Water Pump Product Development Report

2250 Monday Lab
Team 1
Spring 2018

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Product Specifications

Max Power

Estimate flow rate from geometry of piston pump

1. Stroke length = Diameter of rotation of the yoke's pin
    a. Stroke length = 1.56 in
2. Max volume displaced = Stroke length * Cross-sectional area of piston
    a. Max volume displaced = 1.56 in * π * (.89 in)^2 = 3.88 in^3
3. RPS of scotch yoke = RPM of motor / (60 * Sprocket ratio)
    a. RPS of scotch yoke = 869 / (60 * 70/6) = 1.24
4. Flow rate = Max volume displaced * RPS of scotch yoke * 2 pistons
    a. Flow rate = 3.88 in^3 * 1.24 * 2 = 9.62 in^3/s = .157 L/s

Calculate power from flow rate

1. Power = Flow rate * Density of water * Head * Gravity
    a. Power = .0157 m^3/s * 1000 kg/m^3 * 1.5 m * 9.81 m/s^2 = 231.1 W

Max efficiency

Calculate efficiency from known powers

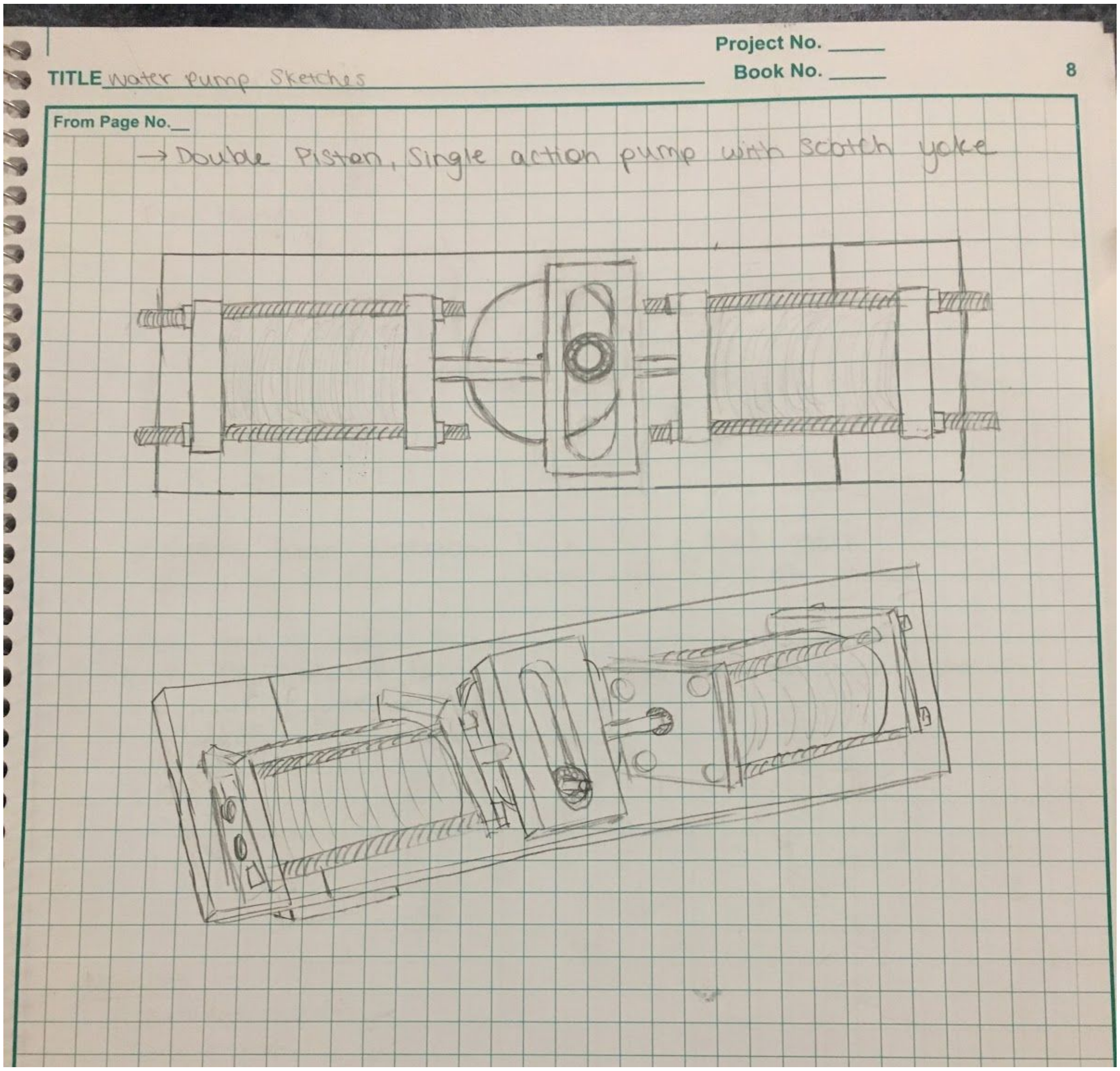
1. Max efficiency = Pump max power / Motor power supplied * 100%
    a. Max efficiency = 231.1 W / 560.0 W * 100% = 41.2%

Weight: 5.165 lbs

Mass Production Costs

Part Name	Cost per unit	Amount	Total Cost			
Retaining Ring	$0.08	2	$0.16		NRE Design Hours	20
Set Screw	$0.07	1	$0.07		Manufacturing Hours	15
1/4" Ball Bearing	$5.42	1	$5.42		Machined Parts/Surfaces	67
1/2" Ball Bearing	$6.27	1	$6.27		**Prototype Cost**	**$3,061.19**
3" Aluminum Cylinder	$5.49	1/2"	$5.49		**Single Production Product Cost**	**$3,141.59**
1/4"-20 1" Screws	$0.40	12	$4.80		**Product Cost per Pump**	**$83.46**
1/4"-20 Hex Nuts	$0.03	8	$0.24			
McMaster Total ($30)			**$22.45**			
Threaded Rods	$1.02	5	$5.10			
Two Hole End Cap	$1.00	2	$2.00			
One Hold End Cap	$1.00	2	$2.00			
3" Aluminum Cylinder	$1.00	2	$2.00			
2"x3" Aluminum Rod	$3.00	1	$3.00			
1/4" Steel Rod	$0.10	17	$1.70			
1/2" Steel Rod	$0.23	4	$0.92			
1/2"x4" Aluminum Stock	$1.18	14	$16.52			
1 7/8" Plastic Rod	$0.86	3	$2.58			
1/4"x2 1/4" Aluminum Stock	$0.73	4	$2.92			
Emerson Total ($45)			**$38.74**			
Total Material Costs			**$61.19**			

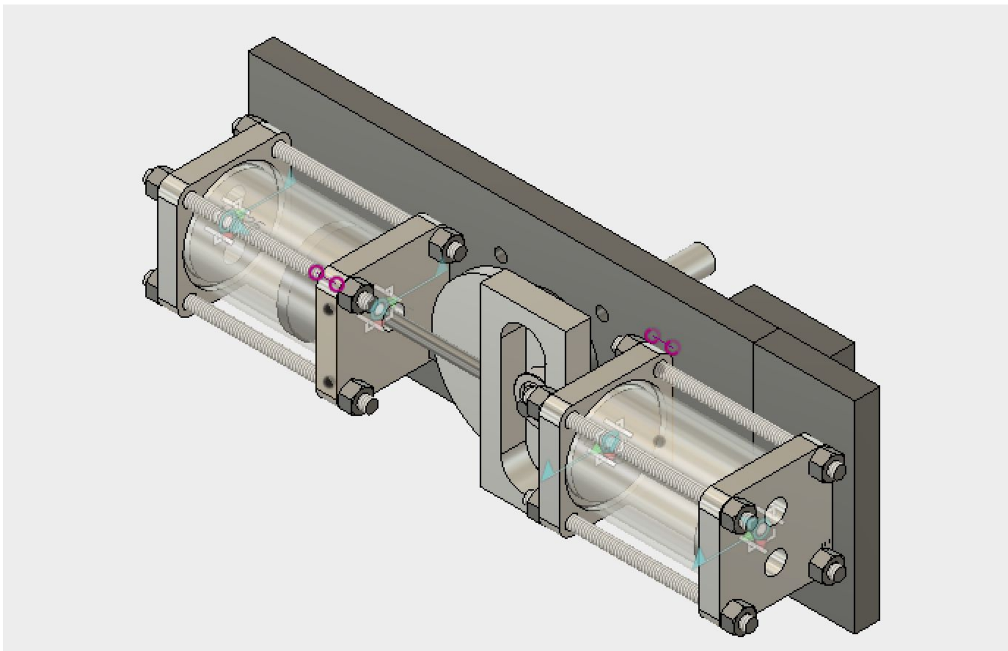
Hand Sketches



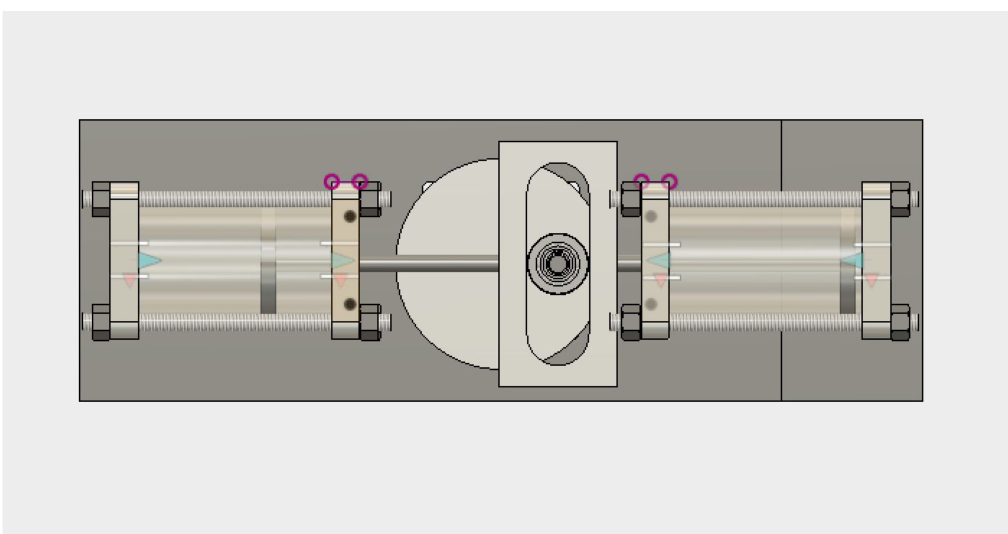
The image shows our team's sketch of the piston pump. It is a double piston, single action pump with a scotch yoke. We designed our CAD based on this drawing.

CAD Assembly

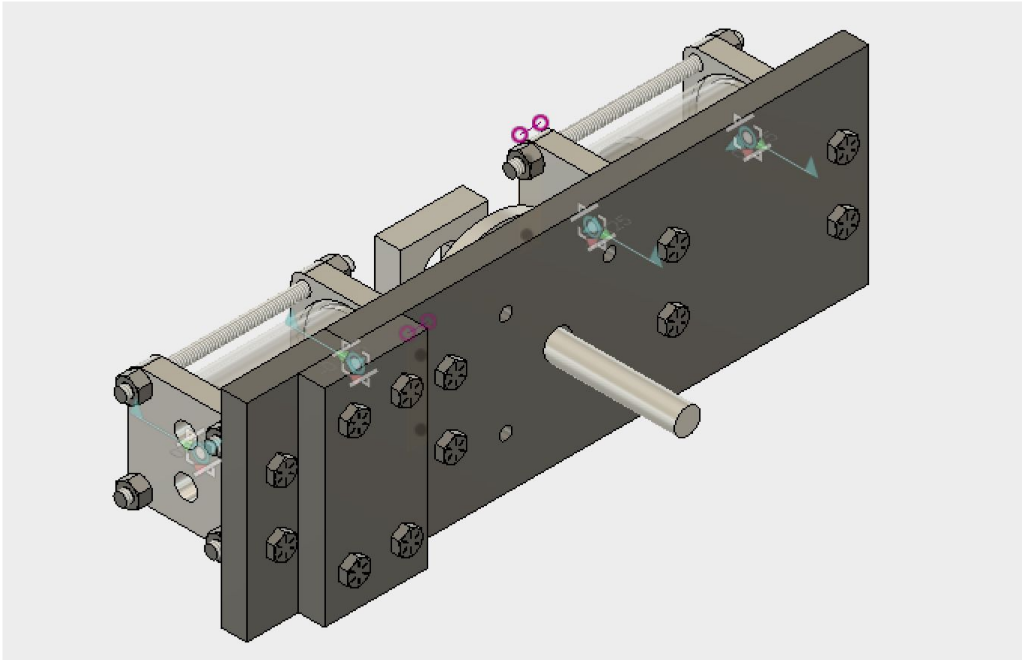
The CAD assembly was based on our sketch of the pump. We assembled our components in Fusion 360, which helped us ensure fit of components. Our machined pump is based on this CAD assembly.



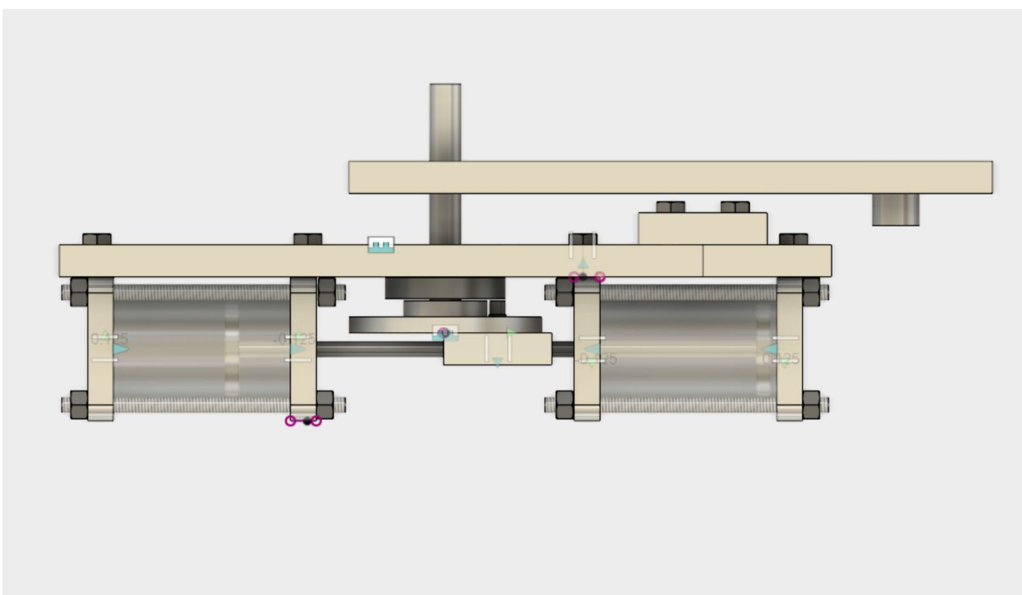
Front view from upper right corner



Front view



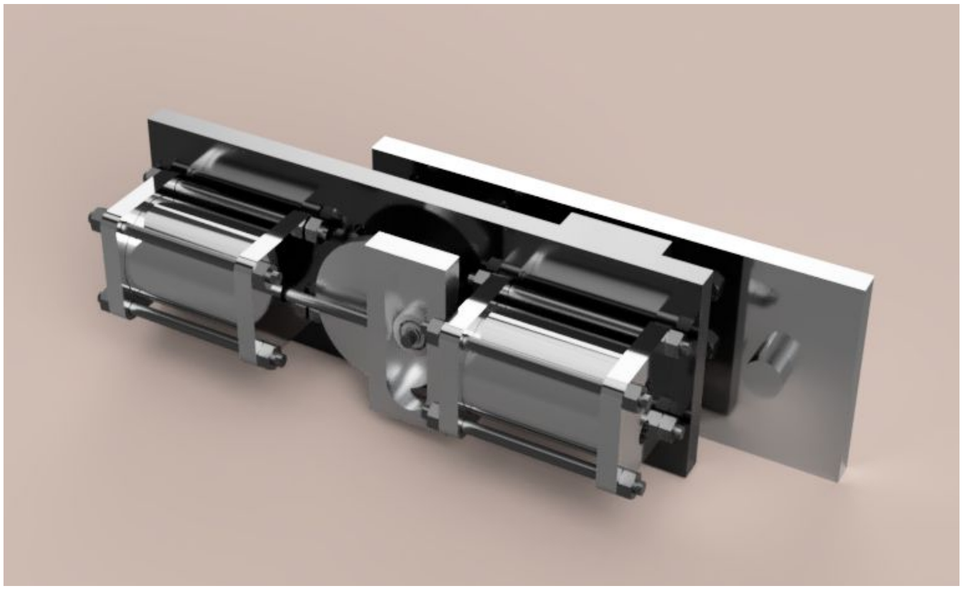
Back view from upper right corner



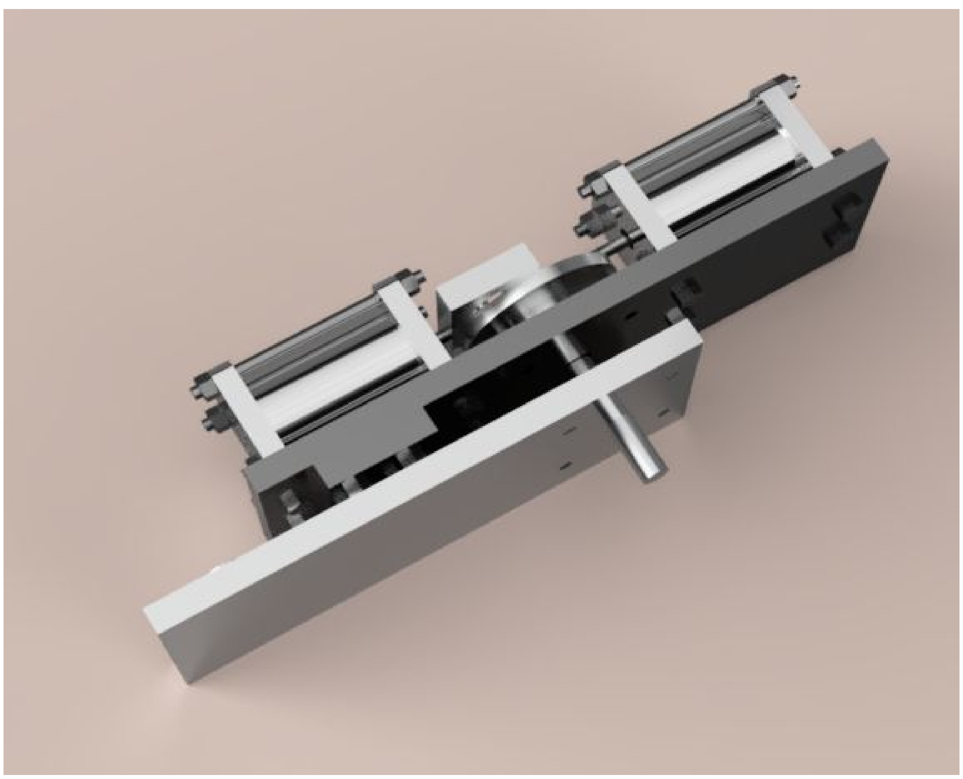
Top View

Rendered CAD Images

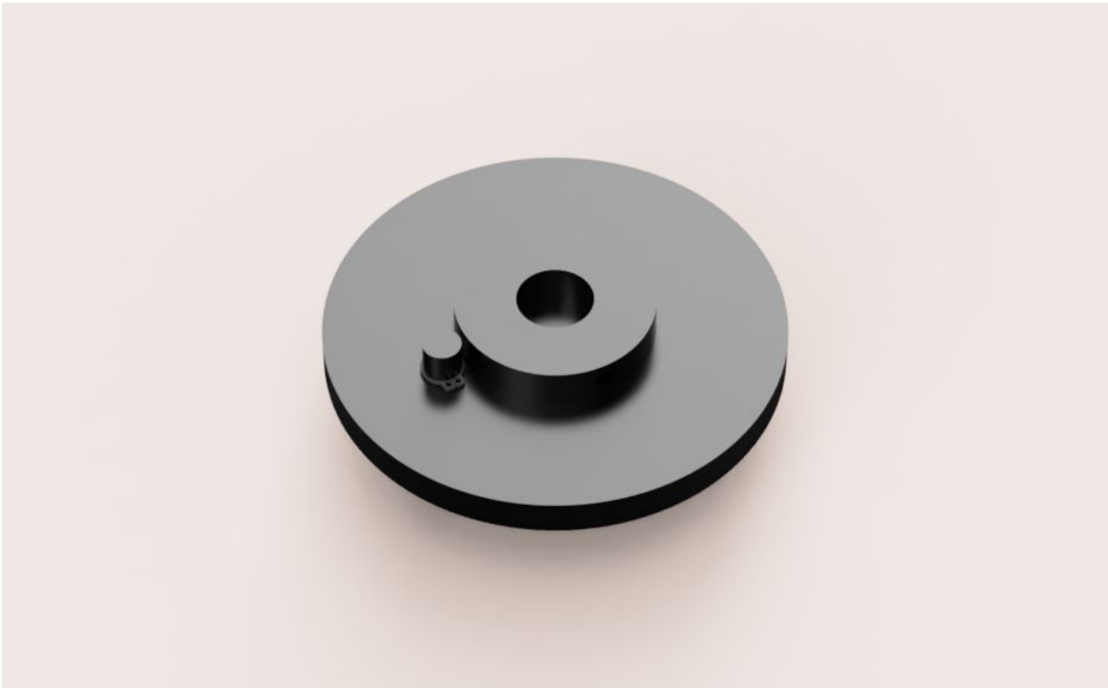
The rendered CAD images show us a realistic picture of how the pump should appear. It takes into account the properties of materials to show an image of the pump before any assembly.



Front view from upper right corner



Back view from upper right corner

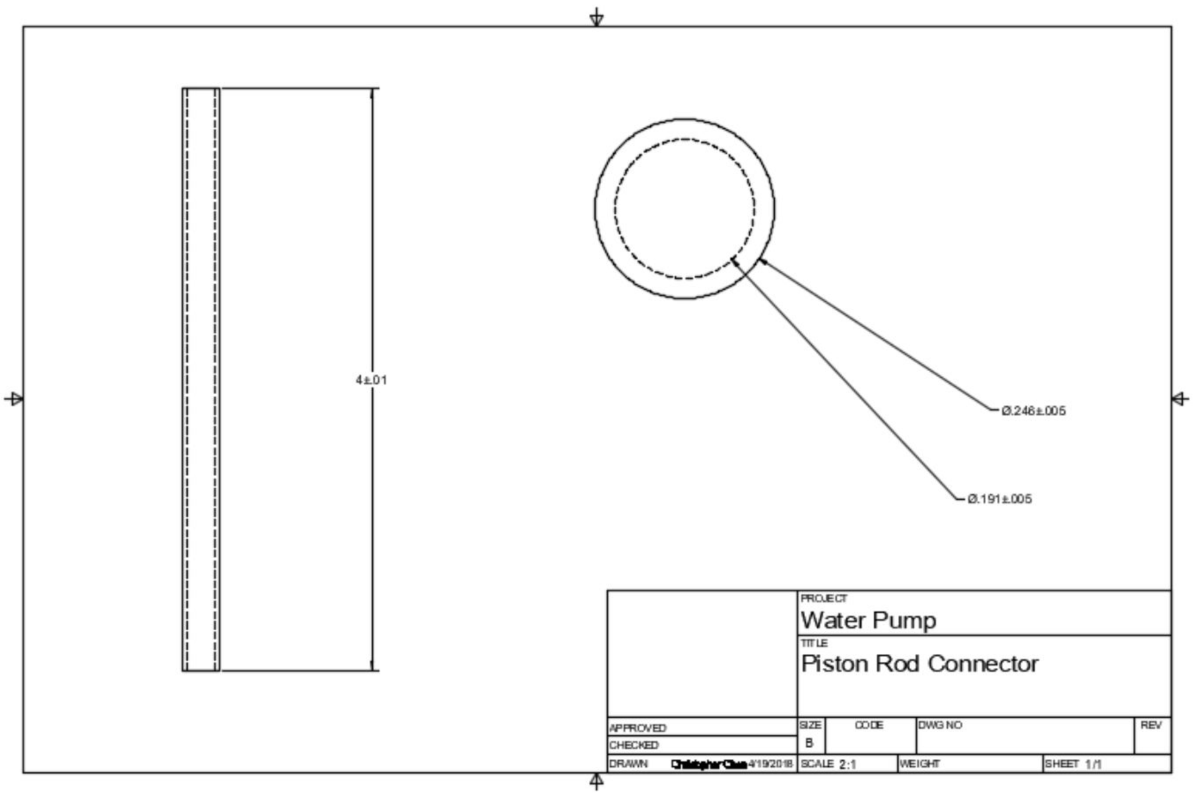


Pin and wheel, front-top view

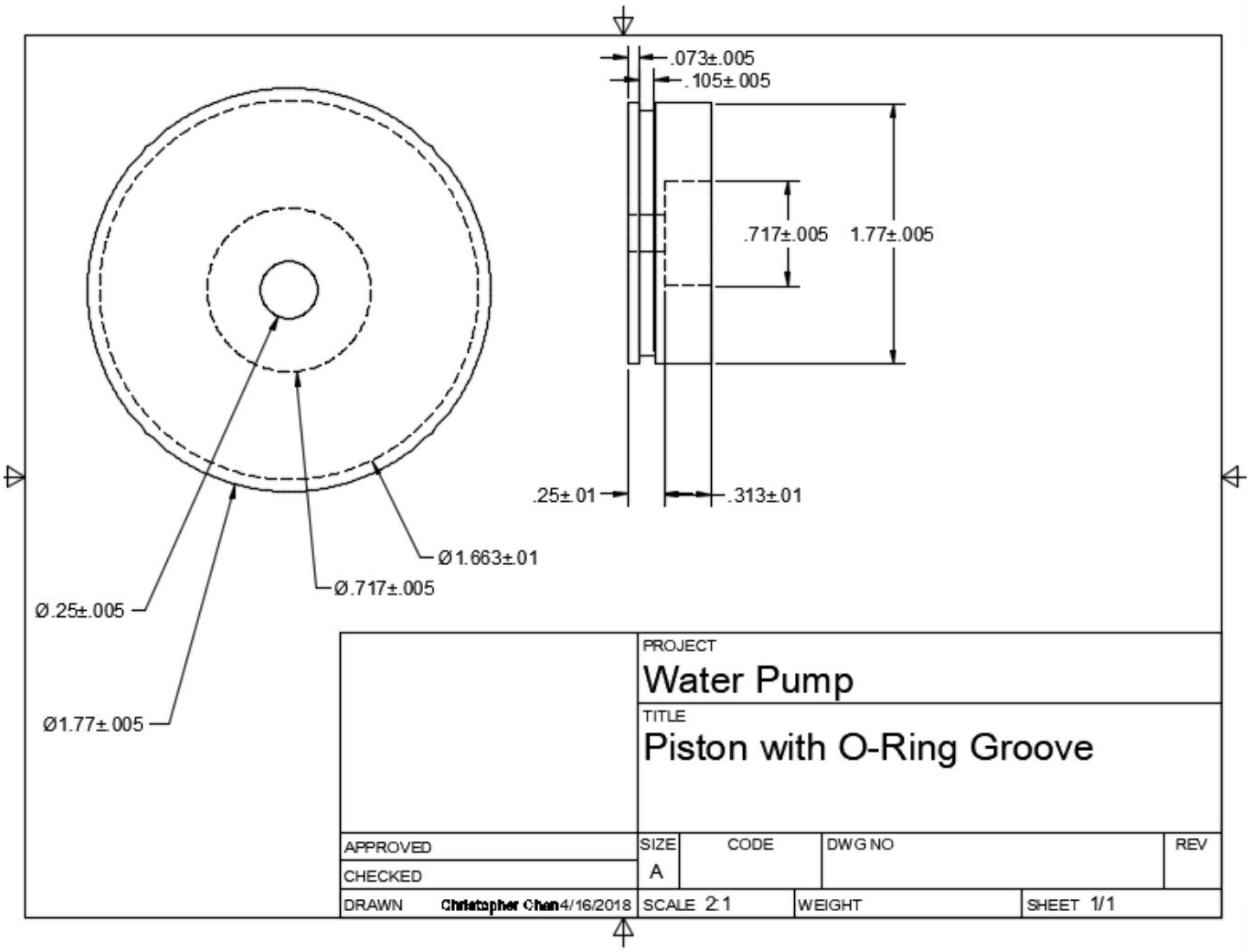
Pin and wheel, side view

CAD Drawings

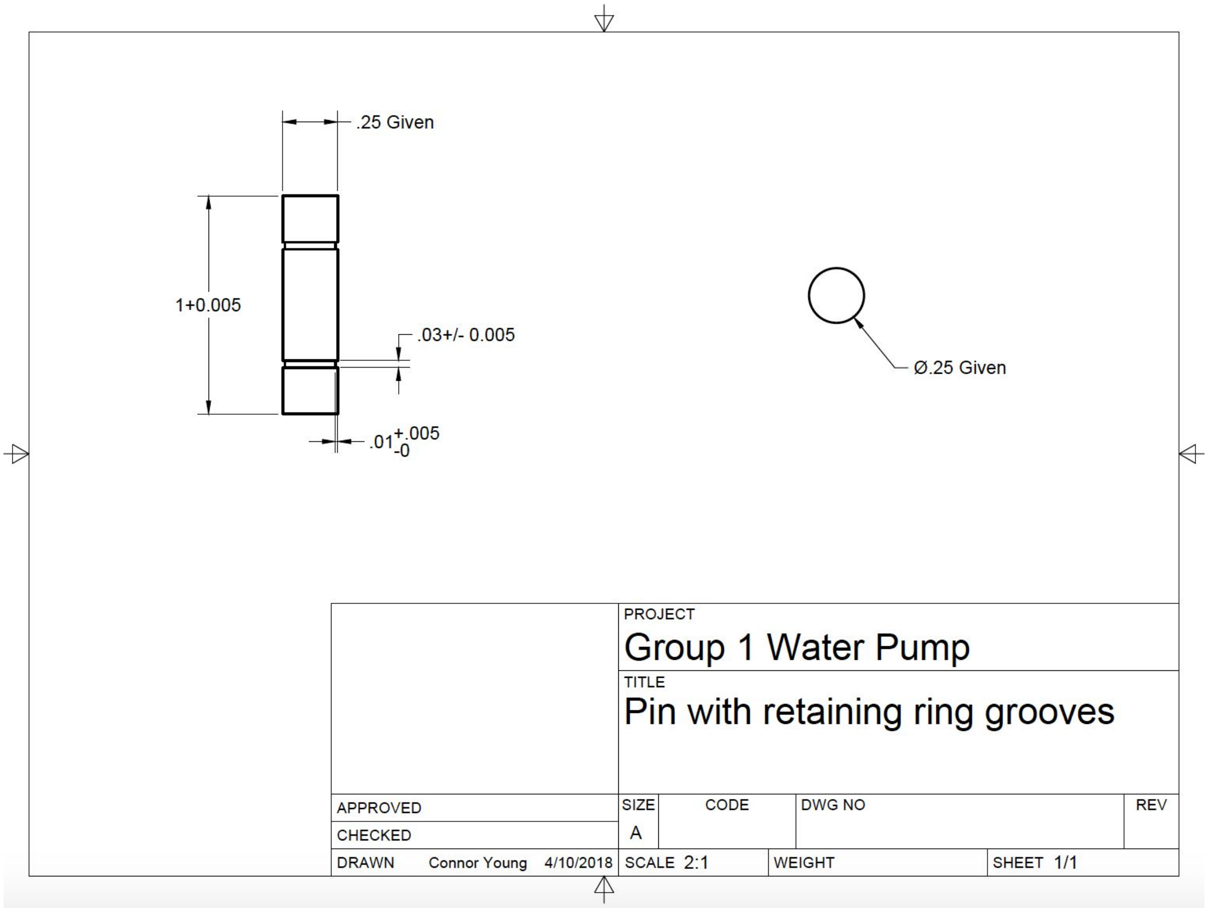
The CAD drawings were created from our final assembly. These were used in the machine shop to machine parts to their correct dimensions and tolerances.



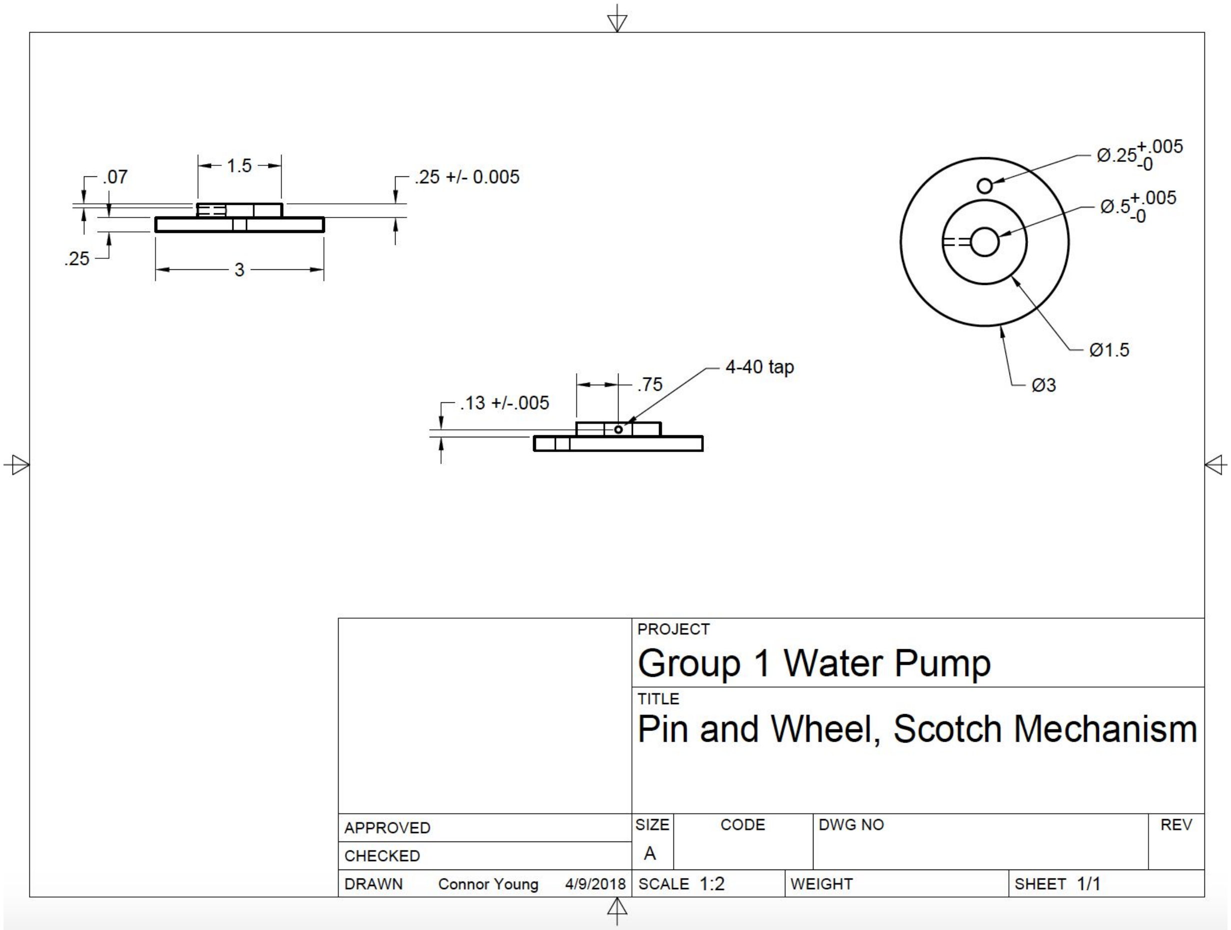
Piston Rods



Piston Heads

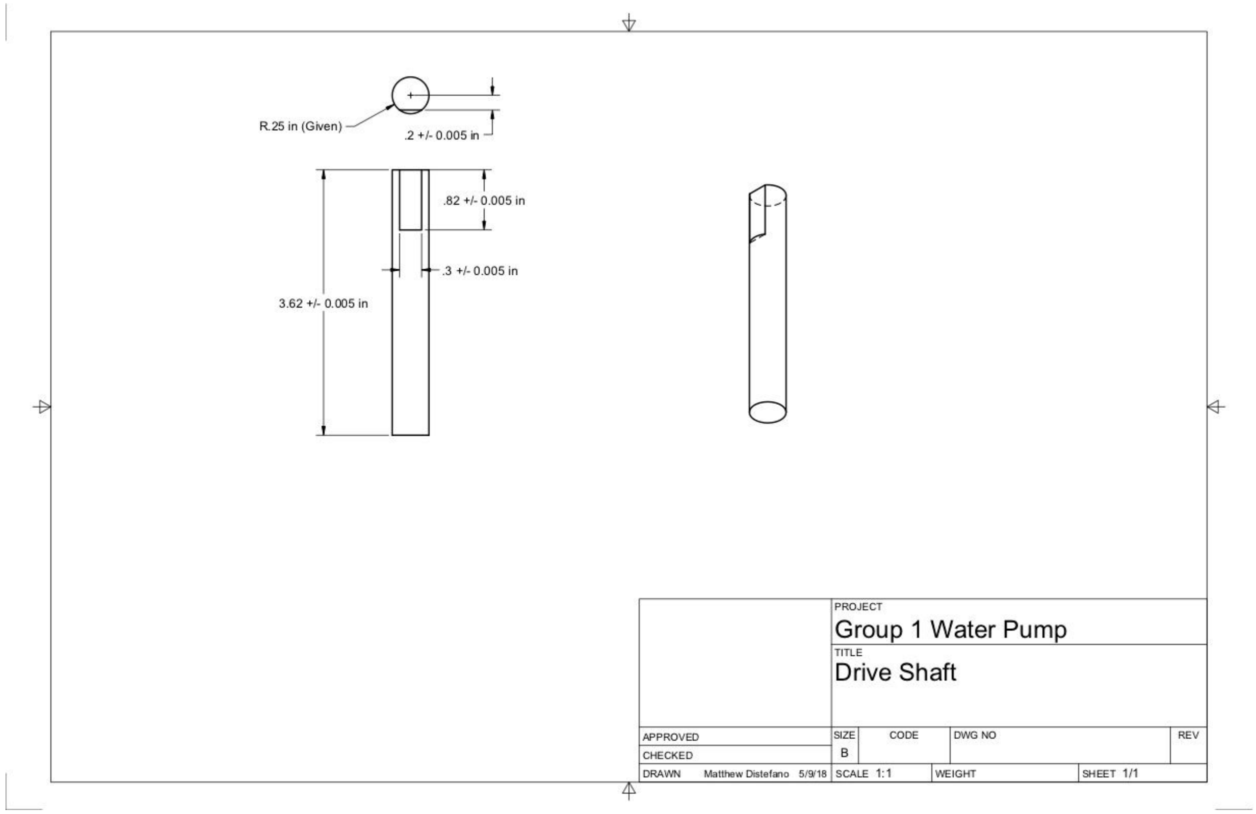


Pin (Holds bearing in scotch)

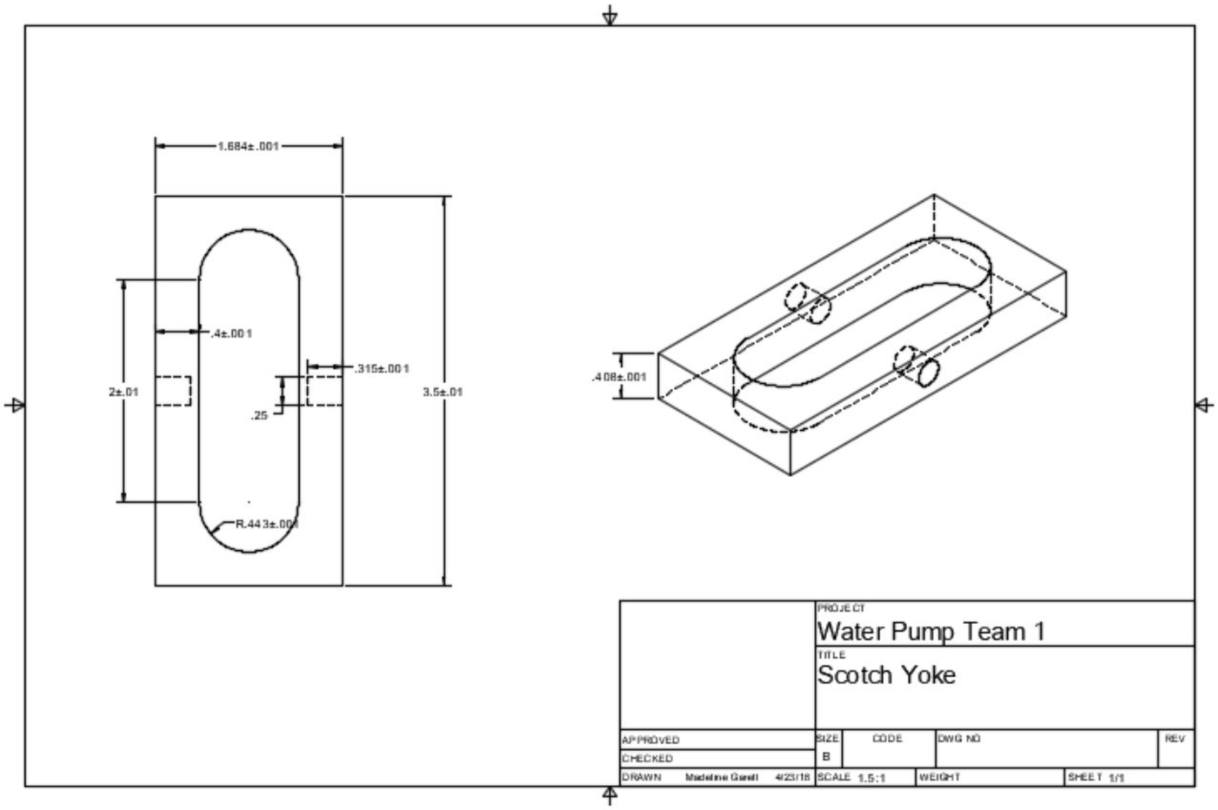


.07
1.5
.25 +/- 0.005
.25
3
.13 +/-.005
.75
4-40 tap
Ø.25 +.005 -0
Ø.5 +.005 -0
Ø1.5
Ø3
PROJECT
Group 1 Water Pump
TITLE
Pin and Wheel, Scotch Mechanism
APPROVED
CHECKED
DRAWN Connor Young 4/9/2018
SIZE A
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1

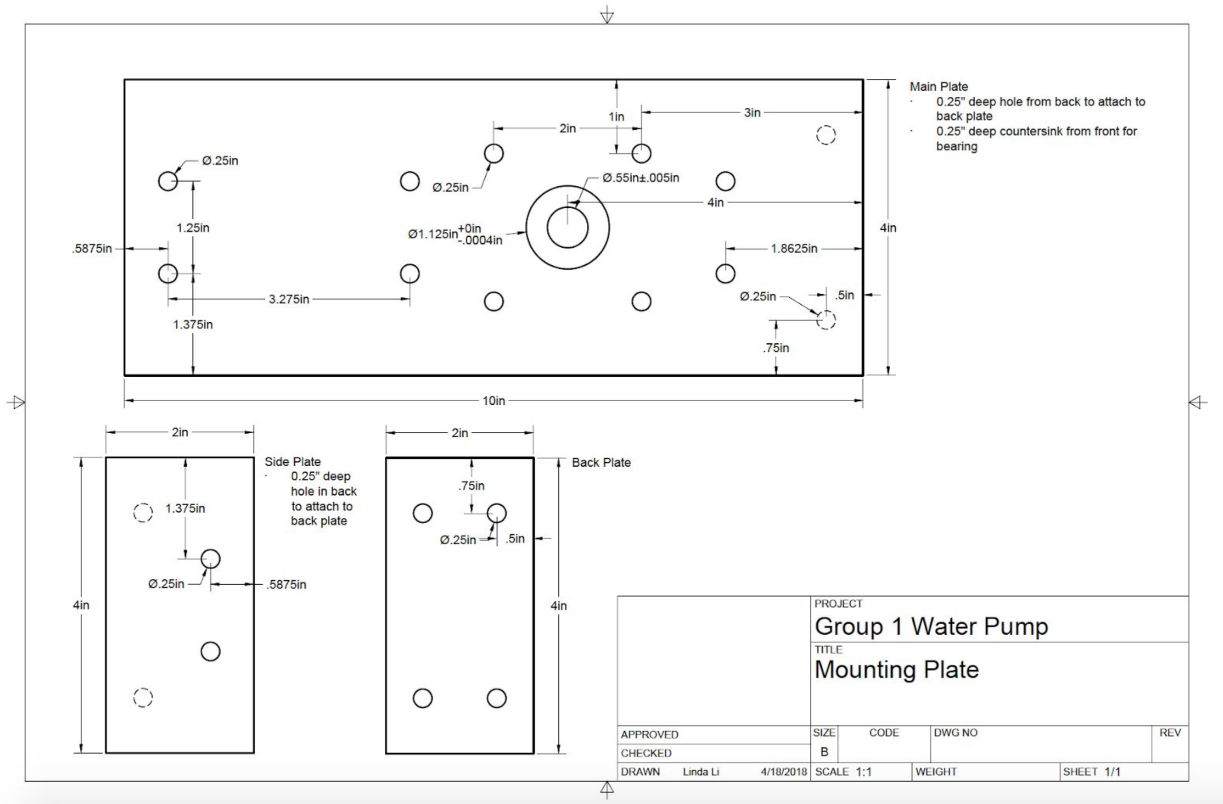
Wheel


R.25 in (Given)
.2 +/- 0.005 in
.82 +/- 0.005 in
.3 +/- 0.005 in
3.62 +/- 0.005 in
PROJECT
Group 1 Water Pump
TITLE
Drive Shaft
APPROVED
CHECKED
DRAWN Matthew Distefano 5/9/18
SIZE
B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1

Drive Shaft


1.684±.001
.4±.001
.315±.001
2±.01
.25
3.5±.01
R.443±.001
.408±.001
PROJECT
Water Pump Team 1
TITLE
Scotch Yoke
APPROVED
CHECKED
DRAWN
4/23/18
SIZE
B
CODE
DWG NO
REV
SCALE 1.5:1
WEIGHT
SHEET 1/1

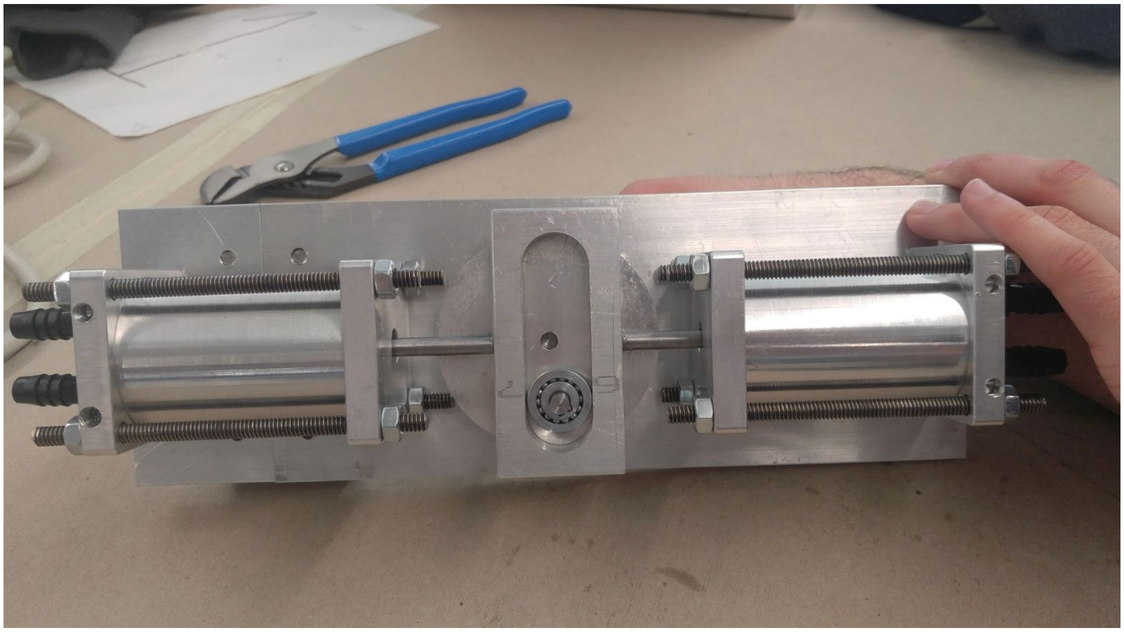
Scotch yoke



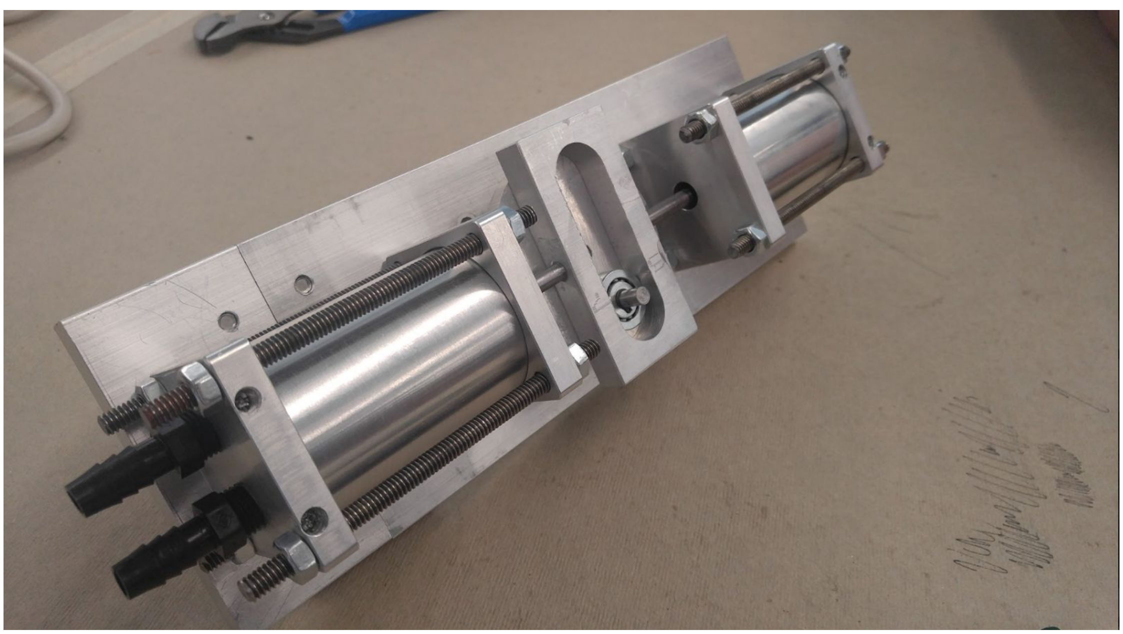
End plate (Mounting Plate)

Photos of Assembled Pump

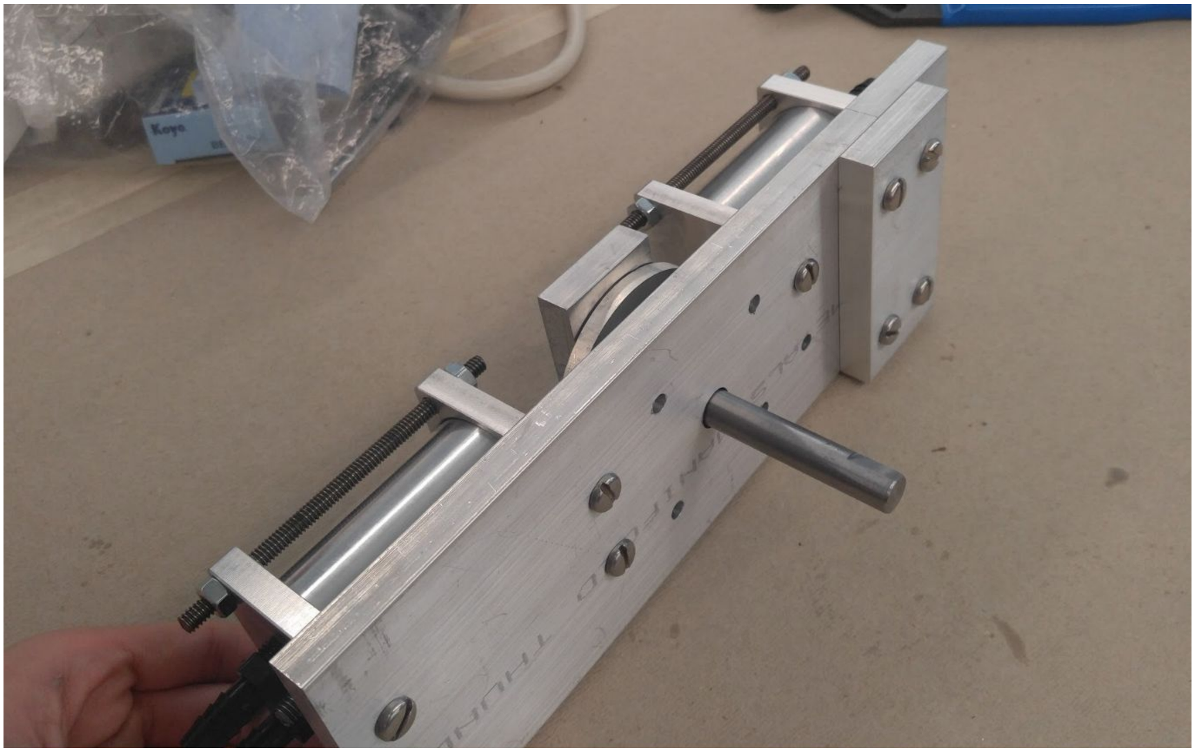
These photos show our assembled pump. It is based on the CAD and drawings from previous pages. It is machined using aluminum, PVC, stainless steel, and parts from the Emerson Machine shop and McMaster.



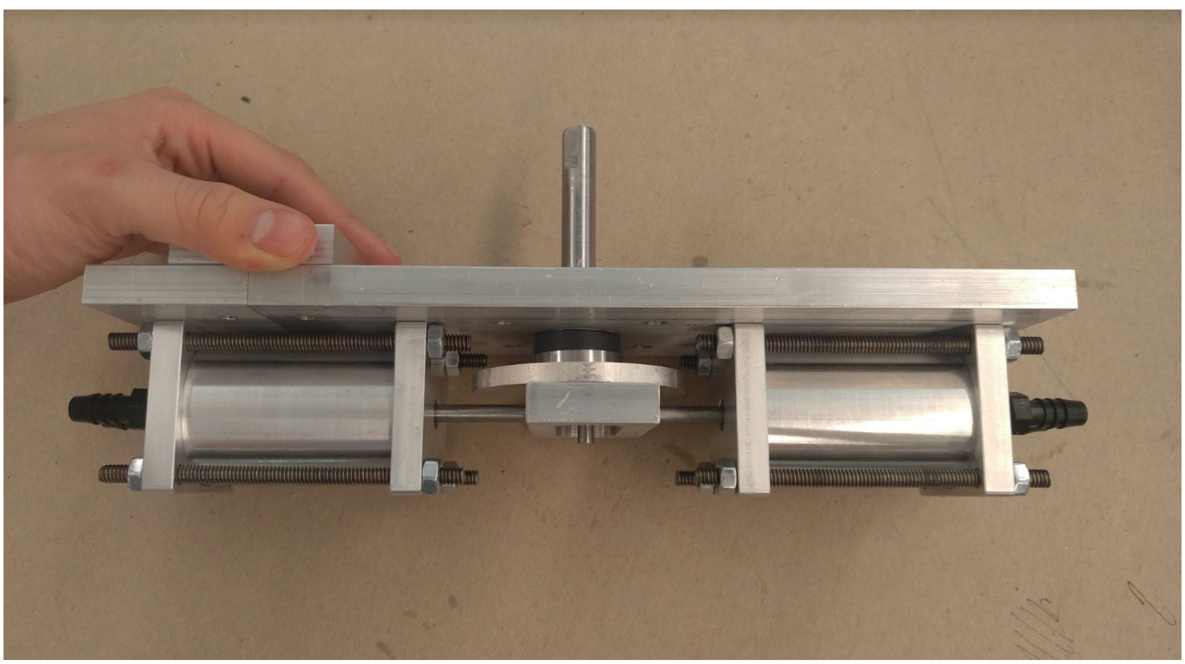
Front view



Front view from lower right corner



Back view from upper right corner, showing the end plate and drive shaft



Top View, showing connection between drive shaft, scotch yoke, and piston rods

Design Process

As our team came together, we decided to create a piston pump based on a Pugh Decision Matrix of piston, centrifugal, and gear pumps. Our initial design took manufacturability and functionality as priorities by minimizing the number of design constraints in the most number of parts. Using a morph chart, our initial design consisted of a single acting dual piston setup. We used PVC pistons heads with o-rings and connected the two pistons to the drive shaft using a scotch yoke. The scotch yoke was chosen because it converts rotational motion to linear motion in few parts. The availability and size of Emerson parts such as piston sleeves, rods, and piston end caps were our first constraint in the design. We placed these components into our initial CAD and sized the other components to fit the design and maximize our efficiency.

In order to make sure that we did not have binding on the scotch mechanism, we used a bearing attached to a quarter inch diameter pin rod, held in place axially using a retaining ring. This features in the second CAD render on page 10. Note that the retaining rings were spaced far apart enough to allow the pin to move axially, but also allowed a bearing to rotate freely. Thie ball bearing then interfaced with the yoke mechanism to transform the rotational motion of the wheel into smooth linear motion of the piston heads in the cylinders.

Following our initial design and first meeting, we made a few changes to focus on manufacturability. Binding was our main concern, so we added bearings to the drive shaft and slotted link. We changed the piston head material to aluminum because we thought it would be easier to machine and fit the o-ring. We wanted to CNC the scotch yoke because it was the component that needed to have the most accurate tolerances due to binding concerns. In order to fit both pistons on a base plate, our plate needed to be lengthened from the stock provided by Emerson, so we added 2 inches to the end plate using an overlapping piece.

Our changes were incorporated into the Final Design Presentation. Feedback from the TAs were positive, but there were some suggestions to our design. There was a concern with the metal-on-metal contact between the piston sleeve and piston head, so we went back to the original design using PVC. We also removed the o-ring, hopeful that our tight tolerances would be a sufficient seal. There was a concern that the threaded rods used for the piston rods would bend during operation. Although we calculated the bending force calculations to be extremely small, we switched material to stainless steel with threaded ends. In order to increase the stroke of the piston, we removed the nut at the top of the piston head, and instead decided to thread the piston head onto the piston rod. For the sake of time, and after input from advisors in the machine shop, we machined the scotch yoke mechanism on the mill instead of using a CNC.

Machining of the parts went smoothly, but there were some changes to address issues we had. The circular wheel with the roller bearing and piston head were both machined to size on the lathe and drilled using the mill with no issues. However, the thread holes on the end plate used to mount the piston heads and holes on the yoke were accidentally sized too large to tap for the screws that we had ordered. We resized the holes on the end plate to fit ¼’’-20 screws that we found in the extra parts bin. The yoke issue was remedied by using epoxy to adhere the piston rods to the yoke.

Assembly of the pump went smoothly, and we again focused on the smoothness of operation. We sanded the piston heads to minimize the friction between it and the piston sleeve due to remnants from machining. There was a gap between the back face of the wheel and the back plate, so we decided to quickly machine a spacer made from PVC to minimize the play. We tired to constrain all ranges of motion as much as possible. Our pump was able to move with minimal torque applied to the drive shaft and had no issues during the dry test.

The water test did not go as smoothly as our dry test. We discovered that we had sanded down the piston heads too far, and its loose seal allowed for too much leakage. Our first test yielded a pump rate of .5 L/min, an efficiency of 2.18%. We took apart our pump and added thin tape to the edge of piston heads to increase their diameter and fit. The fix was successful, but during a subsequent test, we discovered that the increase in required force on the pistons caused our set screw securing the wheel to the drive shaft to come loose. We brainstormed a solution and thought that reversing the drive shaft so that the smaller set screw would be able to sit in the groove we originally made for the motor set screw would be enough to hold the set screw. Our idea was that the set screw on the motor gear was large enough hold without a flattened groove on the drive shaft. In our third test, our fixes were successful, and we were able to increase our pump output tenfold to 5 L/min, giving our pump an efficiency of 21.8%.