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MEMS 411 Final Report - Plate Pourer II

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MEMS 411 Final Report

Plate Pourer Group II

Patrick Champlin, Minsoo Ha,
Timothy Young

The objective of this project is to create a machine that has the capability to pour Petri dishes. The usage of this machine must be easier than simply performing the task by hand, be automated, capable of producing 120 plates per hour, be sterile, prevent the plates from sloshing, fit in a fume hood, and stack the plates while they are cooling so that they may cool properly. This all was accomplished with a device that drops the plates vertically down, fills them, and then lowers them into storage thanks to their now increased mass and a spring-loaded platform.

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1 Introduction

1.1 Project problem statement

Biologists culture microbes on agar in Petri dishes under aseptic (sterile) conditions. A biologist can pour their own plates or purchase them for $4 each on Amazon. To save time and reduce costs, a biologist at the STLCC Biobench CRO wants to pour plates in the lab with the aid of an automated process.

To automate the pouring process, a design is needed that contains a reservoir for agar medium, a valve to regulate flow of the medium, and a mechanical device to time motion and move plates for the pour. The biologist wants to control the pouring system with a laptop. The system must fit into a hood, be sterile, easy to clean, and allow the biologist to pour 120 plates per hour. (External Customer)

1.2 List of team members

Patrick Champlin, Minsoo Ha, and Timothy Young.

2 Background Information Study

2.1 Design Brief

The objective of this project is to create a machine that has the capability to pour Petri dishes. The usage of this machine must be easier than simply performing the task by hand, be automated, capable of producing 120 plates per hour, be sterile, prevent the plates from sloshing, fit in a fume hood, and stack the plates while they are cooling so that they may cool properly.

2.2 Summary of relevant background information

1. Mediajet Petri Dish Filler (http://www.integra-biosciences.com/sites/us/mediajet.html)
2. Patent US4331262 A (https://www.google.com/patents/US4331262?dg=petri+dish+filler&hl=en&sa=X&ved=0CEIQ6AEwBWoVChMlq-r3q_vMxwlVS5YeCh0LKg5v)
3. Petriswiss PS 900 (http://biotoolswiss.com/agar-filler/ps900/index.html)
4. Fisnar Fluid Dispensing Robots (http://www.fisnar.com/)
5. Labtec Automatic Fluid Dispensing System (https://scilog.com/products/lab/labtec-automated-fluid-dispensing-system)
6. Fishman Corp Automatic Dispensers (http://www.fishmancorp.com/automatic-dispensing-systems/)
7. Patent WO2012015365 A1 (http://www.google.com/patents/WO2012015365A1?cl=en)
8. Patent US4331262 A (https://www.google.com/patents/US4331262)
9. Systec Mediafill (http://800ezmicro.com/equipment/media-preparation/49-systec-mediafill.html)

3 Concept Design and Specification

3.1 User needs, metrics, and quantified needs equations

3.1.1 Record of the user needs interview

Table 1: User Needs Interview

Customer Data: Plate Pouring Device (PP)

Customer: Dr. Mary K. Malast

Address: Washington University in St. Louis Date: 11 September 2015

Question	Customer Statement	Interpreted Need	Importance
How viscous does the agar gel need to be to flow properly?	The agar has viscosity similar to water at temperatures of around 60-70 degrees Celsius.	PP runs the fluid at 60-70°C	5
What issues would you see in the flow of the agar?	Buildup of solid material might be significant. It would be nice if the piping could be cleaned somehow.	PP is easily cleanable	4
Would it help if the device were portable?	Yes optimally. It also needs to be small enough to fit easily in a fume hood.	PP fits in a fume hood PP can be easily transported	5 3
After the plates have been filled, how should they be treated?	They need to quickly be capped, then left relatively undisturbed for up to 30 minutes.	PP caps the plates after filling PP moves the plates minimally after being filled	5 4
How many completed plates would be optimal, in say an hour?	120 at minimum, though the best design would be one that incorporated the 30 minute cooling time into that hour – giving a filling rate of 120 per 30 minutes.	PP completes 2-4 plates per minute.	5
What other capabilities would you like?	The system must be sterile so as not to contaminate the samples.	PP is sterile PP is automated	5 4

	The system must be automated and laptop-controlled. Arduino is recommended. The fluid cannot slosh up the sides during filling without risking contamination.	PP fills plates halfway without sloshing.	4

Table 2: Needs Table for Plate Pourer (PP)

Need Number	Need	Importance
1	PP runs the fluid at 60-70°C	5
2	PP is easily cleanable	4
3	PP fits in a fume hood	5
4	PP can be easily transported	3
5	PP caps the plates after filling	5
6	PP moves the plates minimally after filling	4
7	PP completes 2-4 plates per minute	5
8	PP is sterile	5
9	PP is automated	4
10	PP fills plates halfway without sloshing	4

3.1.2 List of identified metrics

Table 3: Identified Metrics for Plate Pourer (PP)

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1	Fluid Temperature	°C	60	70
2	2	Cleanability	Binary	0	1
3	3,4	Volume of Device	cm^3	0	260,000
4	5	Cap Placement Time	s	0	20
5	6	Filled Dish Movement Acceleration	m/s^2	0	2
6	7	Completion Rate	plates/min	2	4
7	8	Sterility	SAL (Probability of a microorganism being present on the device)	10^{-6}	10^{-5}
8	9	Automation	Binary	0	1
9	10	Maximum Gel Height	Height reached / Height of dish	50%	60%

3.1.3 Table/list of quantified needs equations

Table 4: Quantified User Needs

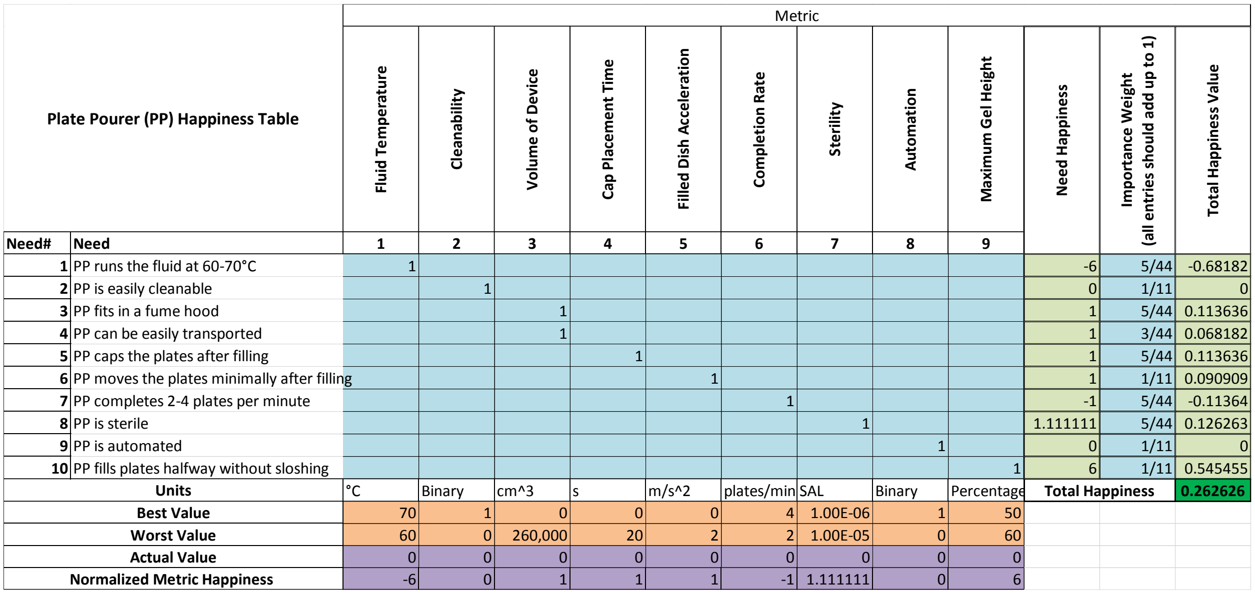


Plate Pourer (PP) Happiness Table		Metric											
		Fluid Temperature	Cleanability	Volume of Device	Cap Placement Time	Filled Dish Acceleration	Completion Rate	Sterility	Automation	Maximum Gel Height	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	**Need**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
1	PP runs the fluid at 60-70°C	1									-6	5/44	-0.68182
2	PP is easily cleanable		1								0	1/11	0
3	PP fits in a fume hood			1							1	5/44	0.113636
4	PP can be easily transported			1							1	3/44	0.068182
5	PP caps the plates after filling				1						1	5/44	0.113636
6	PP moves the plates minimally after filling					1					1	1/11	0.090909
7	PP completes 2-4 plates per minute						1				-1	5/44	-0.11364
8	PP is sterile							1			1.111111	5/44	0.126263
9	PP is automated								1		0	1/11	0
10	PP fills plates halfway without sloshing									1	6	1/11	0.545455
Units		°C	Binary	cm^3	s	m/s^2	plates/min	SAL	Binary	Percentage	**Total Happiness**		**0.262626**
Best Value		70	1	0	0	0	4	1.00E-06	1	50			
Worst Value		60	0	260,000	20	2	2	1.00E-05	0	60			
Actual Value		0	0	0	0	0	0	0	0	0			
Normalized Metric Happiness		-6	0	1	1	1	-1	1.111111	0	6			

3.2 Four (4) concept drawings

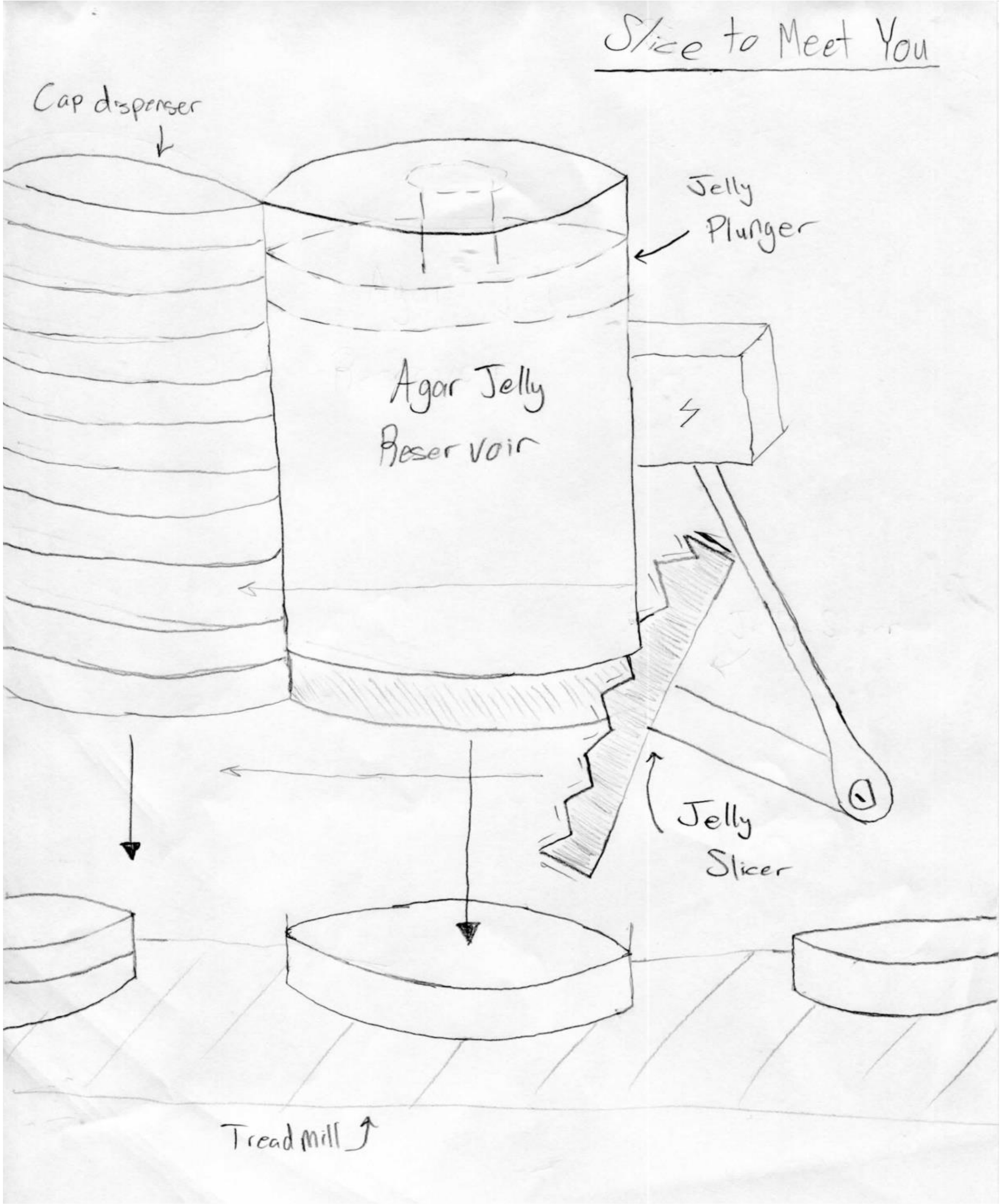


Figure 1 Slice to Meet You

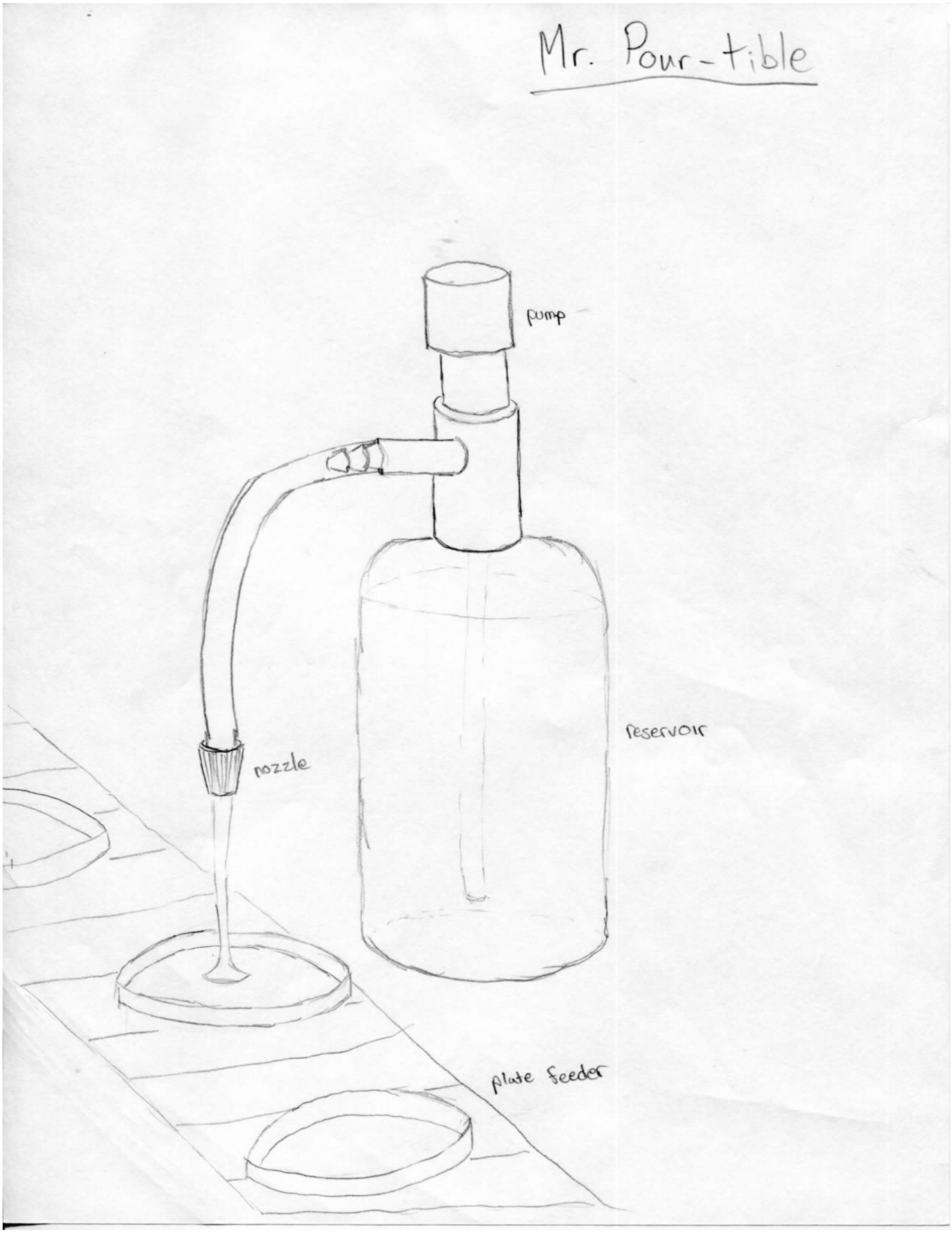


Figure 2 Mr. Pour-tible

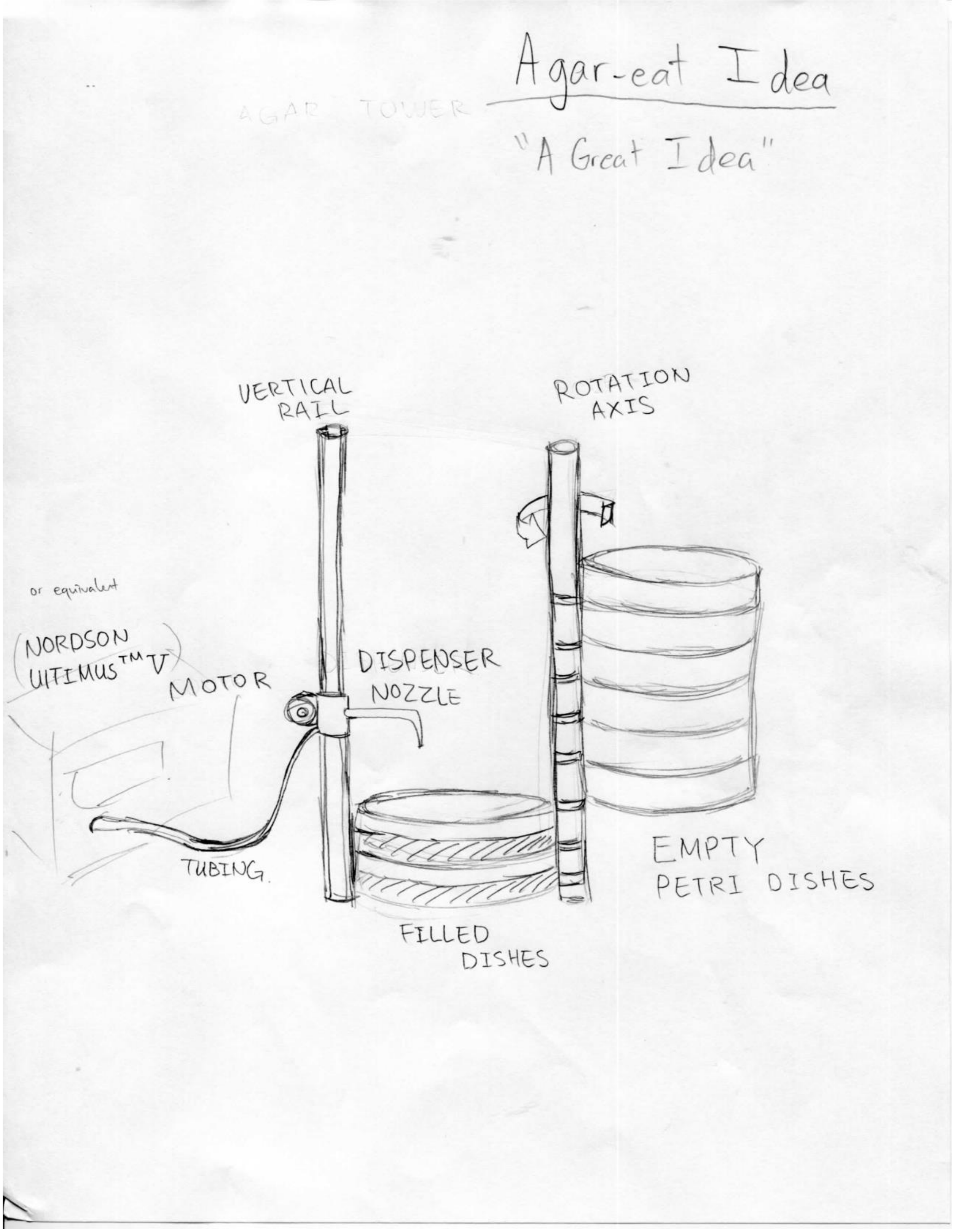


Figure 3 Agar-eat Idea

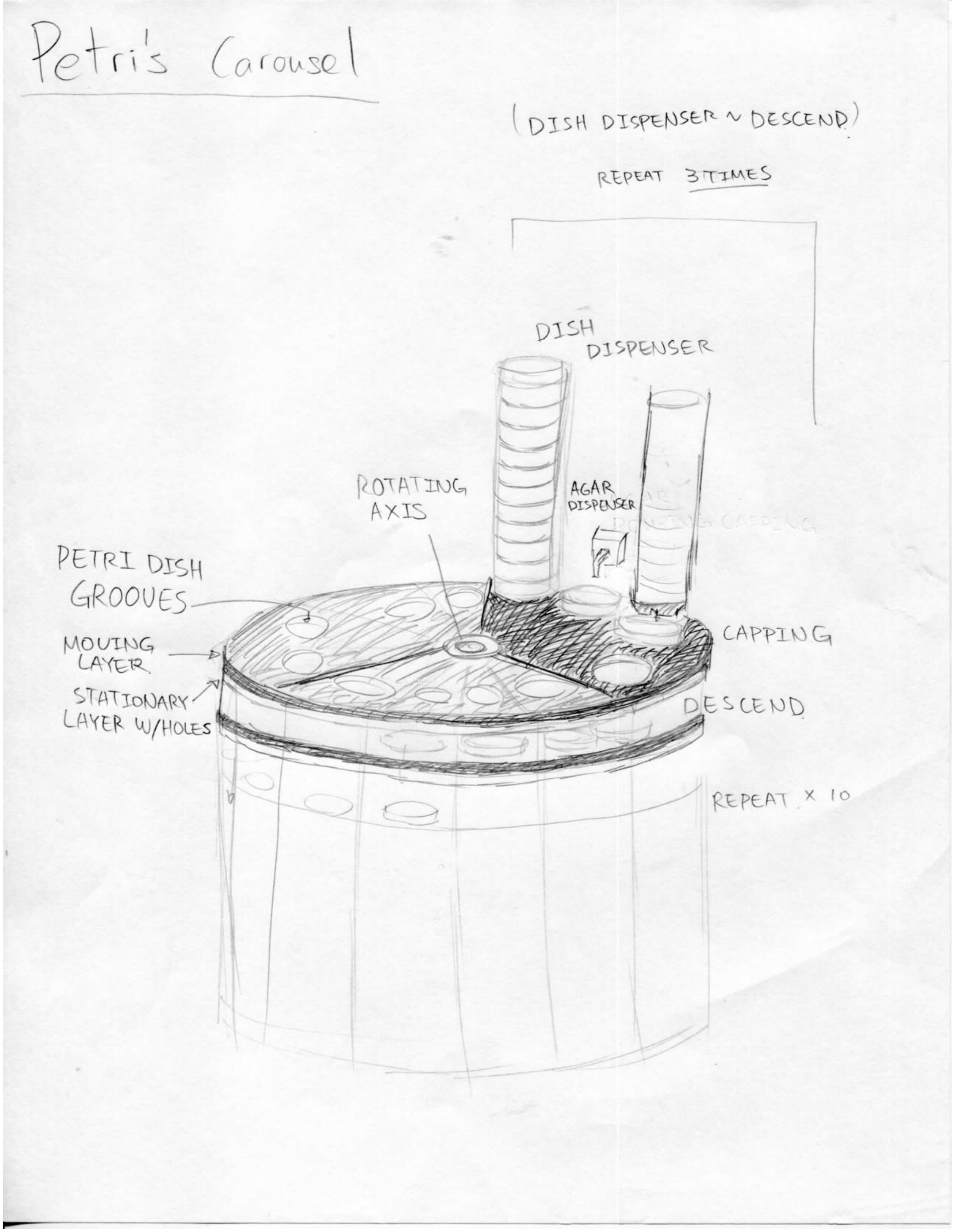


Figure 4 Petri's Carousel

3.3 A concept selection process:

3.3.1 Concept scoring (not screening)

Slice to Meet You: Plate Pourer (PP) Happiness Table		Metric											
		Fluid Temperature	Cleanability	Volume of Device	Cap Placement Time	Filled Dish Acceleration	Completion Rate	Sterility	Automation	Maximum Gel Height	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9			
1	PP runs the fluid at 60-70°C	1									0.000	5/44	0.0000
2	PP is easily cleanable		1								1.000	1/11	0.0909
3	PP fits in a fume hood			1							0.423	5/44	0.0481
4	PP can be easily transported			1							0.423	3/44	0.0288
5	PP caps the plates after filling				1						0.900	5/44	0.1023
6	PP moves the plates minimally after filling					1					0.500	1/11	0.0455
7	PP completes 2-4 plates per minute						1				0.500	5/44	0.0568
8	PP is sterile							1			0.000	5/44	0.0000
9	PP is automated								1		1.000	1/11	0.0909
10	PP fills plates halfway without sloshing									1	1.000	1/11	0.0909
Units		°C	Binary	cm^3	s	m/s^2	plates/min	SAL	Binary	Percentage	Total Happiness		0.5542
Best Value		70	1	0	0	0	4	1.00E-06	1	50			
Worst Value		60	0	260,000	20	2	2	1.00E-05	0	60			
Actual Value		60	1	150000	2	1	3	1.00E-05	1	50			
Normalized Metric Happiness		0	1	0.423	0.900	0.500	0.5	0.000	1	1			

Mr. Pour-tible: Plate Pourer (PP) Happiness Table		Metric											
		Fluid Temperature	Cleanability	Volume of Device	Cap Placement Time	Filled Dish Acceleration	Completion Rate	Sterility	Automation	Maximum Gel Height	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9			
1	PP runs the fluid at 60-70°C	1									1.000	5/44	0.1136
2	PP is easily cleanable		1								1.000	1/11	0.0909
3	PP fits in a fume hood			1							0.423	5/44	0.0481
4	PP can be easily transported			1							0.423	3/44	0.0288
5	PP caps the plates after filling				1						0.500	5/44	0.0568
6	PP moves the plates minimally after filling					1					0.250	1/11	0.0227
7	PP completes 2-4 plates per minute						1				1.000	5/44	0.1136
8	PP is sterile							1			1.000	5/44	0.1136
9	PP is automated								1		0.000	1/11	0.0000
10	PP fills plates halfway without sloshing									1	0.500	1/11	0.0455
Units		°C	Binary	cm^3	s	m/s^2	plates/min	SAL	Binary	Percentage	Total Happiness		0.6337
Best Value		70	1	0	0	0	4	1.00E-06	1	50			
Worst Value		60	0	260,000	20	2	2	1.00E-05	0	60			
Actual Value		70	1	150000	10	1.5	4	1.00E-06	0	55			
Normalized Metric Happiness		1	1	0.423	0.500	0.250	1	1.000	0	0.5			

Agar-eat Idea: Plate Pourer (PP) Happiness Table		Metric											
		Fluid Temperature	Cleanability	Volume of Device	Cap Placement Time	Filled Dish Acceleration	Completion Rate	Sterility	Automation	Maximum Gel Height	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9			
1	PP runs the fluid at 60-70°C	1									0.800	5/44	0.0909
2	PP is easily cleanable		1								0.000	1/11	0.0000
3	PP fits in a fume hood			1							0.519	5/44	0.0590
4	PP can be easily transported			1							0.519	3/44	0.0354
5	PP caps the plates after filling				1						0.750	5/44	0.0852
6	PP moves the plates minimally after filling					1					0.865	1/11	0.0786

7	PP completes 2-4 plates per minute						1				1.000	5/44	0.1136
8	PP is sterile							1			0.222	5/44	0.0253
9	PP is automated								1		1.000	1/11	0.0909
10	PP fills plates halfway without sloshing									1	1.000	1/11	0.0909
Units		°C	Binary	cm^3	s	m/s^2	plates/min	SAL	Binary	Percentage	**Total Happiness**		**0.6699**
Best Value		70	1	0	0	0	4	1.00E-06	1	50			
Worst Value		60	0	260,000	20	2	2	1.00E-05	0	60			
Actual Value		68	0	125000	5	0.27	4	8.00E-06	1	50			
Normalized Metric Happiness		0.8	0	0.519	0.750	0.865	1	0.222	1	1			

Petri's Carousel: Plate Pourer (PP) Happiness Table		Metric											
		Fluid Temperature	**Cleanability**	**Volume of Device**	**Cap Placement Time**	**Filled Dish Acceleration**	**Completion Rate**	**Sterility**	**Automation**	**Maximum Gel Height**	**Need Happiness**	**Importance Weight (all entries should**	**Total Happiness Value**
Need#	**Need**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
1	PP runs the fluid at 60-70°C	1									0.950	0.114	0.1080
2	PP is easily cleanable		1								1.000	0.091	0.0909
3	PP fits in a fume hood			1							0.231	0.114	0.0262
4	PP can be easily transported			1							0.231	0.068	0.0157
5	PP caps the plates after filling				1						0.750	0.114	0.0852
6	PP moves the plates minimally after filling					1					0.990	0.091	0.0900
7	PP completes 2-4 plates per minute						1				0.500	0.114	0.0568
8	PP is sterile							1			1.000	0.114	0.1136
9	PP is automated								1		1.000	0.091	0.0909
10	PP fills plates halfway without sloshing									1	1.000	0.091	0.0909
Units		°C	Binary	cm^3	s	m/s^2	plates/min	SAL	Binary	Percentage	**Total Happiness**		**0.7683**
Best Value		70	1	0	0	0	4	1.00E-06	1	50			
Worst Value		60	0	260,000	20	2	2	1.00E-05	0	60			
Actual Value		69.5	1	200000	5	0.02	3	0.000001	1	50			
Normalized Metric Happiness		0.95	1	0.231	0.750	0.990	0.500	1	1	1			

3.3.2 Preliminary analysis of each concept's physical feasibility

1. Slice to Meet You

While the ability to avoid the inconveniences of handling liquid agar appears appealing at first, several issues with this design prevent it from being feasible. First off, ensuring that the agar is cut evenly will be difficult given agar's jello-like consistency when cooled. Secondly, ensuring the agar remains sterile while being cut is a large concern. Large areas of agar are exposed to open air while being cut and transferred to the petri dish which could facilitate contamination of the agar. These critical issues with consistency and sterilization impede the feasibility of this concept.

2. Mr. Pour-tible

The simplest of the four designs, this pump-action like bottle fulfills many of the design requirements but is simply not automated enough to warrant using over the current agar pouring methods. Additionally, adding components to automate the design would be restrictive in space and portability. A system to only move petri dishes to and from the dispenser would not be compact enough unless integrated together, in which case other designs would fulfill the role better.

3. Agar-eat Idea

The third design, “Agar-eat Idea”, is composed of three parts. 1. An automated dispenser unit that controls the flow and maintains the temperature of the agar fluid, 2. A vertical rail with a motorized dispenser nozzle, and 3. A rotation axis that will rotate the empty petri dishes towards the dispenser nozzle to be filled by the agar fluid. In order for this design to function properly, we will have to make sure the agar does not solidify while it travels from the automated dispenser unit and reaches the dispenser nozzle. We will also have to synchronize the dispenser nozzle and the rotation axis so that the mechanism does not get jammed or spill any fluids. In addition, each arm on the rotation axis will have to rotate individually which will add to the complexity of the design, which may become a high risk factor. We will also have to secure the petri dishes on each arms so the dishes does not slip or fall during the rotation.

4. Petri’s Carousel

The fourth and final design, “Petri’s Carousel”, automatically dispenses an empty plate, fills it with agar, caps the plate, and moves the filled petri dish into storage. The dispensing unit, composed of dish dispenser, agar dispenser, and capping station are held stationary, while the plates are carried by a moving layer with petri dish grooves. Up to 12 petri dishes can be carried by the moving layer of the “carousel”, and after the cap is placed, they are guided to the layer below through a hole. In order for this design to function properly, we must make sure the agar plates will move smoothly on top of each other. Also, we must make sure the descending is smooth enough for the petri dishes so it will not disturb the liquid within. Also the dispensing of the liquid and the rotation of the moving layer will have to be timed correctly to ensure no agar fluid is spilled. This design requires the least amount of manual interaction throughout the process.

3.3.3 Final summary

In the end, the carousel design was chosen for its comprehensive coverage of all the requested properties. The carousel is compact yet allows for easy insertion of petri dishes to begin the pouring process. The design allows for the agar liquid to be kept warm before pouring, ensures minimal movement of the plates after the agar has been poured, and stores the plates during the cooling process. In contrast, the other designs had glaring flaws that made “Petri’s Carousel” the most appropriate design. The “Slice to Meet You” exposed large surfaces of agar to the environment before placing them into each petri dish. Additionally, it would be exceedingly difficult to consistently cut the same amount of agar into each dish due to agar’s jello-like consistency when cooled. The “Mr. Pour-tible” was not comprehensive enough for our purposes. Though simple for pouring agar, the design required additions in order to be able to feed petri dishes and cover them. The “Agar-eat Idea” concept was dismissed due to the complexity of the individual rotating arms.

Another cause for concern in this design was securing the petri dishes on each arm such that they did not fall off during rotation while still making it easy to place or remove the dishes. In the end, the “Petri’s Carousel” provided the most comprehensive automation of the plate pouring process while still remaining not overly complex.

Note here though that due to unexpected constraints this design had to be changed slightly. The stations were combined all into one, and the dishes simply start off by being dropped and filled on the spring-loaded platforms of the original design. This allows for the device to fit within a smaller fume hood, and to require much easier manufacturing. Furthermore, it has the added benefit of moving the plates less after they have been filled. Please see the final drawings for a schematic of this altered design.

3.4 Proposed performance measures for the design

1. The mechanism will have a volume of less than 200,000 cm^3
2. The agar will not drop in temperature below 68 °C before it is dispensed.
3. The ratio of good plates to total plates produced will be greater than 90%. A bad plate is defined to be one in which the agar has been allowed to flow halfway up the plate’s wall.
4. It will produce at least 120 agar plates per hour, or 2 agar plates per minute.
5. The time spent without a cap after the agar has been dispensed will be less than 10 seconds.
6. The contact angle between the agar surface and the wall will be between $\frac{\pi}{3}$ radians and $\frac{2\pi}{3}$ radians.
7. The sterility of the agar plates will be less than 10^{-6} SAL.

3.5 Design constraints

3.5.1 Functional

The entire geometry of the system must be able to fit within the customer's 17 inch deep fume hood. Plate movement should be minimized. The agar fluid should not drop below 68 °C before the plates are filled (so as to maintain its water-like flow properties). Materials used should be easy to sterilize.

3.5.2 Safety

The hot agar fluid should be completely contained within the device, and especially not be allowed to leak on any place the user may interact with so as not to cause burning.

3.5.3 Quality

The system should be able to produce good, useable plates with a fairly high reliability. This threshold has been arbitrarily set to be that a minimum of 90% of the plates produced should be good.

3.5.4 Manufacturing

The parts should all be easy to produce so as to reduce prototyping and manufacturing costs. To further this point, it would be useful if the device could be made from readily available materials, such as stock components or PVC pipes.

3.5.5 Timing

An initial prototype of the device must be delivered by November 7th. A final working prototype must be delivered by November 21st. As for the actual timing of the device, consideration must be taken as to when the plates are being filled and when they are being capped, as these two events cannot occur at the same time.

3.5.6 Economic

As devices that perform this task are already available on the market, this machine finds its niche in being cheap and efficient – but while producing dishes only on the scale needed for a single researcher. (Competitors are generally devices costing thousands of dollars that are made to produce hundreds of plates for entire research laboratories.)

3.5.7 Ergonomic

The device must be fully automatic, producing plates without input from the user.

3.5.8 Ecological

The device will optimally produce no waste, other than perhaps a few bad plates.

3.5.9 Aesthetic

Optimally, the plate storage would be able to for the most part contain the smell of the stinky agar. In addition, it is hoped that the device will be a sleek, Petri-producing work of art.

3.5.10 Life cycle

The machine should be easy to maintenance, and be able to operate for a long time without issue.

3.5.11 Legal

This device must again not cause any harm to the user. Furthermore, the system should be completely original, so as to avoid any issues with intellectual property.

4 Embodiment and fabrication plan

4.1 Embodiment drawing

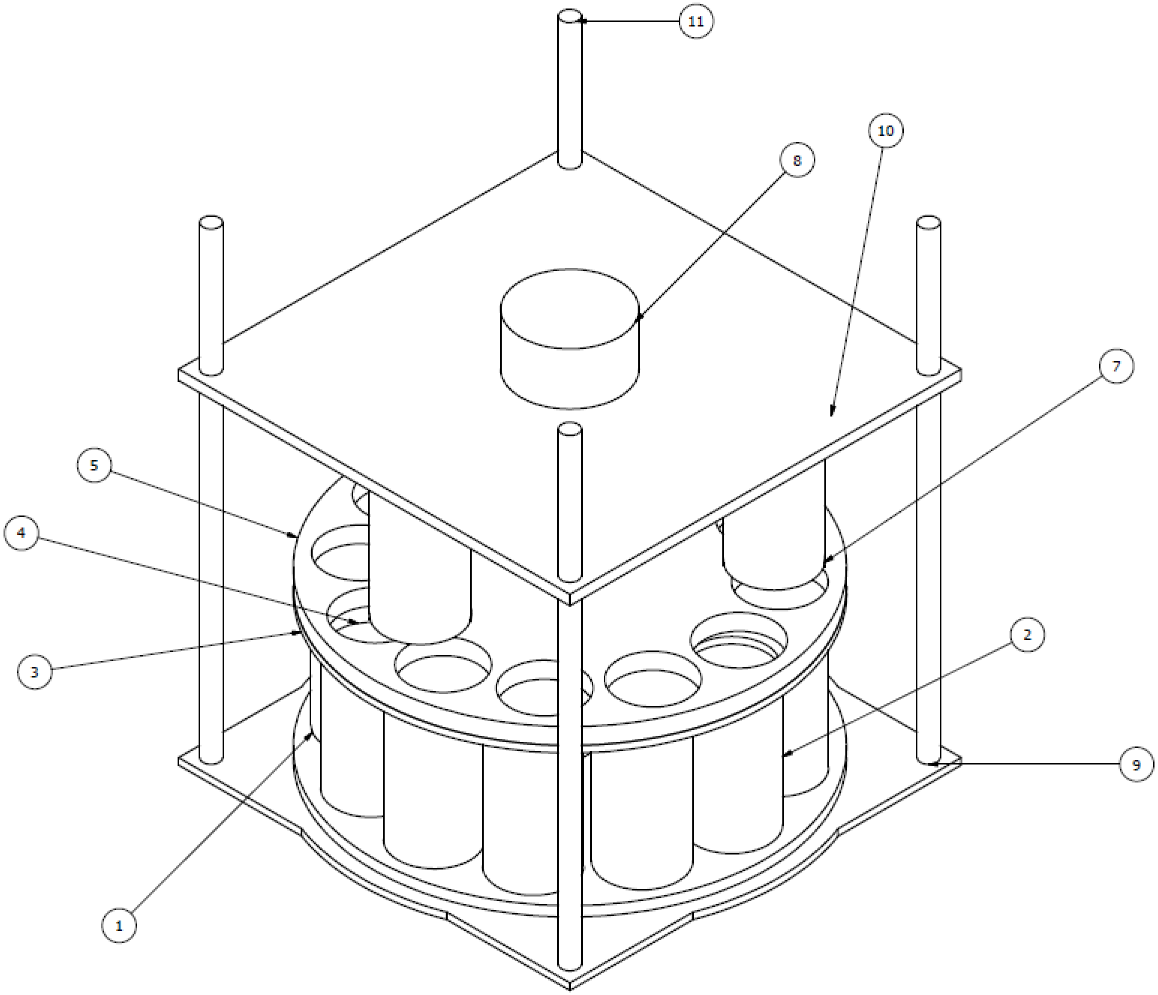


Figure 5 Embodiment Drawing

4.2 Parts List

Parts List					
Item #	QTY	Part Name	Source	McMaster Part No.	Materials Used
1	1	Bottom Base	Fabricated	9011K83	Chemical-Resistant PVC
2	12	Cylinder	Purchased from McMaster-Carr	8705K87	Impact-Resistant Slippery UHMW Polyethylene
3	1	Fall Base	Fabricated	9011K83	Chemical-Resistant PVC

4	12	Suspended Base	Fabricated	94125K177	Compression Spring Stainless Steel, Chemical-Resistant PVC
5	1	Top Base	Fabricated	9011K83	Chemical-Resistant PVC
6	1	Center Column	Purchased from McMaster-Carr	89495K64	Multipurpose 304 Stainless Steel Round Tubes
7	3	Petri Dispenser	Purchased from McMaster-Carr	8705K87	Impact-Resistant Slippery UHMW Polyethylene
8	1	Vat	Purchased from McMaster-Carr	4322T6	Thick-Wall Autoclavable Semi-Clear Plastic Jar
9	1	Bottom Frame	Fabricated	9011K83	Chemical-Resistant PVC
10	1	Top Frame	Fabricated	9011K83	Chemical-Resistant PVC
11	4	Poles	Purchased from McMaster-Carr	89495K64	Multipurpose 304 Stainless Steel Round Tubes

Material List	Use	McMaster Part No	Cost
Chemical-Resistant PVC	Form Base, Frame	9011K83	6.31
Impact-Resistant Slippery UHMW Polyethylene 4 1/2" OD, 4" ID, 1/4" Thickness	Cylinder, Petri Dispenser	8705K87	30.34
Compression Spring Stainless Steel, 90.5 mm Overall, 13.75 mm OD, 1.25 mm Wire	Suspended Platform	94125K177	11.14
Thick-Wall Autoclavable Semi-Clear Plastic Jar	Vat	4322T6	32.30
Multipurpose 304 Stainless Steel Round Tubes, 1" OD	Frame Support Poles	89495K64	18.28
Total			**98.37**

4.3 Draft detail drawings for each manufactured part

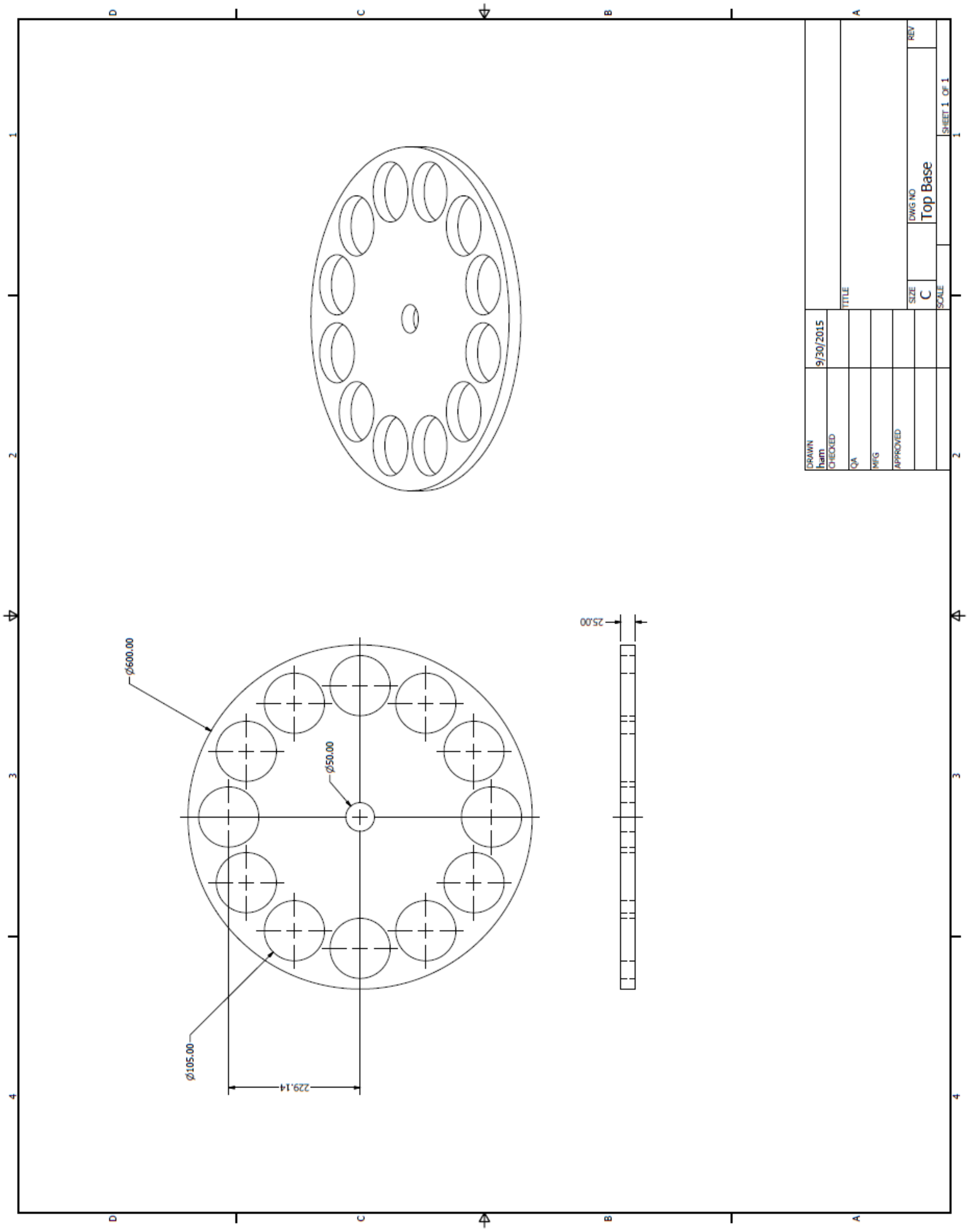


Figure 6 Top Base

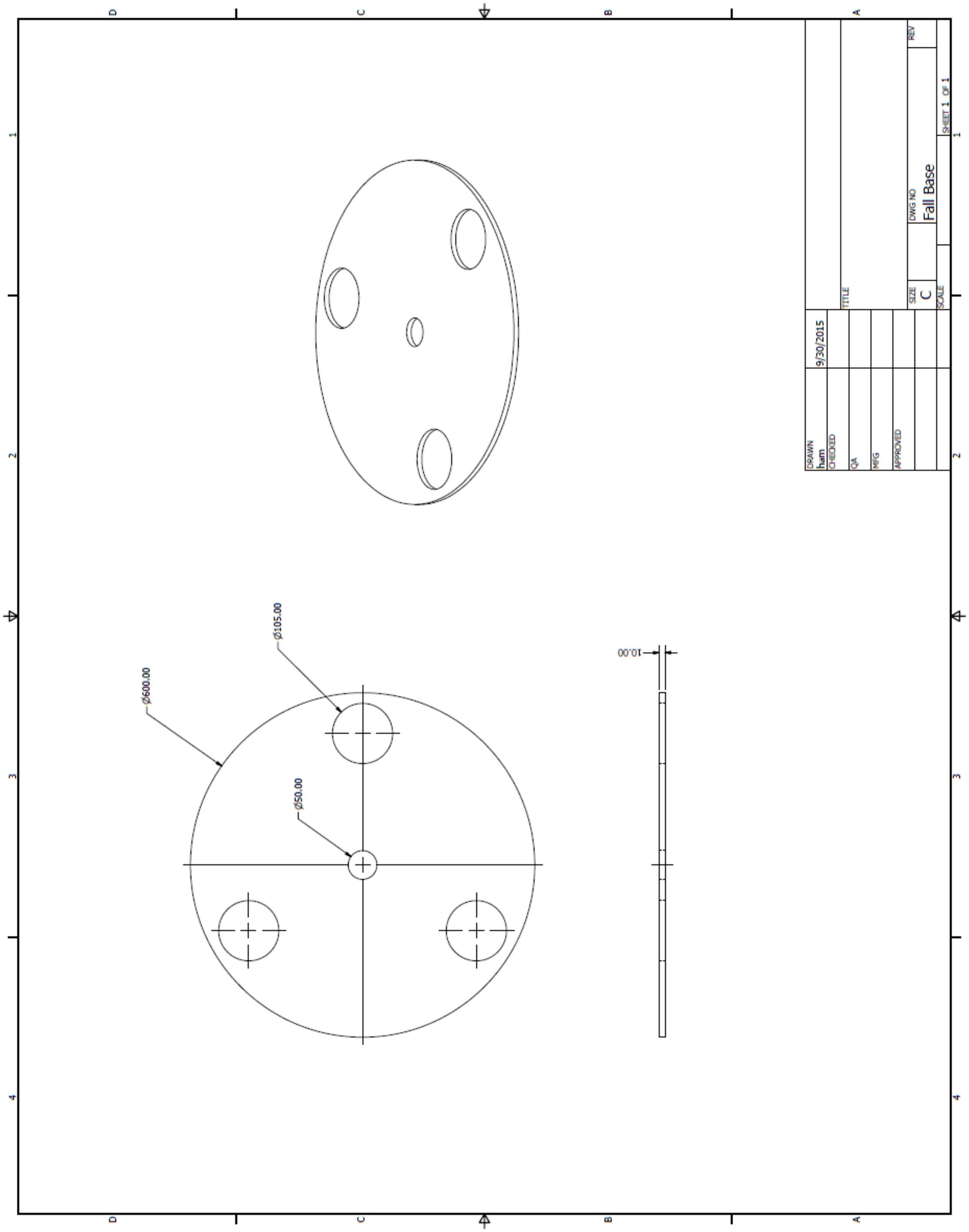


Figure 7 Fall Base

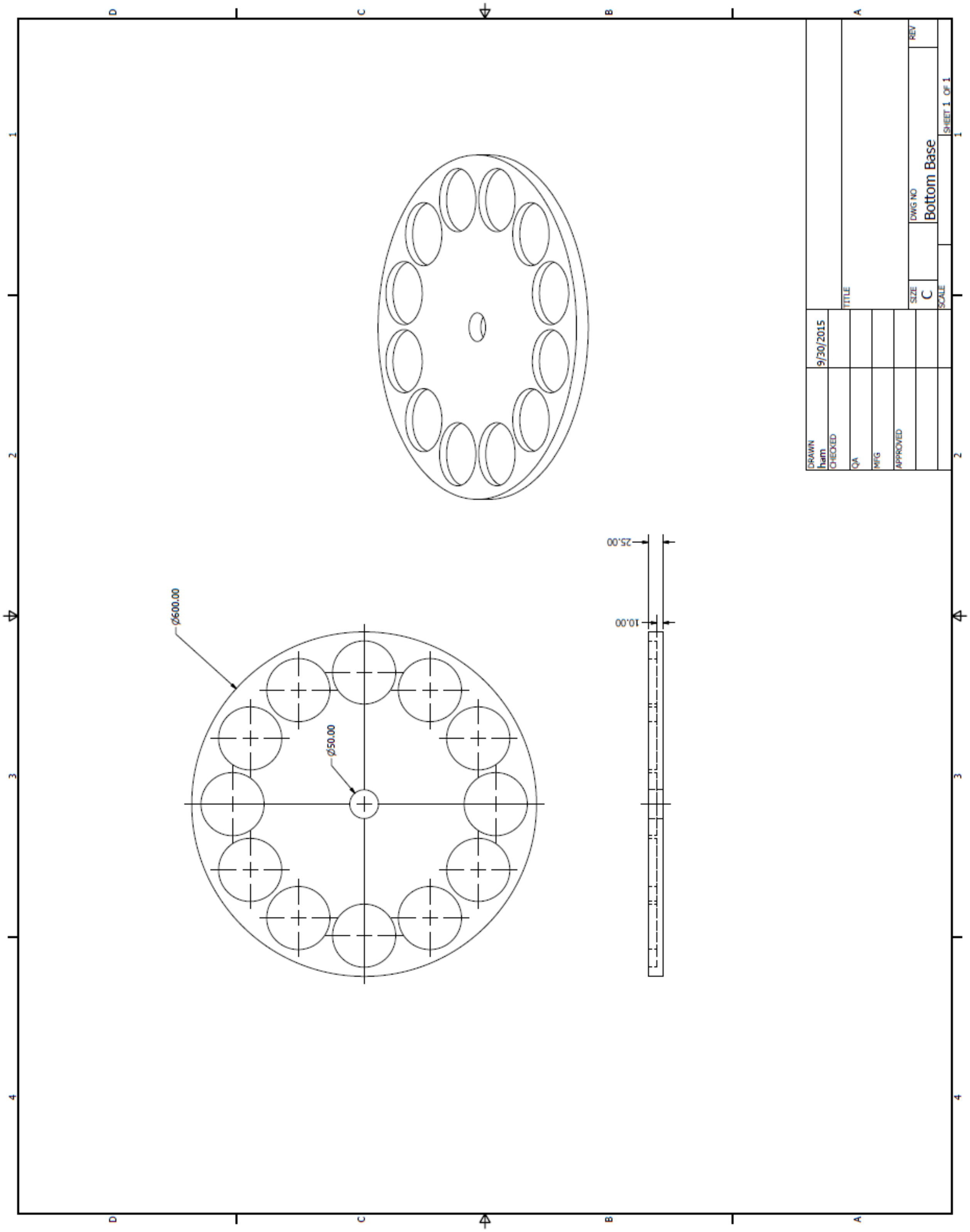


Figure 8 Bottom Base

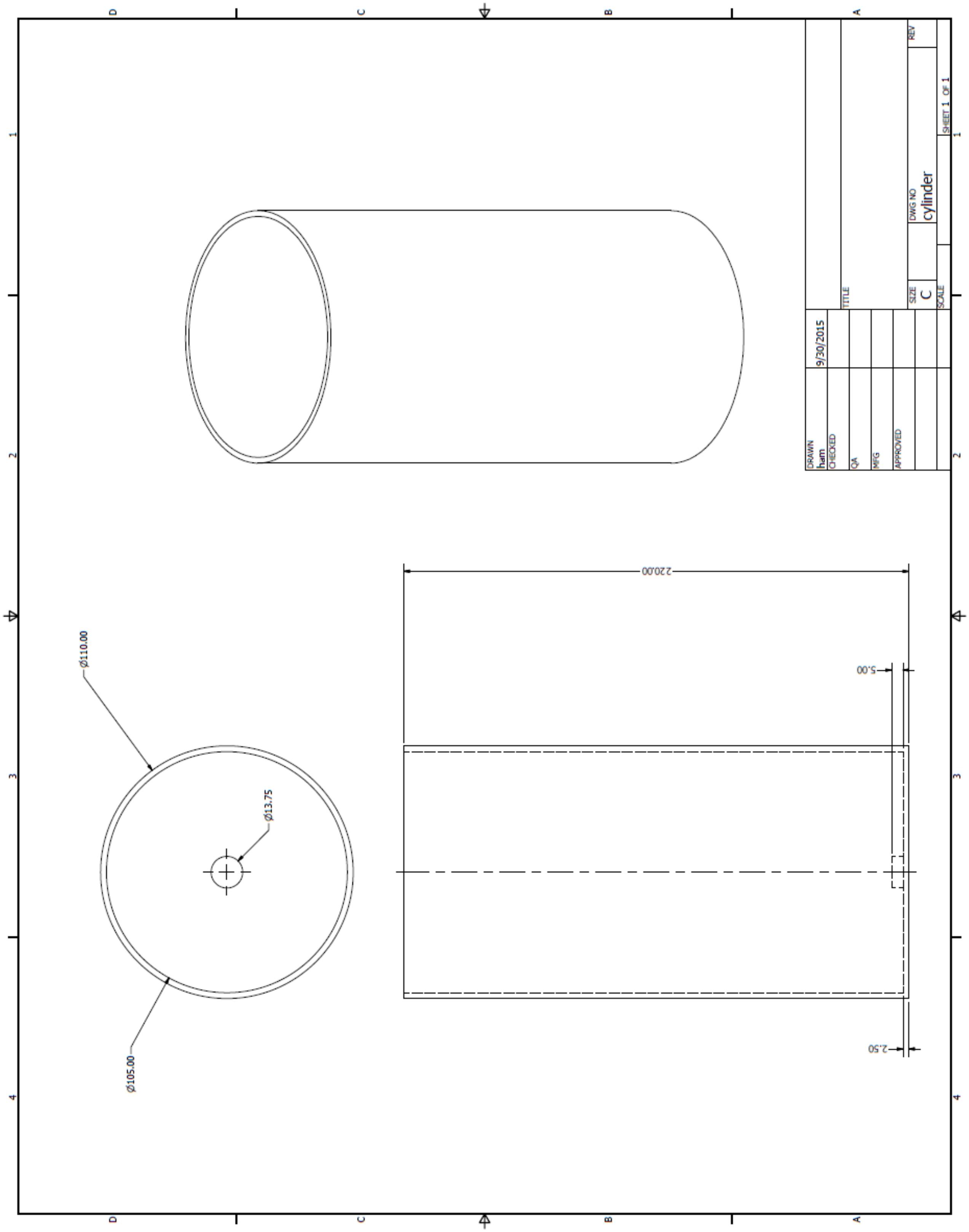


Figure 9 Cylinder

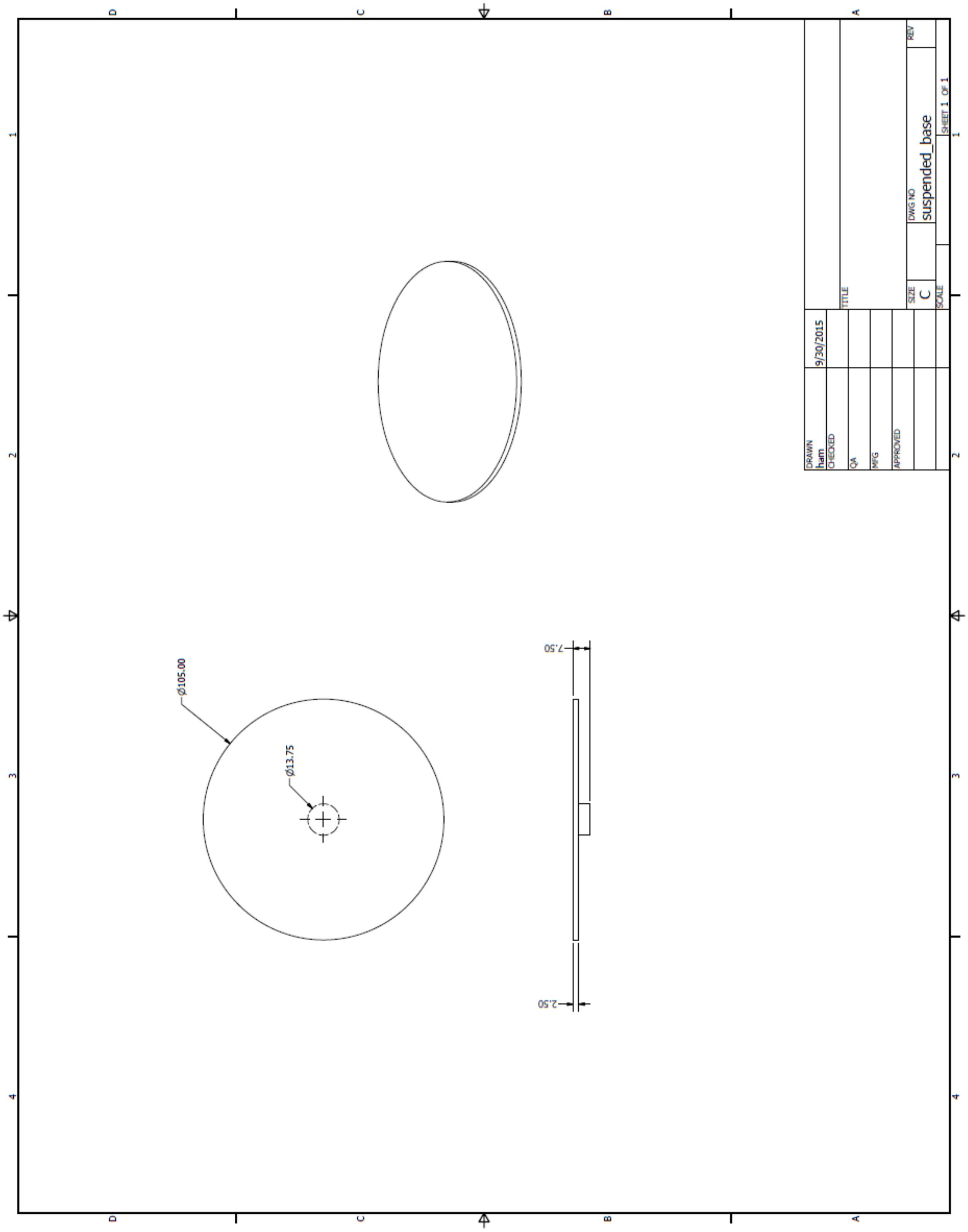


Figure 10 Suspended Base

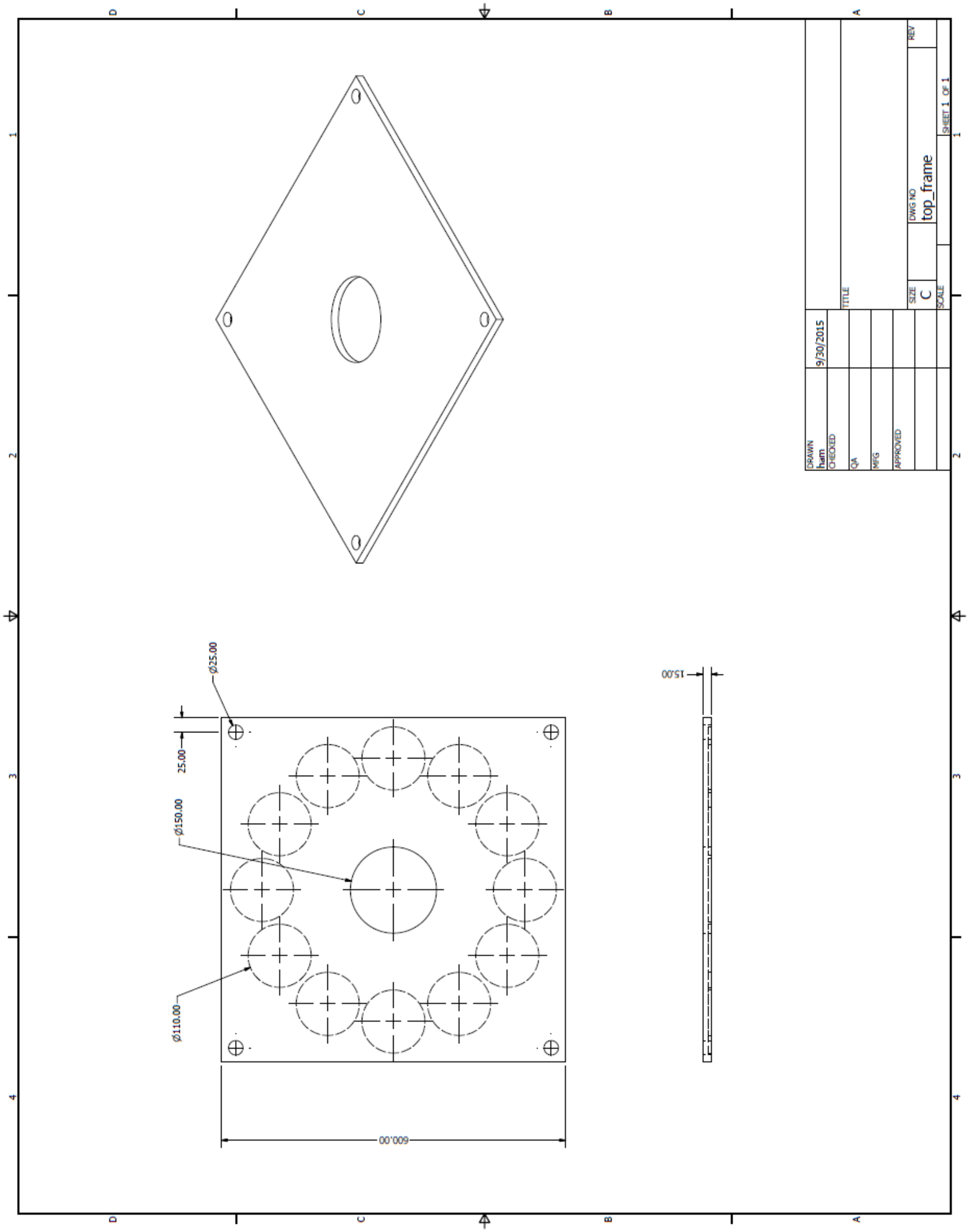


Figure 11 Top Frame

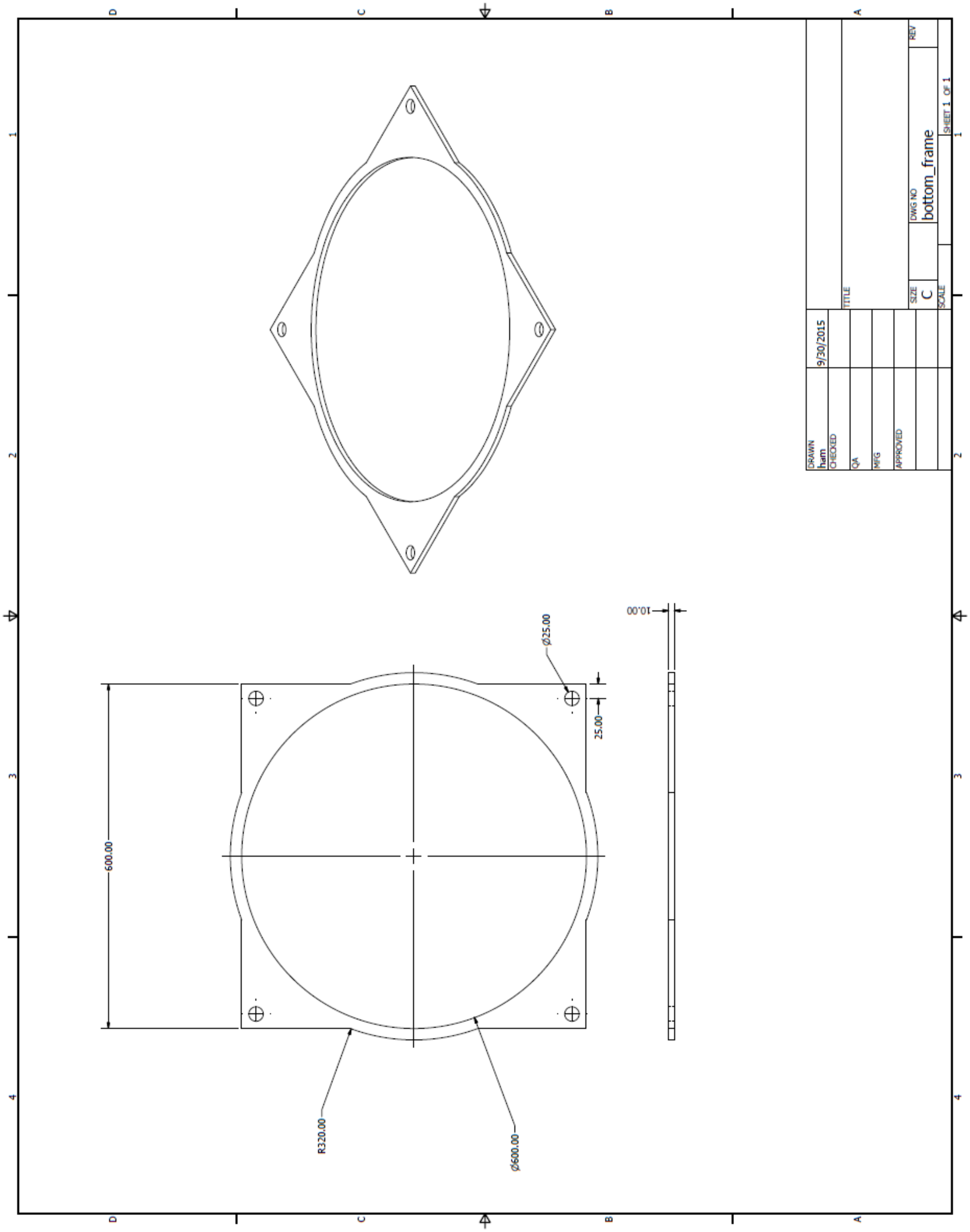


Figure 12 Bottom Frame

4.4 Description of the design rationale for the choice/size/shape of each part

Part 1: Top Base

In order to maximize efficiency, the top base was designed to be able to manufacture multiple plates at once. Featuring three sections with four stations each, the top base is a 600 mm diameter piece of circular plastic with twelve petri dish-sized slots around the circumference. The diameter was chosen so that the twelve stations could fit comfortably. Approximating by setting the circumference of the base equal to the diameter of the twelve plates:

$$\pi D = 12 * d \rightarrow D = \frac{12d}{\pi}$$

where D is the diameter of the base, and d is the diameter of a single station. For d = 105 mm, a “hard” minimum diameter of 401 mm can be found. Note though, that with this value alone, half of each of the plates would be hanging off of the edge of the base. To correct for this, we add the distance that is hanging off on both sides of the circle to the diameter. This value is equal to d, giving a new “soft” minimum of 506 mm. To increase the factor of safety, a final value of 600 mm was then chosen.

Part 2: Fall Base

On the Top Base, the four stations notably in order are the plate dispenser, the filler, the cap dispenser, and the storage station. The Fall Base then is a very important component in the function of this final station. It, as opposed to the top base, only has three holes that will fit under the three storage stations. As it is essentially only there to keep the plates in the other stations from falling down, it was reasoned that it was best for this base to be fairly thin.

Part 3: Bottom Base

Since it was difficult to purchase the specific design we have, since we’re dealing with contamination the material has to be chemically stable and easily cleanable. Therefore we fabricate the sheets of plastic, machine it into adequate design and install it as the base of our structure.

Part 4: Cooling Tubes

Finally, the tubes underneath the Top and Fall Bases are the Cooling Tubes. These are where the plates drop down into from the storage station and were designed so that the plates could move down safely and cool at constant rates. Specifically, there were design constraints of the agar not splashing inside the dishes as they cooled, the plates needing to be stacked while they cooled so as to avoid condensation, and the need to produce 120 plates per hour. To fit these constraints as simply as possible then, the tubes were imagined to have spring-loaded platforms inside that compressed just a bit for each dish. That way, the plates remained stacked and the movement steady.

Then, knowing that the machine needed to store the 120 plates it produced, it was decided to be most efficient to have a total of 12 tubes, each fitting snugly underneath one of the twelve stations. This then gives a required storage capacity of 10 plates per tube. The spring constant then can be solved for by setting the weight of the filled plates equal to the spring force (neglecting the weight of the platform itself):

$$F_g = F_s \rightarrow mg = kh \rightarrow k = \frac{mg}{h}$$

where h is the height of a single plate (the distance the spring needs to compress for each plate), m is the total mass of a plate, g is the gravitational constant, and k is the spring constant of the spring. It is easy then to say that $h = 0.015$ m and $g = 9.81$ m/s^2, but the mass is a bit more complicated. It can be written as the mass of an empty plate added to the mass of the agar as follows:

$$m = m_p + m_a = m_p + \rho_a V = m_p + \frac{\pi \rho_a d^2 h}{8}$$

Where m_p is the mass the empty plate, ρ_a is the density of the agar, and d is the inside diameter of the plate. Knowing $m_p = 0.4$ kg, $\rho_a = 900$ kg/m3, and $d = 0.1$ m, it is then found that our needed value of k is 296 N/m. Finally then, the minimum length of each tube would be ten times the height of one plate, for 15 cm. Again to increase our factor of safety, an actual value of 22 cm was then chosen.

4.5 Gantt chart

Table 5: Gantt chart

Activity	*August*	*September*	*October*	*November*	*December*
Project Selection	■				
Group Formation	■	■			
Design Selection		■	■		
Engineering Analysis			■	■	■
Prototype Construction		■	■	■	
Storage Tubes			■	■	
Spring Loaded Platforms				■	

Pumps			■	■	
Motors				■	
Plate Dropping Mechanism				■	■
Final Presentation				■	■
Final Report					■

5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 Form

ANALYSIS TASKS AGREEMENT

PROJECT: Plate Pourer II NAMES: Patrick Champlin INSTRUCTOR: Professor Malast

Minsoo Ha

Timothy Young

The following engineering analysis tasks will be performed:

Before:

- Fluid mechanics through the pipes
- Heat transfer from the fluid
- Dimensioning
- Tangential acceleration of the plates
- Spring Constant Calculation

After:

- # plates produced per 120 minutes
- Good plate / Bad plate ratio
- Temperature of fluid exiting the pipes
- Average cooling time
- Sterility and cleanability
- Specific part analyses as needed (e.g. Tube improvement analysis, base improvement analysis, etc.)

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

To maintain consistency, the work will mostly be done as a group. The work will be divided as needed should time become an immediate issue.

Instructor signature: ________________; Print instructor name: Mary Malast

(Group members should initial near their name above.)

** As we are waiting for our CAD drawings to be reviewed, we are missing the signature! This is also why we waited until today to turn it in!

5.2 Engineering analysis results

5.2.1 Motivation

The preliminary analysis provides a good guideline for the following design processes. This analysis allows us to verify the viability of the concept by checking whether our design fits within the theoretical constraints while meeting the design requirements.

5.2.2 Summary statement of analysis

For our analysis, five major topics were covered: fluid mechanics through the pipes, heat transfer from the fluid, dimensioning, tangential acceleration of the plates, and the spring constant calculation.

1. Bernoulli equation was used to calculate the fluid mechanics within the tubes. The rate of flow in which the agar flows is important in calculating the exit velocity of the fluid determines whether the liquid will splash out from the plate. The Bernoulli equation is shown below:

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

2. Thin wall approximation was used to calculate the heat transfer within the tubing as the agar flows through. This simplifies the heat transfer coefficient in cylindrical geometry which simplifies the analysis. The approximated convection heat transfer coefficient is shown below:

$$U_o = \frac{1}{\frac{1}{h_1} + \frac{\Delta r}{k} + \frac{1}{h_2}}$$

3. As the mechanism had to operate within a fume hood with relative ease, we constrained the entire design within 17 inches of depth. We also had to fit 12 cylinders in a circular array to maintain the production level.
4. While the loaded petri dishes rotate, the liquid which has not yet set may move and contaminate the contents. By calculating the tangential acceleration the liquid experiences within the machine we can estimate the rate the plates must rotate.
5. Using Hooke's law, which shows the relationship between the spring displacement and the loaded mass, we can calculate the value of the spring constant. The equation of the Hooke's law is shown below:

$$F = -kX$$

5.2.3 Methodology

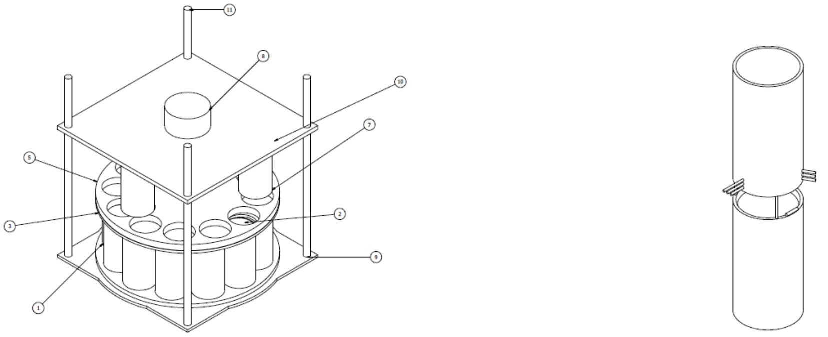
We used Microsoft Excel and hand written analysis. The equations and the diagrams were written by hand and then put into excel to calculate the exact values. We used the equipment from the vibrations lab to experiment and verify whether our hypothesis was correct.

5.2.4 Results

The results were as we expected, and we realized that our initial concerns regarding the properties of the fluid were vastly overestimated. Agar turned out to be a relatively temperate material to manipulate and work with, which in turn made sense as it is used commonly in a modern biology laboratory setting.

5.2.5 Significance

Dimensions were actually which constrained our design significantly as the fume hood of our customer was quite small, much smaller than the fume hoods that we were used to using in Washington University. Therefore, we modified the initial design of a circular carousel and switched into a linear column with motorized dispenser nozzle.



before

after

Figure 13 Before and After

5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design.

Code and standards play an important part in ensuring the safety of the public and the standardization of components used in manufacturing. This optimizes the design and manufacturing process as well as maintaining public safety. By using a readily available component in building our machine instead of manufacturing all the materials we would need, we saved valuable time and money, and proceed to the more important parts of the design process.

5.3 Risk Assessment

5.3.1 Risk Identification

Since our design focuses on low-cost manufacturing process, not all pieces we will be using will be following strict tolerances. Therefore, there is a probability that some pieces may not follow our design specifications.

5.3.2 Risk Analysis

The risk of these factors disrupting our design process may cause great detriment to our project, as we are operating on a very limited timeframe to complete the project. This can be counteracted by taking extra precautions during the manufacturing process.

5.3.3 Risk Prioritization

The top part which holds the empty petri dishes have a more generous tolerance as it will be interacting with petri dishes, but the suspended base and the bottom needs to operate on a strict tolerance as it is susceptible to destabilizing when the petri dishes are loaded. Therefore, we will prioritize on accurately manufacturing the bottom and the suspended base over the precise manufacture of the top.

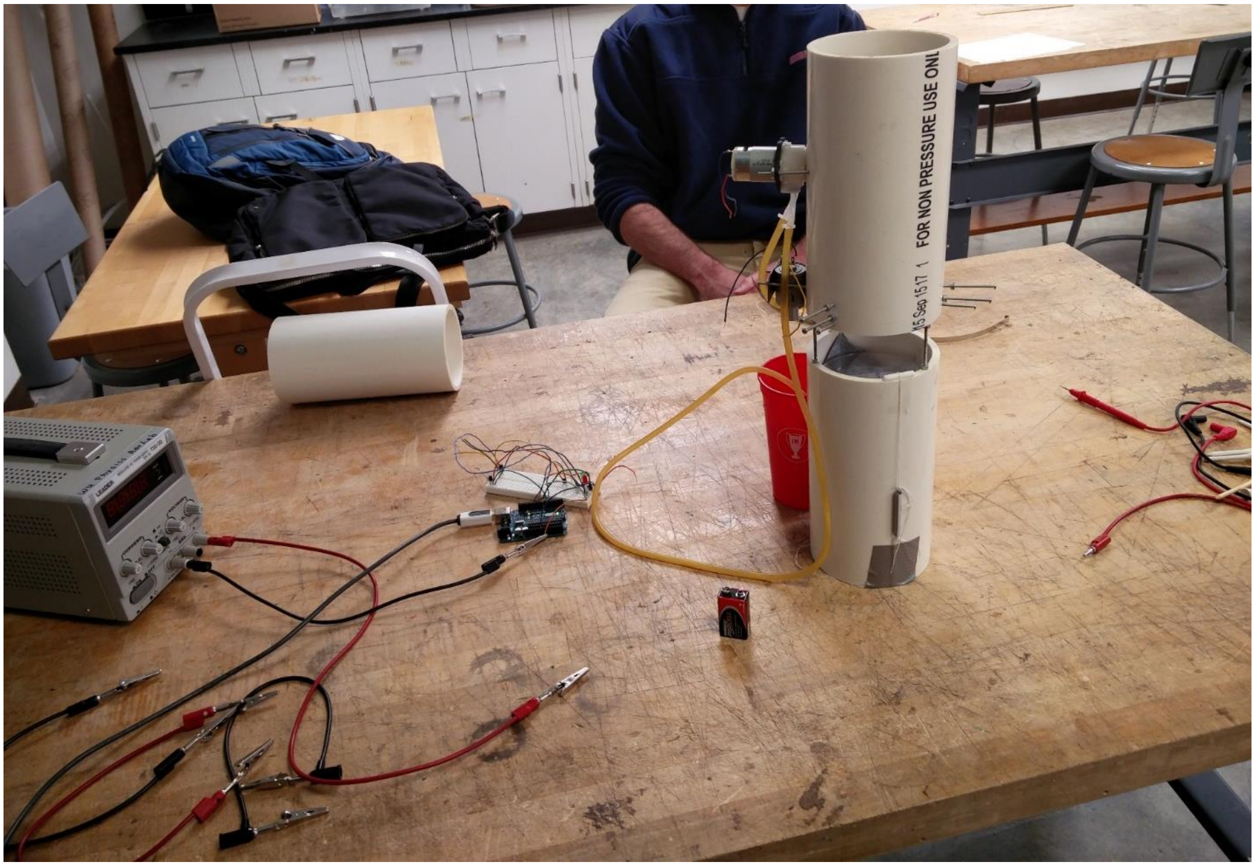
6 Working prototype

6.1 A preliminary demonstration of the working prototype (this section may be left blank).

6.2 A final demonstration of the working prototype (this section may be left blank).

6.3 At least two digital photographs showing the prototype

Figure 14: Overall view of the prototype



This picture shows the device in its entirety. Notice that the upper tube is the storage for the empty petri dishes, while the bottom tube is the storage for the filled petri dishes. The top motor on the left is the pump, which notably pumps the fluid without actually contaminating the fluid. The bottom motor on the left is responsible for the operation of the pump's dispensing armature. The red cup represents the heated agar reservoir that would be provided by the user, and the Arduino circuit to the side controls all mechanisms. The gray box to the left provides 12 V of power (a standard amount).

Figure 15: Second view of the prototype

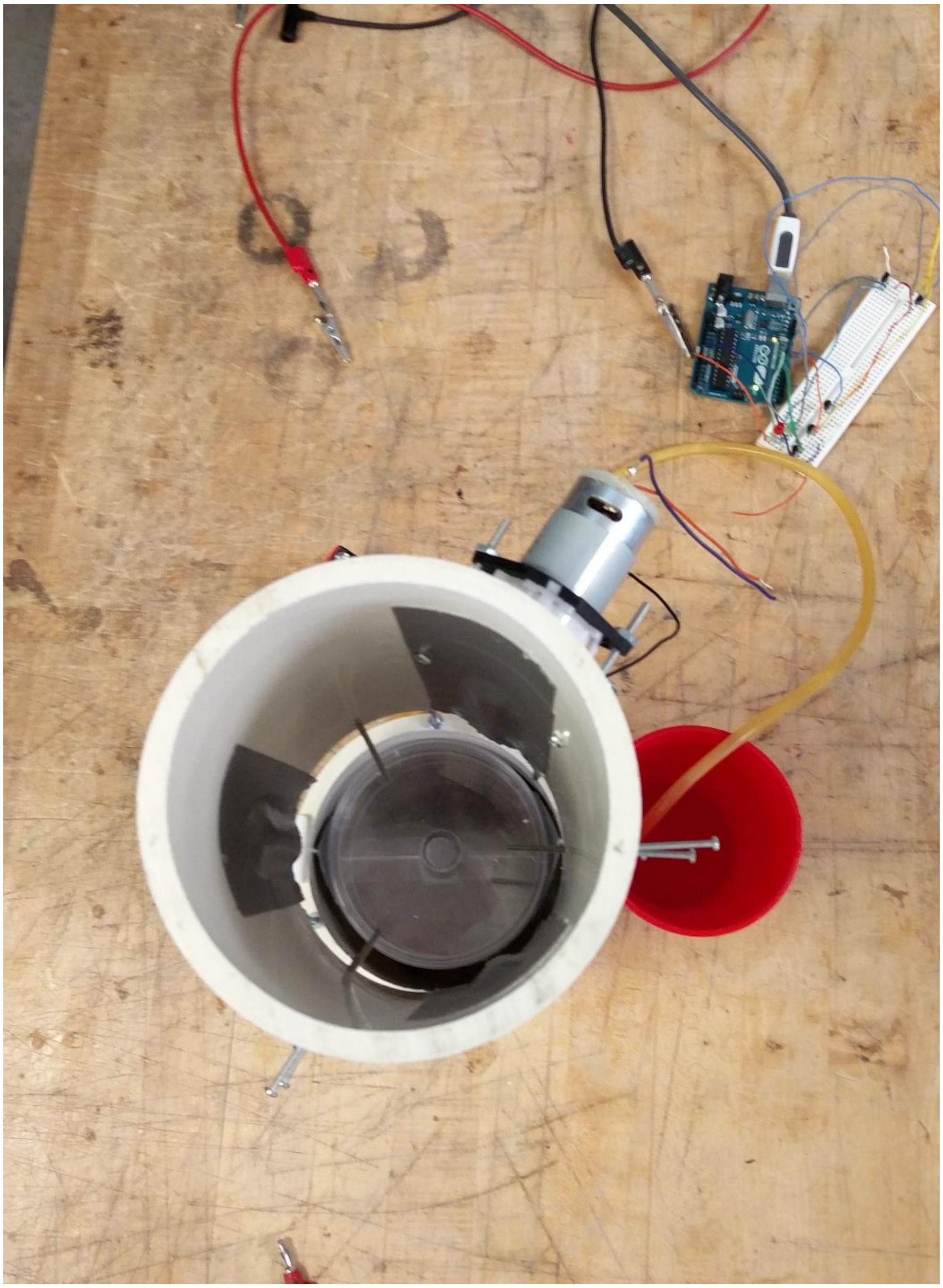
This image more closely shows the device and the mechanisms that compromise it. The screws in the top tube keep the plates from falling, and represent the solenoids (coils of wire that can move an armature in and out a short distance electronically) that would be used in future designs. The screws are operated as follows. Opening the bottom set releases the bottom of the lowest plate onto the platform. This is then filled. The middle screws are opened to release the cap, which drops onto the filled bottom. The bottom screws then are closed. The top nails are opened to lower the stack down a step. The middle screws are closed to support the cap. The process is repeated. Essentially, the bottom two sets of screws separate the plate cap from base, while the top simply keeps the rest of the plates from falling down. The spring-loaded platform is then lowered thanks to the increased mass of the filled plate.

6.4 A short videoclip that shows the final prototype performing

Please see: https://youtu.be/AtLnVmbKzww

6.5 At least four (4) additional digital photographs and their explanations

Figure 16: Top-down view



This figure presents a top-down view of the device. Notice the rails inside that allow the dishes to remain centered, and how the screws are adjusted so that the plates are supported correctly. Also observe that the platform below has a mass glued to it so that the springs are pre-loaded.

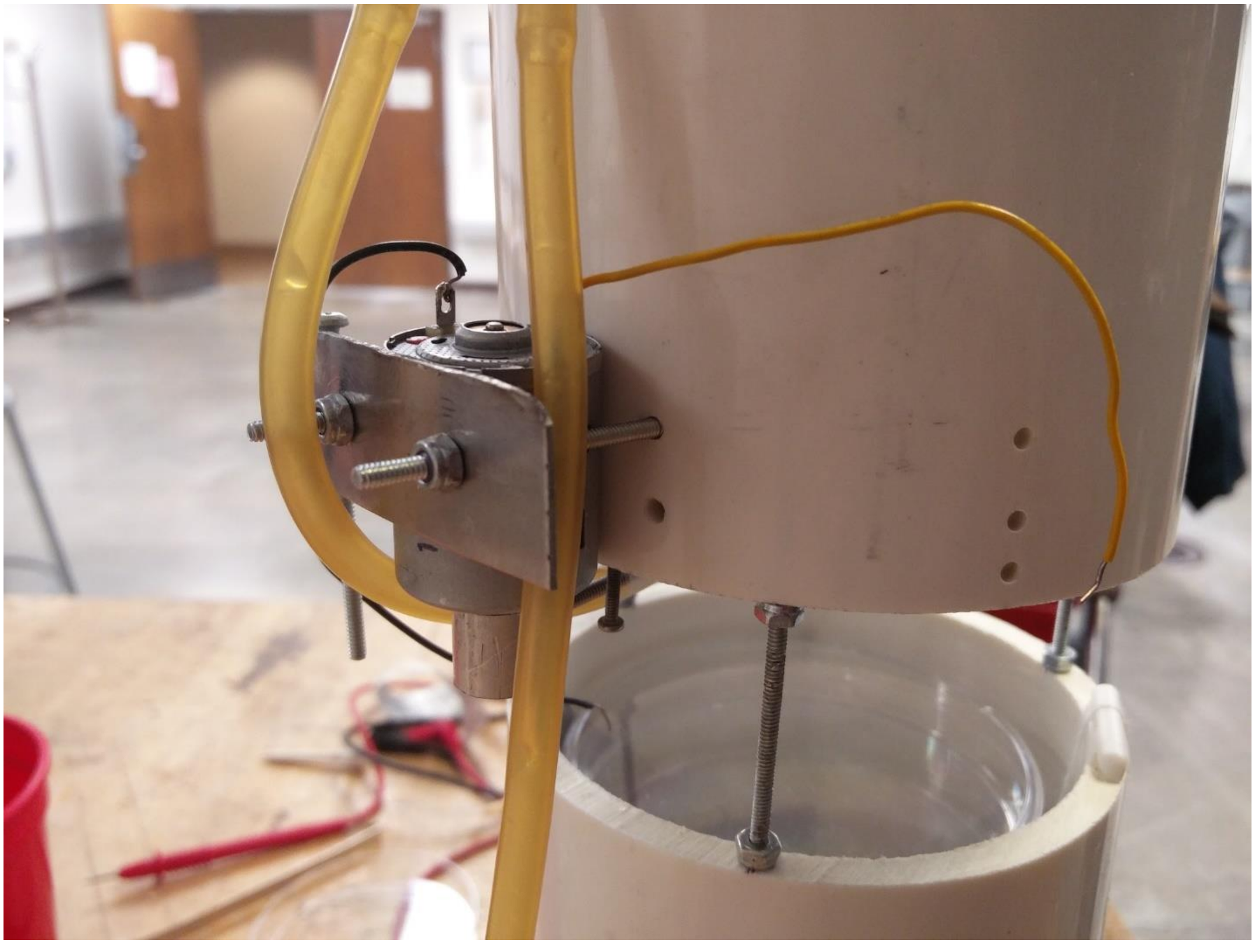
Figure 17: Side view

This figure then shows a side view of the actual filling zone. Notice that the nozzle through which the pump actually dispenses the fluid is attached to an armature that can move it in and out of the filling zone. This is so that the armature will be out of the way when the plate is dropping, then can move to fill the plates after they have dropped.

Figure 18: Alternative side view (pump armature out of the filling zone)

This picture shows the armature after being moved outside of the filling zone. A screw coming down vertically next to the armature can be in this picture seen – this is there to prevent the armature from going too far in the event of an error. The screws coming out of the bottom tube and into the top tube support the top tube and secure the device together. The white strings coming down from the platform notably lead to the tension springs that were utilized in this design and that can be observed in the figures above. Notice that that the white plastic cylinders over which these strings are laid create a pulley system which automatically adjusts in response to the load on the platform.

Figure 19: Motor mounting



This figure finally gives a better view of how the motor is mounted. Notice that the two screws coming perpendicular from the surface of the cylinder constrain a metal plate on the back of the motor, which then holds the motor in place via friction after being tightened. This plate also has the added feature of allowing the piping coming from the pump to remain organized under operation. The pump notably is mounted in a similar manner, except by using the built-in mounting plate.

7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models. *Include units on all CAD drawings.* See Appendix C for the CAD models.

Please see Appendix C for CAD models.

7.1.2 Sourcing instructions

Arduino purchased from Arduino.cc

Pump acquired from Ebay

Springs purchased from MSC inc.

Petri Dishes / Tubing acquired from Washington University Chemistry Department

All other materials were acquired from Home Depot

7.2 Final Presentation

7.2.1 A live presentation in front of the entire class and the instructors (this section may be left blank)

7.2.2 A link to a video clip version of 1

Please see: https://youtu.be/JeDXXl9t2QQ

7.3 Teardown

Our group returned the power supply acquired from the physics lab right after our demonstration. The product we had made functioned quite well, and we decided not to deconstruct the entirety of the project.

8 Discussion

8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

The plate pourer met nearly all of the design constraints, with those that were not met being left for future work. Specifically, the device was easily cleanable, fit well within a fume hood (for a total volume of approximately 13,000 cm3 – 5% of the goal of 260,000 cm3), was easy to transport, capped the plates after filling, did not move the plates laterally at all after filling (0 m/s), was sterile (bleaching gives a sterility of 10-6 SAL), completed a dish every 15 seconds (240 plates per hour, with the first batch being cooled and ready in 30 minutes), had a good plate ratio of 94% (e.g. 94% of plates did not allow for fluid more than 60% of the way up the side of the dish), and correctly stacked the plates vertically while cooling.

The major constraint that was not met was that of complete automation, though this was only due to a lack of solenoids. Therefore, it is left to future iterations of the device to implement the solenoids in place of the screws, which would only involve mounting them to the top tube. In addition to this, it is worth noting that no agar was actually ever run through the device, again due to a lack of agar. Instead, the agar was modeled by water, which was found to accurately represent the hot fluid. Because of this, we are slightly uncertain as to the agar's flow temperature at the exit of the pump. With that said, due to the insulation of the piping, and the rapid delivery of the fluid, it is not expected that the agar would have sufficient time to cool before reaching the plates.

8.2 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

The main issues in sourcing parts came with the solenoids. Those that we could find were only either incredibly overpriced but only took a few days to arrive, or reasonably cheap but that took a time on the order of months to arrive. It is for this reason that we were forced to model the solenoids with the screws – though should this device have ever gone into mass production, a supply chain of the solenoids could be established with relative ease. Scrounging parts of course made a lot of sense, the armature motor specifically was scrounged from a former project. We even were able to scrounge up a few solenoids, though sadly not enough to work for our device! The agar was also surprisingly difficult to acquire, most sites requiring that you be associated with a research lab to purchase any. Aside from these, the only things that were difficult to source were temporarily the petri dishes and the pump tubing – both being eventually acquired from the chemistry store room. Our recommendations for future projects are to try and source everything very early on, and especially to try to minimize ordering parts from the internet as it can prove to be unreliable. Most of the parts we ended up using came from Home Depot!

8.3 Discuss the overall experience:

8.3.1 Was the project more or less difficult than you had expected?

Definitely more difficult, though we suppose that is not out of the ordinary for a design project. It is impossible to predict every little issue, and usually they are these little issues that end up for whatever reason requiring the most work.

8.3.2 Does your final project result align with the project description?

Yes, we actually were very satisfied with our final prototype. Works like a charm!

8.3.3 Did your team function well as a group?

Yes, we all got along well and worked together effectively.

8.3.4 Were your team member's skills complementary?

Yes. Patrick was good at coming up with initial ideas that had the potential to work very well, but that generally would have a few flaws that Minsoo and Tim were quick to point out and provide solutions to. Minsoo especially was good with making quick models and drawings of the designs, while Tim's expertise in computer programming and circuits allowed for the device to operate smooth as butter.

8.3.5 Did your team share the workload equally?

Yes. Generally we either split the work equally, or performed the tasks as a group.

8.3.6 Was any needed skill missing from the group?

The only skill that might have been helpful that was missing in the group was experience with manufacturing plastics. Originally we had wanted to do a large amount with plastics, but we decided to scrap most of those ideas as we had no clue where to start.

8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

Yes, though we never got the chance to meet him in person due to conflicting schedules, we nonetheless corresponded by email. These emails were very helpful in determining the final design of our prototype, the major one being an updated number for the depth of the fume hood. Our original design was a few inches too large for this new measurement, and thus required us to change it into the single-tubed form you see now.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

Yes, there were a few changes to the original requirements. Firstly, as noted above there was the reduced amount of space allowed for the device. Secondly, it was not originally noted that the plates had to be stacked in order to cool properly. Lastly, we were not told that the reservoir of agar fluid would actually be provided by the user.

8.3.9 Has the project enhanced your design skills?

Yes, it has given us a new appreciation for having a fine eye for detail.

8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?

Yes, as now the process would seem more familiar and easy to comprehend.

8.3.11 Are there projects that you would attempt now that you would not attempt before?

Yes, we probably wouldn't mind now doing the sandwich wrapper or the whiteboard pen dispenser if we were to do everything over again.

9 Appendix A - Parts List

Table 8: Parts List

Item #	QTY	Part Name	Materials Used
1	1	Top	10'X4'' PVC pipe
2	1	Bottom	Impact-Resistant Slippery UHMW Polyethylene
3	1	Platform	PVC Petri Dish, 3/4'' Iron Pipe
4	12	Pin	1/8'' Stainless Steel Screw
5	1	Pump	DC 12v D4 Lab dosing pump peristaltic head chemical water liquid 19~100ml/min
6	1	Tubing	Autoclavable 3/8'' tubing
7	1	Circuitry	Arduino, circuit board, transistors

10 Appendix B - Bill of Materials

Table 9: Bill of Materials

Item Number	Description	Quantity	Unit Price	Amount USD
	10'X4'' PVC pipe	1	9.99	9.99
	Hardwood Sheet	3	3.99	11.97
	Gorilla Glue	1	11.99	11.99
	Wood Glue	1	10.99	10.99
	Arduino UNO Rev3	1	24.95	24.95
	USPS First-Class Mail Parcel	1	3.74	3.74
	DC 12v D4 Lab dosing pump peristaltic head chemical water liquid 19~100ml/min	3	11.32	33.96
4075776	1/4X.020X2 SS EXTENSION SPRING PKG10	1	16.16	16.16
91671065	0.240 X 0.018 X 1.50 SS PRECISION EXTSN PACK/3	1	7.34	7.34
91671073	0.240 X 0.018 X 2.00 SS PRECISION EXTSN PACK/3	1	7.34	7.34
2314631	5.4 X 0.4 X 24 SS METRIC COMPRSSN PACK 3	1	11.23	11.23
Total				$149.66

11 Appendix C - CAD Models

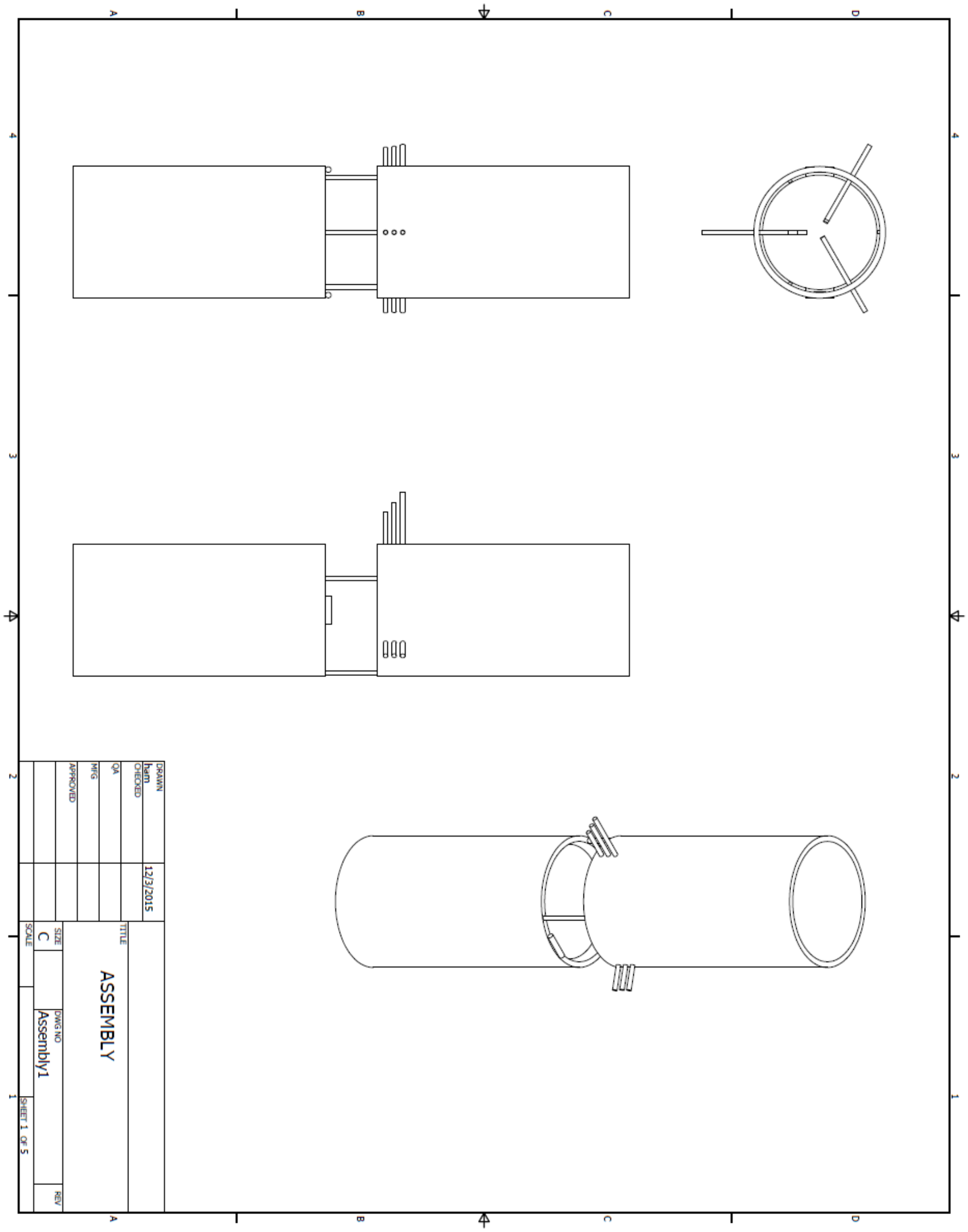


Figure 20 Assembly

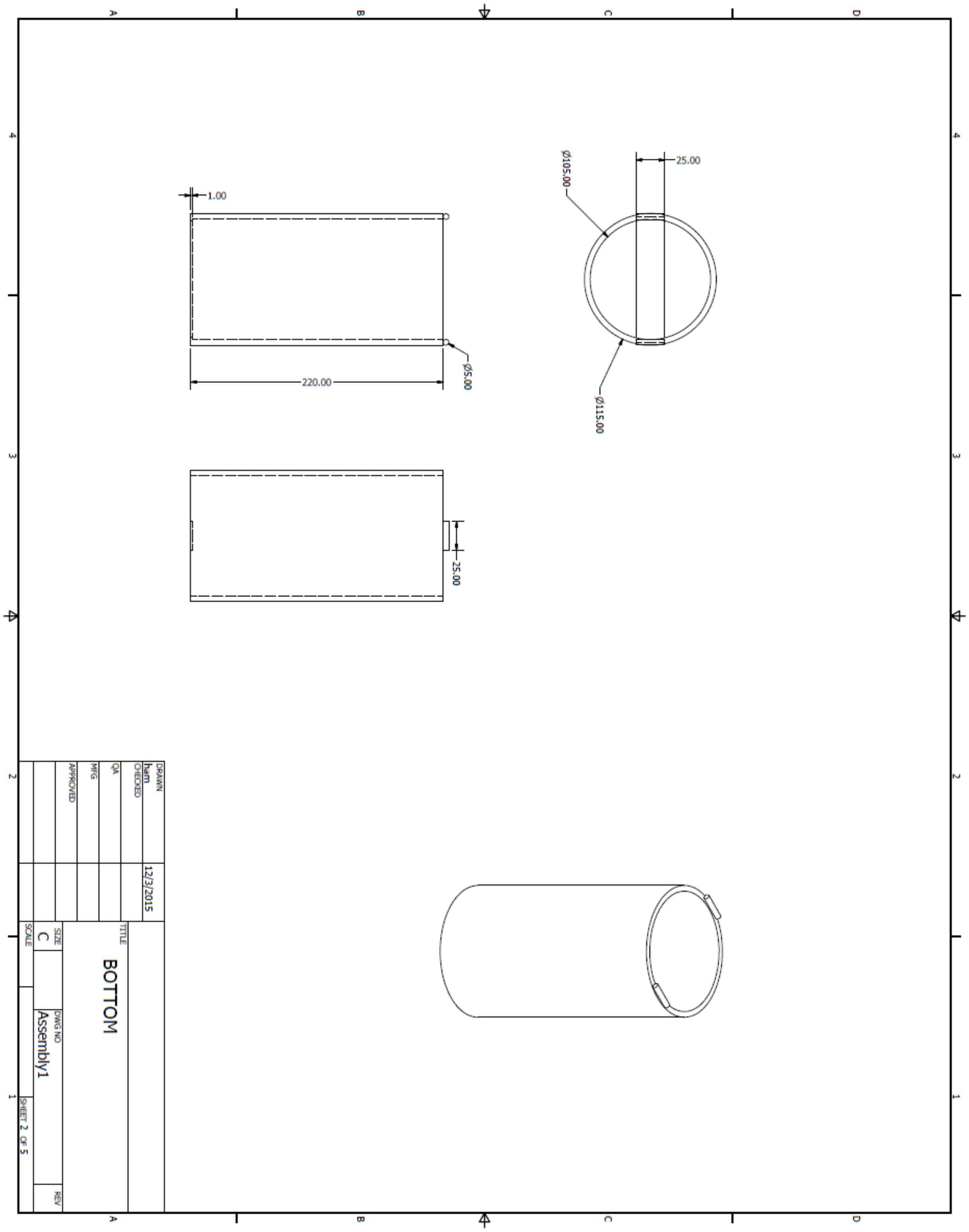


Figure 21 Top

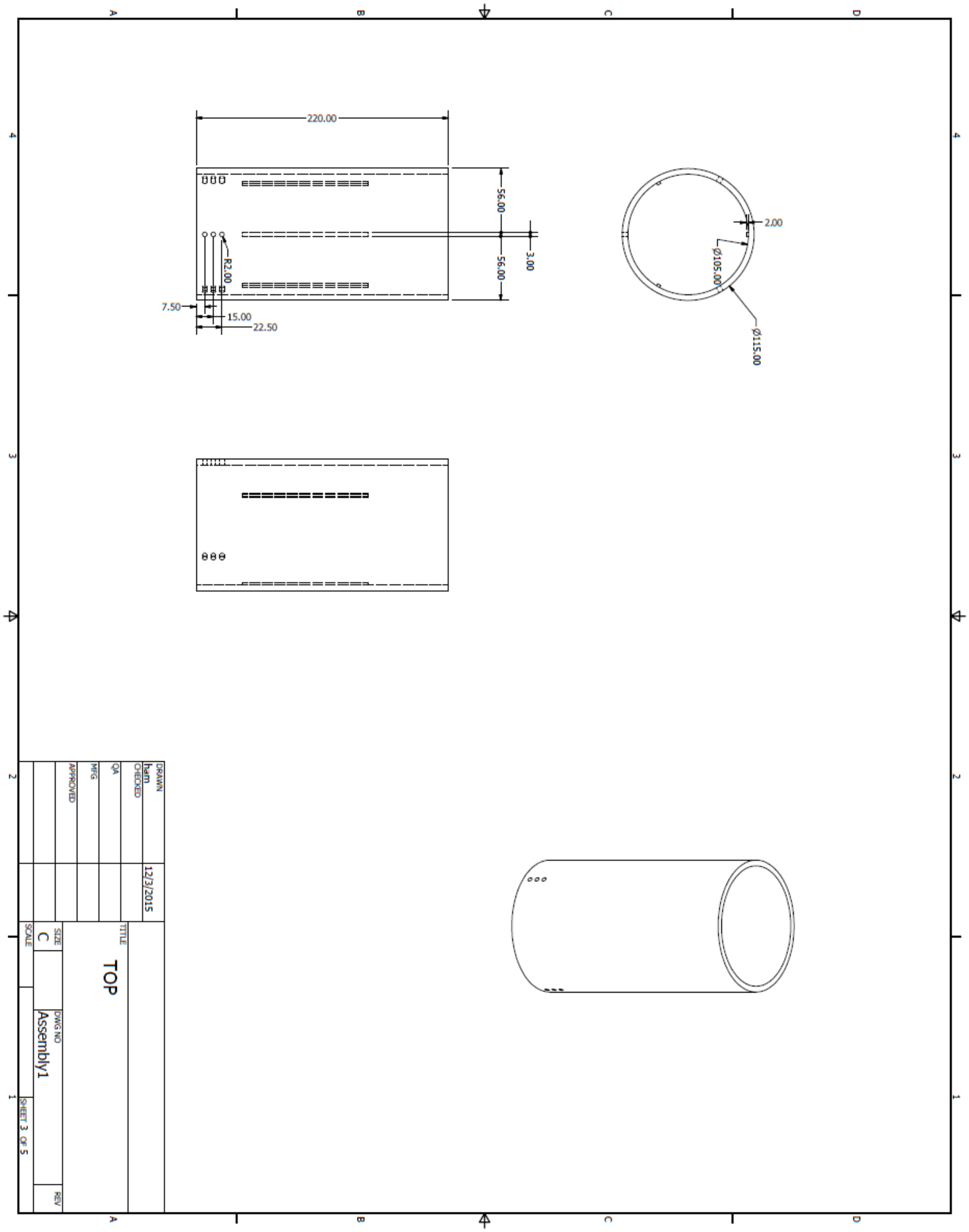


Figure 22 Bottom

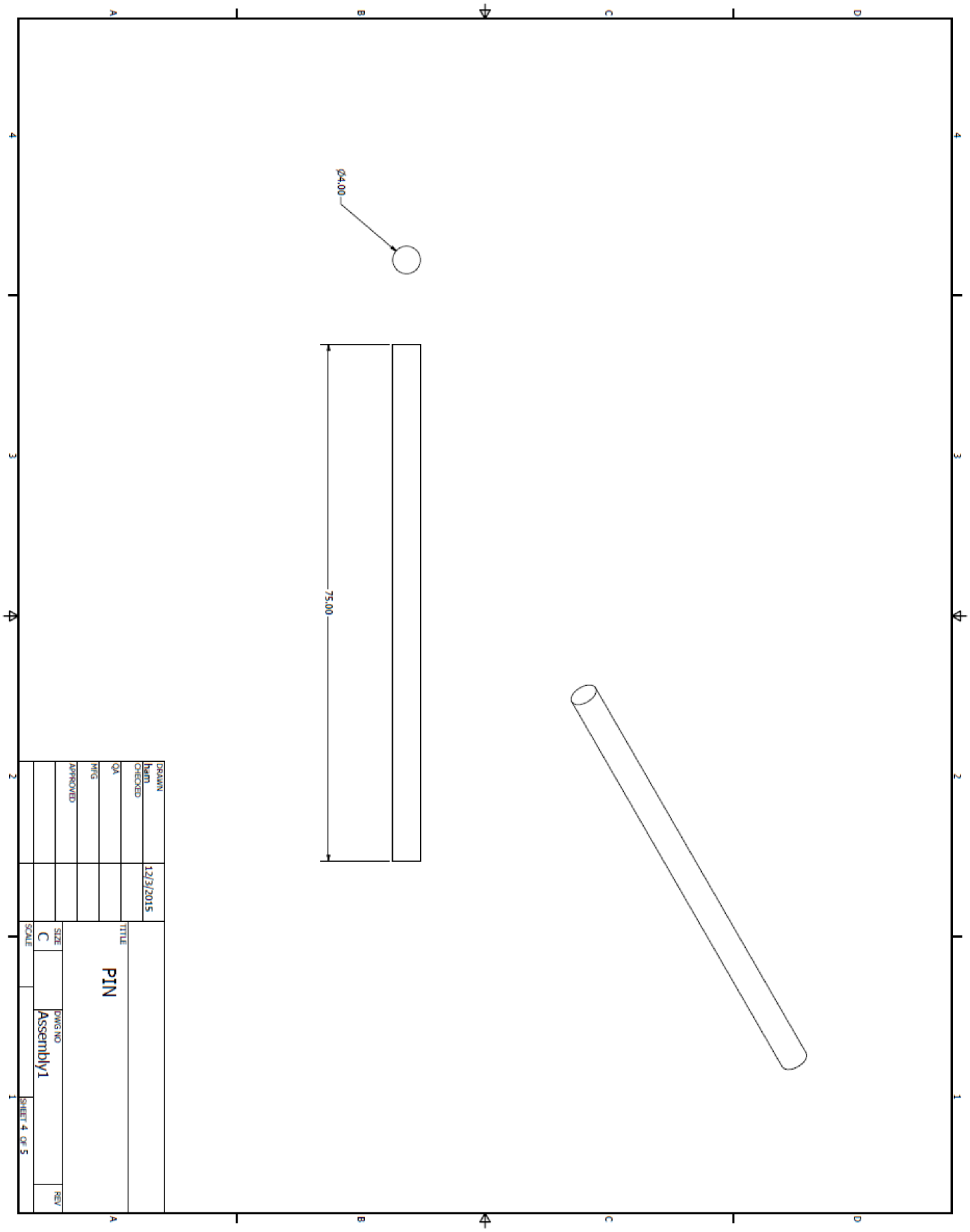


Figure 23 Pin

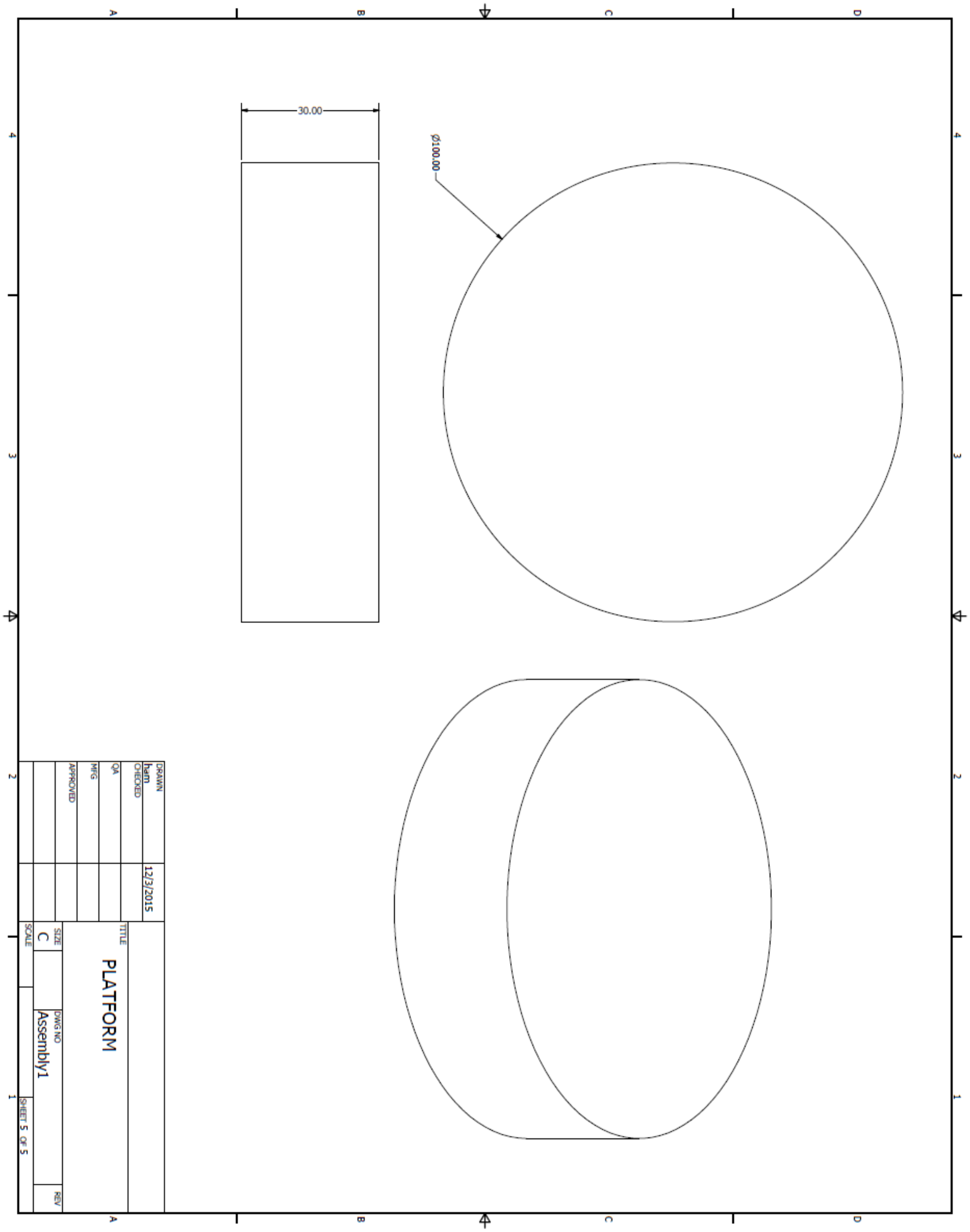


Figure 24 Platform

12 Annotated Bibliography (limited to 150 words per entry)

Rebecca Buxton (2005) Blood Agar Plates and Hemolysis Protocols

The history and the properties of Agar is described in detail with examples of the different kinds of agar and sample images.

Dr. Samuel Porto (2003) Agar-agar Structure, Production process, and Properties

The articled describes in detail of the structure, production process and its properties. The physical properties such as viscosity, setting point and melting point are listed.

Stewart, Becky (2015) Adventures in Arduino

Arduino programming for the absolute beginner, with project-based learning "Adventures in Arduino" is the beginner's guide to Arduino programming, designed specifically for 11-to 15-year olds who want to learn about Arduino, but don't know where to begin. Starting with the most basic concepts, this book coaches you through nine great projects that gradually build your skills as you experiment with electronics. The easy-to-follow design and clear, plain-English instructions make this book the ideal guide for the absolute beginner, geared toward those with no computing experience.

McKeen, Laurence W. (2008) The effect of temperature and other factors on plastics and elastomers

The reference data book covers more than 70 plastics types and the chemistry of each type is summarized. Sections covering polymer chemistry, property measurement, ASTM and ISO testing procedure, as well as polymer selection, provide a basis for understanding the data and how to use it. The inclusion of more than 1000 graphs and tables also allows for easy comparison of a wide variety of plastics products.