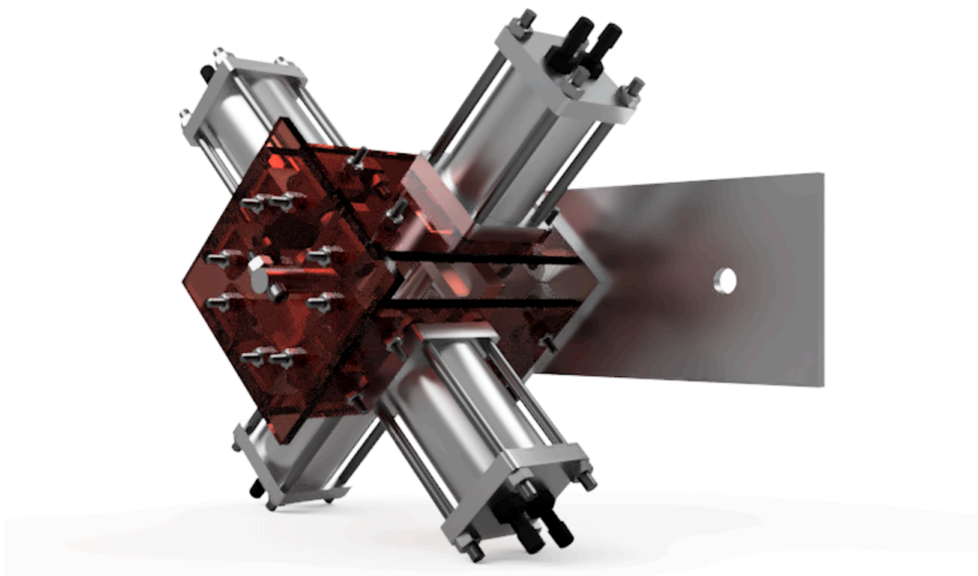
MAE 2250

Water Pump Final Report



Wednesday Lab, Group 2

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1 Design Process

1.1 Pump Description

Our pump uses a double scotch yoke mechanism in combination with four single-acting piston cylinders. The cylinders are mounted onto acrylic side panels that ensure the structural integrity of the pump and constrain the scotch yokes to linear motion. The scotch yokes are driven in a reciprocating motion by a steel crankshaft that is offset 1 inch from the drive shaft. Finally the drive shaft and a supporting shaft at the upper end of the pump are supported by an aluminum mounting plate and an acrylic top plate, respectively.

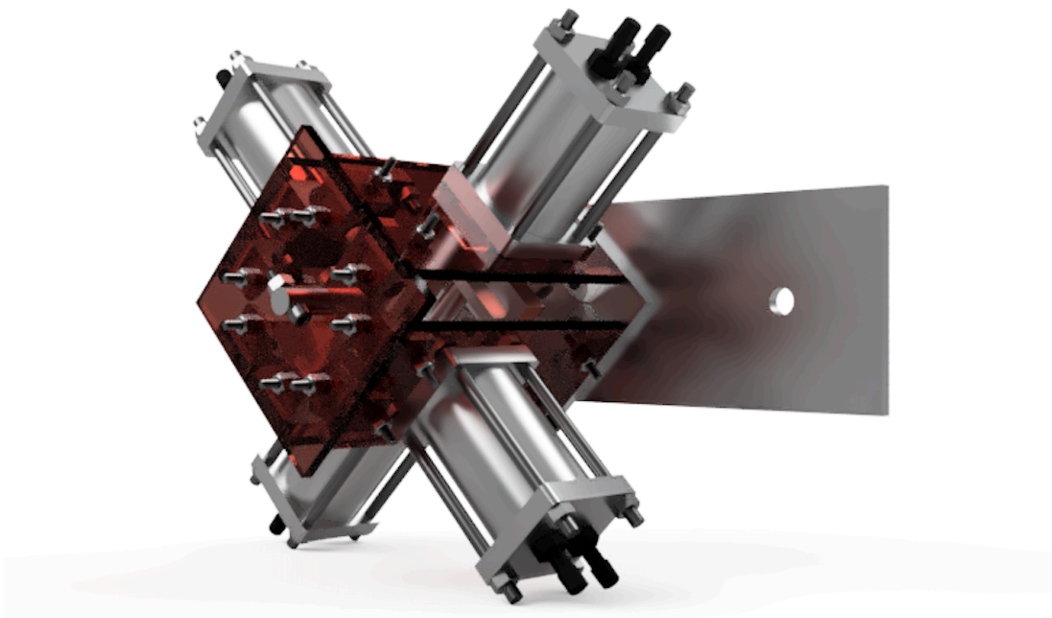


Figure 1: Full assembly render

1.2 Design Rationale

At the beginning of the design process, we were split into three teams of two to create preliminary designs for our water pump. These designs were restricted to linear pistons, so the comparisons made in the rest of this paragraph will be with regards to one single-acting linear piston. The first design featured a set of two single action linear pistons driven by out of phase cranks attached to the main drive shaft. Although this design had a high power efficiency and a high volume, the cranks would be relatively difficult to manufacture and mount.

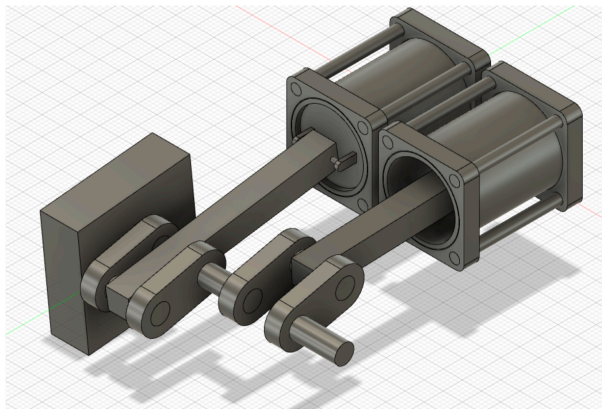


Figure 2: First group's design

The second design featured four piston cylinders driven by two scotch yokes which were driven by a single crankshaft attached to a circular base which would be rotated by the drive shaft. Although this design had a very high volume with relatively simple manufacturability, the design did not communicate a clear mounting solution and there would be potential instability present in the yoke because it was only supported on one end.

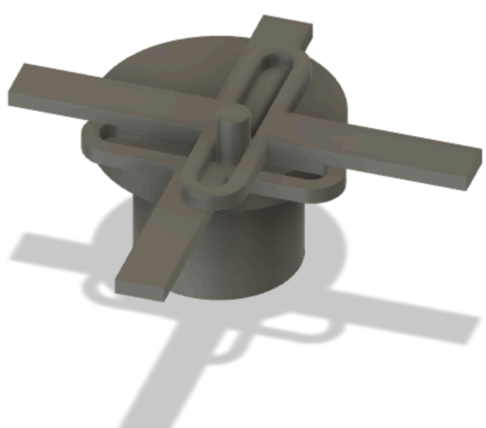


Figure 3: Second group's design

The third design featured two piston cylinders driven by a scotch yoke centered in between two pistons which would be attached to a disk mounted to the drive shaft. Although this design is also relatively more straightforward to manufacture with a high volume, there would be potential interference issues with the pivot and the chosen mounting solution and the design was not cost effective because the cylinders were sealed with expensive gaskets.

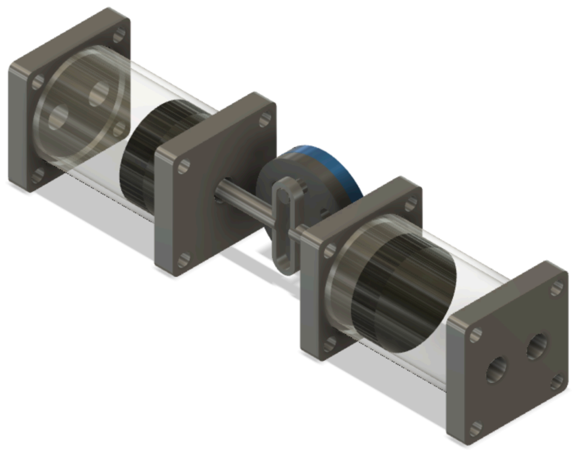


Figure 4: Third group's design

At the end of this process, we compared these initial designs and decided on the key design features we intended to put in our final design. They are as follows:

- Scotch yoke for ease of manufacturing
- Two sets of two single acting pistons to maximize the volume of water pumped
- Out of phase pistons as a result of the scotch yokes for power efficiency

After deciding on these design tenants, we brainstormed some more ideas based on these criteria, and there was one draft that came out as a clear mark for progress. It featured mounting walls for the pistons that attached to the mounting base to ensure the cylinders stayed stable during use, replaced the disk that was present in the initial designs and replaced it with a keyhole-shaped block of aluminum that would drive the crank. However, the walls were designed in an odd shape, which required specialized tools to manufacture. They also required square supports to ensure structural integrity, which would also be relatively difficult to manufacture. Finally, the crankshaft was not properly supported at the top of the design which would result in excess torque present in the shaft.

After we took this design idea as the starting point, we made several changes to reach the final design. The supporting walls were chosen to be made out of acrylic rather than metal plates to keep costs low, and they were mounted to the main mounting plate and the top plate with plastic L brackets and screws rather than any specialized mounting system. The main mounting plate at the bottom of the structure was kept as metal to make sure there was no possibility of deformation of the pump when it was driven. A top support plate made of acrylic was also added to replace the

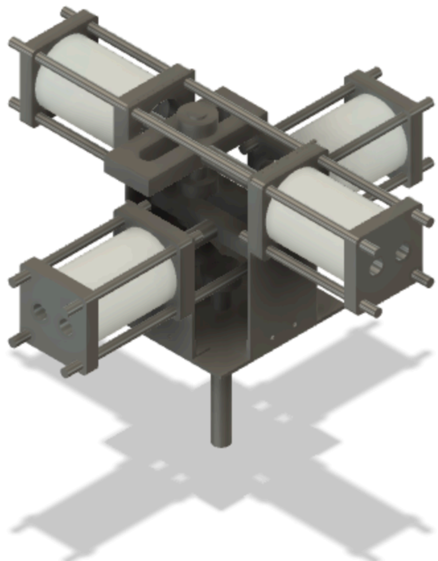


Figure 5: Draft design

square brackets, and the side walls attach to it with the L brackets. For ease of manufacturability, the scotch yokes were split into three individual pieces to lessen the impact of singular error on the efficacy of the part. Finally, the crankshaft bases were made to be rectangles rather than keyhole-shaped to again ensure ease of manufacturability.

During manufacturing we made some final changes to the design as a result of the manufacturing process. The crankshaft bases and the shafts now interface with threaded rods rather than pins due to budgetary concerns (see Figure 11). The holes on the main mounting plate where the L bracket screws interface were threaded to avoid the need of a nut on the other side, allowing us to cut off the excess length, ensuring that the drive shaft would properly interface with the motor.

1.3 Anticipated Challenges

We anticipated some challenges as we finalized our design.

The first was manufacturability, dimensioning, and tolerancing. To alleviate these issues we implemented a system to have all drawings checked for correct dimensioning and manufacturability before continuing on to the manufacturing phase. Unfortunately, some of our drawings still passed through without verification which created some surprises when it came time to assemble.

Also, we had difficulties figuring out how to connect the driveshaft, support drive shaft, crankshaft, and crankshaft base together. We eventually decided to use a threaded rod and nuts to secure them together, but it wasn't easy to screw in the rod through the crankshaft base and the crankshaft or drive shaft. See Sections 2.2.2 and 2.2.3 to see how this part was manufactured.

Lastly, there was the possibility that the yokes would twist. The yokes are connected to the pistons through yoke rods, which translate the rotational motion of the drive shaft, to a linear motion, resulting in smooth back and forth reciprocating cycles of the piston cylinder assemblies. Since the yokes are free to rotate and nothing is there to prevent them from twisting, each cycle causes a slight twist on the yokes. This was one of our highest priority concerns and was one of the main difficulties that presented itself in our cardboard prototype that prevented smooth operation (see the image below). We hoped that the straight drive shaft supported on both ends would alleviate this problem.

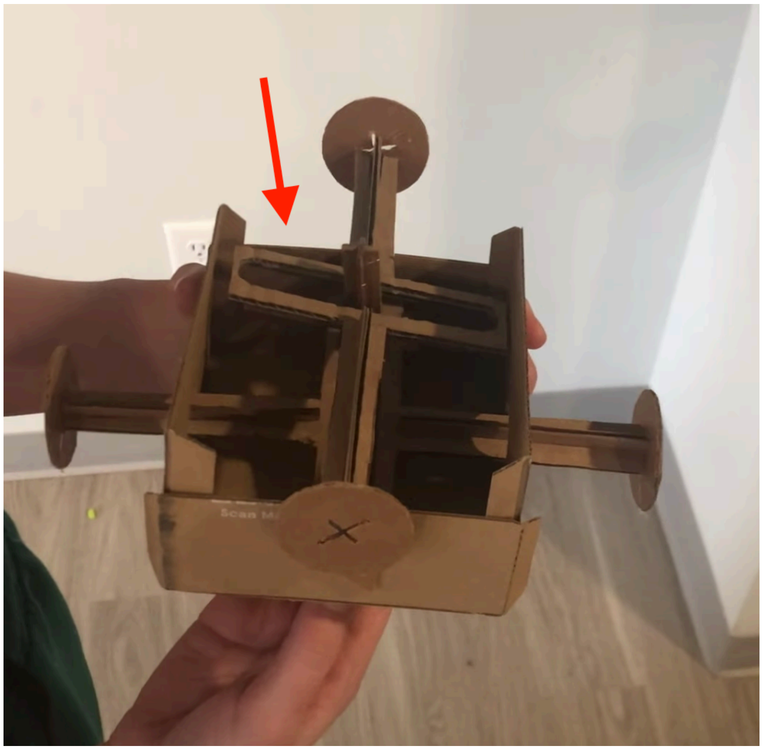


Figure 6: Cardboard prototype with twisting yoke

1.4 Unanticipated Challenges

We also encountered some issues during manufacturing that had to be resolved on the fly.

The first problem was mismanaged clearances. Once example of this is the blank end caps, which were initially designed to have a 1 1/2" hole drilled in the middle of them. However, only a 1/2" clearance was needed for the yoke rod to go through. This was a very tedious job to do in the machine shop, since drilling a 1 1/2" hole required at least 6 step drill bits (see Figure 3). This process took over 1.5 hours. We made an adjustment and drilled the rest of the end caps to a 1/2" clearance. A second example concerned the hole on the aluminum face plate which the drive shaft goes through. The hole was also too big (around 5/8") so with the help of Joe Sullivan, a lubricated bronze brushing was machined to size and added to fill in the gap that cause deflection in the drive shaft. A third example of clearances presenting an unexpected challenge came when manufacturing the crankshaft bases in relation with the crankshaft and the drive shaft clearances. The threaded holes in the crankshaft bases were meant to interface cleanly with the holes in the crankshaft and the drive shaft where threaded rods would act as pins. However, when attempting to assemble this section of the pump, the threaded rods would at times lock up when interfacing with both the threaded rods and the holes on the shafts, indicating that the tolerances were most likely too tight to allow proper clearance between the holes.

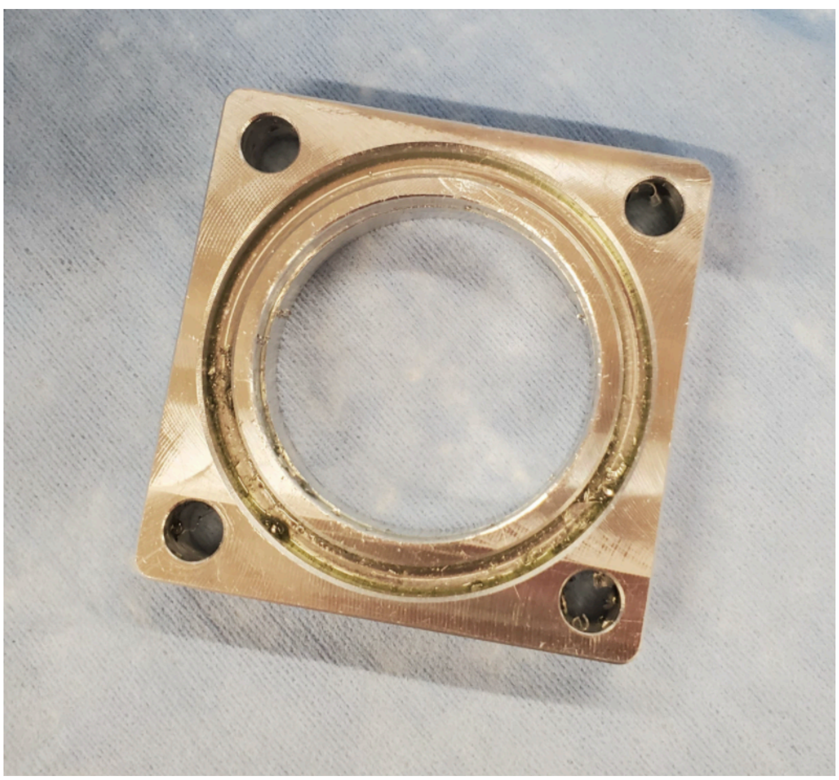


Figure 7: 1 1/2" diameter hole in the end cap

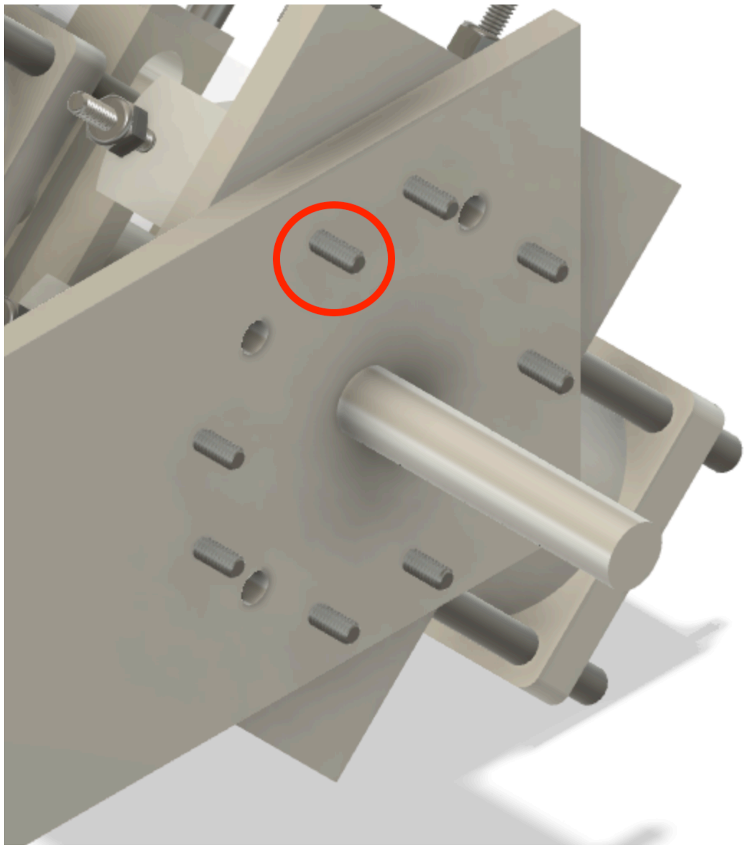


Figure 8: L bracket screws sticking out

A second problem was the L-bracket screws sticking out from the face plate, which prevent a proper connection with the provided rectangular mounting plate. Since the provided face plate has only 4 holes for the screws to mount our pump on, the screws needed to be adjusted as shown in Figure 4 (circled in red) in order to ensure proper fitting. After discussing this with Joe Sullivan, we decided to cut down the screws so they are flush with the surface of the square face plate that they are threaded in. The pump was vised down and the screws were trimmed using a hacksaw, and then flushed with a file.

We also did not include a flat on our drive shaft, so we filed this feature onto our drive shaft later. This was done to get a better connection and eliminate slip when the drive shaft is screwed into the test setup. Loctite was also applied to all the nuts/screws/bolts to prevent loosening of hardware during the 1-minute test run.

In order to have a working water pump, we needed to solve all these challenges and issues. Thankfully, efforts were made to adjust and optimize things to the best of our ability.

1.5 Performance Analysis

Our pump was able to deliver 8.6 liters of water up a height of 1.5 meters in 1 minute. This was 8.6x greater than the 1.0 liter minimum. While viewing the water pumps that other groups made, we observed that their shafts were turning at a faster rate. However, our decision to use four pistons paid off as we were able to deliver a larger volume of water. In addition, the pistons were 90^o out of phase with each other, which meant that there was always water being pumped into the bucket.

In Fusion 360, our pump's mass came out to 3.7 kg (8.0 lbs) after assigning the correct materials to each component. The manufactured pump's weight was measured with a spring scale, which came out to be 2.8 kg (6.2 lbs). There is a 25% difference between the theoretical and experimental weight. This is acceptable considering the filing and sanding that was done on the actual pump.

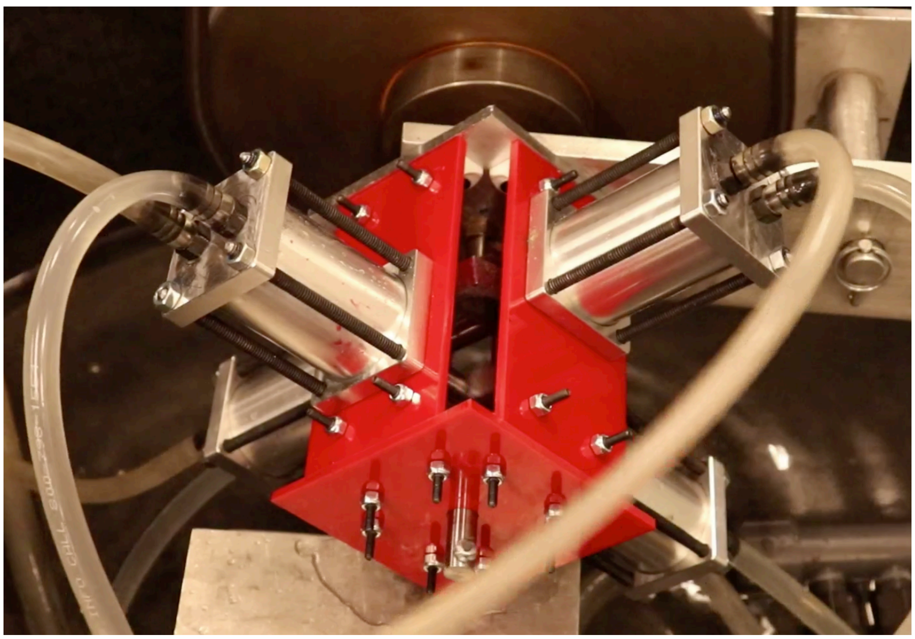


Figure 9: Pump mounted on the testing rig

2 Fabrication Plan

2.1 Manufacturing Analysis

2.1.1 Scotch Yoke

The slot of the yokes was made on the mill. The shape was not too complex and rectangular so the mill was the best manufacturing option.

The rods were manufactured on the lathe. First, the surface of the cross sections was cleaned up. Then, material was taken off the ends and those surfaces were threaded.

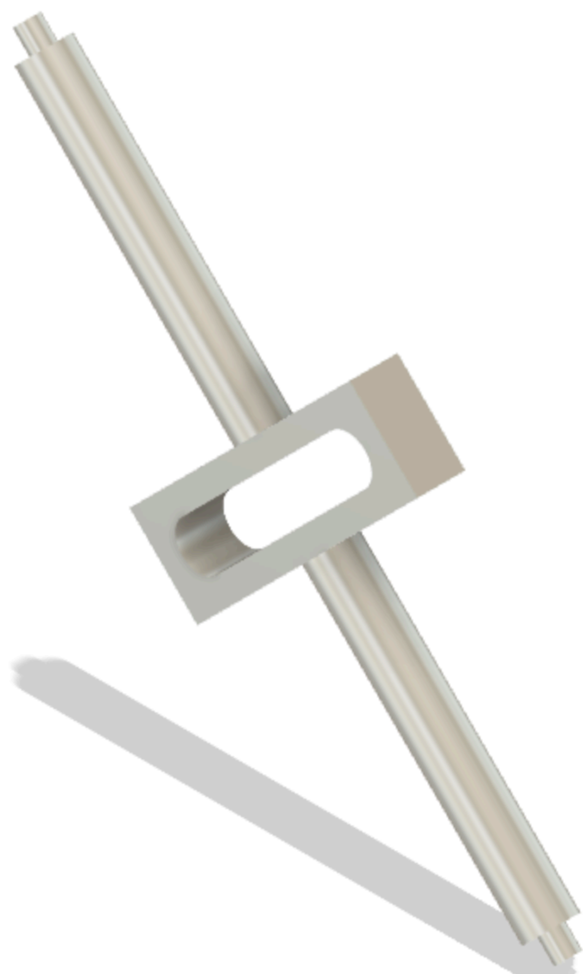


Figure 10: Scotch yoke assembly

2.1.2 Crankshaft and Crankshaft Base

We first used the lathe to finish the surfaces of the cross sections and then decreased the part to the desired length.

Then, we used the mill to drill holes in the aluminum cylinder. Because we were drilling into a curved surface, we needed to clamp the part down to prevent movement. We had two options, a vee block or a collet block. The best option was to go with the collet block since it has a more rigid clamping force. This was also recommended by the Emerson machine shop manager, Joe Sullivan. The holes had to be on the same axis, so a center line was marked across the length of the crankshaft to ensure alignment on both sides.

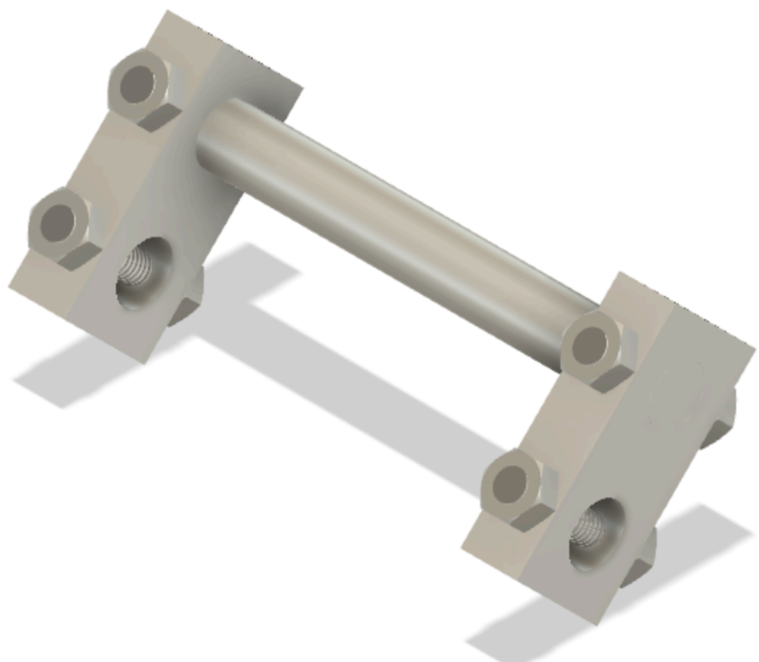


Figure 11: Crank arm assembly

2.1.3 Drive Shaft and Drive Shaft Support

First, we used the lathe to finish the surfaces of the cross sections. Then, we decreased the shaft to the desired length.

After that, we used the mill to drill one end hole using 3 step drill bits.

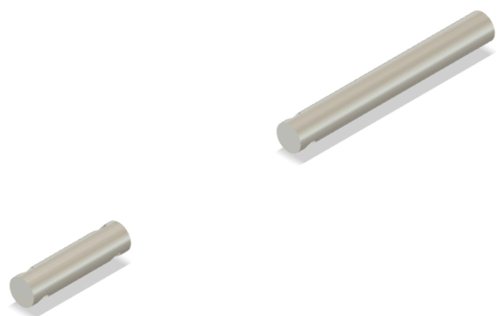


Figure 12: Drive shaft and support drive shaft

2.1.4 End Caps

We used a mill to drill a hole in the center of the blank end cap using 3 step drill bits. This was determined to be the best manufacturing option because the end caps are square and therefore could be easily fixed on the mill using the built-in vice. Also, the only operation we needed to perform was drilling, which could be easily done on the mill.

The end caps with two holes needed to be tapped with 1/4 NTP for the nylon pipe fittings to be threaded in.

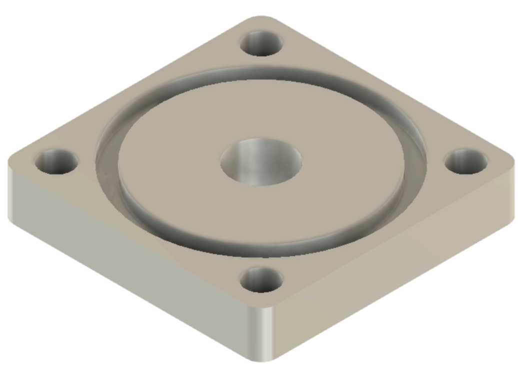


Figure 13: End cap with one hole

2.1.5 Piston Head

The piston heads were cut from a PVC 1 7/8" Diameter Rod. A lathe was used to first resurface the end of the plastic cylindrical stock, and to cut the rod diameter to size from the measurement of the aluminum cylinder's inner diameter. When the diameter was fit, very small passes were taken to decrease the piston diameter such that the piston could fit without sticking or sliding too easily within the aluminum cylinder to create a strong vacuum seal.

The lathe was then used to drill a small hole through the length of the stock (to attach the scotch yokes). Each disk face was counterbored using an endmill before each disk was cut from the stock at consistent thicknesses.

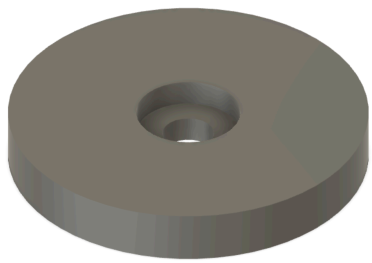


Figure 14: Piston head

2.1.6 Mounting Plate

The mounting plate was manufactured on the mill. All the holes were drilled according to the part drawing (see Appendix B). This piece was fairly simple (just various holes being drilled) and the part was square, so we decided to machine it on the mill.

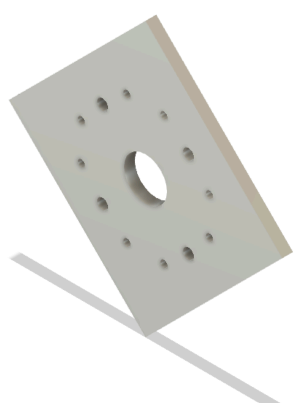


Figure 15: Mounting plate

2.1.7 Side and End Plates

The side and top plates were fabricated from laser cut acrylic. These pieces do not hold much weight so we decided to make them out of acrylic. Using acrylic also had cost and manufacturing benefits. The acrylic stock available was inexpensive and was larger than any aluminum stock available from Emerson. Also, laser cutting is faster than producing parts in the machine shop, which helped speed up production of the pump.

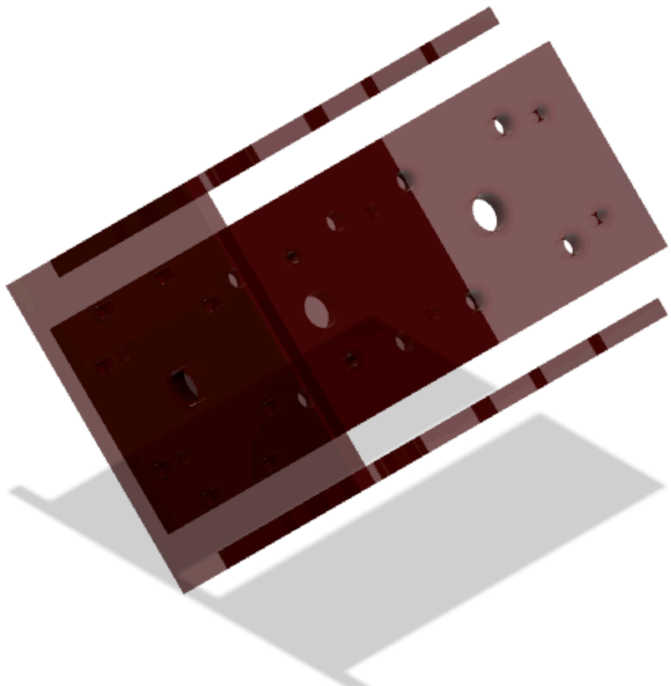


Figure 16: Side and end plates

2.1.8 Exploded View

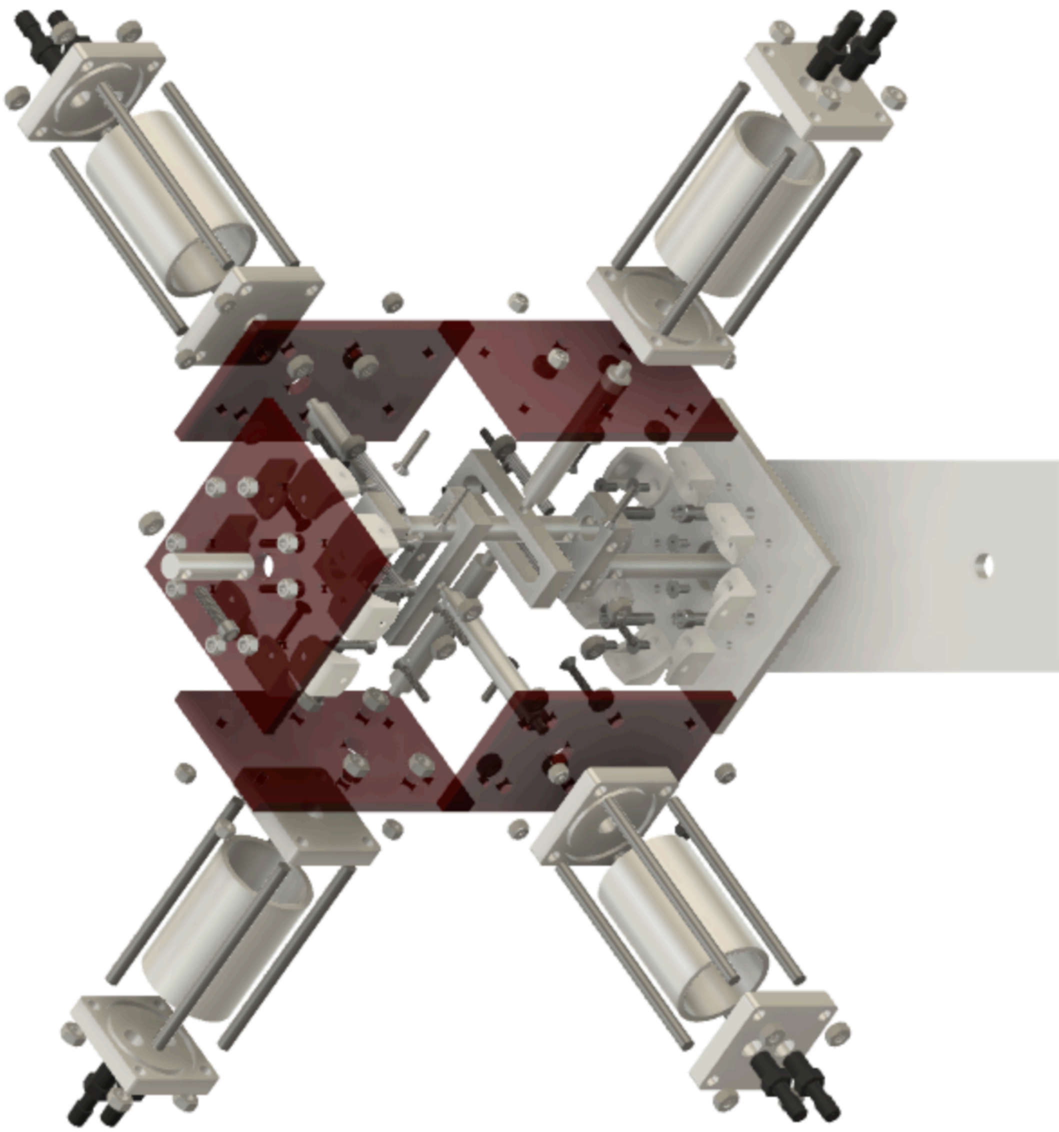


Figure 17: Exploded View

2.2 Ordering Analysis

We decided to obtain the majority of our parts and stock from the Emerson shop as this is what was most cost effective given our budget restrictions. However, there were some parts that were not available from Emerson and had to be ordered from McMaster, such as our our plastic corner brackets. These were used to attach the side supporting plates to the mounting plate and the top plate of our pump. We also ordered flat head screws and nylon insert lock nuts to match the corner brackets that we ordered. We also ordered 6” x 6” x 1/4” aluminum stock as the stock available at Emerson was too small to use for our mounting plate. The parts list is below:

Emerson ($45 Budget):

Description	Unit Price	Quantity	Subtotal
End Cap (Two Holes)	$1.00	4	$4.00
End Cap Blank	$1.00	4	$1.00
Cylinder	$1.00	4	$1.00
1/4-20 threaded rod	$1.02/ft	6.5 ft	$6.63
1/2” Diameter Steel Rod	$0.23/in	22 in	$5.06
1/2” x 2 1/4” Aluminum	$0.73/in	8	$5.84
1/2” Diameter Steel Rod - 1012 steel	$0.23/in	5.5 in	$1.27
1 7/8” Diameter Plastic Rod (piston)	$0.86/in	2 in	$1.72
1/4 - 20 hex nuts	$0.06	32	$1.92
Nylon pipe fittings (3/8” barbed x 1/4” NPT)	$0.55	8	$4.40
1/2” ID x 5/8” OD x 1/2” depth bronze bushings	$0.60	1	$0.60
12”x12”x1/4” Acrylic Sheet	$3.00	1	$3.00
		Total	**$42.44**

McMaster ($30 Budget):

Description	Unit Price	Quantity	Subtotal
White Plastic Corner Bracket: 7/8” x 7/8” x 7/8”	$0.33	16	$5.28
Hex Drive Flat Head Screw: 8-32, 1”	$9.30	1	$9.30
Steel Nylon-Insert Locknut: Zinc-Plated, 8-32	$3.49	1	$3.49
6” x 6” x 1/4” Multipurpose 6061 Aluminum Sheets	$8.85	1	$8.85
		Total	**$26.92**

2.3 Cost Analysis

2.3.1 Prototype Cost

Manufacturing Cost:

Part	Quantity	Hours	Cost/Hour	Subtotal
Yokes (4 rods & 2 yokes)	6	6	$40.00	$240.00
Crank Arm & Bases	1	5.5	$40.00	$220.00
Mounting Plates (4 sides & End & Face)	5	4.5	$40.00	$180.00
Drive Shaft & Support	2	1.5	$40.00	$60.00
End Caps	4	4	$40.00	$160.00
Threaded Rods	20	1.5	$40.00	$60.00
Piston Heads	4	1.5	$40.00	$60.00
Total	**42**	**24.5**	-	**$980.00**

Design Cost:

Hours	Cost/Hour	Total Cost
36	$120.00	$4320.00

Prototype Cost = Manufacturing Cost + Design Cost + Material Cost
Prototype Cost = $980.00 + $4320.00 + $69.36
Prototype Cost = $5369.36

2.3.2 Production Cost, Single Production

Hole Quantity:

Part	Quantity	Holes/Part	Holes
Mounting Plate	1	13	13
Mounting Plates	4	9	36
Face Plate	1	6	6
End Plate	1	9	9
End Caps	4	1	4
End Drive Shaft	1	2	2
Crank	1	10	10
Yokes	2	1	2
Drive Shaft	1	1	1
		Total	**83**

Operation Quantity:

Operation	**Quantity**
Holes	83
Threadings	32
Reamings	0
Milled Flat Surfaces	44
Turned Straight Surfaces	0
Curved, Turned, or Milled Surfaces	0
Inches of Weld	0
Cuts	22
Hand Finished Edges or Surfaces	0
Bends	0
Total	**181**

Operation Cost:

Operations	**Cost/Operation**	**Total Cost**
181	$1.20	$217.20

Single Production Cost = Prototype Cost + Operation Cost

Single Production Cost = $5369.36 + $217.20

Single Production Cost = $5586.56

2.3.3 Production Cost, Mass Production

Mass Production Cost Per Pump = Prototype Cost/1000 + Operation Cost

Mass Production Cost Pump = $5369.36/1000 + $217.20

Mass Production Cost Per Pump = $222.57

2.4 Fabrication Timeline

WBS	Task	Assigned To	Start Date	Days	End Date
3	**Manufacturing**		**4/29**	**14**	**5/12**
3.1	Yokes	Govind C	4/29	14	5/12
3.2	Crank Arm	Mohammad M, Roman T	4/29	14	5/12
3.3	Mounting Plate	Michael E	4/29	6	5/4
3.4	Side Plates	Courtney K	5/5	4	5/8
3.5	End Plate	Courtney K	5/9	4	5/12
3.6	End Caps	Mohammad M	4/29	7	5/5
3.7	Drive Shaft	Mohammad M	5/6	7	5/12
3.8	Pistons	Eleanor G	5/8	5	5/12
4	**Integration**		**5/13**	**7**	**5/19**
4.1	Assembly	Michael E, Eleanor G, Mohammad M, Roman T	5/13	7	5/19
5	**Testing**	**All**	**5/19**	**1**	**5/19**
5.1	Finalize Pump	Courtney K, Mohammad M, Roman T	5/19	1	5/19

This is an excerpt from our Gantt chart, so the work breakdown structure starts at 3. Refer to Appendix E for the full work breakdown structure and a link to our Gantt Chart.

3 Supporting Information

3.1 Power Calculation

$\dot{x} = R\dot{\theta}\sin\theta$ from pump kinematics

$\dot{Q}(\theta) = -A\dot{x}(\theta)$

$P(\theta) = \rho g h \dot{Q}(\theta)$

$\dot{\theta} = \left(\frac{R_o}{R_1}\right)\omega \Rightarrow \theta = \left(\frac{R_o}{R_1}\right)\omega t$

$\dot{x} = \left(\frac{R_o}{R_1}\right)\omega R \sin\left(\frac{R_o}{R_1}\omega t\right)$

$Q(t) = \left|\left(\frac{R_o}{R_1}\right)AR\omega\sin\left(\frac{R_o}{R_1}\omega t\right)\right| + \left|\left(\frac{R_o}{R_1}\right)AR\omega\cos\left(\frac{R_o}{R_1}\omega t\right)\right|$ since we have 4 pistons $\frac{\pi}{2}$ rads out of phase

$P(t) = \left|\left(\frac{R_o}{R_1}\right)AR\omega\rho g h\sin\left(\frac{R_o}{R_1}\omega t\right)\right| + \left|\left(\frac{R_o}{R_1}\right)AR\omega\rho g h\cos\left(\frac{R_o}{R_1}\omega t\right)\right|$

$\bar{P} = \frac{4}{\pi}\left(\frac{R_o}{R_1}\right)AR\omega\rho g h$ since $\frac{1}{2\pi}\int_0^{2\pi}|\sin\omega t|\,dt = \frac{2}{\pi}$, $\frac{1}{2\pi}\int_0^{2\pi}|\cos(\omega t)|\,dt = \frac{2}{\pi}$

$\omega = 900$ rpm ≈ 94.25 rad/s $R_o = 9$ $R_1 = 70$ $\rho = 1000$ kg/m^3, $g = 9.8$ m/s^2 $h = 1.5$ m $R = 0.032$ m

$A = 0.0016$ m^2

$\bar{P} = 11.61$ W Theoretical

$P = \rho g h \dot{Q}$

$\dot{Q} = 8.6$ L/min $= 1.4\times10^{-4}$ m^3/s

$P = 2.06$ W Actual power going into useful work

The loss in actual vs theoretical power can be attributed to friction and other mechanical losses.

3.2 Functional Decomposition

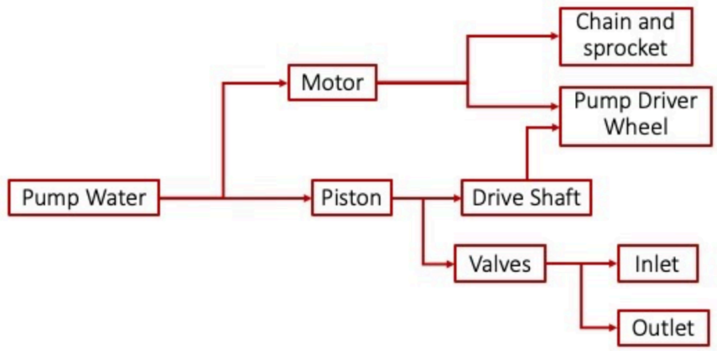


Figure 18: Morphological Chart

3.3 Morphological Chart

Our design is in the fourth row, second column (four-piston scotch yoke).

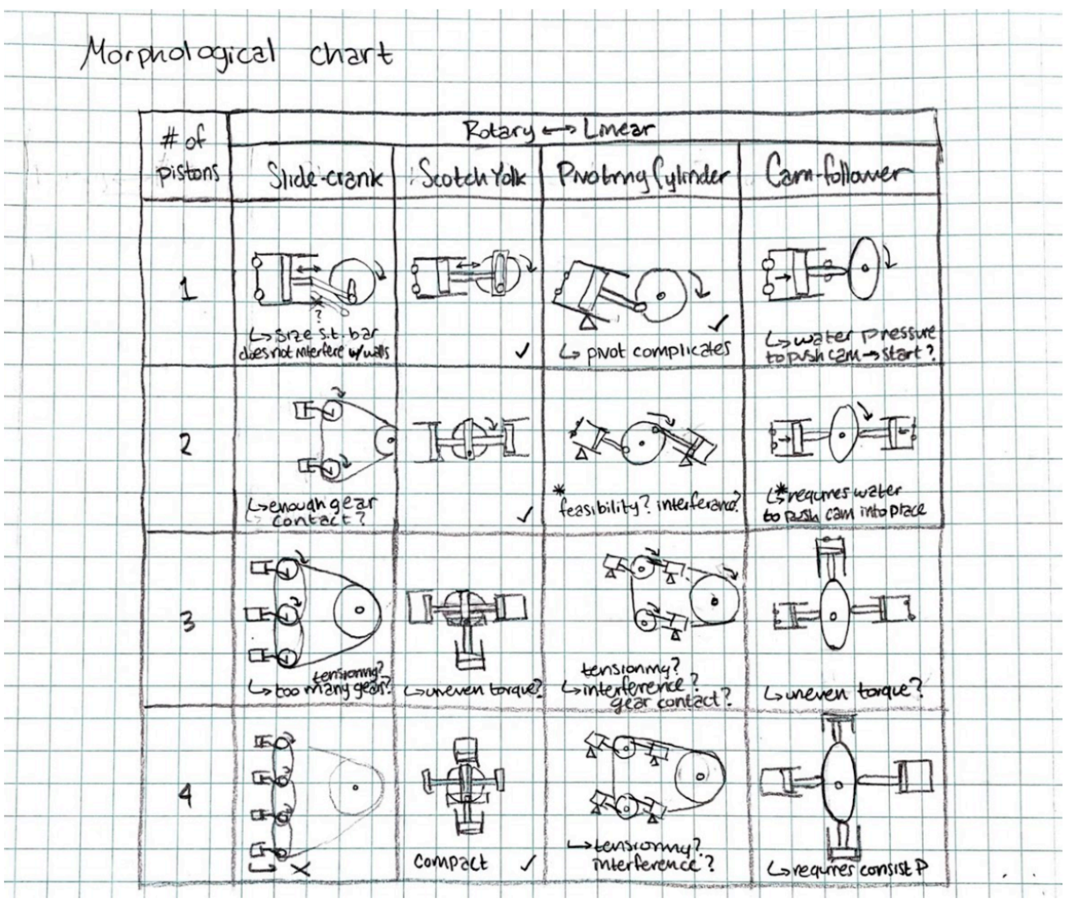
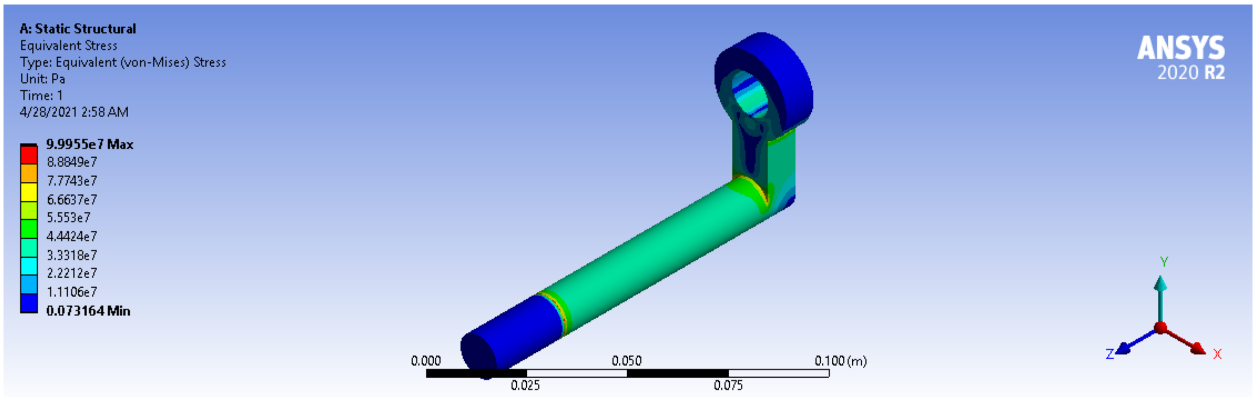


Figure 19: Morphological Chart

3.4 Analysis

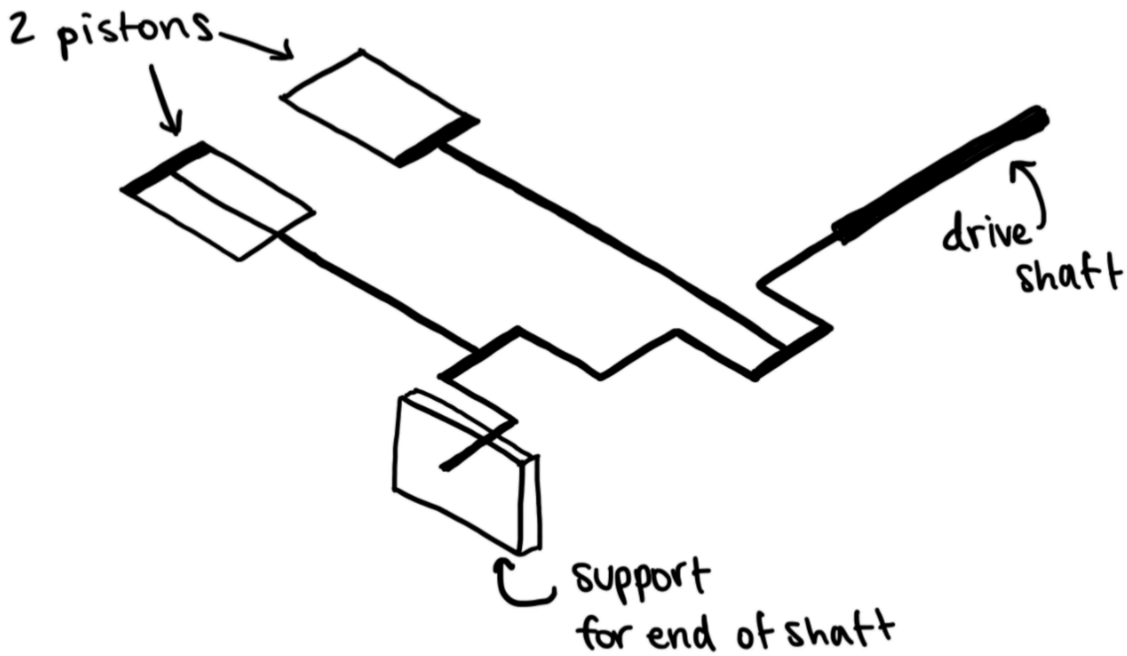
In order to see whether our design could hold up to the expected loads, we performed a static structural analysis in ANSYS on our crankshaft. We put in an applied torque boundary condition at the driven part of the shaft and a fixed boundary condition where the driveshaft contacts one of the yokes. We used about 50% of the stall torque of the motor as the boundary condition, since we never expect the driveshaft to support the full stall torque. An image of the post processing is shown below.



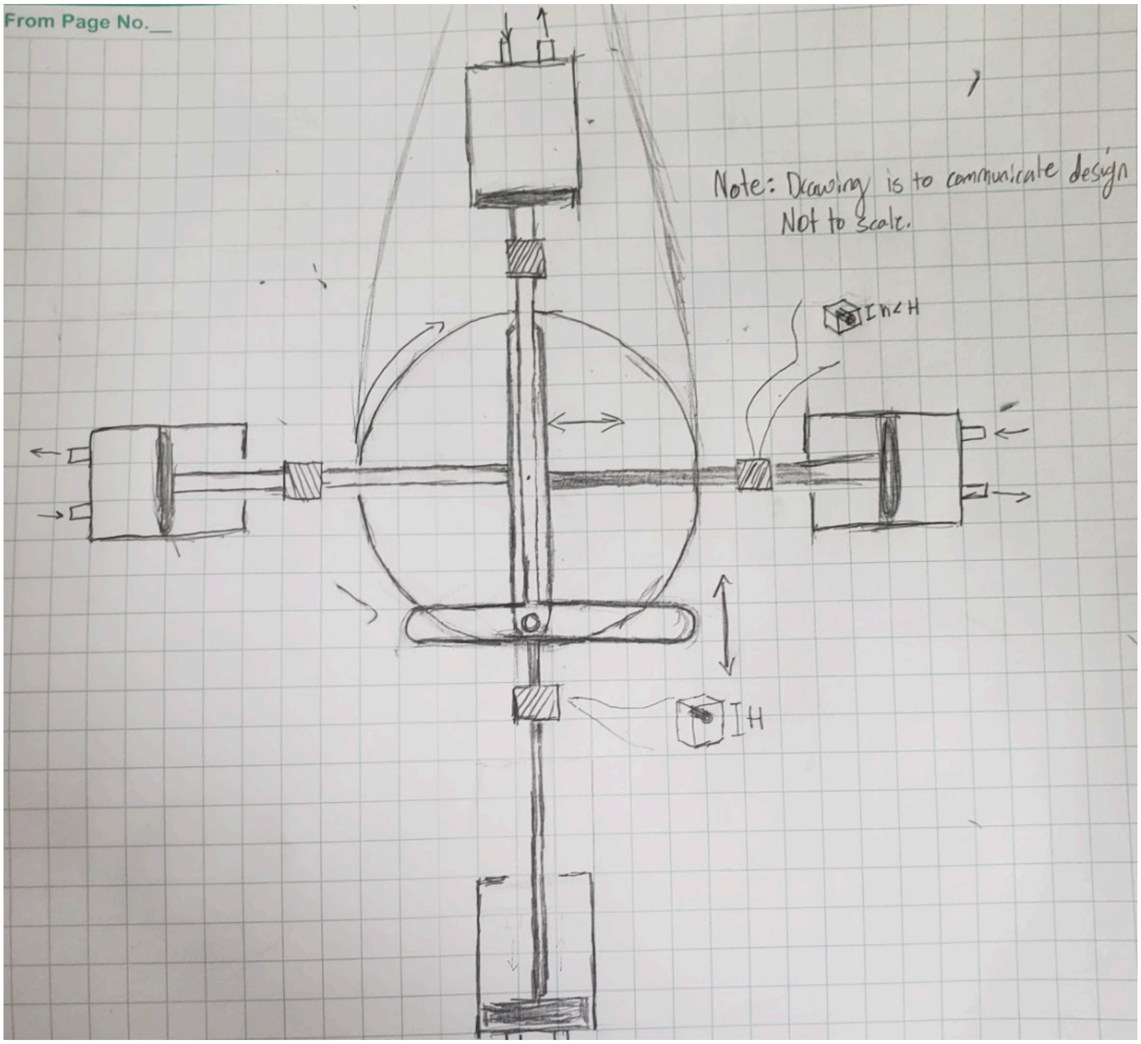
The maximum stress in this analysis is 100 MPa although this is likely inaccurately high since the 90 degree corner in the shaft where the max stress is experienced has a theoretically infinite stress concentration, which is unrealistic. The yield strength of 6061 Aluminum is 250 MPa, so we are very confident that our driveshaft will hold up.

A Sketches

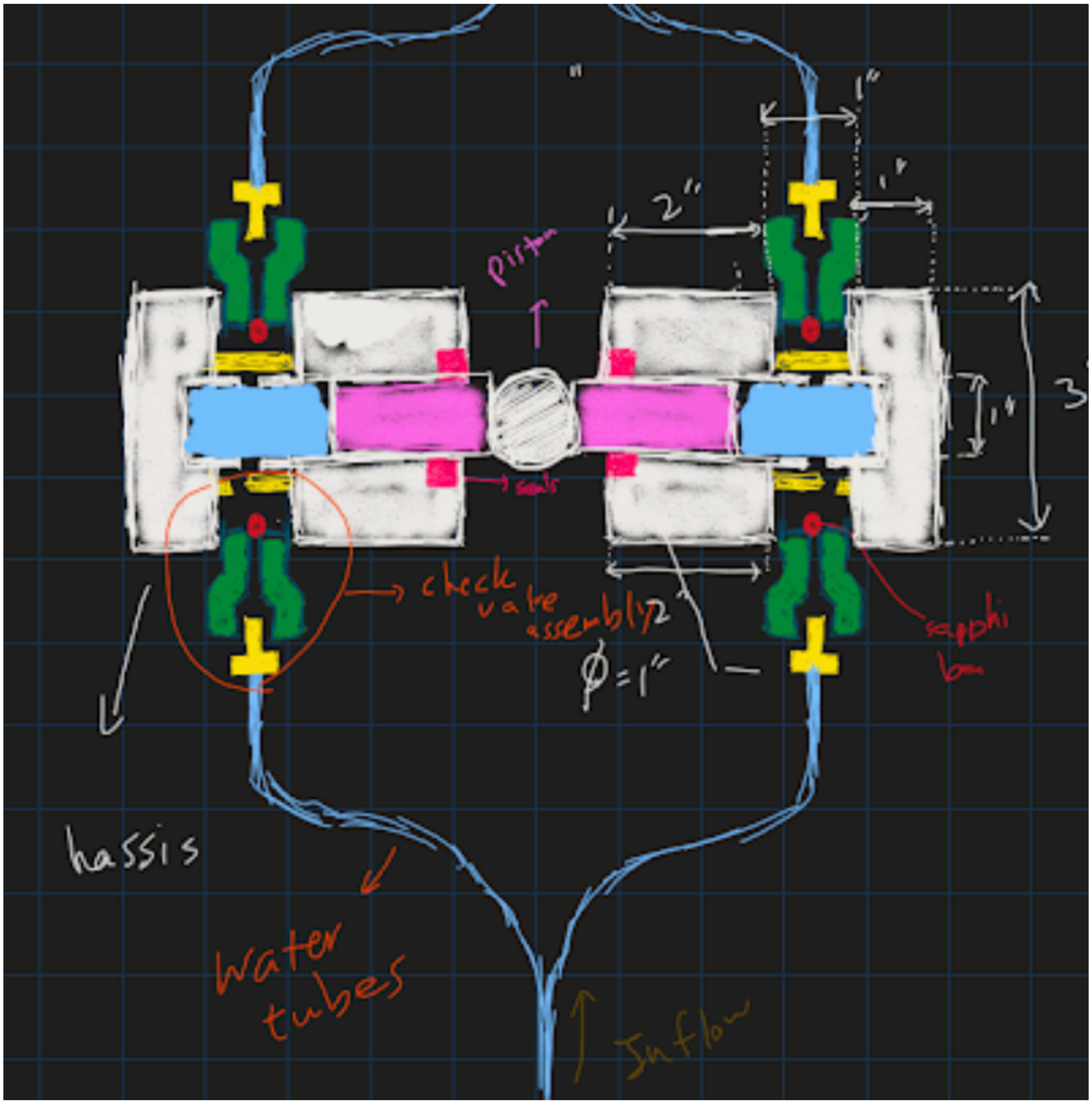
First group's sketch:



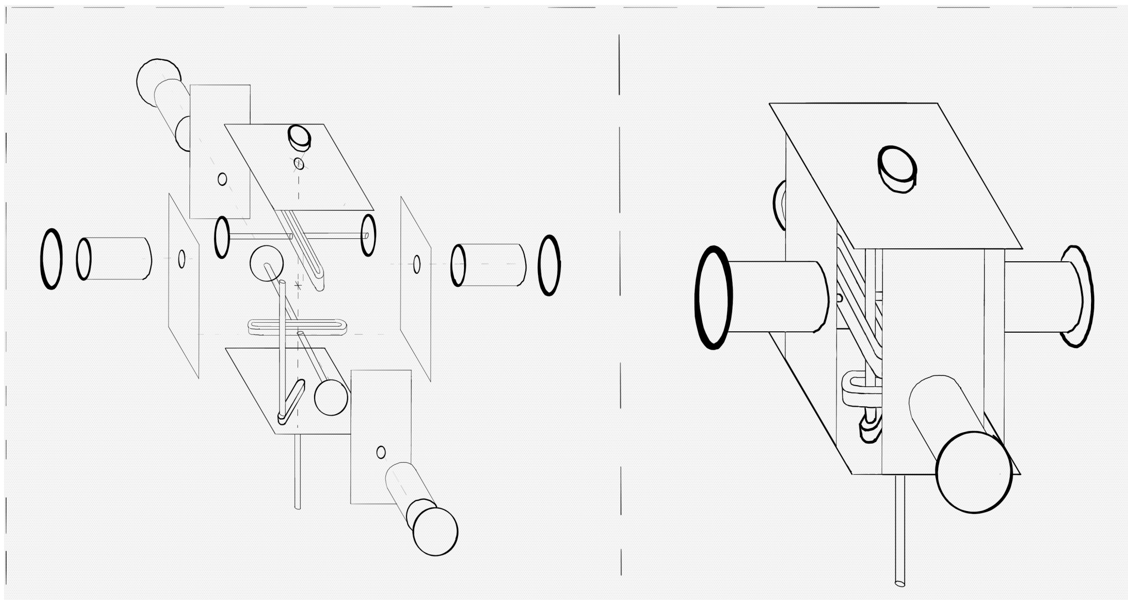
Second group's sketch:



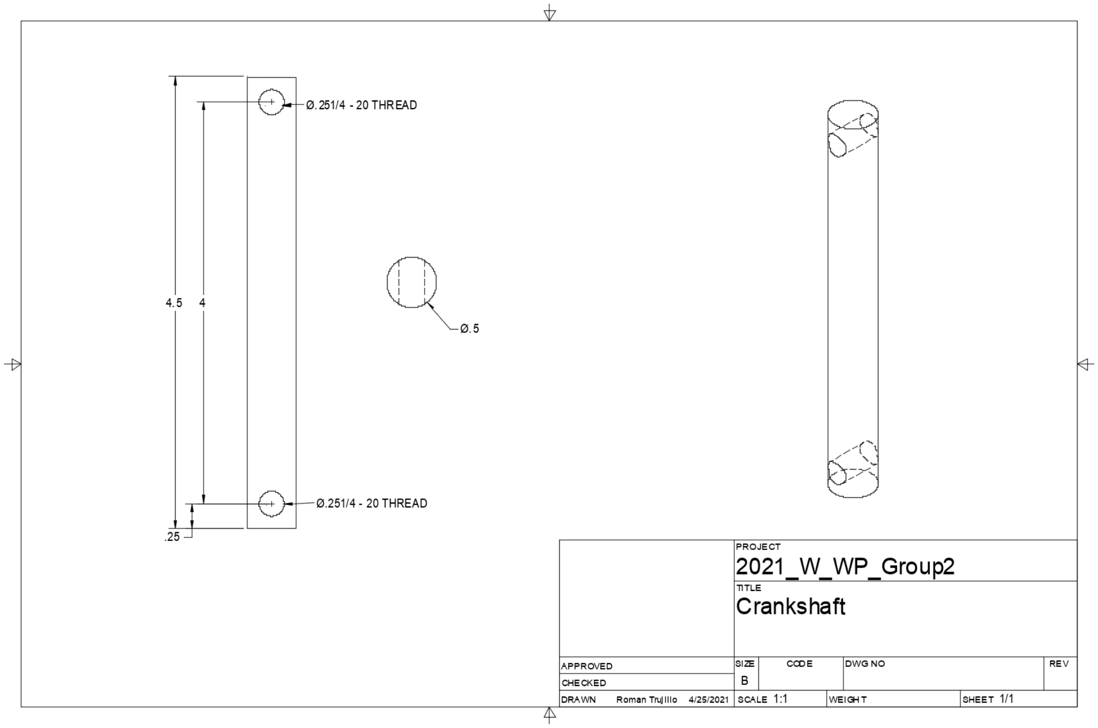
Third group's sketch:

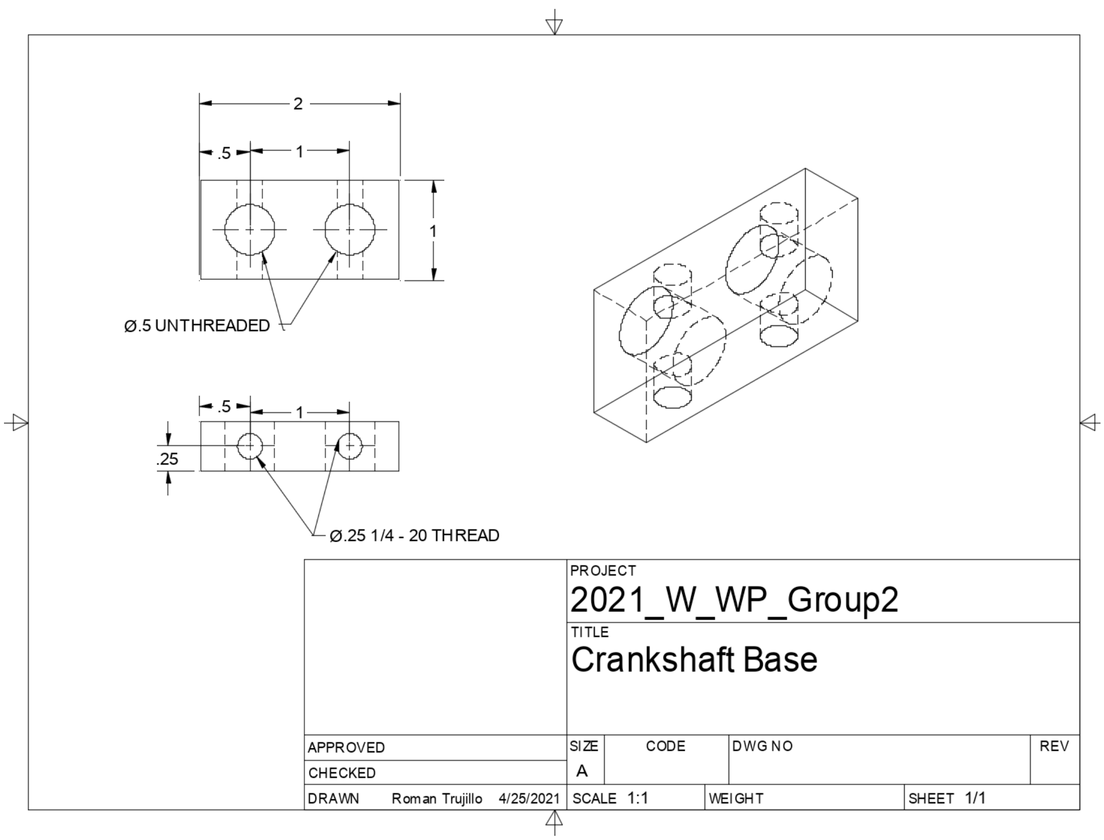


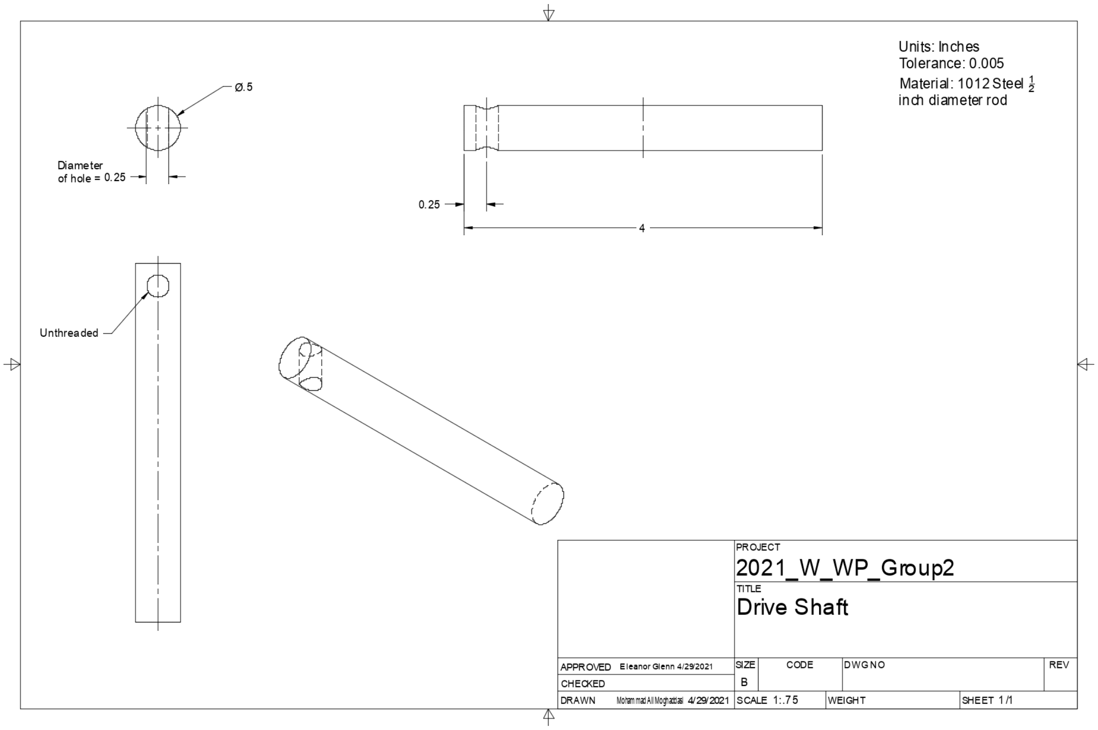
Draft design sketch:

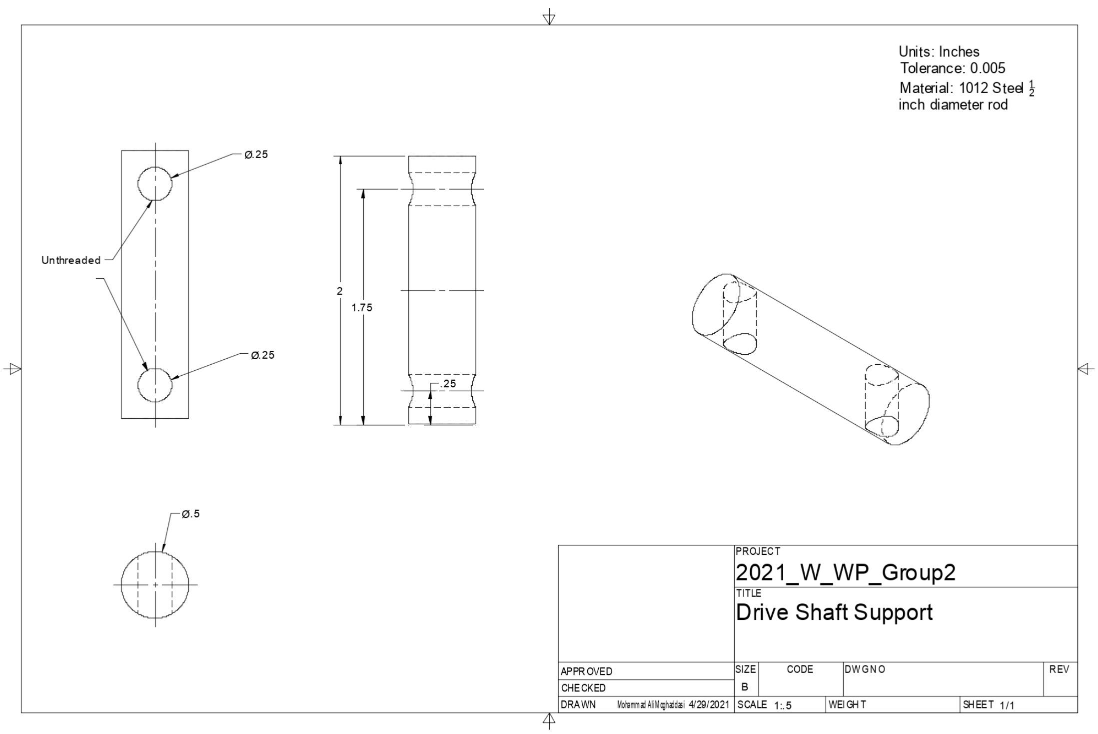


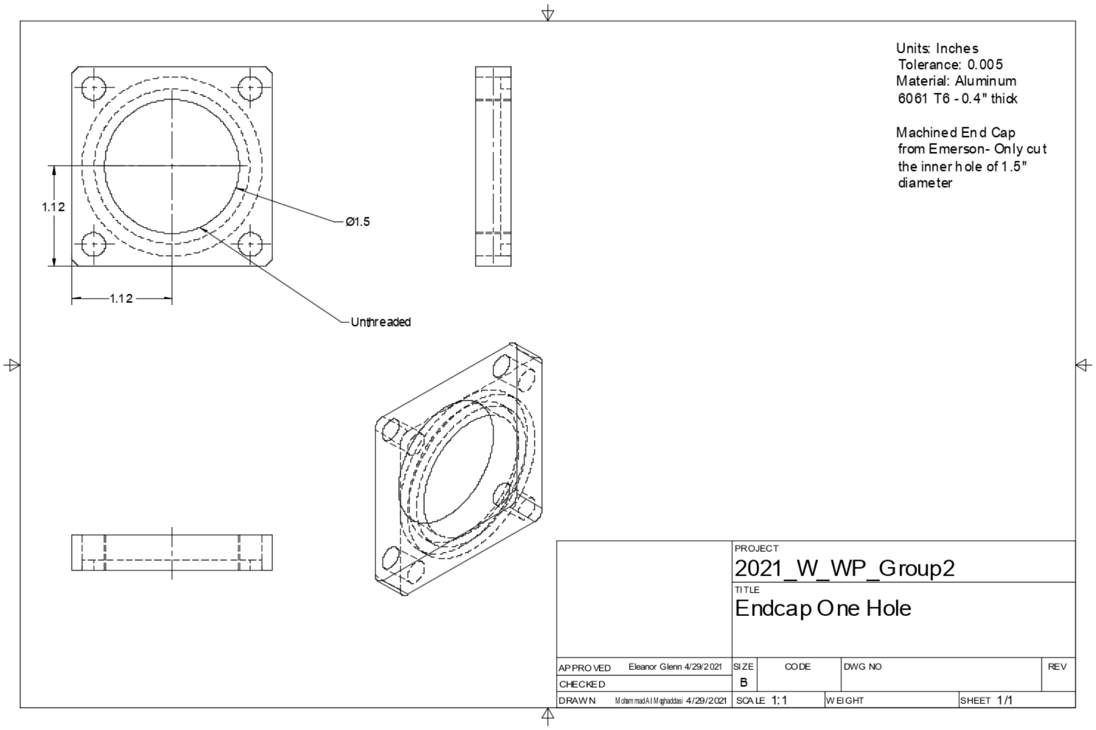
B Part Drawings

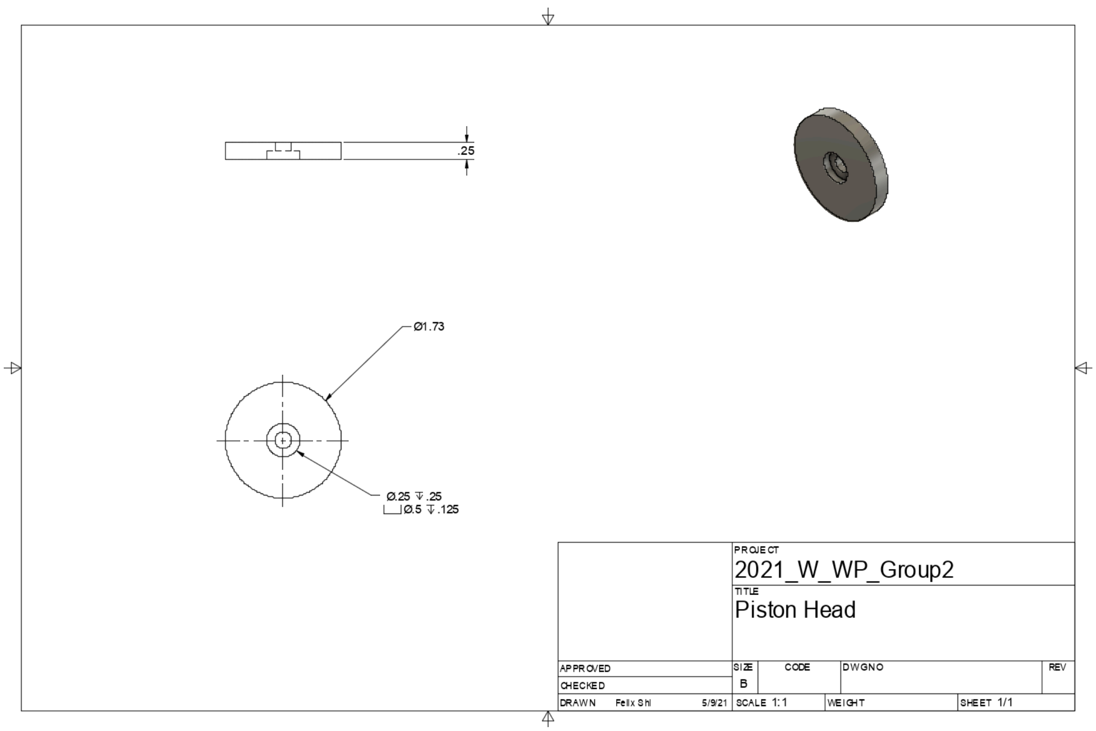


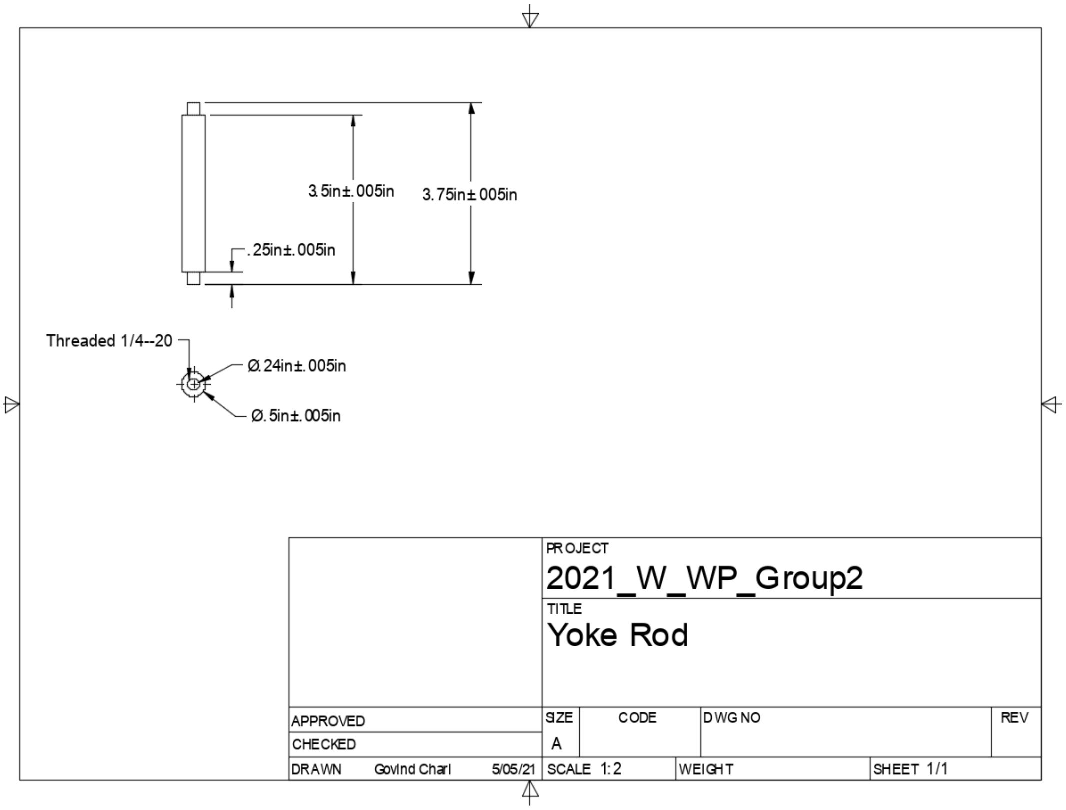


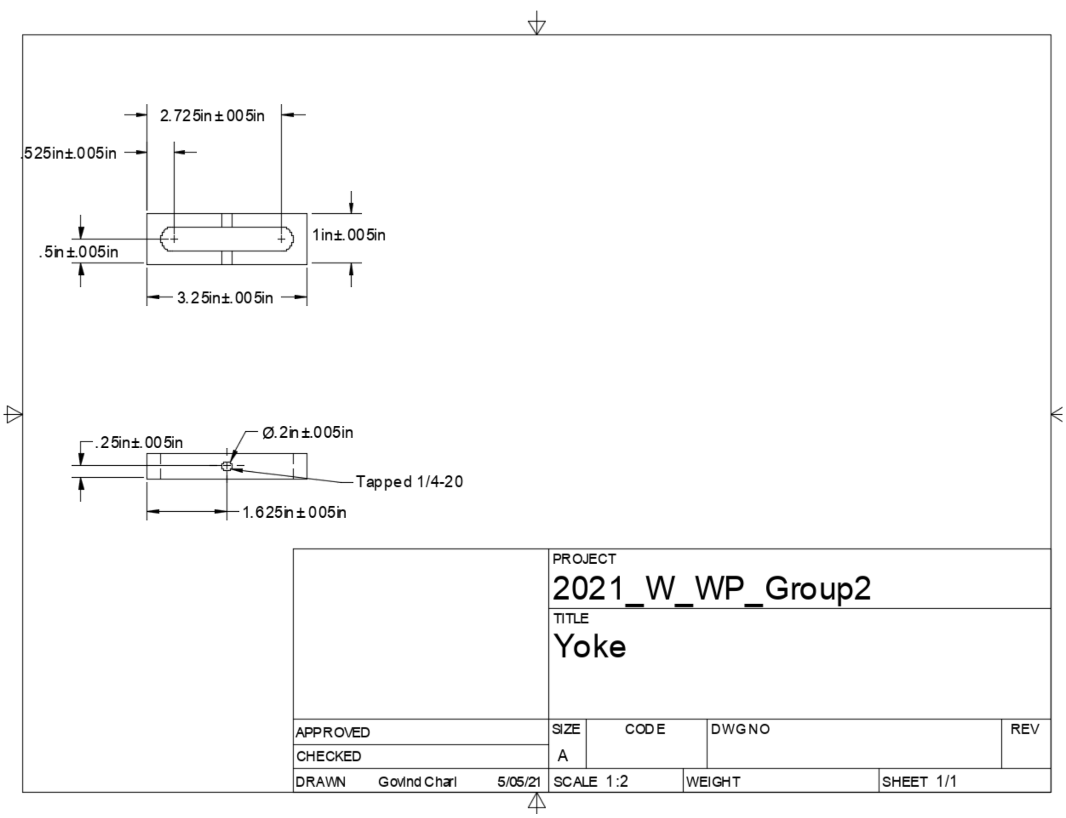

Units: Inches
Tolerance: 0.005
Material: 1012 Steel ½ inch diameter rod
Ø.5
Diameter of hole = 0.25
0.25
4
Unthreaded
PROJECT
2021_W_WP_Group2
TITLE
Drive Shaft
APPROVED Eleanor Glenn 4/29/2021
CHECKED
DRAWN 4/29/2021
SIZE B
CODE
DWG NO
REV
SCALE 1:.75
WEIGHT
SHEET 1/1


Units: Inches
Tolerance: 0.005
Material: 1012 Steel ½ inch diameter rod
Ø.25
Unthreaded
Ø.25
2
1.75
.25
Ø.5
PROJECT
2021_W_WP_Group2
TITLE
Drive Shaft Support
APPROVED
CHECKED
DRAWN 4/29/2021
SIZE B
CODE
DWG NO
REV
SCALE 1:.5
WEIGHT
SHEET 1/1


Units: Inches
Tolerance: 0.005
Material: Aluminum
6061 T6 - 0.4" thick
Machined End Cap
from Emerson- Only cut
the inner hole of 1.5"
diameter
1.12
1.12
Ø1.5
Unthreaded
PROJECT
2021_W_WP_Group2
TITLE
Endcap One Hole
APPROVED Eleanor Glenn 4/29/2021
CHECKED
DRAWN 4/29/2021
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1


.25
Ø1.73
Ø.25 ⟂ .25
⌴Ø.5 ⟂ .125
PROJECT
2021_W_WP_Group2
TITLE
Piston Head
APPROVED
CHECKED
DRAWN Felix Shi 5/9/21
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1


3.5in±.005in
3.75in±.005in
.25in±.005in
Threaded 1/4--20
Ø.24in±.005in
Ø.5in±.005in
PROJECT
2021_W_WP_Group2
TITLE
Yoke Rod
APPROVED
CHECKED
DRAWN Govind Chari 5/05/21
SIZE A
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1


2.725in±.005in
.525in±.005in
1in±.005in
.5in±.005in
3.25in±.005in
.25in±.005in
Ø.2in±.005in
Tapped 1/4-20
1.625in±.005in
PROJECT
2021_W_WP_Group2
TITLE
Yoke
APPROVED
CHECKED
DRAWN Govind Chari 5/05/21
SIZE A
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1

C Team Charter

From: W_WP_2—Govind Chari, Michael Errico, Eleanor Glenn, Courtney Kraft, Mohammad Ali Moghaddasi, Felix Shi, Roman Trujillo

To: MAE 2250 Instructors

Re: Team Charter

Date: 3/31/21

W_WP_2 Team Members:

Name	Email
Govind Chari	gmc93@cornell.edu
Michael Errico	me428@cornell.edu
Eleanor Glenn	epg46@cornell.edu
Courtney Kraft	cjk234@cornell.edu
Mohammad Ali Moghaddasi	mm3247@cornell.edu
Felix Shi	fcs54@cornell.edu
Roman Trujillo	rt427@cornell.edu

Team Logistics and Coordination:

A. The team will move documents around using the shared Google Drive folder. It is expected that members will check this folder for new information daily. Updates on progress and/or new information in the drive will be given via Facebook Messenger.

B. The team will store outside sources in a shared Google Doc that will be in the 2250_S21_W_2 folder. Citations will be formatted by hand or using the bibliography function in Google Drive.

C. The team will meet weekly on Sundays from 12:00 pm to 2:00 pm over Zoom.

Teamwork and Collaboration

A. Specialized skills

Name	Skills
Govind Chari	CAM/CNC: 3rd axis Haas in the shop, ANSYS: Static Structural, Transient Thermal, Steady-State Thermal, Fluent, CFX, CAD
Michael Errico	TIG Welding, Soldering, CAD
Eleanor Glenn	CAD, ANSYS, Cardboard Crafts, Machining, Drawings
Courtney Kraft	CAD
Mohammad Ali Moghaddasi	CAD, ANSYS (Static Structural)
Felix Shi	CAD, ANSYS
Roman Trujillo	Light MIG and TIG Welding Experience, CAD

B. Felix Shi will be the primary leader/scheduling coordinator and Courtney Kraft will be the secondary leader/scheduling coordinator.

   a. This role is defined by the following responsibilities:

      i. Making and leading Zoom meetings

      ii. Ensuring design/manufacturing deadlines are scheduled and monitoring that appropriate progress is being made

      iii. Ensuring that necessary materials are ordered from the Emerson Shop and the McMaster Carr shop as necessary

      iv. Managing the budget of the design

C. Mohammad Ali Moghaddasi will take the role of the Frontend Integrator and Eleanor Glenn will take the role of the Backend Integrator.

   a. The role of the Frontend Integrator is defined by the following responsibilities:

      i. Ensuring that any ordered parts are correctly sized and appropriate for the design

      ii. Preliminary Testings on parts

      iii. Ensure all parts fit each other after manufacture

      iv. Assembling the final water pump system

   b. The role of the Backend Integrator is defined by the following responsibilities:

      i. Sizes and identifies all necessary parts, sizes each component from the model

      ii. Ensure all models are of correct dimensions and correct functioning

      iii. Edits all drawings to send to manufacture

iv. Ensures everything is manufacturable

D. Design and Manufacturing

Name	**Responsibilities**
Govind Chari	Machining, Analysis
Michael Errico	Machining, CAD
Eleanor Glenn	CAD Manager, Paper Prototype
Courtney Kraft	CAD, Ordering
Mohammad Ali Moghaddasi	Machining, Paper Prototype
Felix Shi	CAD, Scheduling
Roman Trujillo	Machining, CAD

Each person doing CAD will design one part and send it to Eleanor to get checked. Once it is approved, they will create a part drawing for that part.

E. Everyone will have one grace day throughout the whole project to finish their deliverable. If a team member misses a deadline and doesn't have a grace day left, they will have to show up to lecture in a clown hat.

F. Please see Appendix E for the schedule

G. Each team member has discussed their desired grade for the project.

D Equations

$$\dot{x} = R\dot{\theta}sin(\theta) \tag{1}$$

$$\dot{Q} = -A\dot{x}(\theta) \tag{2}$$

$$P(\theta) = \rho gh\dot{Q} \tag{3}$$

E Gantt Chart

WBS	Task	Assigned To	Start Date	Days	End Date
1	**Planning**		**4/1**	**5**	**4/5**
1.1	Research	All	4/1	5	4/5
1.2	Team Charter	All	4/1	5	4/5
2	**Design**		**4/6**	**23**	**4/28**
2.1	Sketching	All	4/6	6	4/11
2.2	Cost Analysis	Michael E, Mohammad M	4/10	5	4/11
2.3	CAD Models	Govind C, Eleanor G, Courtney K, Felix S, Roman T	4/10	9	4/18
2.4	Parts List	Eleanor G, Courtney K	4/10	3	4/12
2.5	Paper Prototype	Govind C, Eleanor C	4/19	7	4/25
2.6	Part Drawings	Michael E, Eleanor G, Courtney K, Felix S, Roman T	4/19	7	4/25
2.7	Fabrication Plan	Govind C, Mohammad M	4/22	7	4/28
2.8	Analysis	Mohammad M	4/22	7	4/28
3	**Manufacturing**		**4/29**	**14**	**5/12**
3.1	Yokes	Govind C	4/29	14	5/12
3.2	Crank Arm	Mohammad M, Roman T	4/29	14	5/12
3.3	Mounting Plate	Michael E	4/29	6	5/4
3.4	Side Plates	Courtney K	5/5	4	5/8
3.5	End Plate	Courtney K	5/9	4	5/12
3.6	End Caps	Mohammad M	4/29	7	5/5
3.7	Drive Shaft	Mohammad M	5/6	7	5/12
3.8	Pistons	Eleanor G	5/8	5	5/12
4	**Integration**		**5/13**	**7**	**5/19**
4.1	Assembly	Michael E, Eleanor G, Mohammad M, Roman T	5/13	7	5/19
5	**Testing**	**All**	**5/19**	**1**	**5/19**
5.1	Finalize Pump	Courtney K, Mohammad M, Roman T	5/19	1	5/19

To view the entire Gantt Chart with the visual timeline, click on this link.