Atomizing Impeller by loosening the set screw (1/16" allen wrench), located on the impeller tube near the impeller blades, and pull away from system.
   a) Depending on the intensity of mineral deposits this may be difficult to do and care should be taken to not pull on the motor cover as it is secured by silicon only. Instead a long skinny rod, such as a flat head screw driver can be used to press down on the motors shaft while pulling up on the impeller. This shaft can be accessed from the impeller tube assuming the Archimedes Screw has been removed.
3) When cleaning the Impeller be sure to focus on the six holes distributed radially around the motor shaft hole.

Appendix I - Notes

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