MAE 2250:
Water Pump Final Report

By

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Description of Design Process

Design Selection

The objective of this water pump project is to pump the water at least 1.5m above the axis of the drive shaft at a rate of at least 1 L per minute. In order to design a water pump that would achieve the goal, our group divided into 3 different subgroups to research about 4 different types of pumps – which are piston pump, gear pump, centrifugal pump, and peristaltic pump. We then compared the 4 pumps by collecting information and presenting a functional decomposition, morphological chart, parts analysis, calculations, and potential design sketches to the entire group. Considering customer requirements, the budget given for the production, and the simplicity of the pump designs, our group came to a general consensus that we should make a piston pump – particularly a lift piston pump. Lift piston pump only requires a total of 3 piston strokes to pump a fluid, and it has strong advantages in efficiency and consistency in flow rate compared to any other pumps that we considered. The downsides of the pump include expensive operation cost and the frequency of maintenance, but it was not a concern for this project.

Pump Description

For our water pump design, we decided to utilize a lift piston pump design. The rationale behind this choice of pump took into consideration the following factors: design simplicity, manufacturing simplicity, and inexpensiveness.

Firstly, there was the ease of design. The design consists of a piston head, end caps, piston chamber, crank arm, crank, and a mounting plate. The parts were very simple to design, since all of the components were very simple and few machining operations had to be done in order to take the parts from the state in which they were ordered to the state in which we needed them for our design.

Secondly, there was the ease of manufacturing. Since our design used simple components, the manufacturing and assembly of the pump was very straightforward, with minimal time being spent in the machine shop to minimize the time required for manufacturing. There was also minimal room for error when manufacturing the parts. Parts could be milled or lathed once with ease.

Finally, there was the cost. The simplicity of our design allowed us to manufacture our pump for much less than the 50 dollar budget, leaving us with plenty of money to spend on modifications or fabrication if necessary after initial testing. The parts ordered from McMaster-Carr were inexpensive, which also aided in leeway when it came to manufacturing errors. Also, the minimal time spent machining the pump allowed us to not have to seriously take labor costs into account in regards to real-world labor regulations.

Mode of Action

Our design involved very few parts that contributed to the mode of action. Firstly, there was the piston head, responsible for creating the vacuum for suction and pumping out the water. The piston head was propelled forwards and backwards by the crank arm. The crank arm converted the rotating motion of the crank into linear motion to propel the piston. Finally, the crank arm carried the rotation from the motor shaft to the crank arm.

Challenges

There were few challenges with the overall design processes. After our initial research, we already had a good idea as to what design we would pursue. The piston pump design presented very few challenges when it came to manufacturing.

The main concern with the manufacturing process was the piston head, specifically the tolerance between the piston chamber wall and the piston head. This was taken care of as precisely as possible with the lathe. However, while machining the slots on the piston head using the mill, we encountered some challenges keeping the head stable while machining. To counteract this lack of stability, we attached the piston head to a flat, rectangular piece before using the mill. However, the cuts still turned out slanted and there was some scoring on the piston head. We observed that these issues did not affect the performance of the pump in regards to its suctioning ability, hence there was no need to machine a second piston head.

Performance Analysis

Overall the design was successful in its mission, being able to pump 1.4 liters of water in one minute. While a few problems occurred during the test, we were able to solve them and prevail.

The first problem that arose during testing, was the compatibility of our mounting plate with the mounting plate provided by the staff at the test. While the holes in our plate and their plate aligned, there was a clearance issue with the hole for the shaft on the provided plate and our plate. This issue was resolved with the use of long screws and washers that were able to give us the clearance necessary.

The second issue that arose was the seal between the end of the piston chamber and the end caps. When the pressure began to build within the piston chamber, water began to spray out of the gap. We were worried that this would affect the performance of the pump drastically, however we were still able to pump over the required amount of water within the allotted time period.

Finally the last issue that arose was that we failed to provide a shaft to connect to the motor. We realized we had misread some of the early requirements of the water pump design and did not purchase a shaft. Therefore, we had to find a shaft before we were able to test. Thankfully, the Teaching Assistants were able to source us a shaft that allowed us to test our pump.

Given the simplicity of the design and the ease through which we were able to manufacture and assemble, we believe the whole process was a success. Our design philosophy of keeping things simple and cheap allowed us to succeed using a small fraction of the budget and the time allocated for the project.

Images and Renders

CAD Renders (1080p) (Piston Cylinder is Glass for Observation Purposes)

Figure 1: Piston Pump CAD Render front view

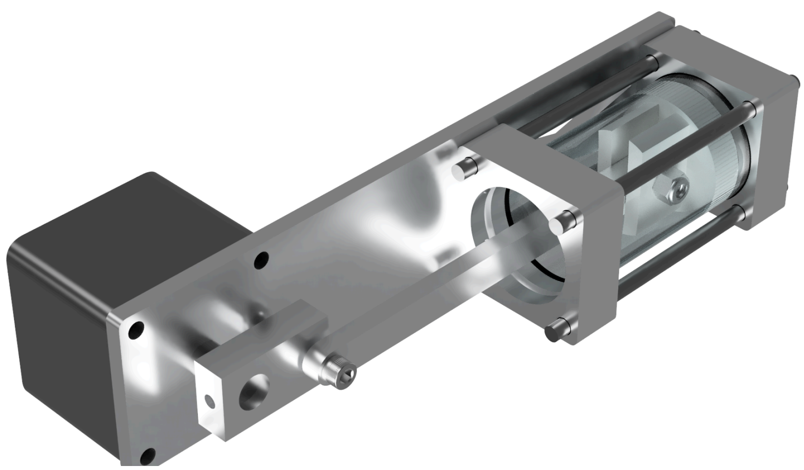


Figure 2: Piston Pump CAD Render upper-left view

Figure 3: Piston Pump CAD Render upper-right view

Exploded View

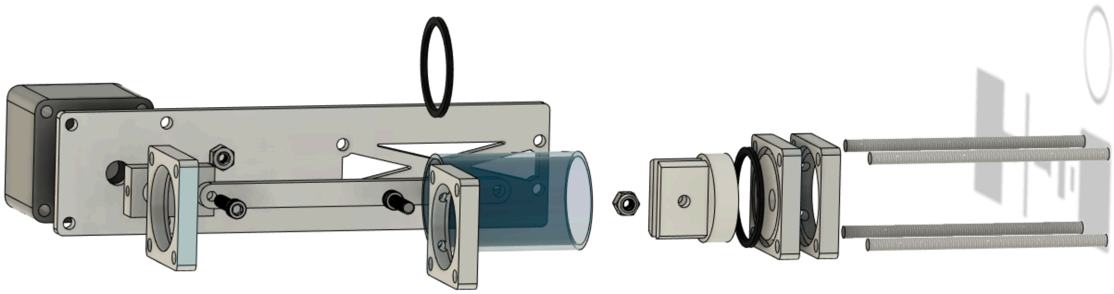


Figure 4: Piston Pump CAD Render exploded view 1

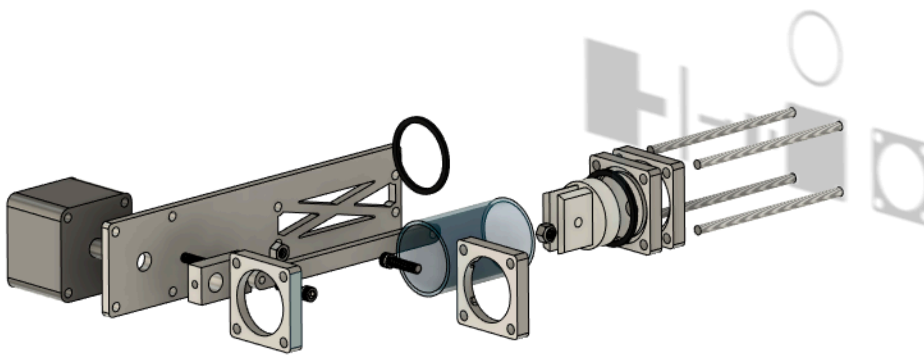


Figure 5: Piston Pump CAD Render exploded view 2

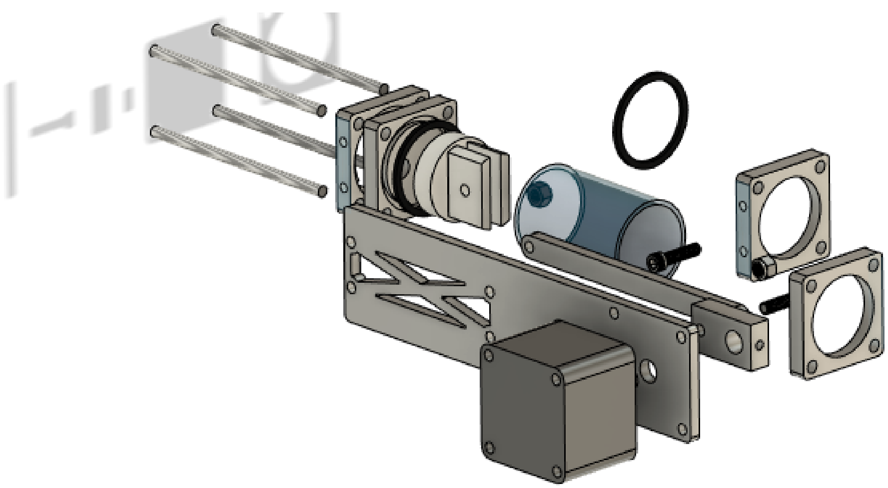


Figure 6: Piston Pump CAD Render exploded view 3

Part Drawings with Tolerances and Multiple Perspectives

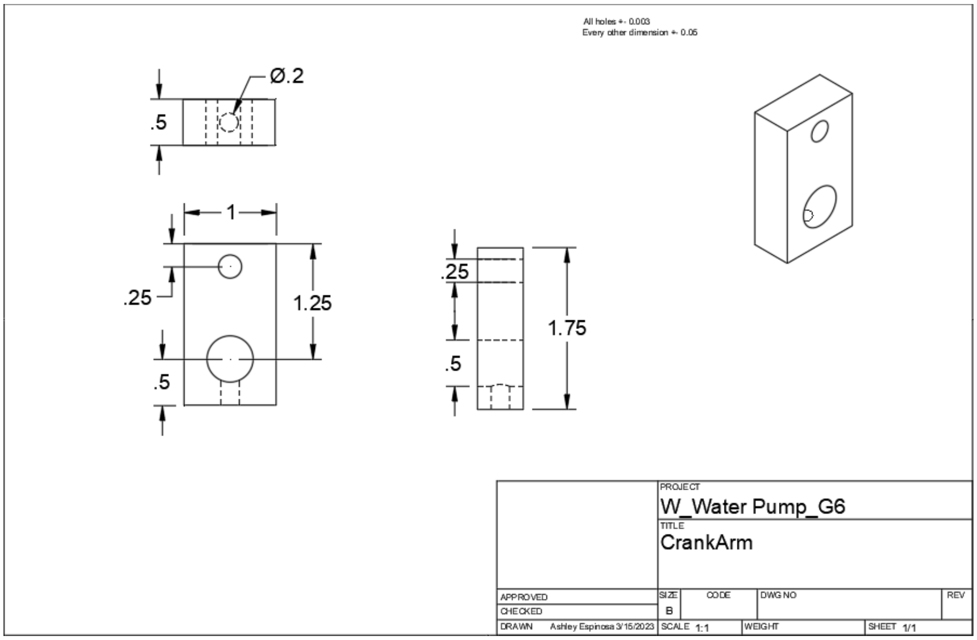


Figure 7: Crank Arm Part Drawing

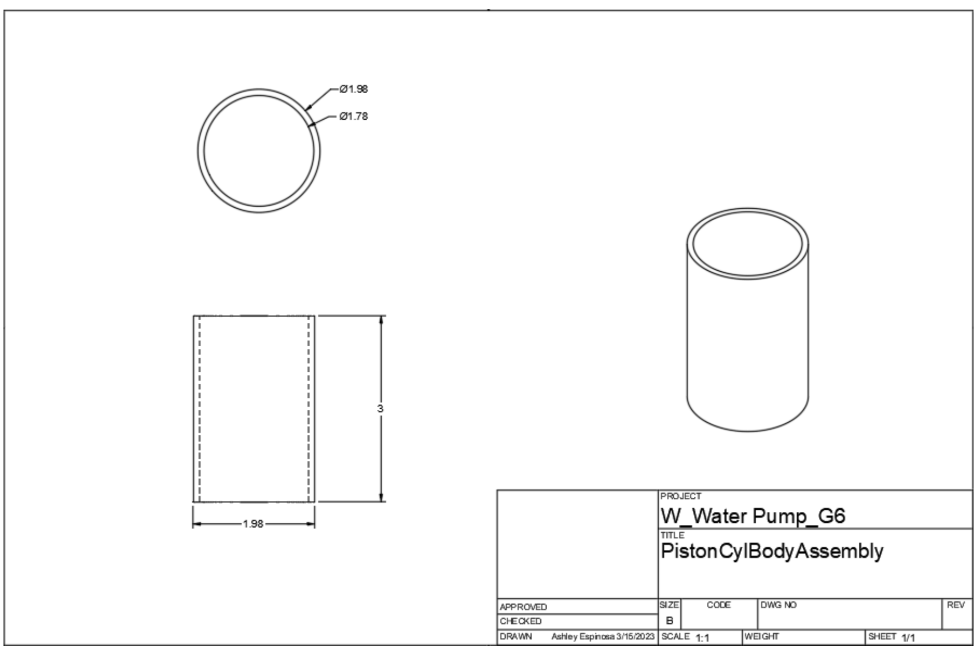


Figure 8: Piston Body Part Drawing

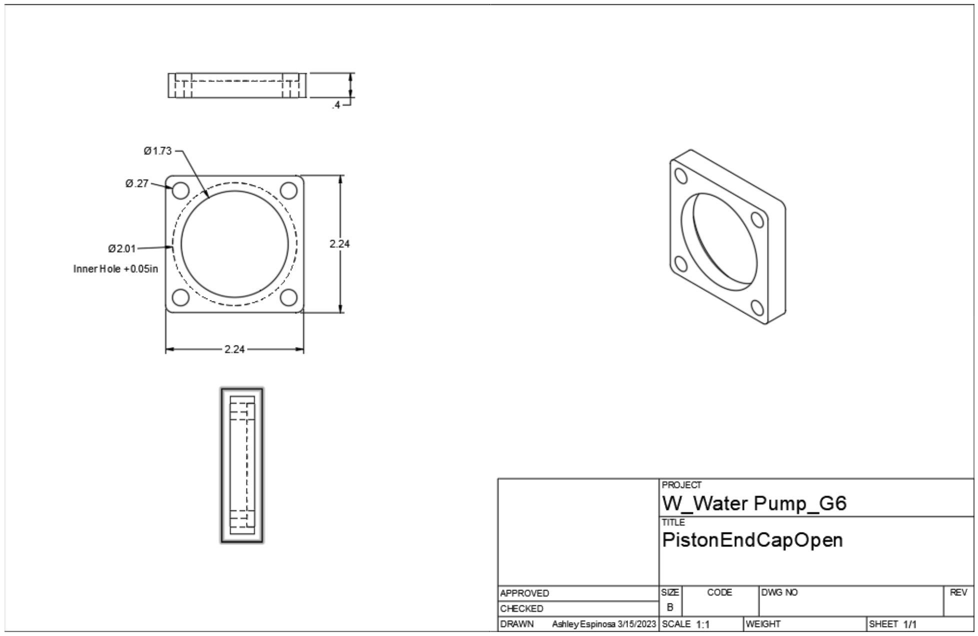


Figure 9: Piston Open End Cap Part Drawing

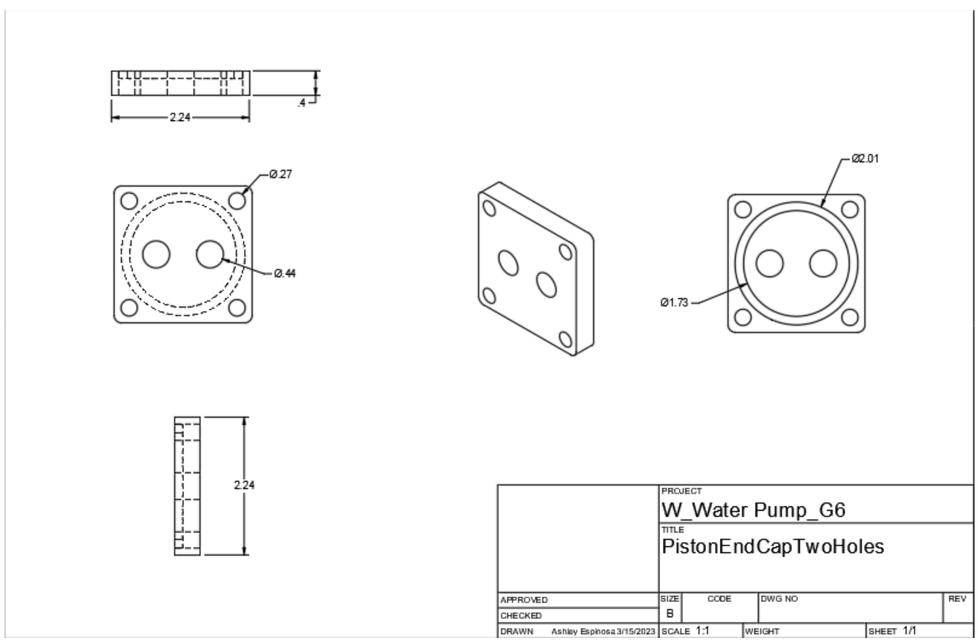


Figure 10: Piston End Cap with two holes Part Drawing

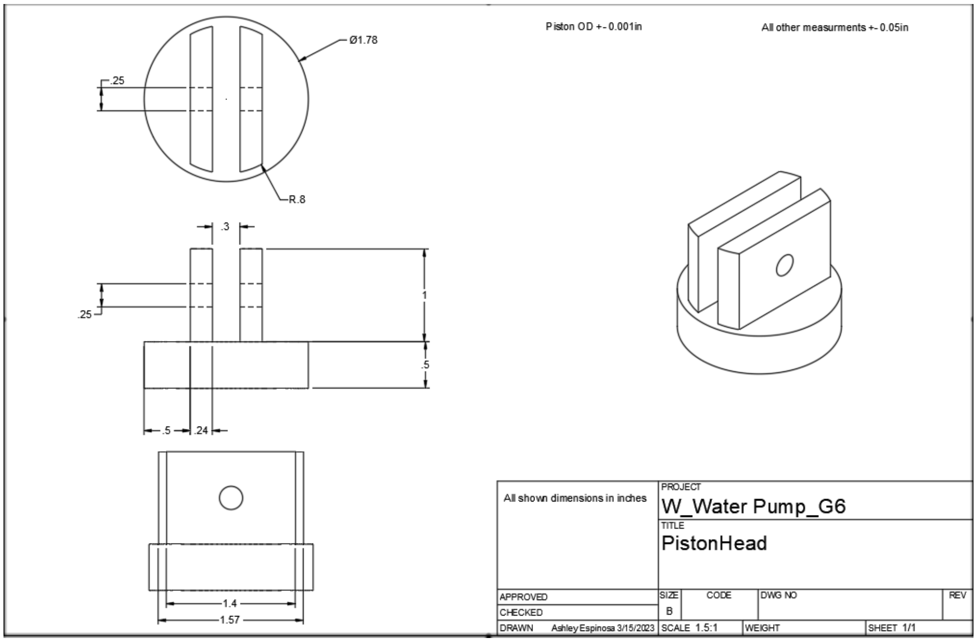


Figure 11: Piston Head Part Drawing

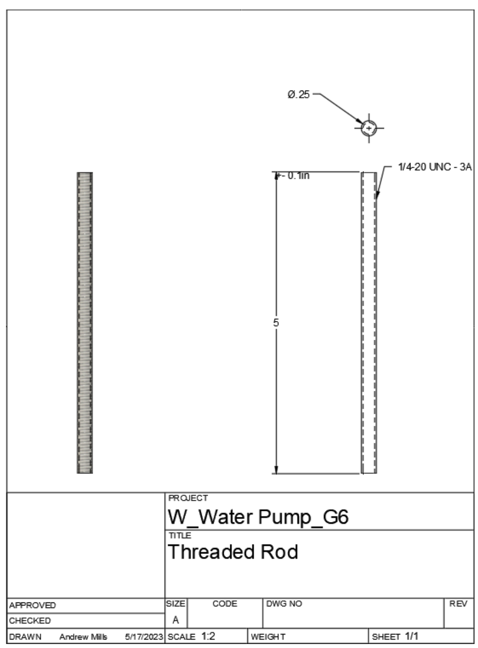


Figure 12: Threaded Rod Part Drawing

Fabrication Plan

Fabrication Timeline

Table 1: Machining tasks per week

Week	**3/15-3/22**	**3/22-3/29**	**3/29-4/12**
Tasks	-Order parts from Emerson -Laser cut plate -Machine piston head	-Machine crank arm -Machine crank -Machine end caps	-Assemble pump -Check that pump functions

The above fabrication timeline was created to stay on track with the manufacturing of our water pump. However, our team proved more efficient than the above supposed timeline and finished a majority of the manufacturing within the first week and finalized the assembly of it the second week.

Fabrication Responsibilities

Table 2: Machining parts and member responsibilities

Part	**Team Member Responsible**	**Production Method**
Piston Head	Caio Schwam Marques	Lathe + Mill
Machine Crank Arm	Ashley Espinosa	Mill
Machine Crank	Katelyn Li	Mill
Machine End Caps	Aleira Sanchez	Mill
Mounting plate	Andrew Mills	Laser cut

All of the machined components were divided amongst all the members who were not leads, as seen in Table 2. As Assembly Lead, Andrew was responsible for the assembly of the water pump after the components were machined. Seojin, our Team Lead, ordered the materials and ensured parts were provided for other members in a timely manner.

Fabrication Plan

Manufacturing Process and Reasoning:

Piston Head

The piston head was the hardest part that had to be manufactured for our water pump. It required a combination of the lathe and mill to fabricate. The lathe was used to bring down the plastic stock to size to fit within our piston cylinder. A mill was then used to cut the gap and shape the head such that the crank shaft could attach. The mill was also used to make the hole to bolt the crank arm to the piston head. For Part Drawing see Appendix figure 23.

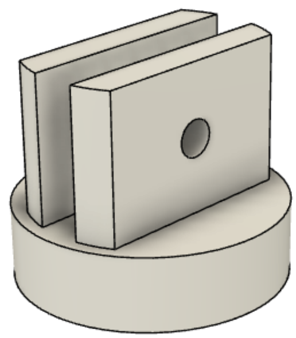


Figure 13: Piston Head

Crank Arm

The crank arm was a relatively simple part to machine on the mill. The mill was used to cut the stock down to size both width and length wise. It was also used to drill the holes which were necessary for attaching the crank arm to the piston head and crank. For Part Drawing see Appendix figure 20.

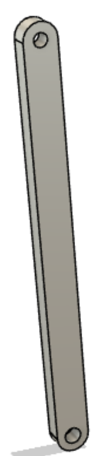


Figure 14: Crank Arm

Fabrication Plan

Crank Arm

The crank arm was our smallest part that had to be machined, and it was done on the mill. The stock had to be milled down to size to prevent it from colliding with the bolts that mount to the acrylic mounting plate. Holes were drilled so that the crank can connect to the drive shaft and the crank arm. A hole was also drilled and tapped through the end of the crank so that a bolt could tighten against the shaft, so that the drive shaft could operate successfully. For Part Drawing see Appendix figure 21.

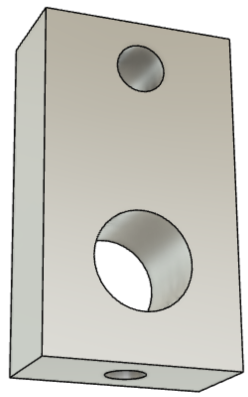


Figure 15: Crank Arm

End Caps

The end caps were purchased from Emerson but then were modified. Using the mill, we were able to bore a hole through the center of the end caps such that the piston cylinder could be secured between the end caps. It also allowed us to insert rubber gaskets so that we could produce a good seal for our pump. For Part Drawing see Appendix figure 22.

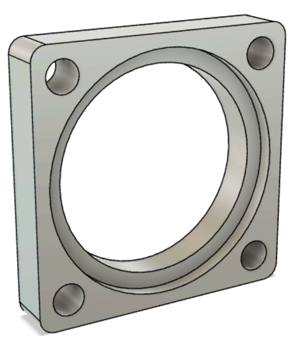


Figure 16: End Caps

Fabrication Plan

Table 3: Cost Analysis & Parts List

Description	**Quantity**	**Unit of Measurement**	**Total Cost**
Bored Cylinder, 4"	1	each	$1.00
Machined End Caps	4	each	$4.00
3/32" gasket (10A-40A durometer)	25	sq in	$1.50
1/4 - 20 allen socket head cap screw (1")	4	each	$0.68
1/4 - 20 lock nuts	2	each	$0.30
Aluminum Bars, 1/4" x 1"	10	in	$1.40
1/4 - 20 threaded rod	1	ft	$1.02
1/4 - 20 hex nuts	4	each	$0.24
Nylon pipe fittings (3/8" barbed x 1/4"NPT)	2	each	$1.10
7/8" Diameter Plastic Rod (piston)	1.5	in	$1.29
Acrylic (0.217" thickness)	1	each	$6.08
		TOTAL COST	$18.61

Graphs, Charts, Tables

Power Calculation

h: distance water travels up

$h = 1.5\,m$ (given)

A: distance crank is from edge

$A = R_{pist.head} = 2.75\,in / 2 \approx 1.38\,in = 0.0349\,m$

R: radius in which the crank moved in

$R = length_{small\ crank\ arm} = 1.75\,in = 0.04445\,m$

R_0: radius of sprocket connected to motor

R_1: radius of sprocket connected to the shaft

$R_0 / R_1 = 9/70$ (given)

w: speed of sprocket connected to motor

motor speed: $\dot{\theta}_0 = 900$ RPM (given)

$\omega = \dot{\theta}_0 = 900\,RPM$

$$\bar{P}_{pump} = \rho_{water}\, g h \left(\frac{AR}{\pi}\right)\left(\frac{R_0}{R_1}\right)\omega$$

$$\bar{P}_{pump} = (997\,kg/m^3)(9.8\,m/s^2)(1.5\,m)\left(\frac{0.0349\,m \cdot 0.04445\,m}{\pi}\right)(9/70)(900\,RPM)$$

$$= (9780.57\,kg/\cancel{m^2} \cdot s^2)(1.5\,m)(0.0004938\,\cancel{m^2})(9/70)(900\,rev/min)$$

$$= (4.8296\,kg/s^2)(1.5\,m)(900\,\cancel{rev}/\cancel{min})(\cancel{min}/60\,secs)(2\pi\,rad/\cancel{rev})$$

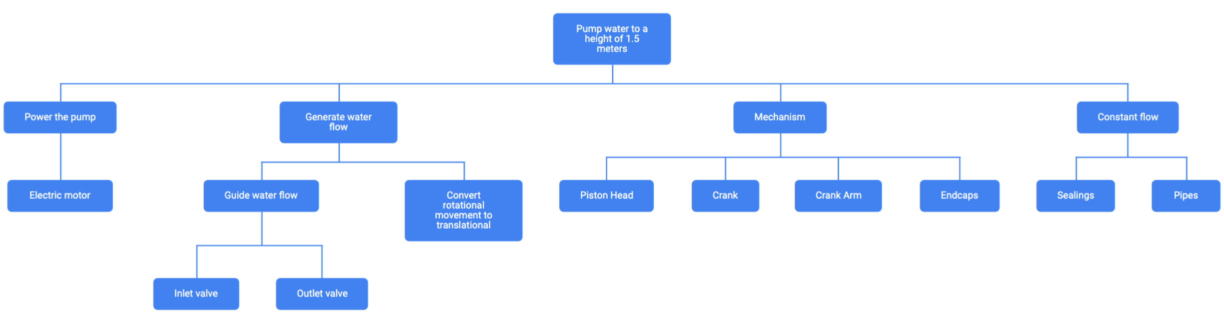
$$= (72.444\,kg/s^3)(1.5\,m)(2\pi\,rad)$$

$$\bar{P}_{pump} = 682.769\,kg \cdot m/s^3$$

Figure 17: Handwritten power calculations with values measured/given

Functional Decomposition

Chart 1: Functional decomposition of piston water pump. Click the link for a wider view.



Morphological Chart

Table 4: Subproblems and partial solutions

Category	**Function**	**Solutions**			
Power	Source of power	Electric motor			
Mechanical	Pumps the water upward	Crank Arm	Piston Head	End Caps	Crank
Structural Controls	Constant water flow	Input Valve	Output Valve	Sealing	Pipe

Appendix

Sketches and Part Drawing

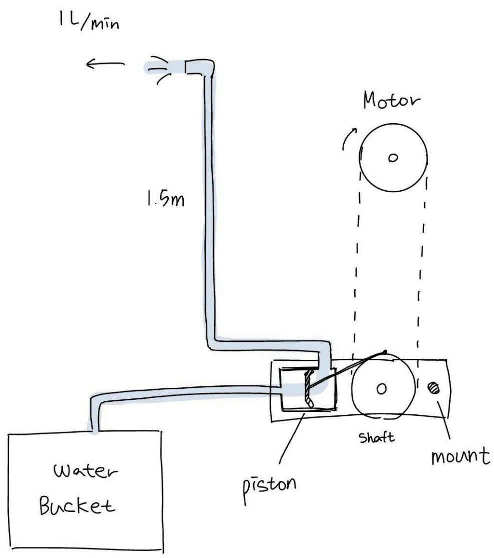


Figure 18: Initial Sketch of Piston Idea

Figure 19: Piston CAD Model Rendering

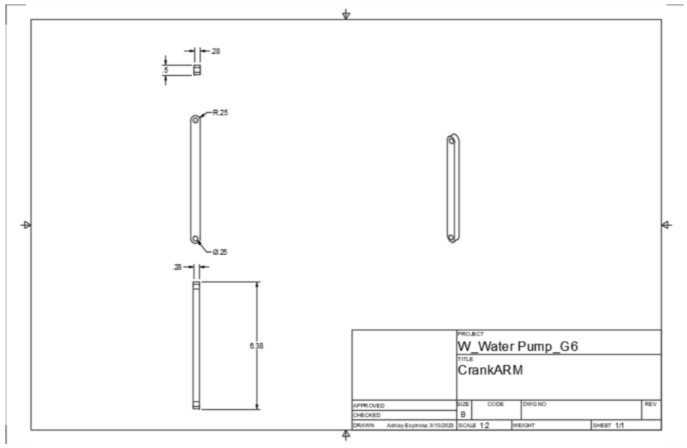


Figure 20: Part Drawing of Crank Arm CAD

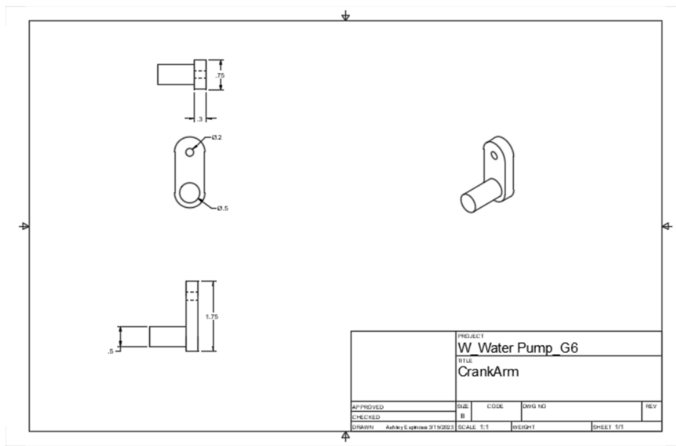


Figure 21: Part Drawing of Crank Arm CAD

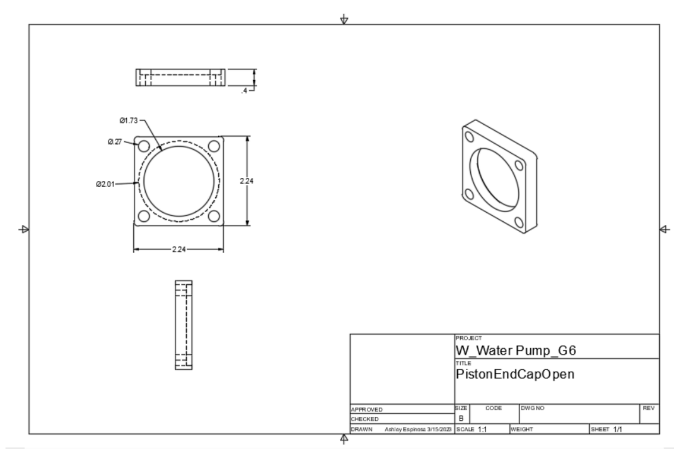


Figure 22: Part Drawing of Piston Open End Cap CAD

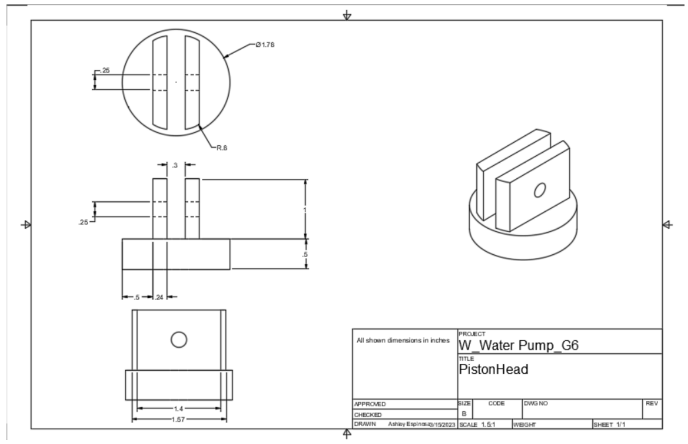


Figure 23: Part Drawing of Piston Head CAD

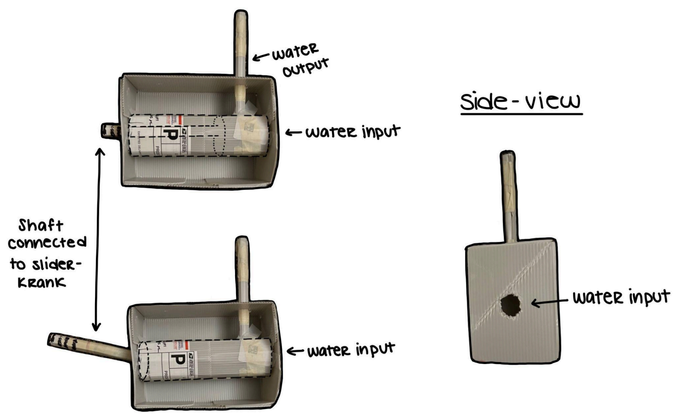
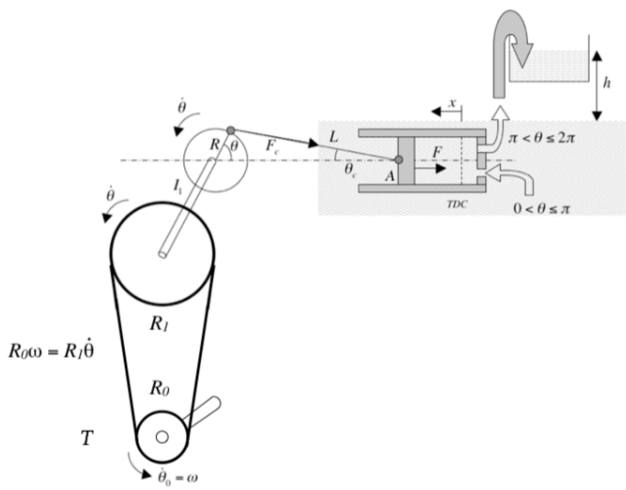


Figure 24: Cardboard Prototype of Piston Design

Equations



$$\bar{P} = \rho_w g h \dot{Q}$$

$$\dot{Q} = \frac{AR\dot{\theta}}{\pi}$$

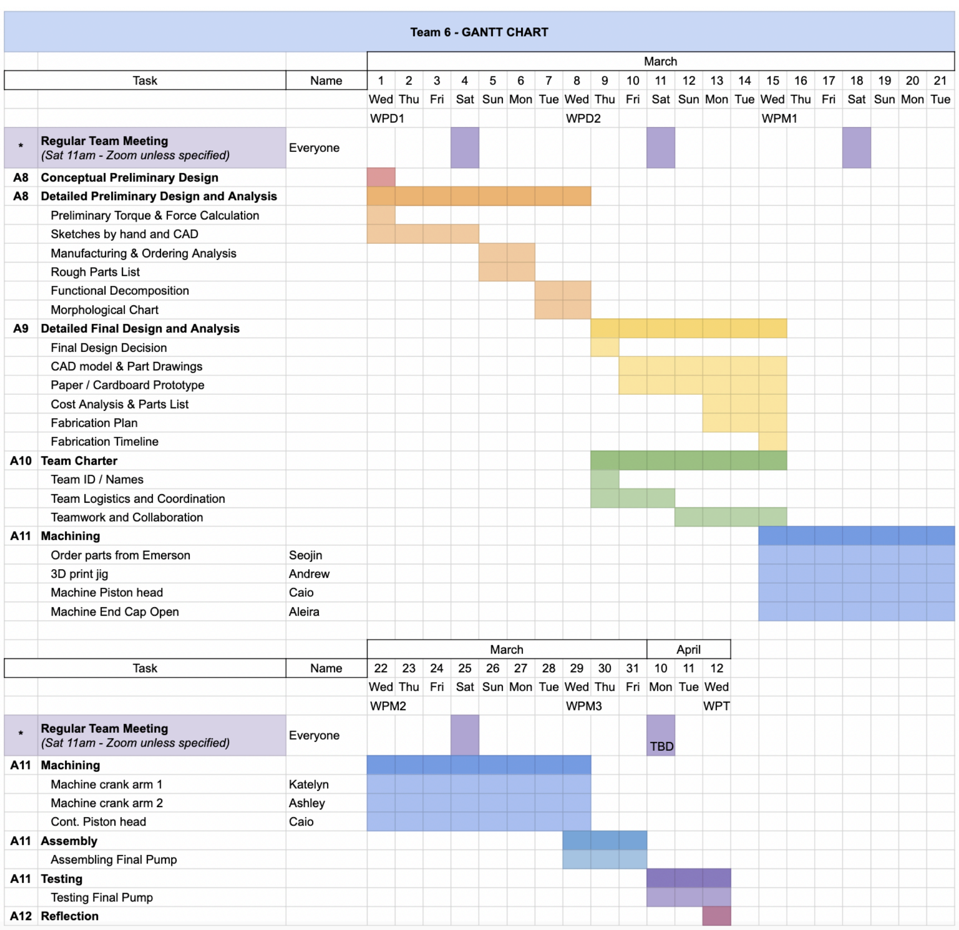
$$R_0\omega = R_1\dot{\theta}$$

$$\bar{P} = \rho_W g h \left(\frac{AR}{\pi}\right)\left(\frac{R_0}{R_1}\right)\omega$$

Figure 25: Water pump analysis and equations provided in class

Calendar

Chart 2: Gantt Chart with team's schedule



Timeline

Table 5: Fabrication Timeline

3/15 - 3/22	3/22 - 3/29	3/29 - 4/12
1. Order parts from Emerson (Seojin) 2. 3D print jig (Andrew) 3. Machine Piston head (Caio) 4. Machine End Cap Open (Aleira) *Harder parts first*	1. Machine crank arm 2 (Ashley) 2. Machine crank arm 1 (Katelyn) 3. Cont. Piston head (Caio)	1. Assembly (Andrew) 2. Check if all parts fit and fix if needed 3. Present pump

Team Charter

Table 6: Names and IDs of team members

Team 6 - SACK			
Name	Net ID	Phone Number	Email
Seojin Lee	sl3423	(607)-882-1680	sl3423@cornell.edu
Ashley Espinosa	ase47	(862)-432-8400	ase47@cornell.edu
Andrew Mills	amm484	(925) 278-3444	amm484@cornell.edu
Katelyn Li	khl59	(917)-789-4227	khl59@cornell.edu
Aleira Sanchez	ans222	(787) 948-1230	ans222@cornell.edu
Caio Schwam Marques	cs945	(321)-314-7486	cs945@cornell.edu

Team Logistics and Coordination:

1. **Describe how the team will move documents and ideas back and forth.**

- The team will move documents back and forth by sharing a team google drive folder as well as move ideas back and forth through a slack group chat forum.

- The expectation for using the slack group chat is to respond as soon as they see the slack notification, by either an emoji or direct message. The app has a feature where users can react to a message with emojis, allowing teammates/members to respond to the announcements and information easily and readily. Slack allows the team to share the links to their google drive folder within the chat which makes files accessible in a timely manner. If a message sent in the slack is not responded to within 4-5 hours (depending on the circumstances), the team will tag the person's name so that they can be notified once again. Another emergency method to contact team members is by simply calling them, since we have all shared phone numbers.

2. **Where will outside sources be stored? Will you use an automated citation formatting service? If so, decide on that process and plan.**

- The outside sources will be stored within the shared google drive, and we will be using an automated citation system from the website, or use a citation machine from the internet such as citationmachine.net.

3. **When and where will the team meet outside of class on a regular basis? Decide on a weekly time where the team can meet for at least 1-2 hours.**

- Polled available times through When2Meet (link below).
- https://www.when2meet.com/?19199464-Xhtjd
- Since members of the team have different schedules from each other, it was difficult to choose a time of the week that fit everyone. Therefore, based on the When2Meet above, the team has decided on a tentative time of 11am on Saturdays over Zoom unless specified otherwise. This can fluctuate, however, due to weekly circumstances and, if it does, teammates are required/ expected to notify the team via the slack group chat.

Teamwork and Collaboration:

1. **In some good detail, describe here the specialized skills that each team member can bring to this project.**

- Each member of our team has specialized skills that they can bring to the project. Ashley has hands-on assembly experience, considerable experience operating the mill in the machine shop, and proficiency in using various CAD programs and tools. Katelyn has demonstrated exceptional critical thinking skills in designing and manufacturing projects while working with her project team, which is complemented by her artistic background and strong spatial thinking abilities. Seojin is experienced in CAD and in producing precise and detailed drawings for products through her research project. She also has an ability to organize and keep track of the team schedule. Andrew has spent a lot of time in the machine shop from baja and project teams, and he is very comfortable with his part designing and machining skills. Caio has an ability to manually assemble pieces and create models or sketches by hand within specific design parameters given his drawing background and experience as a mechanic. Aleira likes to find diverse solutions to what could be a simple common problem, and she is a fast learner. She is happy with anything as long as it is explained at first, if necessary.

2. **The team should choose a leader / schedule coordinator. A full description of the responsibilities of this position is required.**

- The leader/schedule coordinator of our team is Seojin. As a team leader, she will be responsible for keeping track of design/manufacturing deadlines and will communicate efficiently with teammates in order to achieve the team's goal. Seojin will also work to solve time or workload conflicts among the teammates if problems arise, and manage changes to the project plan if needed.

3. **The team should choose a design integrator / coordinator: A full description of the responsibilities of this position is required. The integrator is (at least) responsible that all of the designs / purchased parts fit together and they will also assemble the final pump from all delivered parts.**

- The design integrator/coordinator of our team is Andrew. As a design integrator, he will be responsible that all of the designs and purchased parts are within the budget, and that they all fit together as a whole. Andrew will also assemble the final pump once all the parts arrive.

4. **Other design and manufacturing responsibilities should be outlined here. Everyone, except the leader and integrator above will have to design and machine one or two parts for the pump and deliver them to the integrator.**

- 3D-printed jig: Andrew
    - The "3D-printed jig" referred to above is a piece that we are expecting to use while machining the piston head. This is because the piston head has an inner circle that is hard to maintain while using the machines. The "jig" is supposed to function as a placeholder to stop any sort of deformation from happening. This is printed before the piston head is made.
- Machine piston head: Caio
    - As this will be the hardest part to make, we may need more than one day to make this. However, we expect it to be finished within 3 days provided the 3D-printed jig is made beforehand.
- Machine end cap: Aleira
- Machine crank arm 2: Ashley
- Machine crank arm 1: Katelyn
    - These last 3 parts are easier to manufacture and wil take significantly less time than the piston head. Since our design is so simple, we are also thinking of expanding it into a more-than-one-piston design. We are considering stacking 2 or more pistons together (as we have a lot of money left in our budget) and this will take up more machining time. If this were to be true, then members would take turns making the extra parts.

5. **Outline in detail what actions will happen if a team member misses an internal team deadline.**

- Whenever a group member does not complete their assigned task by the deadline, the goal is to have them bring food for the next team meeting. The food the team member brings should correlate with the importance of the part or how long after the deadline the member completes his task. For example, if someone were to be late on a component that takes a long time and effort to machine, that member must bring in a dozen donuts to compensate. If the part is simpler such as a crank arm, then candy might suffice. From that point onwards, the member will be given more time to complete the task handed to him. However, if after a certain period of time the task still hasn't been completed, group members will decide whether to give the task to someone else and contact the TAs.