



Cornell University

MAE 2250 Wind Pump



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1. Introduction

1.1. Team Members and Communication Protocols

Team Member	Aviv Blumfield	Nick Serger	Malkiel Frager	Andrew Mathews	Priscilla Wong
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Our main method of communication was GroupMe and we created a Google Drive Folder where we share all information. The naming convention we used is: Name_revisionNumber. Our normal meeting times were during MAE 2250 lecture times with extra meetings scheduled as necessary.

1.2. Mission Statement

We are **PumpForward** and our goal is to “**Pump Communities Forward**” by providing a cheap and reliable water pumping alternative. By implementing our pump in communities in need of water relief in developing countries, our pump would create sustainable communities and help these developing countries grow.

1.3. Customer Specifications

The specifications provided by the customer as follows (problem statement provided via blackboard):

“Your customer is developing a water pump driven by wind power for energy storage. They have asked you to develop a small-scale prototype of an efficient piston water pump. The pump drive shaft attaches to a customer-supplied plate and sprocket as specified below. For the prototype, a commercial fan at a realistic wind speed of around 7 m/s will drive the wind turbine. The wind turbine blades have a radius of 0.75 m. As a prelude to this project, you will have measured the torque and power characteristics of the turbine.”

2. Phase 0 - Planning

2.1. Project Timeline

2.1.1. Gantt Chart

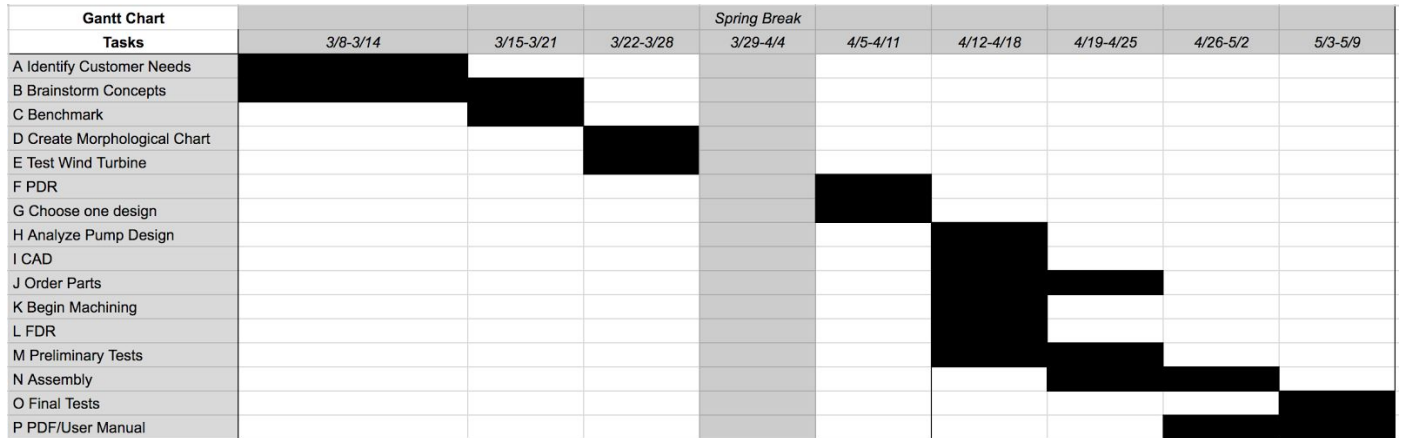


Figure 1: The Gantt chart was modified over time to reflect changes in our schedule. This is the final version

2.1.2. PERT Chart

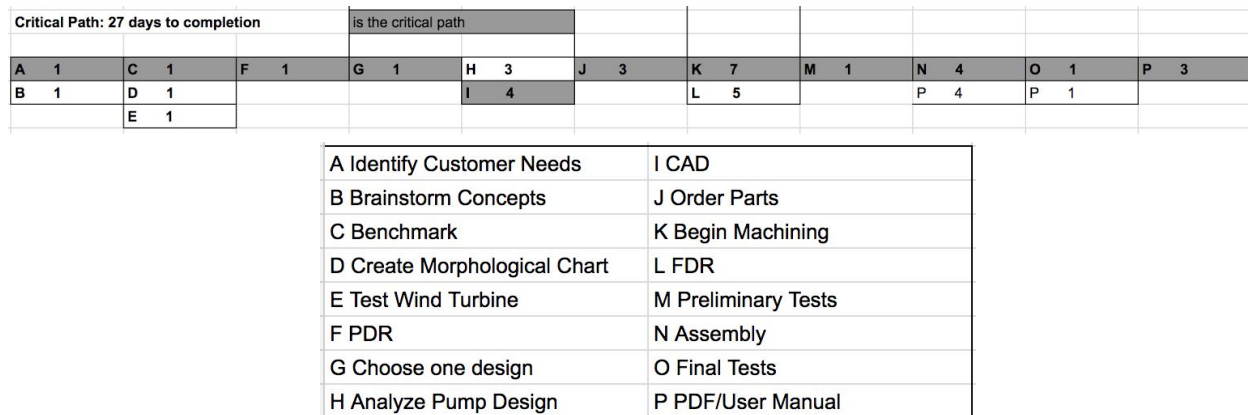


Figure 2: PERT chart with the corresponding key. This was not updated as time went on to highlight the difference between our initial expected schedule and our final schedule.

3. Phase 1 - Conceptual Design

3.1. Identify Customer Needs

Customer Specifications	Interpretation
The prototype should pump water from an input reservoir with water level at the height of the drive shaft to an output reservoir with water level at an elevation at least 1.5m above the axis of the drive shaft at a rate of at least 1 liter/min	Pump must elevate water by at least 1.5m Water output flow ≥ 1 liter/min
The cylinder bore diameter should be machined to an appropriate fit with the piston stock (1.875").	Pump's shaft input (turbine connection) is a hole with diameter of 1.875"
The pump must sit stably on a 7"x7" horizontal plate supplied by the customer.	A 7" x 7" base is provided for the pump to rest on
The output drive shaft must be a 1/2" diameter rod extending 2 1/2" beyond the supplied face-plate (1/2" thick). Its axis will be located 5 ± 2 " above the horizontal plate. The pump will be attached to the face-plate by 4, 1/4"-20 thread screws located on the faceplate as shown on sketches provided on BLACKBOARD.	Output drive shaft is 1/2" diameter rod Extends 2.5" from face plate Axis 5 ± 2 " above horizontal plate Pump is attached to face-plate by 4 screws
The overall dimensions of the pump must be such that it fits into a volume no greater than 14"x14"x14". It will sit on the 7"x7" horizontal plate (see sketch on BLACKBOARD). The height of the horizontal plate is adjustable so that the distance from the horizontal plate to the drive shaft accommodates your motor within the range specified in the previous paragraph. The pump will be surrounded by ambient air, and placed in a tub to collect possible water leaks.	The pump must not be larger than 14"x14"x14". The pump must also be able to adjust its height to meet the requirements of the provided motor.
Water will be fed to and from the pump through 3/8" lines connected to the input and output reservoirs. The elevation of the input reservoir water level will be the same as the shaft's.	Water inputs and outputs are 3/8" diameter, the input is at the same height as the reservoir
The input torque will be provided by the customer-supplied wind turbine. You will have measured the torque-power characteristics of the turbine in weeks WP2 and WP3.	Pump must run off of power provided by wind turbine.

Figure 3: The customer specifications were taken from blackboard and were translated into interpreted needs.

From these interpreted needs we determined the following pump characteristics that we should focus on and numerical metrics that we can use to benchmark different types of pumps:

Important Characteristics	Numerical Metrics
---------------------------	-------------------

Maximize flow rate	Flow rate
Minimize cost	Head pressure ranges
Maximize efficiency	Horse power ranges
Minimize friction	Cost
Minimize weight	Weight
The pump should be easy to make	Rpm ranges of operation
The pump should be durable	Temperature ranges
The pump should be safe to use	Vibration

Figure 4: Important Characteristics and Numerical Metrics that were considered during the pump design phase. The Numerical Metrics marked in red were the ones used for later benchmarking.

3.2. Generate Concepts

During this phase we created a list of many methods that we could convert from rotational motion to linear motion. Included in this list are some other design decisions that could be made.

- Piston Pump
 - Single acting
 - Double acting
 - Scotch-Yoke
 - Slider Crank
 - Driving Gear
 - Watt's Linkage
 - Hoeken's Linkage
 - Chebyshev Linkage
- Linear actuating pump
- Peristaltic pump
- Single output
- Multiple outputs
- Centrifugal pump
- Rotary vane pump
- Swashplate
- Archimedes' screw

From this list we focused on four different pump designs to analyze more closely:

Type of Pump	Pros	Cons
Centrifugal	• Efficient • High flow rate • No drive seals • Can pump liquids with solids • Smooth, pulse free, flow	• Complex • Inability to provide suction power, meaning the pump must be installed below the liquid or primed before it can work
Piston	• Simple • Easy to make, • Has many variations • Self-priming • Are able to deliver fluid at high pressure	• Reciprocating pumps give a pulsating flow. • Not good for viscous liquids
Peristaltic	• Lightweight • Self priming • Can be run dry • No seals • Steadier flow	• Constant squeezing of pump tube weakens (degrades) the tube, and feed rate is slowly diminished. • Squeezing the pump tube requires the drive motor to be under a constant load which uses more power. • Low flow rate
Rotary vane pump	• Efficient • Good flow rate	• Difficult to make • Expensive (carbon fiber parts) • Not usually made for water

Figure 5: The four pump designs we decided to focus on during the concept generation process. The pros and cons come from researching how each pump is made and what it specializes in.

3.2.1. Sketches

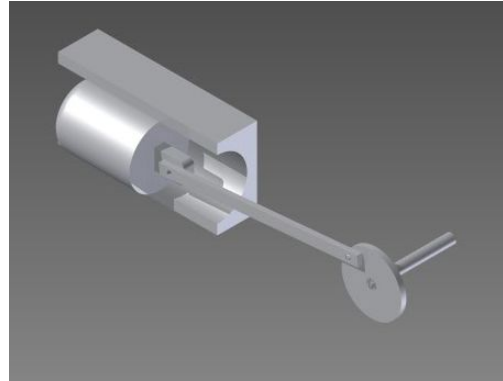
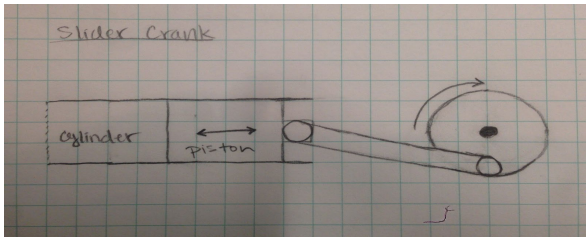


Figure 6: Initial sketch and CAD of slider crank mechanism

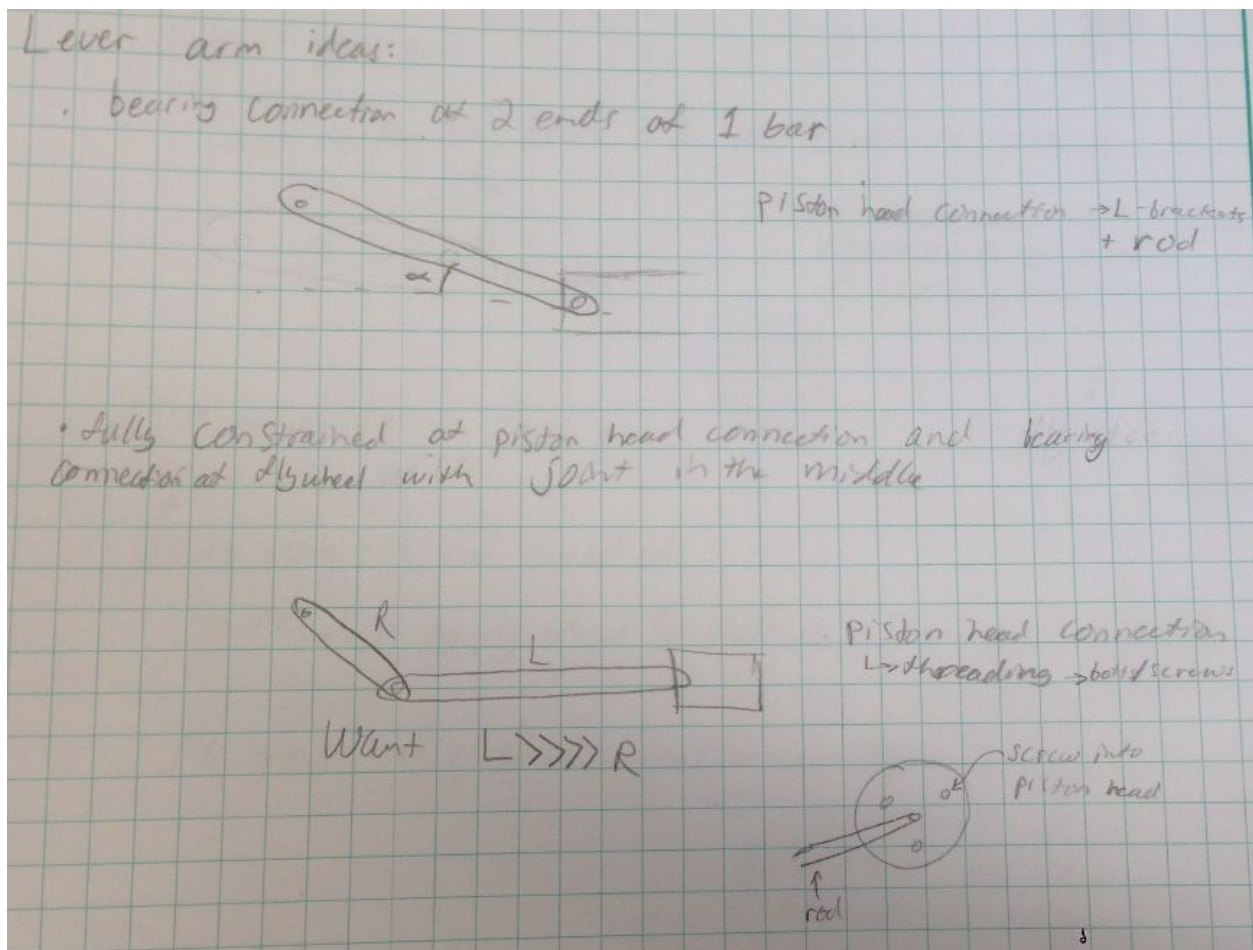


Figure 7: Two different concepts on how to implement a slider crank mechanism

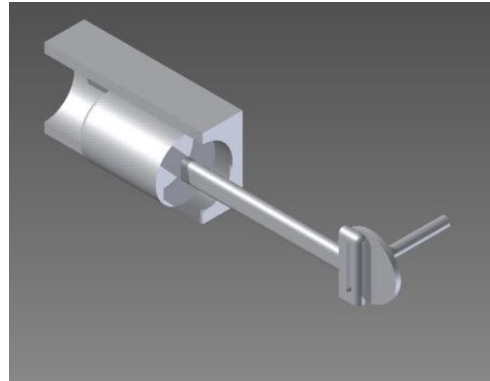
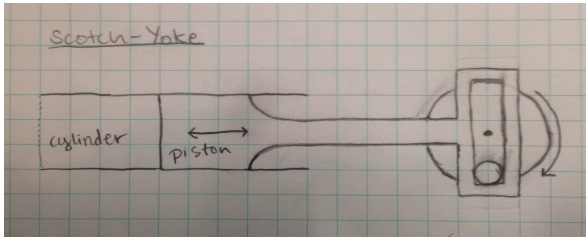


Figure 8: Initial sketch and CAD of scotch yoke mechanism

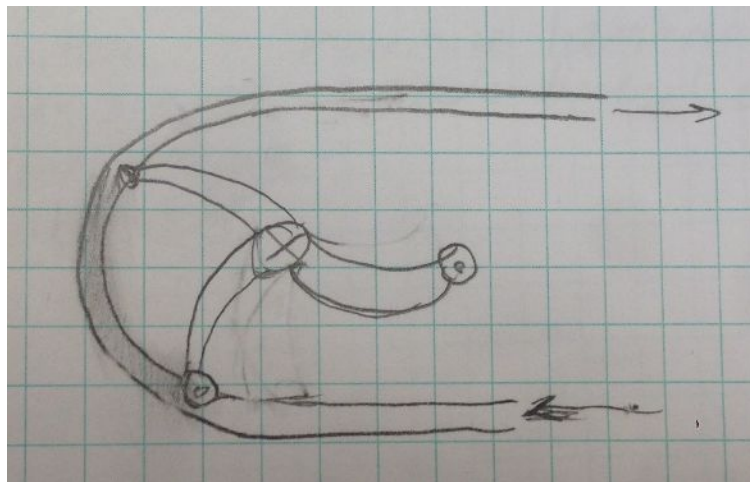


Figure 9: Sketch of a peristaltic pump

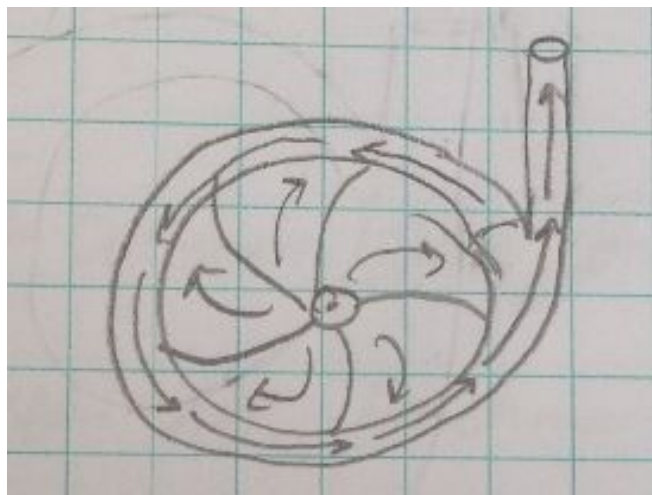


Figure 10: Sketch of centrifugal pump

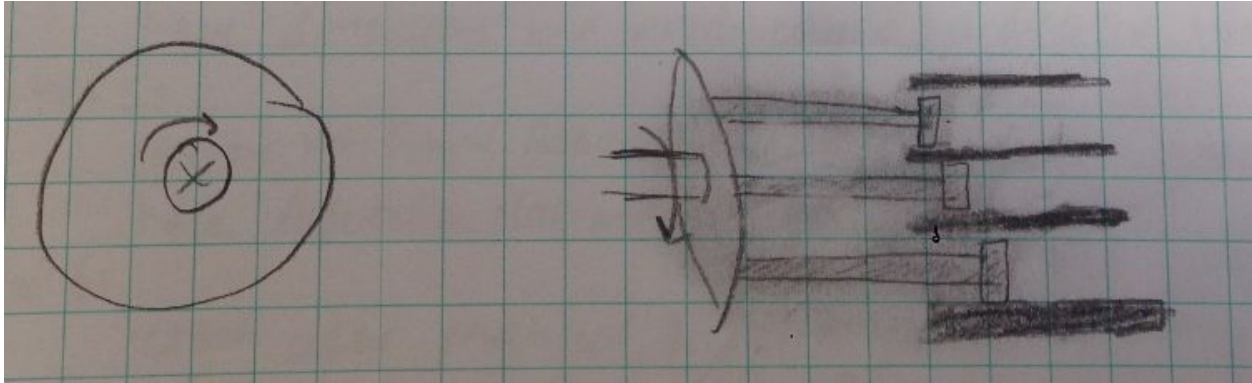
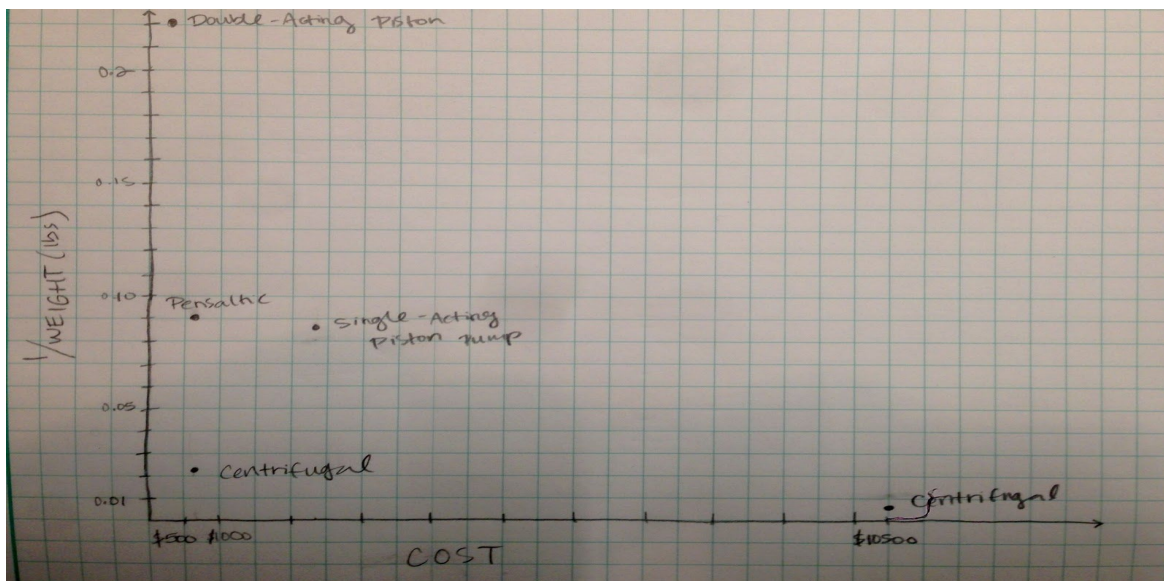


Figure 11: Sketch of swash plate mechanism

3.3. Benchmarking

3.3.1. Pareto Front

Our benchmarking was based off of commercial pumps found online. Five different pumps were chosen and a Pareto Front was used to rank the pumps in terms of cost and weight.



Pump	Model Number	Flow Rate (GPM)	Cost (\$)	Weight (lb)	1/Weight (lb ⁻¹)
Peristaltic	Vantage 3000 R3i	0.86	600	11	0.09090909091
Centrifugal	AMT 4297-98	59	650	42	0.02380952381
Centrifugal	TPOW80-220(I)	475	10500	181	0.005524861878
Double Acting Piston	5330C-HRX	3	281	4.5	0.2222222222
Single Acting Piston Pump	APP 0.6 180B3048	1.78	2375	11.5	0.08695652174

Figure 12: Pareto Front comparing five different pumps.

3.4. Concept Selection

3.4.1. Design Pugh Decision Matrix

The Design Pugh Decision Matrix was used to decide between a piston pump, centrifugal pump, and peristaltic pump. The selection criteria come from the important aspects determined by the interpreted needs mentioned in section 3.1. Each group member ranked the importance of each selection criteria between 1 and 10, these values were averaged to create a weighted value of importance for each criteria. Then each member rated how well they believed each pump design would perform at fulfilling the selection criteria; this rating was between 1 and 5. The individual ratings were summed up and multiplied by the averaged importance of each criteria to create a weighted score. The weighted scores for each pump were summed to a total score. The pump design with the highest total score was chosen.

						Pump Concepts																		
							Piston						Centrifugal					Peristaltic						
Selection Criteria	Weight					Avg		Rating				Weighted Score		Rating				Weighted Score		Rating				Weighted Score
Flow Rate	8	8	8	6	5	7	3	4	3	4	2	112	5	4	5	5	5	168	1	2	2	1	4	70
Cost	6	6	7	8	9	7.2	4	3	5	4	5	151.2	1	3	2	1	2	64.8	2	3	2	3	3	93.6
Easy to Make	9	9	8	9	8	8.6	5	4	5	5	4	197.8	1	2	2	1	1	60.2	3	3	3	2	2	111.8
Reliability/Durability	5	5	6	7	8	6.2	4	3	4	5	4	124	4	4	4	4	4	124	2	2	2	2	2	62
Efficiency	8	5	4	3	7	5.4	3	3	2	2	2	64.8	5	4	5	4	5	124.2	4	4	4	5	4	113.4
	Total Score						649.8							541.2						450.8				
	Rank						1							2						3				
	Continue?						Yes							No						No				

Figure 13: Design Pugh Decision Matrix. The piston pump received the highest score.

3.4.2. Morphological Chart

The Morphological Chart was used to decide the physical embodiment of the piston pump. The mechanism with which angular motion is converted to linear motion was left undecided. Other decisions were made to ensure that machining the parts would be as simple as possible. We chose to use one cylinder so that we would not have to machine more parts. We chose a medium sized pump to avoid machining small parts while also trying to minimize weight and cost. We chose single acting to keep the design simpler and to reduce machining time; for this same reason we chose to have only one input and output. The method of transferring power from the turbine to the drive shaft was provided for us. For the materials used we decided to include all three materials. We used plastic in areas with low forces to reduce weight. We used

aluminum in areas that would be under higher loads. Steel was used for the drive shaft as it was the only half inch diameter rod available in emerson.

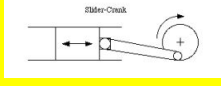
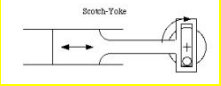
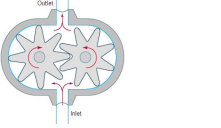
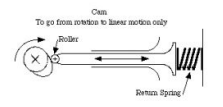
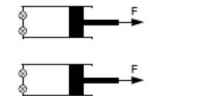
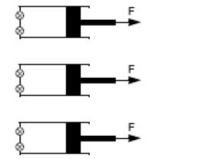
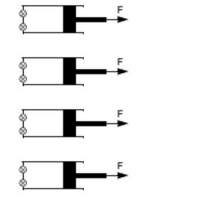
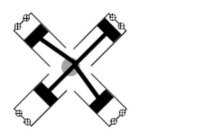
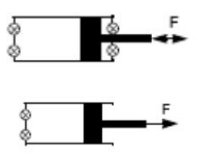
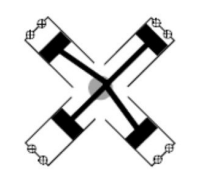
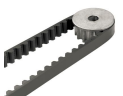
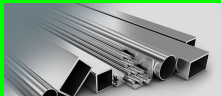
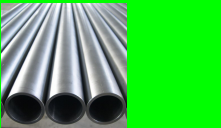
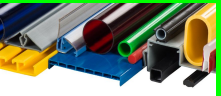
Functional Requirements				
Converting Rotational motion to linear motion	Slider Crank 	Scotch Yoke 	Driving Gear 	Cam 
Number of Cylinders	1 	2 	3 	4 
Size	Small	Medium	Large	
Motion of piston	Single Acting 	Double Acting 	Quadruple Acting 	
inputs/outputs per cylinder	1 	2 	3 	4 
Method of transferring power from wind turbine to piston pump	Belt Drive 	Chain Drive 	Direct/Shaft Drive 	
Material	Aluminum 	Steel 	Plastics 	

Figure 14: Morphological chart. Yellow means yet to be decided, green means decided, blue means provided.

3.4.3. Piston Pump Pugh Decision Matrix

The Piston Pump Decision Matrix was used to decide between a slider crank mechanism and scotch yoke mechanism. The weighted averages of the importance of the selection criteria were taken from the Design Pugh Decision Matrix. The each group member rated each mechanism with a 1, 0 or -1 to indicate whether they believe that this mechanism would be good, neutral, or bad at fulfilling the criteria. Some useful information we found to help us decide which mechanism is more efficient is as follows: "One of the main reason that Scotch and Yoke mechanism is seldom used is because of high frictional losses. Slider crank mechanism comprises of 3 Revolute joints and 1 Prismatic joint. On the other hand Scotch and Yoke mechanism consists of 2 Slider and 2 Prismatic Joints. Since we know that the coefficient of rolling friction is lesser than sliding friction. Thus along with losses, we would have to change the components more often which is not acceptable for automobiles."⁽¹⁾ and "In the case of scotch and yoke mechanism will have a slider at that place which is prone to out of plane bending because there is one extra link between revolute and prismatic joint. So rigidity factors might also be one of the factors."⁽¹⁾ From this information we decided that due to frictional losses a scotch yoke is less efficient than a slider crank.

							Pump Concepts												
							Slider Crank						Scotch Yoke						
Selection Criteria	Weight						Av g	Rating					Weighted Score	Rating					Weighted Score
Flow Rate	8	8	8	6	5	7	0	0	0	0	0	0	0	0	0	0	0	0	
Cost	6	6	7	8	9	7	1	-1	1	1	1	21.6	1	1	0	1	0	14.4	
Easy to Make	9	9	8	9	8	9	1	1	1	1	1	43	0	-1	-1	-1	-1	-25.8	
Reliability/ Durability	5	5	6	7	8	6	1	1	1	1	1	31	0	-1	-1	0	-1	-12.4	
Efficiency	8	5	4	3	7	5	1	1	1	1	1	27	-1	0	-1	-1	-1	-21.6	
	Total Score						122.6						-45.4						
	Rank						1						2						
	Continue?						Yes						No						

Figure 15: Piston Pump Pugh Decision Matrix. The slider crank mechanism received the highest score.

4. **Phase 2 - System Design**

4.1. Preliminary CAD Design (Autodesk Inventor)

The preliminary CAD design was an idealized pump design that borrowed concepts from real world applications. The most influential application in the pump design was that of the internal combustion engine. The 100 year old lineage of the slider-crank mechanism used in the internal combustion engine resulted in a wind pump design that was primarily focused on durability and reliability as evidenced by the counter-balanced shape of the crankshaft and the all aluminum/steel construction.

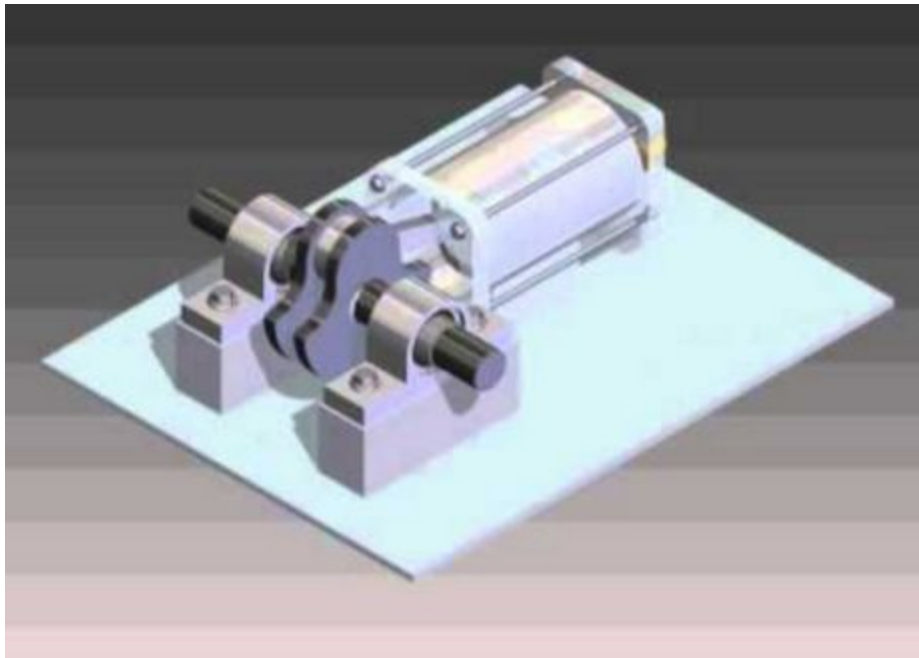


Figure 16: Idealized Pump made in Autodesk Inventor

4.1.1. Stress Analysis

To further develop our final CAD design a stress analysis was run on the preliminary CAD model. This analysis emphasized important areas of stress concentrations such as the wrist pin and the head of the connecting rod. In addition the analysis provided some key values such as a safety factor of 15 and a max stress of 0.5654 MPa. Using this information we determined what areas needed to utilize stronger metals and which can use lighter polymers.

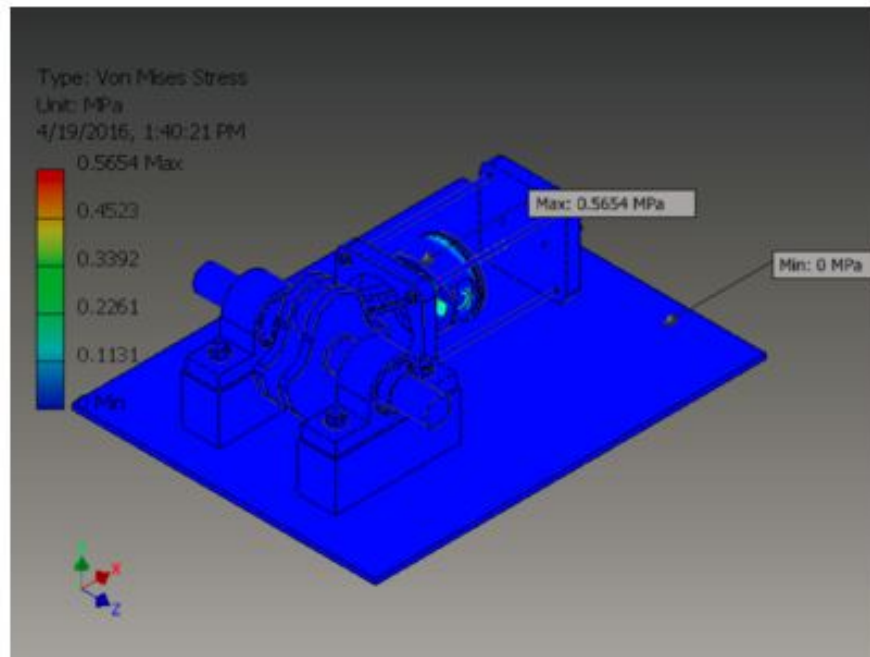


Figure 17: Stress Analysis of pump in Figure 16

Result Summary

Name	Minimum	Maximum
Volume	3033530 mm ³	
Mass	10.5717 kg	
Von Mises Stress	0.000000000116651 MPa	0.565368 MPa
1st Principal Stress	-0.210036 MPa	0.558128 MPa
3rd Principal Stress	-0.756148 MPa	0.133082 MPa
Displacement	0 mm	0.000624664 mm
Safety Factor	15 ul	15 ul
Stress XX	-0.717323 MPa	0.251949 MPa
Stress XY	-0.174942 MPa	0.212612 MPa
Stress XZ	-0.17568 MPa	0.170649 MPa
Stress YY	-0.53332 MPa	0.551644 MPa
Stress YZ	-0.162173 MPa	0.166124 MPa
Stress ZZ	-0.576682 MPa	0.470786 MPa
X Displacement	-0.000624604 mm	0.00000770905 mm
Y Displacement	-0.0000590003 mm	0.0000803271 mm
Z Displacement	-0.0000760583 mm	0.0000751765 mm
Equivalent Strain	0.0000000000000177074 ul	0.00000769776 ul
1st Principal Strain	-0.00000000116972 ul	0.00000520232 ul
3rd Principal Strain	-0.00000905252 ul	0.000000000456056 ul
Strain XX	-0.00000801678 ul	0.00000483281 ul
Strain XY	-0.00000234967 ul	0.0000025037 ul
Strain XZ	-0.00000339121 ul	0.00000329409 ul
Strain YY	-0.00000481483 ul	0.00000423544 ul
Strain YZ	-0.00000313048 ul	0.00000320675 ul
Strain ZZ	-0.00000565185 ul	0.00000514486 ul
Contact Pressure	0 MPa	1.05099 MPa
Contact Pressure X	-0.527291 MPa	0.242538 MPa
Contact Pressure Y	-0.960477 MPa	0.773675 MPa
Contact Pressure Z	-0.366083 MPa	0.364697 MPa

Figure 18: Stress Analysis Data

4.2. Preliminary CAD Designs (SolidWorks)

This CAD model was used in the FDR presentation. Since this model the following changes were made:

- Washers, thrust washer, correct screws, nuts, and pipe fittings were all added so that the CAD would reflect the final product better.
- The crank arm was changed from a $\frac{1}{8}$ thickness bar to a $\frac{1}{4}$ in thickness bar which tapers down to a $\frac{1}{8}$ in thick section at the connection point to the piston head



Figure 19: Picture of full assembly

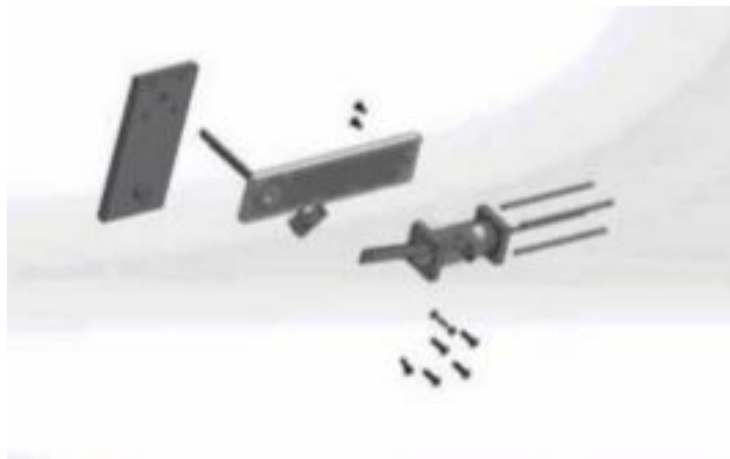


Figure 20: Picture of exploded view

4.3. Wind Turbine Data

eData_1  

File View Insert Format Data Tools Add-ons Help Last edit was on April 5



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 Arial 10 B I S A
 










B	C	D	E	F	G	H	I	J
Trail 1					Trail 2			
		oscillates a lot	stable				oscillates a lot	stable
test num	rpm	left gauge (grams)	right gauge (grams)		test number	rpm	left gauge (grams)	right gauge (grams)
1	885	560	0		1	860	550	0
2	830	640	0		2	670	850	0

Figure 21: Data from testing the capabilities of the wind turbine

To extrapolate from this data we plotted the points on a graph and used a best fit line which includes the point (0,0). This point was included because when the turbine is turned off there is a zero measurement for both torque and rpm. From the graph we saw that the turbine's maximum operating capabilities are described by an applied torque of 0.8 Newtons per meter and an angular velocity of 60 radians per second, providing a power output of 48 Watts.

$$\begin{aligned} \text{Torque (N} \cdot \text{m)} \cdot \text{angular velocity } \left(\frac{\text{radians}}{\text{second}} \right) &= \text{Power (Watts)} \\ 0.8 \text{ (N} \cdot \text{m)} \cdot 60 \left(\frac{\text{radians}}{\text{second}} \right) &= 48 \text{ W} \end{aligned}$$

4.4. Performance Analysis

We found the minimum power requirement to lift one liter of water 1.5 meters per minute as 0.245 Watts by using the density of water as 1 kilogram per liter and multiplying this by the height requirement and the acceleration due to gravity. In order to compare this value to the power output of our pump, we first had to calculate the angular velocity of the crankshaft and the flow rate for our pump. We calculated the angular velocity of the crankshaft using gear ratios for the sprockets and the angular velocity of the input shaft which we calculated from our maximum RPM from our torque analysis. The flow rate for the pump was calculated using the area of the piston head, the crankshaft radius, and the angular velocity of the crankshaft. Finally, we calculated the average power output of the pump by multiplying this flow rate by the density of water, the acceleration due to gravity, and the height requirement, giving our pump an average power output of 2.09 Watts. Comparing this power output to the minimum power requirement means that we need an efficiency of 11.7% in order to meet the problem requirement of lifting 1 liter of water 1.5 meters.

Requirement: Lift 1 liter of water 1.5 meters

$$1 \text{ liter water} = 1 \text{ kg}$$

$$\begin{aligned} \text{Minimum Power Required} &= mgh = (1 \text{ L/min}) * \left(\frac{1 \text{ kg}}{\text{L}}\right) * \left(9.81 \frac{\text{m}}{\text{s}^2}\right) * (1.5 \text{ m}) \\ &= 14.715 \frac{\text{Joules}}{\text{minute}} = 0.245 \text{ Watts} \end{aligned}$$

$$\text{Smaller Sprocket Radius, } R_0 = 1.67 \text{ in}$$

$$\text{Larger Sprocket Radius, } R_1 = 11.43 \text{ in}$$

$$\text{Input Shaft Angular Velocity} = 60 \frac{\text{rad}}{\text{sec}} \text{ (from Torque analysis)}$$

$$\text{Angular Velocity of Crankshaft, } \dot{\theta} = \frac{R_0}{R_1} * \omega = \frac{1.67 \text{ in}}{11.43 \text{ in}} * 60 \frac{\text{rad}}{\text{sec}} = 8.766 \text{ rad/sec}$$

$$\text{Crankshaft Radius} = 1.125 \text{ in} = 0.028575 \text{ m}$$

$$\text{Piston Head Diameter} = 1.875 \text{ in} = 0.047625 \text{ m}$$

$$\begin{aligned} \text{Flow Rate, } \dot{Q} &\cong \frac{AR\dot{\theta}}{\pi} = \frac{\pi \left(\frac{0.047625 \text{ m}}{2}\right)^2 * 0.028575 \text{ m} * 8.766 \frac{\text{rad}}{\text{s}}}{\pi} \\ &= 1.420 \text{E-4} \frac{\text{m}^3}{\text{sec}} = 8.52 \frac{\text{L}}{\text{min}} \end{aligned}$$

$$\text{Average Power Output, } \bar{P} = \rho_w gh\dot{Q}$$

$$\begin{aligned} \bar{P} &= \left(\frac{1 \text{ kg}}{\text{L}}\right) * \left(9.81 \frac{\text{m}}{\text{s}^2}\right) * (1.5 \text{ m}) * \left(8.52 \frac{\text{L}}{\text{min}}\right) * \left(\frac{\text{min}}{60 \text{ secs}}\right) \\ \bar{P} &= 2.09 \text{ Watts} \end{aligned}$$

$$\text{Minimum Efficiency} = \frac{0.245}{2.09} = 11.7\%$$

Figure 22: Power Analysis for Pump. The pump has an average power output of 2.09 Watts.

We can also compare the power output of the pump to the power output of the wind turbine to see that our overall efficiency given a flow rate of 8.52 Liters per minute is 4.35%

$$\text{efficiency} = \frac{\text{Power out}}{\text{Power in}} = \frac{2.09 \text{ Watts}}{48 \text{ Watts}} = 4.35\%$$

To confirm our flow rate value, we calculated the area of the piston head and stroke length which is twice the crankshaft radius and multiplied these values to get the volume displaced by each stroke. After calculating the angular velocity of the crankshaft using the same method as we did above, we multiplied this angular velocity by the volume

displaced by each stroke to get the flow rate, which is the same as our value we calculated earlier.



$V = \text{Usable Cylinder Volume} = \text{Area of Piston} \times \text{Stroke}$

$$A = \text{Area of Piston} = (\pi)(r)^2 = (\pi)\left(\frac{1.875}{2} \text{ in}\right)^2 = 2.76117 \text{ in}^2$$

$H = \text{Stroke} = 2.25 \text{ in}$

$$V = A \times H = (2.76117 \text{ in}^2) \times (2.25 \text{ in}) = 6.21262 \text{ in}^3$$

One revolution of the crankshaft is one full cycle of the piston stroke

Therefore, One revolution of the crank draws in and expels one V

@ max torque the speed of windmill = 572.95 RPM

$$\text{Speed Crankshaft} = \frac{(r_{\text{small}}) \times (\text{speed}_{\text{small}})}{(r_{\text{large}})} = \frac{(0.835 \text{ in}) \times (572.95 \text{ RPM})}{(5.715 \text{ in})} = 83.71 \text{ RPM}$$

$$F = \text{flow rate} = V \times 83.71 \text{ RPM} = 520.06 \frac{\text{in}^3}{\text{min}}$$

$$F = 8.52 \frac{\text{liter}}{\text{min}} : \text{Assuming no energy losses}$$

In order to decide how long we wanted to make the radius of the crankshaft and the length of the connecting rod, we plugged in various numbers into Matlab to see what flow rate values and other metrics it calculated. We found that increasing the crankshaft radius increases the flow rate while changing the connecting rod length has barely any effect on the flow rate. We found that a crankshaft radius of 1.125 inches and connecting rod length of 6 inches fit our design requirements and gave us flow rate values that we were content with.

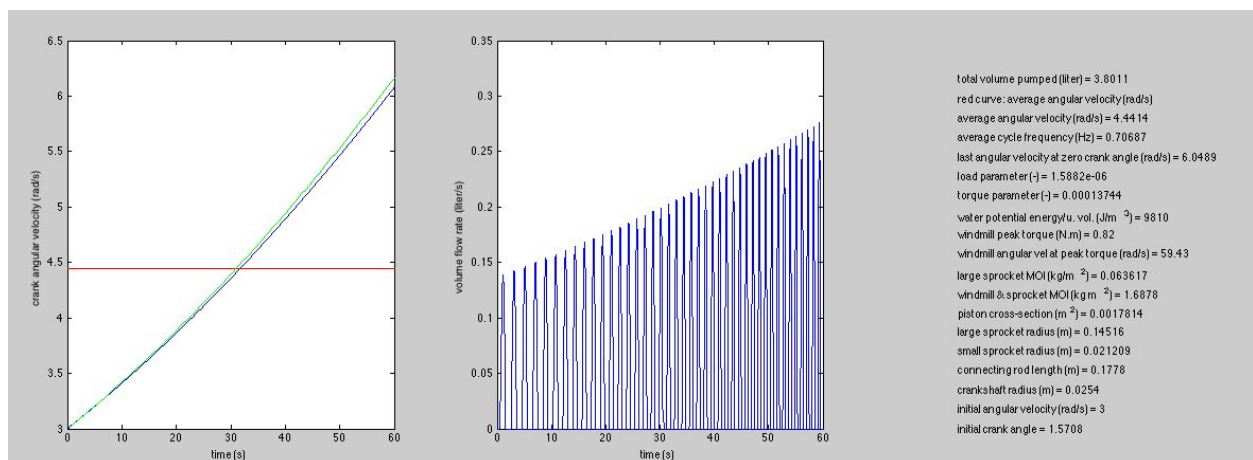


Figure 23: Matlab analysis with input values of 1" for the crankshaft radius and 8" for the connecting rod length.

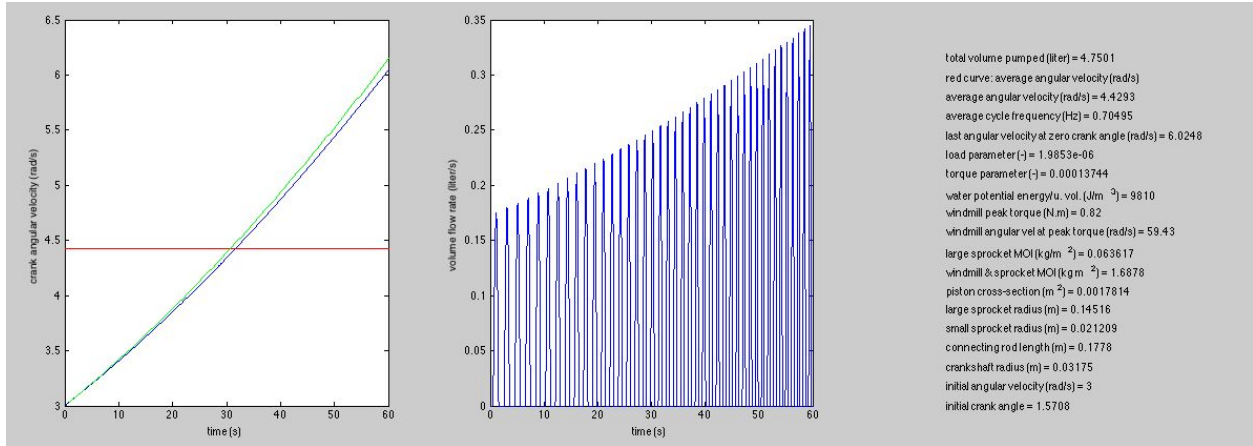


Figure 24: Matlab analysis with input values of 1.25" for the crankshaft radius and 8" for the connecting rod length.

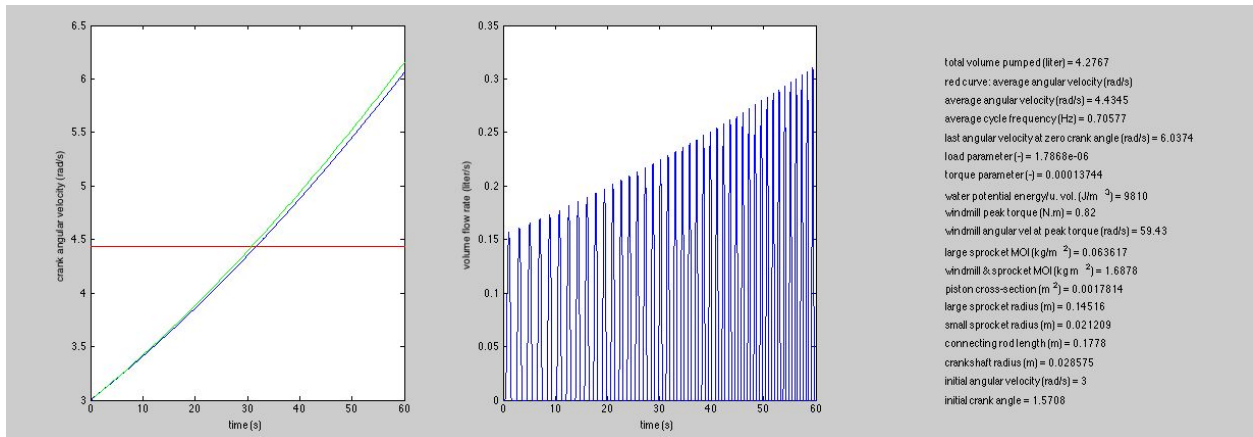


Figure 25: Matlab analysis with input values of 1.125" for the crankshaft radius and 8" for the connecting rod length.

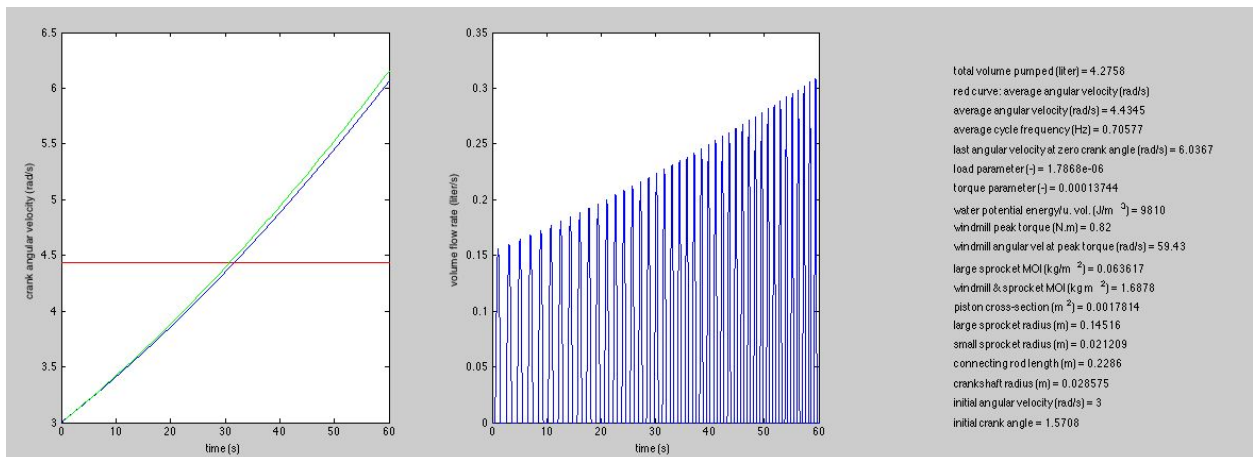


Figure 26: Matlab analysis with input values of 1.125" for the crankshaft radius and 9" for the connecting rod length.

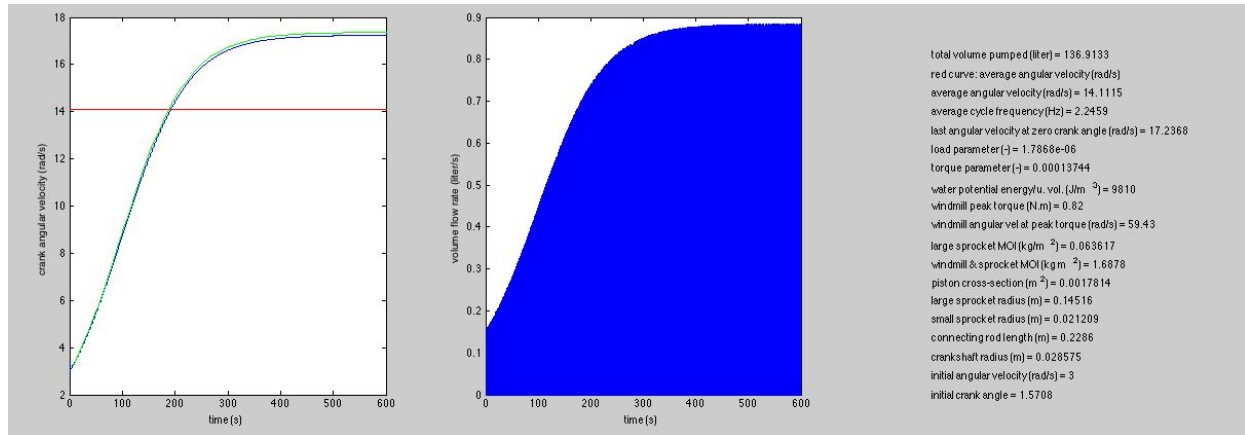


Figure 27: Matlab analysis with input values of 1.126" for the crankshaft radius, 6" for the connecting rod length, and a 10 minute time span.

5. Phase 3 - Final Design

5.1. Final CAD Rendering

5.1.1. Full Assembly

Full Assembly Animation: <https://www.youtube.com/watch?v=nLZ88-3LiX0>

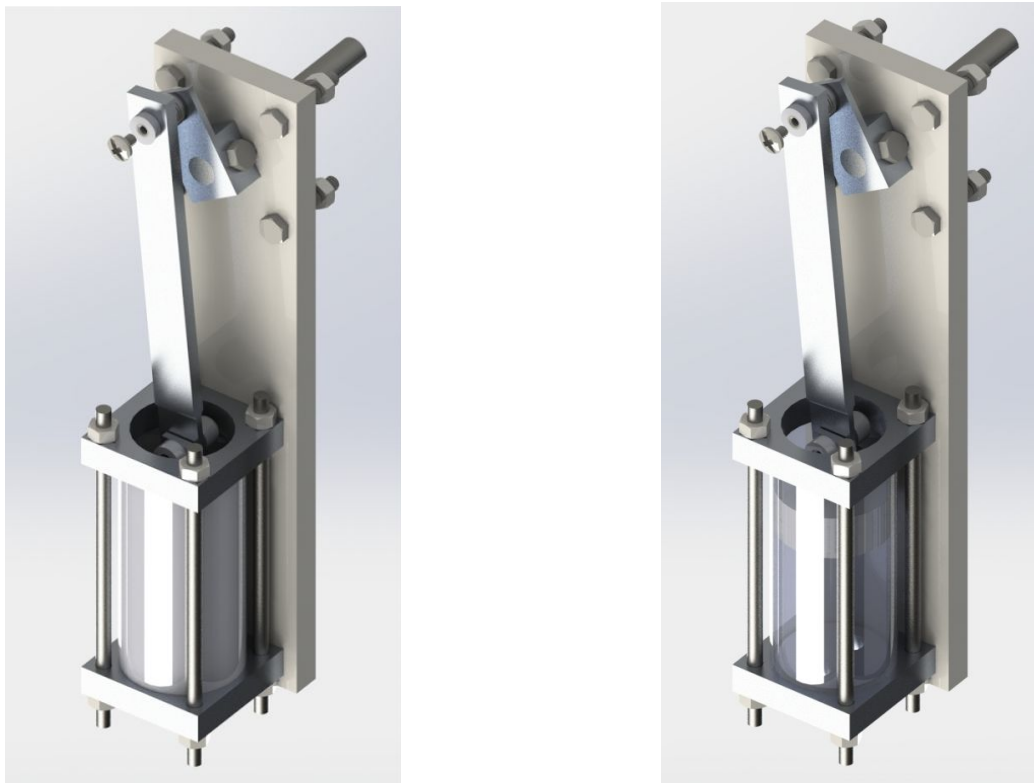


Figure 28: Render of full assembly with opaque cylinder (left) and transparent cylinder (right)



Figure 29: View of angled pipe fittings in full assembly faceplate



Figure 30: Front view of the connection to the provided faceplate



Figure 31: Back view of connection to provided faceplate and view of connection between PVC plate and endcap

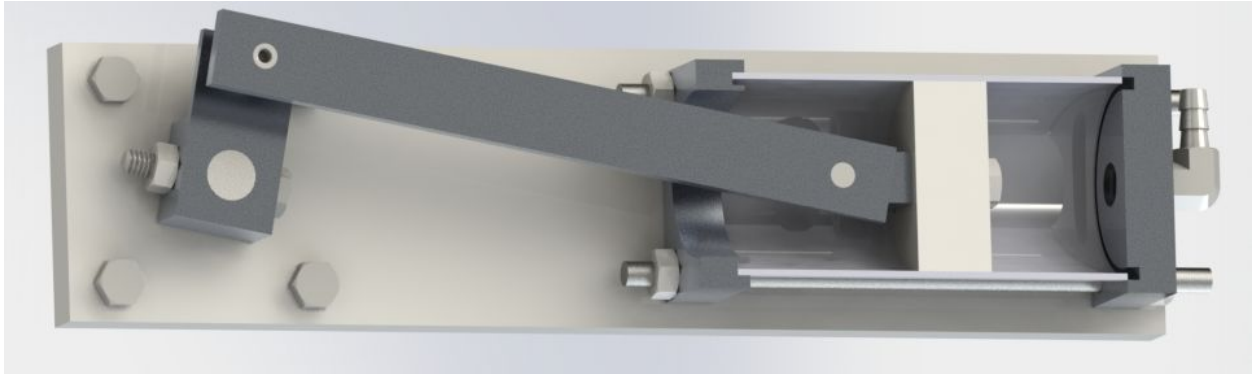


Figure 32: Section view for full assembly

5.1.2. Individual Components

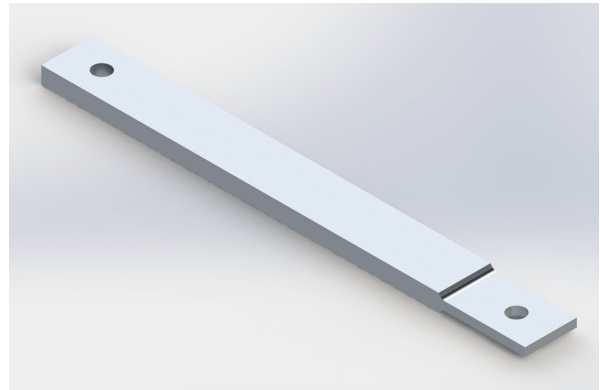
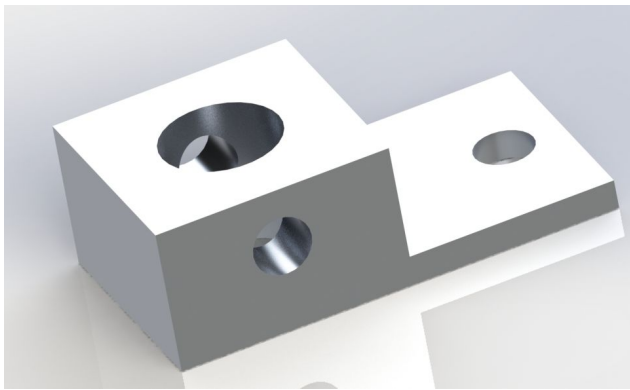


Figure 33: Crank Render (left) Crank Arm Render (right)



Figure 34: Cylinder Render (left) Drive Shaft Render (right)

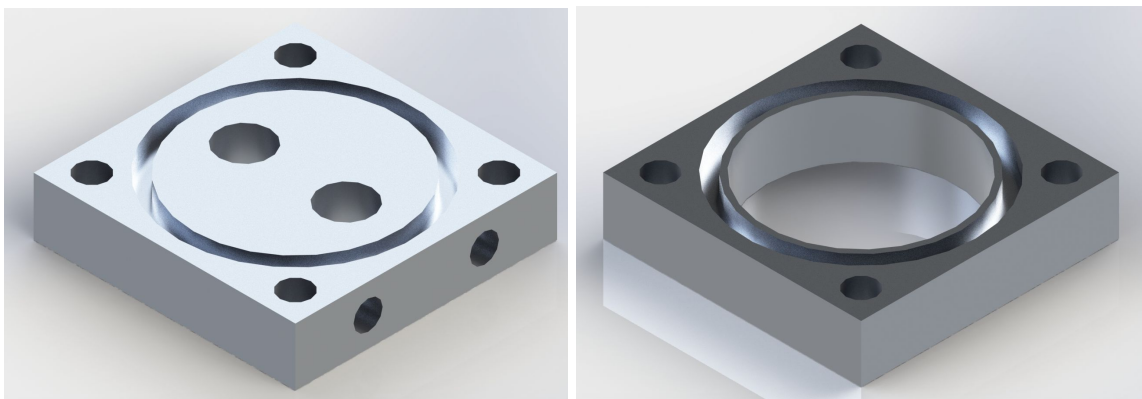


Figure 35: Main Endcap Render (left) Secondary Endcap Render (right)



Figure 36: PVC baseplate Render

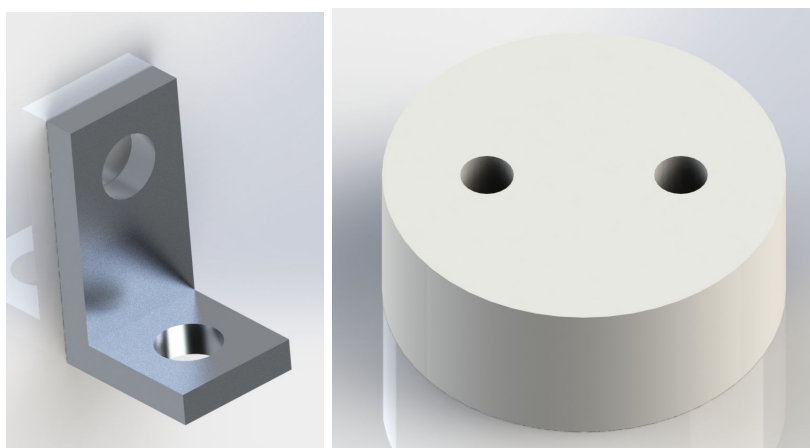


Figure 37: L-Bracket Render (left) Piston Head Render (right)

5.1.3. Tolerancing

In general all parts were attempted follow the drawings within 0.005 inches. Some parts are outside of this tolerance but due to the design choices we made the difference in size from the CAD can be accounted for by using washers for spacing.

5.2. Materials

5.2.1. Materials Purchased

Material	Purchased From	Quantity	Unit of measurement	Cost	Purpose
Multipurpose 6061 Aluminum 90 degree Angles	McMaster	12	inch	\$2.94	L-Brackets
Zinc-Plated Steel Binding Post for 1" to 1-1/8" Thick Material, 1/4" Diameter Barrel	McMaster	10	Binding posts	\$4.50	Binding Posts
Zinc-Plated Steel Binding Post for 1" to 1-1/8" Thick Material, 1/4" Diameter Barrel	McMaster	1	Binding posts	\$3.31	Binding Posts
Low-Strength Zinc-Plated Steel Cap Screw 1/4"-20 Fully Threaded, 1-1/2" Long	McMasters	100	screws	\$8.42	Used to fit between PVC connection plate and provided faceplate
Thrust Ball Bearings	McMasters	1	bearing	\$2.21	Used between crank and crank arm
Nylon Washers	McMasters	100	washers	\$6.63	Used to reduce friction between metal

					on metal contact
4" x 1/2" PVC	McMasters	1	foot	\$12.00*	Connection plate
Flat Washers	Emerson	40	washers	0.80	Used to maintain seals
1/4-20 hex nuts	Emerson	30	nuts	\$0.60	Used to hold screws and rods in place
1 7/8" x 1" Diameter Plastic Rod	Emerson	12	inches	\$10.32	Piston head, and backup piston head
1/2" ID X 13/16" OD x 1/2" depth self-aligning bronze bushings*	Emerson	1	bushing	\$3.00	Reduce friction between connecting plate and drive shaft
Brass pipe fittings (3/8" barbed x 1/4"NPT)	Emerson	2	fittings	\$2.86	Connect to main end cap so that water can go in and out of the cylinder
Lock Washers	Emerson	15	washers	\$0.30	Hold pieces in position
1/4" x 1" Aluminum Bar	Emerson	8	inches	\$1.12	Crank arm
1" x 2" Aluminum Bar	Emerson	2	inches	\$2.36	Crank
1/2" x 2 1/4" Aluminum Bar	Emerson	11	inches	\$8.03	Original connecting plate
Machined End Caps	Emerson	2	caps	\$2.00	End caps
Bored Cylinder	Emerson	4	inches	\$1.00	Cylinder
1/4 -20 x 1" screws	Emerson	8	screws	\$1.36	General purpose screws

1/4 -20 x 3/4" screws	Emerson	4	screws	\$0.60	General purpose screws
1/4-20 Threaded rod	Emerson	2	feet	\$2.04	Connect end caps together
1/2" Diameter Steel Rod	Emerson	5	inches	\$1.15	Drive shaft

*Traded 90 1/4"-20 fully threaded 1-1/2" long screws, 1 binding post for \$3.31, and 8 binding posts in the pack of 10 for the 12" of PVC

The above table includes all of the different parts that were ordered. We ordered \$37.54 worth of parts from the Emerson Machine Shop and \$28.01 worth of parts from McMaster's. We traded several of our unused parts with another group for their unused PVC.

5.2.2. Materials Used

Material	Purchased From	Quantity	Unit of measurement	Cost	Purpose
Multipurpose 6061 Aluminum 90 degree Angles	McMaster	1	inch	\$0.25	L-Brackets
Zinc-Plated Steel Binding Post for 1" to 1-1/8" Thick Material, 1/4" Diameter Barrel	McMaster	2	Binding posts	\$0.90	Binding Posts
Low-Strength Zinc-Plated Steel Cap Screw 1/4"-20 Fully Threaded, 1-1/2" Long	McMasters	5	screws	\$0.42	Used to fit between PVC connection plate and provided faceplate
Thrust Ball Bearings	McMasters	1	bearing	\$2.21	Used between crank and crank arm
Nylon Washers	McMasters	21	washers	\$1.39	Used to reduce

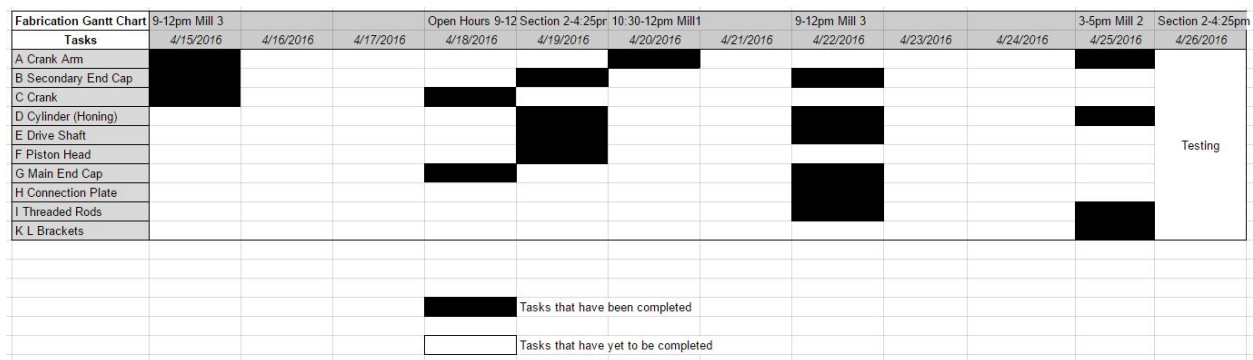
					friction between metal on metal contact
2.75" x 1/2" PVC	McMasters	11.5	inches	\$7.91	Connection plate
Flat Washers	Emerson	10	washers	\$0.20	Used to maintain seals
1/4-20 hex nuts	Emerson	12	nuts	\$0.24	Used to hold screws and rods in place
1 7/8" x 1" Diameter Plastic Rod	Emerson	3/4	inches	\$0.65	Piston head, and backup piston head
1/2" ID X 13/16" OD x 1/2" depth self-aligning bronze bushings*	Emerson	1	bushing	\$3.00	Reduce friction between connecting plate and drive shaft
Brass pipe fittings (3/8" barbed x 1/4"NPT)	Emerson	2	fittings	\$2.86	Connect to main end cap so that water can go in and out of the cylinder
Lock Washers	Emerson	4	washers	\$0.08	Hold pieces in position
1/4" x 3/4" Aluminum Bar	Emerson	7	inches	\$0.73	Crank arm
1" x 2" Aluminum Bar	Emerson	3/4	inches	\$0.88	Crank
Machined End Caps	Emerson	2	caps	\$2.00	End caps
Bored Cylinder	Emerson	4	inches	\$1.00	Cylinder
1/4 -20 x 1" screws	Emerson	4	screws	\$0.68	General purpose screws
1/4-20 Threaded rod	Emerson	2	feet	\$2.04	Connect end caps together

1/2" Diameter Steel Rod	Emerson	4	inches	\$0.92	Drive shaft
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The above table includes all of the materials actually necessary for 1 pump. For example we purchased 4"x1/2"x12" of PVC but we only used 2.75"x1/2"x11.5" of PVC so the price of the PVC for the pump is not \$12.00 but \$7.91. Using these calculations for the actual materials used, the Material Cost for one pump is 28.36.

5.3. Machining

5.3.1. Fabrication Gantt Chart



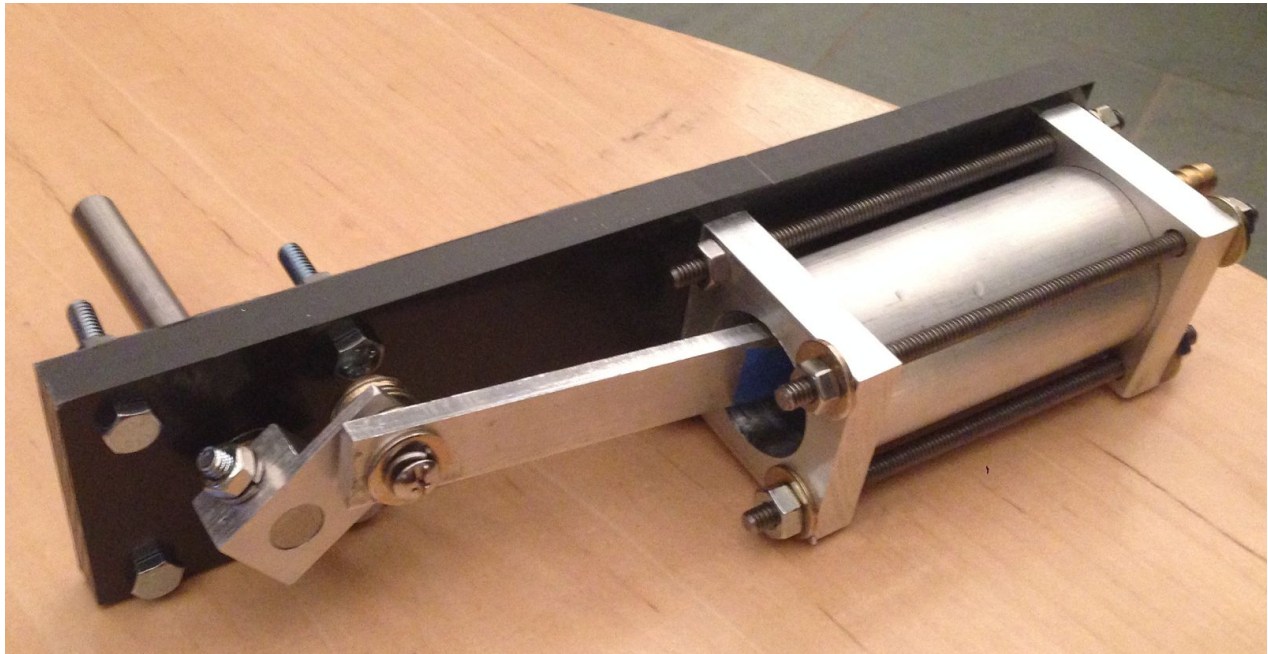
The chart above shows the actual times that were spent machining each part. We machined on Friday 4/15 from 10:00-11:30, Monday 4/18 9:00-12:00, in section on 4/19, on 4/20 from 10:30-12:00, on Friday 4/22 from 9:00-12:00, and on Monday 4/25 from 9:00-12:00 and 3:00-5:00.

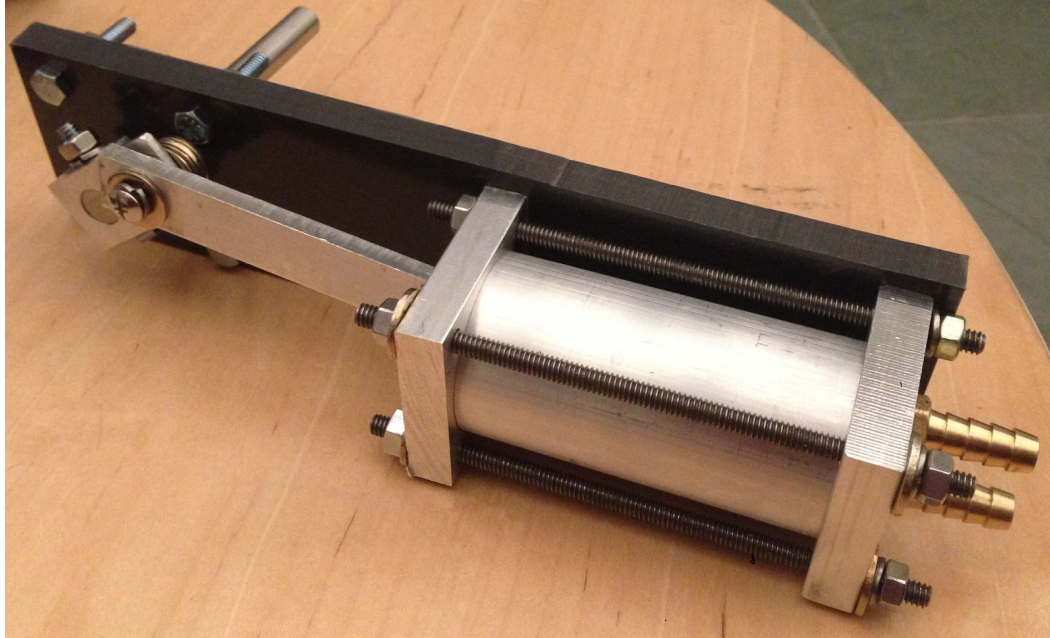
5.3.2. Individual Part Descriptions

Part	Machine Used	How it was made
Crank	Mill	7 milled surfaces, 3 drilled holes
PVC	Bandsaw, Mill	Bandsaw to cut from 4" to about 2.75" then milled to 2.75" and milled 4 surfaces and drilled 7 holes.
Threaded Rod	Bandsaw, Belt Sander	Cut 4, 6" sections and used the belt sander to make the ends smooth
Secondary End Cap	Mill	Faced 2 surfaces, drilled 1 hole
Main End Cap	Mill	Faced 2 surfaces, drilled 2 holes, threaded 4 holes
Crank Arm	Mill	Faced 5 surfaces and drilled 2 holes

Cylinder	Lathe, Honing Tool	Laethe to cut to 4", and Honing tool to hone the cylinder
Drive Shaft	Mill	1 milled surface, 1 drilled hole
Piston Head	Lathe, Mill	2 lathed surfaces, 2 drilled holes
L-Brackets	Bandsaw, Mill	Bandsaw to cut L-Brackets to about ½" wide, then milled 3 surfaces and drilled 2 holes

5.3.3. Photos of Full Assembly





5.4. Cost Analysis

The Cost Analysis was performed twice. Once as estimates before machining began and once after the pump was completed which is how much the pump actually costs. In the Cost Analysis there were four different types of costs that were considered. The first is the Material Cost which was calculated by determining how much material is used to produce one pump. The next type of cost was the Total Prototype Cost. This was calculated using the equation:

$$Total\ Prototype\ Cost = (Engineering\ Hours) * \frac{\$120}{hr} + (Machining\ Hours) * \frac{\$40}{hr} + Material\ Cost$$

The next type of cost is the Product Cost for a Single Production Pump. This was calculated using the equation:

$$Product\ Cost\ for\ a\ Single\ Production\ Pump = Total\ Prototype\ Cost + (\# holes + \# threadings + \# reamings + \# milled\ flat\ surfaces + \# turned\ straight\ surfaces + 10 * (\# curved\ turned\ or\ milled\ surfaces + \# inches\ of\ weld + \# cuts + \# hand\ finished\ edges\ or\ surfaces + \# bends) * \$1.20$$

The final type of cost used in the Cost Analysis is the Product Cost if 1000 pumps were produced. This cost was calculated using the equation:

$$Product\ Cost\ for\ 1000\ Pumps\ Made = Total\ Prototype\ Cost + (\# holes + \# threadings + \# reamings + \# milled\ flat\ surfaces + \# turned\ straight\ surfaces + 10 * (\# curved\ turned\ or\ milled\ surfaces + \# inches\ of\ weld + \# cuts + \# hand\ finished\ edges\ or\ surfaces + \# bends) * \$1.20$$

When we made our cost estimates, we estimated the Material Costs would be \$30.40, the Total Prototype Costs would be \$1562.00, the Product Cost for a Single Production Pump would be \$1622, and the Product Cost per pump if one thousand pumps were sold would be \$61.51.

When we performed our actual analysis, we found that the Material Cost is \$28.36, this was found using the Materials Used Charts above. The Total Prototype Cost was found to be slightly larger than expected. This is because in planning we expected to spend 8 hours of Engineering Hours and 13 hours of Machining Hours, but we actually spent 9 hours of Engineering Hours and 17.5 Machining Hours. This made our Total Prototype Cost \$1808.36. The Product Cost of a Single Production Pump was also slightly larger than our estimated value because of the increased Total Production Costs. From our finished water pump, there are 22 holes, 4 threadings, 2 reamings, 27 milled flat surfaces, and 1 turned straight surface. Putting these values into the equation and knowing that all other values are 0, we get that the Product Cost for a Single Production Pump is \$1875.56. The actual Product Cost for 1000 Pumps was also higher than our estimated cost because we underestimated the number of milled flat surfaces that we ended up making. In the end, the Product Cost for 1000 Pumps made was \$69.00.

5.5. Performance Estimation

Before we built our pump, we made two different performance estimations about our pump. The first performance analysis was $\frac{Flow\ Rate}{Mass}$. Our estimated flow rate was 8.52 L/min and our estimated mass was 2.03 lbs, this gave us an estimated flow rate/ mass of 4.20 L*lbs/min. The other analysis was a $\frac{Flow\ Rate}{Product\ Cost\ per\ Pump}$. Our estimated Product Cost per Pump was \$61.51 which gave us an estimated value of flow rate/ product cost per pump of 0.1385 L*\$/min.

After the pump was fully assembled we calculated the performance estimations using the final values of mass and product cost. The final mass was 2.412 lbs resulting in 3.53 L*lbs/min. The final product cost was \$69.00 resulting in 0.12348 L*\$/min.

6. Testing and Refinement

Testing was performed in Upson 207 with the provided wind turbine set up. The drive shaft of the pump was connected to the provided sprocket via a set screw. The PVC plate was connected to the provided faceplate via 4 screws with washers on the back end of the faceplate. The pump was angled downwards and the provided 7 inch by 7 inch base was not used.

6.1. Preliminary Testing

The fan was turned on to the lowest setting and the pump was tested without water. The point of this was to determine if the pump functioned as expected.

6.1.1. Results

The pump was able to start without any external forces provided but was very slow, once an external force was provided to the chain driving the sprocket the pump operated at a quick speed. Due to the orientation of the pump, the brass pipe fittings for the hose connections were pointed towards the ground an approximately half an inch off of the ground. We suspect that this will cause the hoses to kink near the connection to the pump and reduce the flow rate.

6.1.2. Design Changes

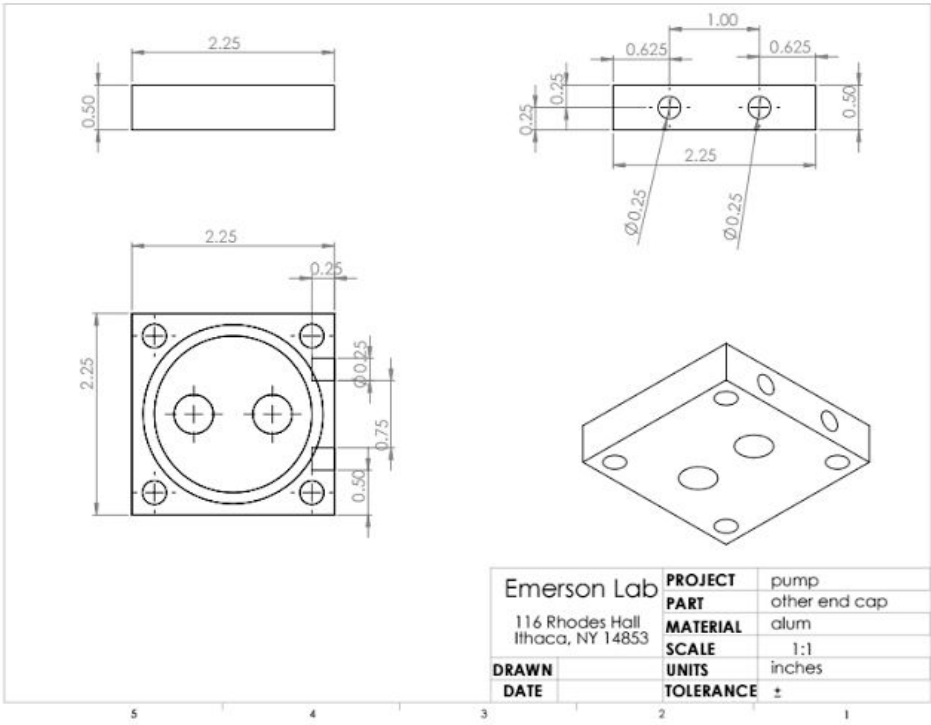
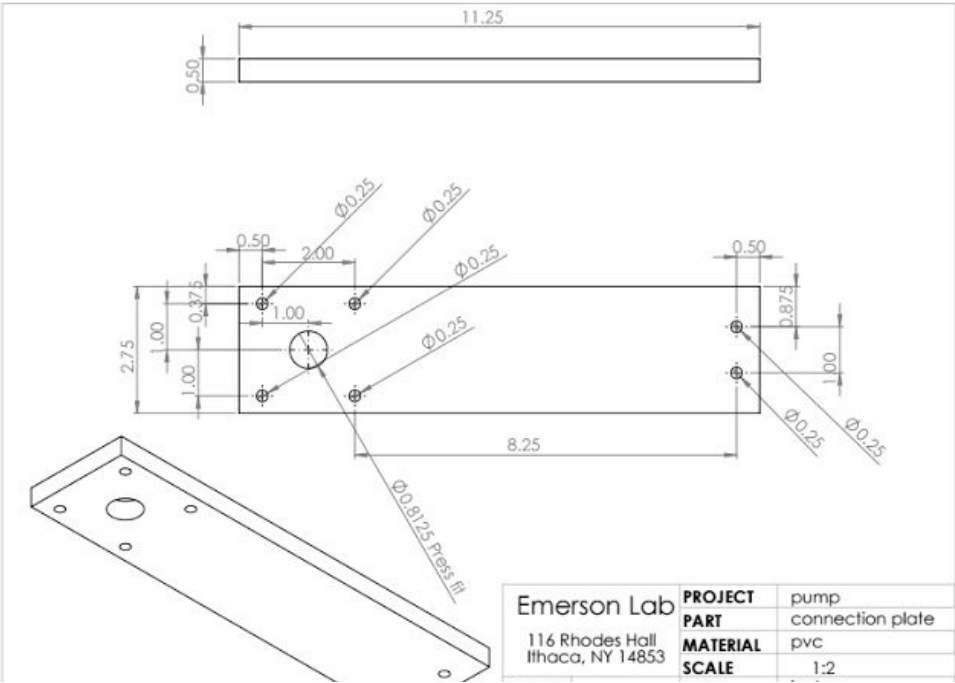
To alleviate the space constraint caused by our pumps orientation we switched from straight brass pipe fittings to plastic pipe fittings angled at 90 degrees. This change allows for those hoses to be connected in a horizontal orientation with ample space.

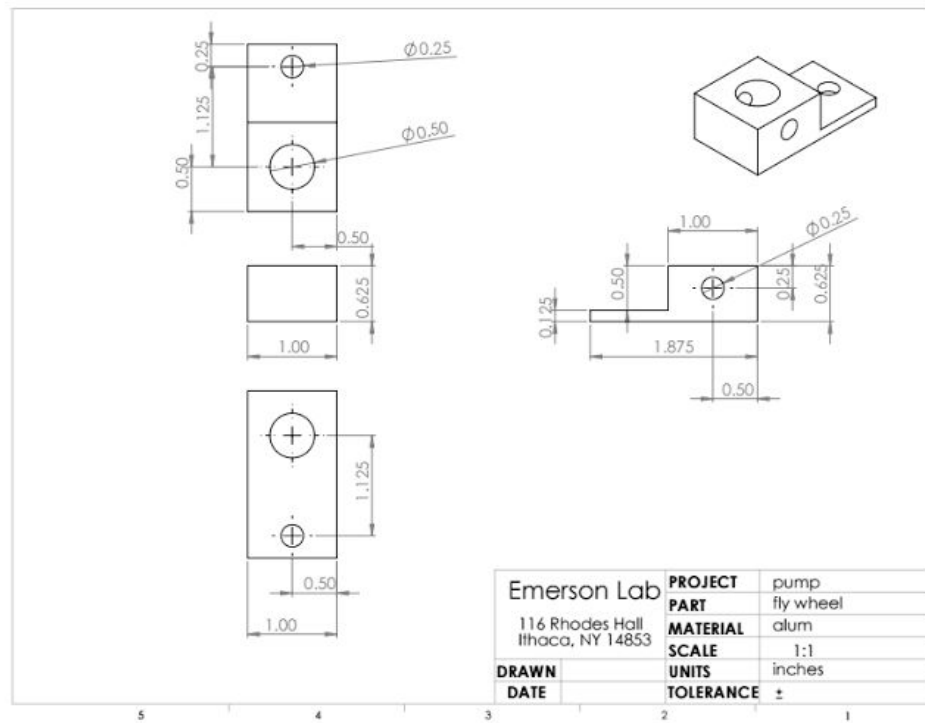
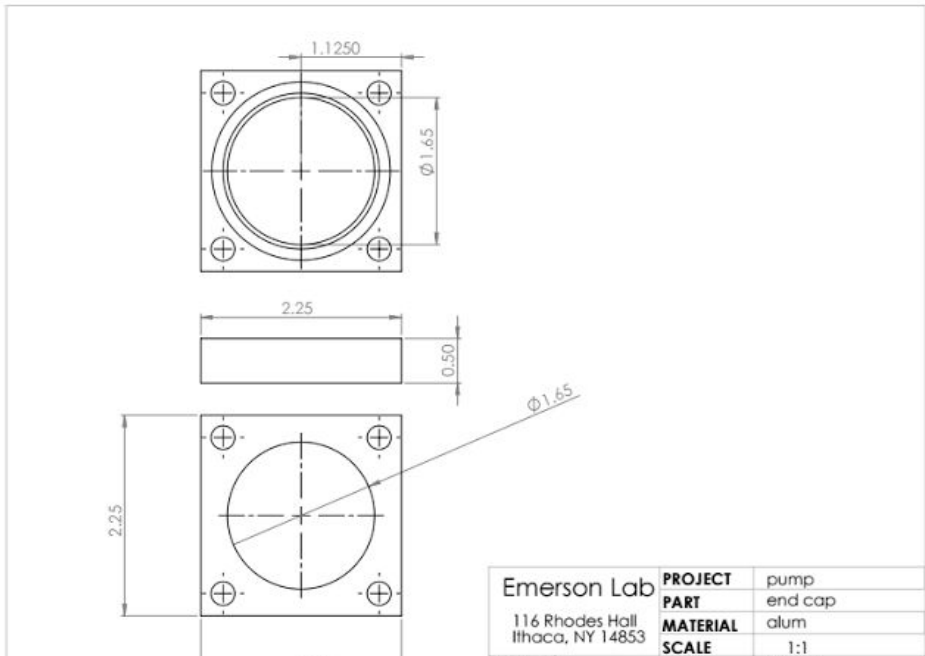
6.2. Final Testing

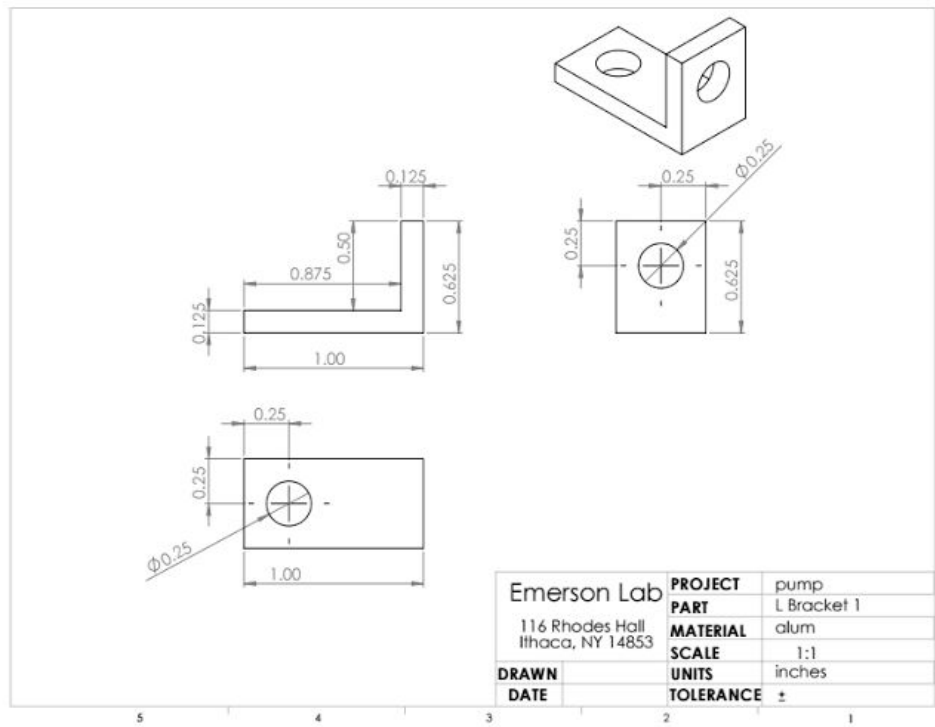
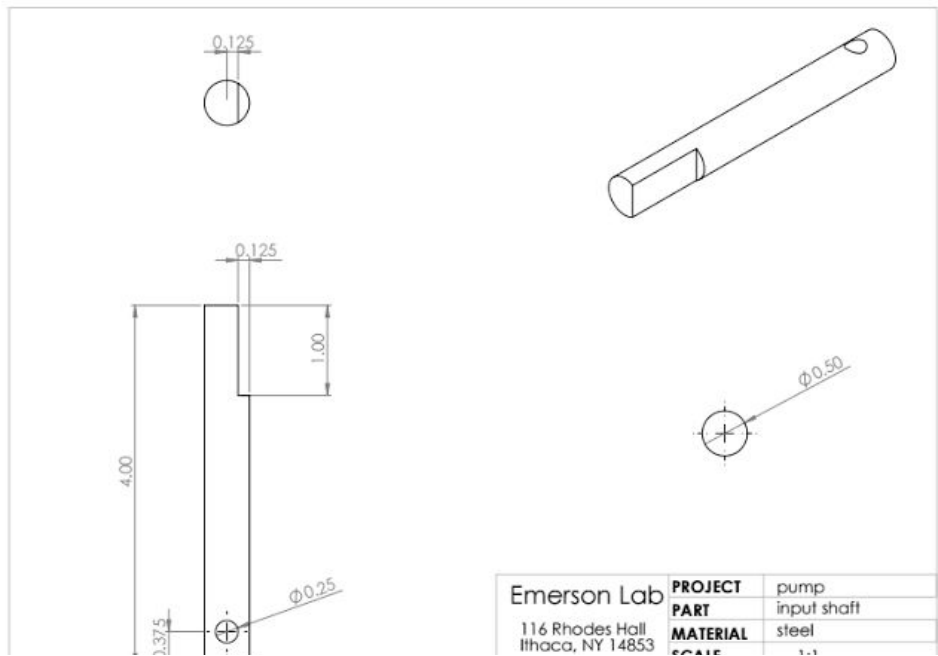
Final Testing will be performed on the same day as the due date of this report.

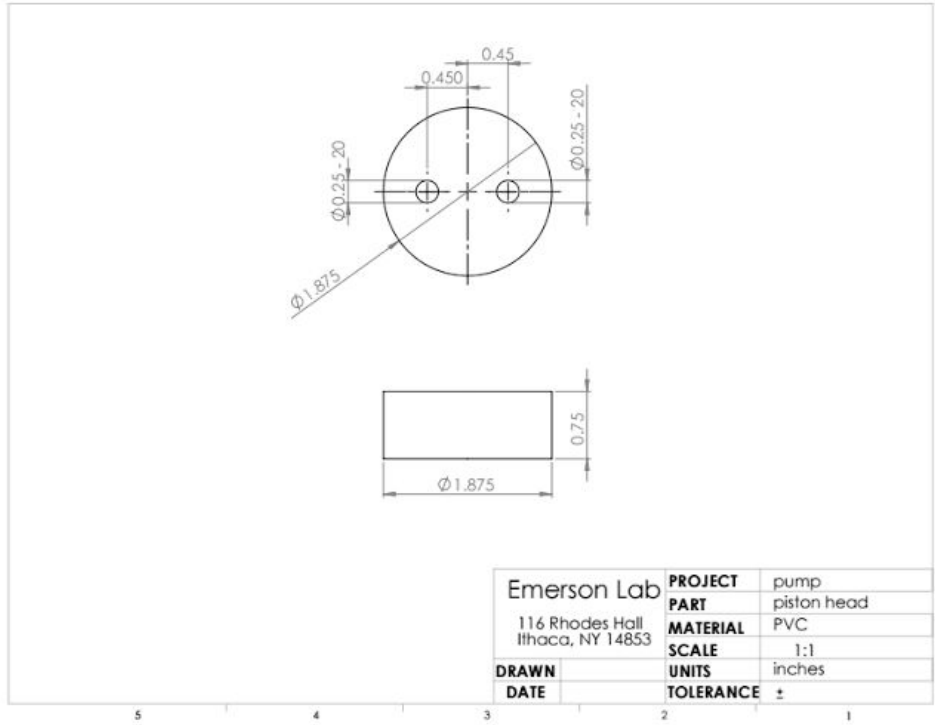
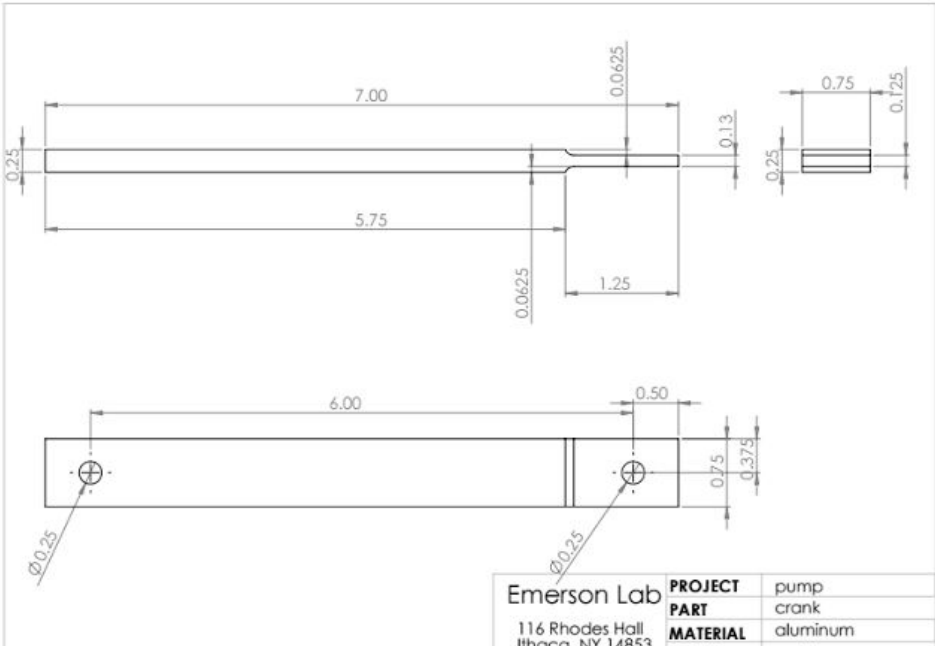
7. Appendix

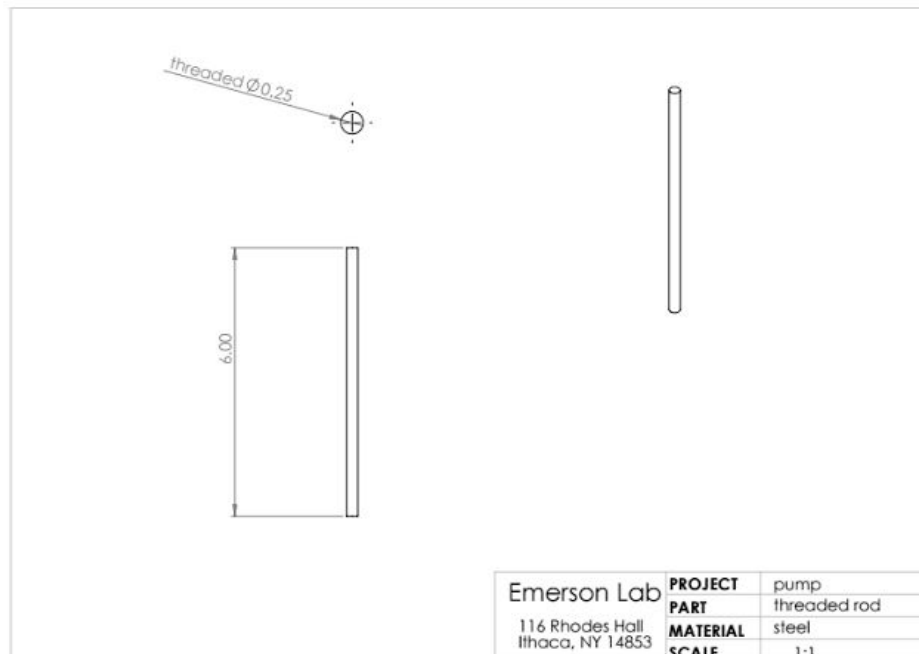
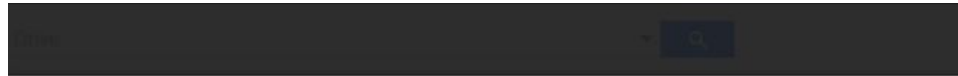
7.1. Cad Drawings











7.2. Division of Labor

Task	Date Completed	Description
Identify Customer Needs	3/14	Nick, Aviv, Malkiel, and Drew read the customer specifications and interpreted the needs from that.
Generate Concepts	3/15	Nick, Aviv, Malkiel, and Drew researched different types of pumps that could be created.
Pugh Decision Matrix	3/15	Everyone weighted the importance of the customer needs and decided how well the piston, centrifugal, and peristaltic pumps met those needs
Gantt & PERT Chart	3/22	Everyone worked together to plan how the group would complete the water pump project.
Morph Chart	3/22	Malkiel, Nick, and Drew worked on making the Morph Chart and everyone voted on the different concepts

Sketches	3/22	Drew made sketches for different types of piston pumps
Benchmarking	3/22	Everyone in the group searched online to find benchmarking information
Pareto Front	3/22	Drew used the data from the benchmarking research to create a Pareto Front
Concept Selection Matrix	4/4	Everyone voted on whether we wanted to make the slider crank or scotch-yoke piston pump.
Preliminary CAD Design (Autodesk Inventor)	4/4	Malkiel made the idealized preliminary design in Inventor.
Stress Analysis	4/4	Malkiel also performed a stress analysis on the idealized pump.
PDR Slides	4/4	Drew made the Customer Needs and Benchmarking slides. Aviv made the Morph Chart, Pugh Decision Matrix, and Gantt Chart slides. Malkiel worked on the 2 Selected Concepts and Designs and the sketches/CAD slides. Nick worked on the Decisions for Final Concept and Plans moving Forward slides. Priscilla worked on the brainstorming slide.
Preliminary CAD Designs (Solidworks)	4/11	Aviv created the pump in SOLIDWORKS and made the exploded view. Nick made the pump animation.
Drawings	4/11	Aviv also made drawings for each part and updated the drawings as our designs changed.
Tolerancing	4/11	Aviv made the tolerancing in the SOLIDWORKS drawings.
Performance Analysis	4/17	Drew and Malkiel made the performance analysis based off of the MATLAB code provided and other analysis.
Cost Analysis	4/17	Nick performed the cost analysis.
FDR Slides	4/19	Drew talked about the Minimum Power Requirement, Flow Rate Analysis, Power Analysis, and In-Depth Analysis Slides. Malkiel talked about the CAD - 1st Revision and Stress Analysis slides. Aviv talked about

		the CAD - 2nd Revision, Animation, and Exploded Views Slides. Nick talked about the Weight Estimates, Cost Estimates, and Efficiency Estimates slides. Priscilla talked about the Fabrication Gantt Chart.
Materials Purchased	4/25	Nick, Aviv, and Malkiel worked on determining which materials needed to be purchased based off of the CAD Designs. Orders were placed by Nick and Aviv on 4/11, 4/17, 4/21, and 4/25
Machining	4/26	All machining was completed by 4/26. Below is a description of who worked on which part and when each part was machined.
Secondary End Cap	4/22	Drew worked on the initial hole on 4/15, Nick and Drew continued to enlarge the hole on 4/19 in section, and Drew finished enlarging the center hole on 4/22
Crank	4/18	Aviv milled all 7 sides and drilled all 3 hole. He worked on it on 4/15 and 4/18
Cylinder	4/25	Malkiel honed the cylinder on 4/19 in section, Aviv and Drew then cut the length of cylinder to 4" and then Aviv rehoned the cylinder on 4/25
Drive Shaft	4/26	On 4/19, Aviv drilled a hole in the drive shaft. On 4/22 Nick, Aviv, and Drew milled the shaft to get a flat edge. On 4/26 Drew cut the drive shaft down to about 4".
Piston Head	4/22	On 4/19, Malkiel cut the piston head down to the diameter of the cylinder. On 4/22, Nick cut the piston head to $\frac{3}{4}$ " and drilled 2 holes in the piston head.
Main End Cap	4/22	On 4/18, Aviv drilled and threaded 2 small holes underneath the end cap to connect the end cap to the connecting plate. On 4/22, Drew threaded the 2 main holes that connect to the pipe fittings.
Connection Plate	4/22	On 4/22, Aviv faced 3 edges and drilled 7 holes.
Threaded Rods	4/25	On 4/22, Drew used the bandsaw to cut 4 rods to 6" lengths. Because of the way the rods were cut, nuts could not be screwed on the rods so on 4/25, Aviv used the belt sander to clean the initial threads.

L Brackets	4/25	On 4/25, Aviv used the bandsaw to cut the 2 L Brackets to about ½". Then Nick faced each edge and drilled 2 holes in each L Bracket
Crank Arm	4/25	On 4/15, Priscilla faced 3 edges of the arm and drilled 1 hole. Then on 4/20, Nick drilled the other hole. Then because we increased the thickness from ⅛" to ¼", but forgot to adjust for that in the distance between the holes in the piston head, Nick remilled 1 end of the crank arm so that its thickness was about ⅛".
Presentation to Customers Slides	4/25	Drew made the Target Customers, Example Target Customer, and Mission Statement Slides. Aviv worked on the Pump Design and Why You Should Buy Our Pump Slides. Nick worked on the Cost Analysis Slides. Malkiel worked on the Global Applications slides. Priscilla worked on the company logo.
Preliminary Testing Design Changes	4/26	Aviv, Drew, and Priscilla saw that the pipe fittings were too long. Aviv made changes to the CAD, and got new fittings from Joe.
Final CAD Rendering	4/29	The final renderings were made by Aviv.
Individual Components	4/29	Aviv also made renderings of the individual components.
Materials Used	4/29	Nick determined how much of each material was used based on the materials that were purchased
Fabrication Gantt Chart	4/29	The initial designs were made on 4/17, but the final and accurate Gantt Chart was finished by Nick.
Photos of Full Assembly	4/29	Aviv took photos of the full assembly.
Division Labor	4/30	Nick made the division of labor table
Individual Part Descriptions	4/30	Nick made the individual part description in the pdf.

7.3. Meeting Minutes

Meeting Minutes are left in unedited with the exception of removing charts and figures that are present in other locations of this document.

Date	Duration(minutes)	Proceedings
3/14/16	45	Setup method for communication. Our main method of communication will be GroupMe and we will create a Google Drive Folder where we share information. Naming convention for files: Name_revisionNumber Our normal meeting times will be during the MAE 2250 Lecture times. Nick Serger: (703)-501-9056 Aviv Blumfield: (914)-420-5981 Malkiel Frager: (347)-803-8404 Priscilla Wong: (646)-203-6871 Drew Mathews: (650)-773-0215 Customer Specs Brainstorming Different Pumps we could make: ● Piston Pump ○ Single acting ○ Double acting ○ Scotch-Yoke ○ Slider Crank ○ Driving Gear ○ Watt's Linkage ○ Hoeken's Linkage ○ Chebyshev Linkage ● Linear actuating pump ● Peristaltic pump ● Single output ● Multiple outputs ● Centrifugal pump ● Rotary vane pump ● Swashplate ● Archimedes' screw Important aspects: ● Minimize friction - maximize laminar flow ● Minimize size and cost (grade based on output/mass and output/cost) ● Maximize output volume ● Ensure reliability

		○ Must also be durable ● Safety Planning: Schedule: ● Week 1: ○ Create customer specifications, brainstorm ideas, plan ● Week 2: ○ Brainstorming continued, benchmark and half section tests ● Week 3: ○ Preliminary design review, test for power output of turbine, morph charts, 3D sketches of selected concepts ● Week 4: ○ Analyze technical aspects of selected pump from WP3, have dimensions and performance predictions for pump ● Week 5: ○ Prepare for Final Design Review presentation, finish CAD model, have fabrication plan and detailed timeline ● Week 6: ○ Create user manual, prepare Presentation to Customers (PC), complete construction of pump
3/15/16	45	Numerical Metrics: ● Flow rate: ● Head pressure ranges ● Horse power ranges ● Cost ● Mass ● Rpm ● Temp. ranges ● Vibration ● Friction http://www.pumpscout.com/articles-scout-guide/pump-types-guide-aid100.html http://www.catpumps.com/products/pumps-positive-displacement-triplex-piston.asp
3/22/16	60	PDR Requirements: Needs specs, morph charts, 2 concepts (Different Types of Piston pumps)

		PERT chart/Gantt chart 3D sketch/ view from CAD of morph chart results Morphological Chart Today we created a Gantt Chart, Pert Chart, Benchmarking Chart, Pareto front, and made 3D sketches and CAD Designs of two possible concepts. What they expect for PDR - put all of this in a powerpoint and present in: Sketches - isometric views from different angles Customer needs Brainstorming Include data analysis - why is it significant/relevant Morph charts At least 2 concepts and designs for pump Gantt/PERT Decision matrix After PDR: Start getting materials, finalizing design
4/4/16	45	Making the PDR: • Brainstorming - Priscilla • Customer needs - Drew • Wind-water pump specs (benchmarking stuff) - Drew • Morph charts - Aviv • Pugh decision matrices - Aviv • Gantt chart - Aviv • 2 selected concepts and designs - Malkiel • sketches/CAD - Malkiel • Relevant analysis to understand design and manufacture process - everyone • Decision for final concept : make another pugh matrix, fill it out and then go based off of that - Nick • Plans moving forward - Nick Scotch-Yoke vs. Slider Crank (found this online) http://functionspace.com/topic/3725/Slider-crank-mechanism-vs-Scotch-and-Yoke-mechanism

	One of the main reason that Scotch and Yoke mechanism is seldom used is because of high frictional losses. Slider crank mechanism comprises of 3 Revolute joints and 1 Prismatic joint. On the other hand Scotch and Yoke mechanism consists of 2 Slider and 2 Prismatic Joints. Since we know that the coefficient of rolling friction is lesser than sliding friction. Thus along with losses, we would have to change the components more often which is not acceptable for automobiles. In the case of scotch and yoke mechanism will have a slider at that place which is prone to out of plane bending because there is one extra link between revolute and prismatic joint. So rigidity factors might also be one of the factors. Analyze torque test data Predict performance of our pump using some type of analysis CAD simpler version of slider crank so that it can be machined Order Parts CAD: Piston head with L bracket attchmetns Attachment plate - specs on blackboard Cylinder with endcap - sld file on black board wheel/ arm attaching piston head to wheel L-Brackets: http://www.mcmaster.com/#corner-brackets/=11vai0q http://www.mcmaster.com/#corner-brackets/=11vai3m Washers: \$0.02 each from emerson shop Threaded rods with non threaded center regions: http://www.mcmaster.com/#standard-threaded-rods/=11vpbsr http://www.mcmaster.com/#standard-threaded-rods/=11vpbz4 Thread the inside of these then attach a bolt to each end to constrain bearing support: http://www.mcmaster.com/#aluminum-hollow-rods/=11vr54u
--	--

		If we use this one probably will need to machine own I brackets: http://www.mcmaster.com/#aluminum-hollow-rods/=11vrbqz
4/8/16	60	Parts List Aluminum Bars: • (1) 1/4" x 1" x 8" : \$1.12 @ \$ 0.14/in ---> Connecting Shaft Between Piston and Crank • (1) 1" x 2" x 2" : \$2.36 @ \$1.18/in ---> "Crankshaft" • (1) 1/2" x 2 1/4" x 11" : \$8.03 @ \$0.73 ---> connecting "plate" PVC Rod: • (1) 1 7/8" x 1" Diameter Plastic Rod : \$0.86 @ \$0.86/in ---> Piston • 1/2" Diameter Steel Rod 5 inches \$1.15 Machined part: • (2) Machined End Caps : \$2.00 @ \$1.00/each • (1) Bored Cylinder, 4" : \$1.00 @ 1.00/each Screws: • (12) 1/4" screws for general attachment • 1/4-20 Threaded rod 2' : \$2.04 @ \$1.02/ft • 20 Flat Washers: \$0.40 @ \$0.02/each • 15 Nuts 1/4-20 hex nuts: \$0.30 @ \$0.02/each • 5 Lock Washers: \$0.10 @ \$0.02/each McMaster: • Multipurpose 6061 Aluminum 90 degree Angles : \$2.94 @ \$2.94/ft ---> Angle Brackets ◦ http://www.mcmaster.com/#8982k87/=11xy6e0 • (1 set) 1" length Binding Posts from McMaster : \$3.31 @ \$3.31/(set of 10) ---> Pivots ◦ http://www.mcmaster.com/#92463a406/=11xcjnc • Teflon tape to seal piston 3/4" width : \$3.40 @ 3.40/roll ◦ http://www.mcmaster.com/#4591k13/=11xygpz • Low-Strength Zinc-Plated Steel Cap Screw 1/4"-20 Fully Threaded, 1-1/2" Long: \$8.42 ◦ http://www.mcmaster.com/#91309A546 • Chemical-Resistant PVC 1' @12.03/foot ◦ http://www.mcmaster.com/#pvc/=120u4n5
4/12/16	150	Analysis For FDR: -fabrication Gantt chart for machining, day by day -weight estimate for pump -cost estimates for prototyping and mass producing

		-detailed CAD with multiple views and animations -notebooks will be checked
4/17/16	180	Altered parts of the design and ordered the changed parts. Worked on FDR Created: • Material Cost Spreadsheet • Fabrication Gantt Chart • New Order List • Pump Animation in SOLIDWORKS • Exploded View of Pump in SOLIDWORKS • Analysis of pump performance
4/25/16	90	Spoke with prof. Ruina about different ways that we could improve our pump design • Make piston head larger to reduce chance of piston locking in cylinder • Use thrust washer between crank and arm connection • Replace all washers with nylon washers to reduce friction • Use lock nuts to constrain moving pivots • Create custom bearing to remove metal to metal contact in crank to pivot connection • Space connections appropriately to decrease the space between the slider crank and the baseplate as much as possible to reduce the moment acting on the shaft. Give our time constraints and other duties we picked a few of the more easily implemented suggestions that Ruina had: • Bought thrust and nylon washers from mcmasters • Create custom bearing from spare pvc stock • Space the connections appropriately by varying the location of washers along the pivot connection between the crank and arm.
4/25/16	200	<u>Presentation to Customers</u> PC is a sales pitch that your group would deliver to the TAs and the class. This is to sell your pump to the customers by showing how differentiated and unique your pump is. This is very open-ended so be creative with it. • This is a 15min sales pitch. • Make a company and brand your product. ○ Define your customers. Who's buying this thing? - Drew ○ Company Image. Who are you and what do you stand for? - Drew ○ Make a cool logo. - Priscilla

		• Costing ○ How much does it cost to make this? 1 unit? Many units? - Nick ○ Cost to sell your pump? - Nick ■ Take the price from the FDR and increase a little bit so that we make a profit but not too much so that we can sell it for reasonably cheap • Sell it to us. ○ Why should we buy your pump? What are its pros? - Aviv ■ Its simple, lightweight, less moving parts ○ CAD model and animation. (You already did this). - Aviv ○ ○ Make your presentation look nice! Have nice pictures and themes. Don't forget that we are your customers. - Everyone ○ Physical demo (your pump should be turning by now) - Everyone ○ What's your plan for selling this thing? Are you going retail, wholesale, catalogs, online, black market trades on the 3rd floor of Upson, etc... - Malkiel ■ Look up potential customers/competition • Creativity: however you want to present it - Everyone Most of this can be pulled directly from FDR and changed so that it is presented for a customer instead of a boss. We're going to focus on selling to rural/poorer areas. Sell to companies that provide aid in 3rd world countries. Base presentation off of drew's link and the FDR Company name ideas: EarthPump PumpAware PumpSimply PumpImpact PumpEthical PumpForward - Aviv,Drew, Nick DoPumpMe IPumpYou PrisPump https://cornell.box.com/s/ogxjybpf9ycmb2puhjf1jcns5cw78n1 https://cornell.box.com/s/d6k9qqbe1ojrwkp8q8oveiheimswrigc Assembled pump
4/29/16	300	Begin working on PDF and user manual

7.4. PDR Slides

Wind Pump

Nick Serger, Aviv Blumfield, Drew Mathews, Malkiel Frager, Priscilla Wong

Brainstorming

Different Pumps we could make:

- Piston Pump
 - Single acting
 - Double acting
 - Scotch-Yoke
 - Slider Crank
 - Driving Gear
 - Watt's Linkage
 - Hooke's Linkage
 - Chebyshev Linkage
- Linear actuating pump
- Peristaltic pump
- Single output
- Multiple outputs
- Centrifugal pump
- Rotary vane pump
- Diaphragm
- Archimedes' screw

Important aspects:

- Minimize friction - maximize kinetic flow
- Minimize size and cost (grade based on output/mass and equipment)
- Maximize output volume
- Ensure reliability
 - Must also be durable
- Safety

Wind/Water Pump Specifications

- Pump must elevate water by at least 1.5m
- Water output flow $\gg 1$ liter/min
- Pump's shaft input (turbine connection) is a hole with diameter of 1.875"
- The pump must fit in an allotted area of at most 7" x 7" and must be rigidly connected to the plate
- Output drive shaft is $\frac{1}{2}$ " diameter rod
- Extends 2.5" from face plate
- Axis 5/32" above horizontal plate
- Pump is attached to face-plate by 4 screws
- The pump must not be larger than 14"x14"x14". The pump must also be able to adjust its height to meet the requirements of the provided motor.
- Water inputs and outputs are $\frac{1}{2}$ " diameter, the input is at the same height as the reservoir
- Pump must run off of power provided by wind turbine.

Customer Needs

- Flow rate
- Low Cost
- Easy to Make
- Reliable/Durable
- Efficient

Load as PDF

Print

Gantt Chart



PERT Chart



2 Selected Concepts and Designs

Slider-Crank Mechanism

Scotch-Yoke Mechanism

Sketches and CAD Drawings

Decision for Final Concept

Selection Criteria	Weight	An #	Pump Concepts			
			Slider Crank		Scotch Yoke	
			Rating	Weighted Score	Rating	Weighted Score
Flow Rate	9	0	0	0	0	0
Cost	6	7	0	0	0	0
Ease to Make	9	0	0	0	0	0
Reliability	5	6	7	8	1	1
Durability	5	6	7	8	1	1
Efficiency	5	4	3	7	5	1
Total Score				122.6		-67.4
Rank				1		2
Continue?				Yes		No

Decision for Final Concept - Slider Crank!

- Less energy lost to friction in a slider crank piston than Scotch-Yoke
- Easier to manufacture
- Longer lasting because there is less friction
- Approximately equal flow rates

Plans Moving Forward

- Determine dimensions and performance predictions of pump
- Order parts
- Begin Machining

7.5. FDR Slides

Group 5 FDR

Aviv Blumfield, Nick Serger, Malkiel Frager, Drew Mathews, Priscilla Wong

Minimum Power Requirement

$$\begin{aligned} \text{Minimum Power Required} &= mgh = (1 \text{ L/min}) \cdot \left(\frac{1 \text{ kg}}{\text{L}}\right) \cdot \left(9.81 \frac{\text{m}}{\text{s}^2}\right) \cdot (1.5 \text{ m}) \\ &= 14.715 \frac{\text{Joules}}{\text{minute}} = 0.245 \text{ Watts} \end{aligned}$$

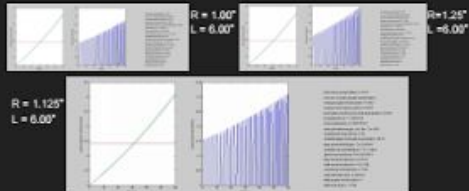
Flow Rate Analysis

$V = \text{Usable Cylinder Volume} = \text{Area of Piston} \times \text{Stroke}$
 $A = \text{Area of Piston} = (\pi D^2) = (\pi) \left(\frac{1.00}{2}\right)^2 = 0.7854 \text{ in}^2$
 $N = \text{Stroke} = 2.25 \text{ in}$
 $V = A \times N = (0.7854 \text{ in}^2) \times (2.25 \text{ in}) = 1.76715 \text{ in}^3$
 One revolution of the crankshaft is one full cycle of the piston stroke
 Therefore, One revolution of the crank drives in and expels one V
 $\Phi = \text{maximum the speed of crankshaft} = 572.95 \text{ RPM}$
 $\text{Speed (Crankshaft)} = \frac{572.95 \text{ RPM}}{(2/1)} = 286.475 \text{ RPM}$
 $F = \text{flow rate} = V \times \text{RPM} = 1.76715 \text{ in}^3 \times 286.475 \frac{\text{in}^3}{\text{min}} = 506.84 \frac{\text{in}^3}{\text{min}}$
 $\bar{F} = 8.52 \frac{\text{L}}{\text{min}}$ Assuming no energy loss

Power Analysis

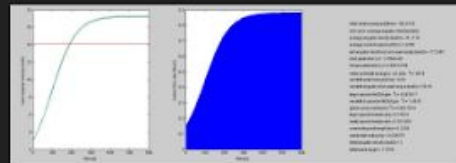
$$\begin{aligned} \bar{P} &= \rho_w g h \bar{Q} = \left(\frac{1 \text{ kg}}{\text{L}}\right) \cdot \left(9.81 \frac{\text{m}}{\text{s}^2}\right) \cdot (1.5 \text{ m}) \cdot \left(8.52 \frac{\text{L}}{\text{min}}\right) \cdot \left(\frac{\text{min}}{60 \text{ secs}}\right) \\ \bar{P} &= 2.09 \text{ Watts} \end{aligned}$$

In-Depth Analysis

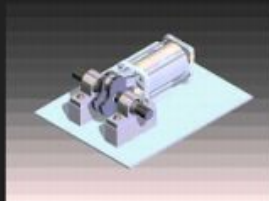


In-Depth Analysis Continued

$R = 1.125^\circ$ $L = 6.00^\circ$ Time-Lapse = 10 minutes

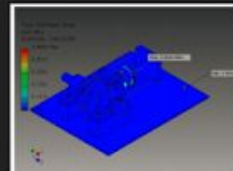


CAD - 1st Revision



Stress Analysis

Item	Material	Properties
1	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
2	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
3	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
4	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
5	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
6	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
7	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
8	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
9	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%
10	Aluminum 6061-T6	Yield Strength: 276 MPa, Tensile Strength: 324 MPa, Elongation: 12%



CAD - 2nd Revision



CAD - Exploded Animation



CAD - Exploded View



Fabrication Gantt Chart

Weight Estimate for Pump

From SOLIDWORKS excluding given faceplate: 2.03 lbs

Cost Estimates for Pump for prototyping and mass production

- Material Costs: \$30.40
- Product Cost, Single Production Pump: \$1,622.00
 - Product Cost, Single Production Pump: if only one unit: (\$pump) = Total prototype cost + (# holes + # threads + # reamings + # milled flat surfaces + # turned straight surfaces + 10" # curved turned or milled surfaces + # inches of weld + # cuts + # hand finished edges or surfaces + # bends)/\$1.20
- Product Cost, per pump: \$61.51
 - If one unit 1000 pumps (\$pump) = Total prototype cost/1000 + (# holes + # threads + # reamings + # milled flat surfaces + # turned straight surfaces + 10" # curved turned or milled surfaces + # inches of weld + # cuts + # hand finished edges or surfaces + # bends)/\$1.20

Estimated Efficiency

- Flow Rate/ Mass = 8.52 (L/min)/ 2.03 (lbs) = 4.20 (L*lbs/min)
- Flow Rate/ Product Cost per pump = 8.52 (L/min)/ 61.51 (\$) = 0.1385 (L*\$/min)

7.6. Presentation to Customers Slides



...

Aviv Blumfeld, Malkiel Frager, Nick Serger, Drew Mathews, Priscilla Wong

Target Customers

Organizations that implement water systems in rural areas

- Pump to be implemented in rural areas to provide water relief to communities in need



Example Target Customer - Engineers Without Borders

- EWB implement water pump systems in rural areas to provide water to villages in developing countries
- Ex: Calcha, Bolivia
 - EWB would implement solar panels for input power to the pump and a pipe system to irrigate water to the town of Calcha
 - Our pump would work with these components to pump water to the town
- Our pump is ideal for situations like this because our pump is simple
 - Easy to repair in remote areas
 - Durable/Reliable
 - Portable/Lightweight



Mission Statement: "Pump Communities Forward"

- Help developing countries grow
- Create sustainable communities
- Technology with a purpose



Pump Design



Why You Should Buy Our Pump

Its lightweight coming in at a low 2.775 lbs



Why You Should Buy Our Pump

Why You Should Buy Our Pump

Cost Analysis

Product Cost, Single Production Pump: \$1,622.00

Product Cost, per pump if 1 million pumps are sold: \$60.00

We will sell our pump for...



\$70.00



Global Applications - Large Customer Base

- Our simple, light, and cheap pump has the ability to supply water to people in areas of need all over the globe.
- Our company would cater to large organizations that provide disaster relief and humanitarian aid.
 - ◆ Key customers include government and private relief organizations:
 1. "FEMA"
 2. "The American Red Cross"
 3. "Water to Thrive"
 4. "H2O for Life"



7.7. Matlab Source Code for Analysis

This code was provided by Professor Louge and used to analyze the effects of changing the crank radius and crank arm lengths on flowrate:

```
function [tiarr,tharr,vearr,vfr,omef,freq,volp] = windpump(inpI,the0,ome0,tfI)

% Calculates and plots the dynamics of a windpump entrained by a
% single-cylinder, single-acting piston-slider-crank mechanism
% of negligible inertia and friction, raising water a known height through
% a line without losses, using a frictionless chain of negligible inertia
% to entrain the pump from the windmill. Sprockets and windmill inertia are
% considered.
%
% Michel Louge 2/11/2010
%
% input - inpI = parameter input column vector including
%           rcrank = crankshaft radius (m)
%           lcrank = connecting rod length (m)
%           R0 = radius of small sprocket (on windmill, m)
%           R1 = radius of large sprocket (on pump, m)
%           A = piston cross-section (m^2)
%           I0 = moment of inertia of windmill, shaft and sprocket (kg.m^2)
%           I1 = moment of inertia of large sprocket (kg.m^2)
%           om = windmill ang. vel. at peak torque (rad/s)
%           Tm = max. windmill torque (N.m)
%
%           Note: assume that windmill torque vs. ang. vel.
%                 is an inverted parabola passing through
%                 the origin.
%
%           rgh = required water potential energy/u. vol. (J/m^3)
%
% - the0 = initial crank angle (radians); = 0 at top dead center (TDC)
% - ome0 = initial angular velocity of the windmill (rad/s)
% - tfI = final simulation time (s)
%
% output - tiarr = array of times (s)
%          tharr = array of crank angles modulo 2pi
%          vearr = array of crank angular velocities
%          vfr = array of volume flow rates (liter/s)
%          omef = last angular velocity when crank angle was zero (rad/s)
%                (zero if system did not complete a whole cycle)
%          freq = average cycle frequency (Hz)
%                (zero if system did not complete a whole cycle)
%          volp = total volume pumped (liter)
%
% global variables if present, postscript I denotes an input variable destined to
%                  become global (avoids confusing Matlab)
%
% - loa = dim(-) load parameter
% - reduc = reduction ratio R1/R0
%
% to access the proper directory on Louge's computer, type
% cd ~/Michel_files/Classwork/MAE_225/Spring_2010/projects/wind-pump/Matlab_dynamics
%
% Scales for evaluating dimensionless variables:
%
% time made dim(-) with om
% torque made dim(-) with Tm
%
% Examples:
%
%           variable    example below
%           rcrank = 0.03 m
%           lcrank = 0.12 m
%           R0 = 0.04 m
%           R1 = 0.15 m
%           A = pi/4*0.04^2 m^2
%           I0 = 8000*pi/2*R0^4*0.01+3*(1/3)*2000*0.1*0.02*.75^3 kg.m^2
%           I1 = 8000*pi/2*R1^4*0.01 kg.m^2
%           om = 50 rad/s
%           Tm = 0.6 N.m
%           rgh = 1000*9.81*1 J/m^3
%           the0 = pi/2 rad
%           ome0 = 3 rad/s
%
% inpI = [.03;.12;.04;.15;pi/4*.04^2*8000*pi/2*.04^4*.01+2000*.1*.02*.75^3;8000*pi/2*.15^4*.01;50;.6;1000*9.81] ;
% [tiarr,tharr,vearr,vfr,omef,freq,volp] = windpump(inpI,pi/2,3,60); % base case
%
% other internal variables
%
% - span = dim(-) time span
% - s = dim(-) time
% - Y = column vector Y(1,1) = crank angle (rad)
%           Y(2,1) = dim(-) angular velocity
%           Y0(1,1) = initial crank angle (rad)
%           Y0(2,1) = initial dim(-) angular velocity
%           Y0(3,1) = initial dim(-) volume pumped
%
% - dis = array of piston displacements/2/crankshaft radius, with
%         origin at top dead center (TDC) (not used here)
% - vel = array of piston velocity/2/crankshaft radius/crankshaft angular velocity
```

```

% - dim = size of the solution array
% - save0 = array index when crank angle first passed through zero
% - save1 = array index when crank angle last passed through zero
% - numcyl = number of whole cycles
% - maxdt = max time step for ODE45 integration
% - tf = dim(-) final time
% - tmodel = dim(-) time array for plotting analytical result
% - ee = intermediate variable
% - angmod = angular velocity predicted by analytical solution (rad/s)
% - a0 = dim(-) initial angular velocity
%

```

```

global lr Tmd loa reduc

```

```

% translate inpI into parameters of the system:

```

```

rcrank = inpI(1) ;
lcrank = inpI(2) ;
R0 = inpI(3) ;
R1 = inpI(4) ;
A = inpI(5) ;
I0 = inpI(6) ;
I1 = inpI(7) ;
cm = inpI(8) ;
Tm = inpI(9) ;
rgh = inpI(10);

```

```

% error messages for wrong inputs:

```

```

if rcrank < 0 || rcrank == 0
    error('crankshaft radius <= 0')
end

```

```

if lcrank < 0 || lcrank == 0
    error('connecting rod length <= 0')
end

```

```

if R0 < 0 || R0 == 0
    error('small sprocket radius <= 0')
end

```

```

if R1 < 0 || R1 == 0
    error('small sprocket radius <= 0')
end

```

```

if A < 0 || A == 0
    error('piston cross-section area <= 0')
end

if I0 < 0 || I0 == 0
    error('windmill+small strocket MOI <= 0')
end

if I1 < 0 || I1 == 0
    error('large strocket MOI <= 0')
end

if cm < 0 || cm == 0
    error('characteristic windmill ang. vel. <= 0')
end

if Tm < 0 || Tm == 0
    error('characteristic windmill torque <= 0')
end

if rgh < 0 || rgh == 0
    error('water load <= 0')
end

% calculate the dimensionless numbers of the problem and pass as global variables
% for use in functions that cannot pass these
% variables as arguments; if necessary, use different names for the corresponding inputs
% to avoid confusing Matlab; convention: the postscript I denotes an input
% variable; the same variable without the postscript is the corresponding
% global variable:

lr = lcrank/rcrank ; % ratio of connecting rod length to crankshaft radius
reduc = R1/R0 ; % ratio of large/small sprocket radii
Tmd = reduc^2*Tm/cm^2/(I1+I0*reduc^2) ; % dim(-) torque parameter
loa = rgh*A*rcrank/cm^2/(I1+I0*reduc^2) ; % dim(-) load parameter
tf = tfI*cm ; % dim(-) final time

% initialize variables for the ODE solver:

span = [0 tf] ; % dim(-) time span
Y0(1,1) = the0 ; % initial crank angle (rad)
Y0(2,1) = cme0/cm ; % initial dim(-) angular velocity
Y0(3,1) = 0 ; % initial volume pumped

```

```

options = odeset('MaxStep',maxdt) ; % specify max time step through option call for ODE45
[s,Y] = ode45(@deriv,span,Y0,options) ; % calls 4th-order Runge-Kutta ODE solver using function deriv below
%[s,Y] = ode45(@deriv,span,Y0) ; % without options

%sol = ode45(@deriv,span,Y0) ;
%xint = linspace(0,tf) ; example of use of deval (not used here)
%[sxint, spxint] = deval(sol,xint) ;

dim = size(Y,1) ; % finds the size of the solution array

save0 = 0 ; % initialize the first index when crank angle passes through 0
numcyl = 0 ; % initialize the number of whole cycles

tiarr = zeros(dim,1) ; % prepare the array tiarr for greater execution speed
tharr = zeros(dim,1) ; % prepare the array tharr
vearr = zeros(dim,1) ; % prepare the array vearr

for i = 1:dim
    tiarr(i,1) = s(i)/cm ; % build time array (s)
    tharr(i,1) = mod(Y(i,1),2*pi) ; % build crank angle array (modulo 2pi)

    if i ~= 1
        if tharr(i,1)-tharr(i-1,1) < 0
            savei = i ; % save the last index where modulo crank angle passed through zero
            if save0 == 0
                save0 = i ; % save the first index where modulo crank angle passes through zero
            else
                numcyl = numcyl + 1 ; % number of whole cycles
            end
        end
    end

    vearr(i,1) = Y(i,2)*cm ; % build crank angular velocity array (rad/s)
end

if numcyl ~= 0
    cmef = vearr(savei,1) ; % last angular velocity (rad/s) when crank angle was zero
else
    cmef = 0 ; % if system did not complete a whole cycle
end

if numcyl ~= 0
    freq = numcyl/(tiarr(savei,1)-tiarr(save0,1)) ; % calculate the average cycle frequency (Hz)
end

freq = numcyl/(tiarr(savei,1)-tiarr(save0,1)) ; % calculate the average cycle frequency (Hz)
else
    freq = 0 ; % if system did not complete a whole cycle
end

% Calculate the array of instantaneous water volume flow rates
[dis,vel,acc,extr] = pistonkin(tharr,lx,0,0) ; % calls pistonkin without a plot or excentricity

vfr = -2.*rcrank.*A.*(tharr>pi).*vel.*vearr.*1000 ; % calculate the instantaneous volume flow rate array (liter/s)

volp = 2*A*rcrank*Y(dim,3)*1000 ; % calculate the total volume pumped (liter)

% calculate the analytical solution for comparison:
tmodel = linspace(0,tf) ; % time array in the model (-)

ee = exp(-2.*tmodel/pi*sqrt(pi^2*Tmd^2-pi*reduc*Tmd*loa)) ; % intermediate variable: exponential of time
a0 = cmef/cm ; % dim(-) initial angular velocity

angmod = ((-1 + ee).*loa + ...
    a0.*((-1 + ee)).*pi.*tmodel + (1 + ee).*sqrt((-loa).*...
    pi.*reduc.*tmodel + pi^2.*tmodel.^2))./ ...
    ((-1 + ee)).*pi.*(-1 + a0.*reduc).*tmodel + (1 + ee).* ...
    sqrt((-loa).*pi.*reduc.*tmodel + pi^2.*tmodel.^2)) ; % predicted dim(-) mean angular velocity

%angmod = angmod.*cm ; % convert to dimensional value (rad/s)

scrsz = get(0,'ScreenSize') ; % finds the screen size of the current machine
figure('Position',...
    [1 scrsz(4) scrsz(3) scrsz(4)/2]) ; % reserves space on the screen for the figure

subplot(1,3,1) ; % plot crank angular velocity vs. time
plot(tiarr,vearr,'b',...
    [tiarr(1,1);tiarr(dim,1)], [freq*2*pi;freq*2*pi], 'r',...
    tmodel./cm,angmod.*cm,'g')
xlabel('time (s)')
ylabel('crank angular velocity (rad/s)')

subplot(1,3,2) ; % plot volume flow rate vs. time
plot(tiarr,vfr,'b')
xlabel('time (s)')
ylabel('volume flow rate (liter/s)')

```

```

ylabel('volume flow rate (liter/s)')

subplot(1,3,3)                                     % subplot for displaying parameters
axis off

text(0.1,0,['initial crank angle = ',num2str(the0)])
text(0.1,.05,['initial angular velocity (rad/s) = ',num2str(ome0)])
text(0.1,.1,['crankshaft radius (m) = ',num2str(rcrank)])
text(0.1,.15,['connecting rod length (m) = ',num2str(lcrank)])
text(0.1,.2,['small sprocket radius (m) = ',num2str(R0)])
text(0.1,.25,['large sprocket radius (m) = ',num2str(R1)])
text(0.1,.3,['piston cross-section (m^2) = ',num2str(A)])
text(0.1,.35,['windmill & sprocket MOI (kg m^2) = ',num2str(I0)])
text(0.1,.4,['large sprocket MOI (kg/m^2) = ',num2str(I1)])
text(0.1,.45,['windmill angular vel at peak torque (rad/s) = ',num2str(om)])
text(0.1,.5,['windmill peak torque (N.m) = ',num2str(Im)])
text(0.1,.55,['water potential energy/u. vol. (J/m^3) = ',num2str(rgh)])
text(0.1,.6,['torque parameter (-) = ',num2str(Tmd)])
text(0.1,.65,['load parameter (-) = ',num2str(lca)])
text(0.1,.7,['last angular velocity at zero crank angle (rad/s) = ',num2str(omef)])
text(0.1,.75,['average cycle frequency (Hz) = ',num2str(freq)])
text(0.1,.8,['average angular velocity (rad/s) = ',num2str(freq*2*pi)])
text(0.1,.85,['red curve: average angular velocity (rad/s)'])
text(0.1,.9,['total volume pumped (liter) = ',num2str(volp)])

%-----
function Yprime = deriv(s,Y)
% Calculates the derivative of the column-vector Y
% with respect to s. Implements windpump dynamics.
%
% MYL 2/10/2010.
%
%
% input - Y = column vector      Y(1,1) = crank angle (rad)
%                               Y(2,1) = dim(-) angular velocity
%                               Y(3,1) = dim(-) volume pumped
%
%      - s = dim(-) time
%
% output - Yprime = column vector d(crank_angle)/ds
%                               d(ang_vel)/ds

%
%                               d(ang_vel)/ds
%                               dim(-) vol. flow rate
%
% global variables      postscript I denotes an input variable destined to
%                       become global (avoids confusing Matlab)
%
%      - lr = ratio of connecting rod length to crankshaft radius
%      - Tmd = dim(-) torque parameter
%      - lca = dim(-) load parameter
%      - reduc = reduction ratio R1/R0
%
global lr Tmd lca reduc

% other internal variables
%
%      - modthe = crank angle modulo 2 pi
%
%      - pres = net dim(-) force on piston
%      - dis = piston displacement/2/crankshaft radius, with
%              origin at top dead center (TDC)
%      - vel = piston velocity/2/crankshaft radius/crankshaft angular velocity
%      - acc = piston acceleration/2/crankshaft radius/ang.vel.^2
%      - extr = four angles for TDC,BDC,TDC,BDC,TDC for 4-stroke cycle (not used here)
%      - thec = angle of the connecting rod to cylinder axis (rad)
%
modthe = mod(Y(1,1),2*pi) ; % find the crank angle modulo 2pi

% Calculate the net dimensionless force exerted on the piston
% of the windpump; in this case, the piston experiences no force during
% intake for theta = [0,pi] and the full water load during exhaust for
% theta = [pi,2pi].
%
if modthe < pi
    pres = 0 ; % net intake pressure is zero
else
    pres = -1 ; % exhaust dim(-) force
end

thec = asin(sin(modthe)/lr) ;

```

```

[dis,vel,acc,extr] = pistonkin(modthe,ll,0,0) ; % calls pistonkin without plot or excentricity

Yprime(1,1) = Y(2,1)
Yprime(2,1) = -lca*pres*sin(modthe+thec)/cos(thec) + ...
              Tmd*Y(2,1)*(2-reduc*Y(2,1))
Yprime(3,1) = -vel*Y(2,1)*(modthe>pi)

%-----
function [dis,vel,acc,extr] = pistonkin(theta,ll,dd,flagplot)

% Calculates and plots (if needed) the kinematics of a
% piston and crankshaft with possible excentricity.
% Reference: crank_mech.nb
%
% Michel Louge 4/3/07
%
% input    = theta = array of crank angles
%          = ll    = ratio of connecting rod length/crankshaft radius
%          = dd    = ratio of excentricity/crankshaft radius
%          = flagplot = flag: if = 1, show a plot; if other, then don't
%
% output   = dis   = array of piston displacement/2/crankshaft radius, with
%                  origin at top dead center (TDC)
%          = vel   = array of piston velocity/2/crankshaft radius/crankshaft angular velocity
%          = acc   = array of piston acceleration/2/crankshaft radius/ang.vel.^2
%          = extr  = array of four angles for TDC,BDC,TDC,BDC,TDC for four-stroke cycle
%
% global variables
%
%          = none = none
%
% to access the proper directory, type
% cd ~/Michel_files/Classwork/MAE_225/Spring_2008/projects/AC/Matlab_dynamics
%
% Example:
%
% clear all; [dis,vel,acc,extr] = pistonkin(linspace(0,4*pi),3,0.5,1);
%
% global none
%
% other internal variables

```

```

% other internal variables
%
%          = scrasz = screen size for plots
%          = cost   = cos(crank angle at TDC)
%          = cosb   = - cosine of crank angle at BDC
%
cost = sqrt(1-dd^2/(1+1)^2) ;
cosb = sqrt(1-dd^2/(1-1)^2) ;

extr = [acos(cost) pi+acos(cosb) 2*pi+acos(cost) 3*pi+acos(cosb)] ;

dis = (1/2)*((1+1)*cost - cos(theta) - ...
            sqrt(1+1^2 - (sin(theta) - dd).^2)) ;

vel = (1/2)*(sin(theta) + (cos(theta).* ...
            (-dd + sin(theta))./. ...
            sqrt(1+1^2 - (dd - sin(theta)).^2)) ...
            (4*1+1^2*cos(theta).^2 - ...
            2*sin(theta).*(-dd + sin(theta)).* ...
            (-1 - 2*dd^2 + 2*1+1^2 + cos(2*theta) + ...
            4*dd*sin(theta)) + ...
            sqrt(2)*cos(theta).* ...
            (-1 - 2*dd^2 + 2*1+1^2 + cos(2*theta) + ...
            4*dd*sin(theta)).^(3/2)) ;

if flagplot == 1

scrasz = get(0,'ScreenSize') ; % finds the screen size of the current machine
figure('Position',...
       [1 scrasz(4) scrasz(3) scrasz(4)/2]) ; % reserves space on the screen for the figure

subplot(1,4,1) % plot displacement vs. crank angle
plot(theta,dis)
xlabel('crank angle (rad)')
ylabel('displacement/crankshaft diameter (-)')
axis([min(theta) max(theta)*1.1 min(dis) 1.1*max(dis)])

subplot(1,4,2) % plot velocity vs. crank angle
plot(theta,vel)
xlabel('crank angle (rad)')
ylabel('velocity/crankshaft diameter/angular velocity (-)')
axis([0 max(theta)*1.1 1.1*min(vel) 1.1*max(vel)])

```

```

subplot(1,4,3)                                     % plot acceleration vs. crank angle
plot(theta,acc)
xlabel('crank angle (rad)')
ylabel('acceleration/crankshaft diameter/angular velocity^2 (-)')
axis([0 max(theta)*1.1 1.1*min(acc) 1.1*max(acc)])

subplot(1,4,4)                                     % subplot for displaying parameters
axis off

text(0.1,0,['connecting rod length/crankshaft radius = ',num2str(ll)])
text(0.1,.1,['eccentricity/crankshaft radius = ',num2str(dd)])
text(0.1,.2,['TDC at intake (deg)= ',num2str(extr(1)*180/pi)])
text(0.1,.3,['BDC at compression (deg)= ',num2str(extr(2)*180/pi)])
text(0.1,.4,['TDC at expansion (deg)= ',num2str(extr(3)*180/pi)])
text(0.1,.5,['TDC at exhaust (deg)= ',num2str(extr(4)*180/pi)])

end

```

7.8. References

1. <http://functionspace.com/topic/3725/Slider-crank-mechanism-vs-Scotch-and-Yoke-mechanism>