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JME 4110 Final Design Report - Plant Growth Chamber

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

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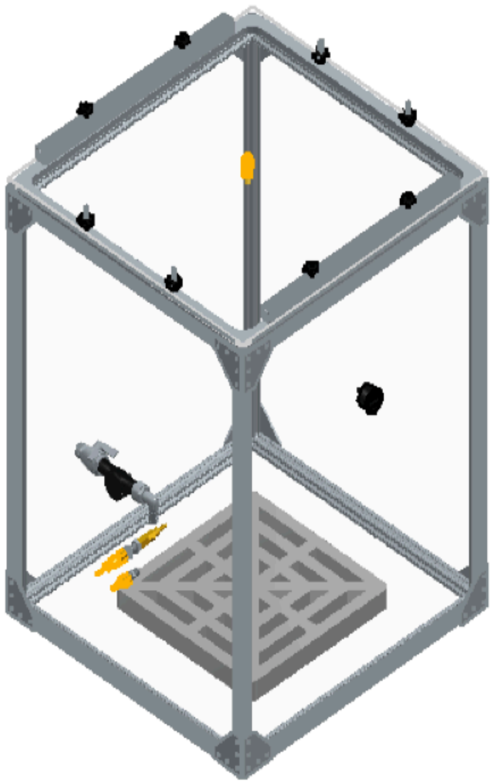
This following report covers a plant growth chamber project. The chamber is for use in the analysis of nitrogen uptake by different root architectures of plants. To analyze nitrogen uptake nitrogen isotopes are pulsed into the chamber. The plant is then examined to determine the number of isotopes absorbed, and the results are compared to the same types of plants, but with different root architectures. The purpose of the chamber is to create an isolated environment in which the isotopes cannot escape and outside air cannot enter. Also, the chamber allows for the plant to be irrigated without build-up of excess water.



JME 4110
Mechanical Engineering
Design Project

Plant Growth Chamber

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1 INTRODUCTION

1.1 VALUE PROPOSITION / PROJECT SUGGESTION

- **Gas saturating, liquid handling chamber for plant biology.** To facilitate study of resource use efficiency in crop plants, it is necessary to pulse-saturate them with certain stable isotopes. This is done by exposing the shoots to gases and the roots to liquid. Design a system to deliver and control this process.

1.2 LIST OF TEAM MEMBERS

- Deontez R Myers
- Chad Szwargulski

2 BACKGROUND INFORMATION STUDY

2.1 DESGIN BRIEF

The background search has yielded only products similar to what is needed by the customer in that there are chambers for plant growth, but they only appear to monitor air and water intake. The product requested by the customer will deliver liquid fertilizer containing stable isotopes of nitrogen to the roots, and deliver stable isotopes of carbon or nitrogen to the shoots of plants. The fertilizer and gas must be delivered in well-regulated quantities. The device will need to store the runoff water/fertilizer solution for later analysis. The device will need to be sturdy enough to handle constant use in a greenhouse environment, and be somewhat transportable. The device should be able to be scalable to handle more and larger plants in the future. The product will need to meet NIH guidelines for safety and will also need to meet ISO standards for product quality since similar products have such certification. A major obstacle is controlling two different environments (soil and air) within the same chamber. Other products use expensive sensing equipment and control systems.

2.2 BACKGROUND SUMMARY

- Fitotron HGC High Specification Growth Chamber.
  The chambers offer a modular concept, high accuracy and reliability in the control of temperature, humidity and lighting. The chamber does not saturate the plants but it does create a controlled environment which is also important when studying plant biology.
  http://www.fitotron.co.uk/products/high-spec-growth-chambers/

Figure 1: Fitotron Growth Chamber.

- US 53411595 A - Environmental Growth Chamber
  This design is an environmental day-lit chamber for plant growth analysis that has a perforated or slotted plant supporting floor for air to be forced vertically through the plant space. This chamber also does not saturate the plants with isotopes but provides an equal distribution of light and air. The controlled environment is necessary for our design and the chamber seems to have room for modification (process for gas saturating the plants).

U.S. Patent Aug. 30, 1994 Sheet 2 of 3 5,341,595

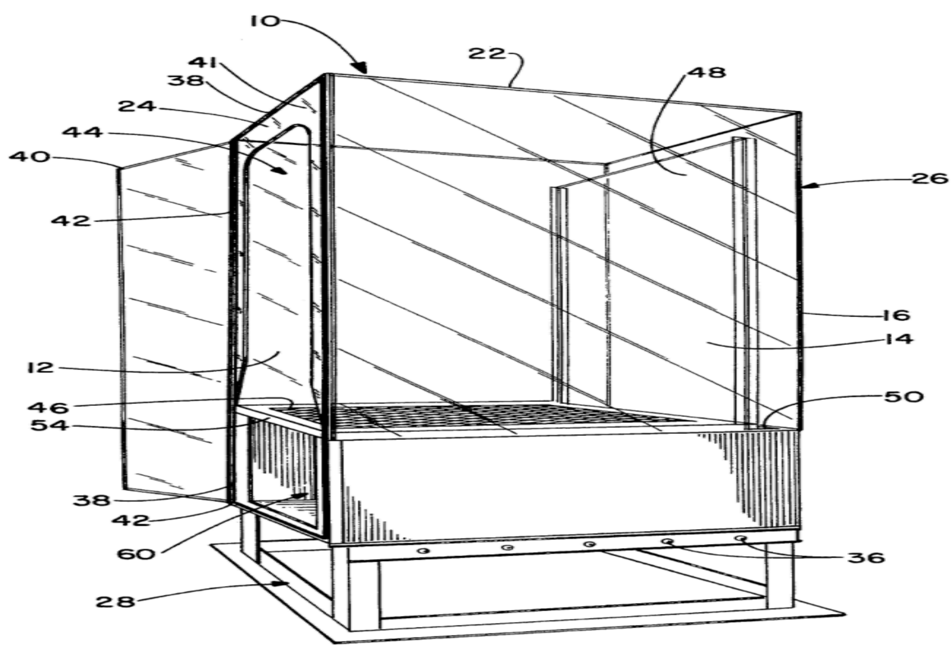

FIG.–1B

U.S. Patent Aug. 30, 1994 Sheet 3 of 3 5,341,595

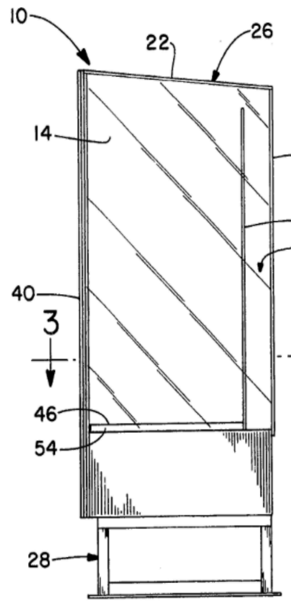

FIG.-2

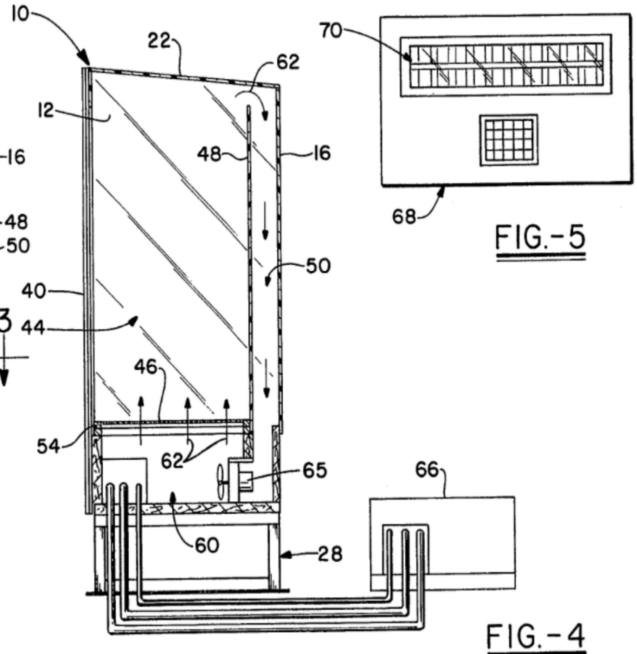

FIG.-4

FIG.-5

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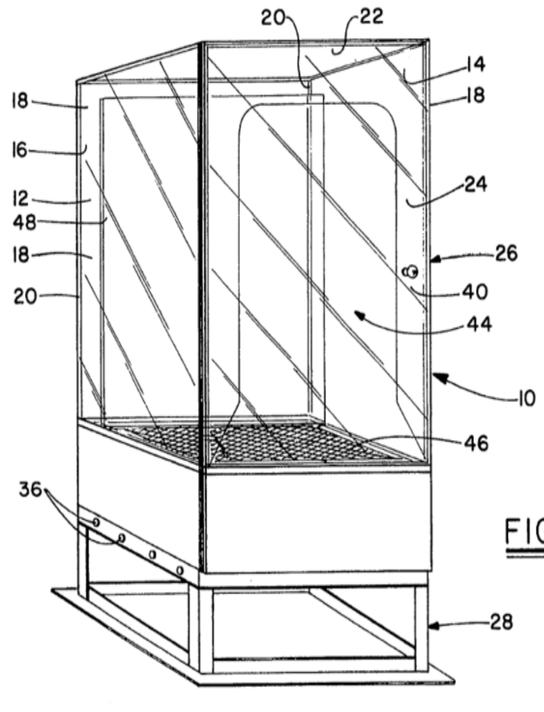


FIG.-1A

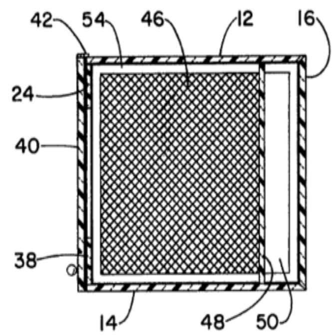


FIG.-3

- Plant Growth Chamber LPGC – 101
  This chamber has a forced air circulation system by a low-noise centrifugal fan which ensures temperature uniformity. The 3-side illumination can be adjusted and the chamber can be used for microorganism cultivation and preservation, plant growth, seed germination, tissue cultivation, environmental protection and forestry, agriculture and research institutes. This device has many of the characteristics needed to house and study plants the way our client intends to but it is not capable of exposing the plant shoots to different isotopes.
  http://www.indianscientific.com/product/plant-growth-chamber-lpgc-101

Figure 2: LPGC Plant Growth Chamber.

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS, METRICS AND QUANTIFIED NEEDS EQUATIONS

3.1.1 Record of the user needs interview

Project/Product Name: Plant Growth Chamber Customer: Christopher Topp Address: Danforth Center 975 N. Warson Road St. Louis, Mo 63132 Willing to do follow up? Type of user:		Interviewer(s): Deontez Myers, JME 4110 student Chad Szwargulski, JME 4110 student Date: 22 June 2017 Currently uses:	
Question	Customer Statement	Interpreted Need	Importance
What is the purpose of the chamber?	Expose shoots gaseous 13C carbon, roots to 15N nitrogen. Recover liquid for analysis.	Chamber around shoots must be airtight. Pump and liquid storage needed	5 5
What do like about currently available growth chambers?	Controlled environment for all plants (lighting, water, etc.). Lighting and temperature control for Device would be provided by other sources	Chamber around shoots must be airtight. Pump and liquid storage needed	5
Where will the chamber be used?	Mostly likely in greenhouse. Possibly in indoor growth chamber. Forklift available to move device.	Device can be transported.	3
What type of plants will be in the chamber?	Initially only corn.	Chamber has room for a plant inside a pot.	5
How many?	1 would be sufficient to prove concept.	Device should be scalable.	4
Does the chamber need to be manually or automatically controlled?	Minimal amount of time needed to perform experiment.	The ability to test “pulse” several plants at once would be sufficient.	3

How often will the chamber be used?	Continuously	Durable	5
For how long?	Depends on what form of testing is being conducted.	Airtight with storage capacity.	4
Skill level of people using the device?	Lab technicians with little mechanical expertise.	Easy to operate with little knowledge of mechanical systems	4
Plants visible without opening the chamber?	Plants will most likely be in greenhouse, clear chamber necessary for sunlight.	Chamber must be clear.	5
Types of chemicals the chamber will be exposed to?	Expose shoots gaseous 13C carbon, roots to 15N nitrogen.	*This need was already addressed	
Does the chamber need to regulate a controlled environment?	Lighting and temperature control for device would be provided by other sources	*This need was already addressed	
Chamber Size?	Able to handle small plants at first to prove concept.	*This need was already addressed	
Material to be used?	Anything that can withstand a humid environment.	Any material that can survive higher temps or humid conditions.	4

3.1.2 List of identified metrics

Metric Number	Associated Needs	Metric	Units	Minimum Value	Maximum Value
1	3,4,7,8	Length	Inches	-	-
2	3,4,7,8	Width	Inches	-	-
3	3,4,7,8	Height	Inches	-	-
4	2,6,7,8,9	Material Weight	Lbs	-	-
5	1,5	Number of Gas Ports	Integer	2	3
6	2,4,5,7,8	Number of Plants Covered	Integer	1	-

3.1.3 Table/list of quantified needs equations

Plant Growth Chamber: Concept 1		Metric										
		Volume	Durability	Weight	Gas/Water Ports	Plants Covered	Air Tight	Pump Water	Light Transmittance	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8			
1	Pulse Gas and Liquid				0.5	0.25	0.25			0.75	0.116	0.087
2	Air Tight									0	0.116	0
3	Fit in Greenhouse	1								0.96	0.07	0.0672
4	Hold potted plants	0.5				0.5				0.98	0.116	0.11368
5	Hold gas for period of time						1			1	0.093	0.093
6	Material won't warp		1							1	0.093	0.093
7	Transportable	0.5	0.25	0.25						0.73	0.07	0.0511
8	Scalable					0.5				0.5	0.094	0.047
9	Clear Chamber								1	0.95	0.116	0.1102
10	Collect and hold water							1		0.7	0.116	0.0812
	Units	in^3	Years	Lbs	Integer	Integer	Integer	GPM	%	Total Happiness		0.74338
	Best Value	50000	10	20	1	3	1	5	100			
	Worst Value	2000	1	100	4	1	0	0	0			
	Actual Value	46000	10	45	2	3	1	3.5	95			
	Normalized Metric Happiness	0.96	1	0.56	0.5	1	1	0.7	0.95			

Figure 3: Happiness Spreadsheet for Concept #1.

3.2 CONCEPT DRAWINGS

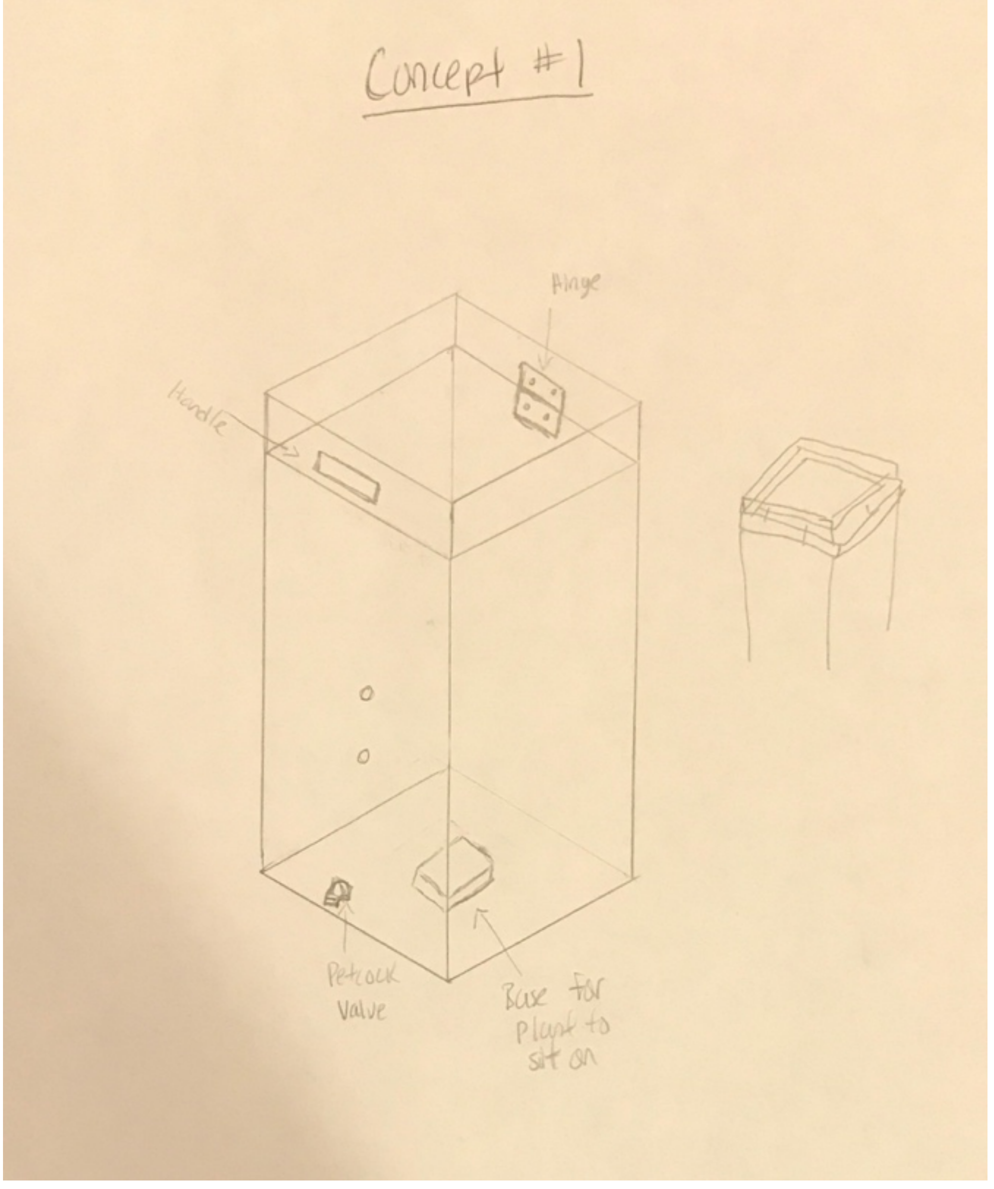


Figure 4: Drawing of Concept #1.

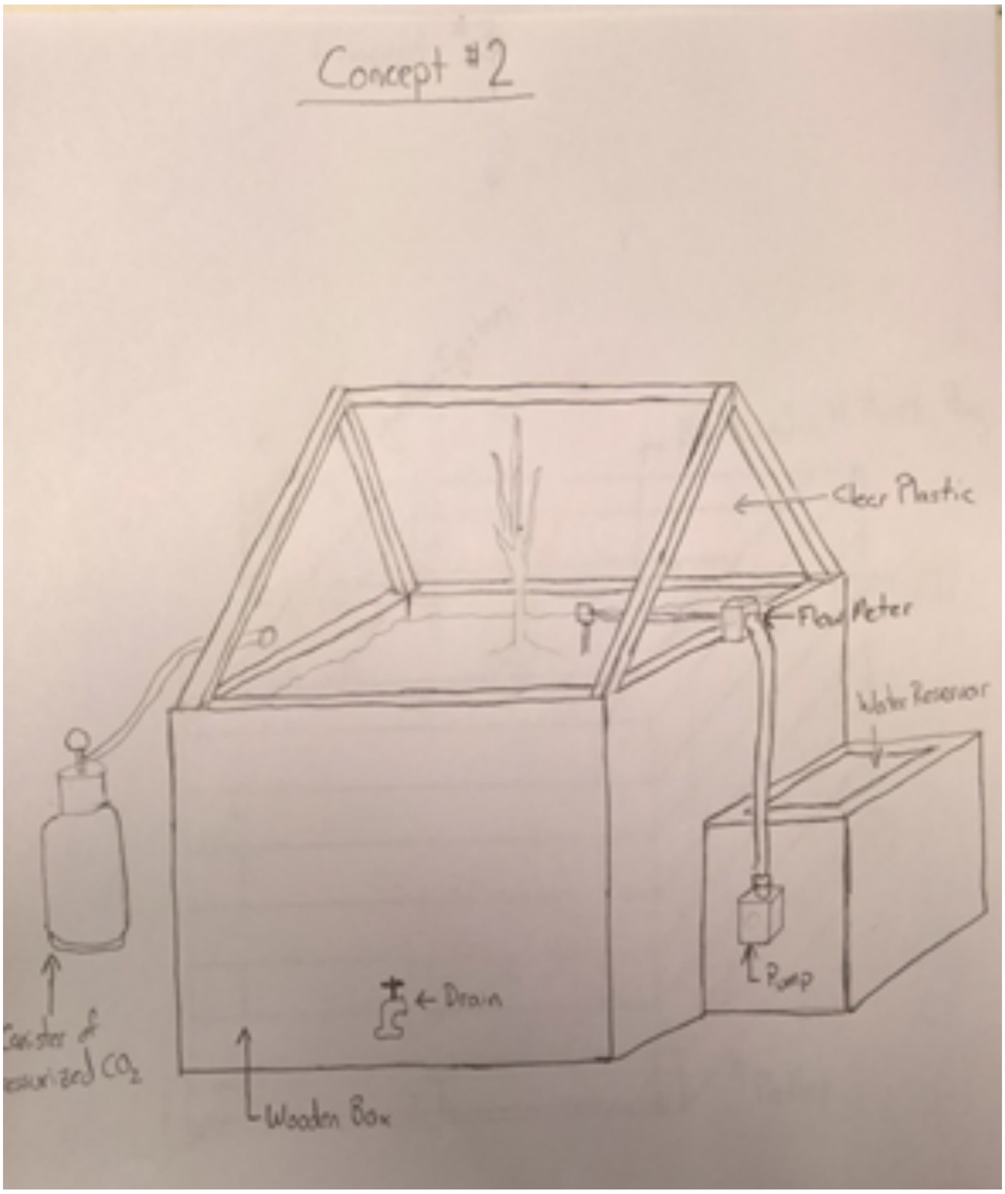


Figure 5: Drawing of Concept #2.

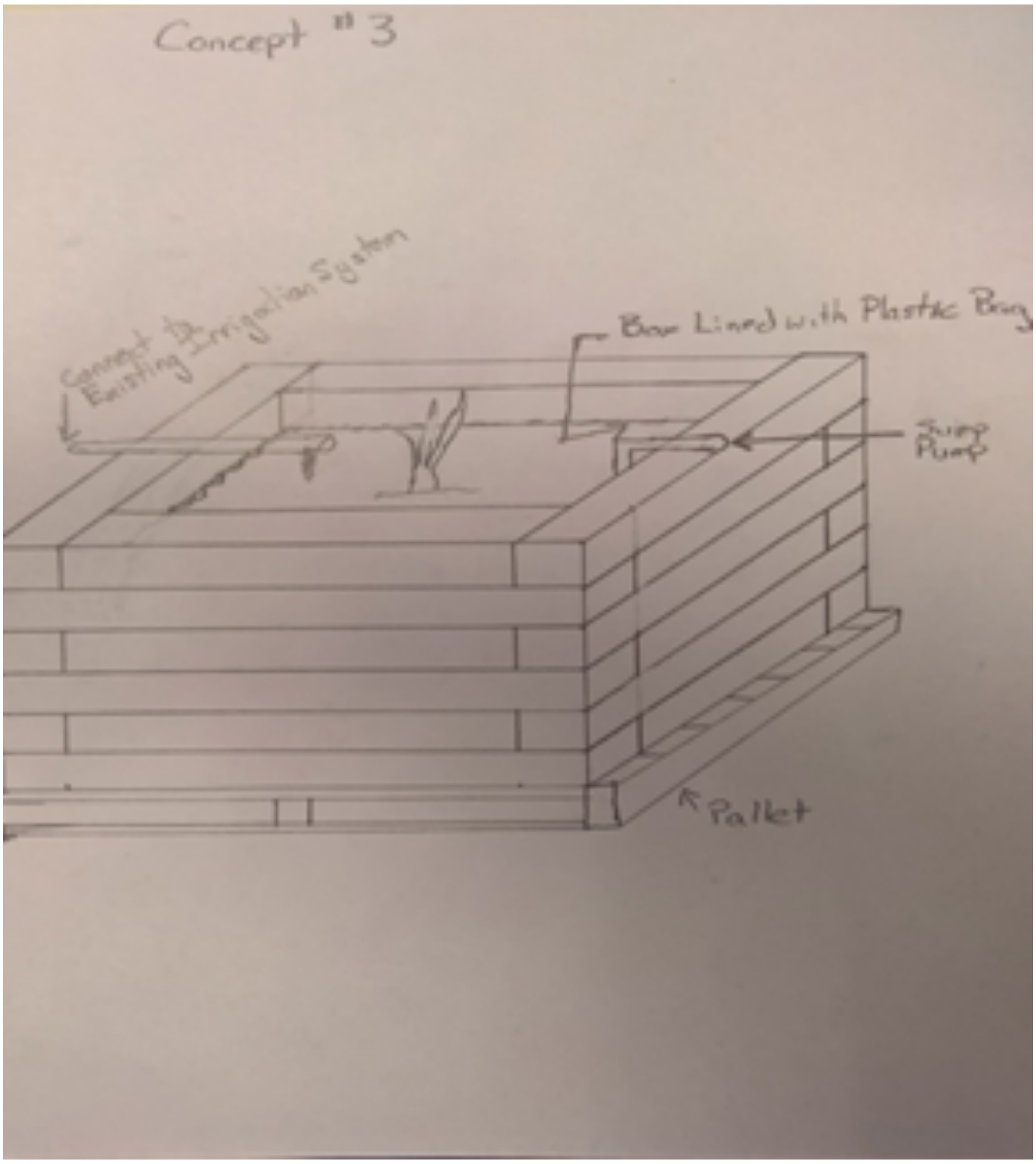


Figure 6: Drawing of Concept #3.

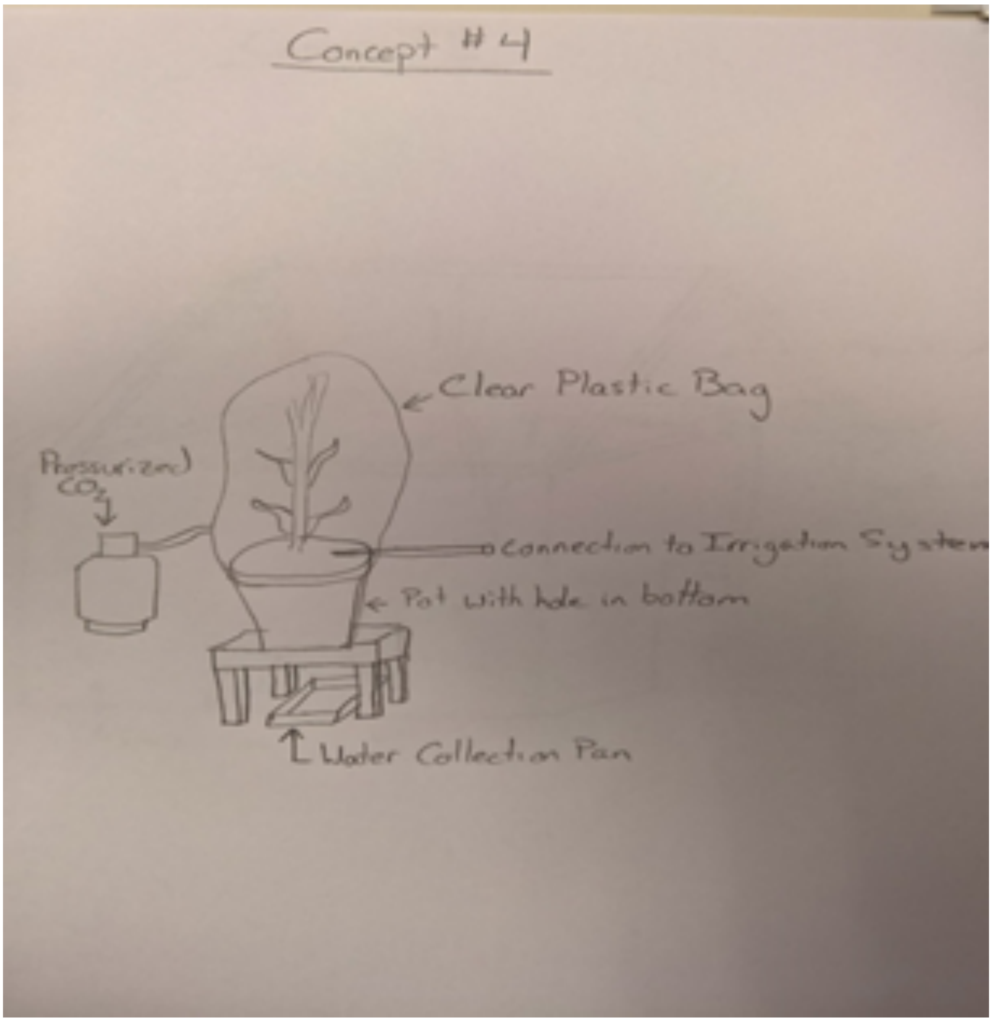


Figure 7: Drawing of Concept #4.

3.3 CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Plant Growth Chamber: Concept 1		Metric										
		Volume	Durability	Weight	Gas/Water Ports	Plants Covered	Air Tight	Pump Water	Light Transmittance	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8			
1	Pulse Gas and Liquid				0.5	0.25	0.25			0.75	0.116	0.087
2	Air Tight									0	0.116	0
3	Fit in Greenhouse	1								0.96	0.07	0.0672
4	Hold potted plants	0.5				0.5				0.98	0.116	0.11368
5	Hold gas for period of time						1			1	0.093	0.093
6	Material won't warp		1							1	0.093	0.093
7	Transportable	0.5	0.25	0.25						0.73	0.07	0.0511
8	Scalable					0.5				0.5	0.094	0.047
9	Clear Chamber								1	0.95	0.116	0.1102
10	Collect and hold water							1		0.7	0.116	0.0812
Units		in^3	Years	Lbs	Integer	Integer	Integer	GPM	%	Total Happiness		0.74338
Best Value		50000	10	20	1	3	1	5	100			
Worst Value		2000	1	100	4	1	0	0	0			
Actual Value		46000	10	45	2	3	1	3.5	95			
Normalized Metric Happiness		0.96	1	0.56	0.5	1	1	0.7	0.95			

Figure 8: Happiness spreadsheet for Concept #1.

Plant Growth Chamber: Concept 2		Metric										
		Volume	Durability	Weight	Gas/Water Ports	Plants Covered	Air Tight	Pump Water	Light Transmittance	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8			
1	Pulse Gas and Liquid				0.5	0.25	0.25			0.5825	0.116	0.06757
2	Air Tight									0	0.116	0
3	Fit in Greenhouse	1								0.63	0.07	0.0441
4	Hold potted plants	0.5				0.5				0.48	0.116	0.05568
5	Hold gas for period of time						1			1	0.093	0.093
6	Material won't warp		1							0.1	0.093	0.0093
7	Transportable	0.5	0.25	0.25						0.34	0.07	0.0238
8	Scalable					0.5				0.165	0.094	0.01551
9	Clear Chamber								1	0.92	0.116	0.10672
10	Collect and hold water							1		0.7	0.116	0.0812
Units		in^3	Years	Lbs	Integer	Integer	Integer	GPM	%	Total Happiness		0.49688
Best Value		50000	10	20	1	3	1	5	100			
Worst Value		2000	1	100	4	1	0	0	0			
Actual Value		30000	1	45	2	1	1	3.5	92			
Normalized Metric Happiness		0.63	0.1	0.56	0.5	0.33	1	0.7	0.92			

Figure 9: Happiness spreadsheet for Concept #2.

Plant Growth Chamber: Concept 3		Metric										
		Volume	Durability	Weight	Gas/Water Ports	Plants Covered	Air Tight	Pump Water	Light Transmittance	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8			
1	Pulse Gas and Liquid				0.5	0.25	0.25			0.75	0.116	0.087
2	Air Tight									0	0.116	0
3	Fit in Greenhouse	1								0.96	0.07	0.0672
4	Hold potted plants	0.5				0.5				0.98	0.116	0.11368
5	Hold gas for period of time						1			0	0.093	0
6	Material won't warp		1							0.1	0.093	0.0093
7	Transportable	0.5	0.25	0.25						0.505	0.07	0.03535
8	Scalable					0.5				0.5	0.094	0.047
9	Clear Chamber								1	0.92	0.116	0.10672
10	Collect and hold water							1		0.7	0.116	0.0812
Units		in^3	Years	Lbs	Integer	Integer	Integer	GPM	%	Total Happiness		0.54745
Best Value		50000	10	20	1	3	1	5	100			
Worst Value		46000	1	100	4	1	0	0	0			
Actual Value		30000	1	100	1	3	0	3.5	92			
Normalized Metric Happiness		0.96	0.1	0	1	1	0	0.7	0.92			

Figure 10: Happiness spreadsheet for Concept #3.

Plant Growth Chamber: Concept 4		Metric										
		Volume	Durability	Weight	Gas/Water Ports	Plants Covered	Air Tight	Pump Water	Light Transmittance	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8			
1	Pulse Gas and Liquid				0.5	0.25	0.25			0.5	0.116	0.058
2	Air Tight									0	0.116	0
3	Fit in Greenhouse	1								0	0.07	0
4	Hold potted plants	0.5				0.5				0.5	0.116	0.058
5	Hold gas for period of time						1			0	0.093	0
6	Material won't warp		1							0.1	0.093	0.0093
7	Transportable	0.5	0.25	0.25						0.025	0.07	0.00175
8	Scalable					1				1	0.094	0.094
9	Clear Chamber								1	0.92	0.116	0.10672
10	Collect and hold water							1		0	0.116	0
Units		in^3	Years	Lbs	Integer	Integer	Integer	GPM	%	Total Happiness		0.32777
Best Value		50000	10	20	2	3	1	5	100			
Worst Value		2000	1	100	4	1	0	0	0			
Actual Value		1500	1	20	2	3	0	0	92			
Normalized Metric Happiness		0	0.1	1	0.5	1	0	0	0.92			

Figure 11: Happiness spreadsheet for Concept #4.

3.3.2 Preliminary analysis of each concept's physical feasibility

Concept 1 – The "box" that would cover the plants would be made from polycarbonate and can cover a maximum of three plants. The design could be modified to accommodate more plants underneath but we thought three would be a good number to begin with. The box will need to be sealed at each edge so that the gas can't escape. We plan to seal the edges with acrylic glue from the inside and acrylic tape on the outside. In addition, there will be an aluminum frame to improve the concepts durability. There will be two ports on the box (one for pumping in gas and another for feeding water to the soil). Also, the box will have cut outs at the bottom that fit snug around the pots to release water but not the gases being pumped in.

Concept 2 – This concept would use a wooden box that would be hollow in the bottom few inches to allow water to drain. There would then be a valve that could be opened to drain the water. A box to the side would hold water that would then be pumped into the growing chamber via a water pump. A flow meter attached to the irrigation hose would measure the amount of water entering the chamber. Another port would allow gas to flow into the chamber. The upper chamber where the plant would be would be framed similar to a tent with clear plastic hung over it and sealed with a drawstring.

Concept 3 – This concept was developed by the sponsor of the project, Christopher Topp. The design is a timber box lined with plastic and has a sump pump in the bottom to pump out the water. The irrigation is provided by connecting to the existing system in the greenhouse. Since this is the sponsor's concept we felt it was important to consider his ideas and incorporate them into some of our designs. This concept did not meet all the criteria as we understand them in that it does not provide any means of sealing in the air. The concept would be more suited for an entire greenhouse that would be "pulsed" with air.

Concept 4 – The "bag" that can be placed over one plant at a time would have two ports (one for pumping in gas and another for feeding water to the soil). It also would have a drawstring so that the bag could be tightened around the pot to keep gas from escaping. The drawstring would pose challenges in being the only method to make the system airtight. The materials would also reduce life span This design would work but does not allow simultaneous study of multiple plants.

3.3.3 Final summary statement

After completing the concept drawings and going over the user needs we determined concept one was the best. Concept one scored the highest happiness score which proves it best meets the client's requests. Concept one allows the user to complete an analysis of multiple plants experiencing the same exposure to sunlight, water and gas. The design also has the capability of being scaled down or larger for studying different sized plants and that was one thing the client wanted done. A few of the other concepts do not cover multiple plants which would be inefficient for our client. Also, the materials needed for designing concept one are not hard to come by and should be within out budget for this project. The wood used in Concept 2 and 3, and the clear plastic bags used in both concepts would cause a significant reduction in useful life of the growth chamber. The materials used in Concept 1, aluminum frame and Plexiglas, will last for many years. Most Plexiglas products are guaranteed for at least ten years. Lastly, the time required to design our concept should not exceed the project deadline.

3.4 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

Changed Specifications:

Before selecting the winning concept, we figured the overall performance measure for our design would be if it is airtight and that still holds true. The client stressed that none of the gas should escape the chamber because of future expenses and maintaining a controlled environment for each plant. The specifications slightly changed after our concept selection. We realized that it was not necessary to use length, width and height as a metric and volume could replace those metrics. Also, we added durability and light transmittance to the metrics table which allowed us to address more needs that our concept satisfied.

Revised Needs Table for Plant Growth Chamber

Need Number	Need	Importance
1	Saturates Plants with Gas and liquid through ports	5
2	Chamber around shoots airtight	5
3	Fits in Growth Chamber or Greenhouse	3
4	Can fit plants inside of pots on the inside	5
5	Contain all gases in enclosure for X amount of time	4
6	Material that won't warp under humid or hot conditions.	4
7	Transportable device.	3
8	Chamber can be scaled to handle larger/more plants.	4
9	Clear chamber	5
10	Collect and pump out stored water	5

Revised Metrics Table for Plant Growth Chamber

Metric Number	Associated Needs	Metric	Units	Minimum Value	Maximum Value
1	3,4,7,8	Volume	Inches	1089	450
3	2,6,7,8,9	Material Weight	Lbs	10	100
4	1,5	Number of Gas Ports	Integer	2	4
5	2,4,5,7,8	Number of Plants Covered	Integer	1	3
2	5,6,7	Durability	Years	1	10
8	9	Light Transmittance	%	0	100
6	1,2,5	Airtight	Integer	0	1
7	10	Pump Water	GPM	0	5

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING/PARTS LIST

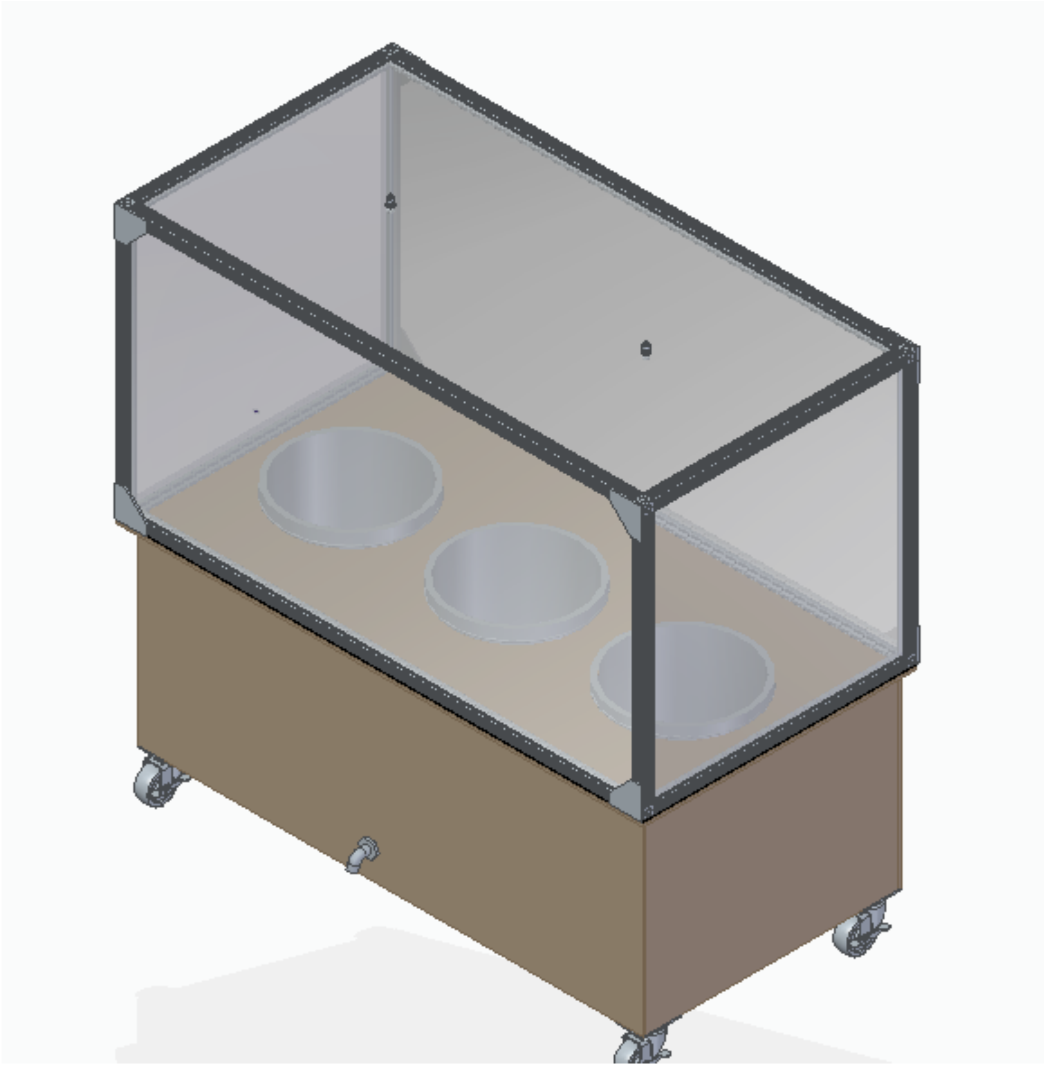


Figure 12: Assembly Drawing

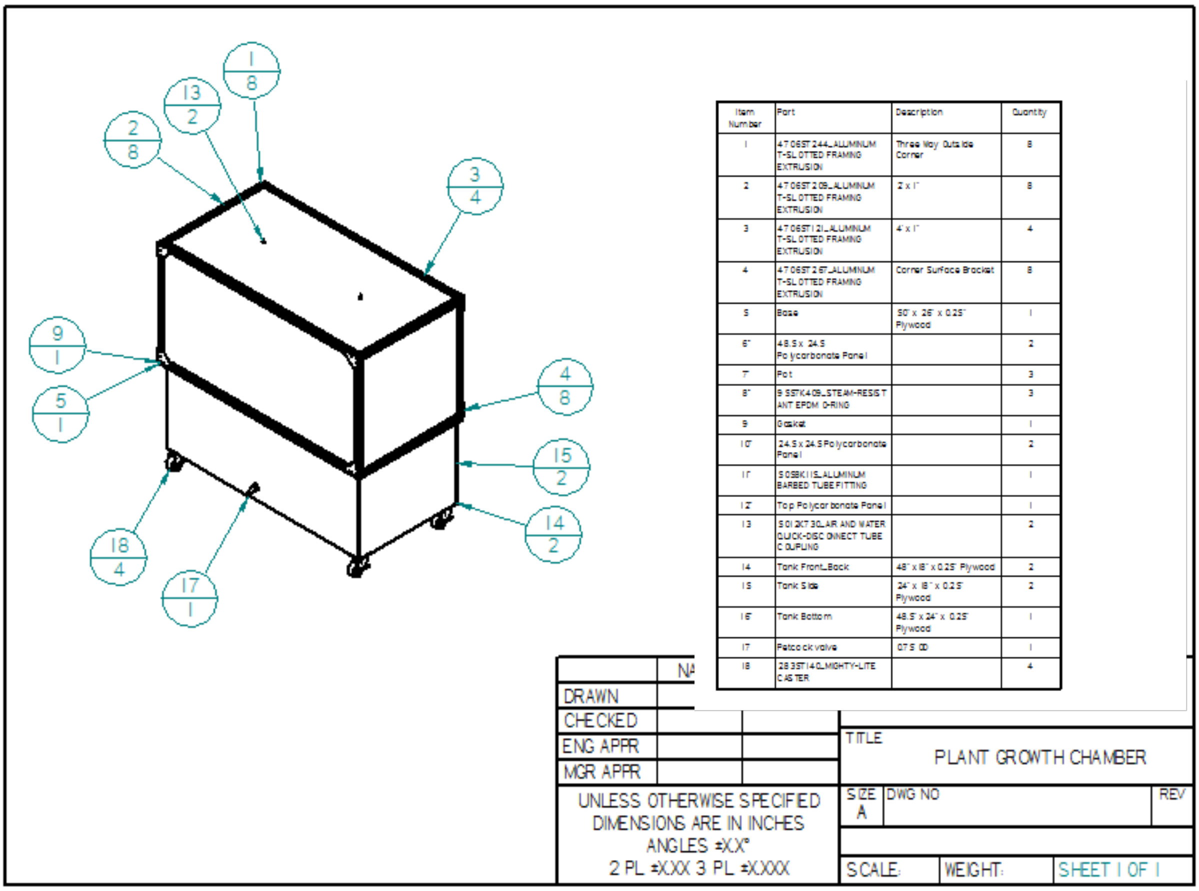


Figure 13: Drawing identifying part location.

Item #	Part #	Description	Qty.	Vendor	Unit Price	Total
1	1010-72	72" T Slotted Aluminum Rail	5	Walmart	$20.72	$103.60
2	-	2'x4' Polycarbonate Panel	4	Greenhouse Mega Store	$16	$64
3	47065T267	Three Way Outside Corner	8	McMaster-Carr	$4.55	$36.40
4	47065T267	Corner Joining Plate	8	McMaster-Carr	$8.47	$67.76
5	-	J-B Weld Plastic Bonder Syringe	1	J-B Weld	$9.49	$9.49
6	988531	4'x8' MDF Panel	1	Home Depot	$16.97	$16.97
7	9557K409	12' ID O-Ring	2	McMaster-Carr	$13.07	$26.14
8	5012K730	Air and Water Quick Disconnect Tube Coupling	2	McMaster-Carr	$2.97	$5.94
9	2835T11	Mighty-Lite Caster	4	McMaster-Carr	$12.09	$48.36
10	5058K115	Aluminum Barbed Tube Fitting	1	McMaster-Carr	$7.91	$7.91
11	-	Plant Pot	3	-	-	-
12	9700K14	Gasket	1	McMaster-Carr	$20.20	$20.20
13	4792K62	Petcock Valve	1	McMaster-Carr	$8.83	$8.83
					TOTAL	**$415.60***

4.2 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

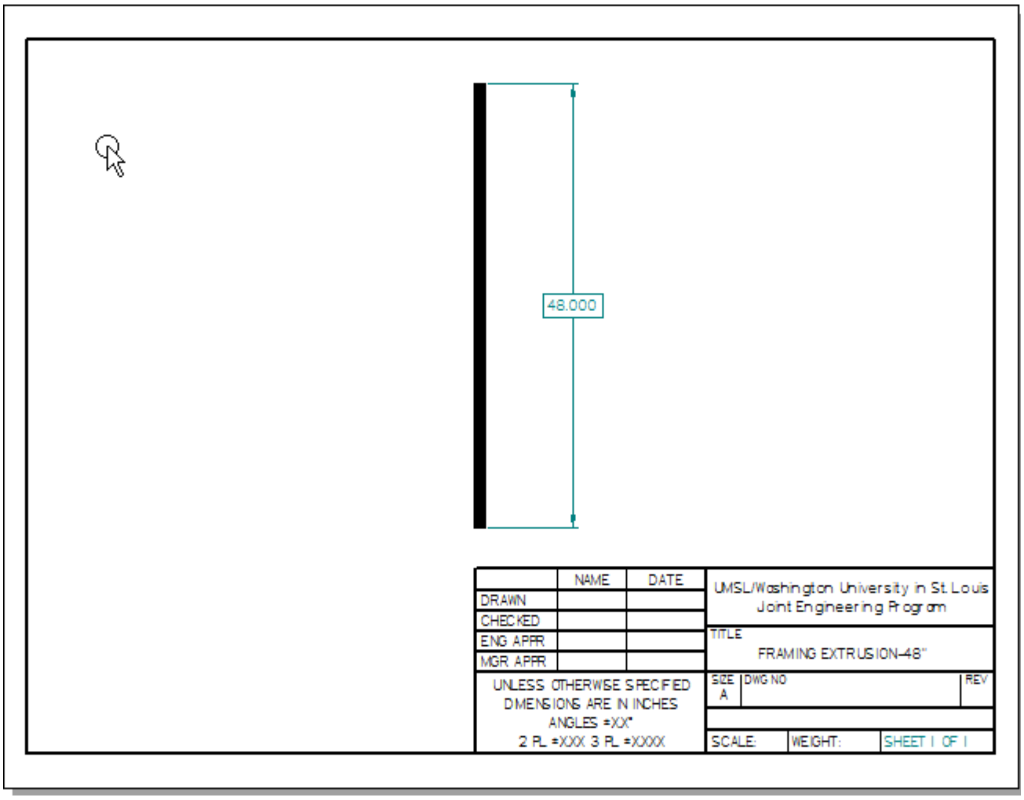


Figure 14: T-Slot extrusion for long side of chamber.

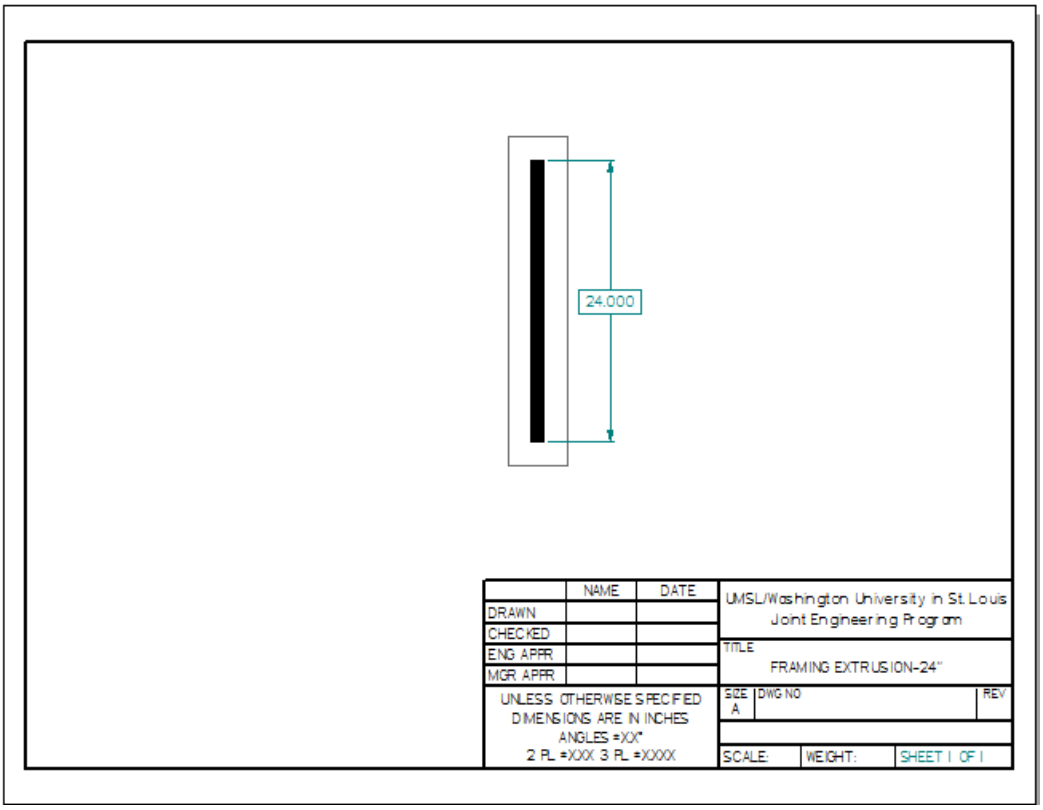


Figure 15: T-Slot extrusion for short side of chamber.

4.3 DESIGN RATIONALE

- The T Slotted Aluminum will be used as the frame and will support the polycarbonate panels. The panels will be inserted into the slots and the rails will be connected with 3- way rounded corner brackets and if more support is needed we will use corner joining plates. Our design is going to be 4’ x 1.5’ x 2’ so 5 rails of 72” x 1” x 1” will be necessary to assemble the frame.

- The Polycarbonate Panels are the same panels used on greenhouses and offer high impact resistance, heat retention and 80% light transmission. We chose this panel because of the inexpensive delivery and location of the warehouse which is in Illinois. Also, the panel dimensions are 2’x4’ with a 6mm depth which will fit into the t slot rails and is the exact size we need for multiple sides of the chamber.

- The Corner Joining Plate will only be used if our frame is not sturdy enough with only the 3-way corner brackets. The corner joining plate is a right-angle plate that supports a sturdy 90˚ angle between two rails.

- The J-B Weld is a plastic to metal bonder and will create the airtight weld we need between the frame and polycarbonate panels. The adhesive is waterproof, has a high tensile strength (3770 PSI) and dries black for a clean look.

- Air and Water Quick Disconnect Tube Couplings are used as a port to push the compressed air and CO2 gases. The quick disconnect type was chosen to make set-up and teardown as quick as possible, and to aid in ease of transportation.
- Through wall connections will be used to connect the gas and water hose fittings together. The through wall connection not only extends the connection but it also creates a more secure connection through the polycarbonate panels.

- The Weather-strip will go around the t-slot rail at the top of the chamber and will be used to seal the lid to the chamber. The weather-strip compresses which makes it great for securing the chamber lid down as airtight as possible.

- The water irrigation pump, on/off valve and PVC right elbow will be used to pump out water from the chamber. These parts will combine to allow pumping out water without opening the chamber which was requested by the client.

- The pressure gauge will be used to monitor the pressure inside the chamber so that the chamber is not filled beyond a safe limit. The gauge measure pressure in four different units making it more universal.

- The water drain grate will be used to prop the plant up so that it isn’t sitting in water and allows the drained water from the plant to flow to the bottom of the chamber so that it can be pumped out.

- The knobs will be used to secure the lid to the chamber and more importantly compress the lid to the chamber as airtight as possible. The tighter you screw down the knobs the closer the polycarbonate compresses against the weather-strip which is running along the top of the chamber.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT
ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT
PROJECT: Plant Growth Chamber
NAMES: Deontez Myers, Chad Szwargulski
INSTRUCTOR: Mark Jakiela

The following engineering analysis tasks will be performed:

INITIAL ANALYSIS: Determine the maximum pressure that the chamber will be able to contain before fracturing the polycarbonate panels using finite element analysis.

PROTOTYPE ANALYSIS: Verify that the chamber is water tight.

The work will be divided among the group members in the following way:

INITIAL ANALYSIS: Chad Szwargulski CS
PROTOTYPE ANALYSIS: Deontez Myers DM

Instructor signature: ________________; Print instructor name: ________________
(Group members should initial near their name above.)

Figure 16: Engineering analysis agreement.

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

The essential function of the chamber is to be air and water tight. The requirements mean that the chamber will be under pressure while in use. Failure under pressure can create a potentially dangerous situation for the user and others around the chamber. With the potential risks involved with a pressure vessel, it is essential to determine at what pressure the chamber could be expected to fail.

5.2.2 Summary statement of analysis done

The high cost and limited time available meant that the only reasonable test that could be conducted was a finite element analysis to determine maximum pressure. The ability to hold water will be tested by filling the chamber with a couple of inches of water, and then pumping it out.

5.2.3 Methodology

The finite element analysis was conducted using ANSYS software. To simulate the conditions that the polycarbonate panels of the chamber would experience, the edges of the panels were held rigid and a uniform pressure distribution was applied to the surface of the panels.

Yield Strength of Polycarbonate Panels: **9000 psi**

Ultimate Strength of Polycarbonate Panels**: 9500 psi**

Strength Testing Method: **ASTM D 638**

The ability to hold water was tested by propping the chamber onto 2”x 4” lumber. Propping the chamber up allowed for the viewing of the underneath of the chamber and the corners so that they could be inspected for leaks. The chamber was then filled with a couple of inches of water from a garden hose.

5.2.4 Results

Finite Element Analysis Results:

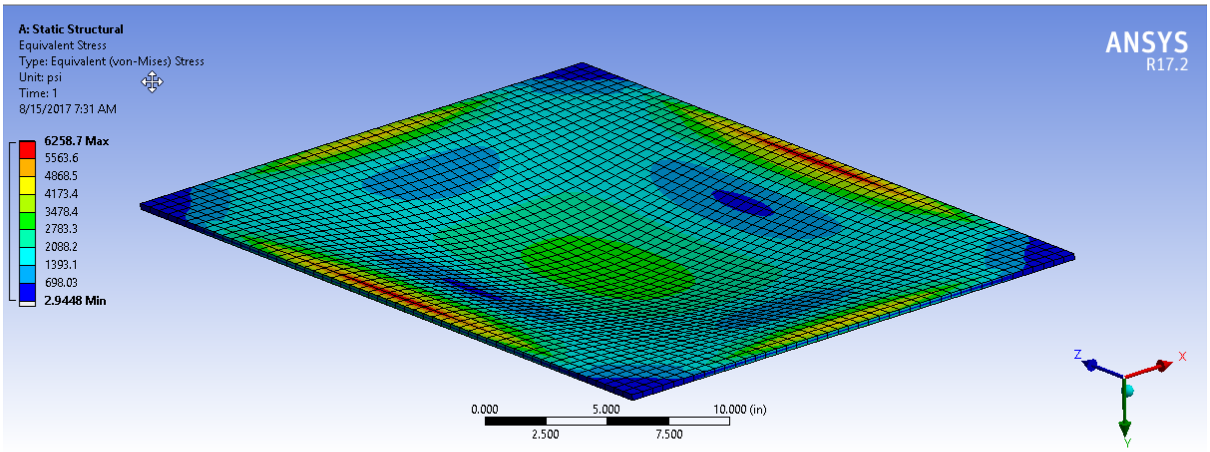


Figure 17: Side panel at 2psi.

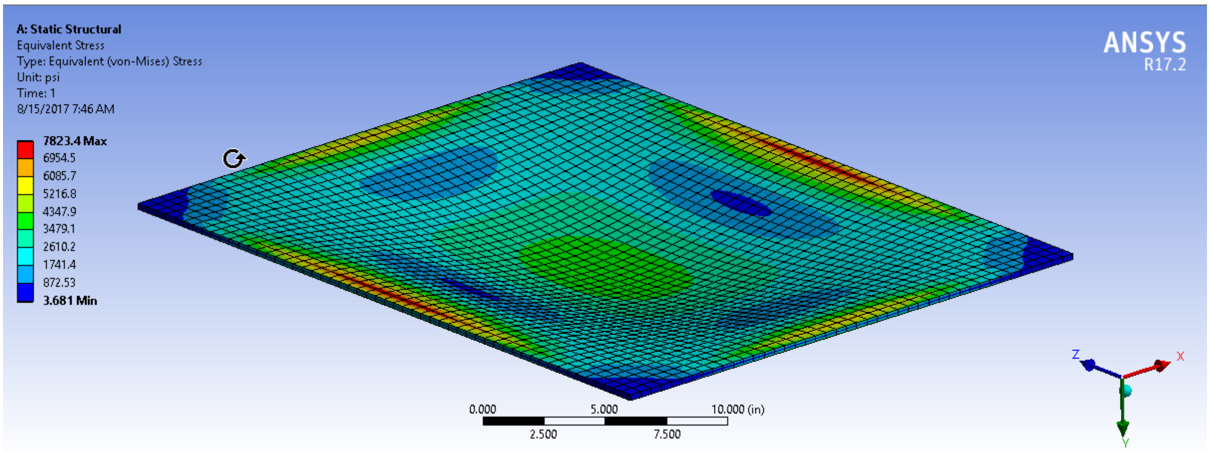


Figure 18: Side panel at 2.5 psi.

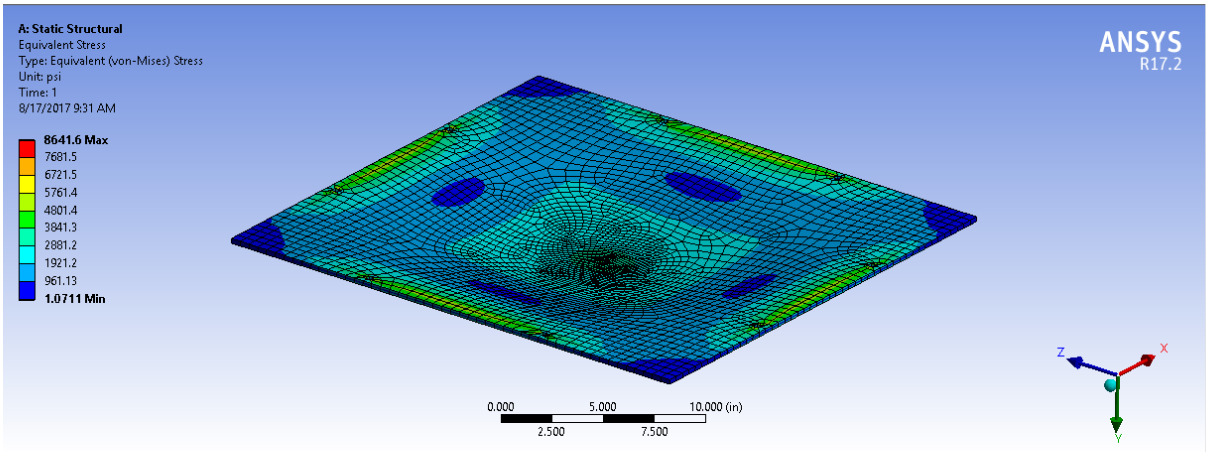


Figure 19: Top panel at 2 psi.

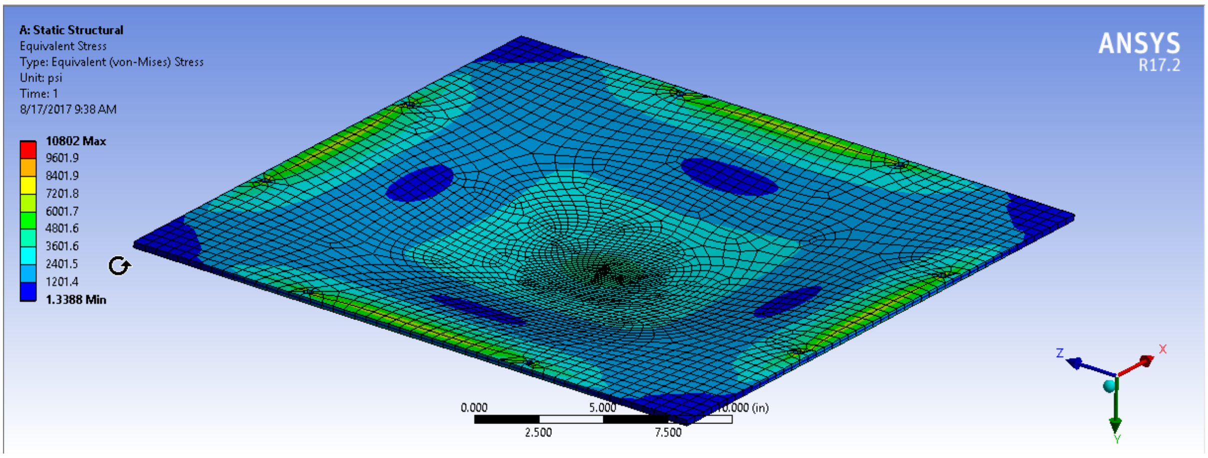


Figure 20: Top panel at 2.5 psi.

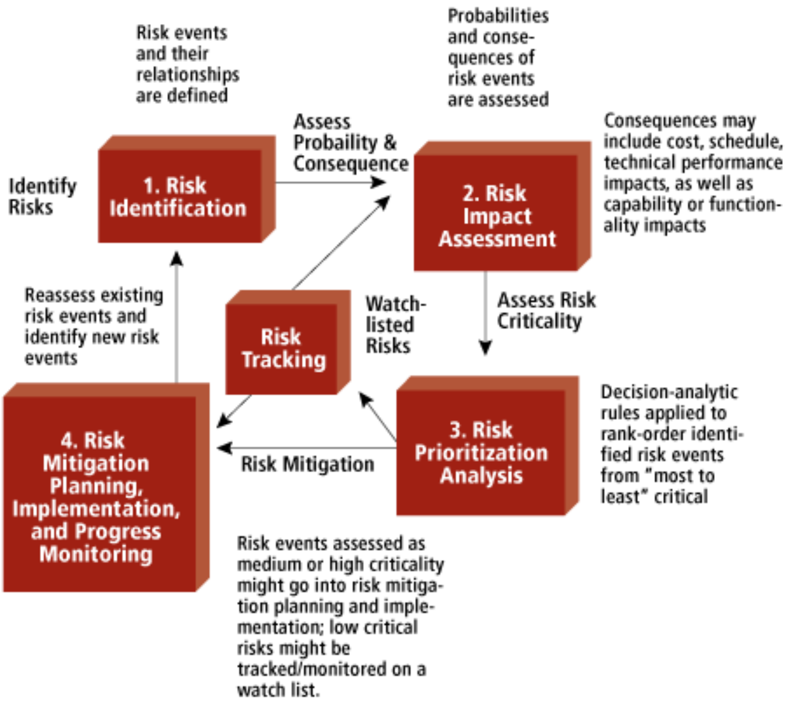
Water Testing Results:

The chamber initially leaked in a couple of corners, but after several more coatings of sealant the issue was resolved.

5.2.5 Significance

From the results of the finite element test it was determined that the maximum pressure that the chamber can hold before failure is 2 psi. While the stress at 2psi does not exceed the yield strength, it is important to have some factor of safety, given that testing to verify the finite element analysis is not practical. The chamber being water tight with 2 inches of water in the chamber means that the chamber is capable of holding more water than the chamber would ever experience in the field.

6 RISK ASSESSMENT



6.1 RISK IDENTIFICATION

- Aligning group member's schedules with the schedules of the Danforth Plant Science Center sponsor's schedule.
- Delays in receiving design approval
- Delays in ordering and receiving parts
- Fracturing the chamber during testing

6.2 RISK ANALYSIS

Aligning group member's schedules with the schedules of the Danforth Plant Science Center sponsor's schedule:

For this project, it is necessary to meet with Danforth Plant Science Center researches and laboratory staff to understand the design requirements. Scheduling will be critical to the success of the project, because, any delays caused by conflicting schedules will result in delays in producing the prototype.

Delays in receiving design approval:

Because the product being developed is going to be used by an actual customer, and not strictly an education experience, it is necessary to get approval for the proposed design from the actual customer. The customer is relying on the product fulfilling a need and are spending money with the expectation that the prototype will work as desired. If the original design is not satisfactory then there will be delays in proceeding further in the design and building of the prototype.

Delays in ordering and receiving parts:

Many of the parts that are required to build the plant growth chamber are not likely readily available locally, or if available will be far greater in price than ordering from other sources. Backorders or other shipping delays could cause serious delays and possibly jeopardize delivering the product on time and on budget.

Fracturing the chamber during testing:

The chamber is essentially a pressure vessel and for the safety of the end user it is important to determine the maximum pressure that the chamber can hold. Pressure testing the chamber could goes complete failure of some of the components. The high cost of the materials and a tight build schedule would make testing to failure prohibitive.

6.3 RISK PRIORITIZATION

To help prioritize the possible risks associated with competing the chamber a chart was made listing all of the risks, the probability of each risk, the impact, and ways to lessen the likelihood of encountering the problems. Risks that would cause late delivery or design failure were given the highest impact rating, and experience from other projects gave insight as to the likelihood of encountering each risk.

RISK	PROBABILITY	IMPACT	MITIGATION
Aligning group member's schedules with the schedules of the Danforth Plant Science Center sponsor's schedule	Moderate	Low	Conduct as much communication as possible via email. Gain as much information as possible during every meeting.
Delays in receiving design approval	Moderate	High	Ask as many questions as possible to provide a workable design quickly.
Delays in ordering and receiving parts	High	High	Determine which parts cannot be sourced locally and order them as soon as possible.
Fracturing the chamber during testing	Moderate	High	Conduct thorough FEA to determine the maximum pressure and just check that the vessel is indeed airtight.

7 CODES AND STANDARDS

7.1 IDENTIFICATION

"ASME Boiler and Pressure Vessel Code." *Asme.org*, 2013, www.asme.org/getmedia/1adfc3df-7dab-44bf-a078-8b1c7d60bf0d/ASME_BPVC_2013-Brochure.aspx.

"UNITED STATES DEPARTMENT OF LABOR." *Occupational Safety and Health Administration*, www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9696.

7.2 JUSTIFICATION

The plant growth chamber is essentially a pressure vessel, in that it is designed to be airtight and to have compressed air injected into it. As such, it was necessary to determine if the plant growth chamber is subject to any codes that provide guidance in the design and materials to be used. After reviewing the code, it was determined that the ASME codes apply to vessels that will be subjected to pressures of 15 psia or greater. As designed the chamber will only hold a maximum of 2 psia.

The chamber is likely to be subject to frequent use inside of a work environment. To minimize possible health risks to the end user it was necessary to consult regulations concerning ergonomics in the work place.

7.3 DESIGN CONSTRAINTS

7.3.1 Safety

A chamber that was at risk of exploding could create a life-threatening situation. The chamber would need to be strong enough to handle the anticipated pressures. While the chamber will not reach pressures great enough to fall under the guidance of the ASME Codes, the possibility of the chamber exploding was still considered. To reduce the health risk if the chamber were to explode polycarbonate panels were chosen over glass. Polycarbonate is stronger than typical laminated glass and is less likely to fracture into pieces with sharp edges.

7.3.2 Ergonomic

The chamber is likely to be subjected to repetitive use, therefore, if the design of the chamber did not consider ergonomics, the chamber could present a health hazard for the end user. The original design would have been able to hold plants over 32" tall, but would require excessive bending over to place a plant in the chamber. To reduce the extent of bending, the chamber was reduced to a height of 32" with the plant sitting on a one inch pedestal. The design changes will reduce the risk of back strain for the end user.

7.4 SIGNIFICANCE

The constraints will impact the design of the chamber by limiting the size and the materials used to construct the chamber. The initial design was to have thin polycarbonate panels designed for use on greenhouses. These panels were not solid and would have been prone to fracture at pressures that are expected to be encountered. The polycarbonate panels chosen for the final design are ¼" thick solid polycarbonate. These panels can handle flexure stresses in excess of 13,000 psi. The change in materials added a safety factor to the chamber that did not exist with the greenhouse panels.

Reducing the height will reduce the risks of injury from normal operation of the chamber. By reducing the height, the same general design could be used, instead of completely changing the design, leading to delays and an increase in costs.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS AND DESCRIPTIONS

The Plant Growth Chamber is essentially a 3’ x 2’ x 2’ polycarbonate and t-slot box. The chamber is sealed airtight with silicon based caulk, JB-weld and weather stripping. In Figure 8-1 you can see the gas fitting, water fitting, water pump, pressure gauge and the corner plates used to lock the rails in 90˚ angles.

Figure 21: Front view of Plant Growth Chamber.

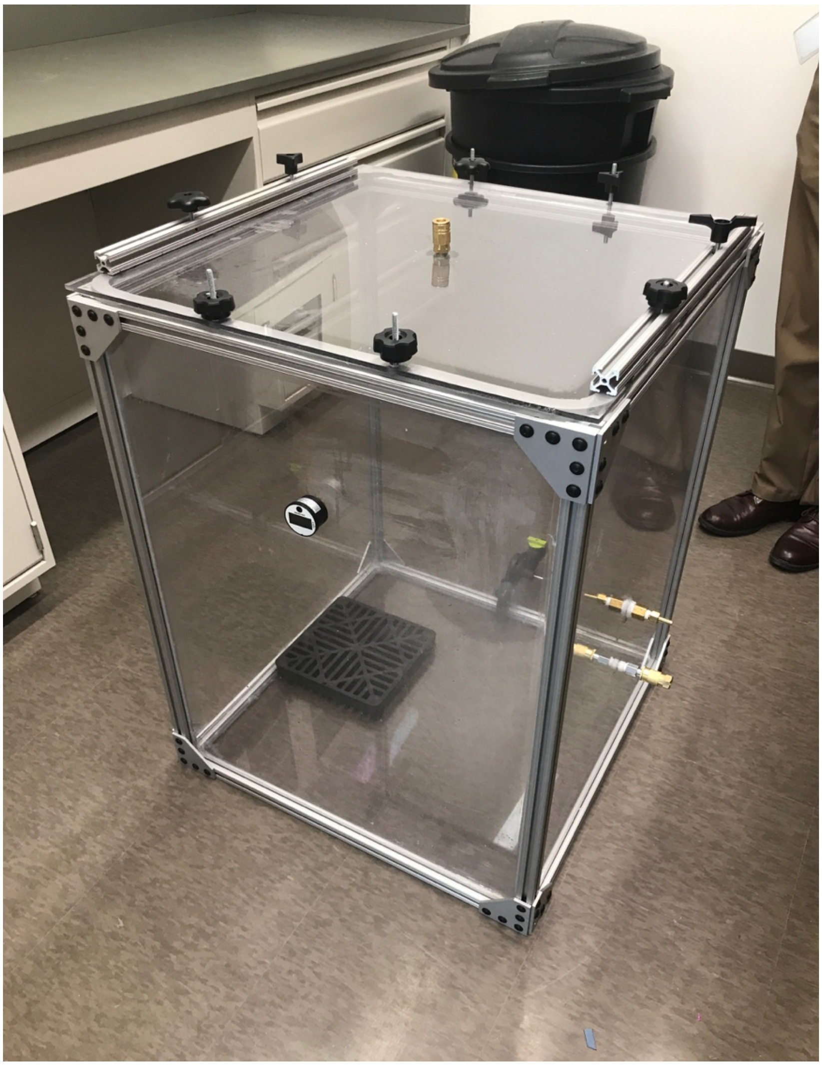


Figure 22: Isometric view of Plant Growth Chamber.

Figure 22 shows a top view of the chamber. You can see the outlet gas connection valve for pumping out gas. When a vacuum is connected to the outlet you can pump out the gas in the chamber while sucking in fresh air from the inlet gas valve. The lid on the chamber is also polycarbonate and has two t-slot rails attached to it which serve as handles. The t-slot attached to the polycarbonate also keeps the sheet flat and does not allow warping in the corners of the lid. There are also 8 knobs which screw onto threaded rods fixed onto the chamber. The knobs compress the lid onto the weather stripping running along the top portion of the chamber frame creating an airtight seal.

8.2 WORKING PROTOTYPE VIDEO

https://youtu.be/08d4-XljJdY

8.3 PROTOTYPE COMPONENTS

Figure 23: Inlet Gas and Water Hose Fitting

Figure 23 shows the inlet hose fittings for the gas (lower fitting) and water (upper fitting). The water fitting is brass and connected to a through wall connection which on the inside has another brass fitting that will supply water to a hose for watering the plant. The gas fitting is also connected to a through wall fitting but the through wall releases directly to the inside of the chamber.

Figure 24: Water Excavation Pump

Figure 24 shows the water irrigation pump. The drill pump is connected to a PVC on/off valve and PVC right angle. The right angle is on the inside of the chamber and is placed slightly above the bottom polycarbonate panel so that it removes majority of the water from the chamber. The on/off valve can be connected to a hose for irrigating the water to different reservoirs and the pump is operated with a handheld drill. This feature allows water to be removed without opening the lid of the chamber.

Figure 25: Digital pressure gauge.

Figure 25 shows the chamber pressure gauge. The gauge reads the pressure inside the chamber so that the user will know when the pressure reaches levels that will compromise the strength integrity of the chamber. It reads in psi, bar, Mpa and Kg.

Figure 26: Outlet Gas Connection

Figure 26 shows the outlet gas connection. The connection is on the chamber lid and is universal. It can be attached to a vacuum to safely remove gas from the chamber. This connection protects the user from being exposed to the chemicals inside the chamber and when the vacuum is attached to the outlet the inlet will suck fresh air into the chamber.

9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

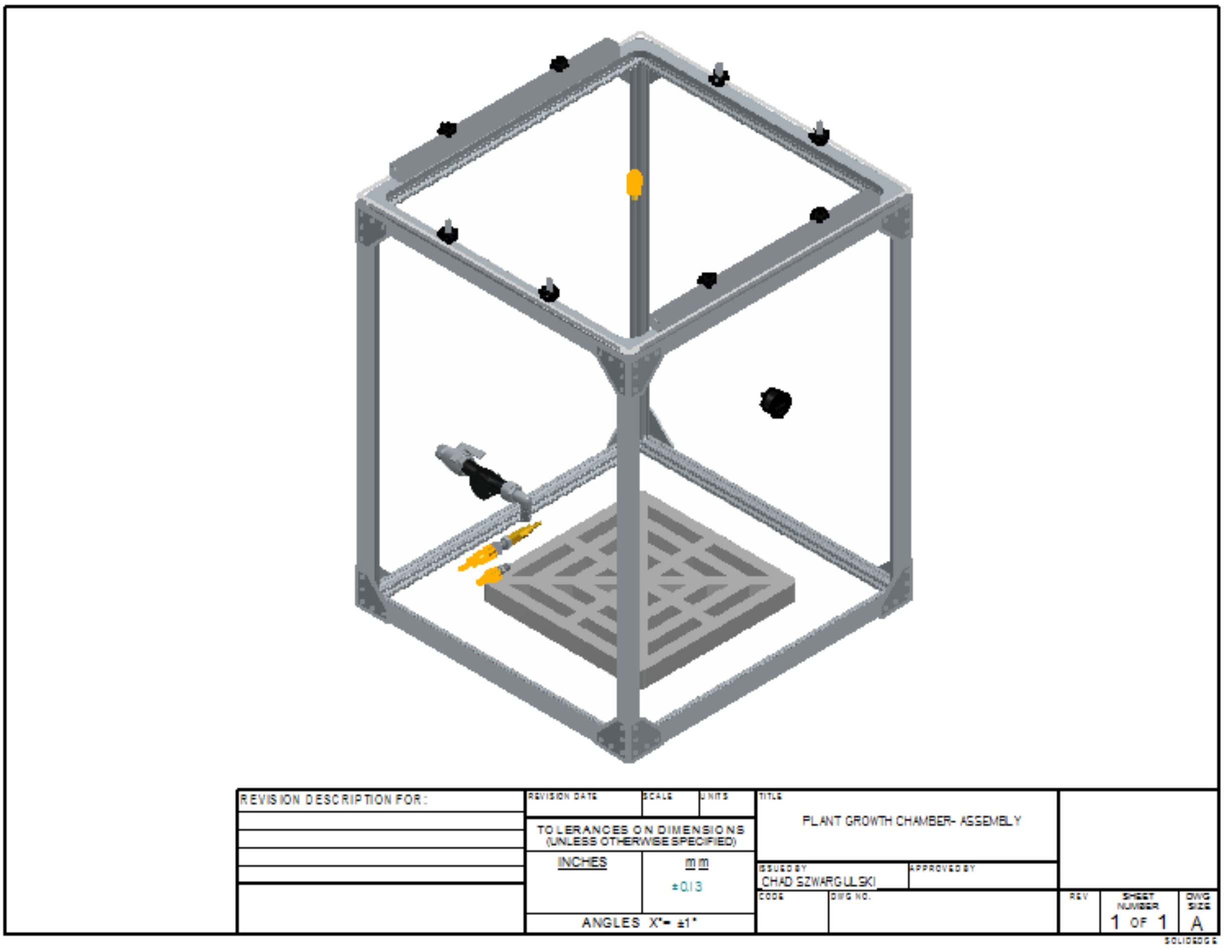
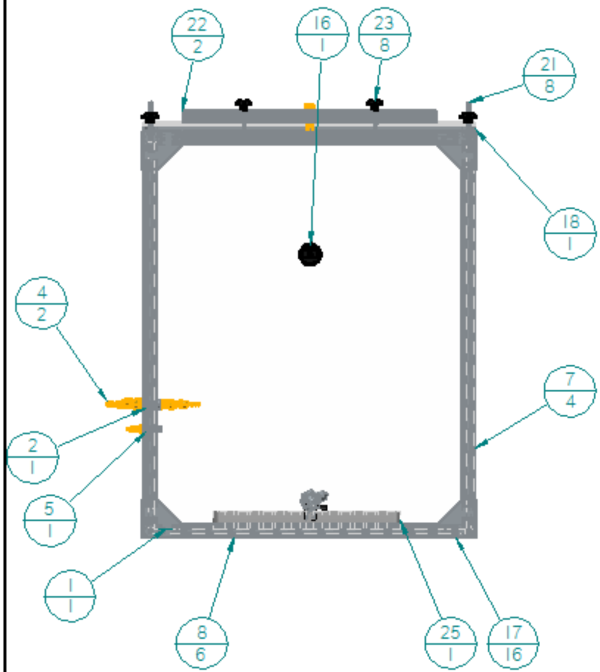


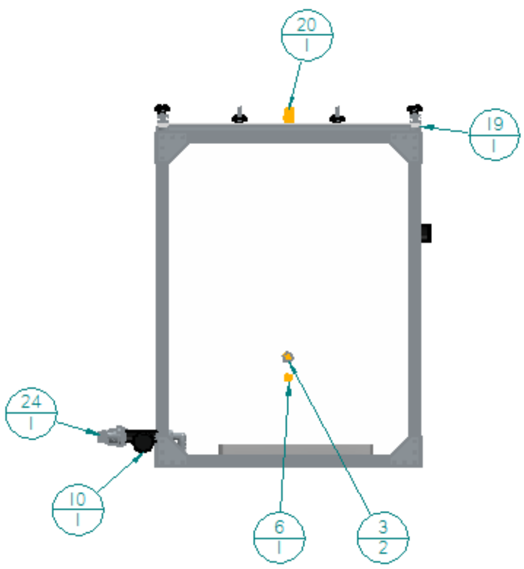
Figure 27:Isometric View of Chamber.



Item Number	Description	Quantity
1	Polycarbonate Panel left	1
2	MINIATURE THROUGH-WALL FITTING	1
4	5346K830_BRASS BARBED HOSE FITTING	2
5	1424T150_NYLON CHECK VALVE W PIPE-TO-PIPE CONNECTOR	1
7	T-SLOTTED FRAMING EXTRUSION 28.5	4
8	T-SLOTTED FRAMING EXTRUSION 25.5	6
10*	Pump	1
16	1287N100_COMPACT DIGITAL GAUGE	1
17	Corner Bracket	16
18	Gasket	1
21	98750A023_ASTM A193 GRADE B7 STEEL THREADED STUD	8
22	T-SLOTTED FRAMING EXTRUSION 20.5	2
23	6092K110_NYLON SEVEN-LOBE KNOB	8
25	Drain Grate	1

REVISION DESCRIPTION FOR:
TOLERANCES ON DIMENSIONS (UNLESS OTHERWISE SPECIFIED) INCHES mm ±0.13 ANGLES X°= ±1°
TITLE: PLANT GROWTH CHAMBER- ASSEMBLY FRONT VIEW
ISSUED BY: CHAD SZWARGULSKI
SHEET NUMBER 1 OF 1 DWG SIZE A

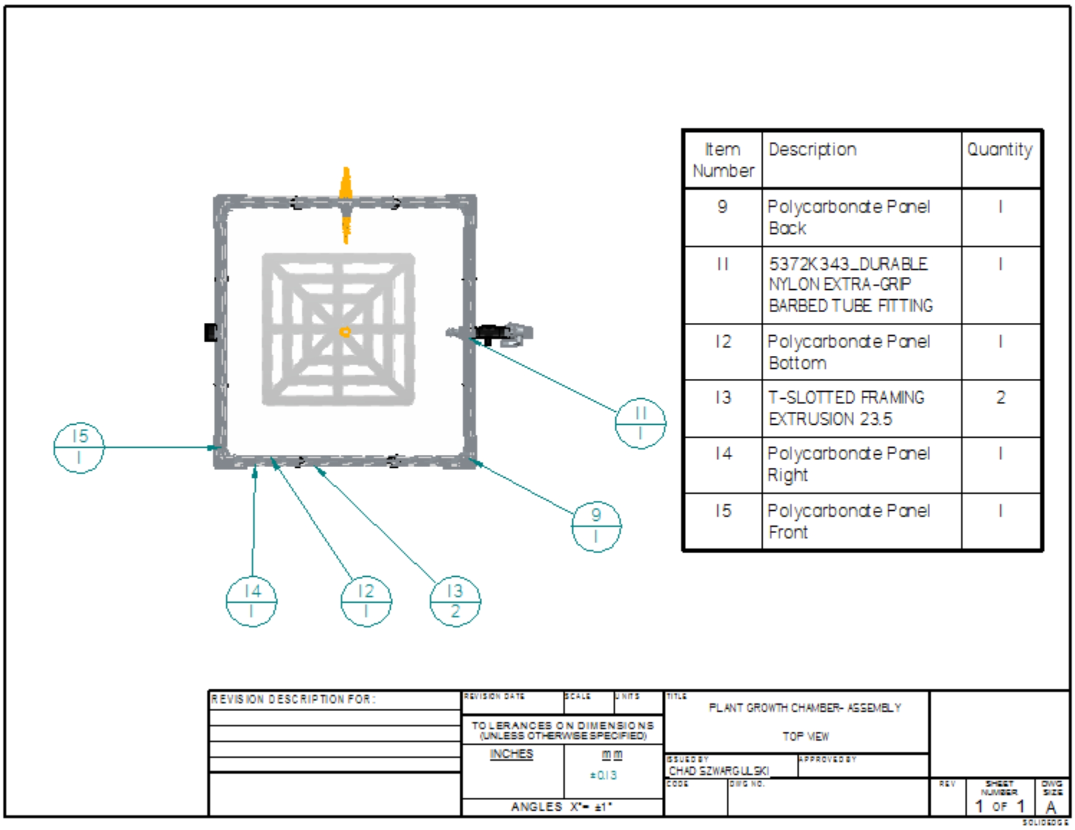
Figure 28: Front View parts list.



Item Number	Description	Quantity
3	4624K330_BRASS MALE-FEM HEX THRD ADAPTER	2
6	6534K560_INDUSTRIAL-SHAPE HOSE COUPLING	1
10	Pump	1
19	Polycarbonate Panel Top	1
20	6536K180_INDUSTRIAL-SHAPE HOSE COUPLING	1
24	9848K210_PVC BALL VALVE WITH GARDEN HOSE THREAD	1

REVISION DESCRIPTION FOR:
TOLERANCES ON DIMENSIONS (UNLESS OTHERWISE SPECIFIED) INCHES mm ±0.13 ANGLES X°= ±1°
TITLE: PLANT GROWTH CHAMBER- ASSEMBLY LEFT VIEW
ISSUED BY: CHAD SZWARGULSKI
SHEET NUMBER 1 OF 1 DWG SIZE A

Figure 29: Left View Parts List.



Item Number	Description	Quantity
9	Polycarbonate Panel Back	1
11	5372K343_DURABLE NYLON EXTRA-GRIP BARBED TUBE FITTING	1
12	Polycarbonate Panel Bottom	1
13	T-SLOTTED FRAMING EXTRUSION 23.5	2
14	Polycarbonate Panel Right	1
15	Polycarbonate Panel Front	1

Figure 30:Top View Parts List.

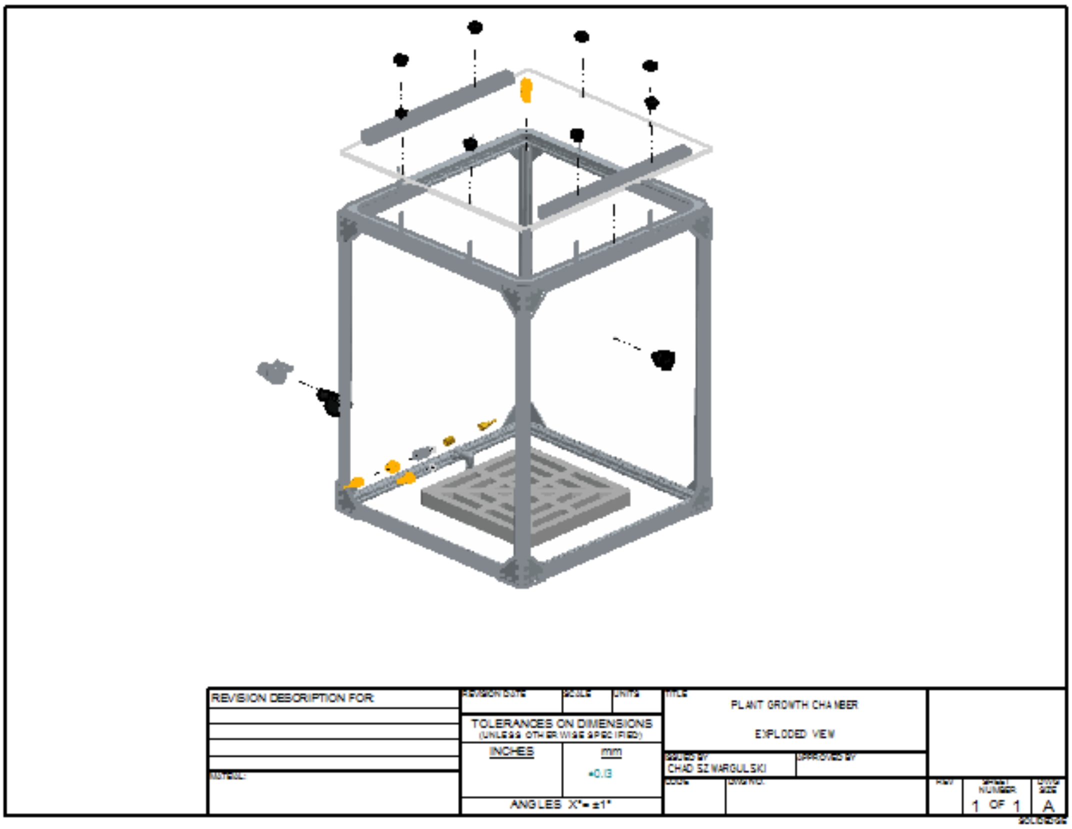


Figure 31: Exploded View.

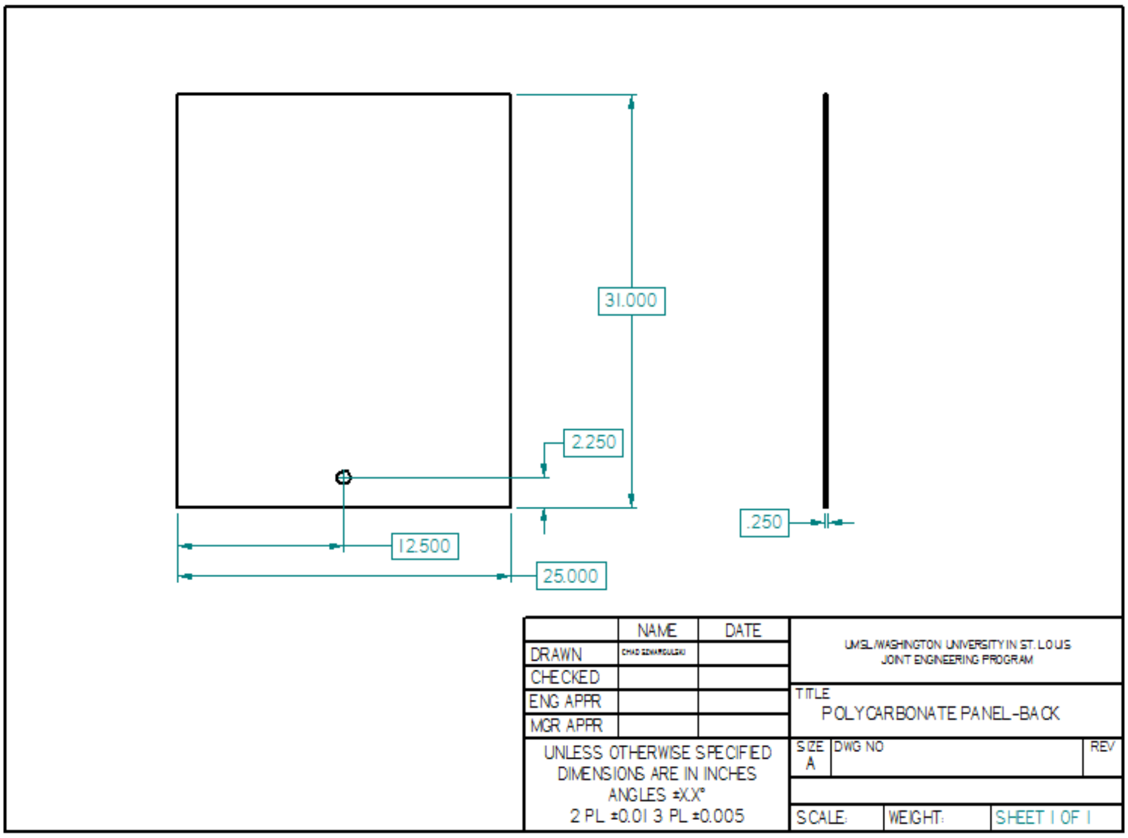


Figure 32: Drawing -Polycarbonate Panel-Back

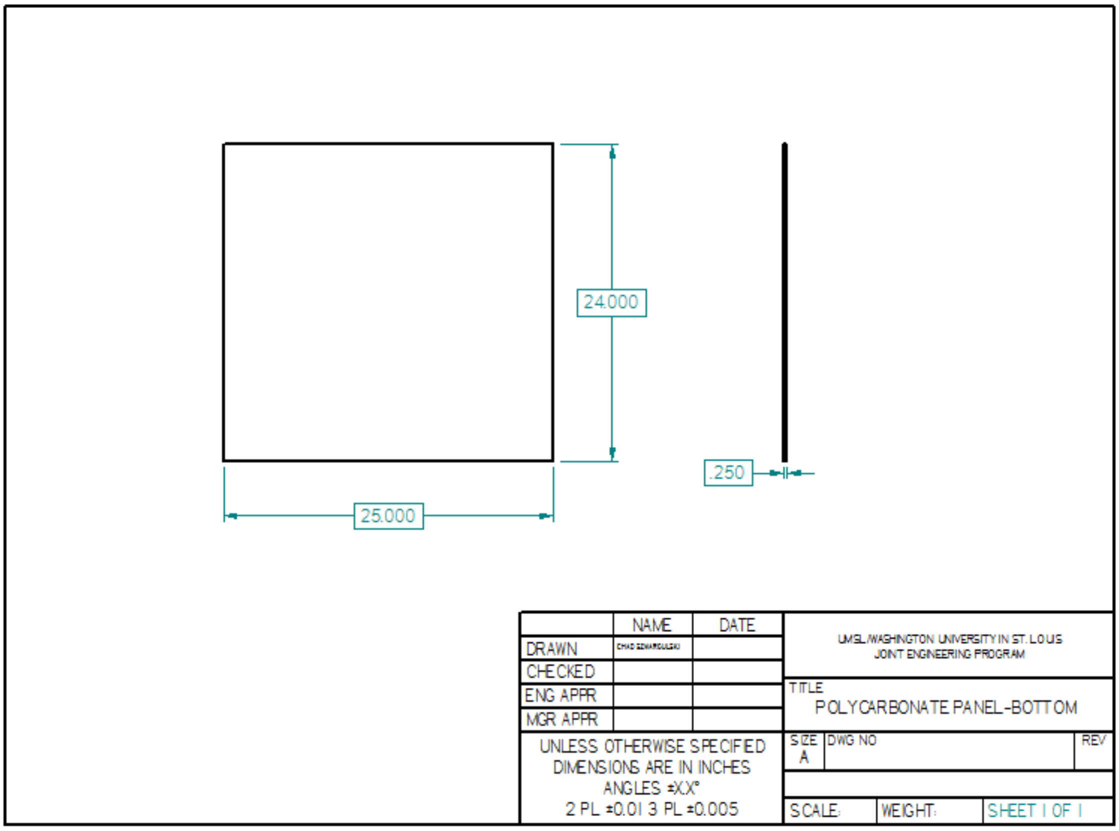


Figure 33: Drawing -Polycarbonate Panel-Bottom.

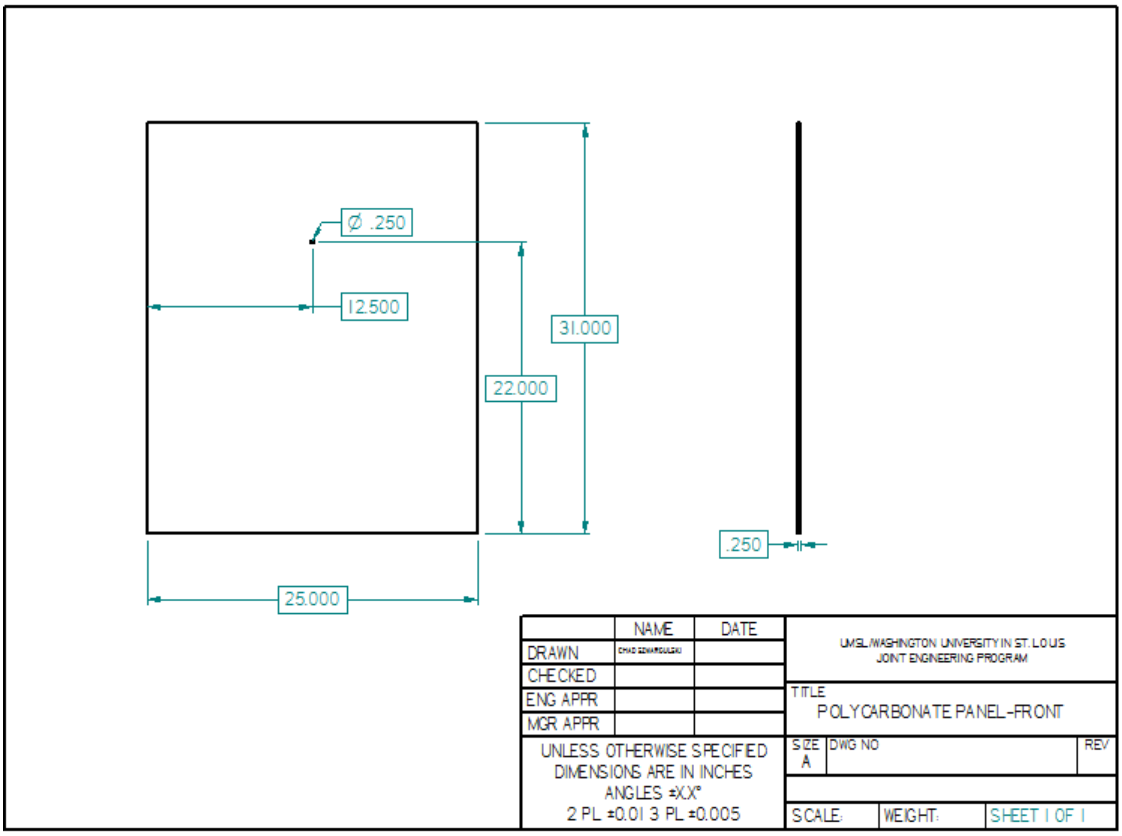


Figure 34: Drawing-Polycarbonate Panel- Front.

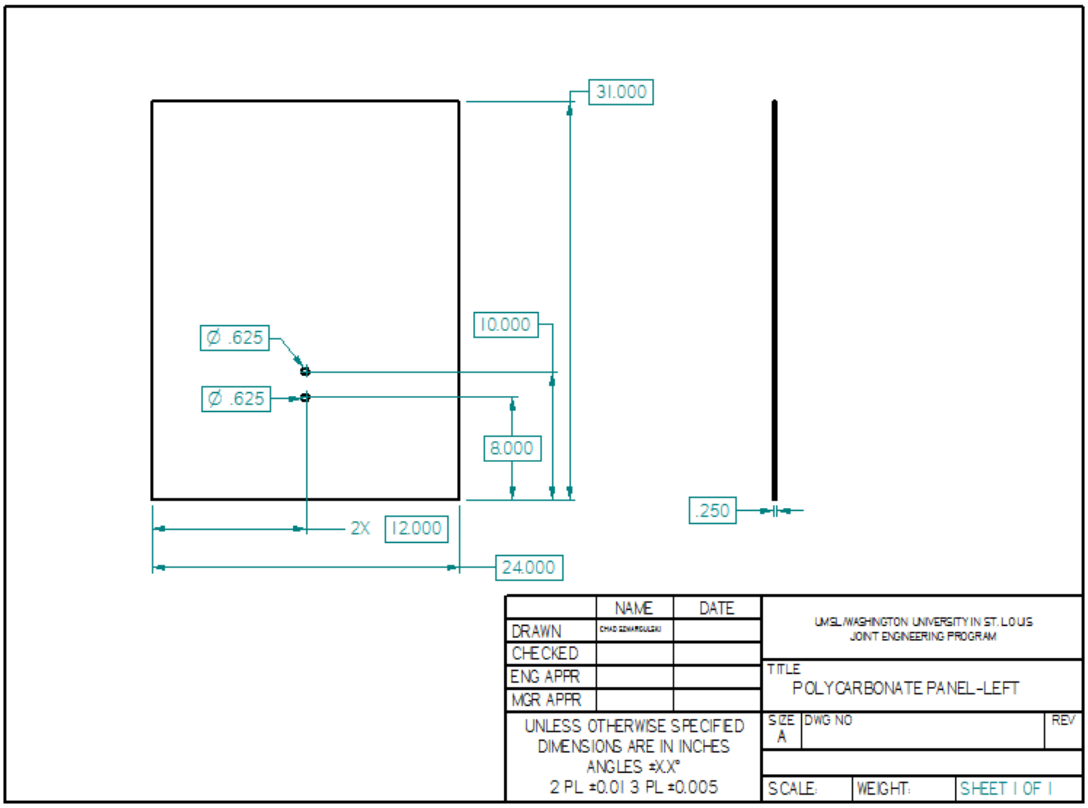


Figure 35:Drawing-Polycarbonate Panel-Left.

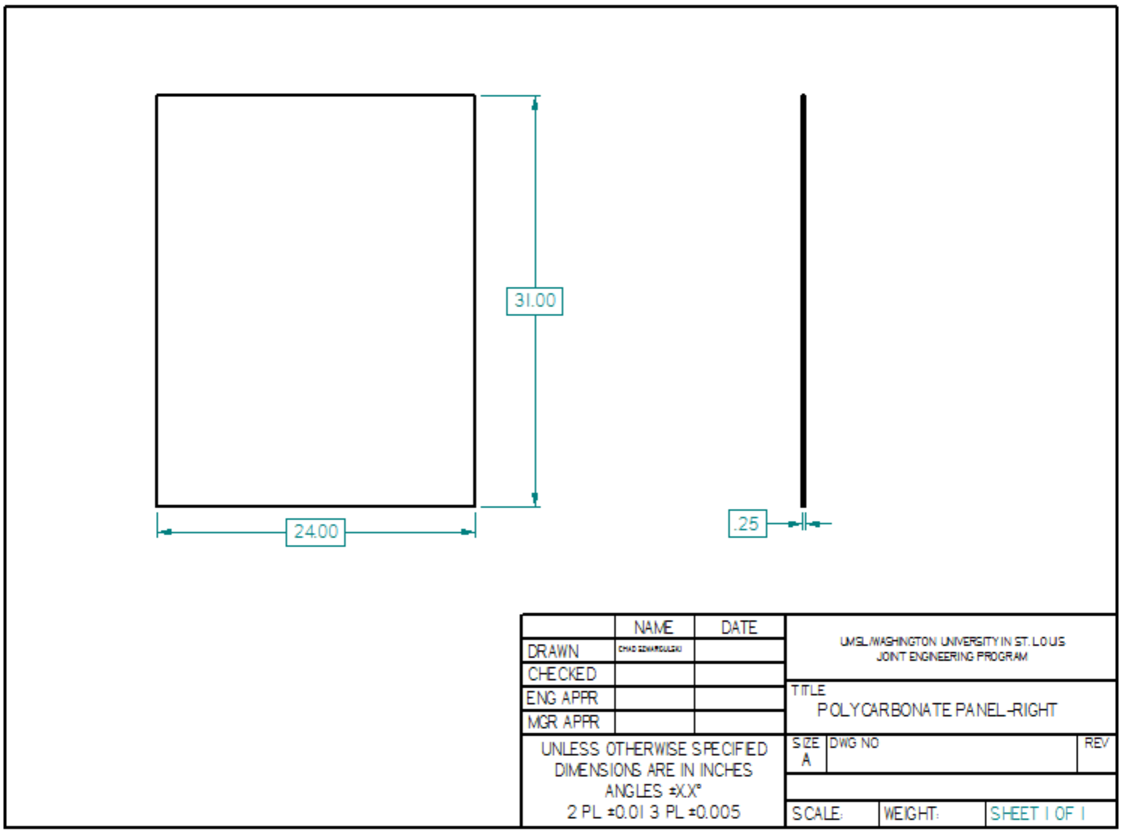


Figure 36: Drawing-Polycarbonate Panel-Right.

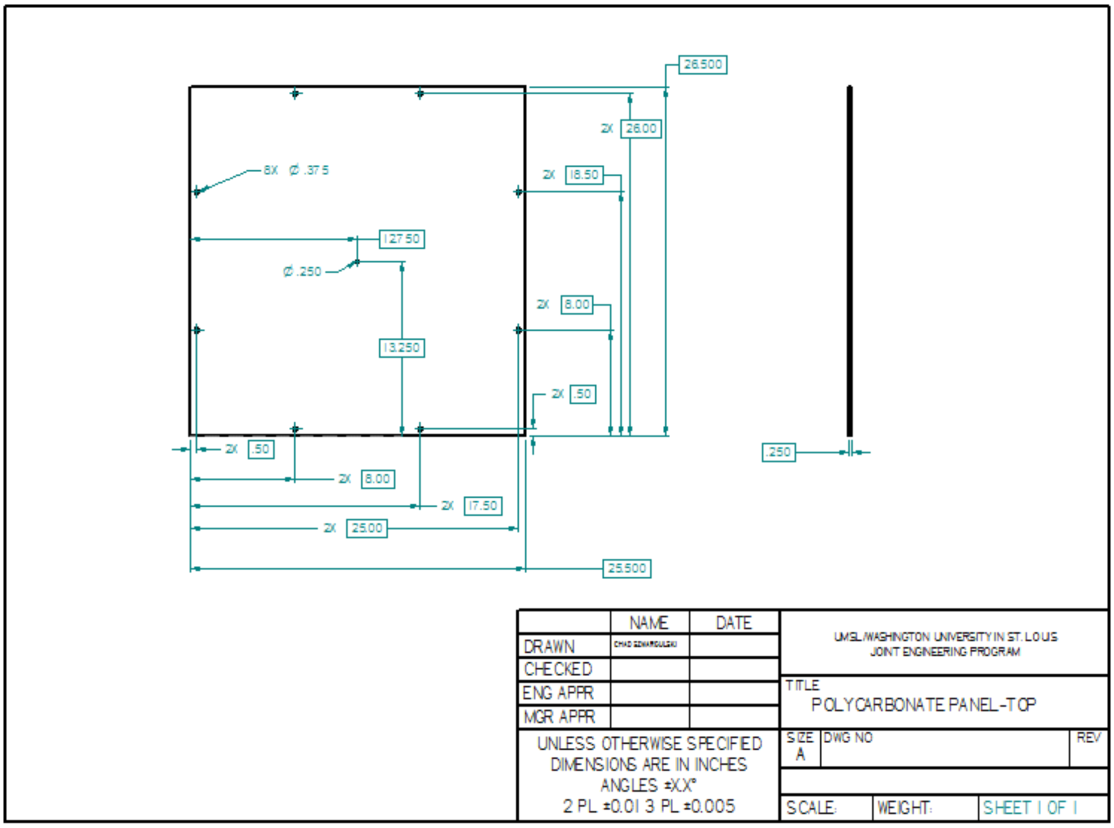


Figure 37: Drawing-Polycarbonate-Top.

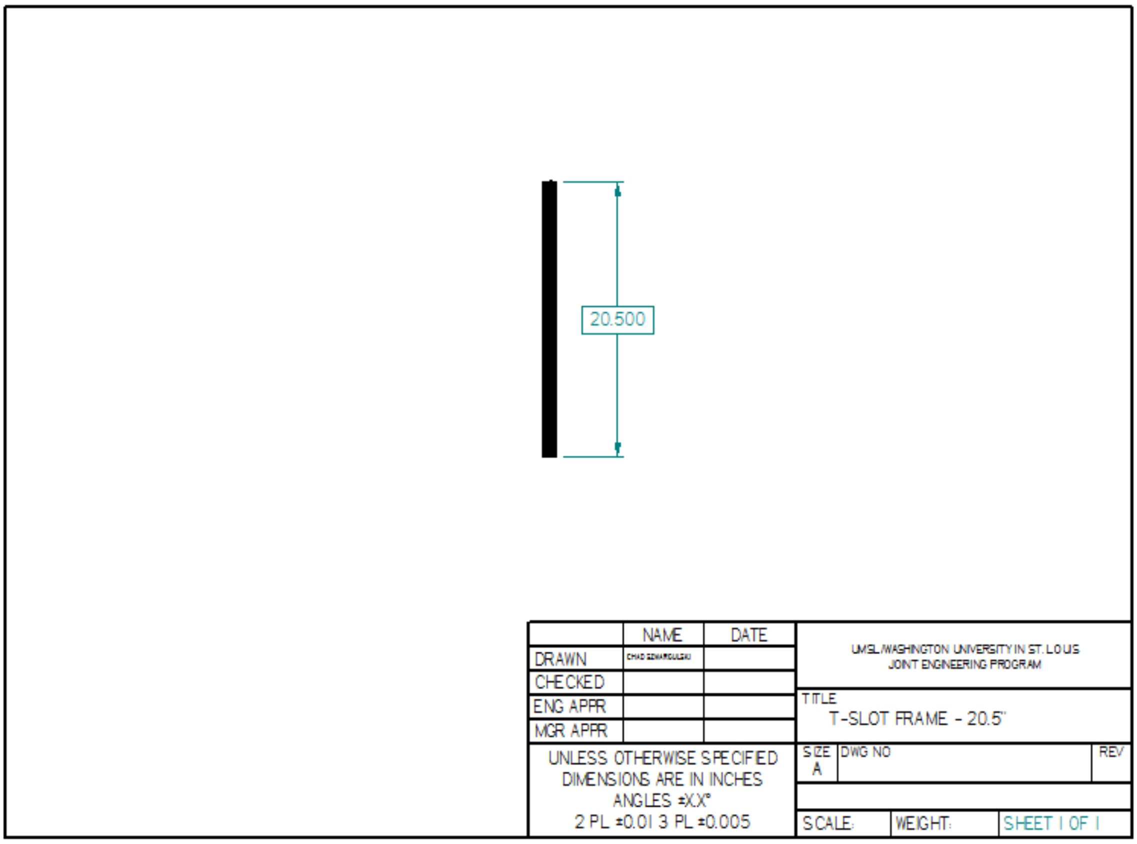


Figure 38: Drawing-T-Slot Frame-20.5".

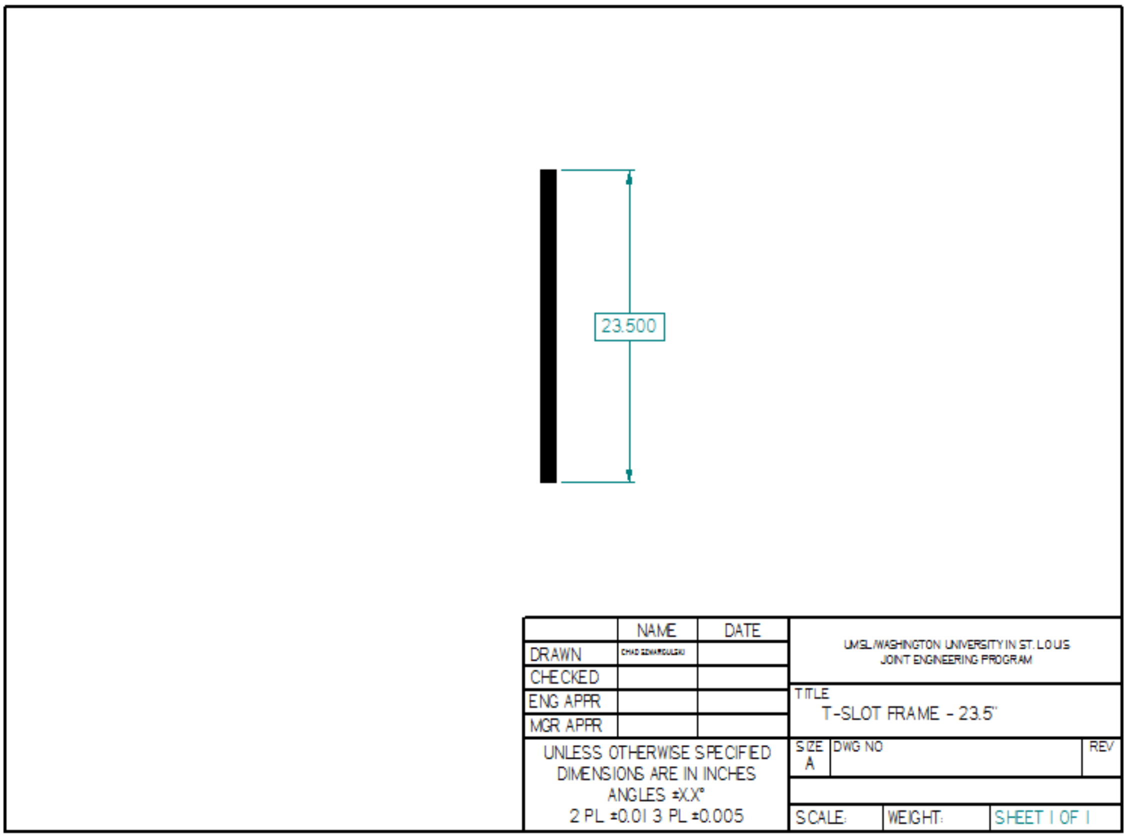


Figure 39: Drawing-T-Slot Frame-23.5".

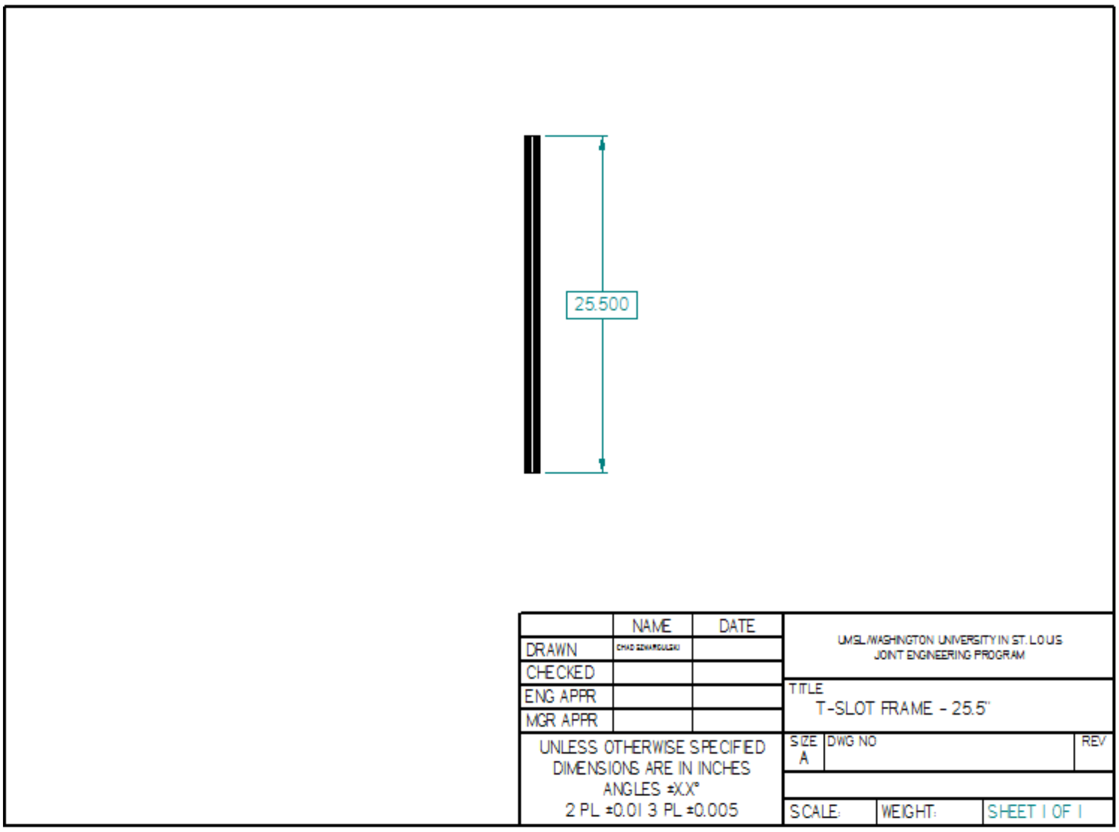


Figure 40: Drawing-T-Slot Frame-25.5".

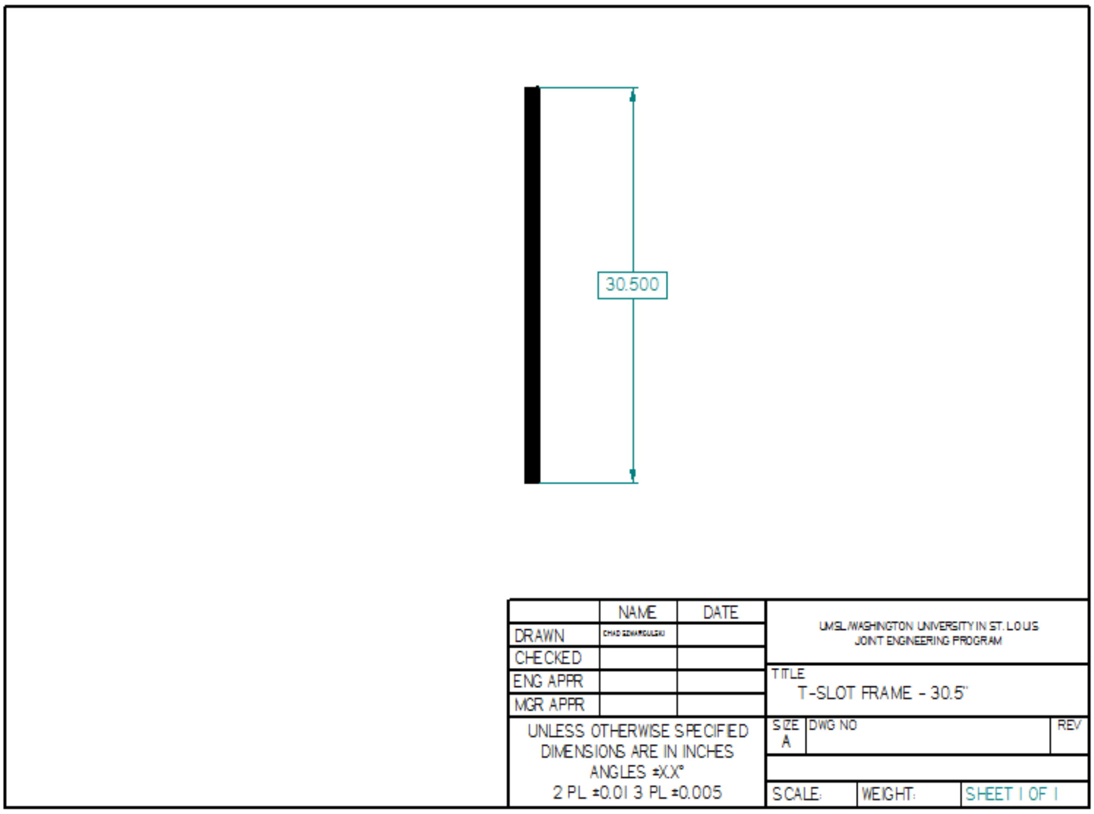


Figure 41: Drawing-T-Slot Frame-30.5".

9.1.2 Sourcing instructions

	PART DESCRIPTION	QUANTITY	VENDOR	PART NUMBER	PRICE	NOTES
1	Polycarbonate Panel-Left	1	N/A			Left wall of chamber. Cut from larger sheet of polycarbonate
2	Miniature Through-Wall Fitting	1	McMaster-Carr	8671T21	$9.52	Fitting to allow hose fittings to attach to chamber
3	Brass Male-Fem Hex THRD Adapter	2	McMaster-Carr	4624K330	$5.17	Reduce the thread size of through wall fitting to fit proper sized barbed hose fitting.
4	Brass Barbed Hose Fitting	2	McMaster-Carr	5346K830	$5.31	Fitting for water irrigation hose.
5	Nylon Check Valve W/Pipe-To-Pipe Connector	1	McMaster-Carr	1424T150	$15.00	Prevent air from escaping from air inlet and allow air to be sucked into chamber
6	Industrial Shape Hose Coupling	1	N/A			Fitting to attach compressed air tank
7	T-Slotted Extrusion 28.5	4	N/A			Four sides of frame structure.
8	T-Slotted Extrusion 25.5	6	N/A			Top and bottom of three sides of frame structure.
9	Polycarbonate Panel-Back	1	N/A			Panel cut from larger sheet of polycarbonate.
10	Pump	1	McMaster-Carr	99705K21	$11.71	Drill pump to remove water from chamber.
11	Durable Nylon Extra Grip Barbed Tube Fitting	1	McMaster-Carr	5372K343	$1.26	Elbow to suck water from bottom of tank.

12	Polycarbonate Panel-Bottom	1	N/A			Panel cut from larger sheet of polycarbonate.
13	T-Slotted Framing Extrusion 23.5	2	N/A			Top and bottom of one side of frame structure.
14	Polycarbonate Panel-Right	1	N/A			Panel cut from larger sheet of polycarbonate.
15	Polycarbonate Panel-Front	1	N/A			Panel cut from larger sheet of polycarbonate.
16	Compact Digital Gauge	1	McMaster-Carr	1287N100	$36.67	Panel cut from larger sheet of polycarbonate.
17	Corner Bracket	16	McMaster-Carr	47065T267	$8.47	Connect the six sides of the chamber.
18	Gasket	1	ACE Hardware	5666854	$3.99	Seal the top of chamber.
19	Polycarbonate Panel-Top	1	N/A			Panel cut from larger sheet of polycarbonate.
20	Industrial Shape Hose Coupling	1	McMaster-Carr	6536K180	$5.63	Connect to compressed air tank or vacuum.
21	Steel Threaded Stud	8	McMaster-Carr	98750A023	$1.72	Studs provide means of securing the top of chamber for airtight seal.
22	T-Slotted Extrusion 20.5	2	N/A			Make the top rigid to improve seal.
23	Nylon Seven-Lobe Knob	8	McMaster-Carr	6092K110	$2.23	The knobs screw on to studs to secure top.
24	Ball Valve W/Garden Hose Thread	1	McMaster-Carr	9848K210	$13.28	The valve seals the tank when not draining water.
25	Drain Grate	1	Home Depot	721271	$14.57	To hold plant above standing water.

9.2 FINAL PRESENTATION

Link to the video: https://youtu.be/QXht6mtN7pA

10 TEARDOWN

TEARDOWN TASKS AGREEMENT

PROJECT: Plant Growth Chamber NAMES: Deontez Myers DM INSTRUCTOR: ____________
Chad Szwargulski CS

The following teardown/cleanup tasks will be performed:

School facilities were not utilized in the fabrication process-no clean-up required.

The Plant Growth Chamber will be delivered to the Danforth Plant Science Center.

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: ________________; Print instructor name: _______________
Date: _______________
(Group members should initial near their name above.)

11 APPENDIX A - PARTS LIST

	PART DESCRIPTION	QUANTITY	VENDOR	PART NUMBER	PRICE
1	Polycarbonate Panel-Left	1	N/A		
2	Miniature Through-Wall Fitting	1	McMaster-Carr	8671T21	$9.52
3	Brass Male-Fem Hex THRD Adapter	2	McMaster-Carr	4624K330	$5.17
4	Brass Barbed Hose Fitting	2	McMaster-Carr	5346K830	$5.31
5	Nylon Check Valve W/Pipe-To-Pipe Connector	1	McMaster-Carr	1424T150	$15.00
6	Industrial Shape Hose Coupling	1	N/A		
7	T-Slotted Extrusion 28.5	4	N/A		
8	T-Slotted Extrusion 25.5	6	N/A		
9	Polycarbonate Panel-Back	1	N/A		
10	Pump	1	McMaster-Carr	99705K21	$11.71
11	Durable Nylon Extra Grip Barbed Tube Fitting	1	McMaster-Carr	5372K343	$1.26
12	Polycarbonate Panel-Bottom	1	N/A		
13	T-Slotted Framing Extrusion 23.5	2	N/A		
14	Polycarbonate Panel-Right	1	N/A		
15	Polycarbonate Panel-Front	1	N/A		
16	Compact Digital Gauge	1	McMaster-Carr	1287N100	$36.67
17	Corner Bracket	16	McMaster-Carr	47065T267	$8.47
18	Gasket	1	ACE Hardware	5666854	$3.99

19	Polycarbonate Panel-Top	1	N/A		
20	Industrial Shape Hose Coupling	1	McMaster-Carr	6536K180	$5.63
21	Steel Threaded Stud	8	McMaster-Carr	98750A023	$1.72
22	T-Slotted Extrusion 20.5	2	N/A		
23	Nylon Seven-Lobe Knob	8	McMaster-Carr	6092K110	$2.23
24	Ball Valve W/Garden Hose Thread	1	McMaster-Carr	9848K210	$13.28
25	Drain Grate	1	Home Depot	721271	$14.57

12 APPENDIX B - BILL OF MATERIALS

	PART DESCRIPTION	QUANTITY	VENDOR	PART NUMBER	PRICE	NOTES
1	Polycarbonate Panel	1	Grainger	1ETT9	$320.25	48"W, 8Ft. L, 0.236"T Sheet used for each panel
2	Miniature Through-Wall Fitting	1	McMaster-Carr	8671T21	$9.52	Fitting to allow hose fittings to attach to chamber
3	Brass Male-Fem Hex THRD Adapter	2	McMaster-Carr	4624K330	$5.17	Reduce the thread size of through wall fitting to fit proper sized barbed hose fitting.
4	Brass Barbed Hose Fitting	2	McMaster-Carr	5346K830	$5.31	Fitting for water irrigation hose.
5	Nylon Check Valve W/Pipe-To-Pipe Connector	1	McMaster-Carr	1424T150	$15.00	Prevent air from escaping from air inlet and allow air to be sucked into chamber
6	Industrial Shape Hose Coupling	2	McMaster-Carr	6536K180	$5.63	Fitting to attach compressed air tank
7	T-Slotted Aluminum	6	McMaster-Carr	47065T101	$19.79	6Ft Long, 1"W, 1"High rails used to frame the chamber.
8	Silicon Caulk	2	Ace Hardware		$13.99	Flex Seal used to seal off all edges corners and sides of chamber.
9	Pump	1	McMaster-Carr	99705K21	$11.71	Drill pump to remove water from chamber.

10	Durable Nylon Extra Grip Barbed Tube Fitting	1	McMaster -Carr	5372K343	$1.26	Elbow to suck water from bottom of tank.
11	Compact Digital Gauge	1	McMaster -Carr	1287N100	$36.67	Panel cut from larger sheet of polycarbonat e.
12	Corner Bracket	16	McMaster -Carr	47065T26 7	$8.47	Connect the six sides of the chamber.
13	Gasket	1	ACE Hardware	5666854	$3.99	Seal the top of chamber.
14	Steel Threaded Stud	8	McMaster -Carr	98750A02 3	$1.72	Studs provide means of securing the top of chamber for airtight seal.
15	Nylon Seven-Lobe Knob	8	McMaster -Carr	6092K110	$2.23	The knobs screw on to studs to secure top.
16	Ball Valve W/Garden Hose Thread	1	McMaster -Carr	9848K210	$13.28	The valve seals the tank when not draining water.
17	Drain Grate	1	Home Depot	721271	$14.57	To hold plant above standing water.
					Total	**$772.31**

13 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

Link to Google Drive containing all of the CAD files:

https://drive.google.com/drive/folders/0BwAx3t2wnQzTU0FuazRQanpManc?usp=sharing

14 ANNOTATED BIBLIOGRAPHY

- US 53411595 A - Environmental Growth Chamber.

This patent was used during our background study to see what was already on the market. It also gave us design ideas for our project.

- "ASME Boiler and Pressure Vessel Code." *Asme.org*, 2013, www.asme.org/getmedia/1adfc3df-7dab-44bf-a078-8b1c7d60bf0d/ASME_BPVC_2013-Brochure.aspx.
  "UNITED STATES DEPARTMENT OF LABOR." *Occupational Safety and Health Administration*, www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9696.

This source was used to determine which codes and standards our project had to abide by. It was very helpful in determining the safe pressure range for the chamber.