Group 4 Section 441:
Peristaltic Water Pump Final Report Group 4

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MAE 2220: Mechanical Synthesis

Professor Robert Shepard

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Team Roles:

- Design Integrator: Ata Zavaro
    - Responsible for making certain parts fit well together and ordering the pre-manufactured parts. Ensures that the design of the pump abides by mathematical calculations and follows project specifications and constraints.
- Leader / Schedule Coordinator: Natalie Sun
    - Oversees the group's timeline and ensures the timeliness of all the internal deadlines of parts. It also ensures that all the rubric points have been met.
- Design Leaders: Bridget Forbes, Hunter Chubik
    - Oversees the production of the CAD; makes sure the assembly is constrained and made correctly. Ensures that parts are manufacturable or within purchasing budget. Oversees the creation of sketches and technical drawings. Creates renders and animations for our design to visualize our outcomes better.
- Manufacturing Leader: Karolina Swedek
    - Oversees manufacturing process for pumps; makes sure everyone in the group is comfortable with making their assigned component and that everything is made to spec and toleranced correctly. Updates the group on stock and ordering needs.
- Testing Leader: Jeffery Cai
    - Oversees the testing process for the final pump design; makes sure everyone knows what the final product needs to accomplish; creates a list of next steps based on testing.

Design Process

Description of Pump:

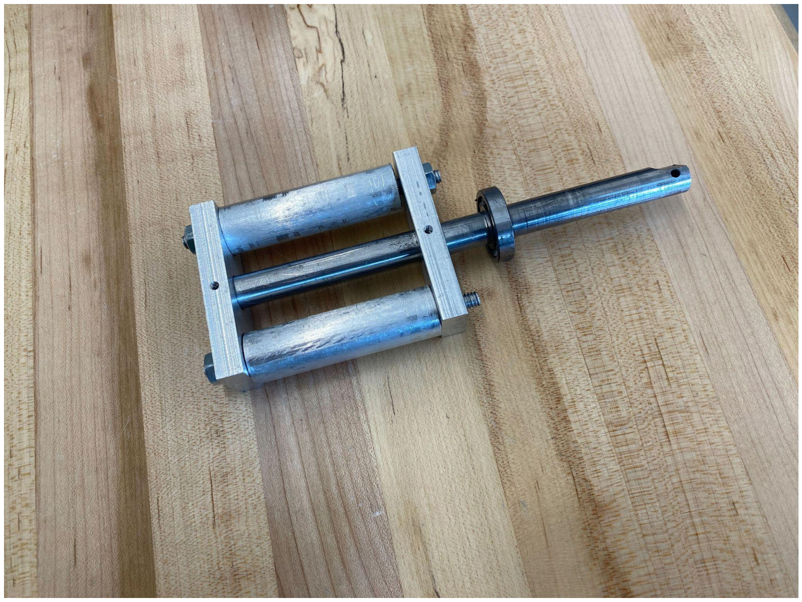
Our pump of choice is the peristaltic pump, which falls into the category of positive displacement pumps. It works by using a rotating roller to squeeze a flexible tube along a curved casing, causing the water to be pushed along the radius. Typically, the peristaltic pump transfers sterile fluids or handles volatile chemicals because the liquid within the pipe never has to come into contact with the moving roller. The function of the pump can also be easily controlled by the speed and direction of the motor, making it flexible.

Design Choice & Rationale:

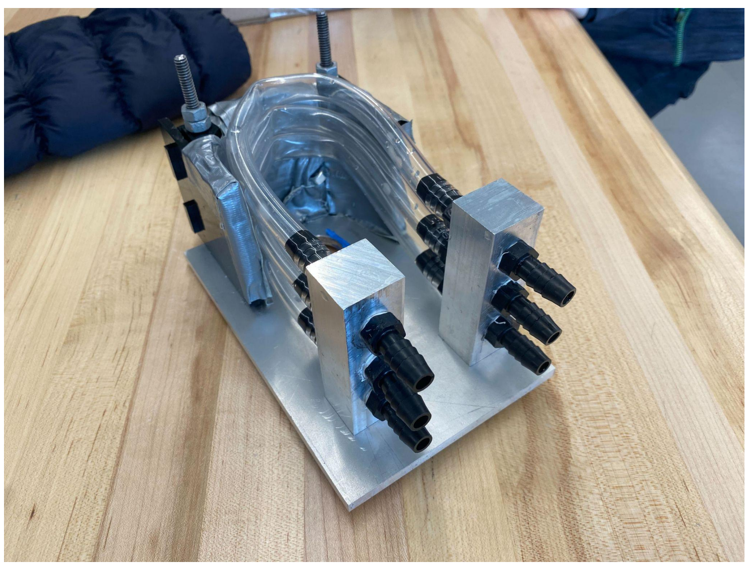
Our team weighed a variety of options when deciding what pump to make; the three pumps we were fixing between were a piston pump, a peristaltic pump, and a gear pump. We chose the peristaltic pump because we thought it would eliminate any potential issues we foresaw for sealing and would challenge our CAD and machining skills. We believed it would be feasible to complete with our given supplies and that it was a more exciting pump design that would fit within our budget. The primary reason for not choosing the piston pump was the sealing issue and less machine shop exposure, and we eventually eliminated the gear pump based on our initial estimates of the pricing and pump power requirements.

Our team's final water pump is a peristaltic pump that compresses water traveling through three tubes. The pump has an aluminum base plate with four screw holes and a hole for a bearing to accommodate the torque transfer shaft. This was the most straightforward way we could figure out to mount the actual pump assembly to the provided testing setup. A stack of acrylic pieces with ¼-20 threaded holes attach to this base plate, with side panels glued to them. This was not our initial plan; we initially had a metal semi-circular casing for the tubes to fit in but had to abandon that idea after it was not machinable or financially feasible. The reinforced acrylic was the most cost-effective and time-efficient solution we could have in our situation. Two aluminum pipe fitting holders also attach to the base plate; they accommodate twelve pipe fittings for the three tubes so the tubes from the testing setup can run throughout the pump. This solution made our pump entirely leakproof and allowed water to pump through.

The shaft runs through the bearing, with two threaded holes for attaching two aluminum 'spinners' with set screws. These 'spinners' accommodate two rollers, the components spinning and compressing the tubes when the pump is in action. Our team selected the roller/spinner solutions for shortening the tubes because it was relatively cheap, easy to manufacture, and effectively utilized the torque transfer from the shaft. Most of these components are fastened together using ¼-20 screws and hex-nuts and took advantage of the hardware and stock available in the RPL and the Emerson machine shop for cost-effectiveness.

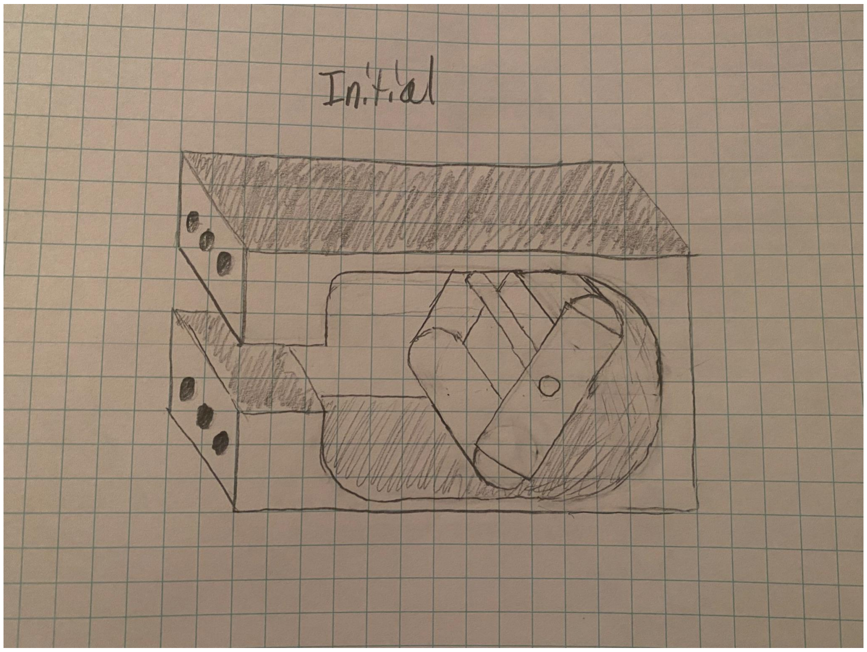


Roller on water pump

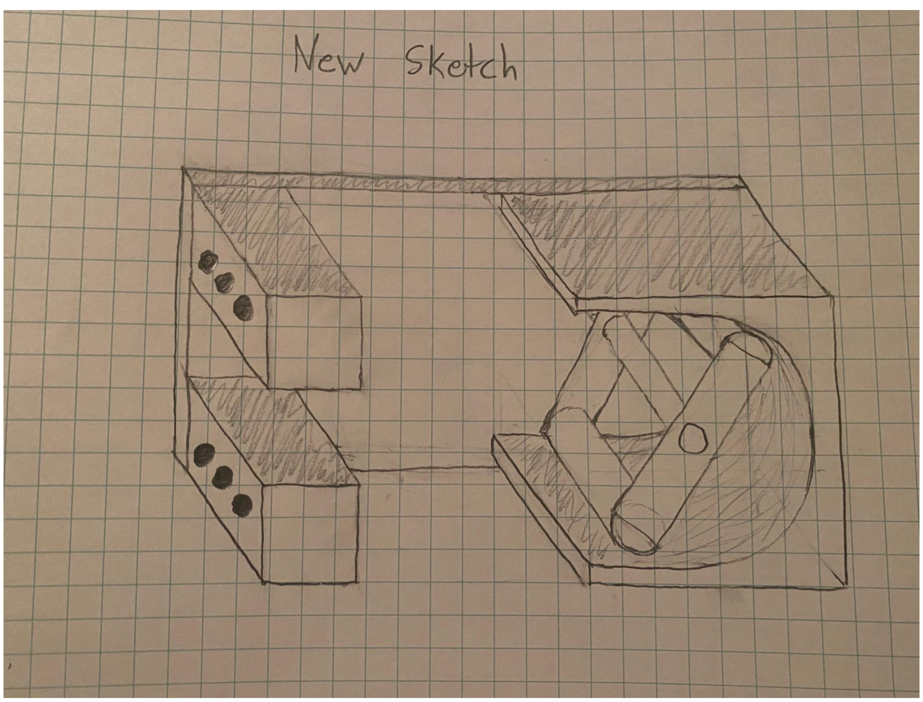


Final assembled pump—components visible: pipe fitting holders, acrylic housing, base plate, and tubes. We did have to line the acrylic with duct tape at the end to improve tube compression.

Initial Notebook Sketches:



Our initial design featured an aluminum metal casing we planned for CNC. After consulting with our section TAs, we realized that manufacturing this type of casing would not be financially feasible and extremely difficult to machine.



Our next design was much more straightforward, with an aluminum mounting plate combined with an acrylic semi-circular attachment to guide the tubes

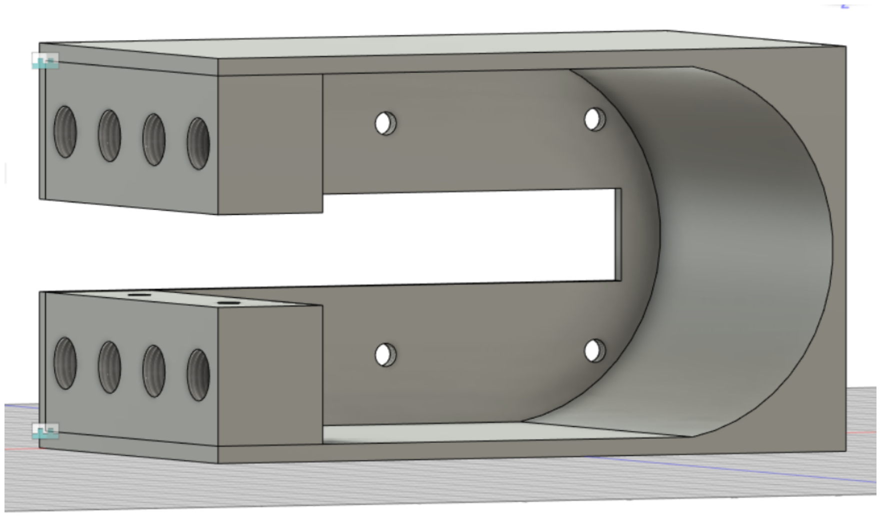
Challenges

Anticipated Challenges:

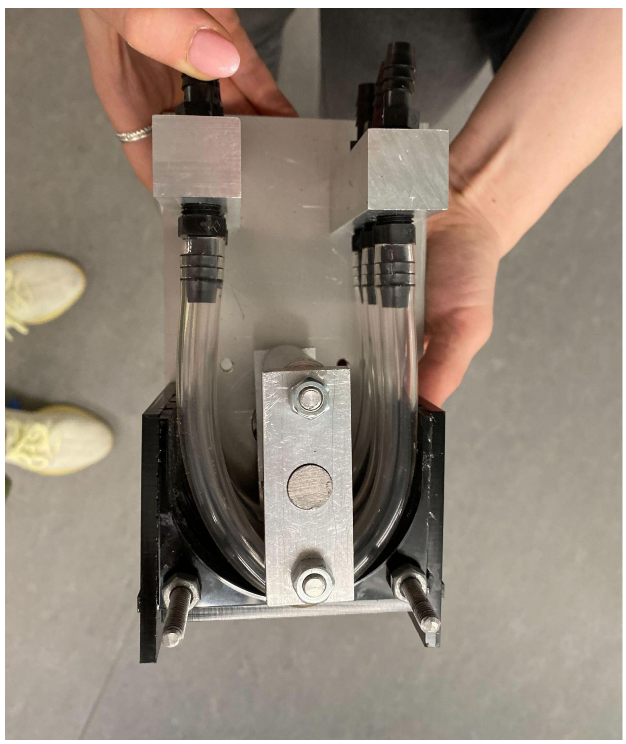
When our team met for brainstorming sessions early on in the design process, we realized that the peristaltic pump had a lot of parts that needed to be machined. As opposed to the piston pump, which had its major components pre-made for purchase in Emerson, we needed to create lots of small parts like the rollers and the side plates to hold the rollers together. We also realized that lots of fasteners would be necessary to assemble our pump – many of the parts in our design could only be manufactured separately, so we focused a lot of attention on how specifically we were going to connect our parts together in a robust way. Our group also identified that these intricate parts would consume a large amount of our budget, so we needed to diligently keep track of our supplies and not waste any amount of material. As a last note, we noted how short the fabrication timeline was, so we planned weekly meetings to address the problems that would inevitably arise in the future.

Unanticipated Challenges:

As expected, there was a significant number of unanticipated problems that we had to resolve during our manufacturing process. The first problem that we encountered was definitely the most problematic one: our initial idea of having the casing of the peristaltic rollers be CNC machined out of metal was not realistic, as the shop had no end mills long enough to create the 4+ inch depth we needed for our casing. The solution we ended up with was to create the casing out of acrylic instead, as that was the cheapest and most time-efficient solution, although it presented challenges of its own. The main unanticipated issue we had with the acrylic was supporting it; initially, we had just planned to stack acrylic pieces for the semicircular shape, but then we had to add extra support side panels once we realized the pump needed support. Another prominent issue was the lack of consistency in our shop parts. Many of our features required several steps on both the lathe and mill, and we had several pieces that took a whole shift to manufacture but turned out to be either slightly too small or slightly askew. These mistakes came up because of our team's lack of experience in the machine shop; other than Karolina, our team was basically new to machining. However, once we became more comfortable with the shop, we completed all of our parts correctly and before the deadline.



Initial housing idea. Even when accommodating for pocketing fillets and other machining features, our housing was fundamentally too expensive and too large to machine easily on a CNC.



Initial Water pump assembly. Visible are the acrylic side panels that were an adjustment from our initial plan of manufacturing the housing out of aluminum. The side walls were added to the semi-circular portion after we realized it was too flimsy.

Performance Analysis:

During testing, it was immediately evident that our pump casing was the weakest link in our design. Firstly, it was not structurally strong enough to resist the torque the spinner provided. The acrylic casing flexed back and forth on each pass of the spinner and caused the entire setup to vibrate violently at higher rotational speeds.

The material choice was likely our major downfall, as acrylic is a material that is too susceptible to bending and snapping and should not have been used in the part that needed to be the most resilient. Unfortunately, it was our best solution because of our time crunch.

Furthermore, when redesigning our initial housing to a simpler stackable version to be laser-cut, we needed to correct the positioning of our casing. The roller would be barely too far away from the middle of the curve, which meant that the tube was not compressing enough in that spot. For a peristaltic pump, this is a critical problem. Since the pipe was not squeezed tight in that area, the water would not be forced to continue along the tube, resulting in little to no water being pumped. This issue was also tricky to fix because of the weakness mentioned above in our acrylic. When we tried to pad the casing to improve the compression of the tube, we found that the additional thickness caused more torque to be applied on the sides of the casing and created even stronger vibrations in our pump. Thus, our pump performed less successfully than expected, but we learned a lot from its design flaws—assembled water pump. On the right side of the tubes, a more noticeable crease is visible, which limits the flow of water. Our team's solution on the testing day was to line it with duct tape to improve compression and use a clamp to reduce the bending of the acrylic. The clamp allowed our pump to get some suction before the hex nut came loose. Our pump showed promise, and we believe with a larger amount of time to design and manufacture, we could have made a great peristaltic pump.

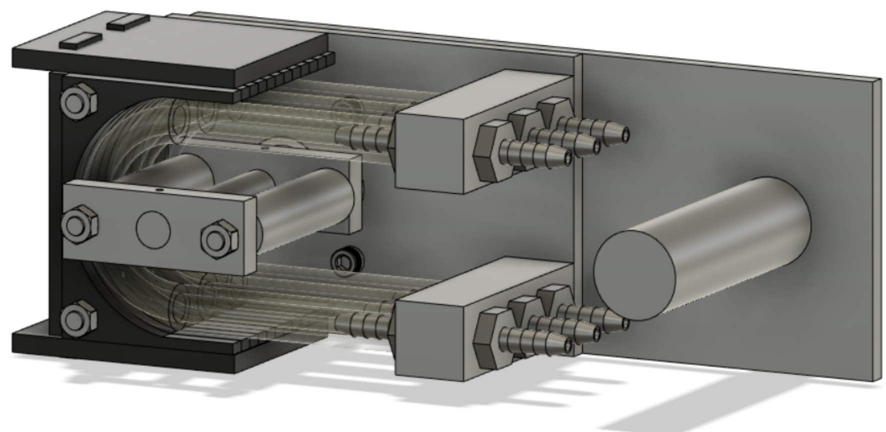
Reflection:

Our overall goal of making a functional pump did not come to fruition, but our team gained much valuable knowledge from this project. We primarily learned about the significance of budgeting accordingly, considering the manufacturability of a part when designing it, and the importance of proper tolerancing and fitting. Early on in our process, we planned to use the majority of our budget on the first iteration of the pump. While this does make sense for a waterfall design process, it left us with less of the budget for fixes that we needed to make during the testing phase. We then learned that designing for manufacturability was a key factor for success. We had a clear plan going into each manufacturing shift, and we were still pressed for time. If we hadn't had detailed discussions of how each part would be made, our parts would have been rough around the edges or incomplete. The last lesson we learned was the importance of having the correct tolerancing, especially when working with parts that need to be press fitted. Our ball-bearing borehole was less than 1/32'' too large because the shop lacked the correct tool. But that difference caused a massive difference when our ball bearing slid out during high motor speeds. Some less technical lessons we learned were about the importance of communication and having scheduled meetings to keep everyone on task and updated on new ideas. We also learned that scheduling isn't perfect because everyone's life is different, and we all have different commitments to fulfill on random schedules.

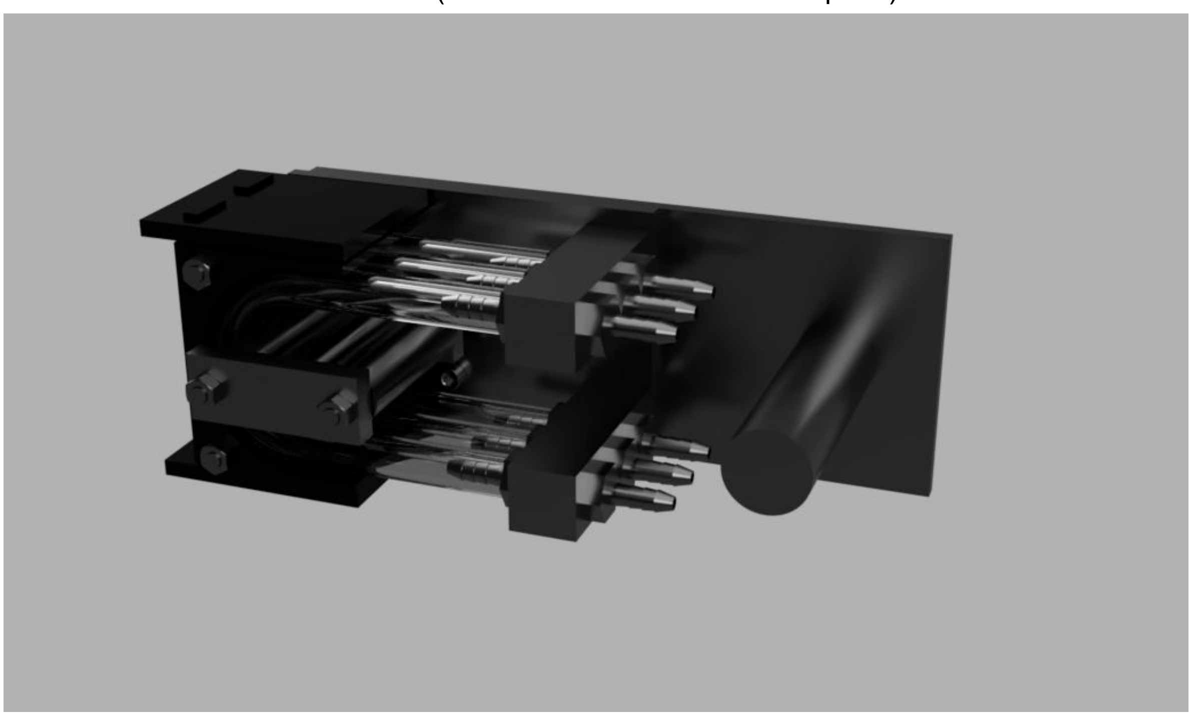
If we were to do this project again, we would likely seek a more straightforward pump casing that did not include acrylic, as the load on our pump was visibly higher than we had expected. We would have also shrunk our design to all for easier pipe compression. Another issue we ran into was that the hex nuts holding our rollers to the spinners would unwind when the motor was active, so we would devise a new way to connect the rollers to the spinners.

Images and Renders

CAD Model:



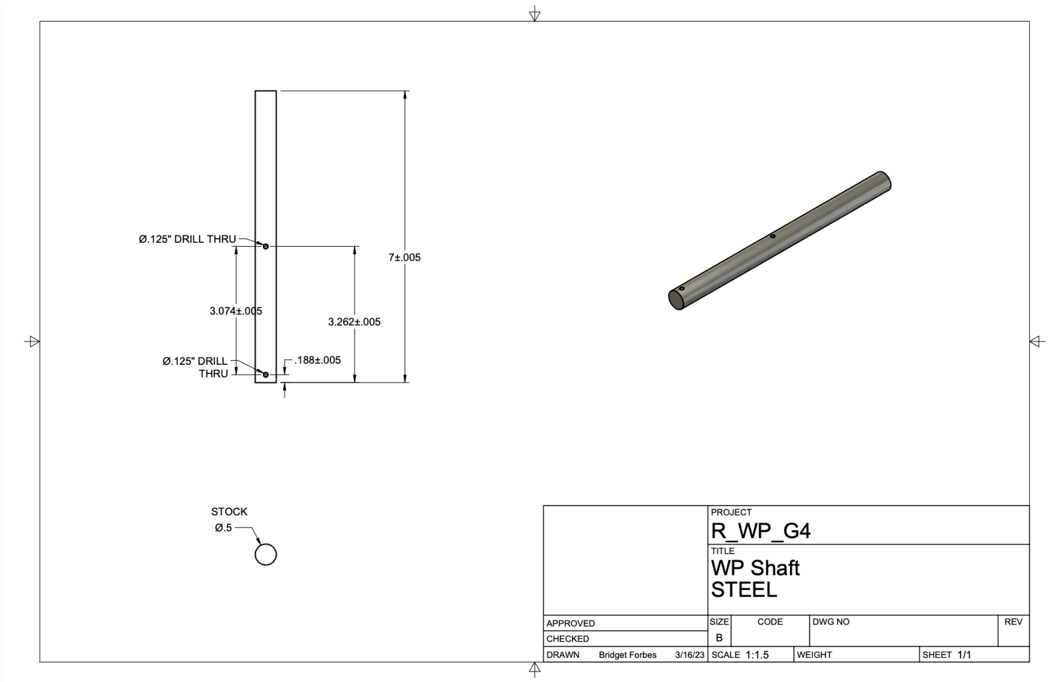
Final CAD (mounted to base attachment plate)



CAD Render

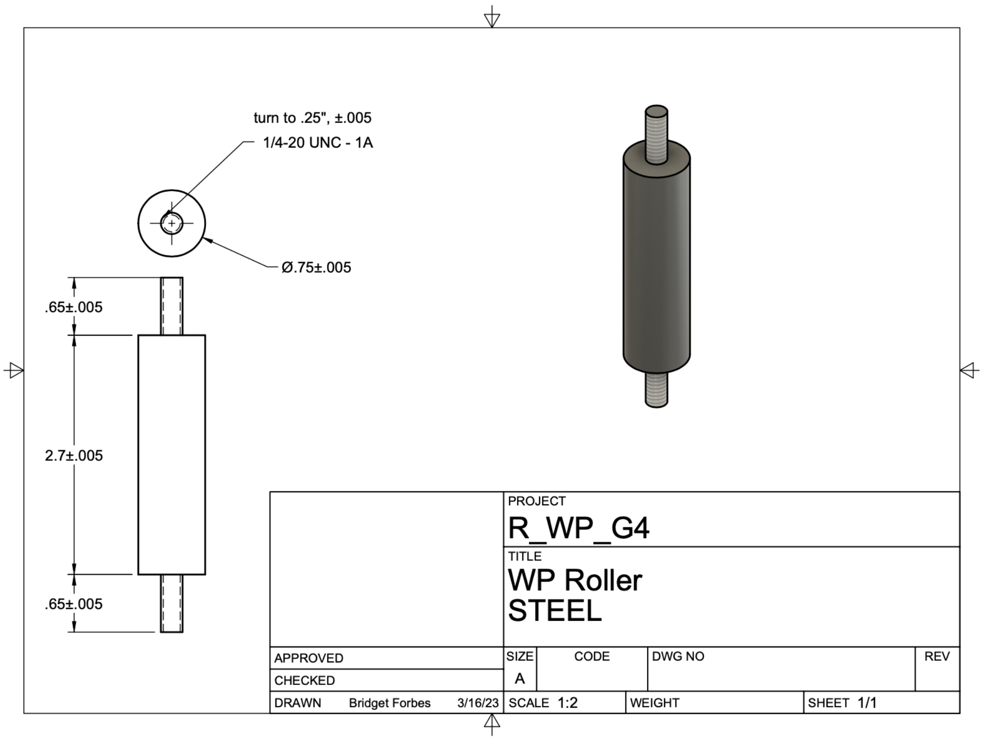
Part Drawings

Drive Shaft



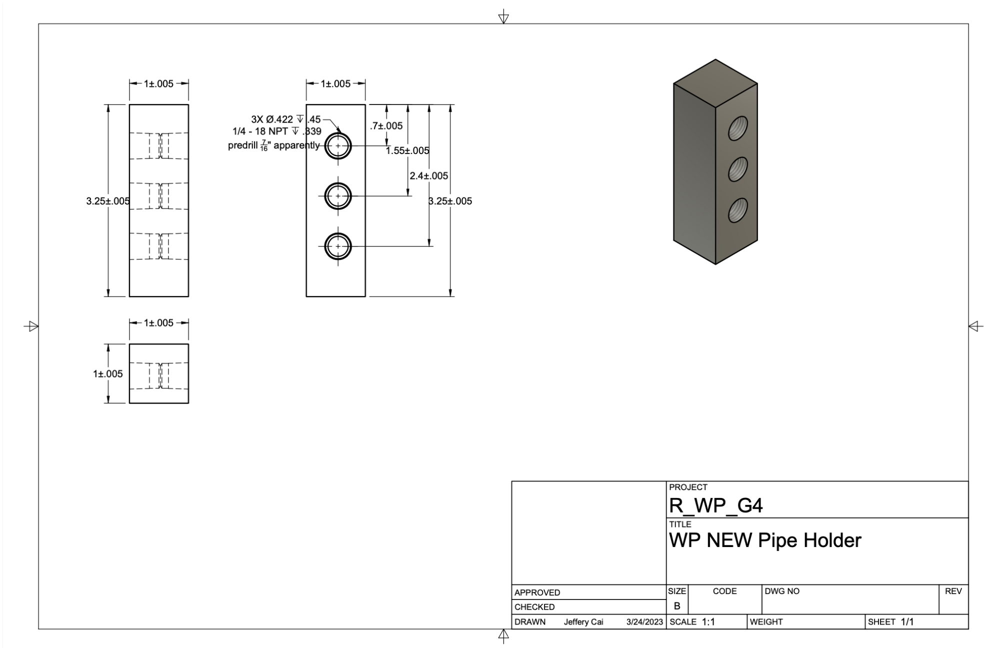
This part was made on the manual mill. It required the use of collet blocks to hold the shaft in place so the holes could be drilled precisely through. The .125” holes were intended to be thru holes for the ends of the set screws that were going to pass in there. To align with the spinners of the pump, the tolerances were kept quite high (+/- .005 in).

Roller



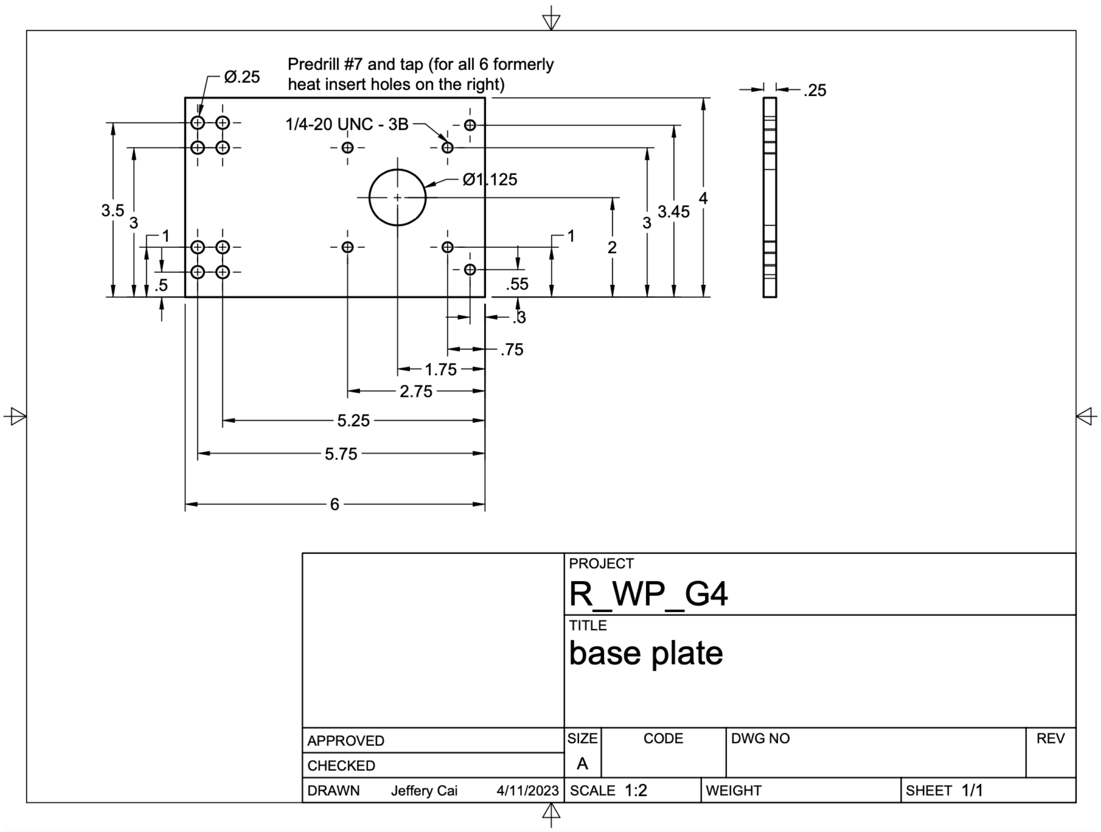
This part was made on the manual lathe. It was a bit challenging to get the fit of the rollers correct, mainly because it required one to zero off of two different sides, which generally isn't advisable when manual machining. To create a proper fit for the ¼-20 tap tool, we turned the diameter of the part down to .25", per the specifications. Again, for alignment reasons, our tolerances were quite tight.

Pipe Holder



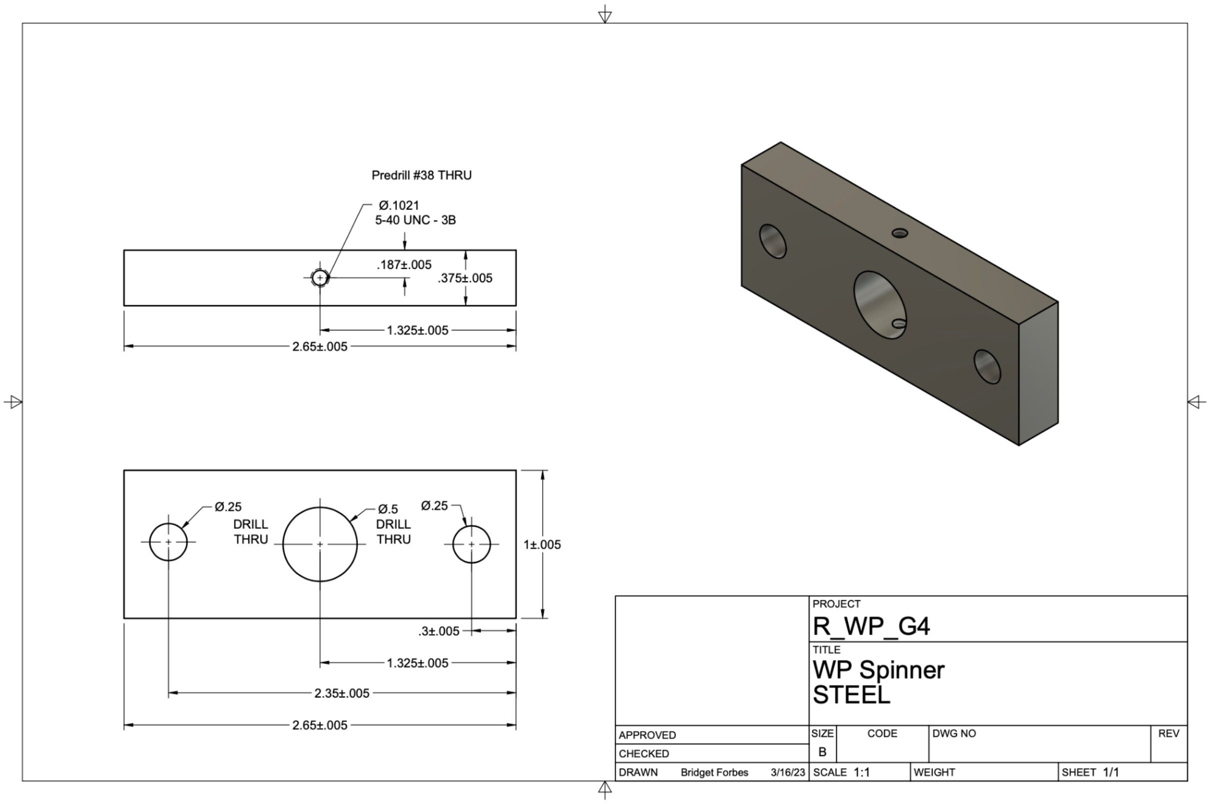
This part was made after realizing we couldn't CNC our housing. This was a necessary connection between the pipe fittings and the tubes. It was made on the manual mill. Based on the chart in the machine shop, we pre-drilled the holes with a 7/16" drill so the tap would fit properly. The tolerances on this part were kept tight but were not as important as other ones, as the alignment of the tubes was not particularly precise.

Base Plate



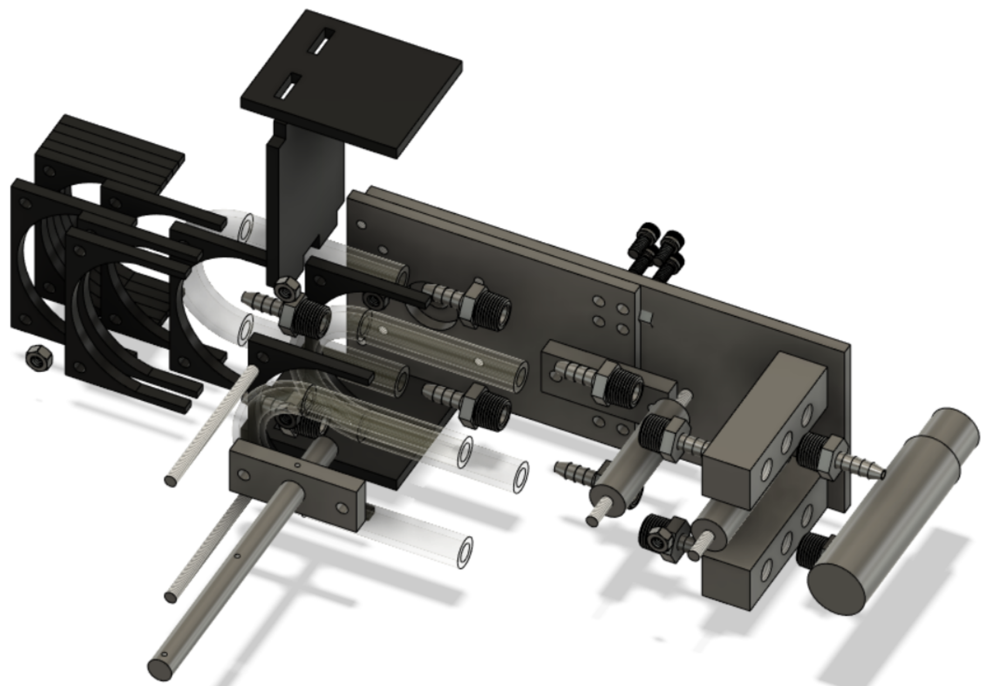
This part was made on the manual mill after realizing our housing couldn't be made on the CNC. Originally, we had planned to make this housing out of acrylic and fit heat inserts but realized aluminum was more cost-efficient. Thus, we pre-drilled holes accordingly based on the tapping chart in the machine shop for the correct drill sizes and faced it down to size. The spacing of the holes was important to align with the test setup, so we kept the tolerances tight at +/- .005.

“Fidget” Spinner

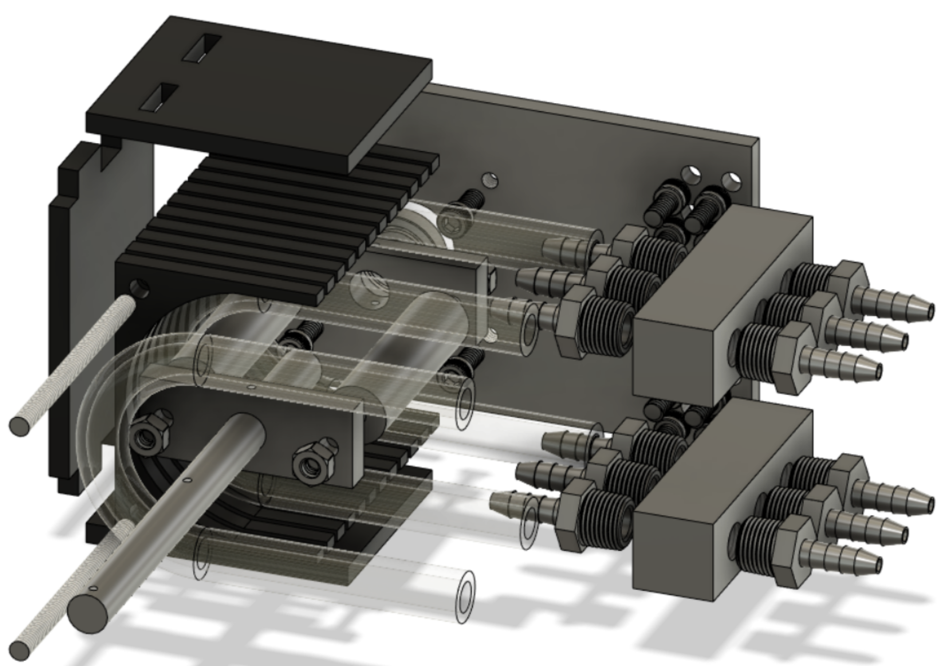


This part was made on the manual mill. It included two operations at different orientations; first, the holes for the set screws to go through for the shaft (pre-drilled with the appropriate drill bit based on the tapping chart in the shop), and then drilled to make thru holes for the ends of the rollers. To align the rollers properly and fit the set screws correctly, tolerances were kept tight at +/- .005.

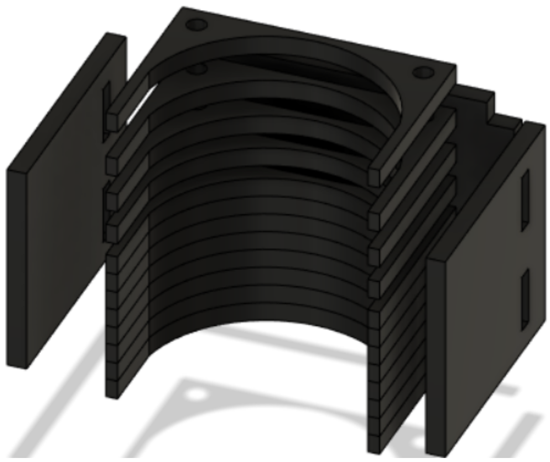
Exploded Views



Exploded View 1



Exploded View 2



Laser Cut Section Assembly Exploded View

Fabrication timeline

Part	**Due Date**
Shaft	March 20
Spinner (2)	March 23
Roller (2)	March 27
Pipe fitting holder (2)	March 28
Base Plate	April 11

Full Gantt Chart Appendix E

Fabrication Plan

Part	Responsible Individual(s)	Manufacturing Type
Spinners (2x)	Jeffery Cai, Hunter Chubik, Bridget Forbes	**Manual Mill**: a flat piece of aluminum stock was faced down to size and then had holes drilled into it in two operations
Rollers (2x)	Ata Zavaro, Natalie Sun, Karolina Swedek	**Manual Lathe**: a round piece of aluminum stock was turned down to the right diameter on both ends and then threaded on both sides
Base Plate	Jeffery Cai, Ata Zavaro	**Manual Mill**: a flat piece of aluminum stock was faced down to size and then had holes drilled into it in one operation
Torque Transfer Shaft	Hunter Chubik, Jeffery Cai	**Manual Mill**: round piece of steel stock was put into collet blocks and had holes drilled into it on the mill
Pipe Fitting Inserts (2x)	Karolina Swedek, Bridget Forbes	**Manual Mill**: a square piece of aluminum stock was faced down to size and had holes drilled into it in two operations, then tapped
Acrylic Housing and Side Panels	Natalie Sun, Hunter Chubik	**RPL:** Acrylic panels and stackable curved pieces for the housing of the pump were laser cut at the RPL from an aluminum sheet and then super glued together

Final Cost Analysis and Parts List:

Bill of Materials:

Name	Units		Per Unit Cost		Total Cost
3/4" Diameter x 6" Aluminum Rod	2	pcs	2.5	$/pcs	5.00
1/2" x 2 1/4" Bar	2.4	in	0.73	$/in	1.75
1/2" Diameter Steel Rod	7	in	0.23	$/in	1.61
1" x 2" (6061 T6)	3.5	in	1.18	$/in	4.13
3/8" ID X 5/8" OD surgical tubing	3	feet	2	$/ft	6
Nylon pipe fittings (3/8" barbed x 1/4"NPT)	12	pcs	0.55	$/pcs	6.6
1/4 - 20 x 3/4" cap screw SHCS	4	pcs	0.15	$/pcs	0.6
1/4 - 20 allen socket head cap screw (1/2”)	8	pcs	0.15	$/pcs	1.2
1/4 - 20 threaded rod	1	feet	1.02	$/ft	1.02
Acrylic sheet	2	each	3	$/sheet	6
1/4 - 20 hex nuts	8	pcs	0.06	$/pcs	0.48
1/2" x 4" (base)	6	in	1.18	$/in	7.08
Total Material(Emerson) Cost					41.47
94105A328 set screws	1	1	6.58	$/pcs	6.58
60355K505 Ball Bearing	1	pcs	6.75	$/pcs	6.75
Total McMaster Cost					13.33
Total Cost					54.80
Total Manufacturing Cost					49.20

Cost analysis:

Total Prototype Cost	5,934.80
Product Cost, Single Production Pump	5,984.00
Product Cost per pump	55.13

Prototype cost is the cost arising from design hours, manufacturing hours, and material costs. Product cost, single production pump is equal to prototype cost summed with manufacturing cost. The product cost per pump is for producing 1000 units.

A majority of our prototype costs came from non-recurring engineering design hours, which were valued at $120/hr. This is expected as, conceptually, we were a team of six engineers that spent multiple hours flushing out our design. Furthermore, manufacturing hours were also expensive. This simply demonstrates why the design phase is rather expensive. It is a one-time expense, especially rigorous in hours spent, that doesn't yield returns for a rather long period of time. Hence, we can see that the design costs became rather trivial only when scaled to 1000 units produced. The majority of our per pump cost is the manufacturing cost, $49.20 (refer to Appendix D for a breakdown), with the remainder adding around $6 only.

Hence, with a 40% profit margin, our retail cost is $92, tax excluded. Unfortunately, making an industry comparison is rather difficult as most pumps focus on high precision and pump rates of around 500ml/min; the requirements from our pump were different from these parameters. Nonetheless, prices often range from $9-$120, depending on quality and pumping capability. Higher-end pumps go well into four figures.

Full Parts List:

Part:	Corresponding Material
Roller Cylinder	3/4" Diameter x 6" Aluminum Rod
Roller wall	1/2" x 2 1/4" (2.40 in)
Shaft	1/4" Diameter Steel Rod, 0.10$/in, 7 inches
Tube fitting wall	1" x 2" (6061 T6), 3.5inches
Tubing	3/8" ID X 5/8" OD surgical tubing
Pipe fittings	Nylon pipe fittings (3/8" barbed x 1/4"NPT)
Cap screws	1/4 - 20 x 3/4" cap screw SHCS, 1/4 - 20 allen socket head cap screw (1/2”)
Acrylic holder	1/4 - 20 threaded rod
Circular wall for pressuring tubes	Cut from Acrylic, 2 pieces
Hex nuts	1/4 - 20 hex nuts
Base plate	1/2" x 4" (base)
Set screws	94105A328 set screws(McMaster-Carr)
Ball bearing	60355K505 Ball Bearing(McMaster-Carr)

Graphs, Charts, and Tables

Power Calculation for Pump Design:

Governing equations:

h = minimum height to reach
d = water line diameter
$\dot{\theta}$ = RPM of motor in rad/sec
ρ = density of water in kg/m^3
g = gravity in m/s^2, 9.81
$\dot{Q}$ = required flow rate (min 1000 m^3/sec)
μ = dynamic viscosity of water, 1.003x 10^-3 Ns/m^3
r = tube radius
R = housing radius

ΔV: amount of water displaced by rollers compressing tubing
$\Delta V = tubes * (\pi * r^2) * (2 * \pi * R)$

$\dot{Q}$: flow rate per rotation of shaft
$\dot{Q} = \Delta V * \dot{\theta} / (2 * \pi)$

v: velocity of fluid in tubing
$v = \dot{Q} / A$

Re: Reynolds number
$$Re = \frac{\rho * \omega * v * d}{\mu}$$

f: friction factor
$$f = \frac{64}{Re}$$

h_f: head loss
$$h_f = \frac{v^2 * f * L}{2 * g * d}$$

h_p from steady flow equations
$h_p = z_2 - z_1 + h_f$ (z is the height needed to pump)

$$P_{ideal} = \rho * g * \dot{Q} * h_p$$

These equations were plugged into a Google Sheets with our parameters:

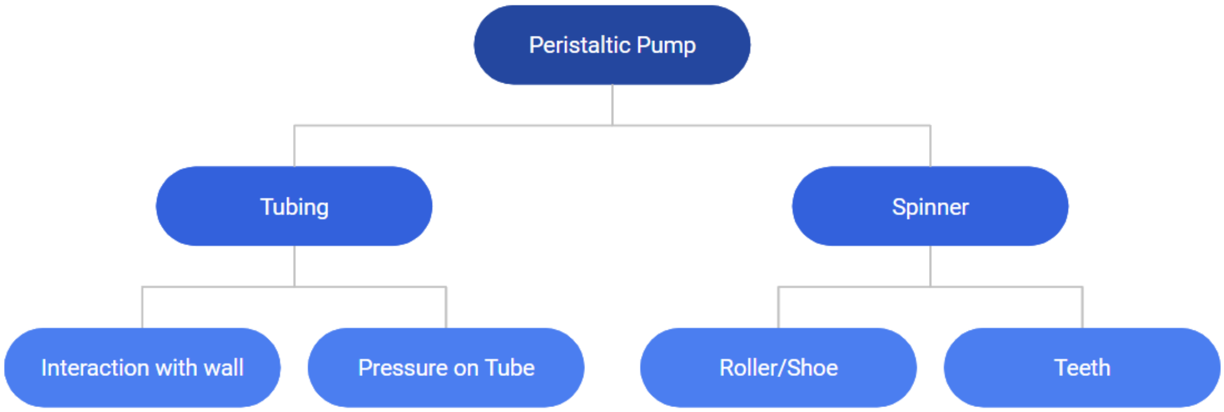
Google Sheets Calculations

GRAVITY (m/s^2)	9.81	us units (inches)	
DENSITY OF WATER (kg/m^3)	997	r	0.375
PUMP HEIGHT	1.5	R	1.25
VISCOSITY OF WATER @20 C	0.001003	d	0.375
WATER LINE DIAMETER	0.00952501905		
REQ FLOW RATE (L/min)	1		
MOTOR RPM BASED ON EARLIER CALCS	115.7		
# TUBES	3		
RADIUS OF TUBING (r)	0.004762509525		
RADIUS OF HOUSING PLATE (R)	0.0317500635		
LENGTH OF TUBING (2*PI*R)	0.1994915325		
omega (rev/sec)	1.928333333		
Change in Volume per Rotation: #tubes*pi*r^2*2*pi*R	0.000042644920		
Q dot (flow rate): Change in Volume per Rotation*omega/2pi	0.000082233621	liters/min:	4.934017295
Power Required by Pump: densitywater*g*h*Qdot	1.206437538		
velocity of fluid in tubing (Q dot /A)	1.154058515		
Reynolds number (density*v*water line diameter)/water viscosity	3642.224013		
friction factor f (64/Reynolds)	0.01757168141		
head loss hf = v^2*f*L/(2*g*diameter)	0.02498207978		
head increase across pump hp = h+hf	1.52498208		
Pideal = density*g*Qdot*hp	1.226530418		

Google Sheets Solution

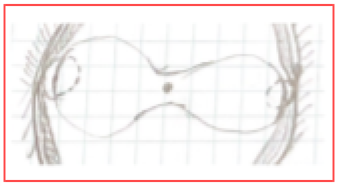
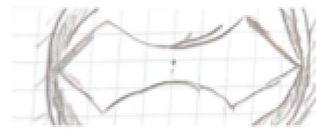
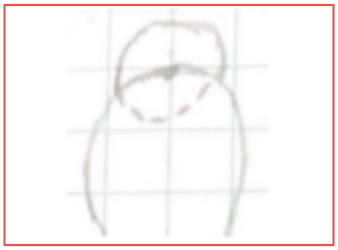
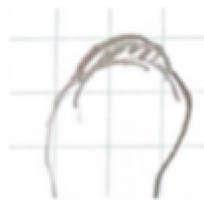
Had our pump functioned correctly; our analysis displayed that our pump should have been able to pump well over the required pump rate for the given height parameters. We weren't entirely sure what the true efficiency of our pump would be. Still, even accounting for a relatively small efficiency, it would have been able to pump a considerable amount, based on our 4.93 liters/min estimation.

Functional Decomposition:



We recognized that our pump has two crucial mechanisms that are needed to run smoothly: the tubing and the spinner. The tubing is the defining feature of the peristaltic pump, so the important things are that it can interact with the casing of our pump without applying too much force on the casing - indicated by our “interaction with wall” branch. This section also involved seeing whether or not there would be too much friction created between the tube and the casing, which was crucial to analyze because it would increase the torque the motor needs to output to keep the pump going. The other side of the tubing sub-tree, pressure on the tube, covers the other requirement for our pump: the volumetric flow rate. We need enough pressure on the tubing to compress the walls of the tubing all the way so that the water inside is properly pushed along the side and up to its destination. On the other hand, the other major component to design for was the spinner. The spinner needed to be not too thin so that it wouldn’t squeeze the tube but not so thick that it would be too difficult to move along the tubing. The teeth were crucial to analyze because they led us to consider how to fasten the spinner together. By breaking it up into the roller and the teeth/connections, we were able to narrow down what parts needed attention during manufacturing. Overall, the functional decomposition process broke down what was a daunting, complex mechanism into several subsystems that can be optimized.

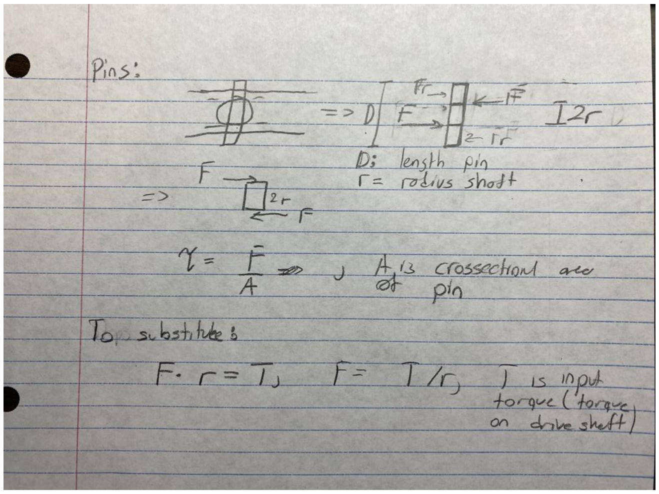
Morphological Chart:

	Option 1	Option 2	Option 3
Spinner Types			
Roller Vs Shoe			
Tube Types	Silicone Rubber Tubing	PVC Tubing	Natural Rubber Hose

After doing our functional decomposition, we recognized that there were three major decisions we needed to make for our design, all of which would have different tradeoffs in performance and manufacturability. First is the spinner type. Many existing peristaltic designs used a three-toothed spinner, which lessens the gap before each subsequent roller makes contact. This would have definitely created a more consistent and faster flow, but we ultimately decided against it simply because it was far too difficult to create. The triangular shape was nigh impossible to make on the manual mill because of how difficult it is to line up the needed cuts parallel to a vice. Between the two-roller choices, it was natural that we picked the round roller design as opposed to the sharper shoes. While the sharper one could perhaps engage the tube and squeeze it more, it could easily puncture or rip the tubing with its higher friction. Thus, we settled on the round rollers, which can apply a radial squeezing force while circumventing frictional resistance by being able to roll. In addition to all of the reasons for friction, we also took into consideration how we would have to create some parts on the lathe due to limited time slots on the mill. With the decision about the spinner type made, our second choice was then obvious: to use a roller rather than a shoe. When choosing tubing, we analyzed the cost of each option and whether its flexibility was suitable for our peristaltic pump. The natural rubber hose we looked at was immediately too rigid. The PVC and silicone rubber tubing were both valid options, but the PVC pipe cost more and was readily available in the Emerson shop (at least to our knowledge).

Static Stress Analysis:

There were two different ways of conducting the static stress analysis. The first was of the rollers themselves to ensure that the force needed to compress the tubes wouldn't break the rollers. This was hand calculated:



$T\ =\ 4.5\ lb\ ft\ =\ 54\ lb\ in$

$r\ =\ 0.25\ in$

$A\ =\ \pi\ *\ 0.25^2$

Where pin radius = 0.25 in

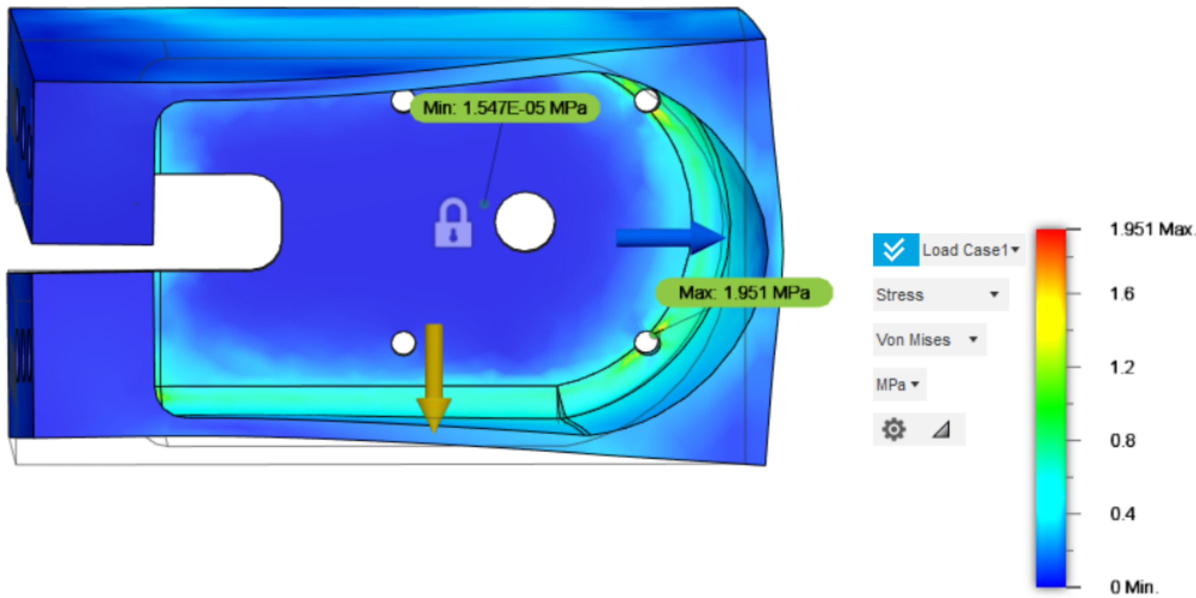
Shear Stress = $1100.08\ lb/in^2$

Material is Steel: 58.6 ksi Tensile Failure stress [1]

sheer is approx ¾ of tensile: [2]

$58.6\ *\ \frac{3}{4}\ =\ 43.95$ ksi

Because the shear stress of the roller was well above the result of our calculations, it was assured that the roller wouldn't break under the compression that it would be subjected to. Our second static stress analysis was of the casing itself to ensure that the casing wouldn't flex. Unfortunately, this was done under the assumption that the casing would be aluminum, which it wasn't in the final product. As shown, we didn't have to worry about flexing in the casing but would have to with the screws that attach the casing to the mounting plate.



However, we switched our casing to acrylic, along with a different design, which severely impacted our casing, allowing it to flex more.

References

Ansari, I. A., Gupta, G. A., Ramkumar, J., & Kar, K. K. (2022). Fly ash-mixed polymeric media for abrasive flow machining process. *Handbook of Fly Ash*, 681–713. https://doi.org/10.1016/b978-0-12-817686-3.00003-7

JoVE Science Education Database. Structural Engineering. Stress-Strain Characteristics of Steels. JoVE, Cambridge, MA, (2023).

Appendix A: Team Charter

From = **Thursday Group** (4) and all team members

To = MAE 2250 Instructors and TAs

Re = Team Charter

Date: 3/9/2023

Team IDs and Names:

Name	**NetID**	**Contact Email**
Karolina Swedek	kas496	kas496@cornell.edu
Bridget Forbes	bcf48	bcf48@cornell.edu
Jeffery Cai	jc2565	jc2565@cornell.edu
Ata Zavaro	az335	az335@cornell.edu
Hunter Chubik	htc28	htc28@cornell.edu
Natalie Sun	ncs79	ncs79@cornell.edu

Team Logistics and Coordination

1. Our team's preferred method of communication will be Slack for any group discussion and queries. We have made a private Slack channel for our group members to communicate in. We will also use Slack to send documents to each other. Our group has agreed to update ourselves on the Slack every 24 hours at the minimum.
2. Outside sources used in our project will be stored in the Google Drive folder or pinned in our private Slack channel.
3. The group will meet every Sunday at 4 pm at Olin Library.

Teamwork and Collaboration:

1. Specialized Skills:
    a. Karolina Swedek: Familiar with manual mill and lathe operation through project teamwork. Familiar with CAD, CAM, and FEA.

b. Bridget Forbes: Autodesk Fusion 360, comfortable with the mill and lathe, comfortable creating part drawings in Fusion 360
c. Jeffrey Cai: Making figures using graph software, MATLAB, etc. Skilled at assembling joints and sketches in Autodesk Fusion 360.
d. Ata Zavaro: Rudimentary experience with Fluid Dynamics; CAD; ANSYS; MATLAB
e. Hunter Chubik: Familiar with Engineering Sketches, Technical Drawings in AutoDesk Fusion 360, and Familiar with CAD software
f. Natalie Sun: Familiar with SOLIDWORKS and Autodesk Fusion 360; Research

2. We will create a team lead system where our members rotate as leads for different phases of the project. Team roles are outlined below:
    - Design Integrator: Ata Zavaro
        - Responsible for making certain parts fit well together and ordering the pre-manufactured parts. Ensures that the design of the pump abides to mathematical calculations and follows project specifications and constraints.
    - Leader / Schedule Coordinator: Natalie Sun
        - Oversees the timeline of the group and ensures the timeliness of all the internal deadlines of parts. Also ensures that all the rubric points have been met.
    - Design Leaders: Bridget Forbes, Hunter Chubik
        - Oversees the production of the CAD; makes sure the assembly is constrained and made properly. Makes sure that parts are manufacturable or within purchasing budget. Oversees the creation of sketches and technical drawings. Creates renders and animations for our design to visualize our creations better.
    - Manufacturing Leader: Karolina Swedek
        - Oversees manufacturing process for pumps; makes sure everyone in the group is comfortable with making their assigned component and that everything is made to spec and toleranced correctly. Updates the group on stock and ordering needs.
    - Testing Leader: Jeffery Cai
        - Oversees the testing process for the final pump design; makes sure everyone knows what the final product needs to accomplish; creates a list of next steps based on testing.

3. Internal deadlines:

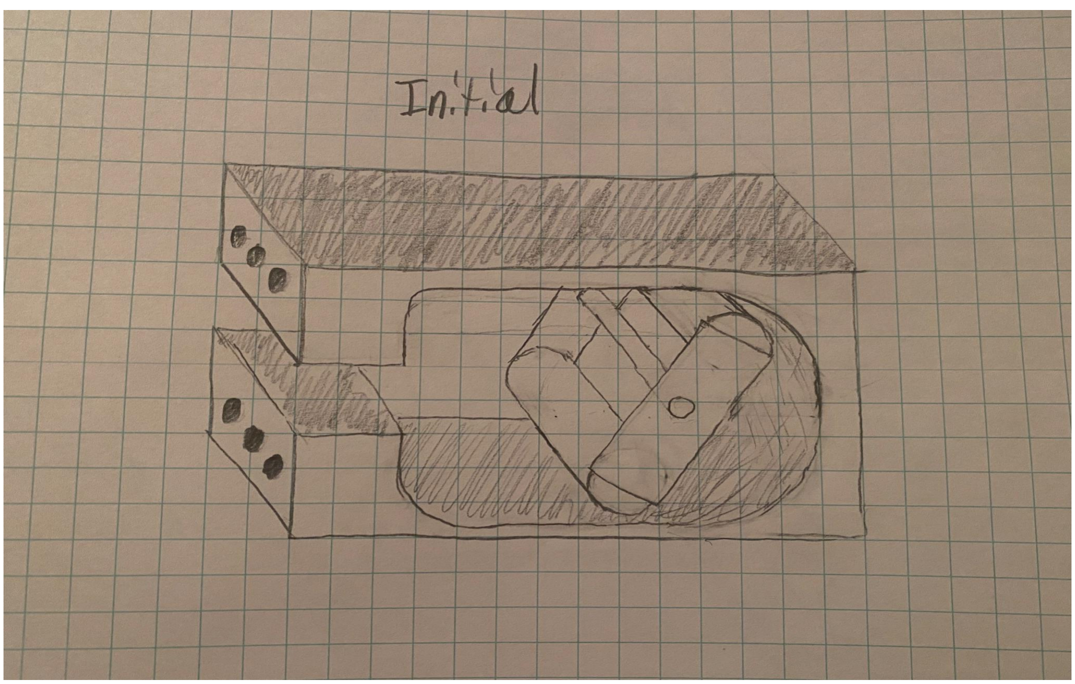
If a team member does not meet an internal deadline for a specified task, they will be responsible for providing the rest of the team members some kind of candy of their choice at the next team meeting.

4. Schedule:

	S	M	T	W	R	F	S			
March					9	10	11			
	12	13	14	15	16	17	18		External Deadlines	Internal Deadlines
	19	20	21	22	23	24	25	External Deadline	March 16th: A9 - WP: Final Design + Paper Prototype	March 20: Order McMaster/Emerson Parts and CNC
April	26	27	28	29	30	31	1	Internal Deadline	April 13th: A11 - Finished Pump	March 31: Finish Machining Parts
	2	3	4	5	6	7	8	Outside Meeting	May 4th: Water Pump Testing	April 11: Assemble Water Pump
	9	10	11	12	13	14	15	Lab Meetings	May 5th: A12 - Water Pump Reflection	
	16	17	18	19	20	21	22	Break	May 16th: Water Pump PDF Report	Cycles
	23	24	25	26	27	28	29	Last Day of Classes	Mon and Wed noon: McMaster Order Submissions	March 20-31: Machining
May	30	1	2	3	4	5	6			March 31 - April 11: Assembly of Water Pump
	7	8	9	10	11	12	13			April 11-13: Finalize Water Pump
	14	15	16	17	18	19	20			

5. We have all discussed and understood our individual goals for this project. We are all on the same page for the grade we want to receive in this class and the amount of work and responsibilities we want to take on. We all understand that life at Cornell is variable and people’s schedules change, we will all do our best to accommodate each other's lives.

Appendix B: Initial Design & Sketches

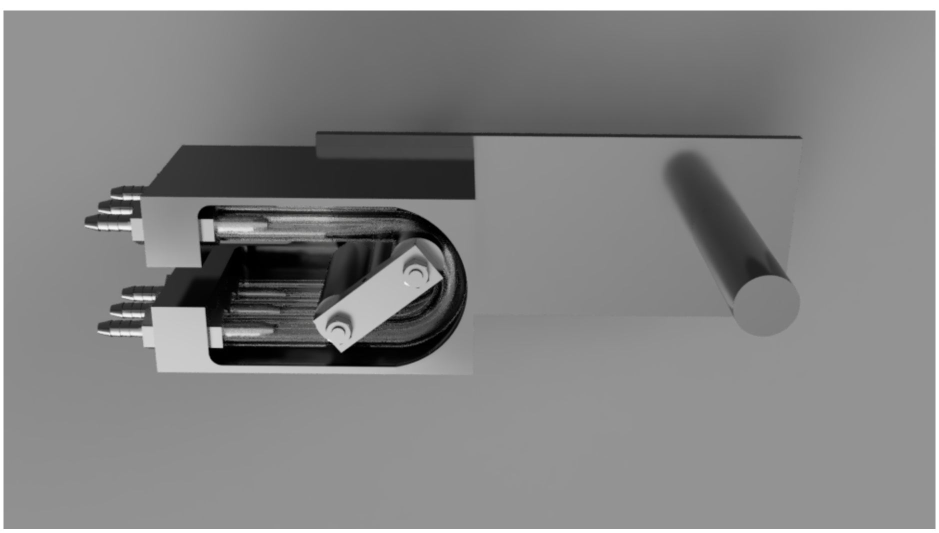


Appendix C: Preliminary Design Review

Design Choices:

- Originally, we wanted to make a three-lobed peristaltic pump because it would constantly enclose some space and create a continuous drawing force
- Considering the difficulty of machining the central roller holder with three lobes, we switched to a design with only two lobes. This way, we can create two linear roller holders, which are exponentially easier to machine.
- The number of pipes was changed from one to three to triple the efficiency of the pump at the expense of needing more power

CAD Model:



Parts List:

Manufactured:

- Two rollers ⇒ ¾ " Diameter x 6" Aluminum Rod, 2 of these
- Spinner ⇒ ½ " x 2 1/4" (2.40 in),(divide into two to make 2.25in go to two 1.1in pcs)
- Base ⇒ CNC
- Shaft ⇒ ¼ " Diameter Steel Rod, 7 inches
- The pins → ¼ " Diameter Steel Rod, two 1.25” pieces (diameter reduced to ⅛”)

Hardware to buy: (30$ limit)

- Tubing ⇒ ⅜ " ID X 5/8" OD surgical tubing , 14in
- Nylon pipe fittings (⅜ " barbed x 1/4"NPT), 12 pieces
- Bolts: ¼ - 20 x 1" cap screw SHCS, 4 pieces
- ¼ - 20 hex nuts, 6 pieces

Fabrication Plan:

- McMaster-Carr parts: order at the beginning of the manufacturing process
- Get metal stock from Emerson: start machining within the week
    - We will go in pairs to manufacture the needed parts
- Once parts arrive: assemble the water pump and test specs

Parts needing machining:

- Pump Housing → CNC order

  - Date Finished: tbd, order to be put in ASAP
- Pump spinner (1 steel bar cut into two) → manual mill
  - Date to be worked on: Karolina Swedek + Ata Zavaro, 3/18 shift
- Spinner rollers (2x steel cylinders) → manual lathe
  - Date to be worked on: Bridget Forbes + Hunter Chubik, 3/18 shift or 3/20 shift
- Pins for input shaft (4x steel bars)→ manual lathe
  - Date to be worked on: Jeffery Cai + Ata Zavaro, 3/20 or 3/21 shift
- Input Shaft hole op (steel bar) → manual mill
  - Date to be worked on: Natalie Sun + Bridget Forbes, 3/21 or 3/22 shift

Initial Calculations:

Governing Equations:

Volume Displacement: $\Delta V = \#\, tubes * (\pi r^2) * (2\pi R)$

Flow Rate per Rotation of Shaft: $Q' = \Delta V * \frac{\omega}{2\pi}$

Velocity of fluid in tubing: $v = \frac{Q'}{\frac{\pi}{4} * d^2}$

Reynold's Number: $Re = \frac{\rho * v * d}{\mu}$

Friction factor: $f = \frac{64}{Re}$

Head loss: $hf = \frac{v^2 * f * L}{2 * g * d}$

Head increase: $hp = \Delta h + hf$

Ideal Power: $Power_{ideal} = \rho * g * Q' * hp$

Final estimated fluid flow rate: 5.9 liters/min

Power, ideal: 1.5 Watts

Power, realistic (~20% efficiency): 7.5 Watts

Appendix D: Bill of Materials

Name	Units		Per Unit Cost		Total Cost
3/4" Diameter x 6" Aluminum Rod	2	pcs	2.5	$/pcs	5.00
1/2" x 2 1/4" Bar	2.4	in	0.73	$/in	1.75
1/2" Diameter Steel Rod	7	in	0.23	$/in	1.61
1" x 2" (6061 T6)	3.5	in	1.18	$/in	4.13
3/8" ID X 5/8" OD surgical tubing	3	feet	2	$/ft	6
Nylon pipe fittings (3/8" barbed x 1/4"NPT)	12	pcs	0.55	$/pcs	6.6
1/4 - 20 x 3/4" cap screw SHCS	4	pcs	0.15	$/pcs	0.6
1/4 - 20 allen socket head cap screw (1/2”)	8	pcs	0.15	$/pcs	1.2
1/4 - 20 threaded rod	1	feet	1.02	$/ft	1.02
Acrylic sheet	2	each	3	$/sheet	6
1/4 - 20 hex nuts	8	pcs	0.06	$/pcs	0.48
1/2" x 4" (base)	6	in	1.18	$/in	7.08
Total Material(Emerson) Cost					41.47
94105A328 set screws	1	1	6.58	$/pcs	6.58
60355K505 Ball Bearing	1	pcs	6.75	$/pcs	6.75
Total McMaster Cost					13.33
Total Cost					54.80
Total Manufacturing Cost					49.20
NRE design hrs	30	hr	120	$/hr	3,600.00
Prototype Manufacturing hrs	57	hr	40	$/hr	2,280.00
#holes	19		1.2	$/pc	22.80
#threadings	10		1.2	$/pc	12.00

#reamings	0		1.2	$/pc	0.00
#milled flat surfaces	2		1.2	$/pc	2.40
#turned straight surfaces	0		1.2	$/pc	0.00
#curved turned or milled surfaces	0		12	$/pc	0.00
# inches of weld	0		12	$/pc	0.00
# cuts	1		12	$/pc	12.00
# hand finished edges	0		12	$/pc	0.00
# bends	0		12	$/pc	0.00

Total Prototype Cost	5,934.80
Product Cost, Single Production Pump	5,984.00
Product Cost per pump	55.13

Appendix E: Gantt Chart

	S	M	T	W	R	F	S			
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