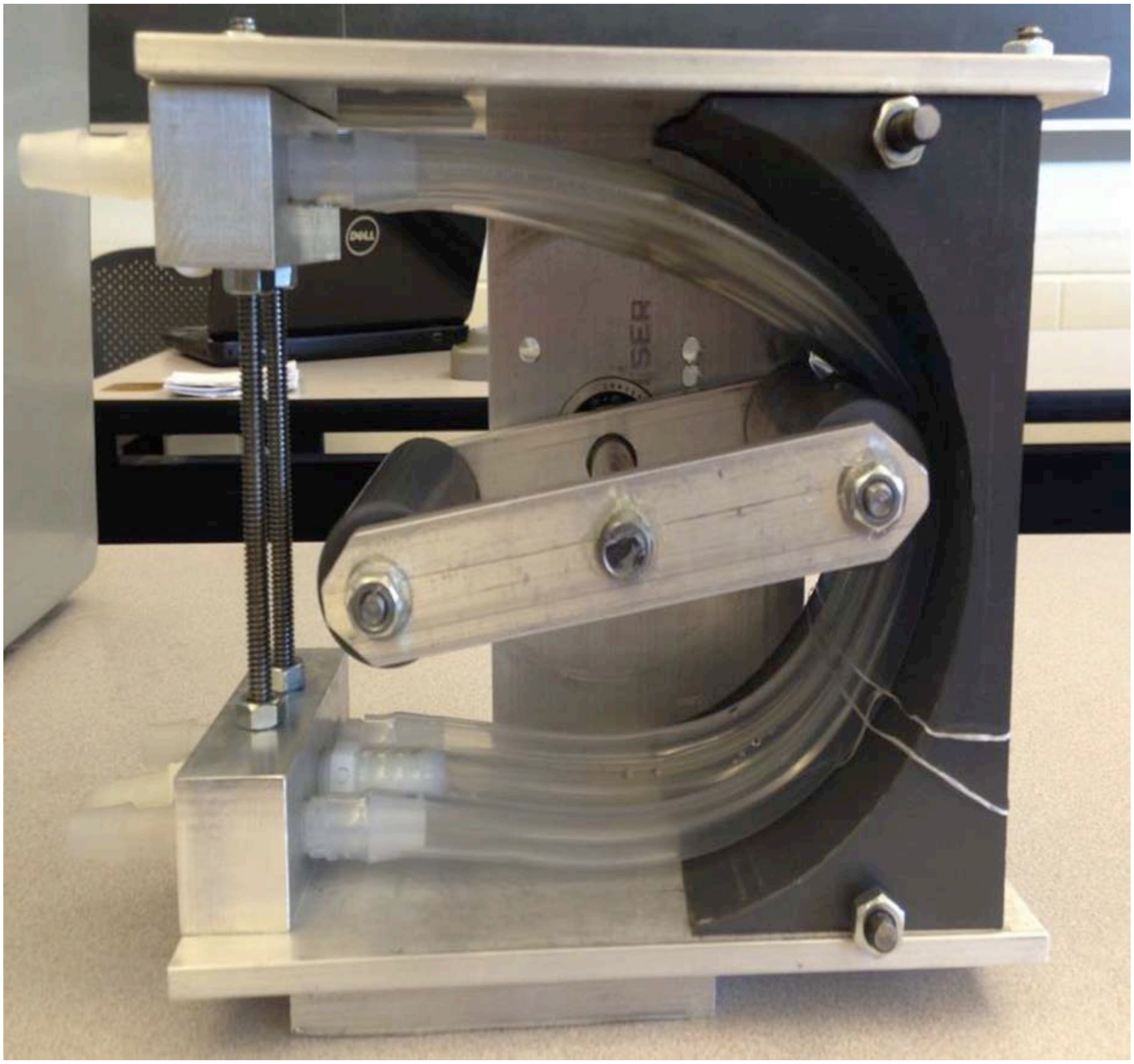
Spring '13



Peristaltic Pump Notebook

by Anjit Fageria

Group 1: Anjit Fageria, Jesse Miller, Saajan Chopra, Timothy Hui, K. Rebecca Jung, Herman Wong

Table of Contents

Project Summary

A customer is developing a water pump driven by wind power for energy storage. They have asked us to develop a small-scale prototype of an efficient piston water pump. The pump drive shaft attaches to a customer-supplied and specified plate and sprocket. 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.

Project Goals

- Experience the full design process from concept to realization.
- Experience optimization of design with respect to objectives and constraints.
- Develop precision fabrication skills.
- Develop team coordination and project planning skills.
- Motivate understanding of kinematics, dynamics and fluid-dynamics.

Group Members

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Phase 1: Conceptual Design

Wednesday 3/27

We met up and discussed what we had to do for this week, what we were hoping to get out of the project, and we got to the conclusion that most of us don't know much about windpumps. We've heard all about them but honestly we had a hard time imagining all the parts that we would need other than a piston and some form of rotation. So we decided we would come back tomorrow after doing some research with a clearer idea in order to do the morph chart. But in the end, I'm not sure how much creativity we could have with this project, I mean, what works, works for a reason, and I'm not sure what else we could do that could actually make our pump original or innovative.

Jesse did the power curve calculations, which really helped us out and let us see where the maximum power output could be had from the fan blades. Rebecca volunteered to start on the morph chart because she said she's a good drawer. Her notes for this day are down below:

- Discuss project overall and start brainstorming parts of wind pump
    - Decided to meet again tomorrow once each of the team member research more about wind pumps in general.

- Since the designs for wind pump are pretty constrained to mechanisms that are already invented and used in the wind pumps of today, it is merely figuring out the functional requirements and what types of mechanisms there are in all, before drawing them out for the morphological chart.

- Things completed
  - Met with project group officially for the first time
  - Jesse has taken the data points we retrieved from the torque test and graphed a power curve on excel (Power vs. Angular velocity). From this graph, we've figured out the point where our pump should be operating to get the most power.
  - Customer Specs [tentatively] done. (What more do we need other than the things listed in the wind pump project information document?)
- Things to-do
  - Rebecca to finish Morphological chart by tomorrow's (03/28) meeting for review by other group members.
  - Each member to report back facts they find and some conceptual thoughts on the wind pump, as well as (maybe) timeline of things.

Thursday 3/28:

(We met for 3 hours)

Today we met up to finish up the morph chart. Rebecca started it by basically copying down some of the things noted on the blackboard presentation slides. Then we went up to Taylor lab to actually take a closer look at the pumps, see how they work, and maybe make a call on what we would want to do. Jane (I forget if this is her name, but I think it is, she's a TA?) was there and we asked her a few questions for tips and tricks when doing the pump.

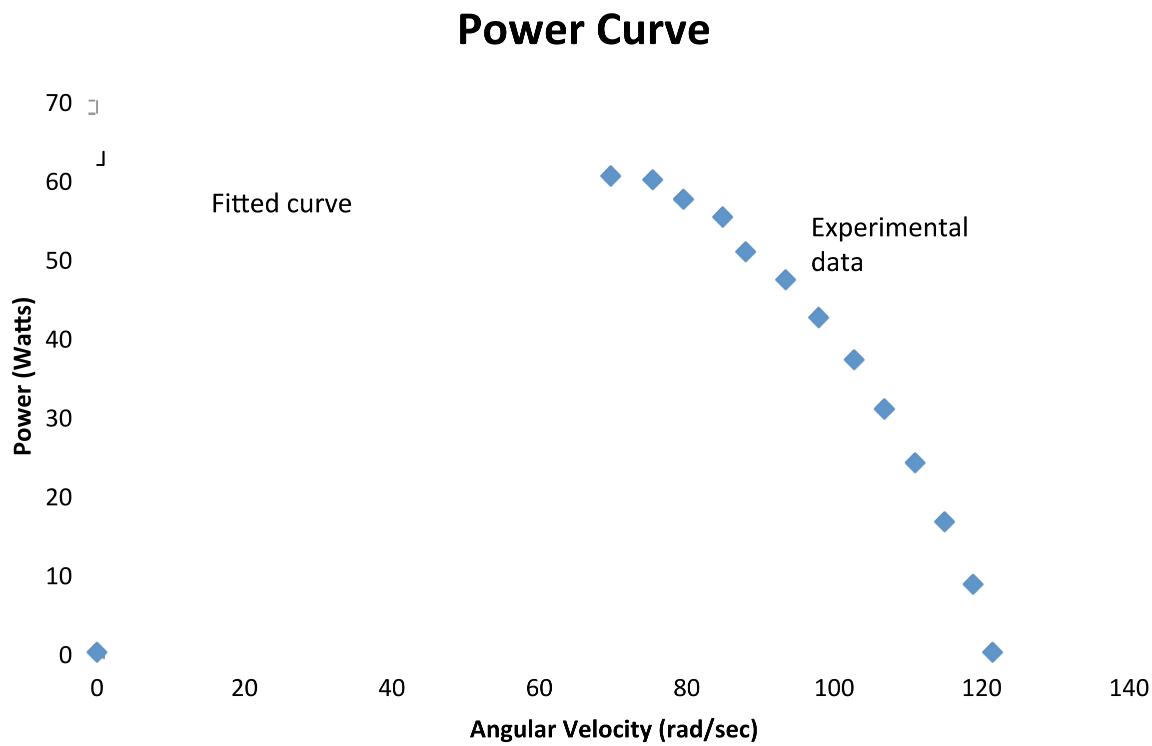
It appears that since most of us don't have that much machining experience that we should stick to something very simple. We saw that most of the pumps there had pistons and slider cranks, so we might go down that road. We also saw that making something too tight wasn't good because that would create too much friction and it wouldn't move. Then also, making it too loose isn't good because it will rattle. Turbines would probably be too difficult to machine at this moment, and Jane told us that the best thing to do would be to cut down on various moving pieces, because the more moving pieces you have, the more prone you are to having one of them malfunction.

We definitely decided on using ball bearings in order to make joint rotations easier, and some sort of piston pump will probably be made, either with one or two cylinders. We debated a bit over scotch yolk and slider crank, so we'll have to check that out next week. Below are Rebecca's notes.

- Brainstorm other components for morphological chart
- Met up at Taylor lab to examine past water/ wind pumps to get ideas and clarification on what kind of pumps we want to use and how each shaft designs work
- Morphological Chart finished by end of meeting (is subjected to change as we come up with new ideas).

Torque Tests:

- Basically, we graphed the power that was outputted from the turbine from a range of angular velocities.
- So, as you can see, the maximum power is about **60 Watts,** and that is located when the angular velocity of the fan blades was at **69 rad/s.**
- We mainly want our pump to operate at the area where the parabola that has been fitted to the points reaches its apex, mainly so that we can achieve the most power from the spinning blades.
- Now we just need to figure out how to keep our pump working in that area, I'm sure we're going to be drowning in calculations very very soon.



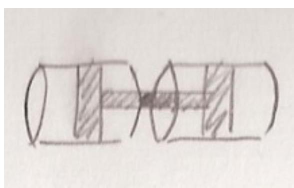
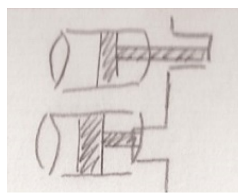
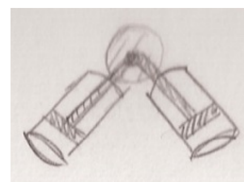
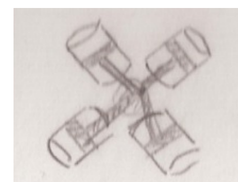
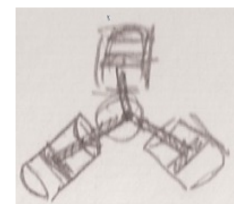
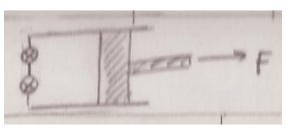
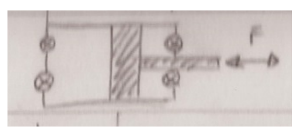
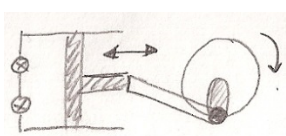
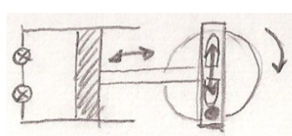
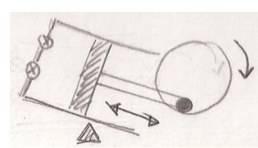
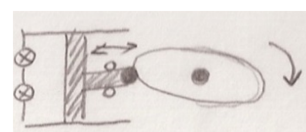
RPM first	RPM second	RPM ave	Load (N)	radius (m)	Torque (Nm)	w (rad/sec)	Power J/s
1150	1170	1160	0	0.07225	0	121.4749159	0
1135	1135	1135	1	0.07225	0.07225	118.8569221	8.587412619
1105	1090	1097.5	2	0.07225	0.1445	114.9299312	16.60737506
1070	1050	1060	3	0.07225	0.21675	111.0029404	24.05988734
1030	1010	1020	4	0.07225	0.289	106.8141502	30.86928941
990	972	981	5	0.07225	0.36125	102.7300798	37.11124132
940	930	935	6	0.07225	0.4335	97.91297104	42.44527294
915	870	892.5	7	0.07225	0.50575	93.46238144	47.26859942
850	830	840	8	0.07225	0.578	87.9645943	50.84353551
820	800	810	9	0.07225	0.65025	84.82300165	55.15615682
780	740	760	10	0.07225	0.7225	79.58701389	57.50161754
730	710	720	11	0.07225	0.79475	75.39822369	59.92273827
670	660	665	12	0.07225	0.867	69.63863715	60.37669841
610	0	305	13	0.07225	0.93925	31.93952531	29.99919915
0	0	0	14	0.07225	1.0115	0	0

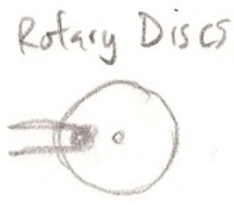
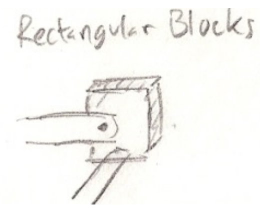
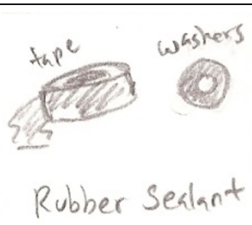
Customer Specs

- 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.
- The cylinder bore diameter should be machined to an appropriate fit with the piston
- stock (1.875").
- The pump must sit stably on a 7"x7" horizontal plate supplied by the customer.
- 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 face plate.
- The over all 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. 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.
- 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.

Morphological Chart

Fig. 1.1. *Morphological Chart*. This chart shows the different routes that we can take with our pump, such as if we go with a piston pump, how many cyclinders we can include and so on.

Functional Requirements	Mechanisms				
Number of Pumps	1	2	3	4	
Types of Pump	Piston	Screw	Gear	Rope	Centrifugal/ Turbine
Orientation of Pumps					
Single/Dual Action					
Shaft Design	 Slider Crank	 Scotch Yoke	 Pivoting Cylinder	 Cam-follower	

Pump Size	Small	Medium	Large		
Rotary Shapes					
Gear Ratios	1:1	1:2	2:1		
Lubrication	Ball Bearings	Making Holes Bigger	Chemicals		
Sealing					

Monday: 4/1/13
(Today we met for 3 hours)

We met today to start working on the PDR so that we wouldn't have to struggle at the end of the week and pull an all-nighter. A pretty decent idea if I might say so myself.

However, we had to decide which pump to follow through on first. Since we wanted something that would be relatively easy to machine and put together, we stuck with the peristaltic pump and the diaphragm pump. Both of these would basically have to have major components purchased on McMaster, so we made a whole pro con list compared which one of them might fail more easily as shown below.

Table 1.1. *Pump Pro/Con*. A Pro/Con chart that shows the pros and cons between a Diaphragm and Peristaltic pump.

Diaphragm Pump		Peristaltic Pump	
Pro	**Con**	**Pro**	**Con**
Cheaper	Diaphragm could rupture	can handle many types of fluids (high viscosity, etc.)	Might not pump enough water volume
Handles a wide range of liquids, including liquids containing solids. Pump is sealless, and can run dry without damaging the pump.	Requires an excellent sealant	fluid only come in contact with tubing, so no concern with other components that may be incompatible with fluid (no contamination)	tubing can degrade over time (though we're not concerned about degradation in this project)
Higher volumetric flow rate	More Machining	Less moving parts	May experience high friction
Works best for high pressure systems, however our pump will be operating at lower pressure		This pump type requires no seal, and keeps the liquid inside the tube, so zero leakage.	Flow is not smooth
		Less machining	
		Less prone to failure	
		Works with low pressure	

Choice of Pump

We figured that the diaphragm pump would require more machining to create the airtight chamber and it would also require some sort of sealant so that the water wouldn't leak out, not to mention the possibility of the rubber plunger part rupturing or not creating the seal necessary to actually pump water. So we went with the peristaltic pump.

So now we have to do the PDR. We divided the presenters up pretty easily, so it worked out well, even with the analysis being switched with the FDR. Jesse and I will present the PDR since next week looks like a total hell week for us.

- PDR – Jesse/ Anjit
- FDR – Rebecca/ Saajan
- Marketing – Tim/ Herman

While we were working on the project we realized that we would have to take into account the size of the pump, so it would most likely be about 8 inches high, 8 inches wide, and maybe 2 inches long if we use the McMaster Soft Abrasion-Resistant Polyurethane Tubing that is made for use in peristaltic pumps. This tubing has a minimum radius of 3 inches when bending, so we can increase in size from there, but it is a bit costly at about 9 dollars per foot. We would most likely need 2 feet of tubing, so that's 18 dollars right there. However, we are going to make some more calculations to see other sized, cheaper tubing that we could buy that would still provide the 1L/min water pumping specification.

We also decided to use ball bearings for the rollers since they would cut down the amount of friction that would otherwise be there with anything else rolling or squeezing the tubing. However, they come at a price of about 5 dollars per bearing.

As Rebecca wrote down so well in her meeting minutes, we discussed the potential machining process and components needed to machine and order, as shown below:

  - For container of the pump, we're thinking we can assemble rectangular plates/ blocks together, but for the corners, we must machine curved portions so that the rollers can work effectively on the tubing and meet every point of contact. Then we have the shaft that will be powered by the wind turbine and make the rollers spins.
  - We're still deciding on shapes of rotating component of the pump and the machining of it will depend on our decision

- Herman and Tim worked on the decision matrices and Herman organized the customer specs/needs
  - They divided the matrix writing process into two parts: decision matrix for types of pumps and then one for the design of the pump we ultimately chose: Peristaltic Pump.
  - Components considered for Peristaltic Pump decision matrix
    - Rotator (Ball bearings/ Discs/ Lobes)
    - Tubing (Plastic, Rubber, etc.)
    - Shape (U, S)
    - Curve Radius (S, M, L)
    - Number of contact points (2-4)
- Jesse and I worked on the Gantt chart.
- Rebecca updated the morphological chart to include more function requirements and also worked on meeting minutes.
- Saajan had some other work to do, but there wasn't much for him to do anyways.

Wednesday 4/3/13

(Today we met for 3 hours)

Saaj, Jesse, and I wandered the halls of Upson and Phillips trying to find a room, and then Rebecca and Tim found a conference room.

We just started from where we left off last time:

- I worked on customer needs/rankings and keeping meeting minutes.
- Tim and Herman finished up the decision matrices.
- Jesse worked on the PDR presentation.
- Saajan worked on the Dependency chart.
- Rebecca worked on the sketch of the pump and I pitched in a bit.

I sent out a Google doc that asked everyone when they would be free to machine in order to sign up for Emerson slots. I also sent Katie and Lauren an email that clarified a few points on the project. We all did our work and finished everything we had to do.

I think that we finally decided on our prototype design as being sketch number 1 in Fig 2.9 below. It should work well, we just need to find the dimensions of the pump.

Thursday 4/4/13

(Today we met for 2 hours)

Jesse and I worked on the PDR today. We just finished up all the slides and distributed the slides so that we would alternate speaking. We even included a slide that showed peristalsis by me squeezing a banana. See the slides below.

Goals for Next Week:

- Ask about the valves – specifically which ones are actually given to us.
- Make calculations so we can see which tubing to buy that would still pump 1L/min.
- Start CADding our final product.
- Make our FDR.
- Make analysis of our product.

Customer Specifications/Needs

Customer Specifications/Requirements	Translation into Our Specifications	Relative Importan[ce] 1-5 (5 being most important)
The prototype should pump water from an input reservoir with water level the at least the height of the drive shaft to an output reservoir of elevation of 1.5m.	Pump action must overcome weight and pressure of a 1.5-meter cylinder of water.	5
The rate of flow is at least 1 Liter/minute.	1 Liter = 1000 cm3. Area of the tubes = .713 cm2. Flow velocity should be 23.39 cm/s.	5
Cylinder bore diameter should be machined to an appropriate fit with piston stock. (1.875 inches)	Bore diameter will allow piston to slide snugly and without excessive friction. Tolerance of .005 inches?	1
The pump must sit stably on a 7"x7" horizontal place supplied by the customer.	Pump must have a side which it may rest on and stably supports the weight distribution of the pump.	4
The output drive shaft must be a ½" diameter rod extending 2.5" beyond the supplied face plate (1/2" thick).	As stated.	5
Its axis will be located 3-7 inches above the horizontal plate, attached by four .25"-20-thread screws as shown on the Blackboard sketches.	As stated.	5
The overall dimensions of the pump must be such that it fits into a volume no greater than 14"x14"x14".	Pump should be able to fit into a 14" cube. Longest distance between any two points should not exceed 24.25", the hypotenuse of the cube.	5
The input torque will be provided by the customer-supplied wind turbine.	The wind turbine should be set to operate at the peak of our power curve. It will be driven by a fan with wind force 7 m/s.	4

Fig 1.2. *Customer Specifications/Needs*. These customer needs basically dictate what our pump has to do, and constrains it in some respects, such as the faceplate and the overall dimensions, but we still have the main freedom of choosing the type of pump to make.

Updated Morphological Chart

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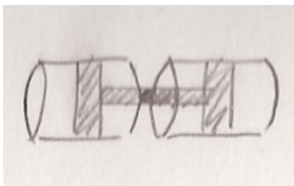
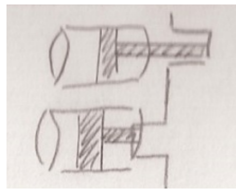
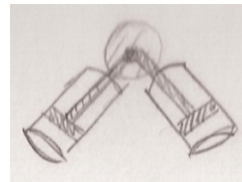
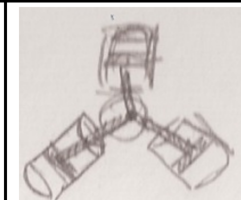
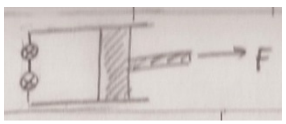
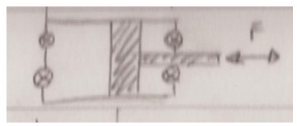
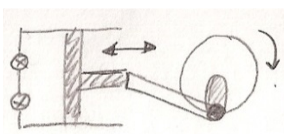
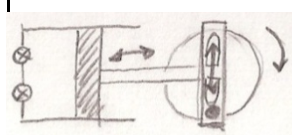
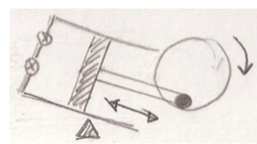
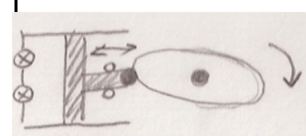
<tr><td>Orientation of Cylindrical Pumps</td><td colspan="4"></td><td colspan="2"></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Single/Dual Action</td><td colspan="4"></td><td colspan="2"></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Shaft Design</td><td colspan="4">
Slider Crank</td><td colspan="2">
Scotch Yoke</td><td colspan="2">
Pivoting Cylinder</td><td>
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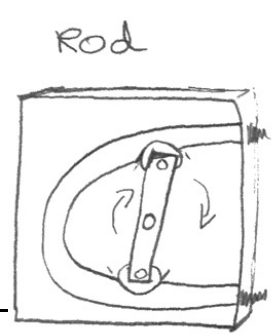
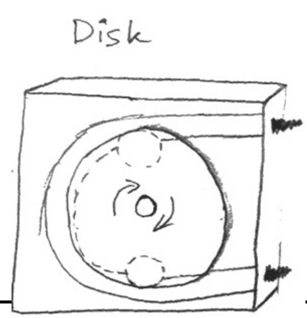
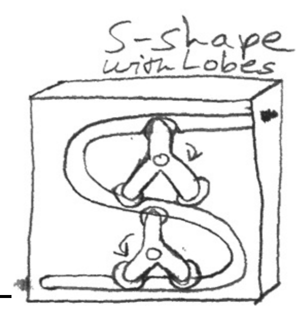
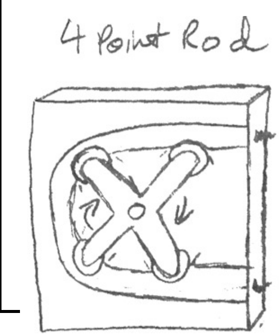
<tr><td>Peristaltic Configurations</td><td colspan="4"></td><td colspan="2"></td><td colspan="2"></td><td></td><td></td></tr>
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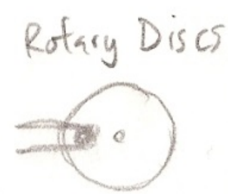
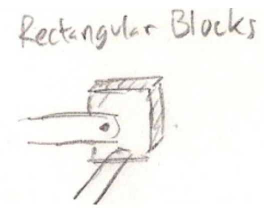
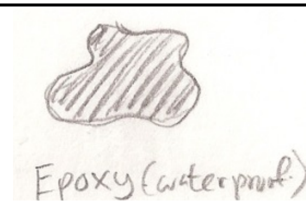
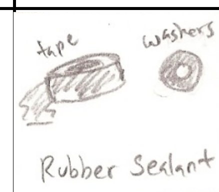
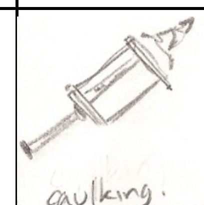
Fig 1.3. *Updated Morphological Charts.* As you can see from the "Peristaltic Configurations" on the bottom, this is an updated version of our Morph Chart.

Pump Size Tube Size	Small	Medium	Large		
Types of Tubing	Polyvinyl Chloride (PVC)	Silicone Rubber	Fluoropolymer		
Variations of other Designs	Hose pump (for high pressure)	Tube Pump (for low pressure)	360 Degree Eccentric Design		
Number of Contact Points	1	2	3	≥ 4	
Number of Gear's teeth	2	3	4	≥ 5	
Rotary Shapes for Shafts					
Gear Ratios	1:1	1:2	2:1		
Lubrication	Ball Bearings	Making Holes Bigger	Chemicals		
Sealing					

Gantt Chart

	Name	Duration	Start	Finish
1	Wind Turbine Test	1d	03/08/2013	03/08/2013
2	Notebook Entries	23d	03/27/2013	04/26/2013
3	Research & Design	18d	03/27/2013	04/19/2013
4	Customer Specifications	4d	03/27/2013	04/01/2013
5	Conceptual Design	8d	03/27/2013	04/05/2013
6	Morphological Chart	4d	03/27/2013	04/01/2013
7	Decision Matrix	4d	04/01/2013	04/04/2013
8	Dependency Chart	4d	04/01/2013	04/04/2013
9	PDR	3d	04/03/2013	04/05/2013
10	Analysis	5d	04/05/2013	04/11/2013
11	CAD	4d?	04/12/2013	04/17/2013
12	FDR	4d	04/16/2013	04/19/2013
13	Order Parts	10d?	04/15/2013	04/26/2013
14	Machining	7d?	04/22/2013	04/30/2013
15	Assembly	8d?	04/22/2013	05/01/2013
16	Testing	1d?	05/01/2013	05/01/2013

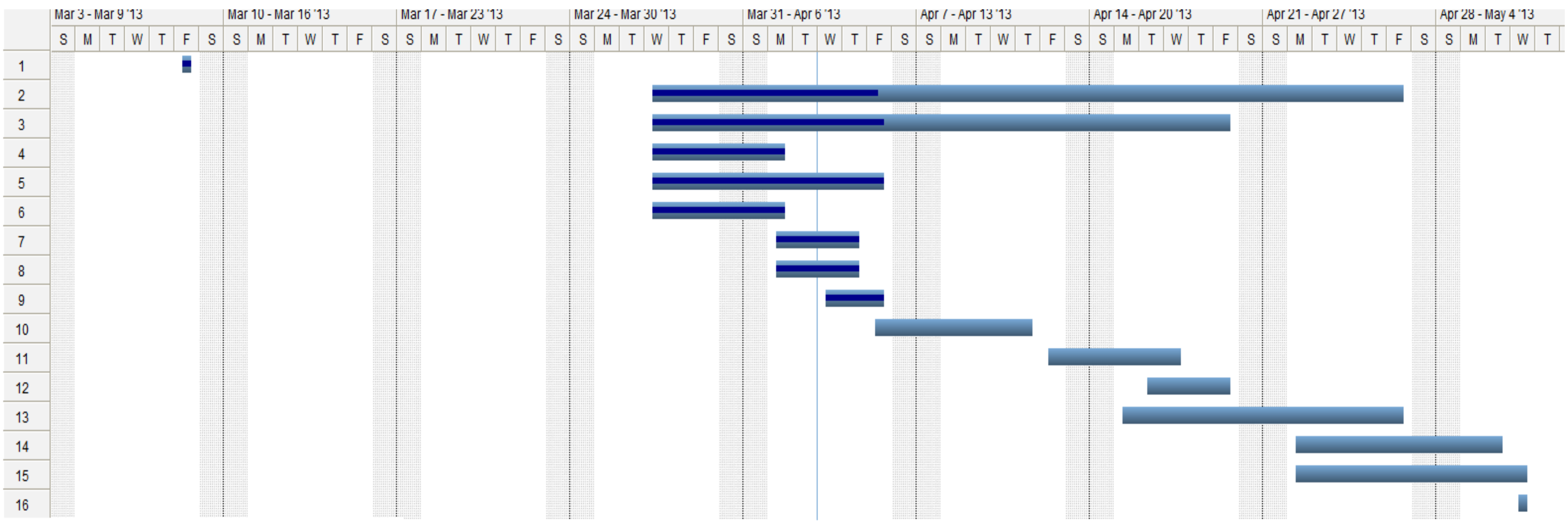


Fig. 1.4. *Gantt Chart*. A chart that shows our initial plans for how long every process should take us to complete.

Dependency Chart

Task		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Wind Turbine Testing	A	X																					
Dependency Chart	B		X																				
Gantt Chart/ Timeline	C		X	X																			
Customer Specifications	D				X																		
Metrics [vs. Needs]	E				X	X																	
Functional Requirements	F				X	X	X																
Brainstorming	G						X	X															
Morph Chart	H							X	X														
Selection Criteria	I				X	X	X			X													
R&D	J								X	X	X												
Decision Matrix	K				X	X	X	X	X	X	X	X											
Concept Selection	L								X	X	X	X	X										
Concept Design	M												X	X									
Product Sketch	N													X	X								
PDR	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
CAD model of product	P															X	X						
Analysis of Product	Q					X								X				X					
FDR	R	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Fabrication of Product/Machining	S			X														X		X			
Testing	T						X											X		X	X		
Technical Document/ User Manual	U					X	X						X									X	
Marketing	V				X		X								X					X			X

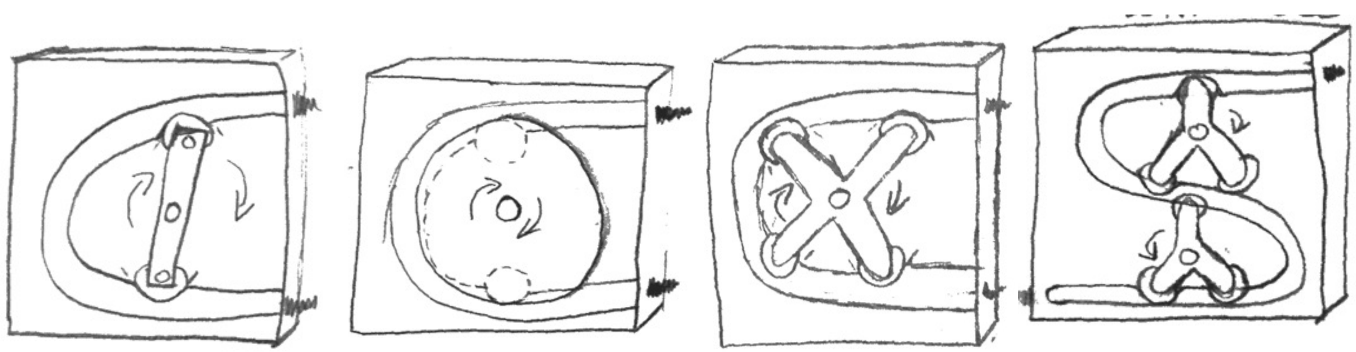
Fig. 1.5. *Dependency Chart*. A chart that shows us what every process and step is dependent on, and since ours shows no Xs to the right of the diagonal of Xs, this means we have no bottlenecks and are good to go.

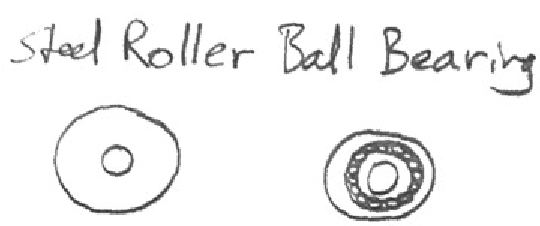
Decision Matrices

Figs. 1.6 – 1.9. *Decision Matrices*. These matrices show how we weighted different criteria in different choices for designs or parts in order to make a selection for our pump design.

		Concept					
		1 - Peristaltic		2 - Diaphragm		3 - Slider-Crank	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cheap to Manufacture	10%	3	0.3	4	0.4	5	0.5
Easy to Manufacture	20%	5	1	4	0.8	3	0.6
High-powered Output	10%	4	0.4	5	0.5	5	0.5
Easy to Operate/Assemble	15%	5	0.75	3	0.45	5	0.75
Can Meet Size Restrictions	10%	4	0.4	4	0.4	4	0.4
Aesthetically Pleasing	15%	5	0.75	4	0.6	2	0.3
Unique Design	20%	5	1	4	0.8	1	0.2
Total Score		2.85		2.55		2.75	
Rank		1		3		2	

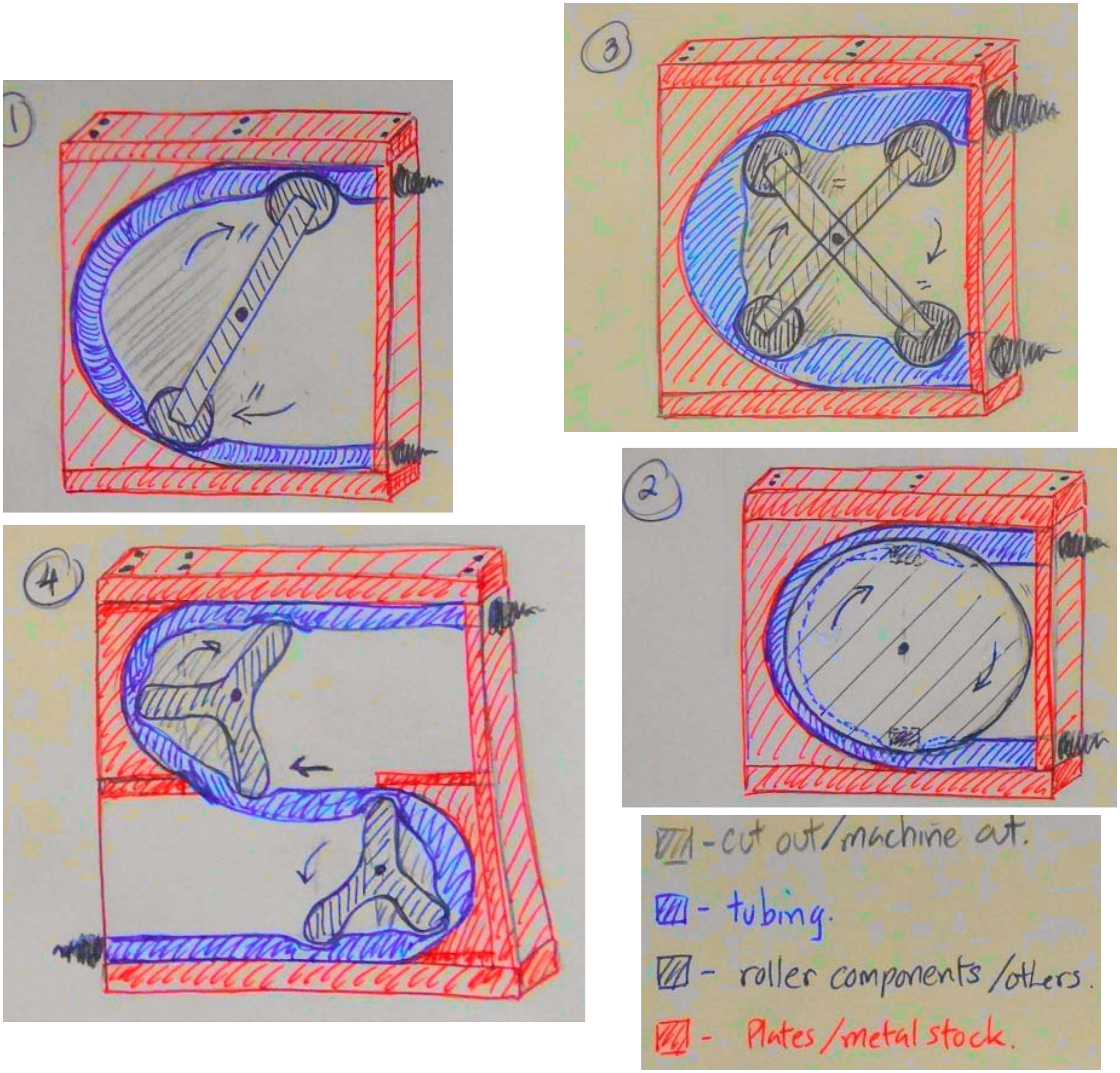
	Design #			
Components	1	2	3	4
Pincher/Roller	Ball Bearing	Disk	Ball Bearing	Lobe
Tubing Material	Plastic	Plastic	Plastic	Rubber
Tube Diameter	Medium	Medium	Large	Small
Shape	U	U	U	S
# of Contacts	2	2	4	3
Curve Radius	Medium	Medium	Large	Small





		Concept							
		Design 1		Design 2		Design 3		Design 4	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Durability	10%	4	0.4	4	0.4	4	0.4	5	0.5
Easy to Manufacture	25%	5	1.25	5	1.25	5	1.25	3	0.75
Cost	25%	4	1	4	1	3	0.75	2	0.5
Easy to Assemble	10%	5	0.5	5	0.5	5	0.5	5	0.5
Maximizes Volumetric Flow rate	15%	4	0.6	4	0.6	5	0.75	4	0.6
Efficiency (Minimizes Friction)	15%	5	0.75	4	0.6	4	0.6	3	0.45
Total Score		3.9		3.75		3.5		2.7	
Rank		1		2		3		4	

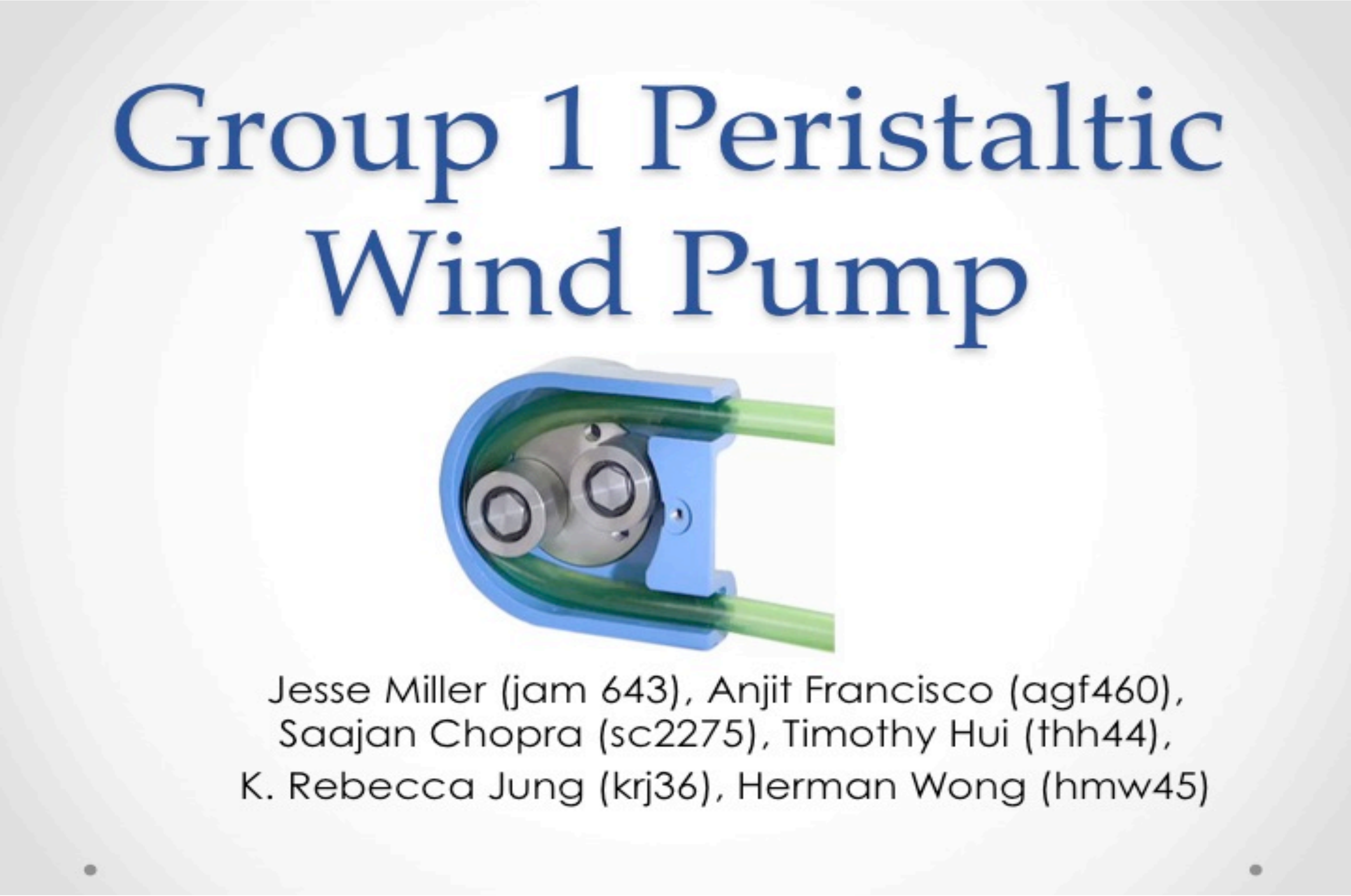
Prototype Designs

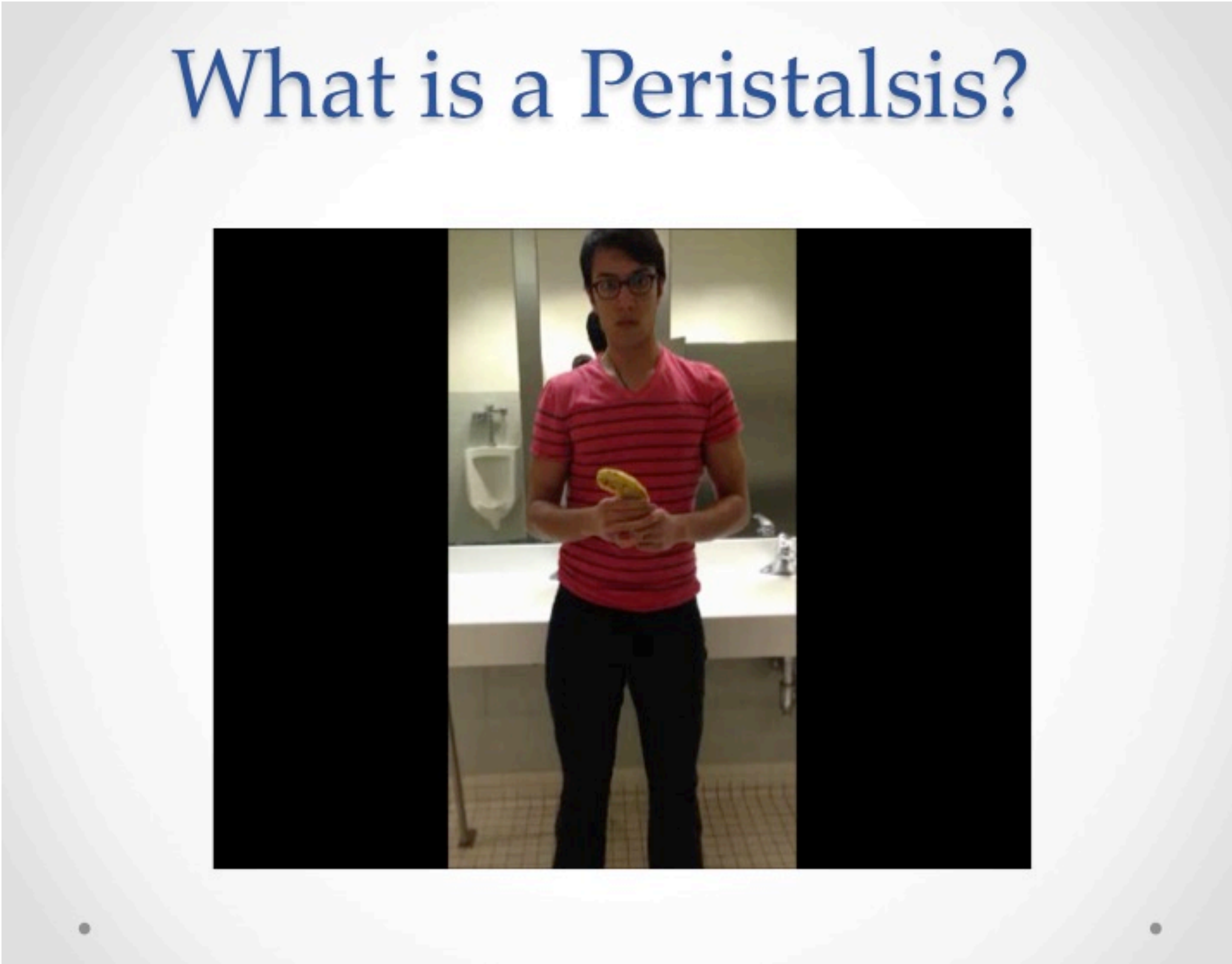


Figs. 1.10. *Prototype Design.* These are different initial designs that we were considering in our Peristalt Pump.

Windpump Preliminary Design Report Slides

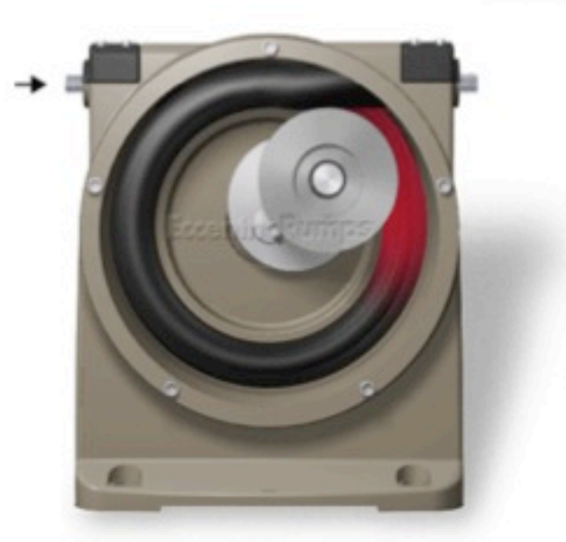
- Figs. 1.11 – 1.12. *PDR Slides*. Below are our slides for our Preliminary Design Report Presentation, where we show our classmates our design decisions and get feedback in order to improve our pump. Any and all feedback can be found in the next Friday entry written after these slides.




What is a Peristalsis?

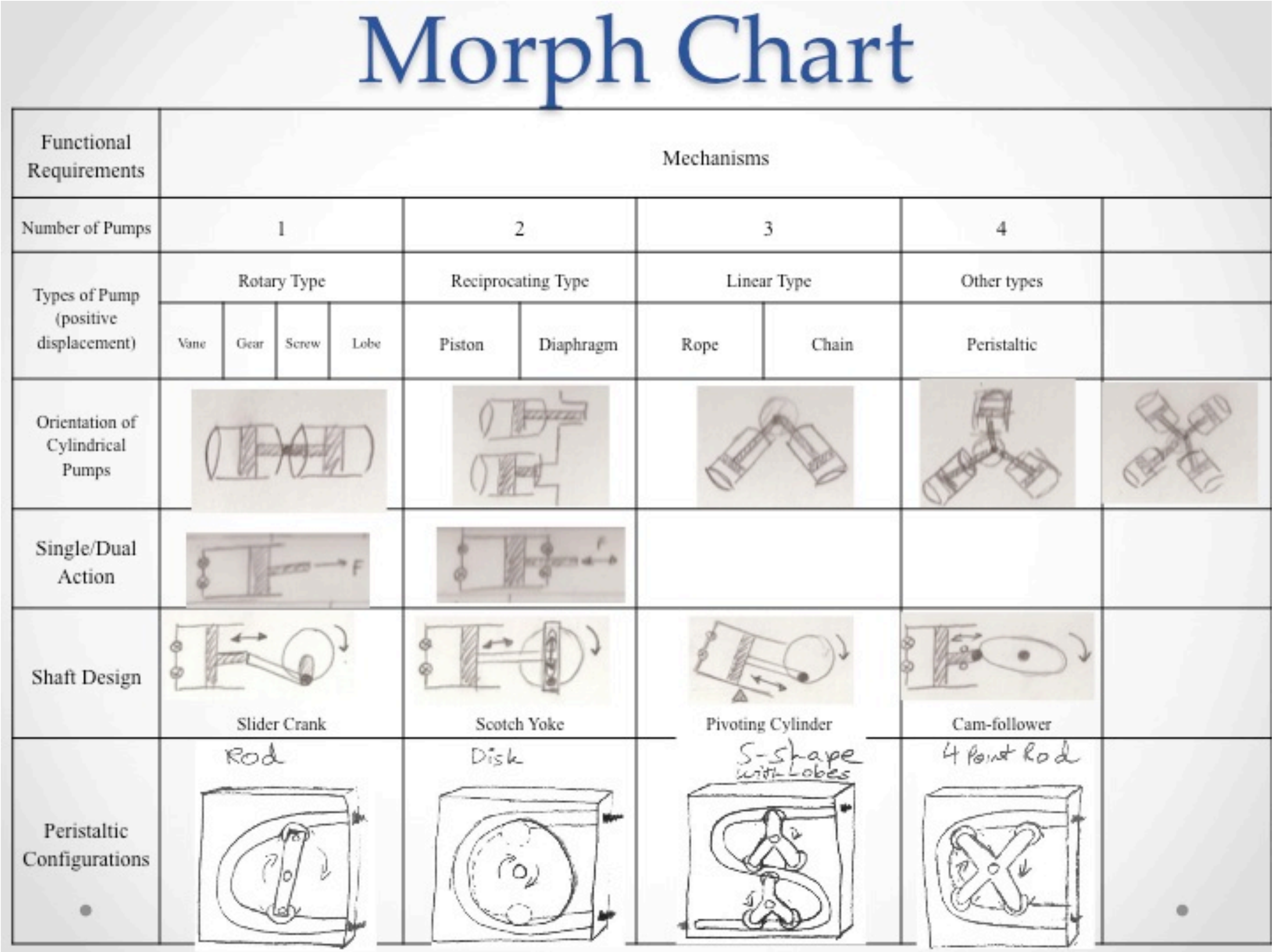
What is a Peristaltic Pump?

- Rollers Compress flexible tube
- Creates high pressure
- Pushes fluid forward

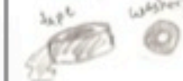
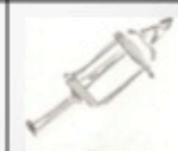


Customer Specs

Customer Specifications/Requirements	Translation into Our Specifications	Relative Importance 1-5
• pump water from an input reservoir to an output reservoir of elevation of 1.5m.	• Pump action must overcome weight and pressure of a 1.5-meter cylinder of water.	5
• The rate of flow is at least 1 Liter/minute.	• 1 Liter = 1000 cm3. Area of the tubes = .713 cm2. Flow velocity should be 23.39 cm/s.	5
• Cylinder bore diameter should fit with piston stock. (1.875 inches)	• Bore diameter will allow piston to slide snugly and without excessive friction. Tolerance of .005 inches?	1
• The pump must sit stably on a 7″x7″ horizontal place supplied by the customer.	• Pump must have a side which it may rest on and stably supports its weight distribution	4
• The output drive shaft must be a ½″ diameter rod extending 2.5″ beyond the supplied face plate (1/2″ thick).	• As stated.	5
• Its axis will be located 3-7 inches above the horizontal plate, attached by four .25″-20-thread screws	• As stated.	5
• The overall dimensions of the pump must be no greater than 14″x14″x14″.	• Pump should be able to fit into a 14″ cube.	5
• The input torque will be provided by the supplied wind turbine.	• The wind turbine will operate at the peak of our power curve, driven by a fan with wind force 7 m/s.	4

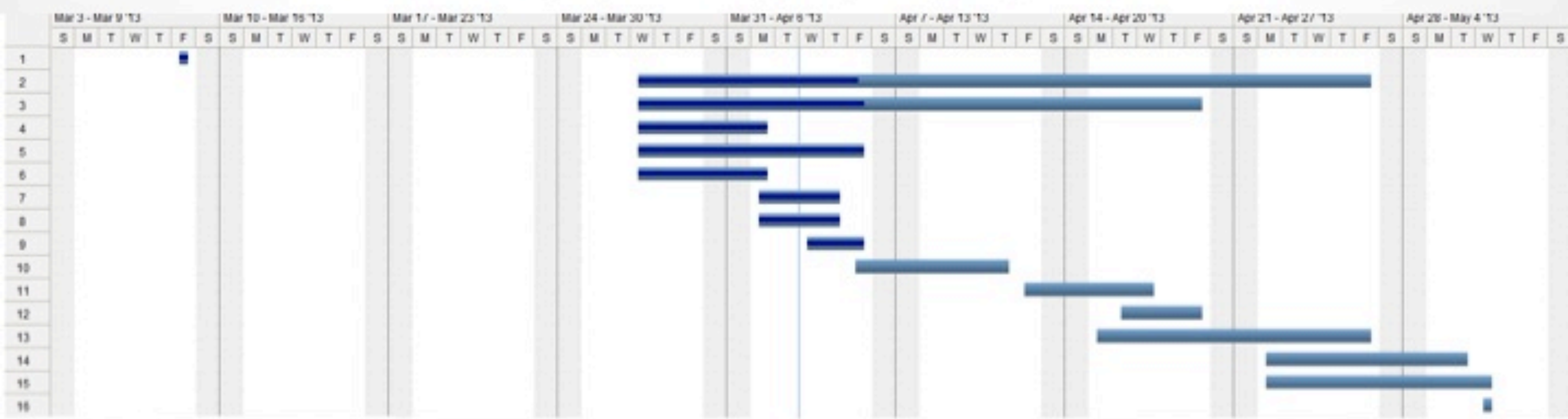

Morph Chart
Functional Requirements
Mechanisms
Number of Pumps
1
2
3
4
Types of Pump (positive displacement)
Rotary Type
Reciprocating Type
Linear Type
Other types
Vane
Gear
Screw
Lobe
Piston
Diaphragm
Rope
Chain
Peristaltic
Orientation of Cylindrical Pumps
Single/Dual Action
F
Shaft Design
Slider Crank
Scotch Yoke
Pivoting Cylinder
Cam-follower
Peristaltic Configurations
Rod
Disk
S-shape with Lobes
4 Point Rod

Morph Chart

Pump Size / Tube Size	Small	Medium	Large		
Types of Tubing	Polyvinyl Chloride (PVC)	Silicone Rubber	Fluoropolymer		
Variations of other Designs	Hose pump (for high pressure)	Tube Pump (for low pressure)	360 Degree Eccentric Design		
Number of Contact Points	1	2	3	≥ 4	
Number of Gear's teeth	2	3	4	≥ 5	
Rotary Shapes for Shafts	Rotary Discs 	Rectangular Blocks 			
Gear Ratios	1:1	1:2	2:1		
Lubrication	Ball Bearings	Making Holes Bigger	Chemicals		
Sealing	 Bolts/Pressure	O-rings 	 Epoxy (waterproof)	tape, washers  Rubber Sealant	 caulking.

Gantt Chart

	Name	Duration	Start	Finish
1	Wind Turbine Test	1d	03/08/2013	03/08/2013
2	Notebook Entries	23d	03/27/2013	04/26/2013
3	Research & Design	18d	03/27/2013	04/19/2013
4	Customer Specifications	4d	03/27/2013	04/01/2013
5	Conceptual Design	8d	03/27/2013	04/05/2013
6	Morphological Chart	4d	03/27/2013	04/01/2013
7	Decision Matrix	4d	04/01/2013	04/04/2013
8	Dependency Chart	4d	04/01/2013	04/04/2013
9	PDR	3d	04/03/2013	04/05/2013
10	Analysis	5d	04/05/2013	04/11/2013
11	CAD	4d?	04/12/2013	04/17/2013
12	FDR	4d	04/16/2013	04/19/2013
13	Order Parts	10d?	04/15/2013	04/26/2013
14	Machining	7d?	04/22/2013	04/30/2013
15	Assembly	8d?	04/22/2013	05/01/2013
16	Testing	1d?	05/01/2013	05/01/2013



Dependency Chart

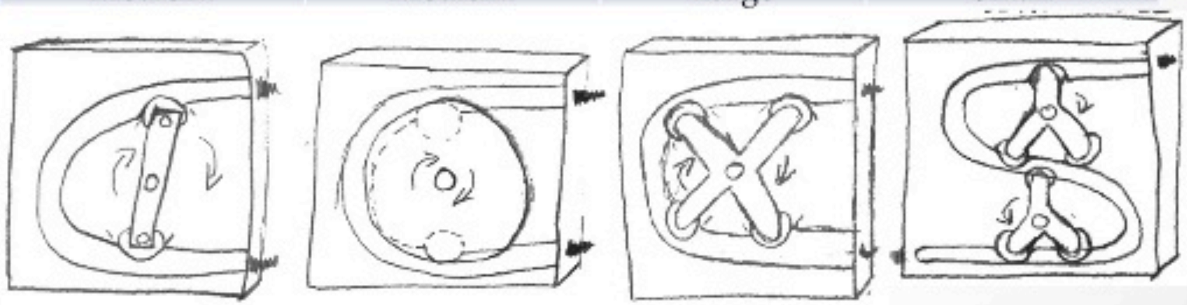
Task		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Wind Turbine Testing	A	X																					
Dependency Chart	B		X																				
Gantt Chart/ Timeline	C		X	X																			
Customer Specifications	D				X																		
Metrics [vs. Needs]	E				X	X																	
Functional Requirements	F				X	X	X																
Brainstorming	G						X	X															
Morph Chart	H							X	X														
Selection Criteria	I				X	X	X			X													
R&D	J								X	X	X												
Decision Matrix	K				X	X	X	X	X	X	X	X											
Concept Selection	L								X	X	X	X	X										
Concept Design	M												X	X									
Product Sketch	N													X	X								
PDR	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
CAD model of product	P															X	X						
Analysis of Product	Q					X								X				X					
FDR	R	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Fabrication of Product/Machining	S			X														X		X			
Testing	T						X											X		X	X		
Technical Document/ User Manual	U					X	X						X									X	
Marketing	V				X		X								X					X			X

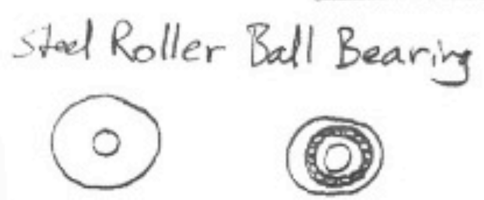
Decision Matrices

		Concept					
		1 - Peristaltic		2 - Diaphragm		3 - Slider-Crank	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cheap to Manufacture	10%	3	0.3	4	0.4	5	0.5
Easy to Manufacture	20%	5	1	4	0.8	3	0.6
High-powered Output	10%	4	0.4	5	0.5	5	0.5
Easy to Operate/ Assemble	15%	5	0.75	3	0.45	5	0.75
Can Meet Size Restrictions	10%	4	0.4	4	0.4	4	0.4
Aesthetically Pleasing	15%	5	0.75	4	0.6	2	0.3
Unique Design	20%	5	1	4	0.8	1	0.2
Total Score			2.85		2.55		2.75
Rank		1		3		2	

Decision Matrices

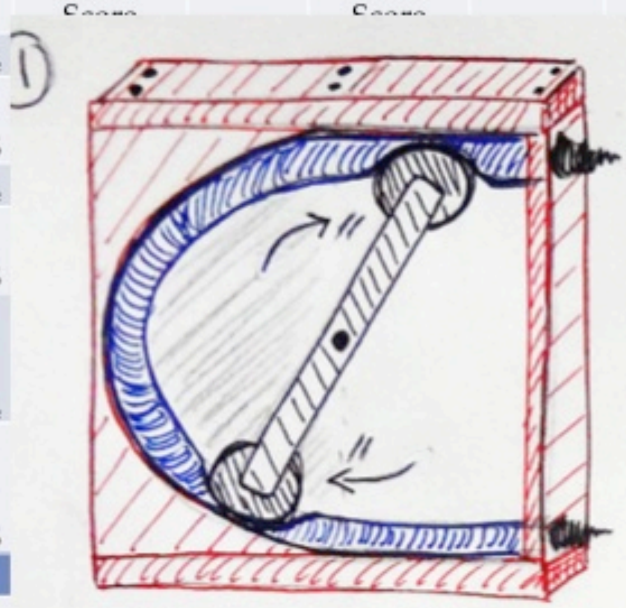
	Design #			
Components	1	2	3	4
Pincher/Roller	Ball Bearing	Disk	Ball Bearing	Lobe
Tubing Material	Plastic	Plastic	Plastic	Rubber
Tube Diameter	Medium	Medium	Large	Small
Shape	U	U	U	S
# of Contacts	2	2	4	3
Curve Radius	Medium	Medium	Large	Small

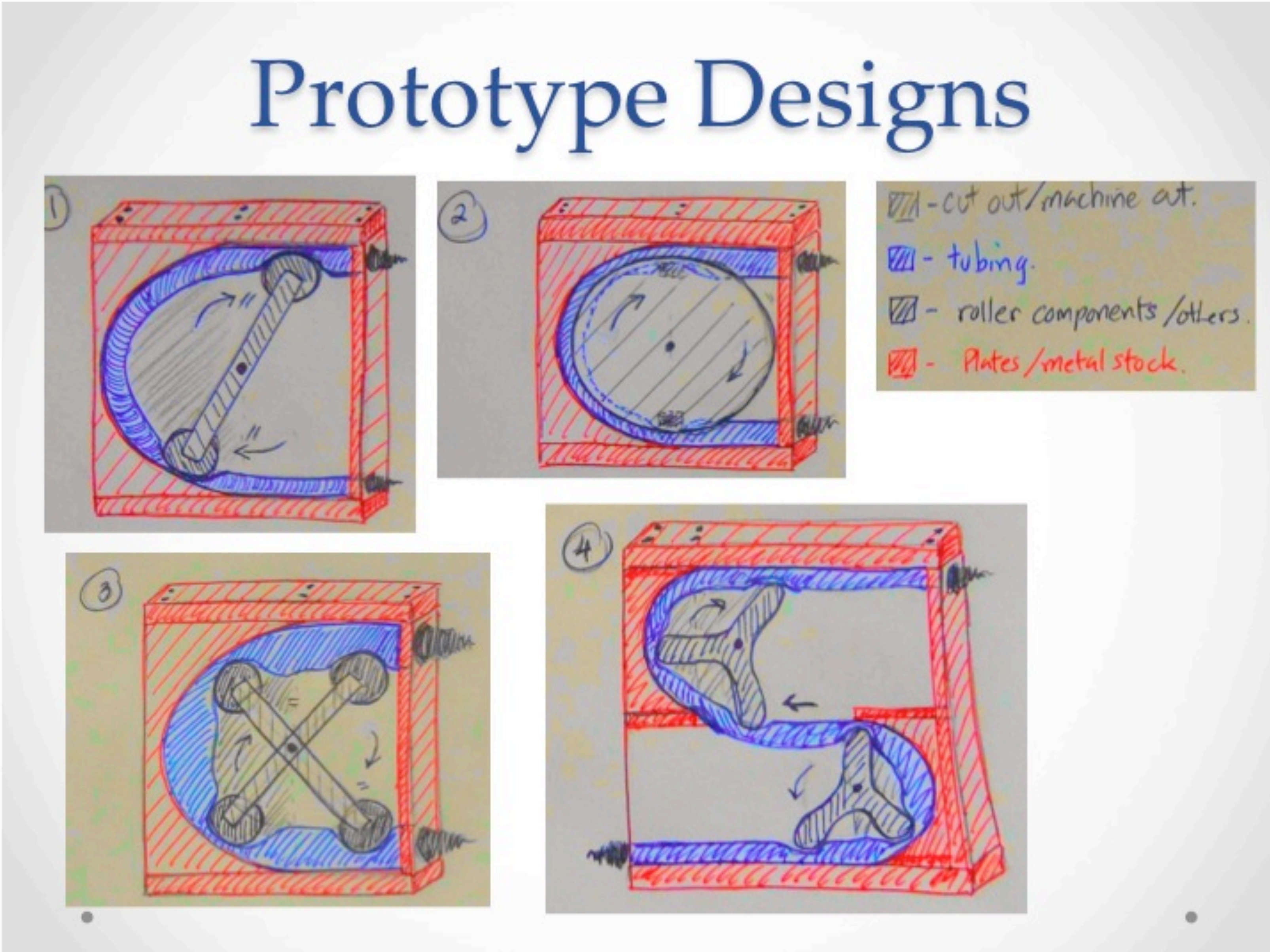


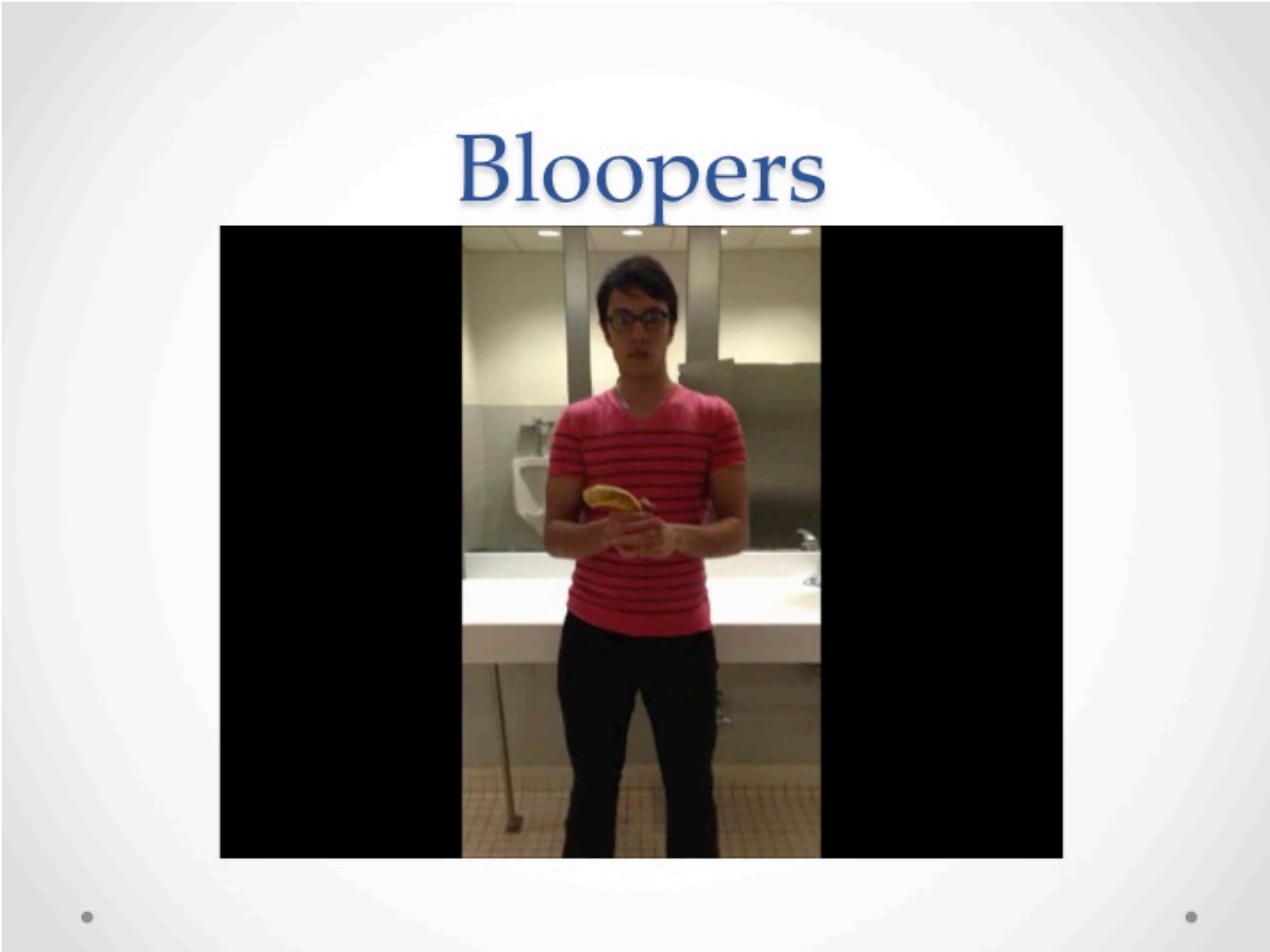


Decision Matrices

		Concept							
		Design 1		Design 2		Design 3		Design 4	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Durability	10%	4	[illegible]	[illegible]	[illegible]	[illegible]	0.4	5	0.5
Easy to Manufacture	25%	5	[illegible]	[illegible]	[illegible]	[illegible]	1.25	3	0.75
Cost	25%	4	[illegible]	[illegible]	[illegible]	[illegible]	0.75	2	0.5
Easy to Assemble	10%	5	[illegible]	[illegible]	[illegible]	[illegible]	0.5	5	0.5
Maximizes Volumetric Flow rate	15%	4	[illegible]	[illegible]	[illegible]	[illegible]	0.75	4	0.6
Efficiency (Minimizes Friction)	15%	5	[illegible]	[illegible]	[illegible]	[illegible]	0.6	3	0.45
Total Score			3.9		3.75		3.5		2.7
Rank		1		2		3		4	




Prototype Designs
1
2
- cut out/machine out.
- tubing.
- roller components/others.
- Plates/metal stock.
3
4


Bloopers

Phase 2-3: Detailed Design and Analysis

Friday: 4/5/13

(Jesse and I met for 3 hours after lab)

Jesse and I presented our PDR today, and we got some great feedback on our pump.

- The substitute TA, Ellery, told us about about increasing the number of our peristaltic pump's tubing, which we decided was a good idea if we could actually afford more tubes.
- Also, people basically told us to keep it as simple as possible, and to definitely avoid the weird S-shaped peristaltic pump.

We worked on the analysis of the pump and seeing how much it would water it would pump, how much power it would use, and how we could design the pump so that it would maximize our output. We decided to make a Matlab program in order to make it easier to input different inputs and get results faster than if we did it by hand. We initially went the route of one big tube being used in our pump, but after realizing that that pump would cost too much, we went the route of 3 3/8" diameter tubes. We also decided that the radius of 3 would be the best, even if the bend radius is smaller than that. After we spent a lot of time on that, we decided we would take a break and meet up tomorrow to finalize a design to be CADded up.

We also asked about the valves, and learned that we would have to actually purchase the valves, that hey would not be given to us.

Saturday: 4/6/13

(Jesse and I met for 2 hours)

Jesse and I worked on the final design, and Jesse basically drew everything out well so that the rest of the team could CAD it, since we were going to be busy most of the week. It was tough deciding what materials to use and what we would have to cut out in order to keep our purchases through McMaster and Emerson less than 30 dollars. It was tough but we decided we would have to get a packet of 10 plastic barbed tube attachments since it would be much cheaper than purchasing them individually through Emerson. The rest of the parts can be seen below on the Cost Analysis.

The Matlab code in its entirety can be found here: https://cornell.box.com/s/vf8e3ymtsb55nzia3xkq

Thursday: 4/11/13

(Jesse and I met for 4 hours)

We finalized our costs and analysis to see how much our pump would actually pump. This is what we decided on. For analysis, see the section below:

1) Our pump operates by using the torque generated by the wind to rotate rollers around in a circle in order to performing a squeezing action on tubes in order to push water up said tubes while also creating a vacuum when the tubes reform.
2) Our RPM is about **1150 revs/min**. We got that value by taking the intersection between the two power curves. The calculations that were made to reach this conclusion did not include frictional forces, or any loss of energy, so in reality it will be much less.
3) Our pump will work since it will ideally operate at 4.239 Watts, while the actual Power needed to pump water up 1.5 meters at a rate of 1L/min is 1.238 Watts, according to our calculations. The flow rate that our pump will achieve, again, stressing the ideal situation, will approximately be

118 L/min. The flow rate was calculated by using the volume displaced per rotation multiplied by the rotations per minute (RPM)

4) Weight is about 86 in^3 * 167 lb/ft^3 *(1ft/12in)^3 **= 8.311 lbs.**

A simple video of the CADded animation can be found here:
https://cornell.box.com/s/h2yqyplsbxhw3onzvege

And check the preliminary CAD rendered images below and our FDR

Goals for Next Week

- Present our FDR
- Update our existing CAD in order to show Joe and make sure that what we are doing is possible.
- Start ordering parts and maybe even machine if possible.Cost Analysis

Cost Analysis

Tables 2.1-2.3. *Cost Analysis*. The first table shows what everything that we're planning on ordering is and how much it costs in total. The second table shows how much everything could have been if we went with the bigger inner diameter tube, and shows that we would have already gone over the limit. The third table shows given materials that we could potentially trade in for other material.

Quantity	3/8 inches items	Cost Per Unit	Total Cost	Product Number
5	Soft Abrasion-Resistant Polyurethane Tubing Blue, 3/8" ID, 1/2" OD, 1/16" Wall Thickness	2.22	11.1	5792K39
1	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	4.46	4.46	5121K411
2	Brass pipe fittings (3/8" barbed x 1/4"NPT)	1.19	2.38	From Tas
1	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	5.88	5.88	6383K45
10	1/4" flat washers	0.04	0.4	From Tas
10	1/4 - 20 hex nuts	0.07	0.7	From Tas
2	1/4 - 20 threaded rod (per foot)	1.41	2.82	From Tas
1	1/2" Steel Rod (per foot)	1.65	1.65	From Tas
		Total	**29.39**	

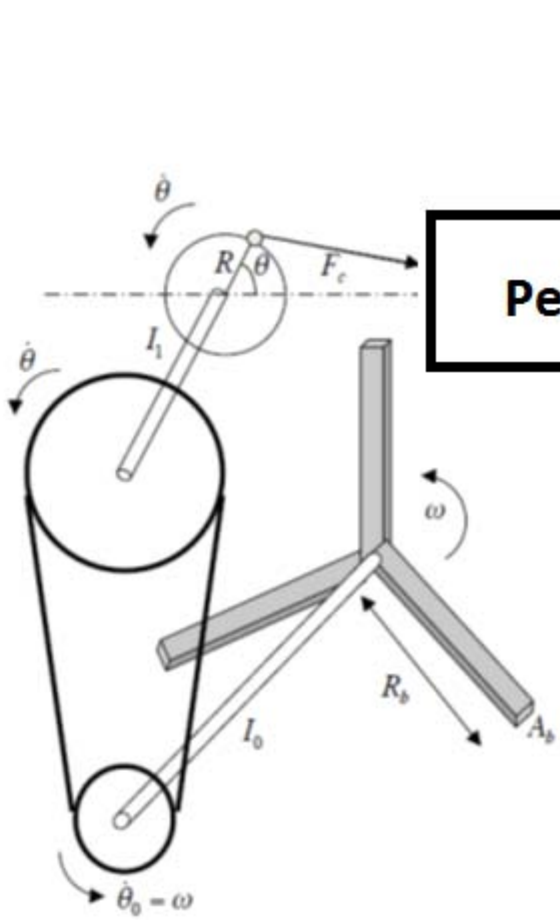
Quantity	3/4 inches items	Cost Per Unit	Total cost
2	ft 3/4 diameter water tubing	8.63	17.26
2	Brass pipe fittings (3/8" barbed x 1/4"NPT)	1.19	2.38
2	Brass pipe fittings (3/4" barbed x 1/2"NPT)	3.69	7.38
1	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	5.88	5.88
?	washers	?	
?	nuts	?	
?	threaded rods	?	
		Total	32.9

Parts to Trade In	Price
1.875 PVC Solid Rod	$6.80
Round cylinder Tubing	$3.91
1/2"x4"Rectangular Bar (Base)	5.03
1/2"" x 2 1/4" Rectangular Bar 12"	11.79
Total Trade in bucks	**$27.53**

Analysis

Below is the analysis that we went through to see which Peristaltic pump design would be the best.

Setup:



A. Height you need to pump the water: h = 1.5 m

B. Diameter of the water lines (plastic tubing): d = 3/8”

C. Gear ratio converting omega to theta dot: R_0/R_1 = 1.67/11.43

D. Density of water: ρ_w = 998 kg/m^3

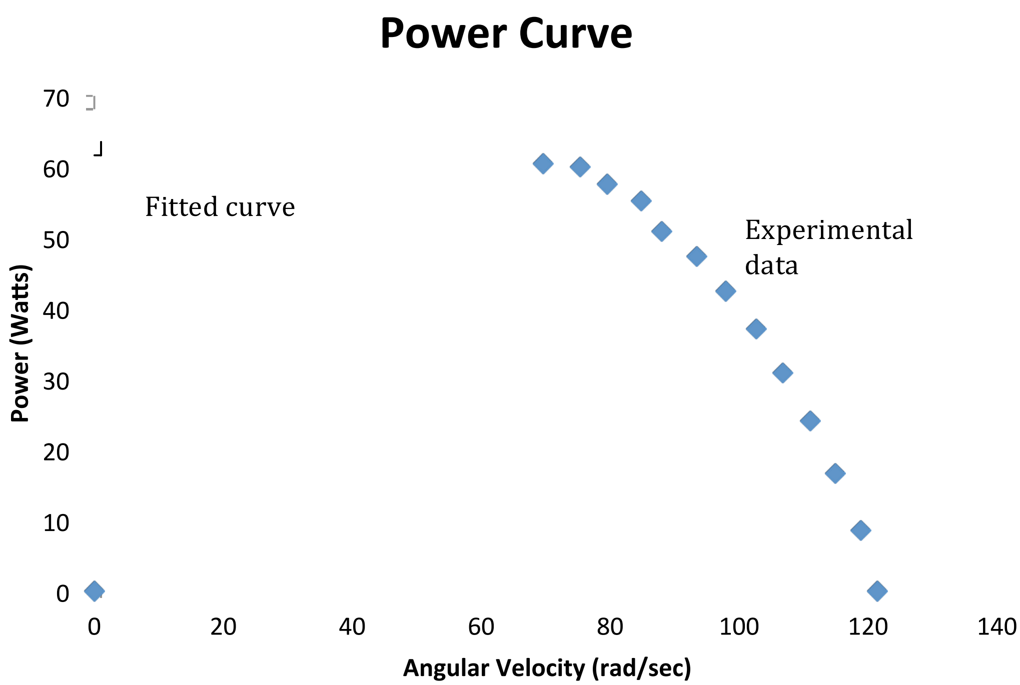
E. Acceleration due to gravity: g = 9.81 m/s^2

F. Required flow rate: Qdot= 1 L/min

G. Dynamic viscosity of water at 20° C $\mu = 1.003 \times 10^{-3}$ Ns/m^2

Power Curve from Torque Test:

We compiled the data from the torque test we did during lab. During the test, we collected two sets of data for the RPM. We then averaged these values to get an average RPM. Using the measure values of force and average RPM we calculated the power vs. angular velocity and got a parabolic line of best fit. Ideally, we would want our pump to operate at around 20 to 50 Watts so that it is relatively high on the power curve without being so high that there is a risk of stalling.



RPM first	RPM second	RPM ave	Load (N)	radius (m)	Torque (Nm)	w (rad/sec)	Power (Watts)
1150	1170	1160	0	0.07225	0	121.474916	0
1135	1135	1135	1	0.07225	0.07225	118.856922	8.587412619
1105	1090	1097.5	2	0.07225	0.1445	114.929931	16.60737506
1070	1050	1060	3	0.07225	0.21675	111.00294	24.05988734
1030	1010	1020	4	0.07225	0.289	106.81415	30.86928941
990	972	981	5	0.07225	0.36125	102.73008	37.11124132
940	930	935	6	0.07225	0.4335	97.912971	42.44527294
915	870	892.5	7	0.07225	0.50575	93.4623814	47.26859942
850	830	840	8	0.07225	0.578	87.9645943	50.84353551
820	800	810	9	0.07225	0.65025	84.8230016	55.15615682
780	740	760	10	0.07225	0.7225	79.5870139	57.50161754
730	710	720	11	0.07225	0.79475	75.3982237	59.92273827
670	660	665	12	0.07225	0.867	69.6386372	60.37669841
0	0	0	14	0.07225	1.0115	0	0

Finding Relationship between Power and omega for our Pump:

The Power required by our pump is. Refer to the setup page for a description of these variables:

The flow rate per rotation of the shaft can be written as a function of theta dot. Delta V is the volume

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

displaced by a single rotation of the shaft:

$$\dot{Q} = \Delta V_{per\ rotation} * \frac{\dot{\theta}}{2\pi}$$

Given the gear ratio, the value of theta dot can be converted to omega:

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

Combining these equations results in the equation of Power required by our pump:

$$P = \rho_w g h \, \Delta V \left(\frac{R_0}{R_1}\right)\left(\frac{\omega}{2\pi}\right)$$

The value of delta V for a peristaltic pump is the amount of volume that is displace by the rollers compressing the tubing in a single revolution. Delta V for a peristaltic pump of our design type is a function of the radius of the inner diameter of the tubing (r), the radius of curvature of the semicircular back plate (R), and the number of tubes in parallel that our pump uses (ntubes).

$$\Delta V = ntubes * (\pi * r^2) * (2 * \pi * R)$$

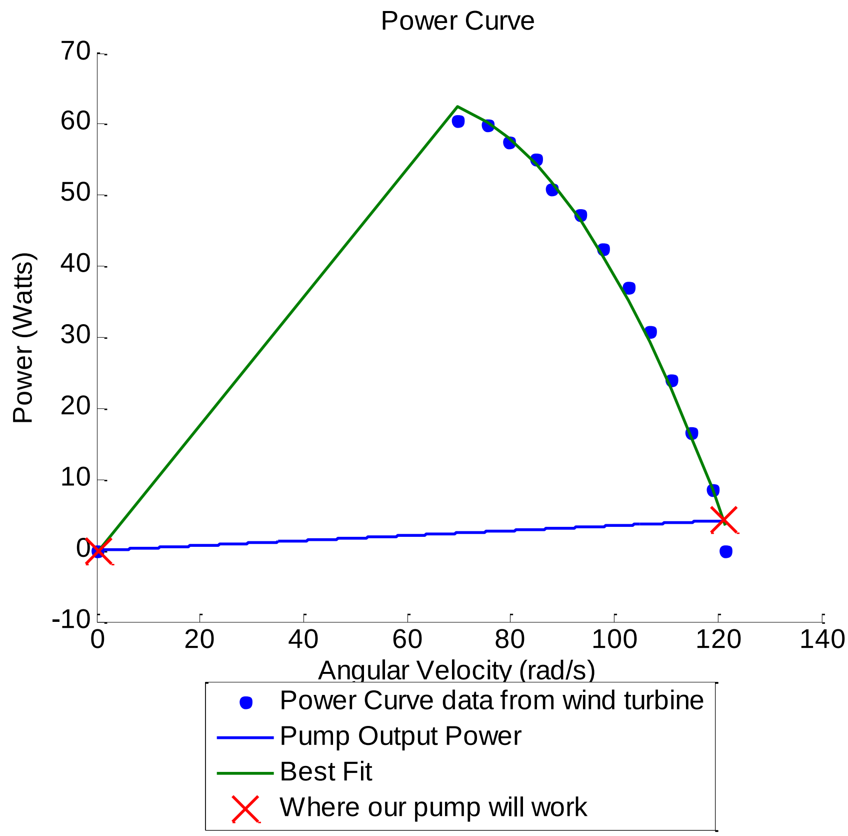
Finding Steady State Operating Point of Our Pump

The following plot, created by our MATLAB function, determines where on the power curve our pump will operate in equilibrium and displays this point as a red X on the graph. The MATLAB function uses the previous equations along with user input to plot two power functions. The first function is the line of best fit for the power curve created from the wind turbine torque test in lab. The second power function is the derived on the previous page and is used to plot the Power for our pump as a function of omega. The inputs that we used to generate these results were, **number of tubes = 3 in parallel, diameter of tubes = 3/8", radius of rotary motion = 3"**. Ideally, the pump should operate somewhat high on the parabola power curve while not being too close to the peak that there would be a risk of stalling. However, due to price constraints we are unable to increase our maximum power which could be achieved by adding more tubes or increasing their diameters.

1) Our RPM is about **169 revs/min**. This value was determined by the intersection between the two power curves and factoring in the gear ratio. The calculations that were made to reach this conclusion did not include frictional forces, or any loss of energy, so in reality it will be less.
2) Our pump will ideally operate at **4.2 Watts**. The flow rate that our pump will achieve will approximately be **3.5 L/min**. This value was calculated by taking the RPM multiplied by the volume displaced per revolution multiplied by 20% efficiency. Even after factoring in loss due to efficiency, we still have a factor of safety greater than three so our design should meet the requirements.

Updated Power Curve:

This is our power curve that was printed from Matlab:



Finding the Minimum Power Needed to Meet the Constraints

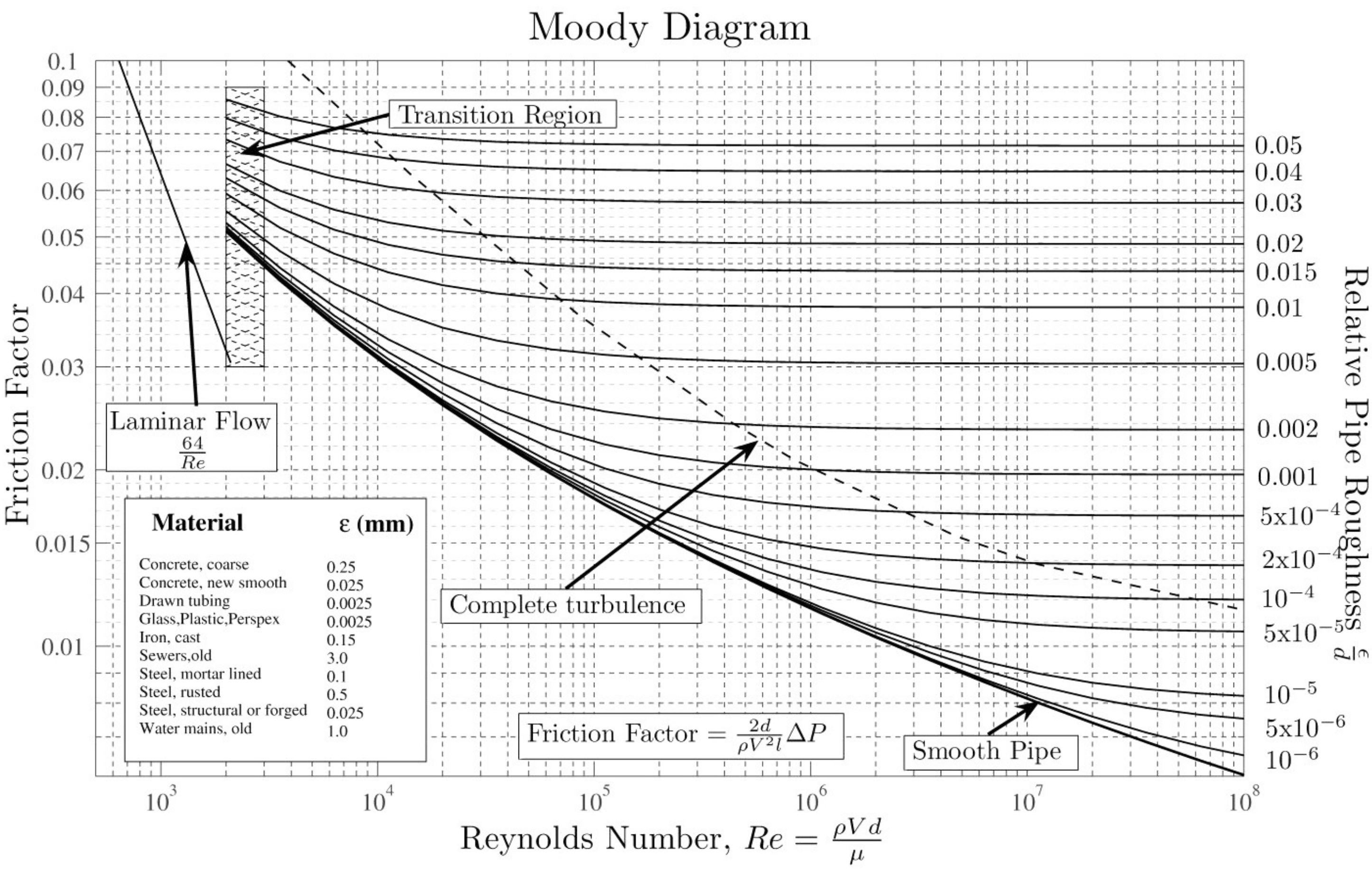
The power that our pump produces in equilibrium must be compared to the minimum power needed to meet the constraints of the setup. The constraints are that the pump must pump at least Qdot=**1liter per minute** a height of **1.5 meters** in a d=**3/8"** diameter tube.
The velocity, v, of the fluid in the tubing can be calculated:

$$v = \frac{\dot{Q}}{A} = \frac{\dot{Q}}{\frac{\pi}{4}d^2}$$

Using the velocity and constants listed on the setup page, the Reynolds number, Re, can be calculated:

$$Re = \frac{\rho_w v d}{\mu}$$

Using the MATLAB function, a Reynolds number of about **Re=2,221** indicated that the flow is just barely over laminar flow (since Re=2,000 is the critical value between linear and turbulent flow).



Using the Moody Diagram, the friction factor, f, can be calculated given a Reynolds number and relative roughness. The calculated Reynolds number of about 2,221 corresponds to the line:

$$f = \frac{64}{Re}$$

Note that this value of friction factor is independent of the relative roughness; therefore the relative roughness does not need to be calculated.
Using this friction factor, the head los can be calculated:

$$h_f = \frac{v^2 f L}{2gd}$$

Minor losses, caused by sudden changes in diameter, can be calculated using:

$$h_m = \frac{v^2}{2g}\sum K$$

The tubing we use in the pump, the tube fittings, and the tube that connects outside the pump all has the same diameter. Therefore the value of K is zero and there are no minor losses.

Using the stead flow energy equation:

$$\frac{p_1}{\rho_w g} + \frac{v_1^2}{2g} + z_1 = \left(\frac{p_2}{\rho_w g} + \frac{v_2^2}{2g} + z_2\right) + h_f + h_m - h_p$$

Where hp is the head increase across the pump. This equation can be simplified knowing that the pressure is constant and the velocity is about zero. From this equation, we find hp:

$$h_p = z_2 - z_1 + h_f + h_m$$

Where Z2-Z1 is the height=1.5 meters that the water must be pumped.
It is now possible to calculate the ideal power (Pideal) that represents the power needed to meet the constraints. This can be calculated using previous values:

$$P_{ideal} = \rho_w g \dot{Q} h_p$$

However, this power does not take into account the fact that our pump will not be 100% efficient. Estimating an efficiency of η=20% the actual required power (Pactual) is,

$$P_{actual} = \frac{P_{ideal}}{\eta}$$

Evaluation:
These equations and values have been run through the MATLAB function. The actual power (Pactual) to meet the constraints was calculated to be about **Pactual=1.24 Watts**. Comparing this to the equilibrium power of our pump of **4.2 Watts**, it is clear that our pump has the necessary power to meet the requirements.

Matlab Function

The Matlab code can be found below, but has to be supplemented by another function that allows for some of the calculations to be made for the Analysis.

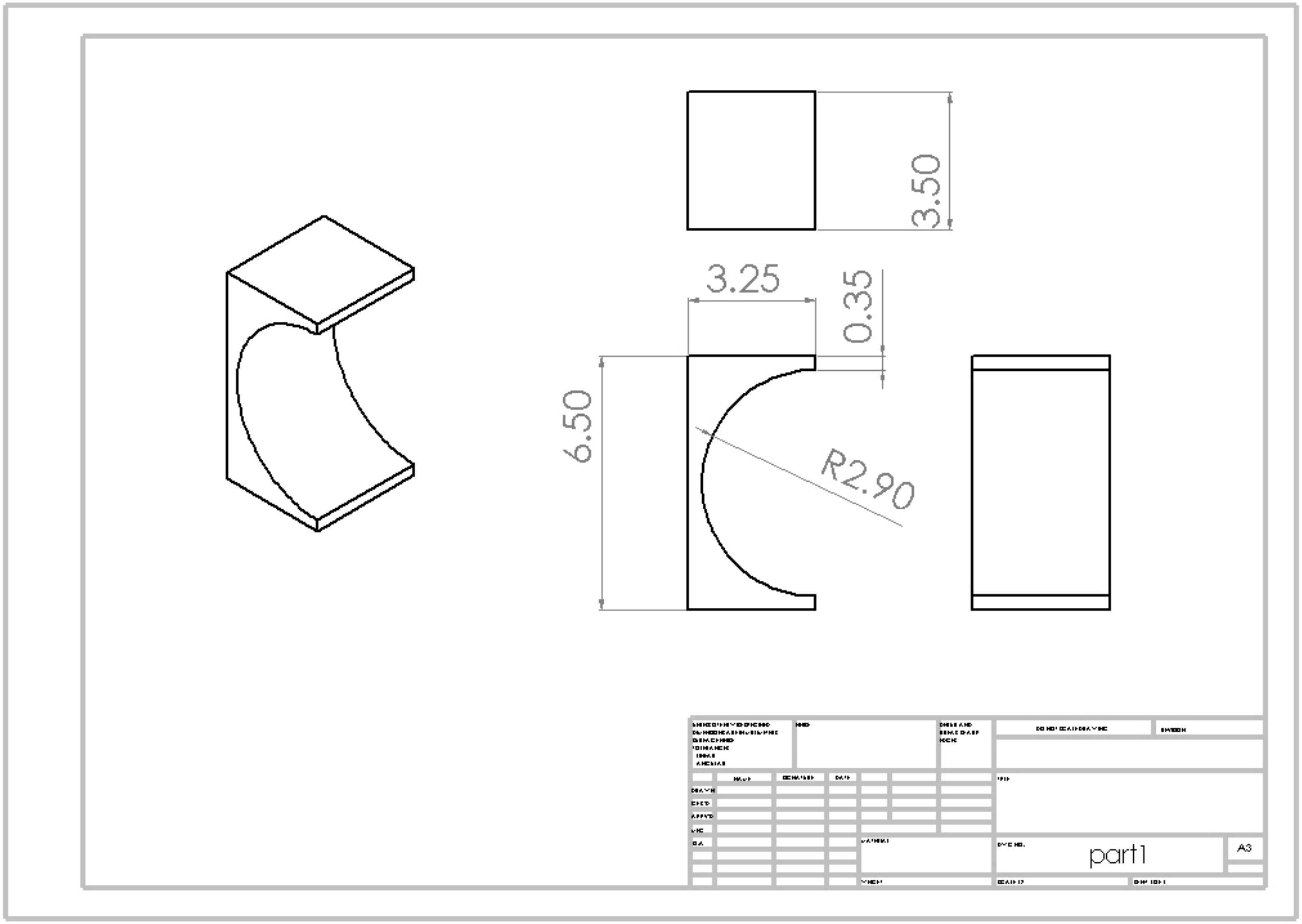
```
function WindpumpAnalysis(ntubes,d,R)
%This function graphs the power curve based on the wind turbine data as
%well as the power that our pump will output at a given angular velocity.
%The point of intersection is recorded as Pmax or the maximum power that
%our pump will operate at. Pmax is then compared to Pactual which is the
%power required to meet the specifications of the assignment.

%The inputs are the number of tubes (ntubes), d is the inner diameter of
our
%tubes in inches, and the R is the radius of the rotary arm in inches.
clc
close all
k = 0; %approximation for not having much change in diameter of the
tubing.
R0 = 1.67; %inches. Diameter of smaller gear
R1 = 11.43; %inches. Diameter of bigger gear
gratio = R0/R1;
rho = 1000; %kg/m^3 water density
g = 9.8; %m/s^2
H = 1.5; %m height being pumped to
inchtom = 0.0254; %convert dimensions to metric
r = (d/2)*inchtom; %converting inches to meters
R = R*inchtom;

%This all reads the power curve text file and then outputs the graph,
finds
%the power that our pump would use up, and then finds the intercept
between
%the two graphs.
M = dlmread('power curve.txt');
wturbine = M(:,1); Pturbine = M(:,2);
deltaV = 2*pi^2*r^2*R*ntubes; %The volume displaced per 1 rotation of our
pump
%w is the angular velocity vector
w = 0:.1:wturbine(1);
%P is the power our pump will produce as a function of angular velocity
P = rho*g*H*deltaV*gratio/(2*pi)*w;

%This function finds where two lines intersect which represents the power
%and angular velocity that our pump will operate at
p = polyfit(wturbine,Pturbine,2);
f = polyval(p,wturbine);
[x0,y0] = intersections(w,P,wturbine,f,1);

%This plots the graph of Power vs. Angular Velocity
hold on
fig=gcf;
```

```
set(findall(fig,'-property','FontSize'),'FontSize',14)
plot(wturbine,Pturbine,'x',w,P,wturbine,f,'-',x0,y0,'.r')
title('Power Curve');
xlabel('Angular Velocity (rad/s)')
ylabel('Power (Watts)')
legend('Power Curve','Pump Operation Power','Best Fit','Where our pump
will work')
hold off
m = length(x0);
rpm = x0(m)*60/(2*pi)*gratio; %RPM of the rotary part of the pump where
the  %two power curves intersect

%This compares the two values of Pactual vs our Pmax. In order for our
pump
%to work, Pmax must be greater than Pactual
[Pactual] = actualpower(rho,H,g,k);
Pmax = max(y0);

%And this prints out whether or not the Pmax produced by or pump meets the
%requirements of Pactual
if Pactual < Pmax
    fprintf('Yes, the pump will work, Pmax = %6.3f W, and Pactual = %6.3f
W\n',Pmax,Pactual)
else
    fprintf('Nope, the pump will not work, Pmax = %6.3f W, and Pactual =
%6.3f W\n',Pmax,Pactual)
end
flowrate = deltaV*rpm*1000*.2; %Estimated value of flowrate using 20%
%efficiency

fprintf('Our pump will rotate at %.2f rev/min, and will pump approximately
%.2f L/min\n',rpm,flowrate)

end

function [Pactual] = actualpower(rho,H,g,k)
%This is the code that calculates the Power needed to pump water according
%to the specifications. These are all the calculations posted by Kathryn
%McQuade
mu = 1.003*10^-3;
Eps = .0015*10^-3;%epsilon constant
Qdot = 1*.001/60; %flowrate
inchtom = 0.0254;
d = 3/8; d = d*inchtom; %tube diameter
A = pi*(d/2)^2; %cross section area
v = Qdot/A; %velocity of water
%calculates Reynold's number and displays whether it's laminar or
turbulent
%flow
Re = rho*v*d/mu;
if Re < 2000
```

```
    display('Laminar Flow')
else
    display('Turbulent Flow')
end

%Finds the relative roughness so we can find the f.
relrough = Eps/d;
f = 64/Re; %calculated from Moody’s table
hf = v^2*f*H/(2*g*d); %Headflow loss
hm = v^2*k/(2*g); %Minor loss
hp = H + hf + hm;
Pideal = rho*g*Qdot*hp; %ideal power before efficiency is factored
eff = .2; %pump efficiency
Pactual = Pideal/eff;%Power required to meet specifications
end
```

Initial Part and Assembly Drawings

Fig 2.1. *Back Arch Part Drawing.* This part will contain the tubes. While the roller rolls on the tubes, this back arch will push back and, between the pushing from the rollers and the back arch, a seal will be created within the tubes which will keep water from sliding back and thus create a vacuum as the rollers move up, making more water be sucked into the tube. We are hoping to make it out of Delrin if possible.



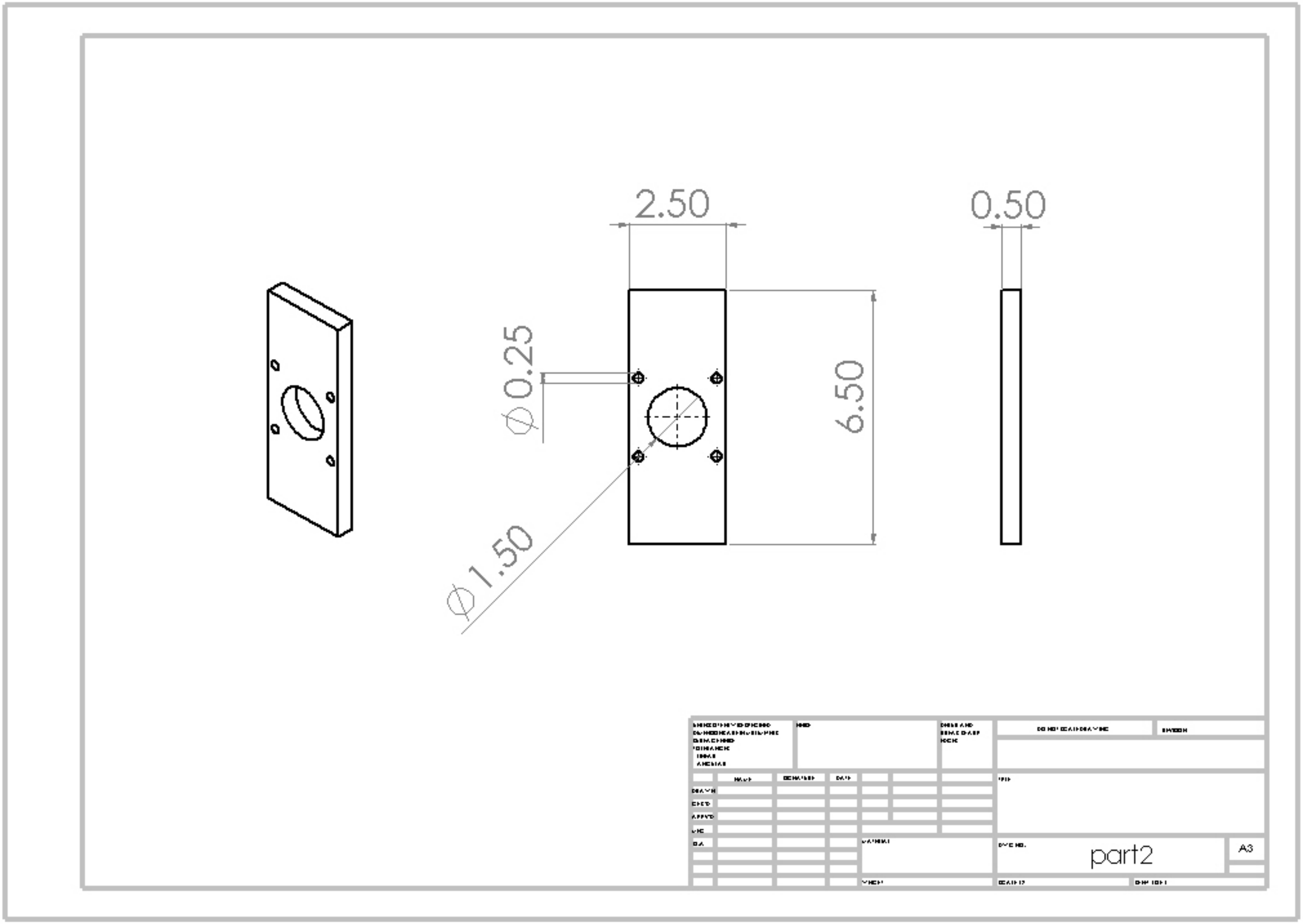


Fig 2.2. *Backplate.* This part will attach to the whole pump and also to the faceplate supplied to us. The main shaft will house a ball bearing which will fit in the big center hole, and this in turn will hold onto a main shaft which will turn the rollers and will connect directly to the gear that will be turned by the fan.

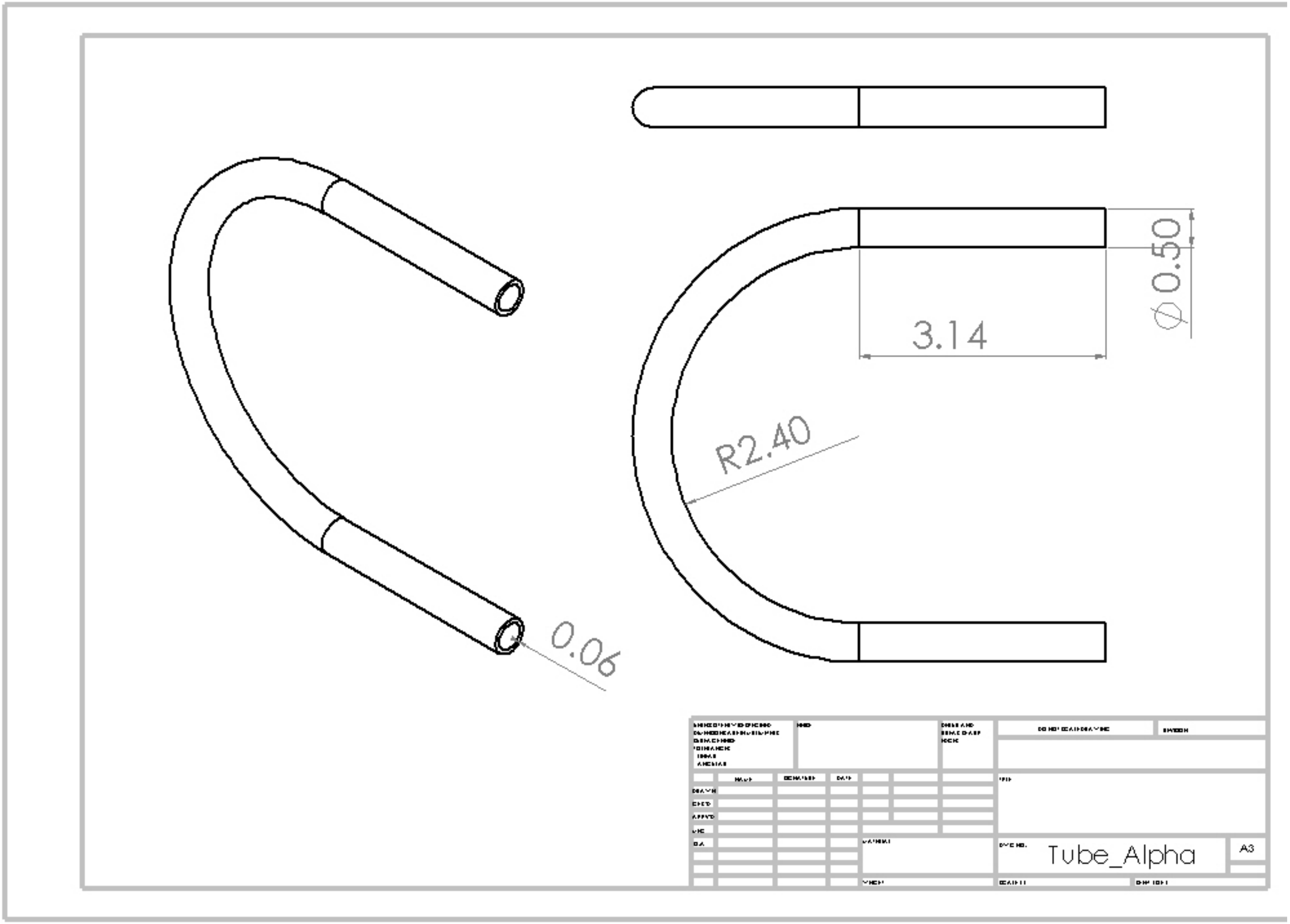


Fig 2.3. *Tubing.* This is a drawing of the tubing that we will be purchasing from McMaster. At the moment it is made out of Polyurethane, and hopefully this tubing will work well with our Peristaltic pump, although McMaster says it does.

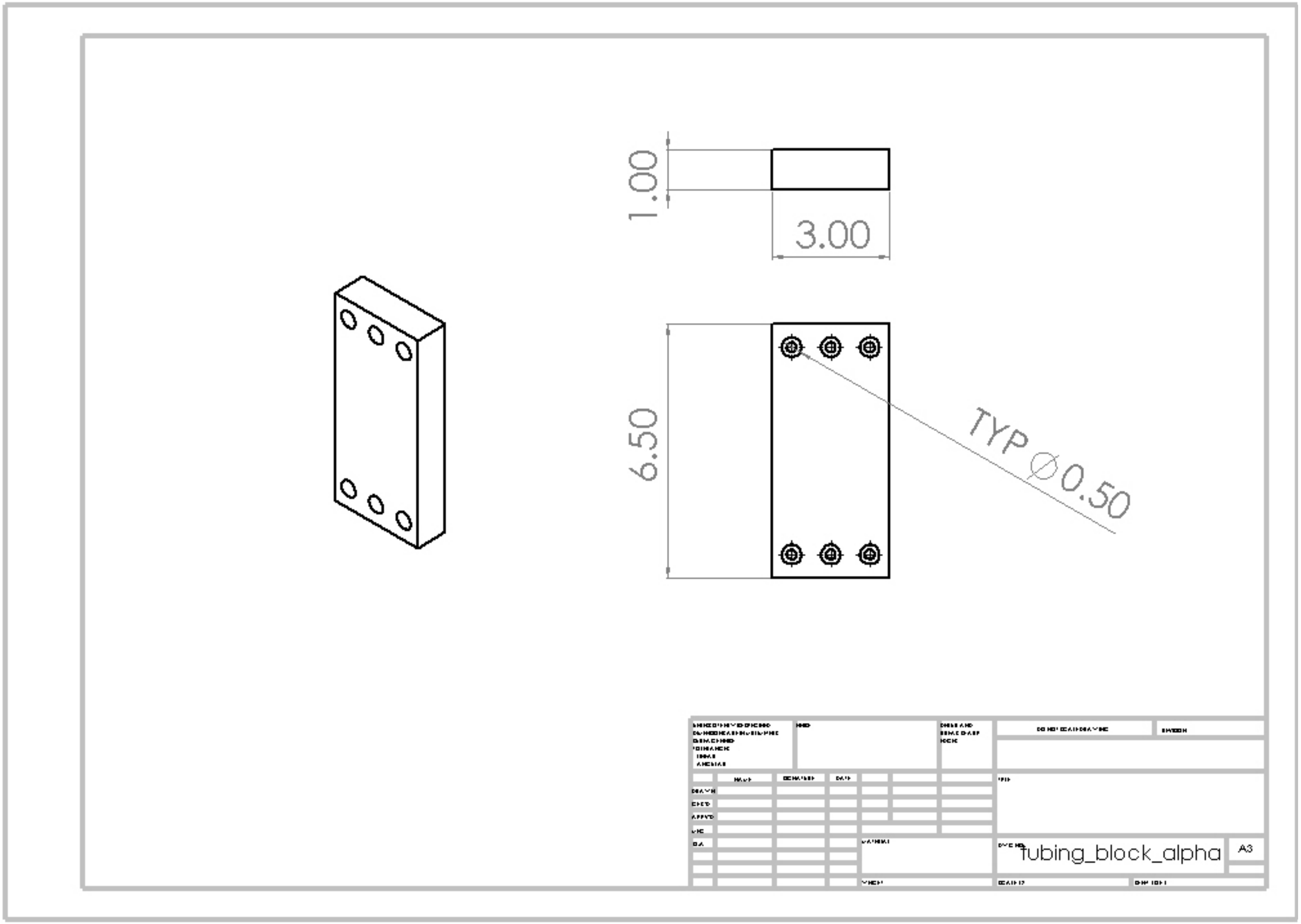


Fig 2.4. *Front Tube Fitting Plate.* This plate will have holes threaded as shown that will contain the tube fittings on both sides in order to hold all the peristaltic tubes that will be used and connect them directly to the incoming and outgoing tubes so that leakage is minimized. These might be changed in order to reduce material however.

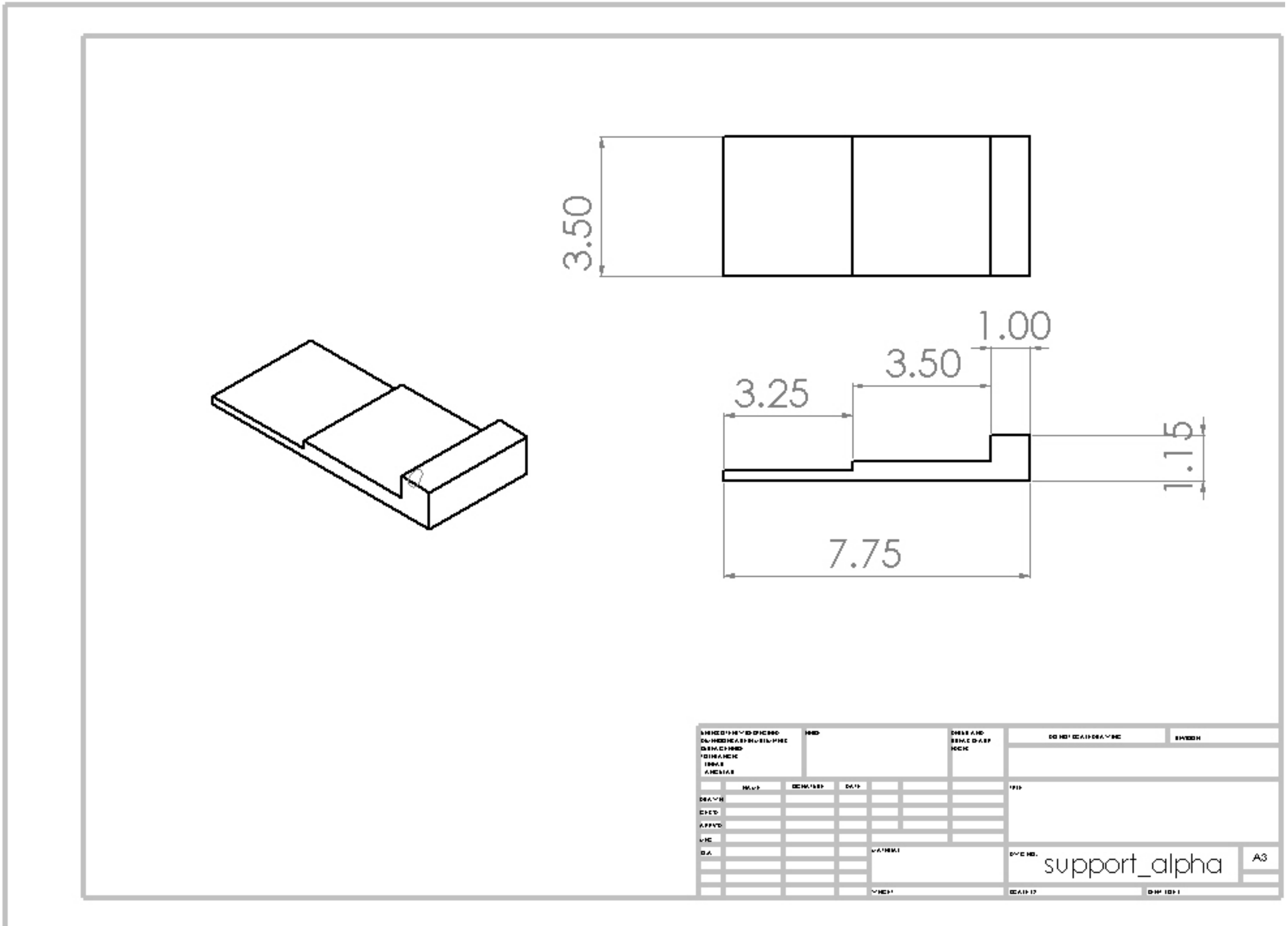


Fig 2.5. *Top and Bottom Support Plates.* This plate will be used to connect to the back arch, and can potentially act as a replacement for the front tube fitting plate, and potentially it will connect to the back plate (we're not entirely sure about that part yet), and it is designed with the odd bump in the middle in order to provide a continuous platform for the tubes.

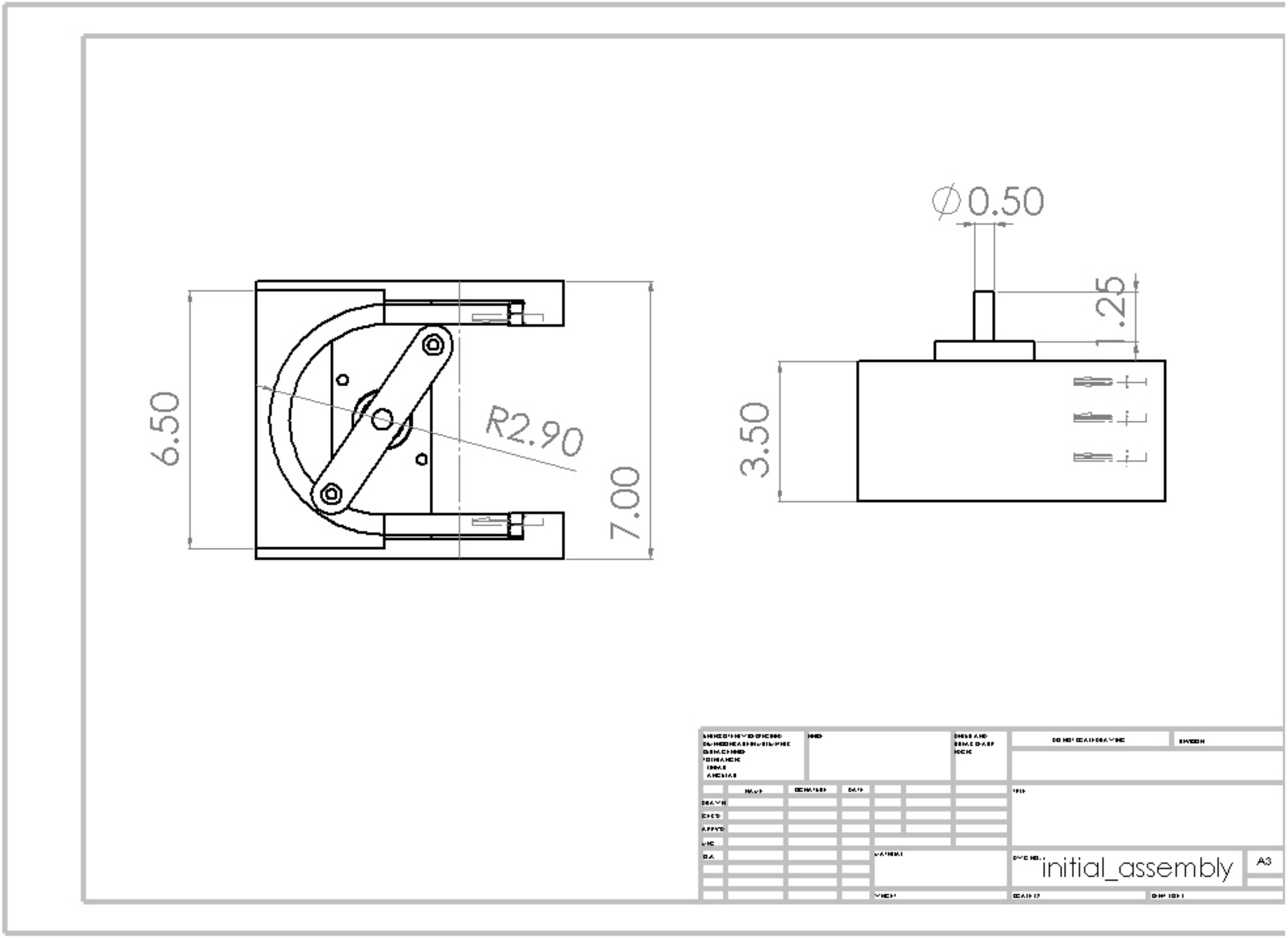
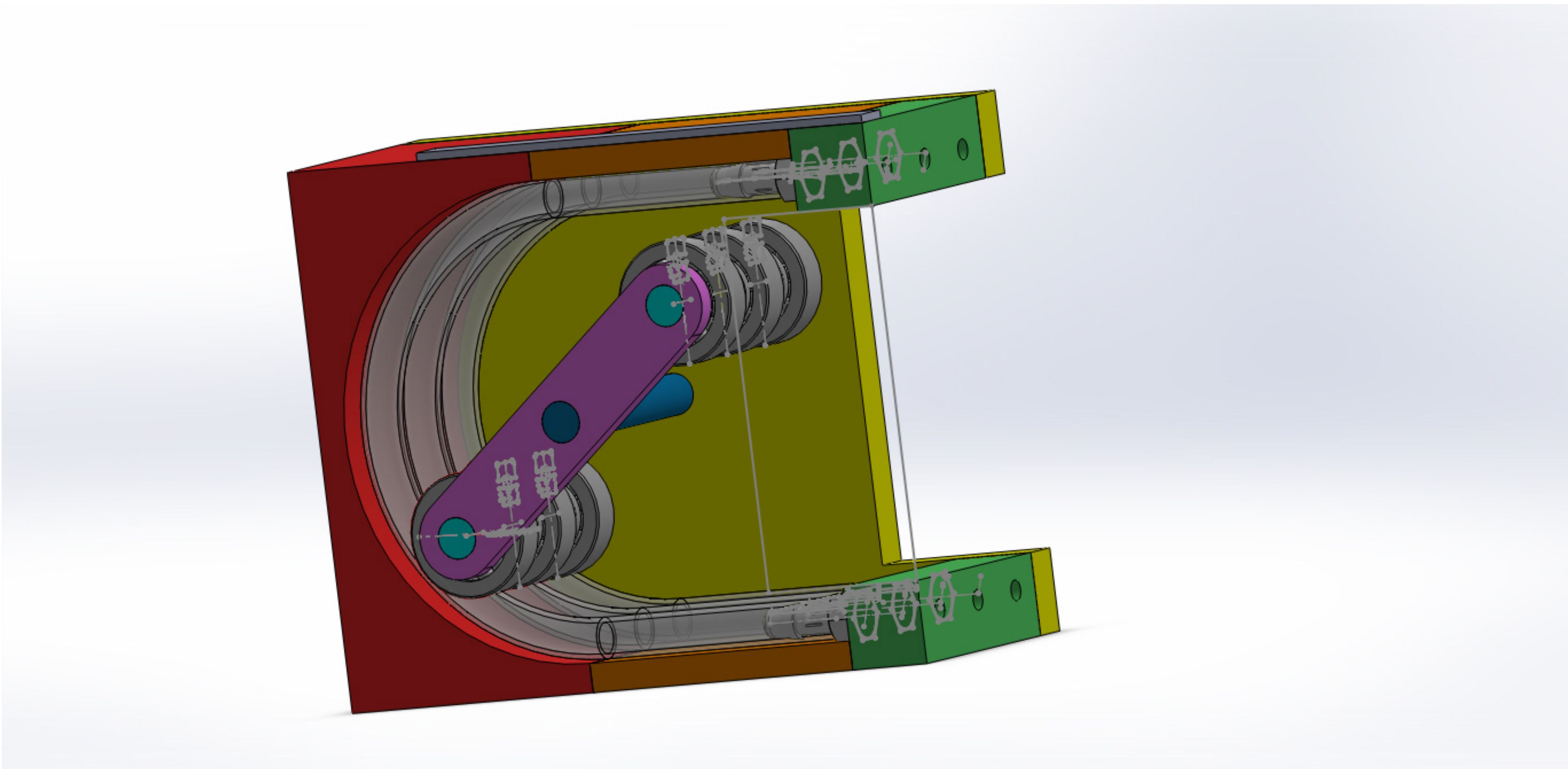
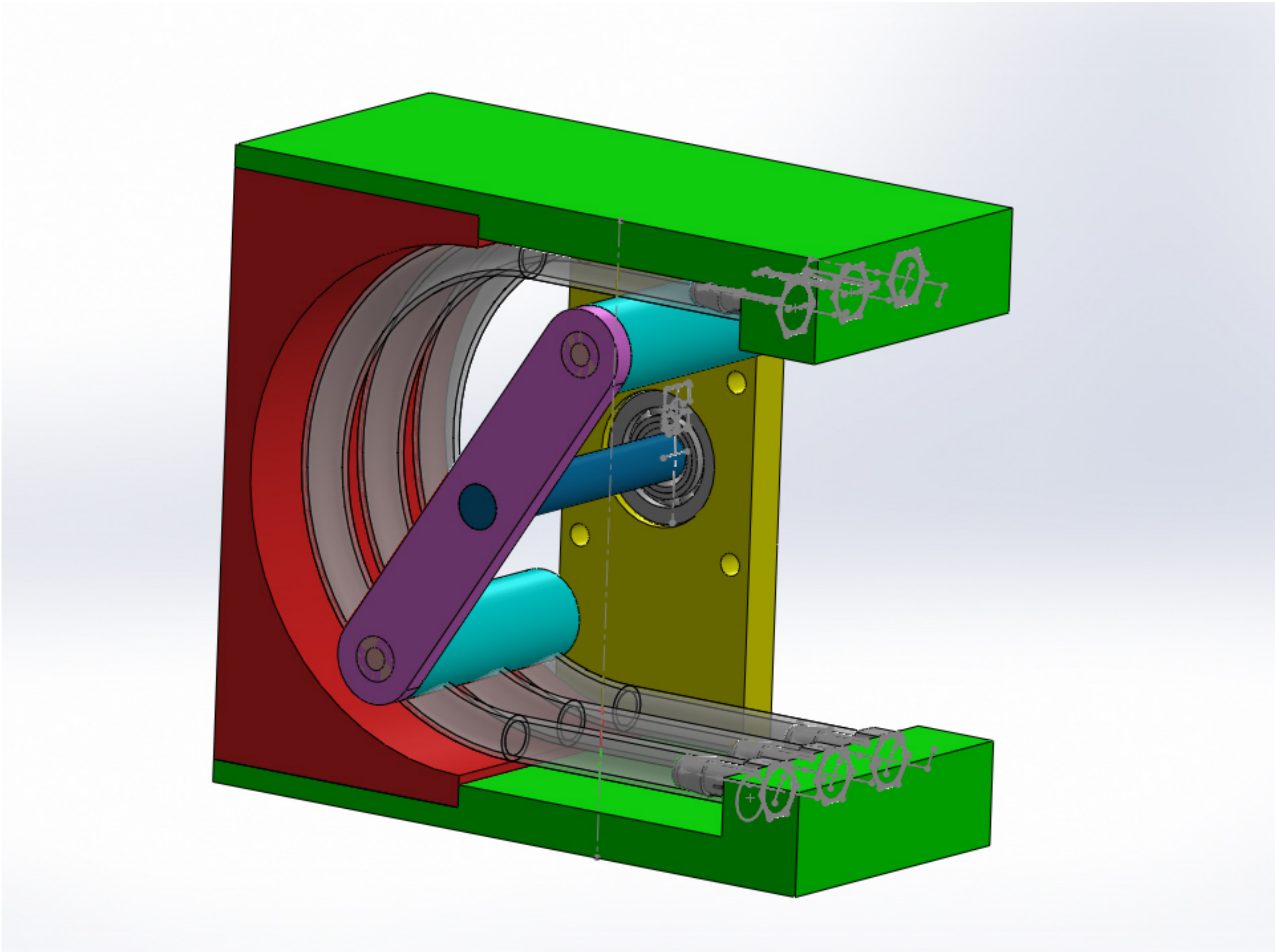


Fig 2.6. *Assembly 1.* This is an example of one of our initial assembly ideas.

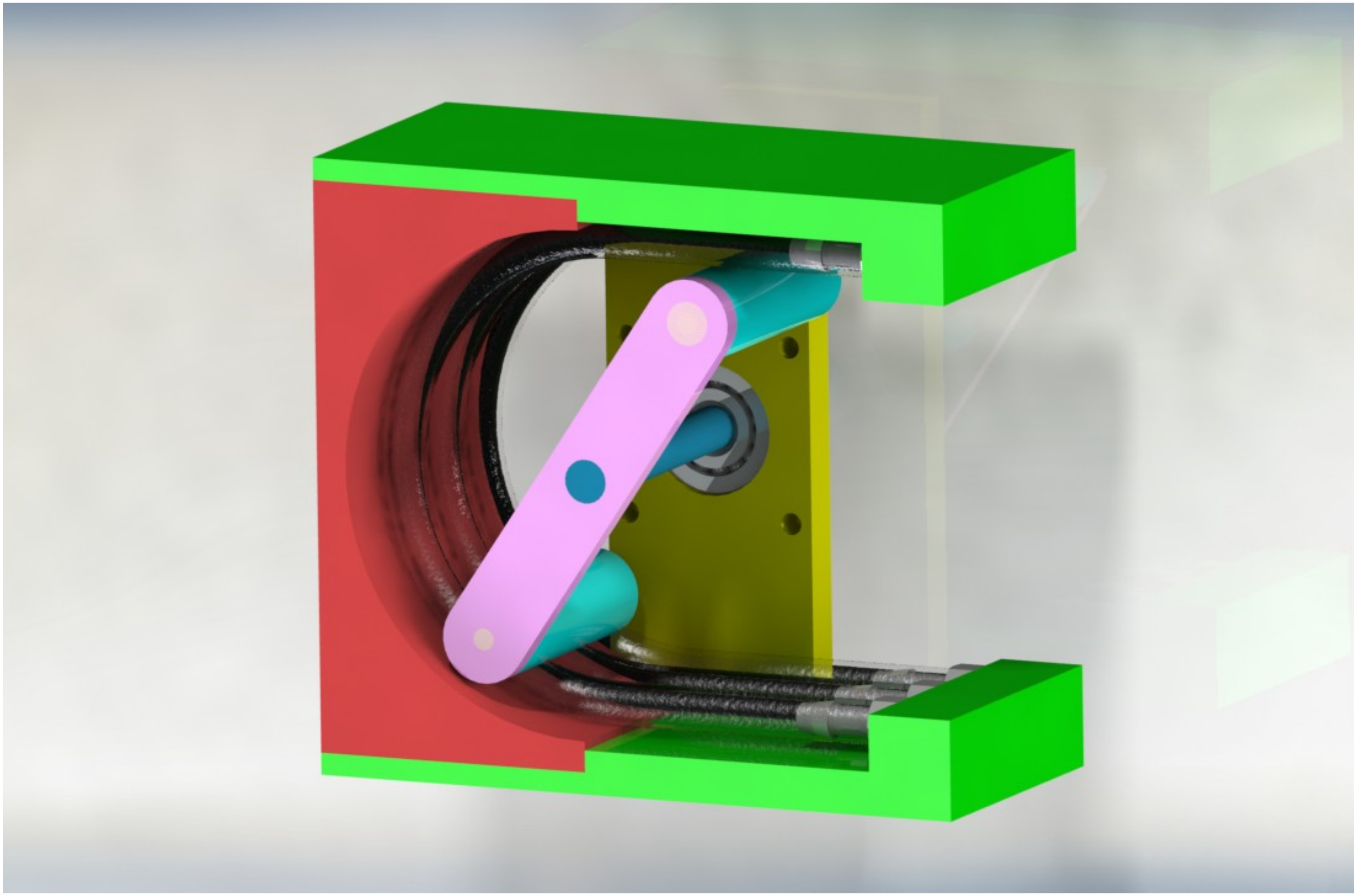
Initial CAD Renderings

Figs 2.7 – 2.11. *Initial Assembly CAD Renderings.* These are different assemblies of potential pumps that we considered making. Notice the evolution of the one piece top and bottom plates to the separated tube fitting holders and top and bottom plates.

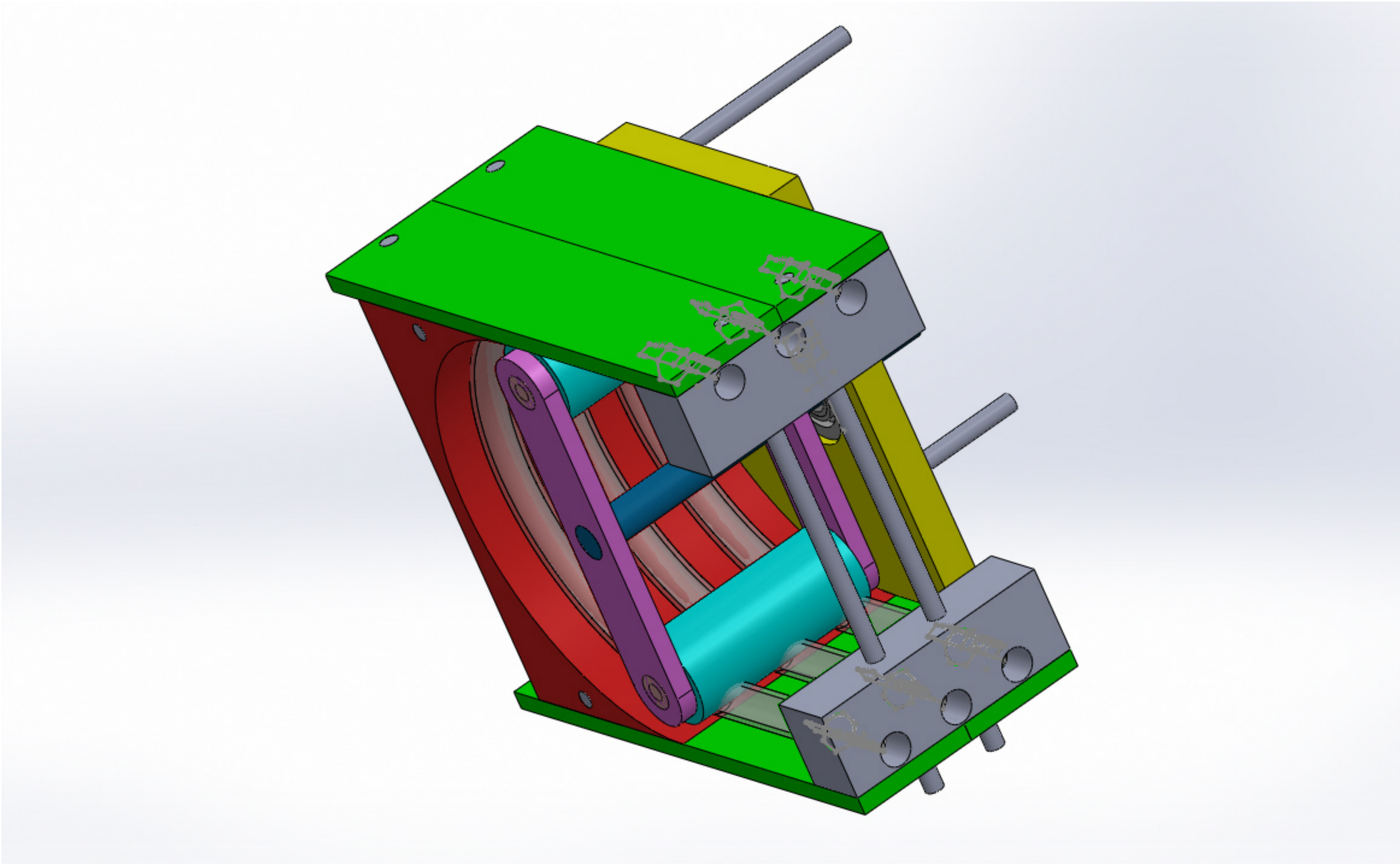




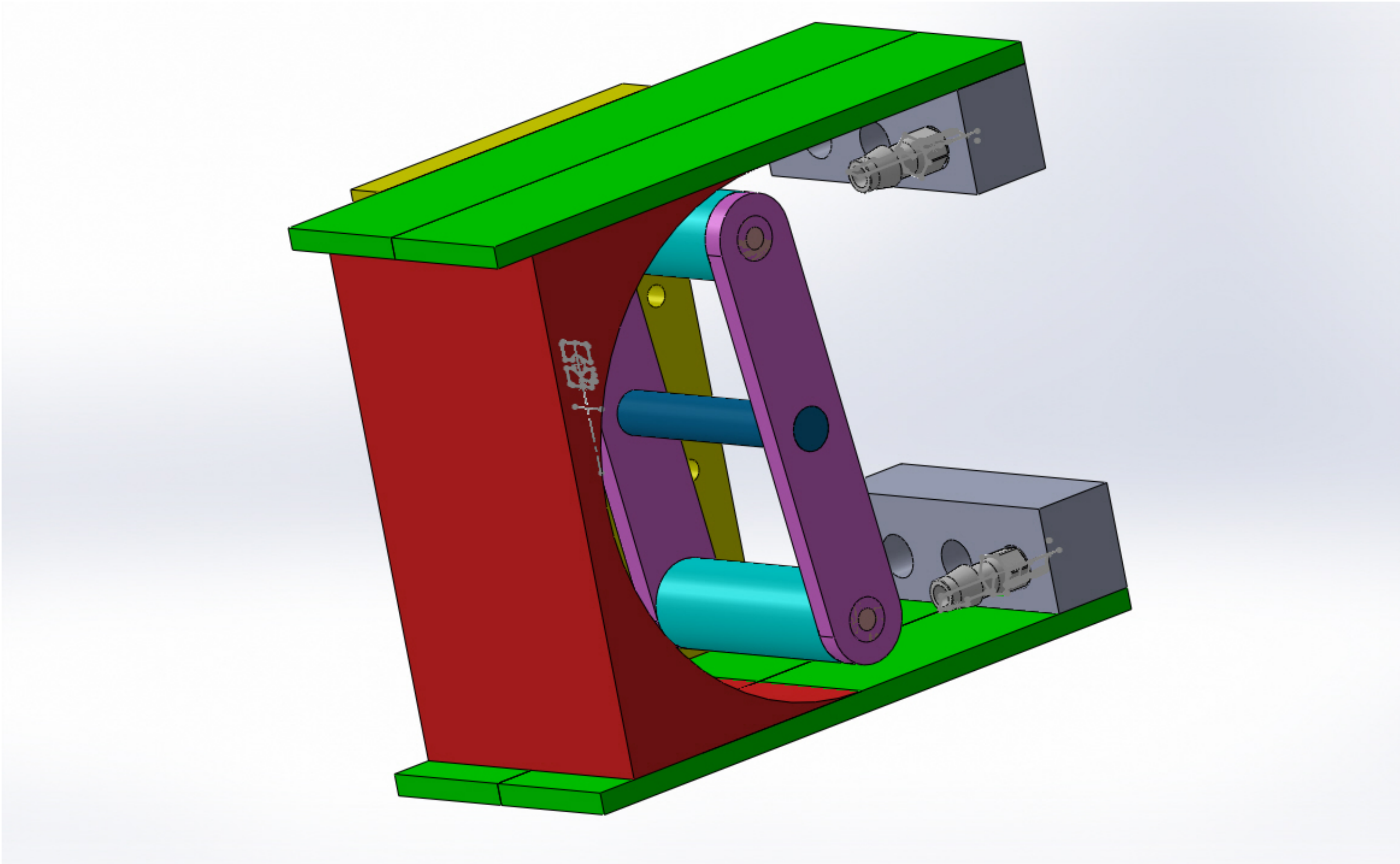
Fageria 5



Fageria 5

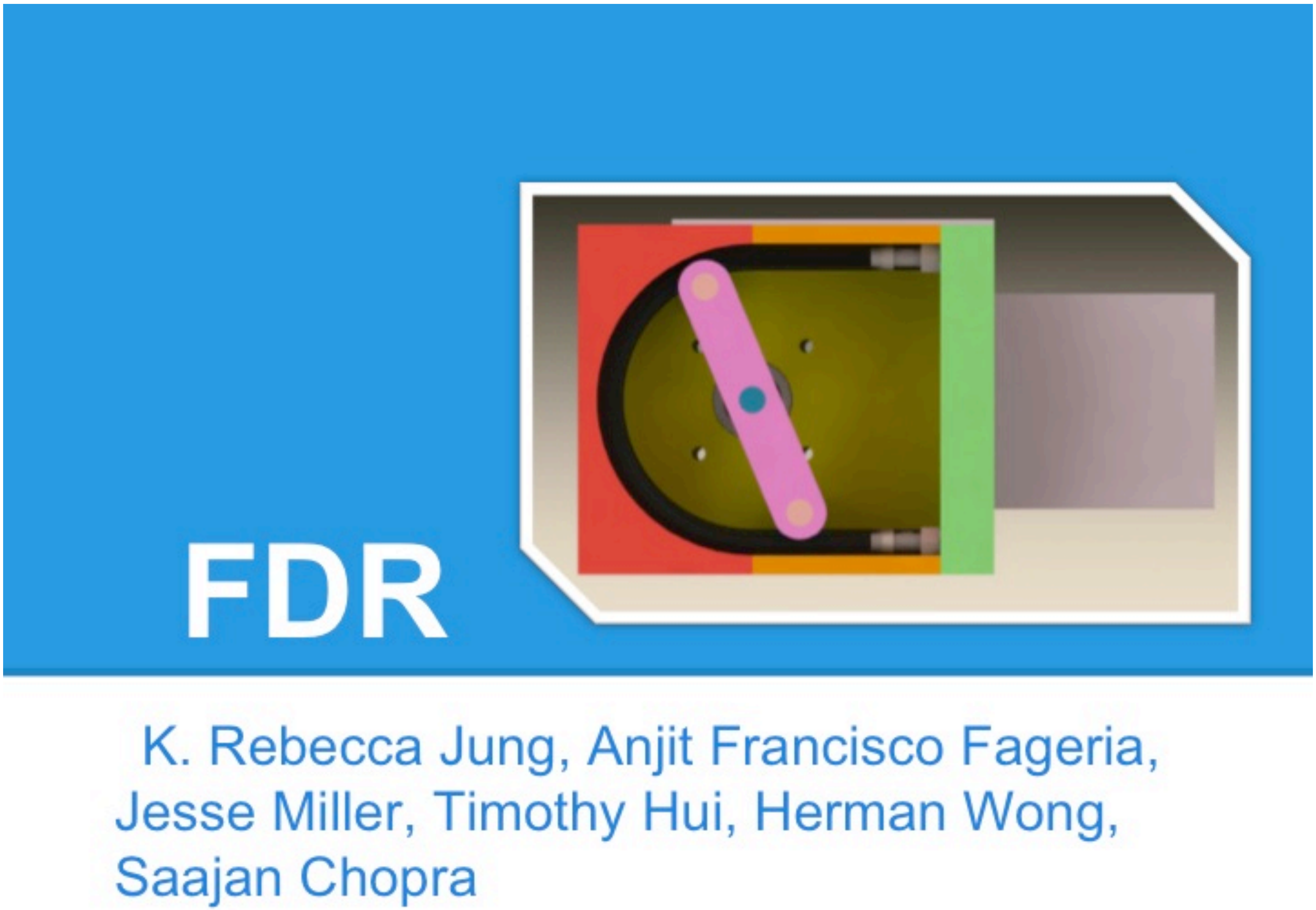


Fageria 5



Final Design Review

Figs 2.12 – 2.32. *FDR Presentation*. These are the slides of our Final Design Presentation. Now, despite the name, we are still making some revisions to the pump design, but this is at least an initial idea of what ours will look like. Any and all feedback can be found in the next Friday entry written after these slides.



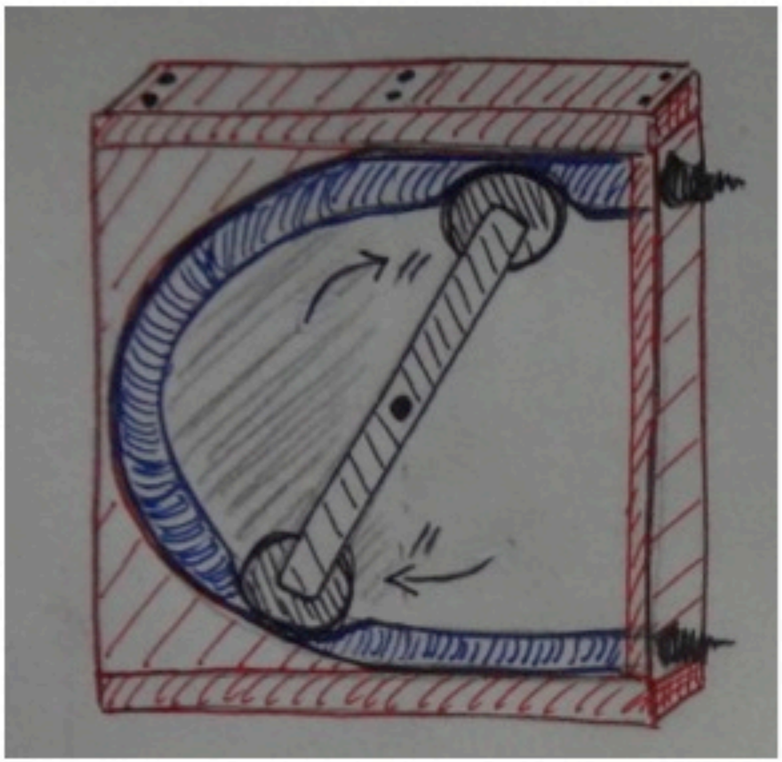
Our Peristaltic Pump

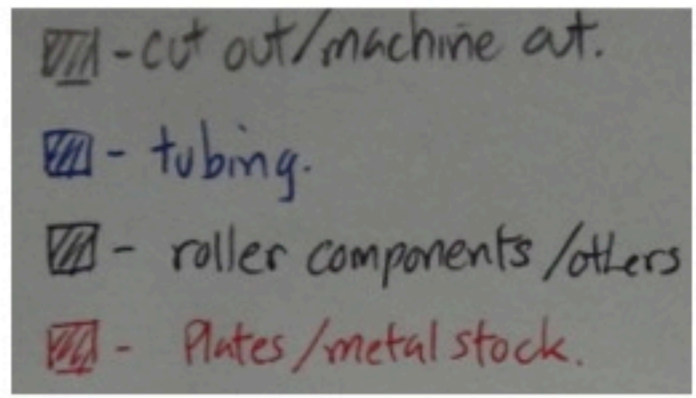
- Why Peristaltic?
  - Simplicity
  - Minimize machining
  - Fewer moving parts
  - Minimize friction
  - Uniqueness

New and Improved

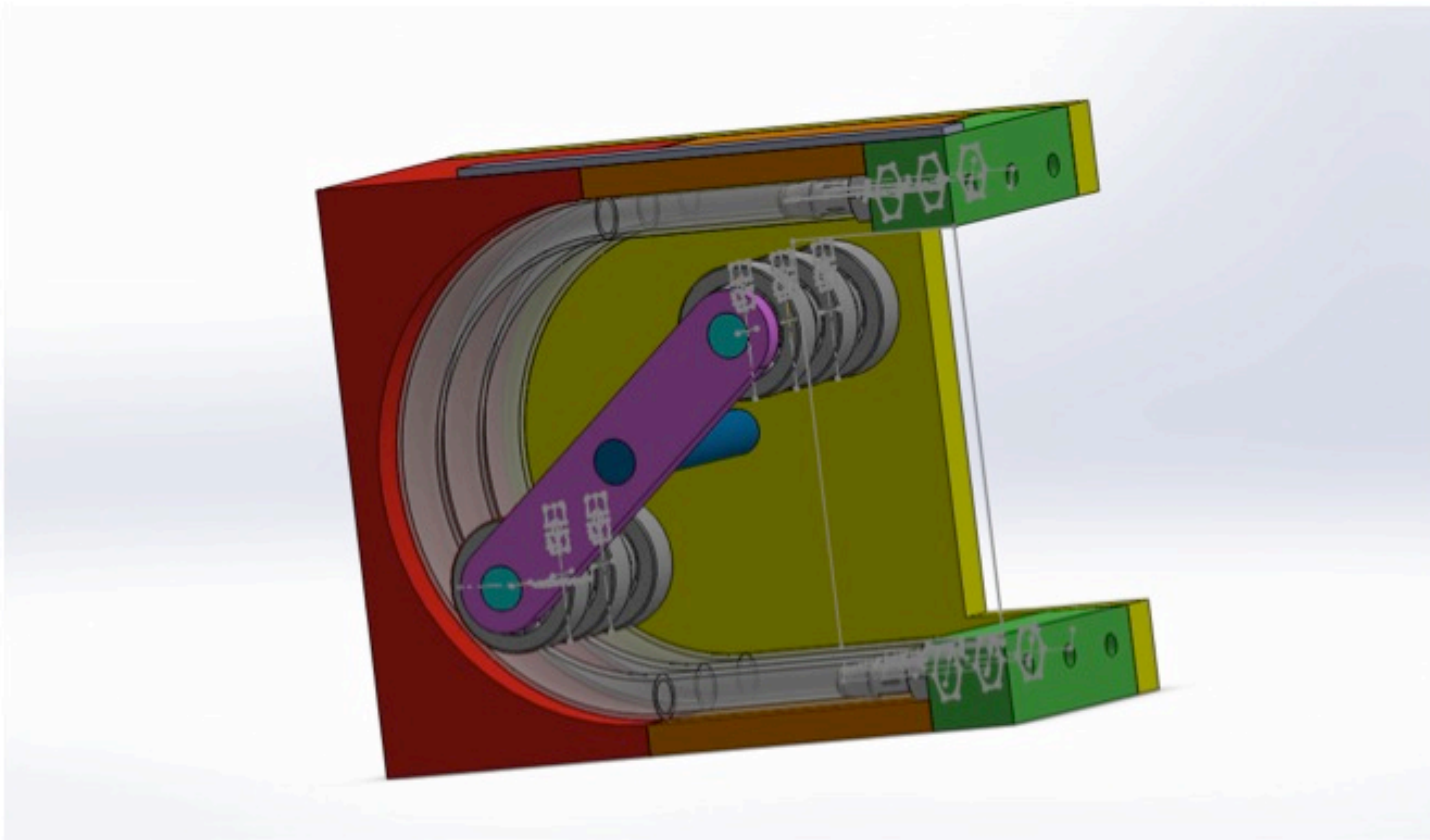
- What's new?
  - Numbers of Tubing: 1 → 3
    - Increase efficiency
  - Rollers: Ball-bearings vs. Machined Rollers
  - Updated Decision Matrix
  - Timeline → Machining Timeline added

From Sketch...

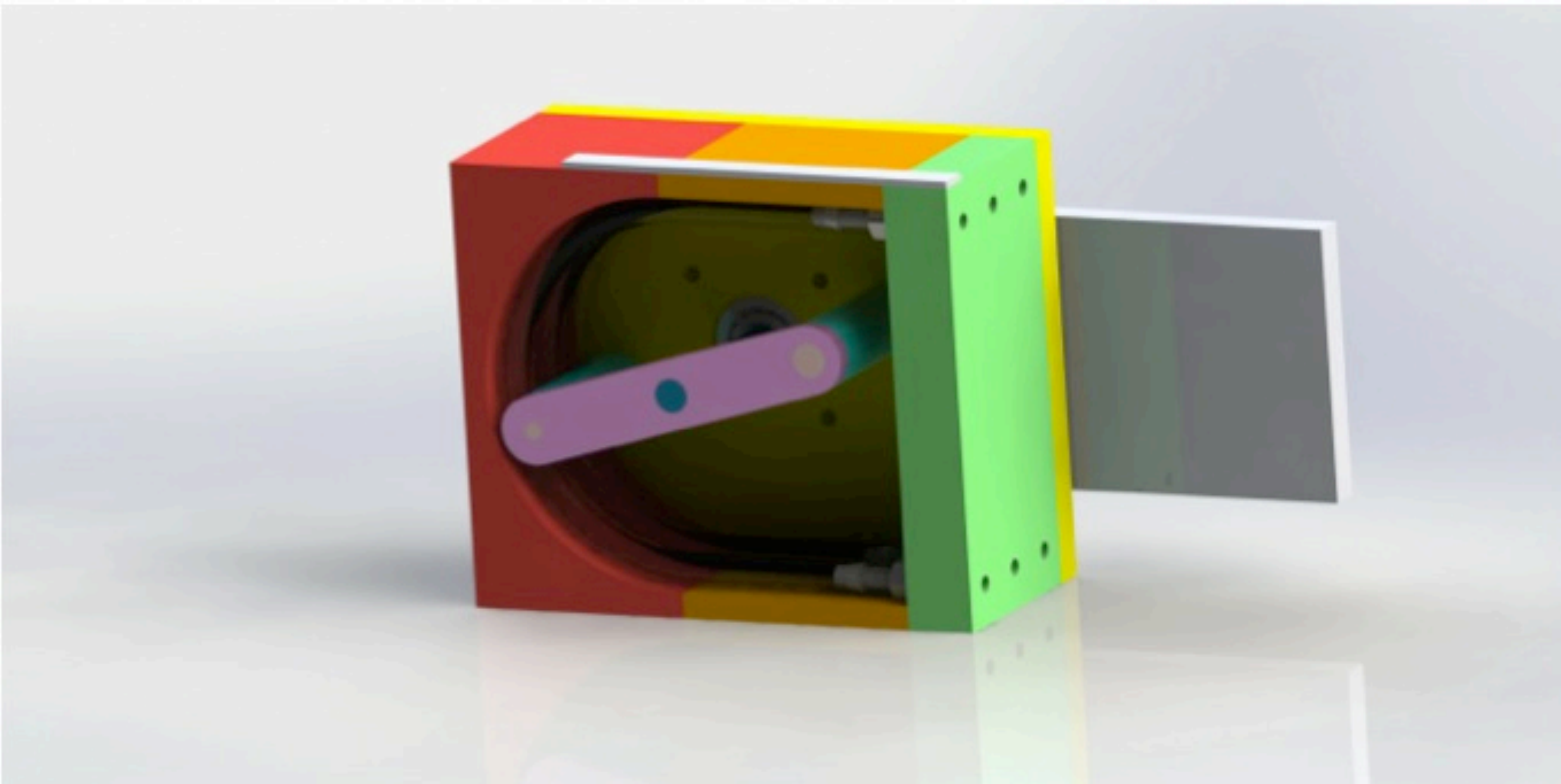



- cut out/machine out.
- tubing.
- roller components/others
- Plates/metal stock.

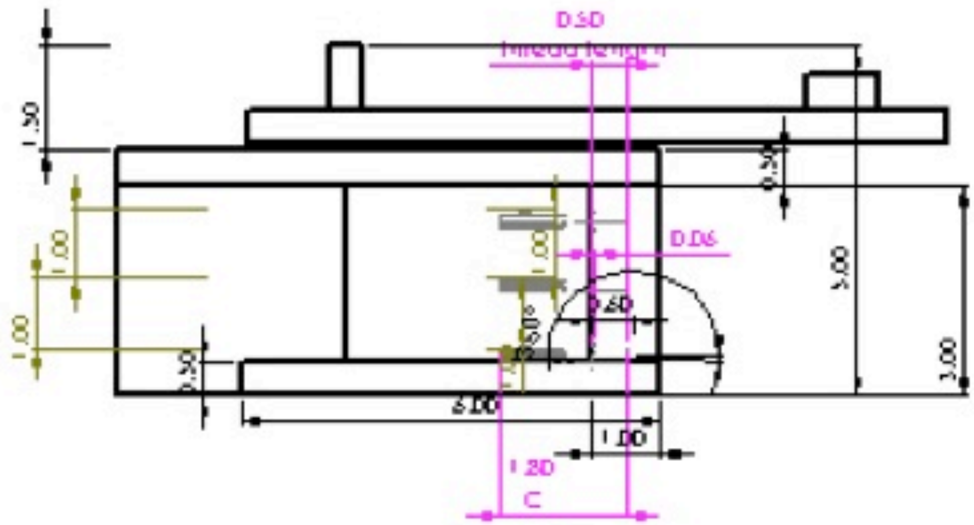
…To First Stage CAD Design…

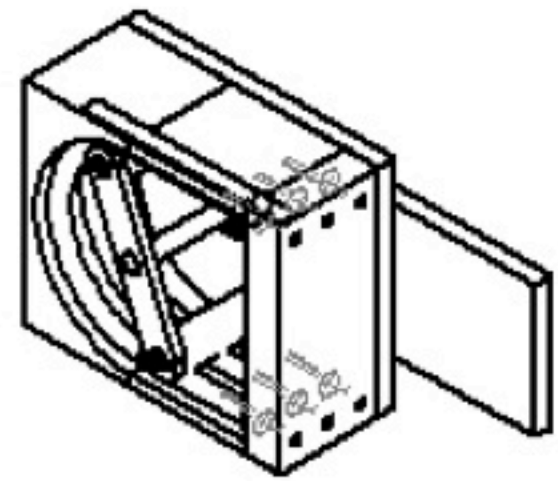


...To Final 3D model

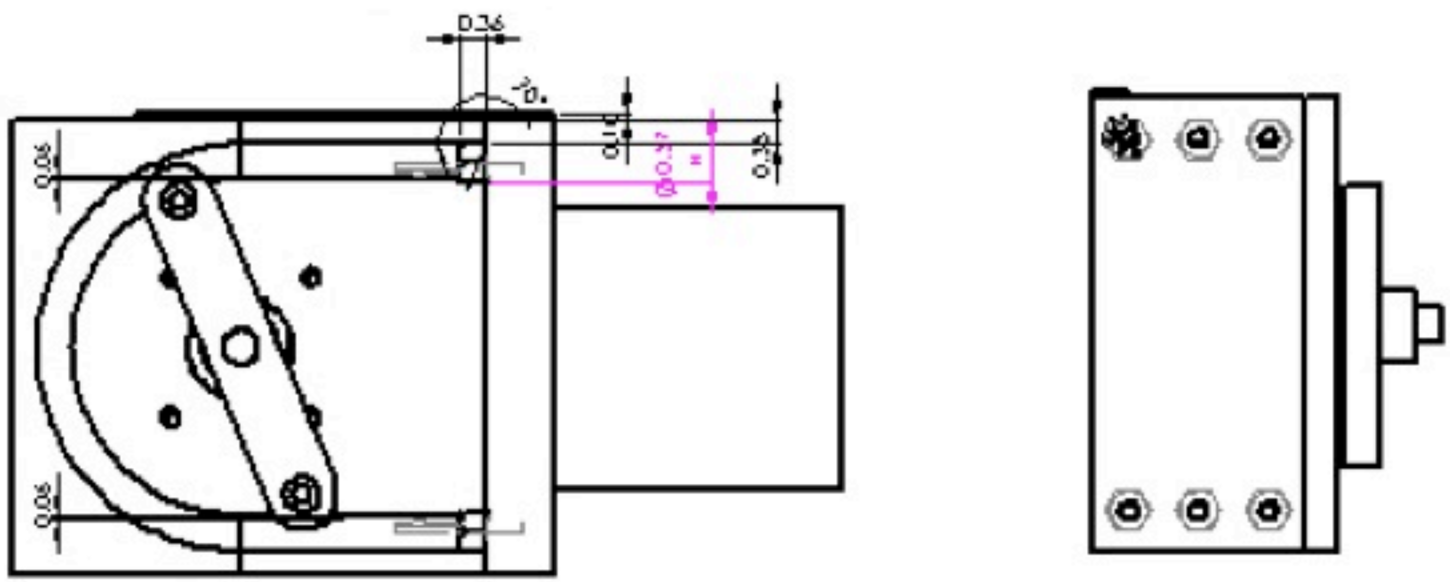


Drawing & Dimensions

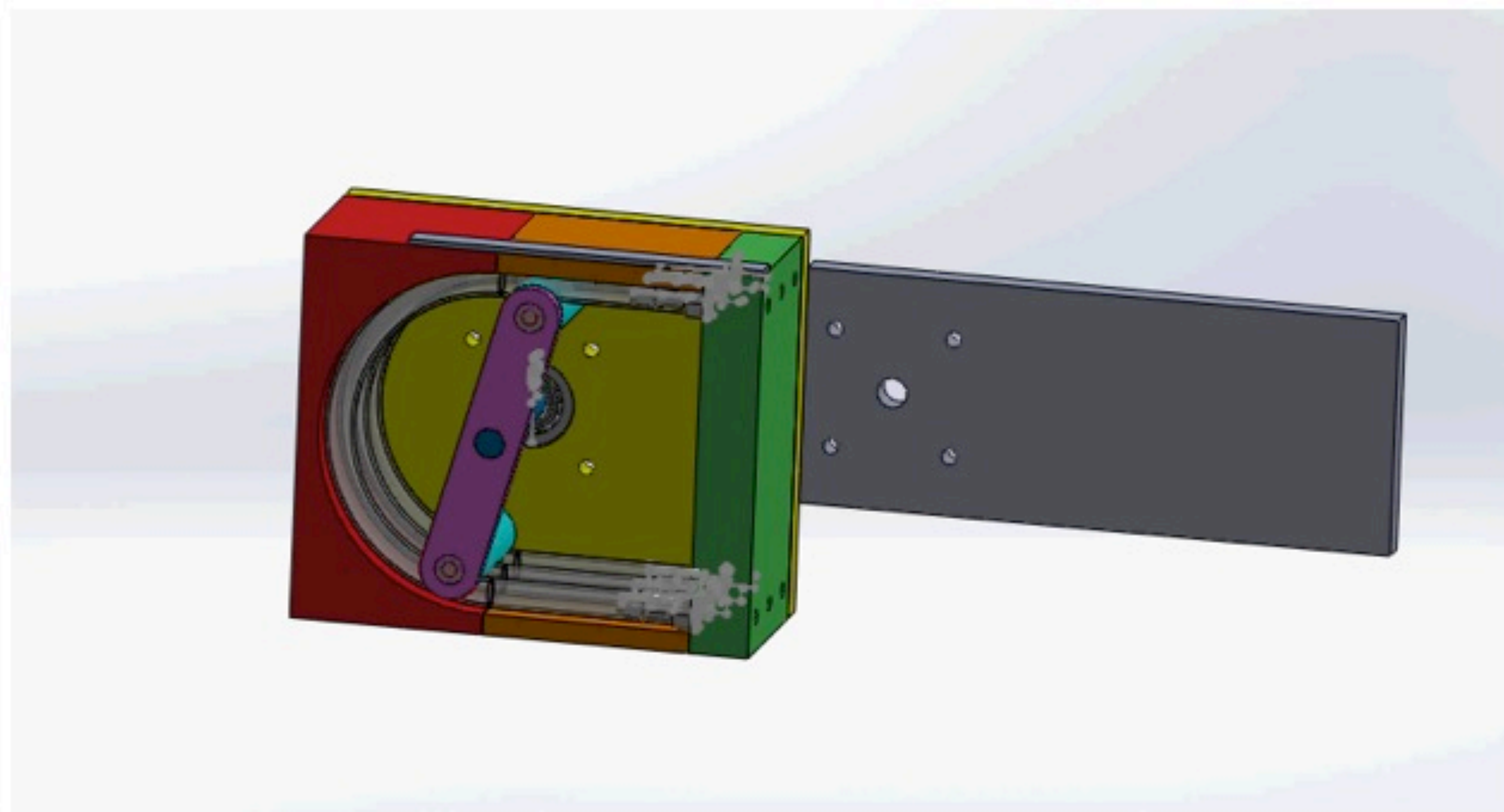




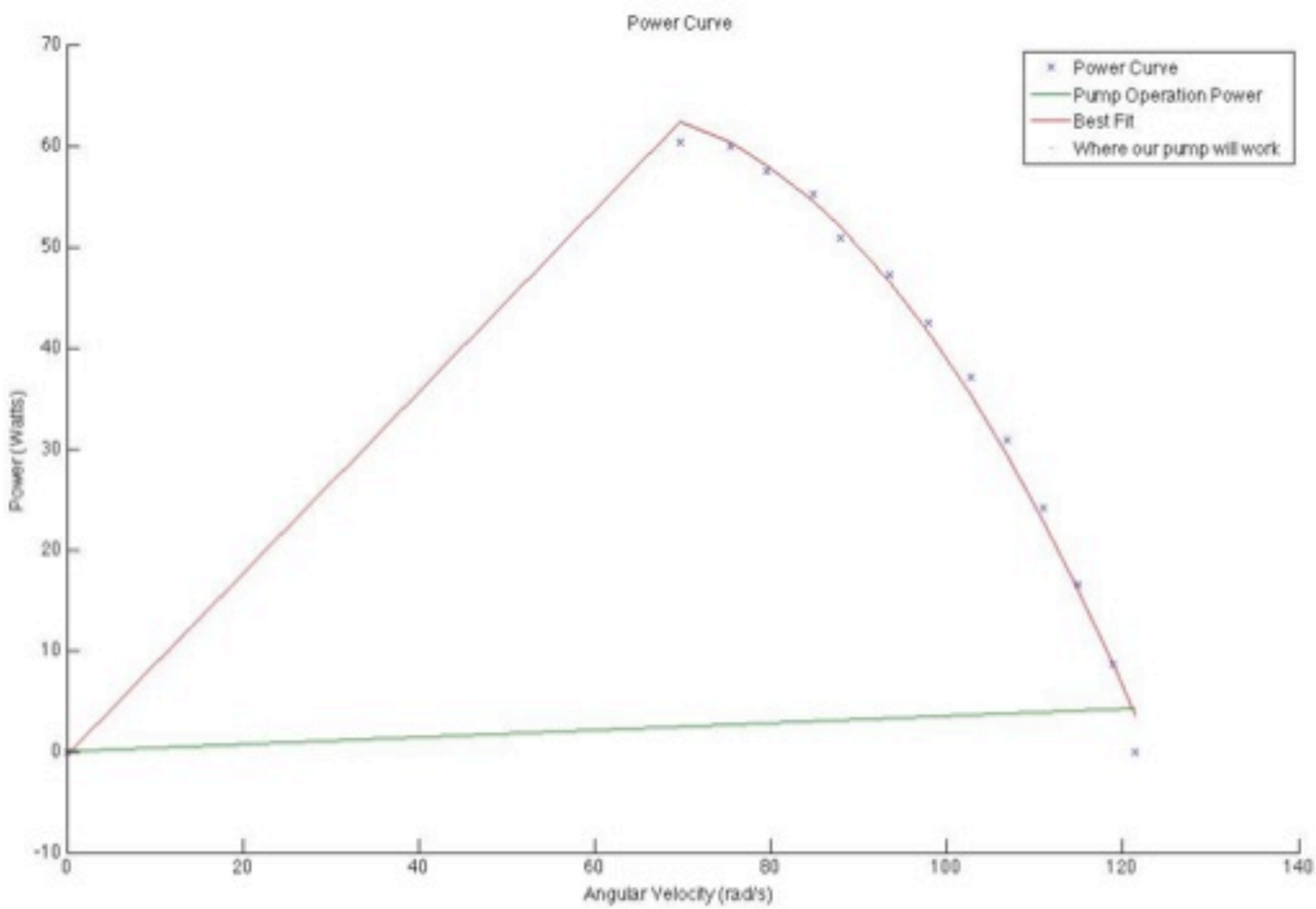
Drawing & Dimensions



Animation: How things work



Pump Performance



Pump Performance : Matlab

```
function WindpumpAnalysis(ntubes,d,R)
%Input is the number of tubes (ntubes), d is the inner diameter of our
%tubes, and the R is the radius of the rotary arm.
clc
close all

k = 1; %approximation for not having much change in diameter of the tubing.
R0 = 1.67; %inches. Diameter of smaller gear
R1 = 11.43; %inches. Diameter of bigger gear
gratio = R0/R1;
rho = 1000; %kg/m^3 water density
g = 9.8; %m/s^2
H = 1.5; %m height being pumped to
inchtom = 0.0254;

r = (d/2)*inchtom; %converting inches to meters
R = R*inchtom;

%This all reads the power curve text file and then outputs the graph, finds
%the power that our pump would use up, and then finds the intercept between
%the two graphs.
M = dlmread('power curve.txt');
wturbine = M(:,1); Pturbine = M(:,2);
deltaV = 2*pi^2*r^2*R*ntubes; %The volume displaced per 1 rotation of our pump
w = 0:.1:wturbine(1);
P = rho*g*H*deltaV*gratio/(2*pi)*w;

%Luckily we found a function that actually finds where two lines intersect,
%even if they are best fit lines that do not have plot points.
p = polyfit(wturbine,Pturbine,2);
f = polyval(p,wturbine);
[x0,y0] = intersections(w,P,wturbine,f,1);
```

Pump Performance : Matlab

```
%This plots the graph
hold on
plot(wturbine,Pturbine,'x',w,P,wturbine,f,'-',x0,y0,'.r')
title('Power Curve');
xlabel('Angular Velocity (rad/s)')
ylabel('Power (Watts)')
legend('Power Curve','Pump Operation Power','Best Fit','Where our pump will work')
hold off
m = length(x0);
rpm = x0(m)*60/(2*pi);

%This compares the two values of Pactual vs our Pmax.
[Pactual] = actualpower(rho,H,g,k);
Pmax = max(y0);

%And this prints out the final values that we will be working at.
if Pactual < Pmax
    fprintf('Yes, the pump will work, Pmax = %6.3f W, and Pactual = %6.3f
W\n',Pmax,Pactual)
else
    fprintf('Nope, the pump will not work, Pmax = %6.3f W, and Pactual = %6.3f
W\n',Pmax,Pactual)
end
Volume = deltaV*rpm*1000;
fprintf('Our pump will rotate at %.2f rev/min, and will pump approximately %.2f
L/min\n',rpm,Volume)

end
```

Pump Performance : Matlab

```
function [Pactual] = actualpower(rho,H,g,k)
%This is the code that calculates the Power needed to pump water according
%to the specifications. These are all the calculations posted by Kathryn
%McQuade
mu = 1.003*10^-3;
Eps = .0015*10^-3;

Qdot = 1*.001/60;
inchtom = 0.0254;
d = 3/8; d = d*inchtom;
A = pi*(d/2)^2;
v = Qdot/A;
Re = rho*v*d/mu;
if Re < 2000
    display('Laminar Flow')
else
    display('Turbulent Flow')
end

%Finds the relative roughness so we can find the f.
relrough = Eps/d;
f = 64/Re;

hf = v^2*f*H/(2*g*d);
hm = v^2*k/(2*g);
hp = H + hf + hm;
Pideal = rho*g*Qdot*hp;
eff = .2;
Pactual = Pideal/eff;
end
```

Pump (Predicted) Performance

- To meet customer specs, we need to pump water up height of 1.5 m at rate of 1L/min
- Ideal case:
  - RPM = 1150 revs/ min
  - Power = 4.239 Watts
    - Actual power needed to meet requirements: 1.238 Watts (frictional force ,etc. included)
  - Flow Rate = 118 L/min
- Weight = 86 in^3 * 167 lb/ft^3 *(1ft/12in)^3 **= 8.311 lbs.**

Initial Cost

Quantity	3/4 inches items	Cost Per Unit	Total cost
2	ft 3/4 diameter water tubing	8.63	17.26
2	Brass pipe fittings (3/8" barbed x 1/4"NPT)	1.19	2.38
2	Brass pipe fittings (3/4" barbed x 1/2"NPT)	3.69	7.38
1	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	5.88	5.88
?	washers	?	
?	nuts	?	
?	threaded rods	?	
		Total	32.9

Final Cost Analysis

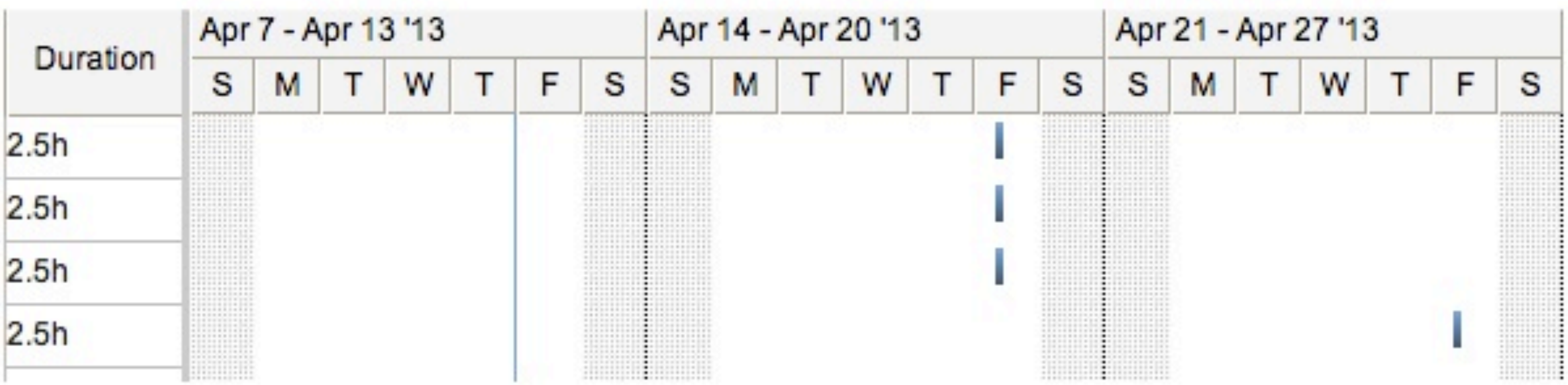
Quantity	3/8 inches items	Cost Per Unit	Total Cost	Product Number
5	Soft Abrasion-Resistant Polyurethane Tubing Blue, 3/8" ID, 1/2" OD, 1/16" Wall Thickness	2.22	11.1	5792K39
1	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	4.46	4.46	5121K411
2	Brass pipe fittings (3/8" barbed x 1/4"NPT)	1.19	2.38	From Jas
1	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	5.88	5.88	6383K45
10	1/4" flat washers	0.04	0.4	From Jas
10	1/4 - 20 hex nuts	0.07	0.7	From Jas
2	1/4 - 20 threaded rod (per foot)	1.41	2.82	From Jas
1	1/2" Steel Rod (per foot)	1.65	1.65	From Jas
		Total	29.39	

Parts to Trade in:

Parts to Trade In	Price
1.875 PVC Solid Rod	$6.80
Round cylinder Tubing	$3.91
1/2"x4"Rectangular Bar (Base)	5.03
1/2"" x 2 1/4" Rectangular Bar 12"	11.79
Total Trade in bucks	$27.53

Machining Timeline

		Name
1		Machine 5 Plates (drill holes too if possible if time permits)
2		Machine Shaft (Flatten one side so we can set-screw the sprocket)
3		Machine Rod (The ones that have the ball bearings attached)
4		Complete Machining plates (Drill holes if they haven't been already

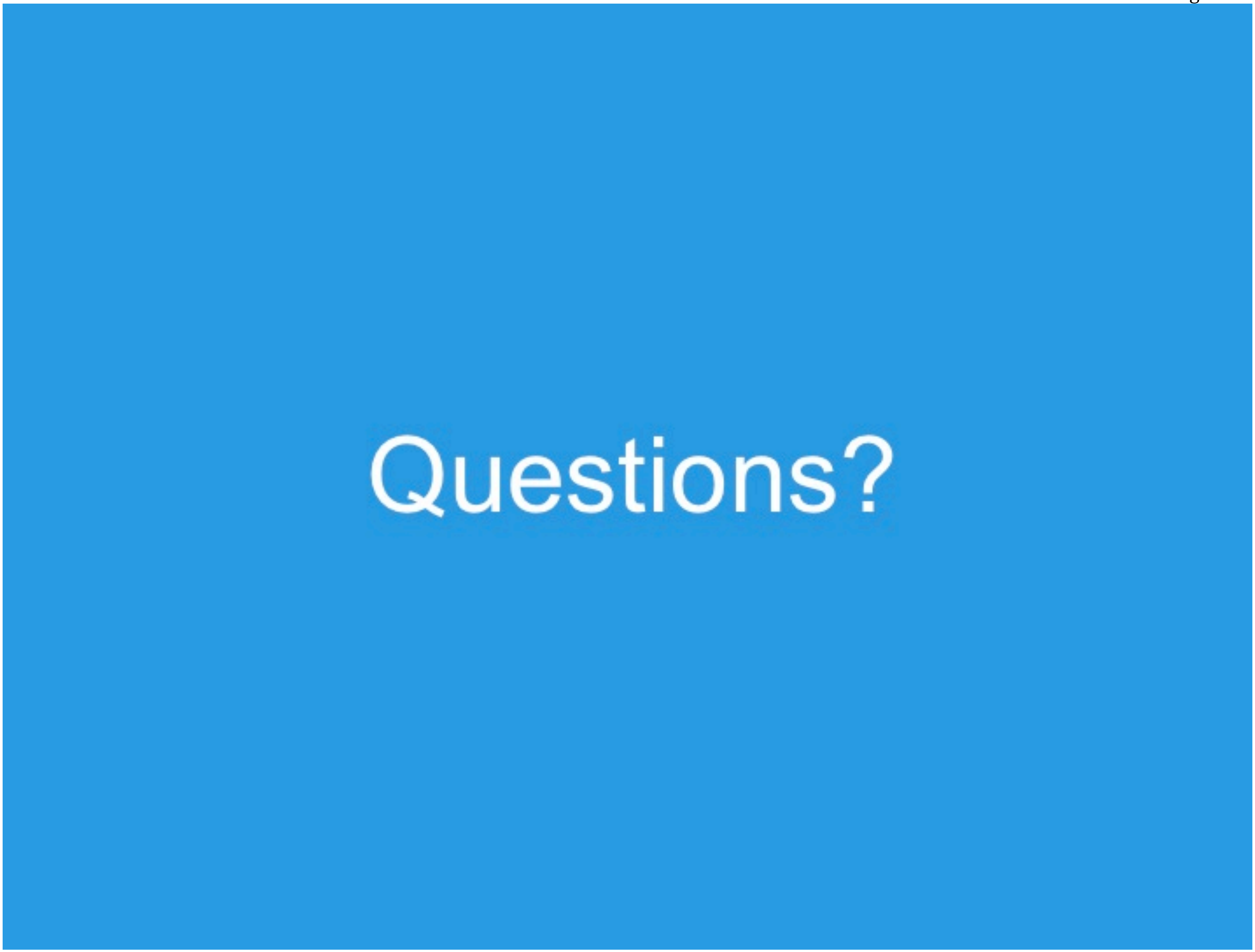


Fabrication Plan

- Interchange Stock components
- Shafts/ Rods
  - To cut down to the dimensions we want, use the Lathe to make small passes to he surface of the cylindrical rod stock we will be given
- Any holes/ rods that needs to be tapped/ threaded, we will just use the threading tool

Fabrication Plan

- Casing Components
  - Use the Mill to trim down plate sides by making small passes across the surface.
  - Once surface is smooth and in the length we want, flip to other side and do the same thing
  - For holes, use the mill to drill down (with increasing increment of drill bit sizes)
- Back Plate
  - 3 Methods: use Boring tool with the Lathe, use the rotary table, buy/ interchange pre-CNCed part from shop


Questions?

Friday: 4/12/13

We all met for 2 hours 30 minutes today.

So today was interesting… We presented our FDR today (The slides can be seen in the figures below), and Rebecca and Saaj did a pretty good job, although it kind of seemed like they did not have an entirely clear idea of what exactly we are doing. and after hearing feedback from the other groups and actually receiving our parts, we realized that our "Final Design" would have to change in order to be more realistic given the stock we are given. We managed to update our design a little bit, but we still do not have a complete final idea, since we did not take the threaded rods, nuts, or washers into account that we were using. After talking to Joe, he told us that we could probably CNC everything that we need to, as long as we bring in a CAD drawing for the part we need him to make. With that in mind, Rebecca, Herman, and I agreed to meet tomorrow to finalize a design so that we could start machining by Monday or so.

Adjustments:

- One of our calculations before said that our pump would spin at 1150 rpm and would pump up 118 Liters per minute, and we thought that those calculations seemed a bit off, but went with it. Now we realize that we did not take the gear ratio into account, so our pump will actually spin at 169.05 rpm, and will pump about 3.46 Liters/min taking into account a loss from friction and other imperfections in our actual pump.

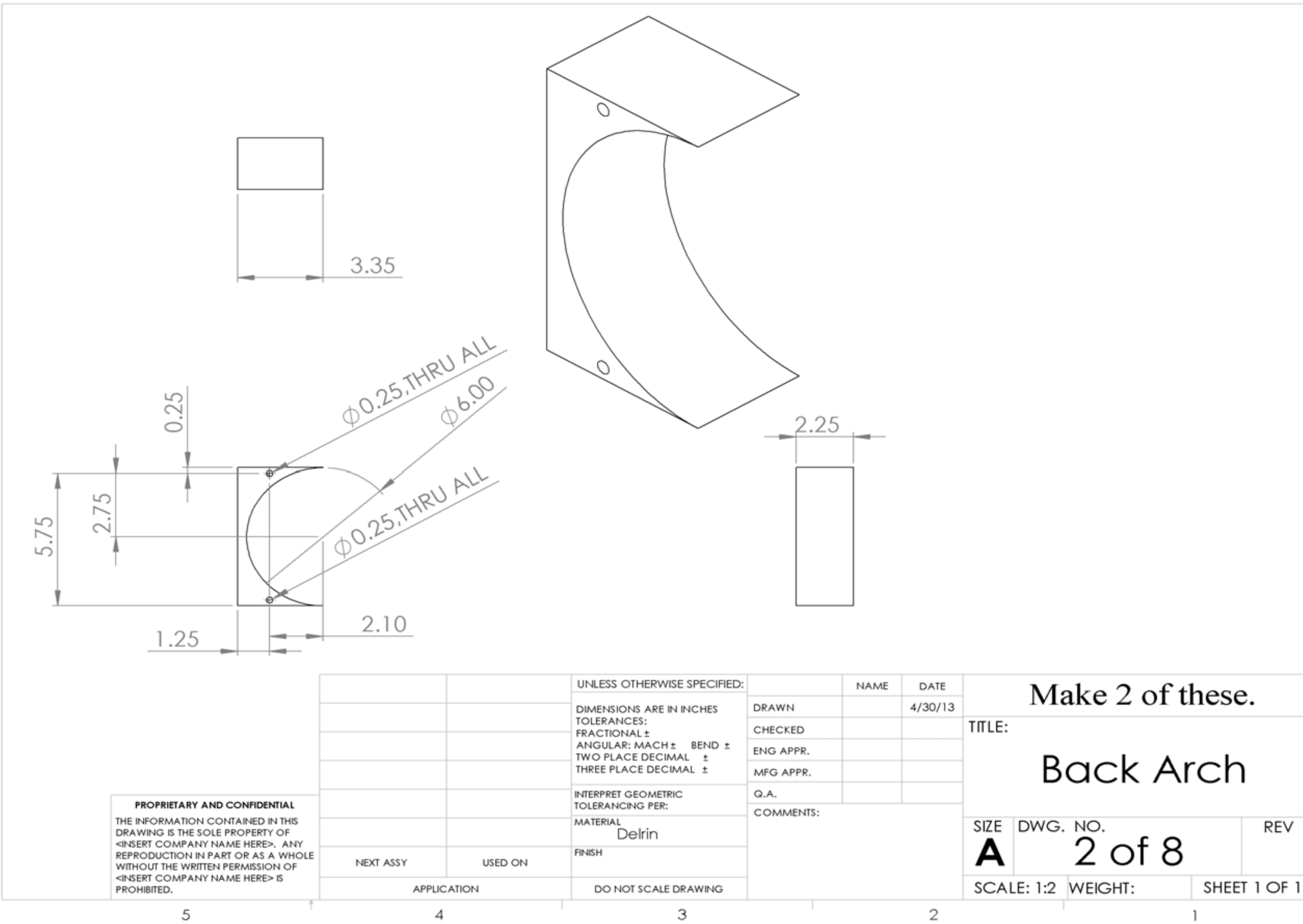
Saturday: 4/13/13

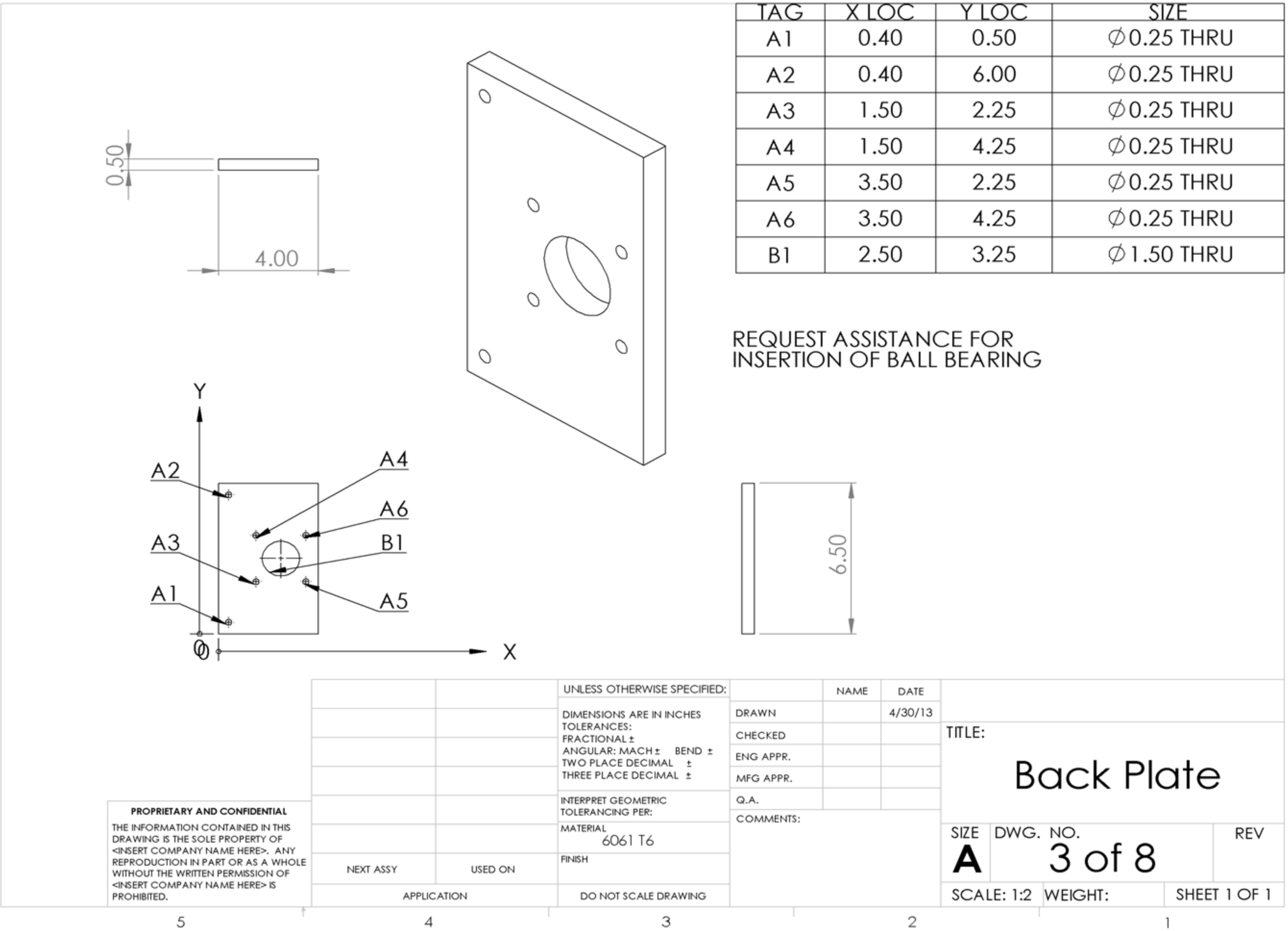
Rebecca, Herman, and I met for 2 hours.

Rebecca, Herman, and I met in my room to redesign our pump using the suggestions that were given during the FDR. The main things were making the pieces more realistic based on what pieces we were given. We managed to make a model that used fewer pieces and also included the connecting pieces (threaded rods, nuts, washers) that each piece would need to stay connected to the main body. We made a sketch, and since Herman was the one who had CADded the design in the first place, he took on the task of remaking the model so we could show Joe and Mike on Monday. Below in the figures you can see the new part drawings and assembly renderings showing what we will be machining.

Updated Part Drawings – Final Version

Fig 3.1. *Back Arch.* This part will contain the tubes. While the roller rolls on the tubes, this back arch will push back and, between the pushing from the rollers and the back arch, a seal will be created within the tubes which will keep water from sliding back and thus create a vacuum as the rollers move up, making more water be sucked into the tube. It will connect to the back plate. We will be making it out of Delrin.





TAG	X LOC	Y LOC	SIZE
A1	0.40	0.50	∅0.25 THRU
A2	0.40	6.00	∅0.25 THRU
A3	1.50	2.25	∅0.25 THRU
A4	1.50	4.25	∅0.25 THRU
A5	3.50	2.25	∅0.25 THRU
A6	3.50	4.25	∅0.25 THRU
B1	2.50	3.25	∅1.50 THRU

Fig 3.2. *Back Plate.* This part will connect to the faceplate that will be provided to us through holes A3 through A6. Then with A1 and A2, this plate will connect to the Back Arch, which will hopefully be enough to keep everything stable and connected to the face plate. A ball bearing will fit in hole B1 and this will house the main shaft which will turn the rollers and be connected directly to the given gears.

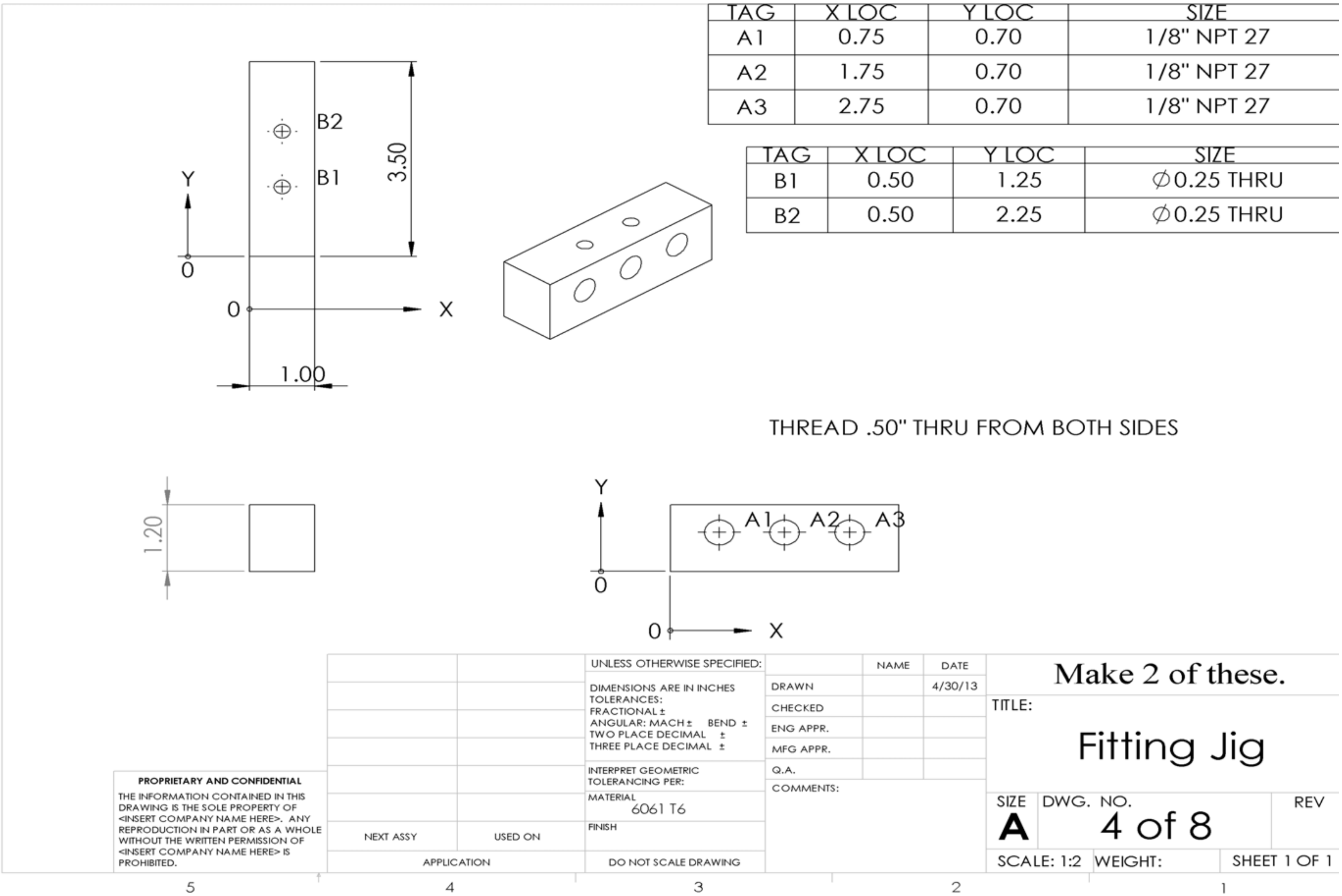


Fig 3.3. *Fitting Jig.* This part will contain the tube fittings which will connect to the pump's tubes and the outgoing and incoming tubes carrying the water as well. The tube fittings connect to holes A1 through A3, and B1 and B2 will be used to connect to the top and bottom Support Plates by using nuts and threaded rods. Two of these jigs have to be made, and one of them will contain a different sized hole in order to accommodate some spare tube fittings that we had to use in order to reduce costs.

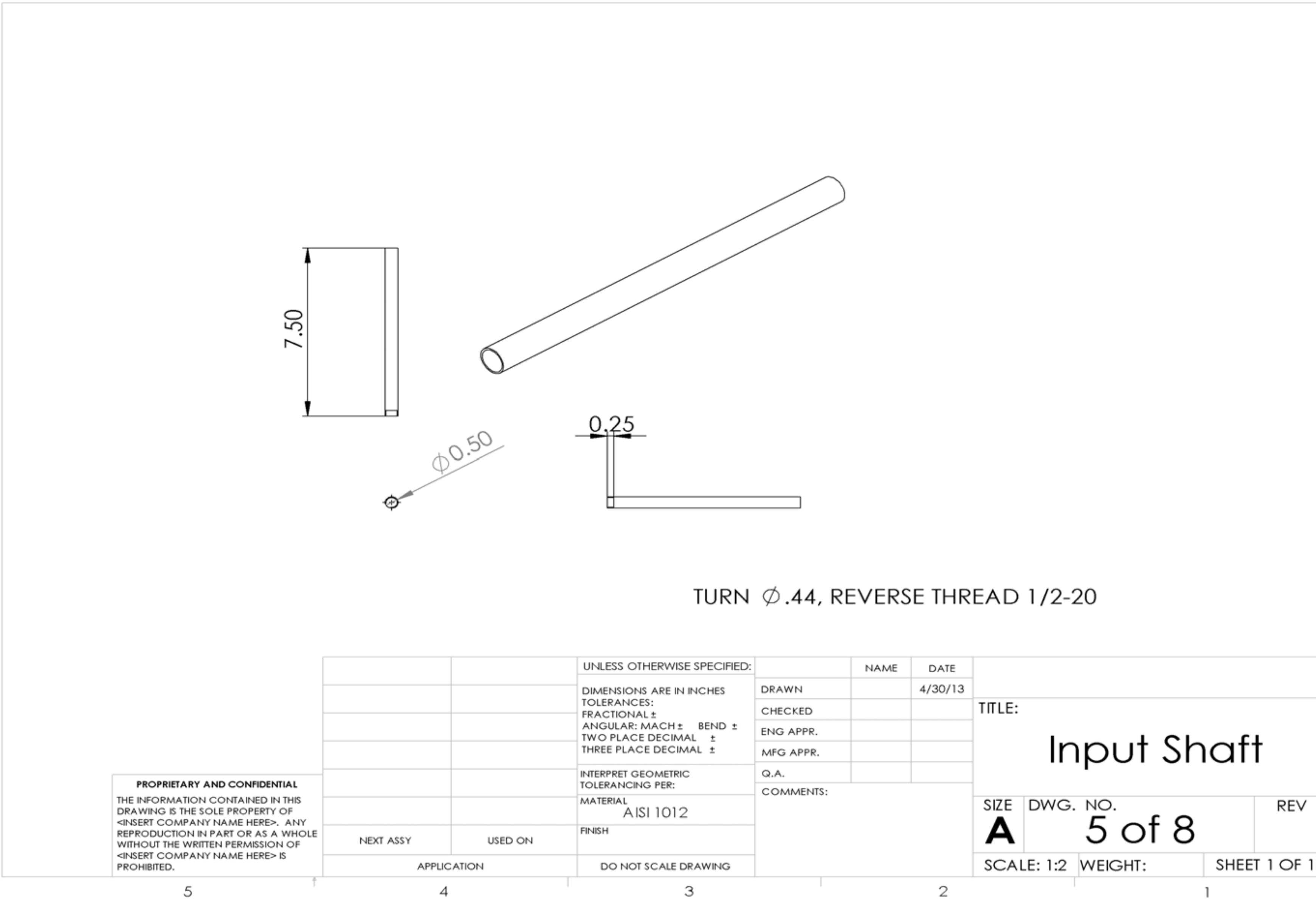


Fig 3.4. *Input Shaft.* This part will connect to the roller locks and the provided gear and will fit in the ball bearing in the back plate. It will turn when the gear turns due to the wind turbine, and will thus rotate the roller locks so that the rollers roll and squeeze the tubes.

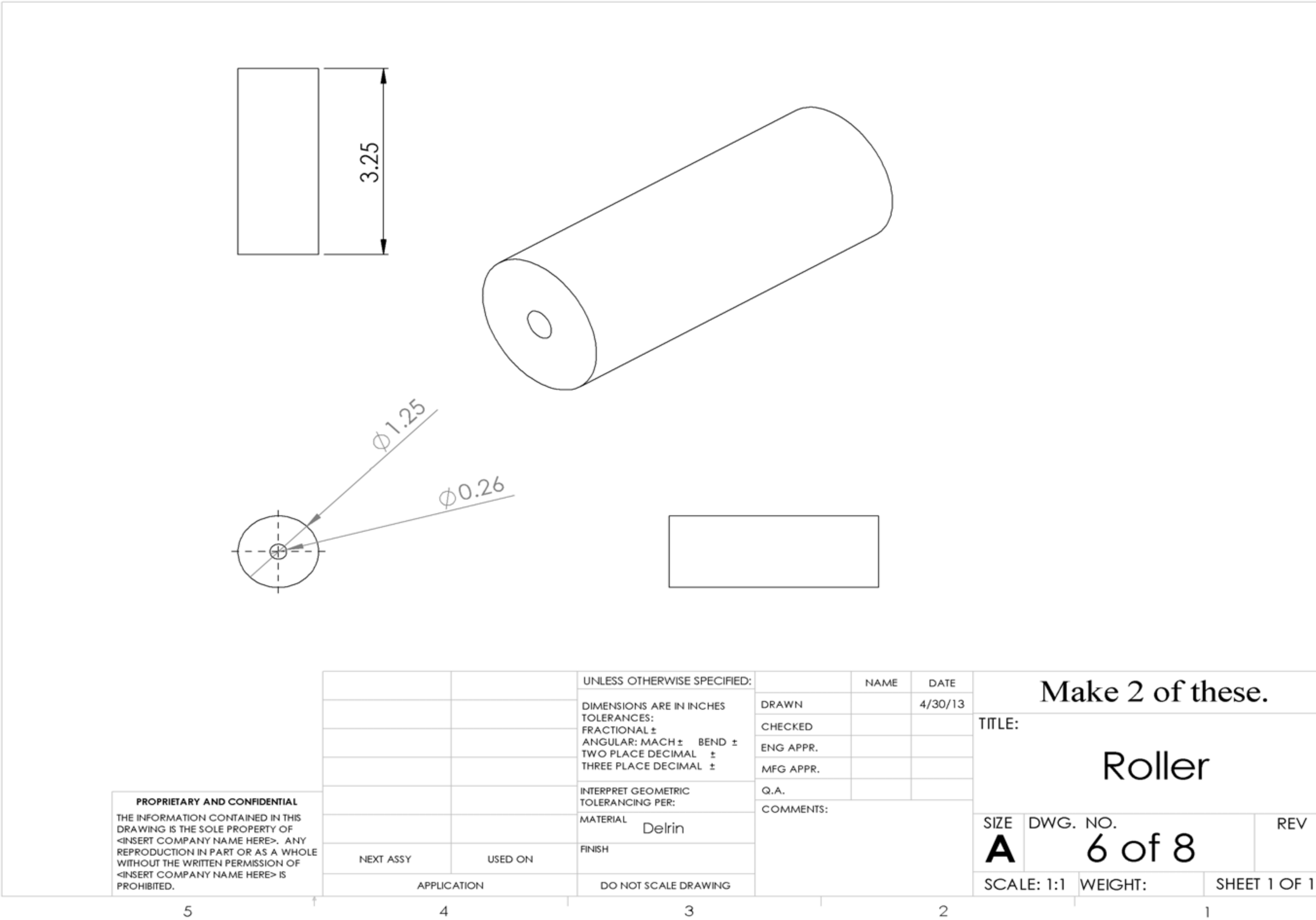


Fig 3.5. *Roller.* This part will connect to the roller locks through the roller shaft and will roll on the tubes freely, squeezing them and causing water to move up the tubes.

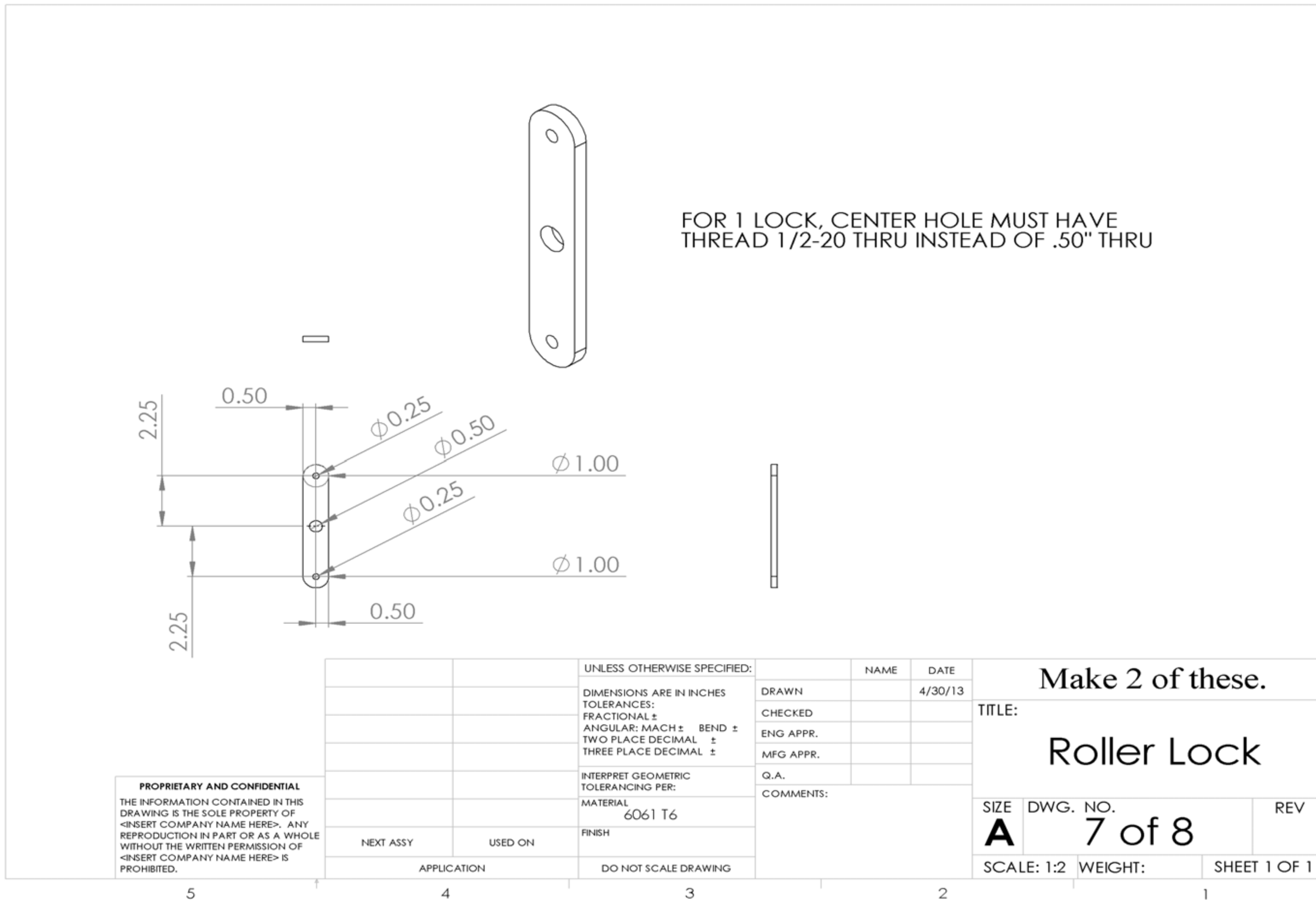


Fig 3.6. *Roller Lock.* Two of this part will be made, one which will be threaded in the middle hole in the clockwise direction in order to attach to the input shaft and get tighter while rotating instead of getting loser. It will connect to the roller shafts and keep them in place by using nuts.

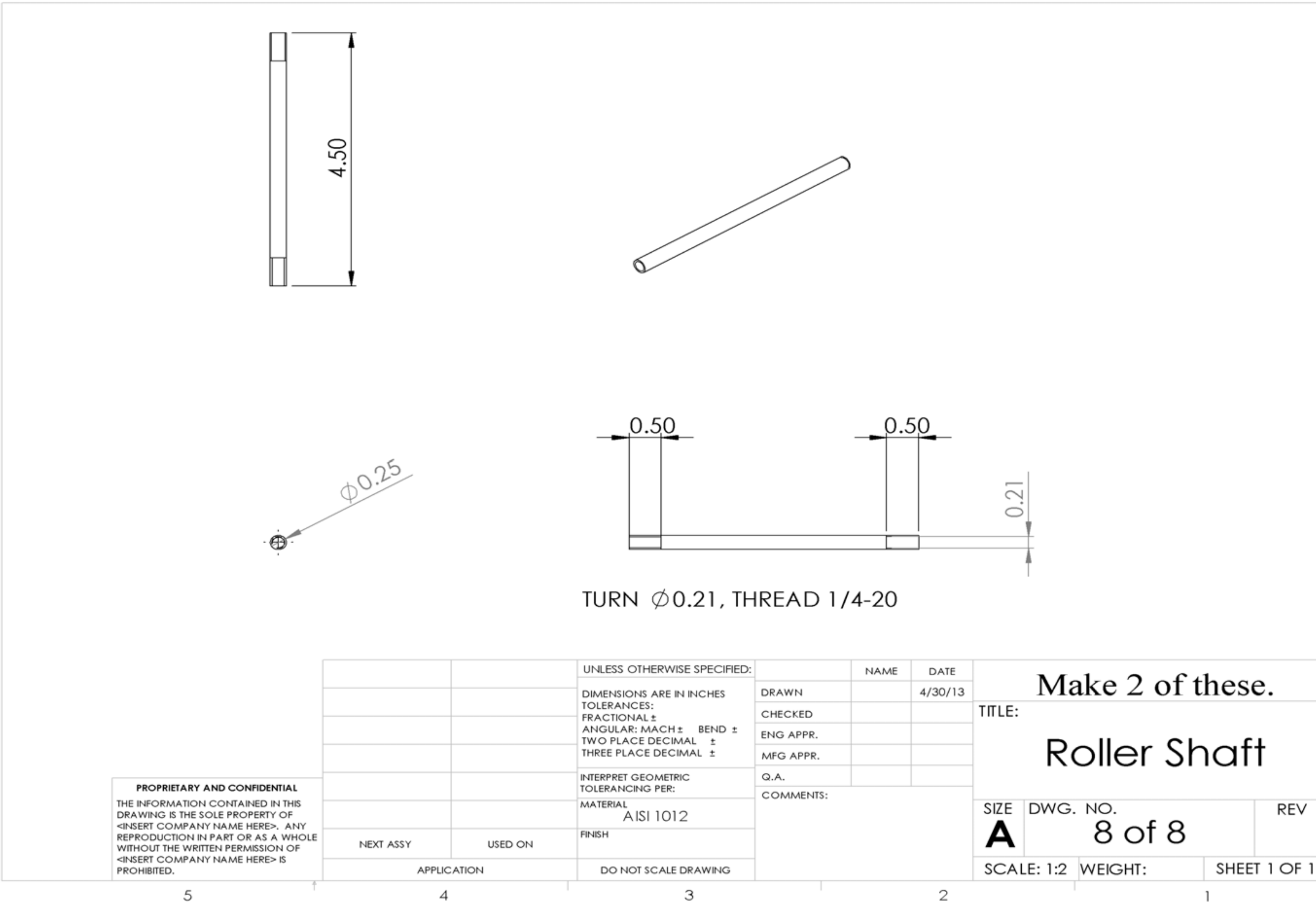


Fig 3.7. *Roller Shaft.* Two of this part will be made and will connect loosely to the rollers by use of nuts and washers to maintain a distance between the roller locks. The tips of these parts have to be threaded in order to use the nuts.

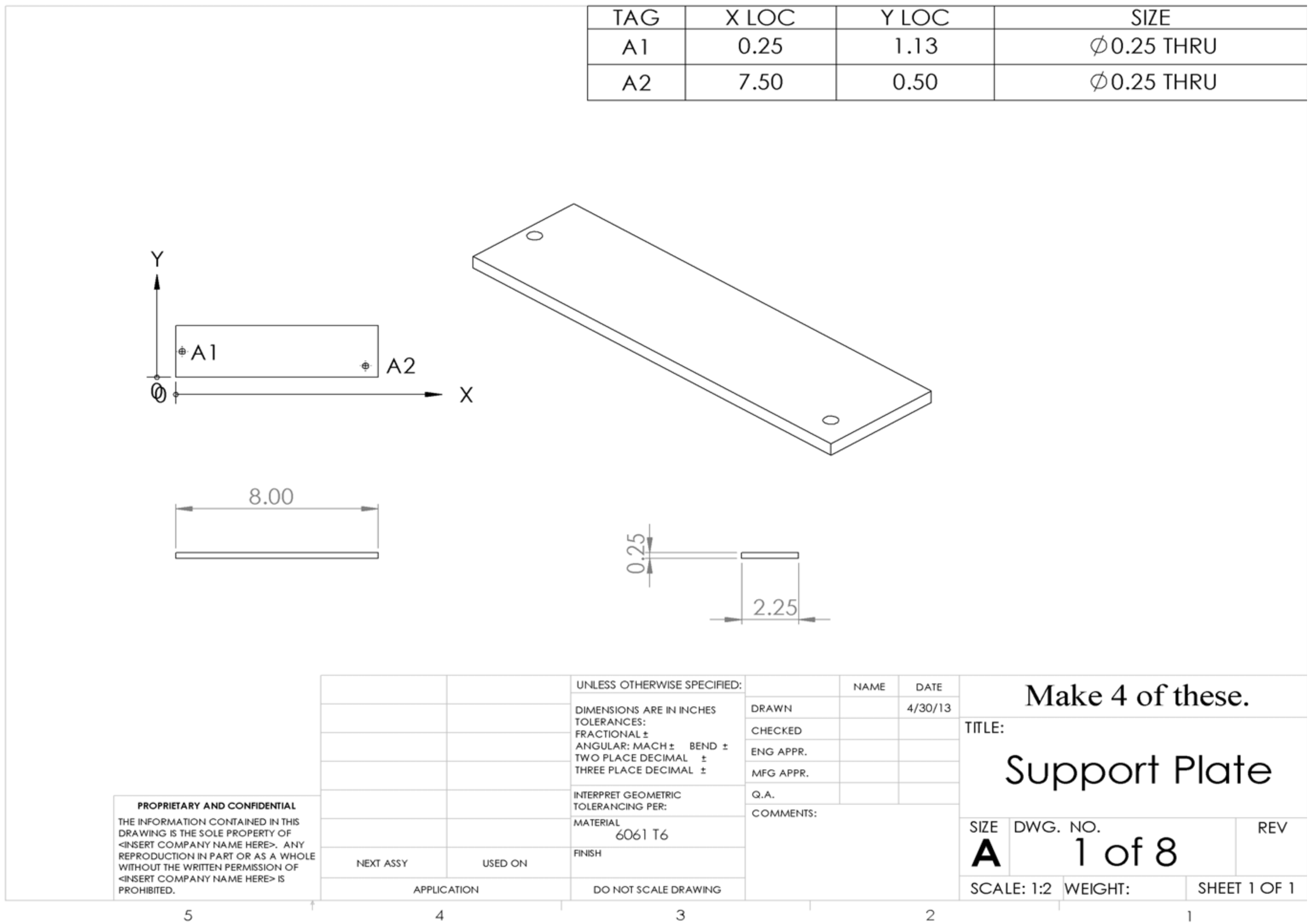


Fig 3.8. *Support Plate.* Four of this piece must be made. These plates will connect to the Fitting Jigs through the off-center edge holes and some threaded rods with nuts and will connect to each other by use of the centered edge holes. These four piece will sandwich the back arch and hopefully keep the whole assembly together.

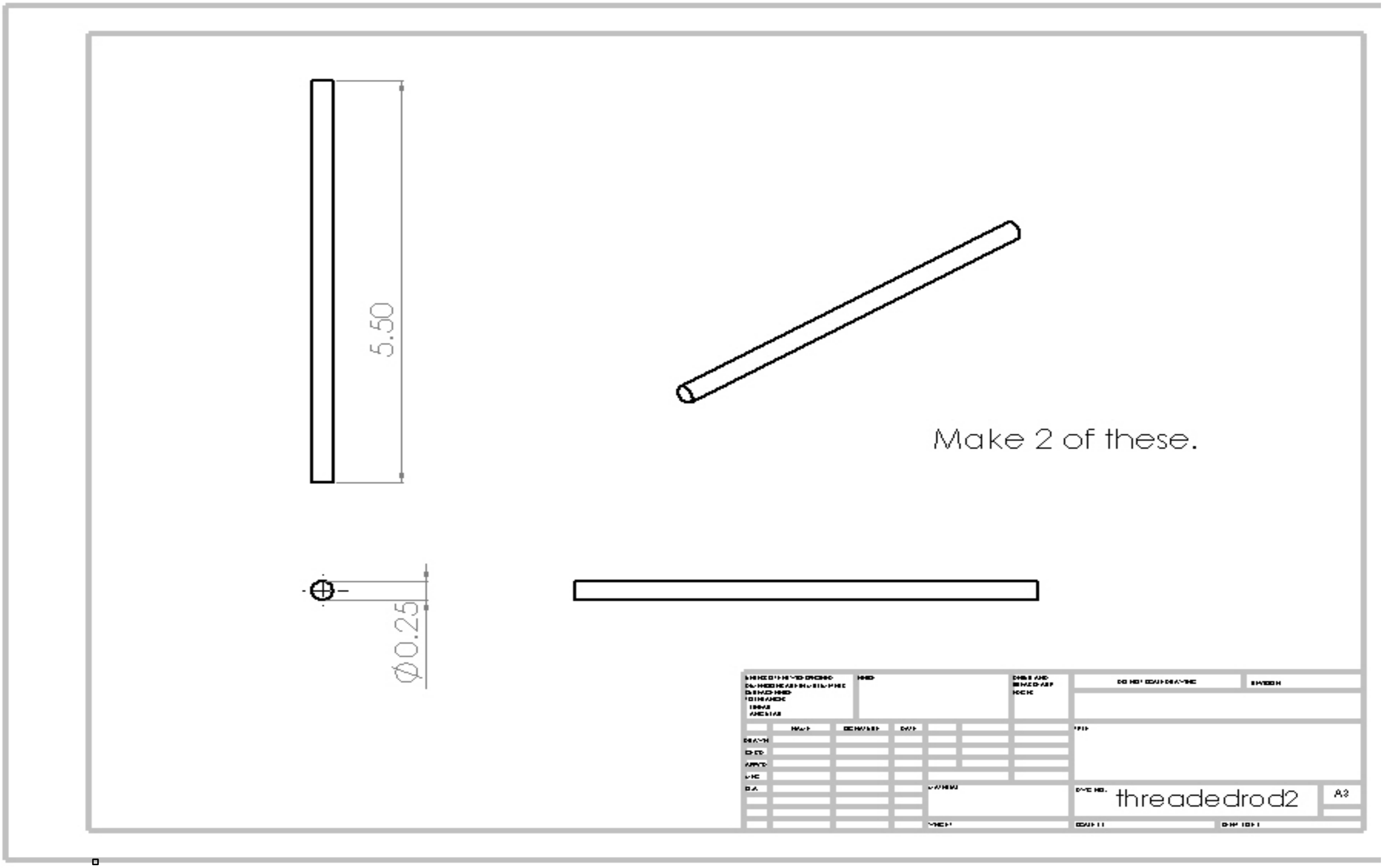


Fig 3.9. *ThreadedRod2.* Two of this part will be purchased. It will connect the back plate to the back arch.

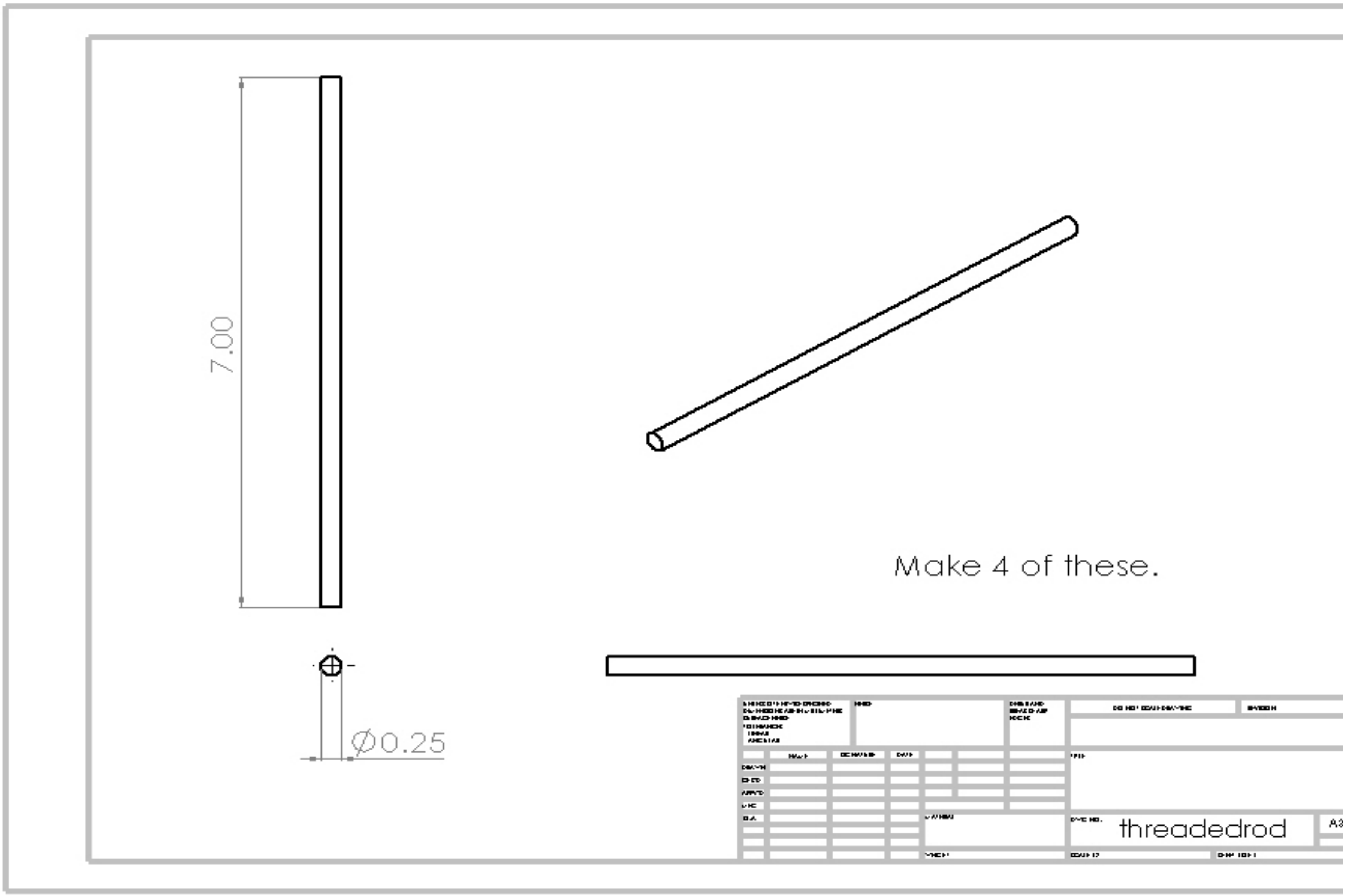


Fig 3.10. *ThreadedRod.* Four of this part will be purchased. They will attach to the four support plates and keep the whole assembly sandwiched together by use of nuts.

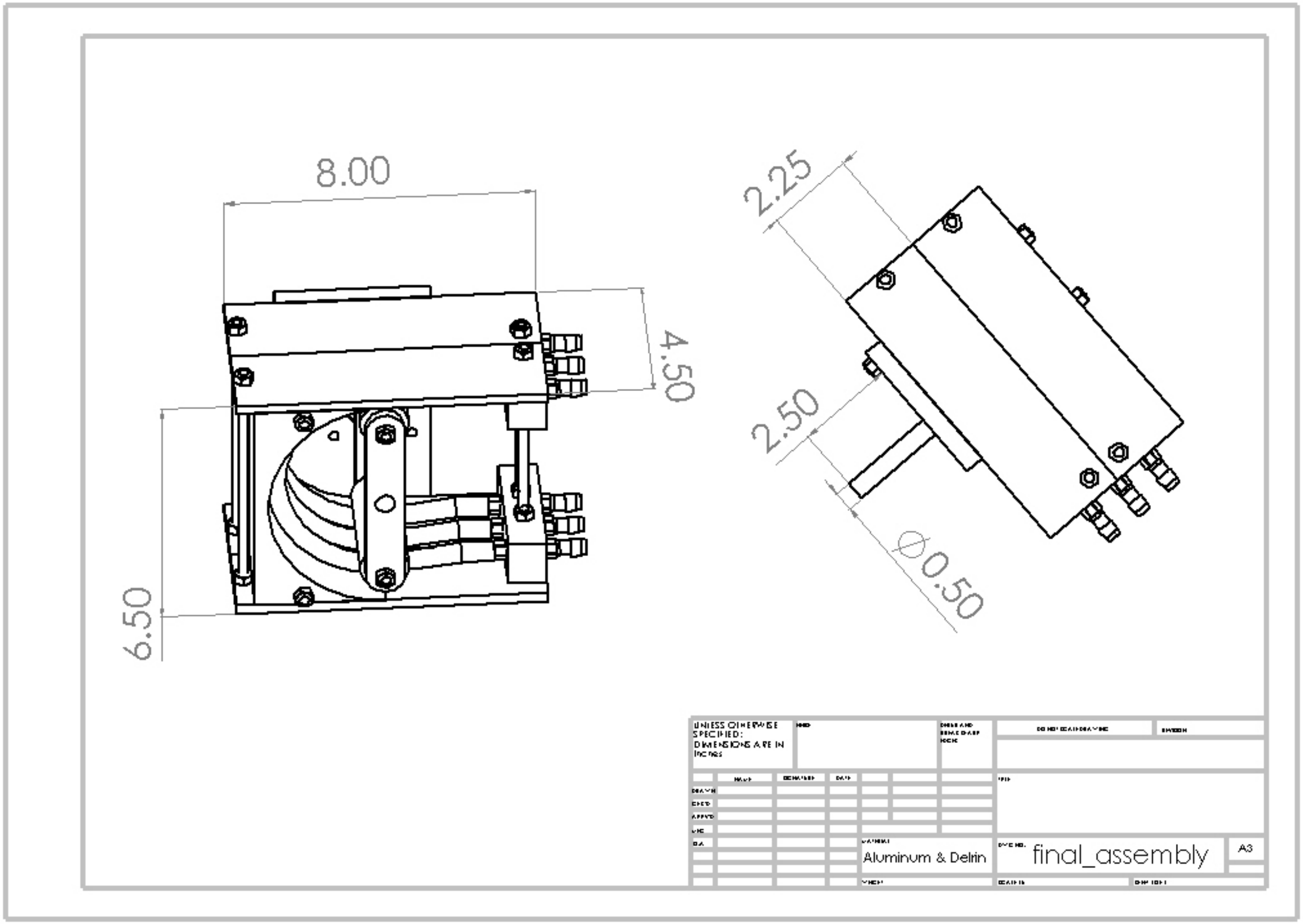
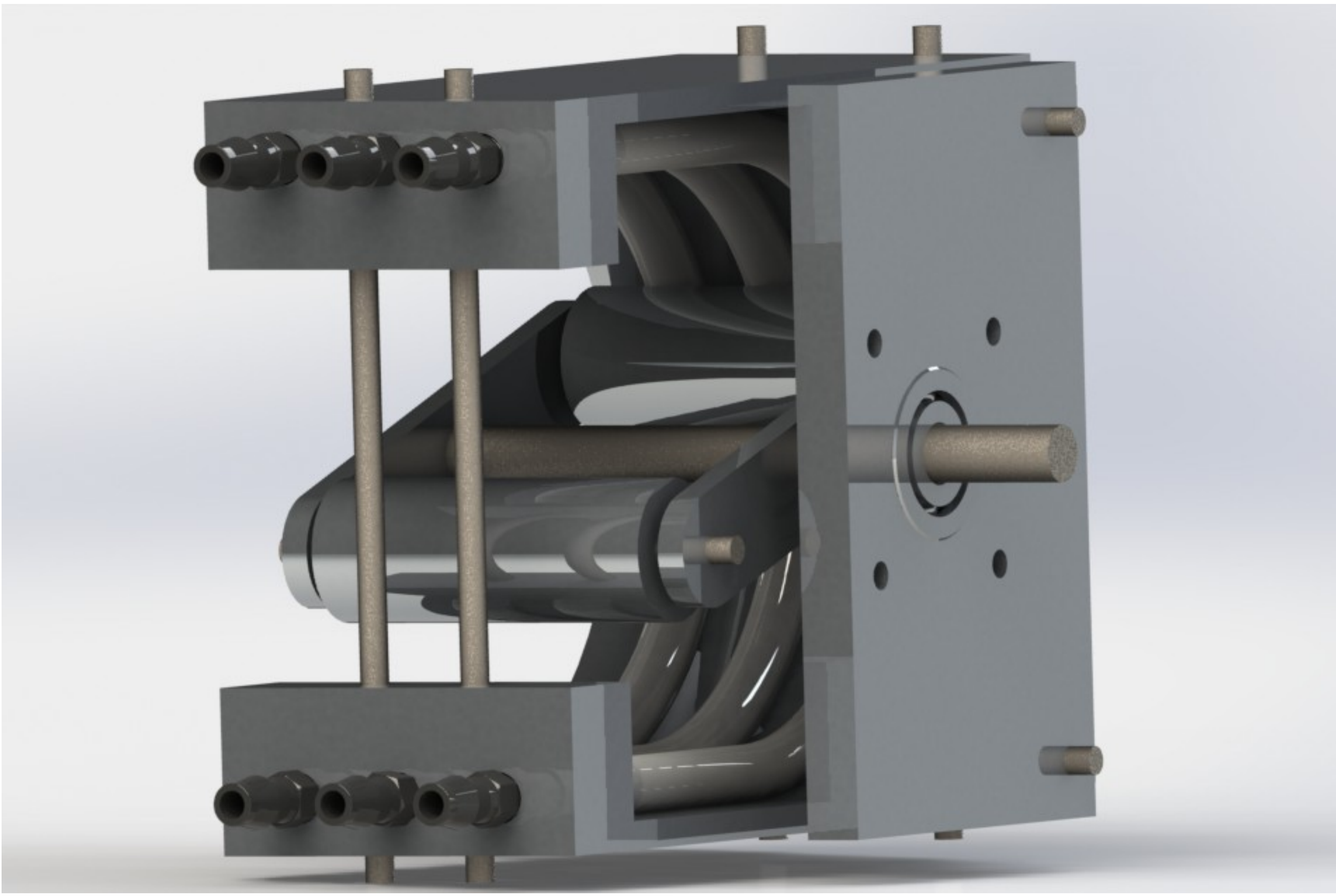
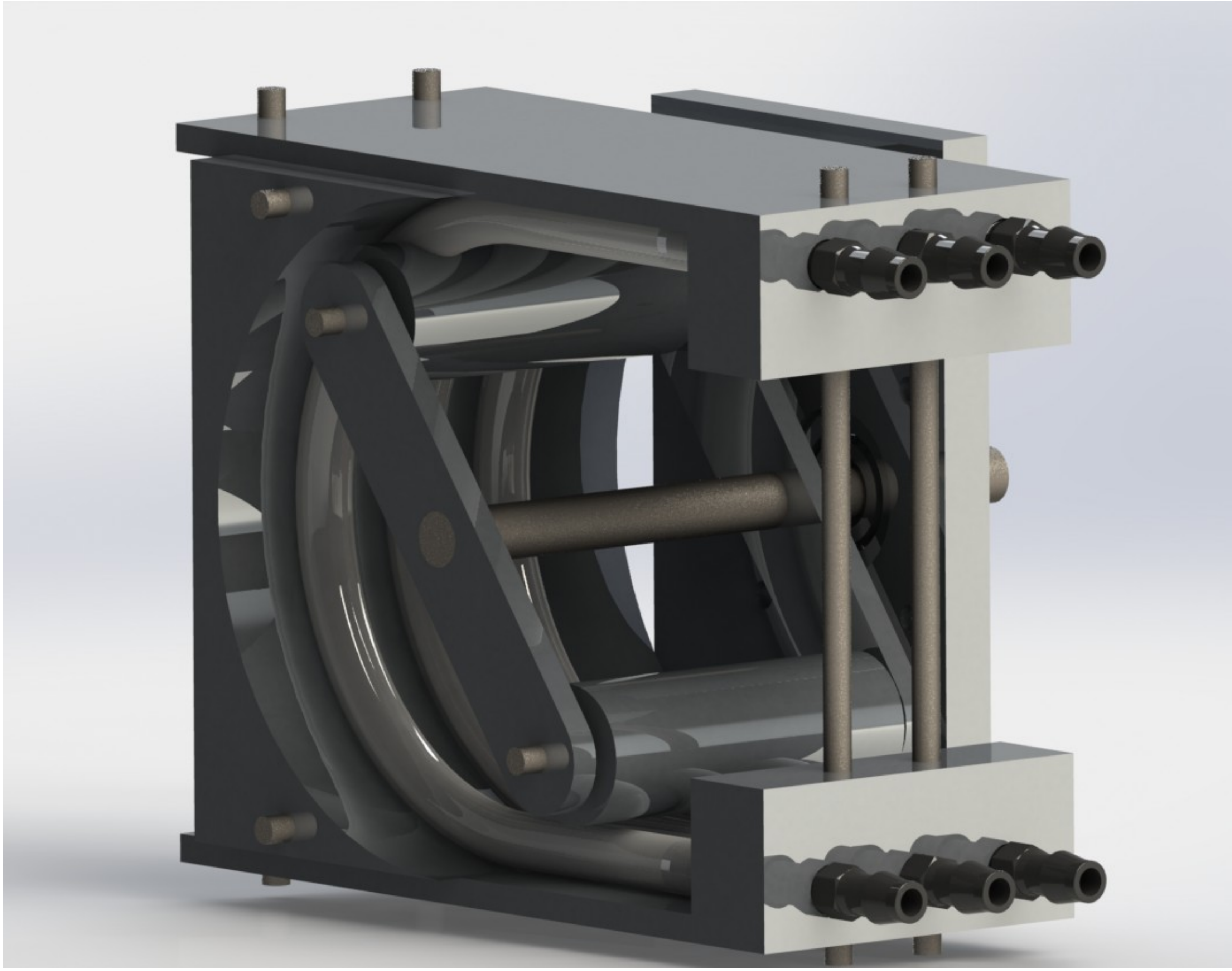


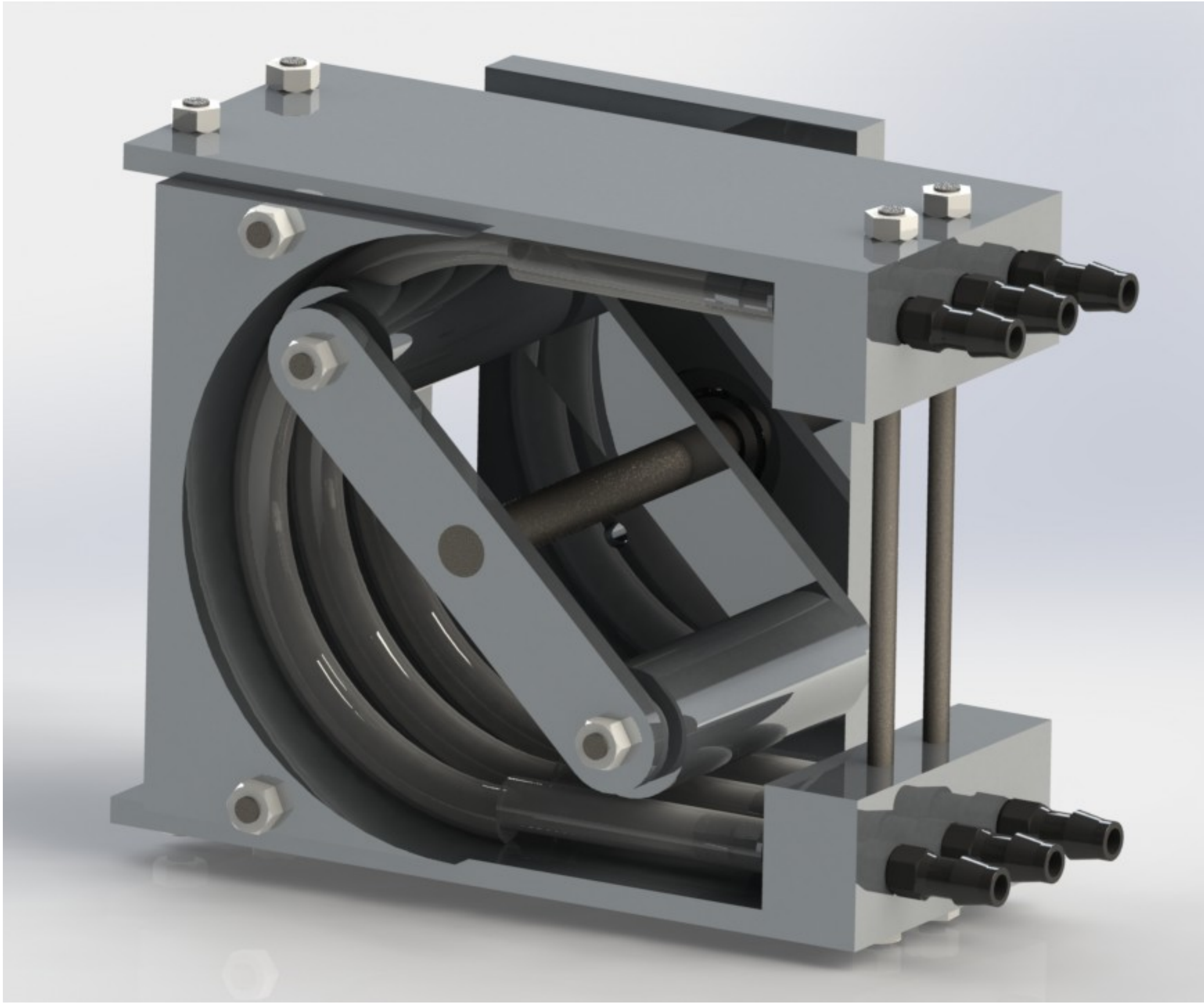
Fig 3.11. *final_Assembly*. This is a drawing of our assembly. It fits in the 14 by 14 by 14 box as required as you can see.

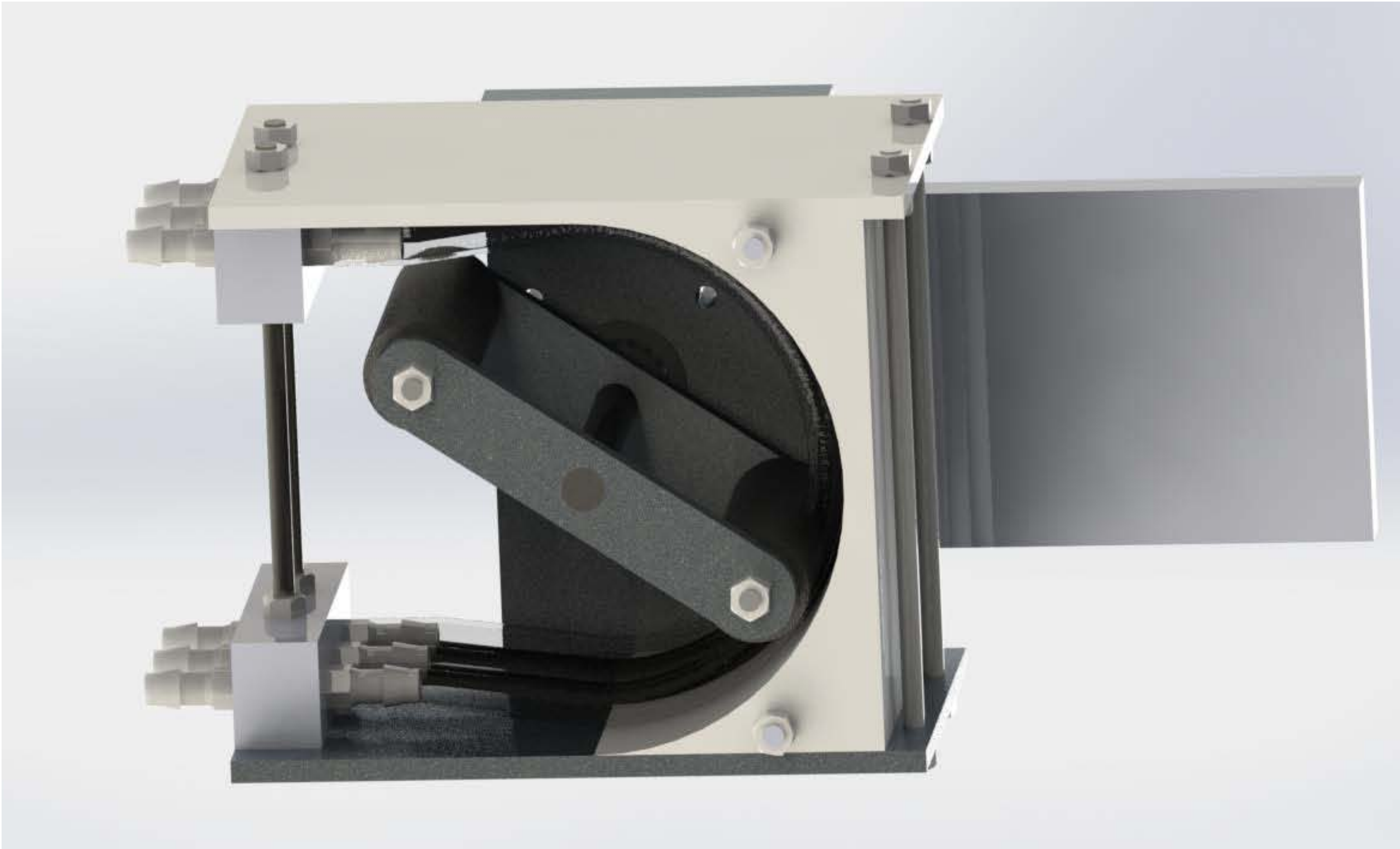
Final CAD Assembly Renderings

Figs 3.12 – 3.15. *Final CAD Assembly Renderings*. These are renderings of our final pump design at different angles.









Figs 3.15. *Final CAD Assembly Render with Face Plate*. This render shows the face plate being attached to our Wind Pump. The image is reversed from what was previously shown just because we realized this is how our pump would have to work in order to pump the water up, but it is the same pump, just flipped around.

CAD Animation and SolidWorks Files

Click the link below for a quick animation of how our design will look and work: https://cornell.box.com/s/f7js9by8k1muvz61dn39

Click the link below for the SolidWorks Files used in this CAD: https://cornell.box.com/s/x1kxa4flzwq027awrvy5

Monday: 4/15/13

Rebecca, Jesse, and I met for 30 min.

We brought the updated CAD to Emerson Lab, and we were about to show it to Mike, when Lauren swooped in and told us that she would have to talk to Katie about letting us CNC the part. This came as a surprise, since we thought that we already got approval from Katie before, but I guess not. So we just clarified a few questions we had with Joe so that we could make sure every part we make works well.

Wednesday: 4/17/13

- Bad news: We can't CNC the part, so we have to actually do it ourselves.
- Good news: I ordered the parts that we need from McMaster-Carr, as can be seen in the table below

McMaster Part Orders

Table 3.1. *McMaster Part Orders*. This table shows the part orders we put through to McMaster and how much everything we ordered cost.

Vendor	Item Name/Description	Part/order #	Quantity	Unit Price	Total
McMaster Carr	Soft Abrasion-Resistant Polyurethane Tubing Blue, 3/8" ID, 1/2" OD, 1/16" Wall Thickness	5792K39	*5*	*$2.22*	*$11.10*
McMaster Carr	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	5121K411	1	*$4.46*	*$4.46*
McMaster Carr	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	6383K45	1	*$5.88*	*$5.88*

Thursday: 4/18/13

We all met, although I stayed for just 20 minutes because I had practice. They met for 2 hours.
Since I wasn't there, here are Saajan's meeting minutes:

- Meet to discuss finalized dimensions so that we are good to go with drawings in lab tomorrow and know exactly what we need to do in the machine shop tomorrow. We need a part drawing for every single part.
- Anjit already ordered all of the pieces, so we're waiting for some things to come in
- Everything is alminum except for the red curved piece and the rollers (Delrin)

• Reviewed email from Lauren concerning CNC à we CANNOT use CNC for the red curved piece that we need to bore out (6" hole)
• How do we attach/cement the bearing into the back plate?
    o We'll have to machine a hole that's a bit smaller than the actual diameter
    o Press fit the bearing into the aluminum
    o Should be snug enough and tight enough to keep it in place
• Moved holes away from edge in the gray pieces. Right now, they're too close to the edge, which makes machining harder and more prone to screw-up
• Measure dimensions of hex nuts and washers

Dimensions
• ¼ " Diameter nut: .211" thick
• ¼ " Washers: .06" thick
• Made final adjustments to drawings so we're ready to go in the shop tomorrow

Goals for Next Week

• Have all part drawings ready
• Let the machining begin!!
• For the mill: use the rotary table to machine the red piece
• For the lathe: see if we can trade in for rollers and bore holes through them tomorrow
• Splitting up work: 2 people on mill, 2 people on lathe, 2 people working on other parts of the assignment (i.e. technical document, marketing analysis, anything else that needs to be completed for the project)
• Add part drawings to notebook

Fabrication/Manufacturing Plan and Assignments

Unfortunately, we weren't able to set for certain when people would be free to machine in stone, because most of us have class during the only open machining hours, which is basically from 9 to 12 noon Monday through Friday. So we'll just have to come in whenever possible. Also, we managed to give everyone jobs based on what pieces have to be made, so they will get them done when they can by our next lab section meeting. Tim wrote a great summary of everything we would have to do in order to machine the various pieces for our pump though.

Piece 1 (Curved Plate) (Anjit):

a. There are 3 possible methods: 1) using the boring tool on the lathe, 2) using the rotary table, or 3) buying the pre-CNCed part from the shop. To machine the component ourselves using method 1 and 2, we will have to be very careful about centering our stock material on the lathe/ table respectively. To be more specific, we will need to know the stock we can exchange and its dimensions, so we will have to gain further information from Joe on Friday after our FDR presentation and team discussion to be more specific on our methods. We will follow the same procedure as every other following plate in trimming down material and making passes to make the plate parallel on each side after proceeding with the circular cut-out.
b. Joe gave us a 10 x 8 x 2.1 inch block of Delrin to work with. It was a monster and can be seen in the machining pictures below.

Piece 2 (Back Plate) (Jesse and Saaj):

c. Since the required piece of stock for this piece is not available from the stock we have been provided with, we will try to trade some of our unused stock pieces in for a stock piece at around ½" x 8" Square Bar 8" 6061 T6 stock.

d. After obtaining this piece, we will then place it on the mill clamping it so that either 8" side will be trimmed down.
e. Do a quick pass on this side to make sure it is nice level and smooth surface. Then unclamp, flip the piece so that the other side is ready to be trimmed and clamp it down again.
f. Since, this only needed around .25" to be cut off, re-measure the width of this piece and figure out how many .03" passes would be needed to get it as close to 7.75" as possible.
g. Once you have completed these passes, re-measure the width and calculate how much this final pass would have to be in order to make the width 7.75". Make the pass.
h. Then moving on to the length, unclamp the piece and then rotate it until the other 8" length side is in position to be trimmed. Then repeat with a similar process in order to make 8" to as close to 6.5" as possible by first moving a quick pass on one side, and then doing passes to cut down the length while re-measuring on the other side.
i. Then re-measure one last time and make the final pass. You are now finished with trimming this piece down because it was already ½" thick to begin with and that is exactly the thickness we need.
j. Then the final step is to drill a hole through this plate so that the shaft from the wind turbine can go through. First measure 3.75" right and 3.25" up from the bottom left corner of your plate.
k. After finding this spot, since the Shaft is ½" diameter and so using the mill we need to drill a hole of size ½", making sure to use drill bits of increasing increments of sizes. You are done with Piece 2.

Piece 3 & 4 (Top & Bottom Plates) (Tim and Herman):

1. Since the required piece of stock for this piece is not available from the stock we have been provided with, we will try to trade some of our unused stock pieces in for a two stock pieces at around ½" x 4" Square Bar 5" 6061 T6 stock.
2. After obtaining these two pieces, place one on the mill clamping it so that 4" side will be trimmed down.
3. Do a quick pass on this side to make sure it is nice level and smooth surface. Then unclamp, flip the piece so that the other side is ready to be trimmed and clamp it down again.
4. Since, this only needed around 1" to be cut off, re-measure the width of this piece and figure out how many .03" passes would be needed to get it as close to 3" as possible.
5. Once you have completed these passes, re-measure the width and calculate how much this final pass would have to be in order to make the width 3". Make the pass.
6. Then moving on to the length, unclamp the piece and then rotate it until the 5" length side is in position to be trimmed. Then repeat with a similar process in order to make 5" to as close to 3.5" as possible by first moving a quick pass on one side, and then doing passes to cut down the length while re-measuring on the other side.
7. Then re-measure one last time and make the final pass. You are now finished with this piece because it was already ¼" thick to begin with and that is exactly the thickness we need.
8. Now just repeat steps 3-9 for the 2nd piece of ¼" x 4" Rectangular Bar 5" 6061 T6 stock and you will have finished both pieces 3 and 4.

Pieces 5 & 6 (Right Half Plates) (Rebecca):

1. Take the 1" x 2" Rectangular Bar 10" 6061 T6 stock. We will probably try to cut it into 2 pieces of length 4" in length using a band saw or trade it in for two smaller pieces of length 4".
2. Place it on the mill clamping it so that either 4" length side will be trimmed down.
3. Do a quick pass on this side to make sure it is nice level and smooth surface. Then unclamp, flip the piece so that the other side is ready to be trimmed and clamp it down again.
4. Since, this only needed around 1" to be cut off, re-measure the width of this piece and figure out how many .03" passes would be needed to get it as close to 3" as possible.

5. Once you have completed these passes, re-measure the width and calculate how much this final pass would have to be in order to make the width 3". Make the pass. You are now finished with trimming this piece because it ~~was~~ already 1" thick and 2" wide to begin with and that is exactly the thickness and width we need.
6. Repeat steps 2-5 for the other 1" x 2" Rectangular Bar 4" 6061 T6 stock.
7. Next, take your piece and turn it so that the width is facing you and the largest face is pointing upwards. Then measure .35" to the right and .4375" up from the bottom left corner.
8. At that point drill a hole of size ¼", making sure to use drill bits of increasing increments of sizes. Drill straight through the piece.
9. Now measure .5625" up from this point and drill the same sized hole in the same way.
10. Repeat step 8 so that after this hole you have three holes of the same size in parallel in the vertical direction.
11. Unclamp the piece and repeat steps 7-9 with the other piece. That finishes Pieces 5 & 6.

Phase 4: Testing and refinement

Although we did not have a certain schedule for who went when, we just assigned parts to be made by the next section to people, as seen in the fabrication plan as seen above. What follows are the times that people worked and what they worked on:

Friday: 4/19/13

Anjit:
2:00pm - 4:30pm - I cut the pieces that we would fasten the tube fittings into from the thick length of aluminum given to us, and I also received the humongous piece of Delrin that we will cut the big circle out of, but since it was late today, Mike helped me set up the rotary table so that I could start cutting into the piece next time.

Rebecca:
2pm - 4:30pm: cut the tubing blocks down to the correct size through using the band and drop saw with Anjit and then use the mill to face them down to the exact size

Jesse:
2:00-4:30 I traded in the Delrin cylinder for one with a smaller diameter (1.25in). I used the dropsaw to cut it into two pieces and used the lathe to drill a hole through it so that we can use it as our rollers.

Saajan:
2-3:30 Traded in Delrin cylinder with Jesse for a smaller diameter. Used the dropsaw to cut it into two pieces (2 rollers)

Monday: 4/22/13

Anjit:
10:00am - 2:00pm - I used the rotary table to cut a circle out of the huge piece of Delrin by rotating it around while making deeper and deeper passes as can be seen in the figures below. Took about 1 hour to do, but it worked, although I broke Joe's drill bit and felt awful about it. I hate using something that someone else entrusted to me and messing it up, it's just a terrible thing to do. I hope I can make it up somehow.

Jesse:
11:15-12:30 I finished machining the rollers on the lathe by facing off the ends, chamfering the holes, and sanding down the sharp edges.

Fig 4.1. *Machining the Back Arch 1.* This image shows me working on drilling the circular part out of the back arch.

Fig 4.2. *Machining the Back Arch 2.* As you can see, this block is huge, so this process takes quite a bit.

Fig 4.3. *Machining the Back Arch 3.* The piece will be shaved down on the top and bottom until I break into the inner circle and thus have a relatively thin point as desired in the part drawings.

Tuesday: 4/23/13

Anjit:
10:00am - 11:30am - I used a fly cutter to even out the tops of the now center-less Delrin and make them parallel so that I could accurately make cuts into the material later on.

Fig 4.4. *Shaving the Back Arch 1.* I'm shaving this puppy down right now, giving it a mean haircut. Shavings get everywhere.

Wednesday: 4/24/13

Anjit:
9:30am - 12:00pm - I used a sort of fly-cutter to cut the block down more and more until there was no top left but the top of the hole and it broke into two separate pieces.

Jesse:
11:15-12:15 I traded in the 1"x.25"x10" aluminum for 1"x.25"x12" aluminum. I used the bandsaw to cut the rotary arm into two pieces. I then used the mill to cut down these pieces to the correct dimensions.

Fig 4.5. *Shaving the Back Arch 2.* I told you the shavings got everywhere.

Thursday: 4/25/13

Jesse:
3:00-5:00 I added holes to the rotary arm to connect to the rollers. Using the bandsaw, I cut of material on the edges to prevent interference.

Herman:
10:00 - 12:00. Tim and I went to the shop and began to work on the support plates. We used the drop saw to cut them down to almost size. On the mill, we cut them down to actual size. By the end, all four plates were the right size. Two of them had the holes drilled and threaded. It later turned out threading wasn't necessary.

Tim:
10:00 - 12:00. Herman and I went to the shop and began to work on the support plates. We used the drop saw to cut them down to almost size. On the mill, we cut them down to actual size. By the end, all four plates were the right size. Two of them had the holes drilled and threaded. It later turned out threading wasn't necessary so on a later day we had to drill through those threaded holes with the correct hole size.

Friday: 4/26/13

Anjit:
11:00am - 12:00am/2pm - 4:30pm - I cut down the sides and shaved the edges so that the pieces were more even and were brought to the specified dimensions. Then I got the rest of the threaded and unthreaded rods, nuts, and washers that we needed from Joe in order to finally put everything together, as can be seen in the table below.

Rebecca:
11am-1pm/ 2pm-4:30pm - finish bringing the tubing blocks down to the exact size. (Made a slight mistake on one of the blocks, so it it is 0.02 smaller than the actual dimension on drawings; not a problem since the holes just need to be moved 0.01 inches down to the left from the original location it's supposed to be drilled in). Note: One of the holes need to be bigger than the others due to different size of tube fittings.

Jesse:
2:00-4:30 Machined the backplate with Saaj. We added a hole for the ball bearing which we press fitted into the plate. We drilled .25" diameter holes to attach to the faceplate. We made an error by drilling a hole in the wrong location but this error did not compromise our design since we just redrilled in the correct location.

Herman:
11:00 - 12:00. Finished drilling holes into all of the support plates. Fixed the other holes.
3:00 - 4:30: Manually threaded the fitting jig holes.

Tim:
11:00 - 12:00 Finished drilling holes into the support plates with Herman.

Saaj:
2:00-4:30 Machined the backplate with Jesse. Made a hole for the ball bearing, which we press fitted into the plate. We made a minor error by drilling a hole in the wrong location but luckily did not compromise our design.

Updated Emerson Part Orders

Table 4.1. This table shows the part orders we put through Emerson and how much everything cost.

Group Number	Vendor	Item Name/Description	Quantity/Ft or container	Unit Price	Total
Group 1	Emerson	1/2" Steel Rod (per foot) 1012 Steel	5/8	*$1.65*	*$1.03*
Group 1	Emerson	1/4 - 20 threaded rod (per foot)	2 1/3	1.41	*$3.29*
Group 1	Emerson	1/4 - 20 unthreaded rod (per foot)	3/4	*$1.41*	*$1.06*
Group 1	Emerson	1/4 - 20 threaded rod (per foot)	0.92	*$1.41*	*$1.29*
Group 1	Emerson	Bolts	20	*$0.07*	*$1.40*
Group 1	Emerson	Washers	4	*$0.04*	*$0.16*
Group 1	Ricky	Epoxy	0.043	*$5.75*	*$0.25*

Updated Cost Analysis

Table 4.3. This table shows the total part orders we actually put through and how close we are to going over the limit. (2 cents!)

Group Number	Vendor	Item Name/Description	Part/order #	Quantity /Ft	Unit price	Total
Group 1	*McMaster Carr*	Soft Abrasion-Resistant Polyurethane Tubing Blue, 3/8" ID, 1/2" OD, 1/16" Wall Thickness	5792K39	*5*	*$2.22*	*$11.10*
Group 1	*McMaster Carr*	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	5121K411	1	*$4.46*	*$4.46*
Group 1	*McMaster Carr*	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	6383K45	1	*$5.88*	*$5.88*
Group 1	Emerson	1/2" Steel Rod (per foot) 1012 Steel		2/3	*$1.65*	*$1.10*
Group 1	Emerson	1/4 - 20 threaded rod (per foot)		2 1/3	1.41	*$3.29*
Group 2	Emerson	1/4 - 20 unthreaded rod (per foot)		5/6	*$1.41*	*$1.18*
		1/4 - 20 threaded rod (per foot)		1	*$1.41*	*$1.41*
		Bolts		20	*$0.07*	*$1.40*
		Washers		4	*$0.04*	*$0.16*
						$29.98

Sunday: 4/28/13

(From Jesse Miller's notebook, I was not present)

- **Meeting Minutes (1 hour)**
  - Herman, Rebecca, and I met up to discuss our game plan for the final week of the project.
  - We discussed the remaining parts that needed to be machined:
    - Two threaded rods for the rollers
    - Holes for the drive shaft in the rotary arms
    - Holes in curved delrin piece
  - We broke up the remaining work and assigned it to people to work on in order to be most efficient.
  - Rebecca sent out a group email describing our game plan for the last week and assigning different people with different jobs:

- Machining: (Team Deadline: MONDAY Please come in and finish at time you're free.)
- - Thread end of shaft & Rotary Arms (hole) - **Jesse**
- - Thread the rod that goes through roller - **Tim?** (you were working on it right?)
- - Drill holes through Delrin - **Anjit**
- - New Part holes (blocks) & thread the holes - **Rebecca** & **Saajan** (I'm planning on going during the 9am -12pm block, can you come in to help thread the holes? text or e-mail me the time you would like to go in)
- We should meet up to assemble the product on Monday afternoon/ Tuesday and IF something (knock on wood) goes wrong, we can go in to machine/fix stuff. I'll bring in a camera and we can take some photos of us assembling the part so that we can put that in one of our reports or something too.
- This week Presentation:
- - Marketing Presentation: **Tim** & **Herman**
- Deliverables:
- - Wind Pump
- - Individual Notebooks
  - User manuals: **Herman** & **Tim**
  - Product development report: **Saajan** & **Rebecca**
  - Technical report: **Anjit** & **Jesse**
  - A single PowerPoint slide (showing rendered CAD image of WP, photo of real WP, hand sketch of WP, team names, year, section, group number, product specifications - weight, max power, max efficiency, mass-production cost) - Jesse e-mailed Katie to ask about it being a "single slide" but this is fairly simple and anyone can pick this up to do.
- - Animation - **Saajan**, do you know how assemble each part in solidworks? If so, do you want to do the animation? :) (Jesse said you can go into exploded view and from there you can assemble stuff in animation even when they are mated)
- - Final CAD files: **Herman** finalize CAD and upload the files to folder
- Misc. Things to do for everyone:
- - Please update the excel file on your google drive that Anjit put up (the one with the color coded thing) with the time and day you went in to machine, so we can calculate the cost from those hours
- - I'm putting up an excel file where everyone can put in hours they work on the product as well in addition to the meeting hours we spent with one another (apparently, every minute counts, even if you just were bored that day and decided to open up your notebook to edit stuff around...just guesstimate it if you didn't jot those individual hours down)
- If you guys have any questions or updates, feel free to add onto this thread. Good luck everyone! And may your week be filled with awesomeness and much needed rest! Final push, guys! Let's GO!

Monday: 4/29/13

(We met for 4 hours)

So I met with Jesse and Herman today to test out the pump for the first time, cutting all the tubes so that they would fit inside the pump and also seeing if the rollers could rotate freely. Herman shaved down one of the roller pins a bit too much, but he was still able to thread it. However, much to our bemusement, the polyurethane tubes were much stiffer than we thought they would be, and this made trying to use the rollers on even one tube ridiculously hard, let alone three.

I was fuming—I cursed, I threatened, a red haze filled my vision—because McMaster had told us particularly that the tube would work for peristaltic pumps. But I'm pretty sure that only Hercules could squeeze these tubes to pump water. We talked to Joe and he told us that Ricky might have some extra tubing that we could check out, and he did have some (the type that the rest of the wind-pump testing assembly uses), but it was still too stiff.

So after a lot of talking things over and me foaming at the mouth, we noticed another peristaltic pump group working on their pump. I talked to them and it seems that they were using Tygon tubing, which was much, much, MUUUCH softer than our current tubing. Herman, Jesse, and I looked it up on McMaster and it did not look too much more expensive, so we contacted Katie and Lauren to see if we could order this tubing for Thursday, but they told us it was too late. So, faced with no other option, and really wanting our pump to work, we decided to order ourselves from McMaster with next day shipping. Herman placed the order and we hope that everything goes well with this, because we don't have much more of an option to do anything else. I also ordered some zip ties and coupling tube fittings, just in case we had to make any more changes.

Rebecca:
11am -12pm - Finished drilling final holes for the tubing blocks; shaft is threaded

Jesse:
11-12 and 2:30-4:30 I added the holes in the center of the rotary arms for the mainshaft. I left handed threaded one of the holes to connect to the mainshaft.

Herman:
3:00 - 4:30. Took over Tim's lathe job. The roller shafts were already cut to size and I threaded the ends.

Tim:
1:00 - 4:00 Cut roller shafts to the right length on the lathe. Then started threading the ends to the right size. Later, handed off the little that was left to Herman, and then moved on to work with Jesse on drilling the center hole for the rotary arms.

Tuesday: 4/30/13
(We met for 3 hours)

To our surprise, the Tygon tubing arrived this morning! We tested it out and it was so much softer than the other blue tubing we had. We tried it out and, using the other tubing that we had accumulated already as input and output tubes, we were able to get a kind of steady flow of water, which is a good sign. Although the pump is a bit shaky, the rollers hit the sides a bit too much and get a bit stuck, and the roller arms also wobble because they aren't fully secured to the main shaft.

We adjusted the height of the top and bottom supports with respect to the big Delrin piece in order to see if that would help the rollers rotate more smoothly, and we placed some washers to create some more spacing, but this took out more of the airtight rotation that we had before, so we were thinking about what we could do to increase flow. We realized that while the rollers kind of bumped with the bottom and top support plates, it did not provide as much contact with the back Delrin arch, so we decided that if necessary, we could add tape or paper to fill in the space between the arch and the tubes in order to make a more precise fit. Also, the main shaft seemed to bend a bit due to the weight of the rollers, so we'll have to see what happens with that, hopefully everything is righted when it is connected to the large gear during testing.

We also learned that our rollers would have to rotate in a direction opposite than the one we thought it would, so our threading that Jesse made that would make the roller arms tighten on the main shaft would be useless and actually make the roller arms loosen and come off, which would ruin our pump. So we decided we would have to use epoxy to seal everything on the rollers together so that it does not come loose.

Adjustments

- We are now using: Ultra-Soft Clear Tygon PVC Tubing 3/8" ID, 1/2" OD, 1/16" Wall Thickness instead of the polyurethane tubing.
- We are epoxying the main shaft to the roller arms as well as all nuts that are involved in that whole part.

Wednesday: 5/1/13

(We met for 2 hours in the morning and then 3 hours at night)

Anjit, Saaj, Jesse:
11:30-1:00 Anjit, Saaj, and Jesse cut off material from the driveshaft with the drop-saw so that it was only sticking out 2.5 inches from the back. We filed down the sharp edges on the rotary arms. Anjit and Jesse used epoxy to secure the mainshaft the rotary arms and also to secure the nuts in place.

Thursday: 5/2/13

(We met for 4 hours)

Today is our test and marketing presentation, so we hurried to finish everything that we had to do. Tim and Herman were doing the presentation so they were preparing that, Saaj and Rebecca were working on the product development report, and Jesse and I worked on making sure that the pump would work and were planning on working on the technical report after the test.

We saw that the tubes kept slipping out of place as the roller kept making passes, so we needed to find some way to keep them in place. Jesse had the great idea to use dental floss to tie them together to the back arch, and this in the end helped keep them fixed while the roller did its work.

We also noticed as we were doing some test runs using some of the extra tubing we had and my Nalgene water bottle that the back arch did not provide the fully airtight seal when the roller rolled over the tubes, so we had to find a back up plan to provide the extra backing necessary for the seal. Jesse again had a great idea to use some pieces of paper, and then he taped them up, so we were ready for our testing tonight. Let the judgment begin!

Updated Cost Analysis – Final

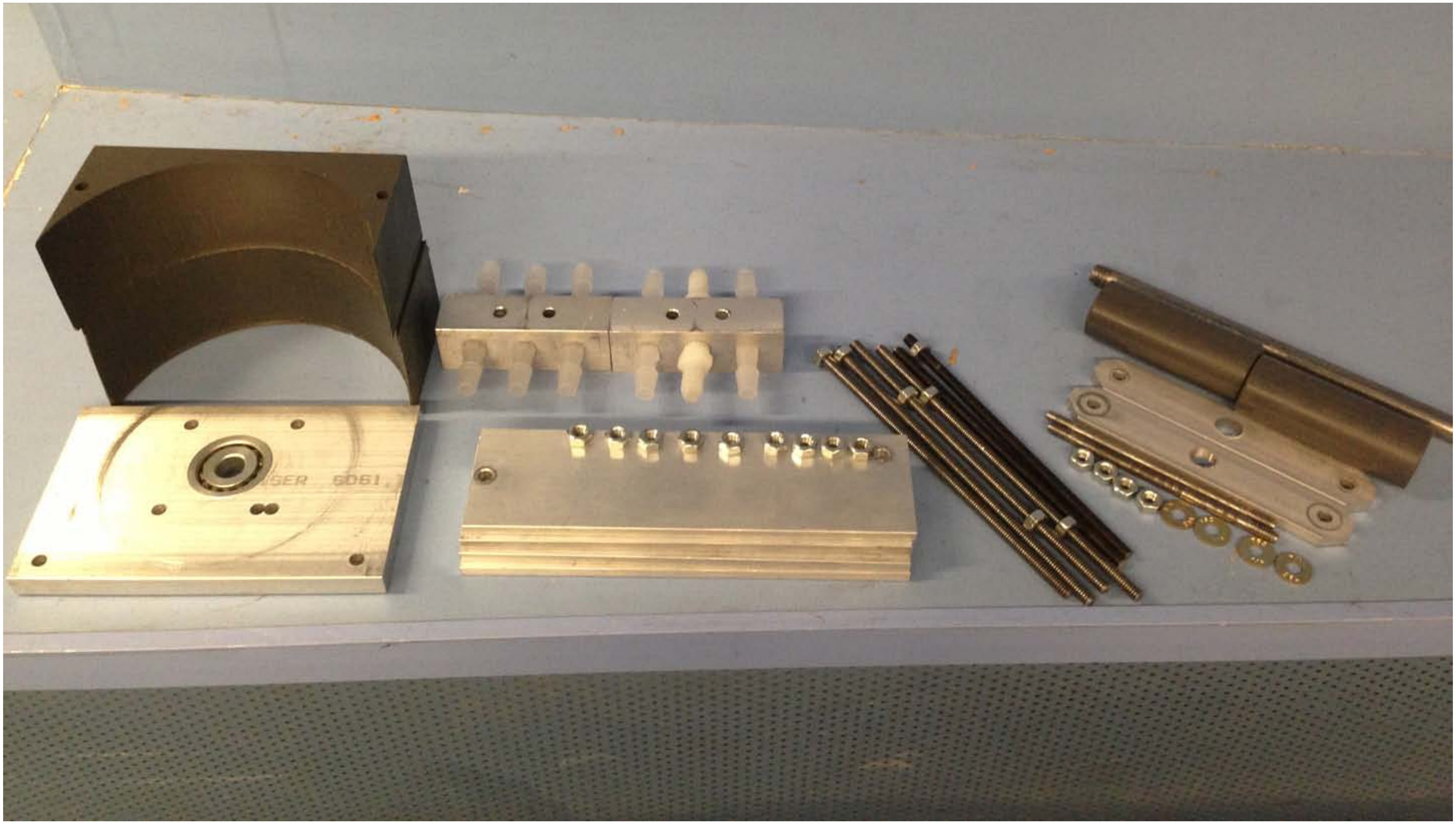
▫

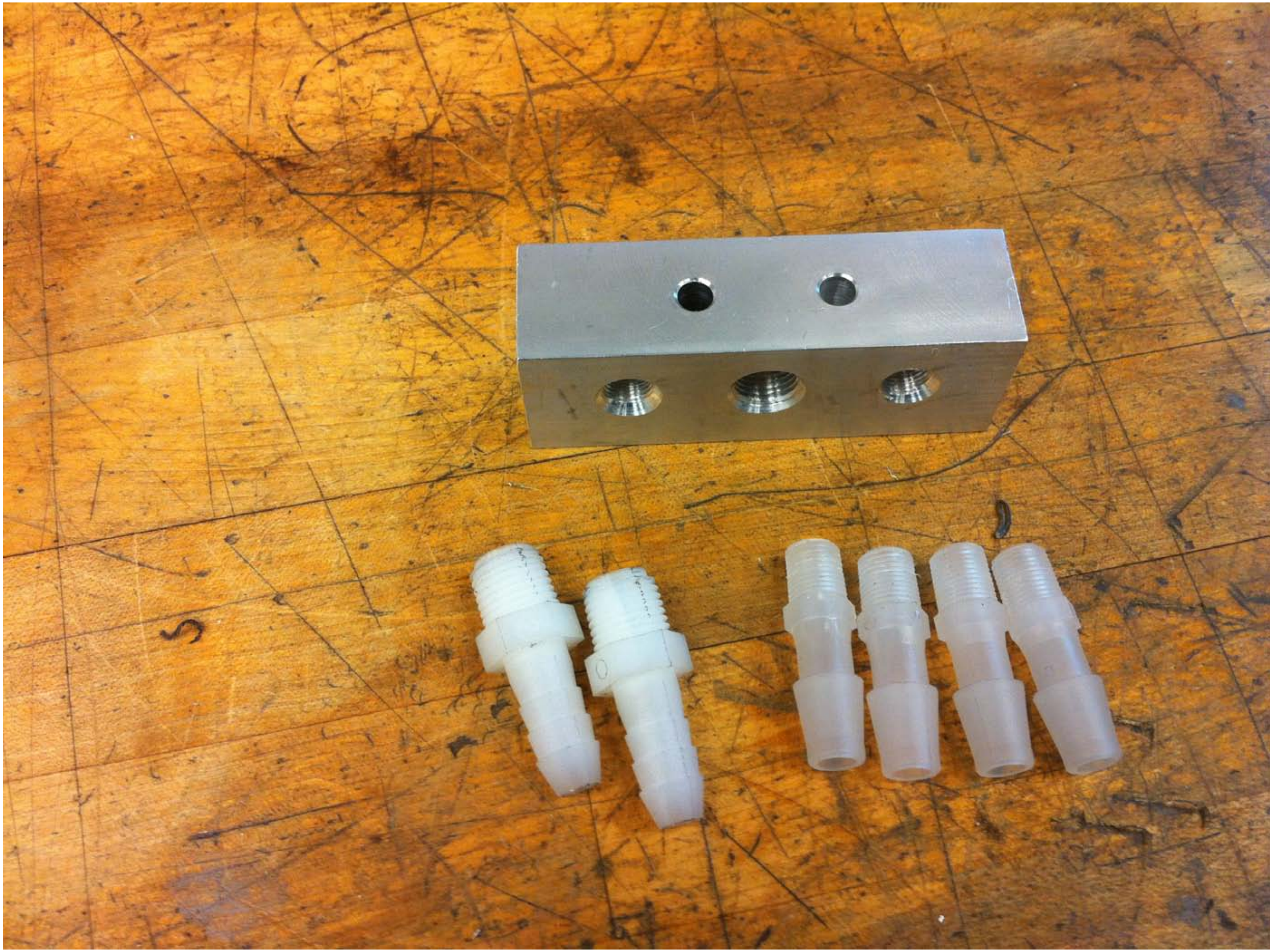
Table 4.3. This table shows the updated cost of everything that we ordered so far, especially noting the updated tubing and including the exact lengths of rods and the epoxy we will use.

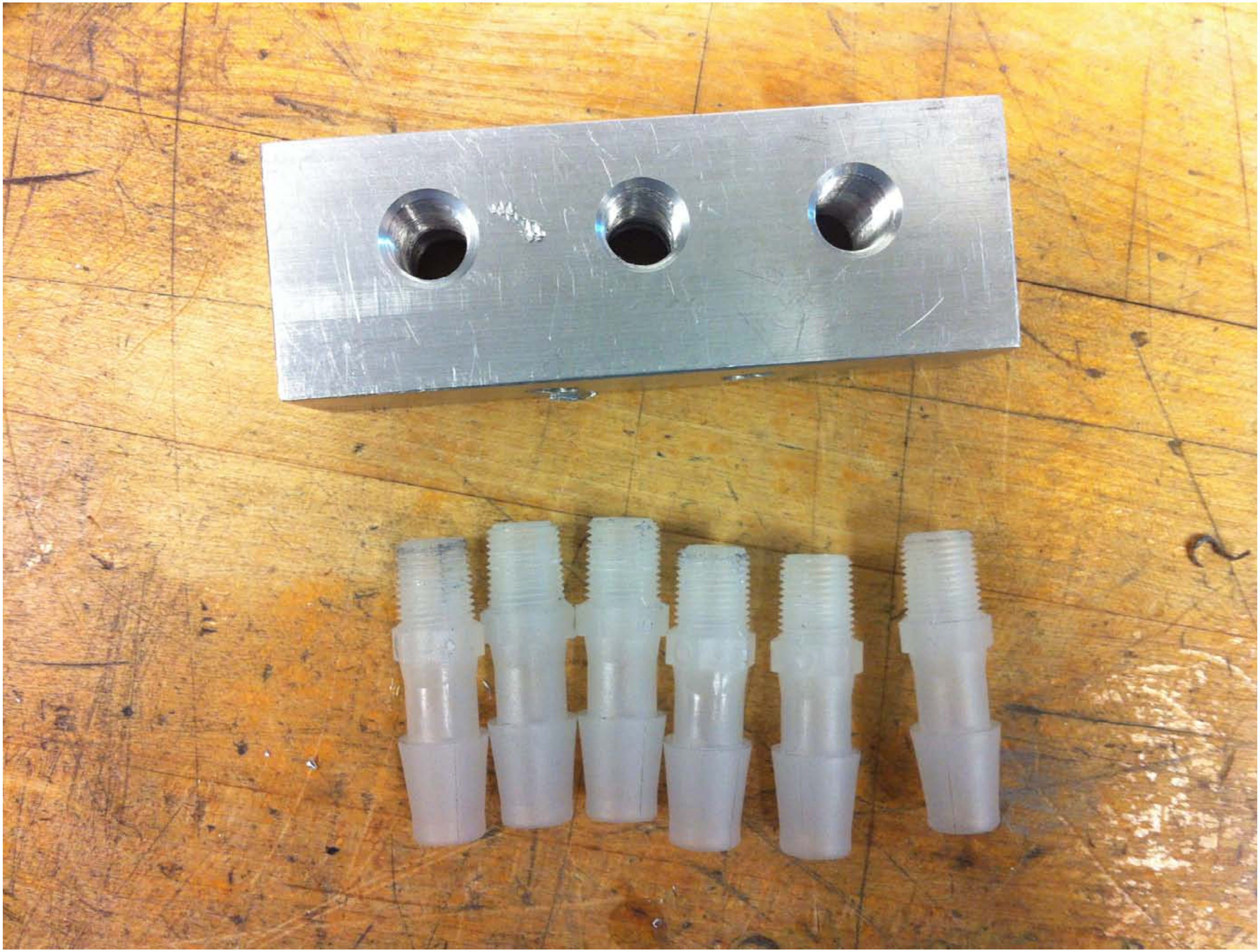
This is after we ordered the different tubing:						
Group Number	**Vendor**	**Item Name/Description**	**Part/order #**	**Quantity /Ft or Package**	**Unit price**	**Total**
Group 1	*McMaster Carr*	Ultra-Soft Clear Tygon PVC Tubing 3/8" ID, 1/2" OD, 1/16" Wall Thickness	5894K37	*3.583333 333*	*$2.87*	*$10.28*
Group 1	*McMaster Carr*	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	5121K411	1.2	*$4.46*	*$5.35*
Group 1	*McMaster Carr*	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	6383K45	1	*$5.88*	*$5.88*
Group 1	Emerson	1/2" Steel Rod (per foot) 1012 Steel		5/8	*$1.65*	*$1.03*
Group 1	Emerson	1/4 - 20 threaded rod (per foot)		2 1/3	1.41	*$3.29*
Group 1	Emerson	1/4 - 20 unthreaded rod (per foot)		3/4	*$1.41*	*$1.06*
Group 1	Emerson	1/4 - 20 threaded rod (per foot)		0.92	*$1.41*	*$1.29*
Group 1	Emerson	Bolts		20	*$0.07*	*$1.40*
Group 1	Emerson	Washers		4	*$0.04*	*$0.16*
		Epoxy		0.043	*$5.75*	*$0.25*
						Total:
						$29.99

Real Part and Assembly Images

Figs 4.6 – 4.26. *Part and Assembly Images.* The images below show all the pieces that were machined and purchased and that go into the building of our Peristaltic Pump. Note the ideally positioned garbage smear on the wall of Taylor Lab. I will comment whenever I deem it necessary.







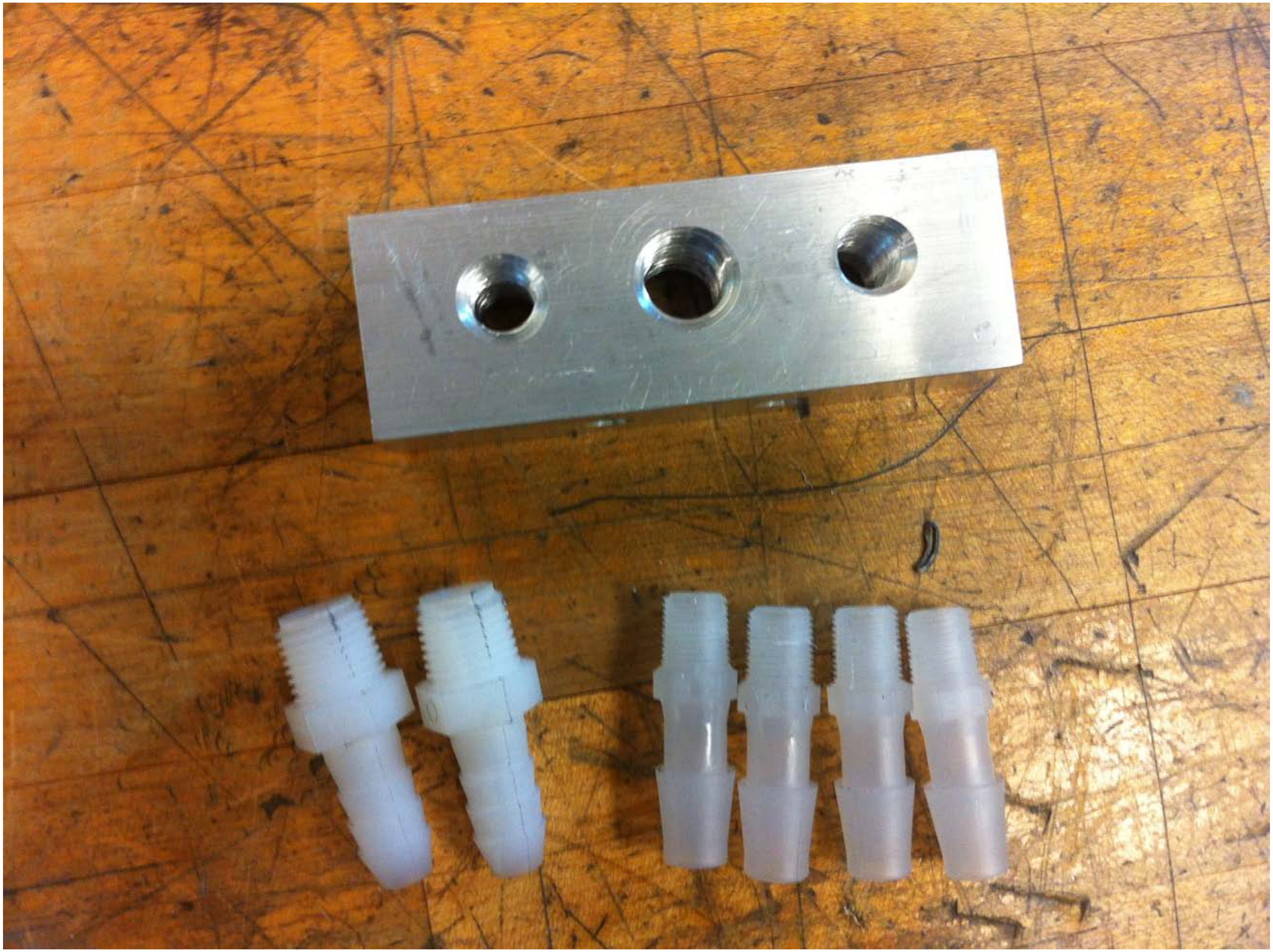
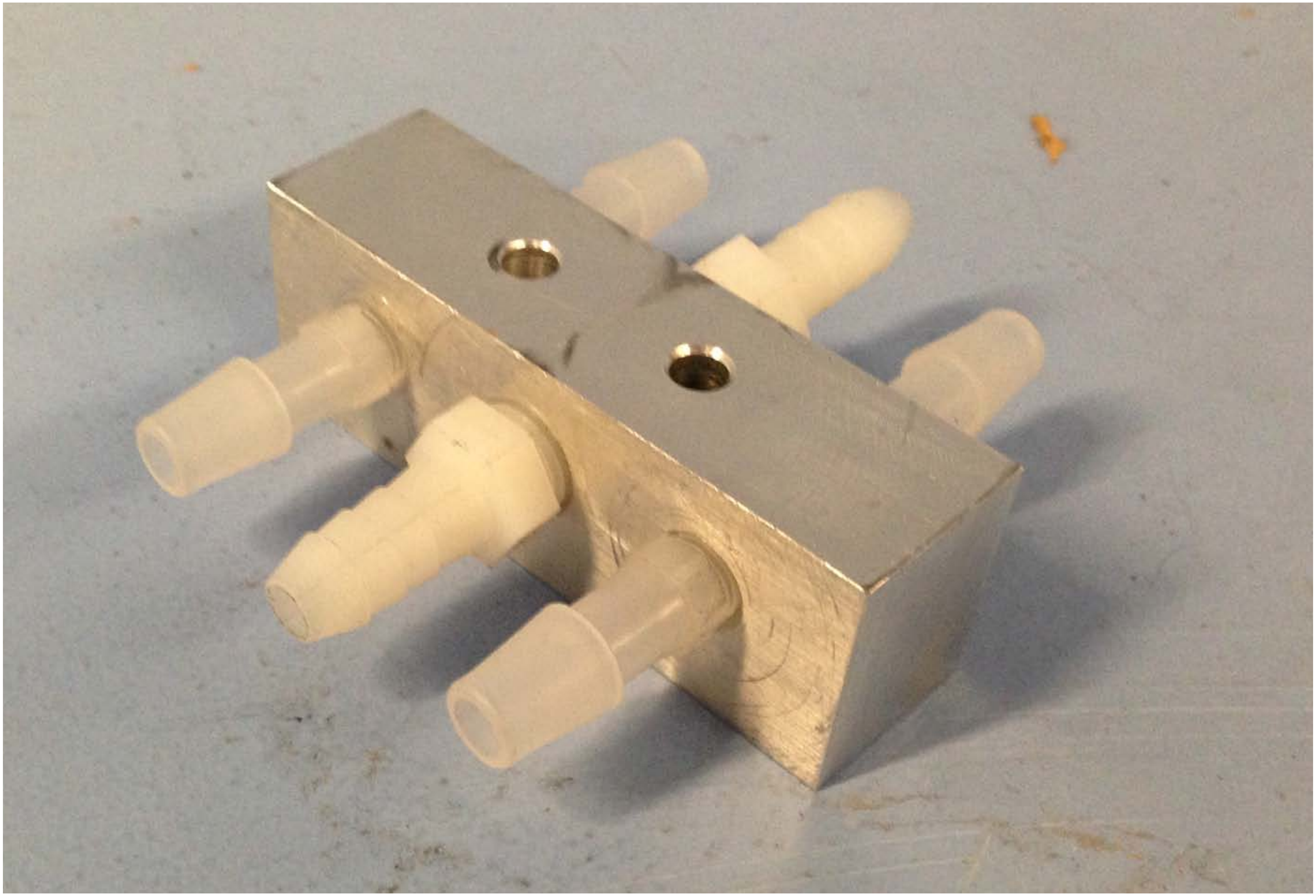
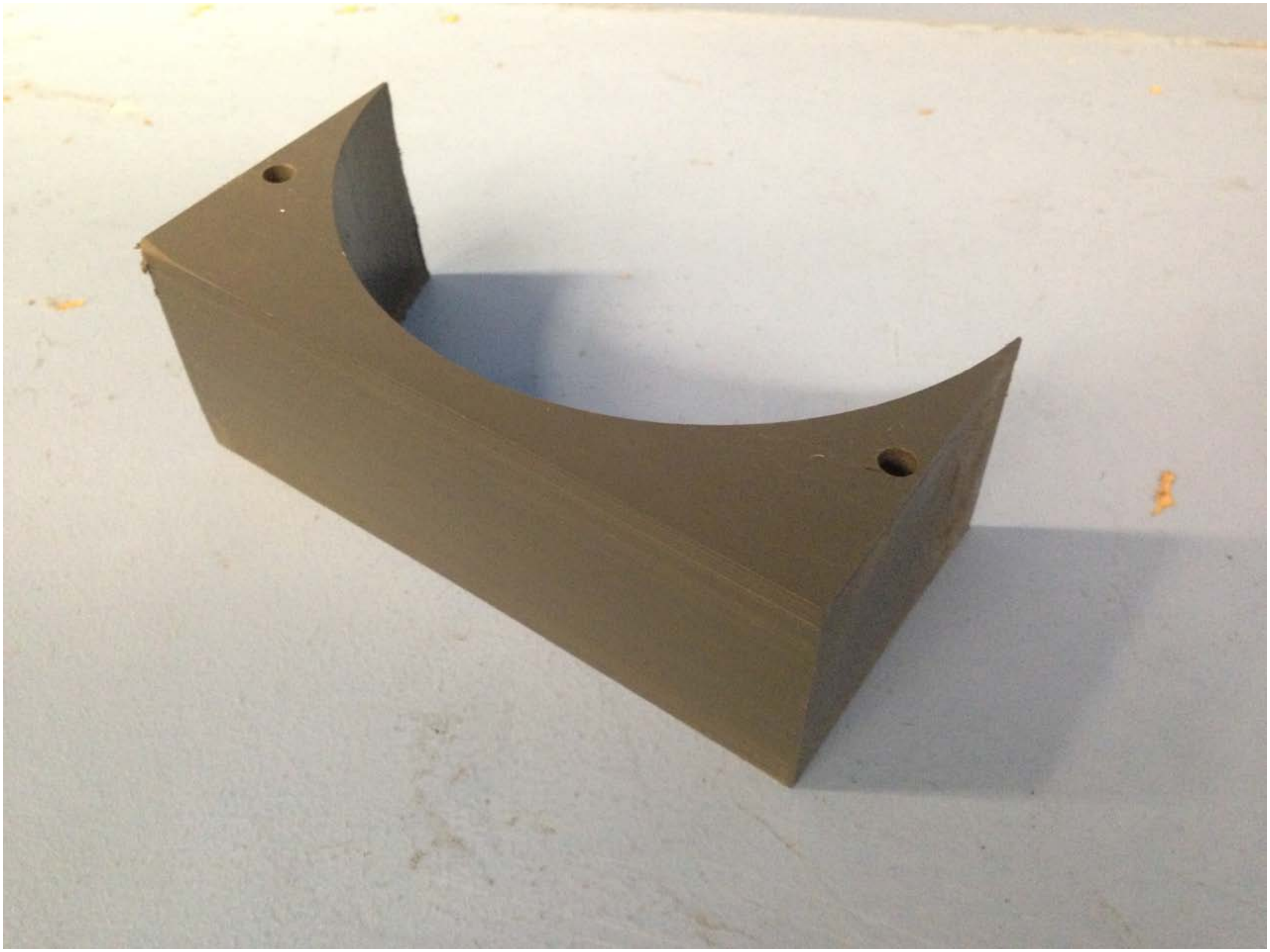


Fig 4.10. *Fitting Jig 2*. Note the bigger hole drilled in and threaded in order to accommodate the larger spare tube fittings we found.





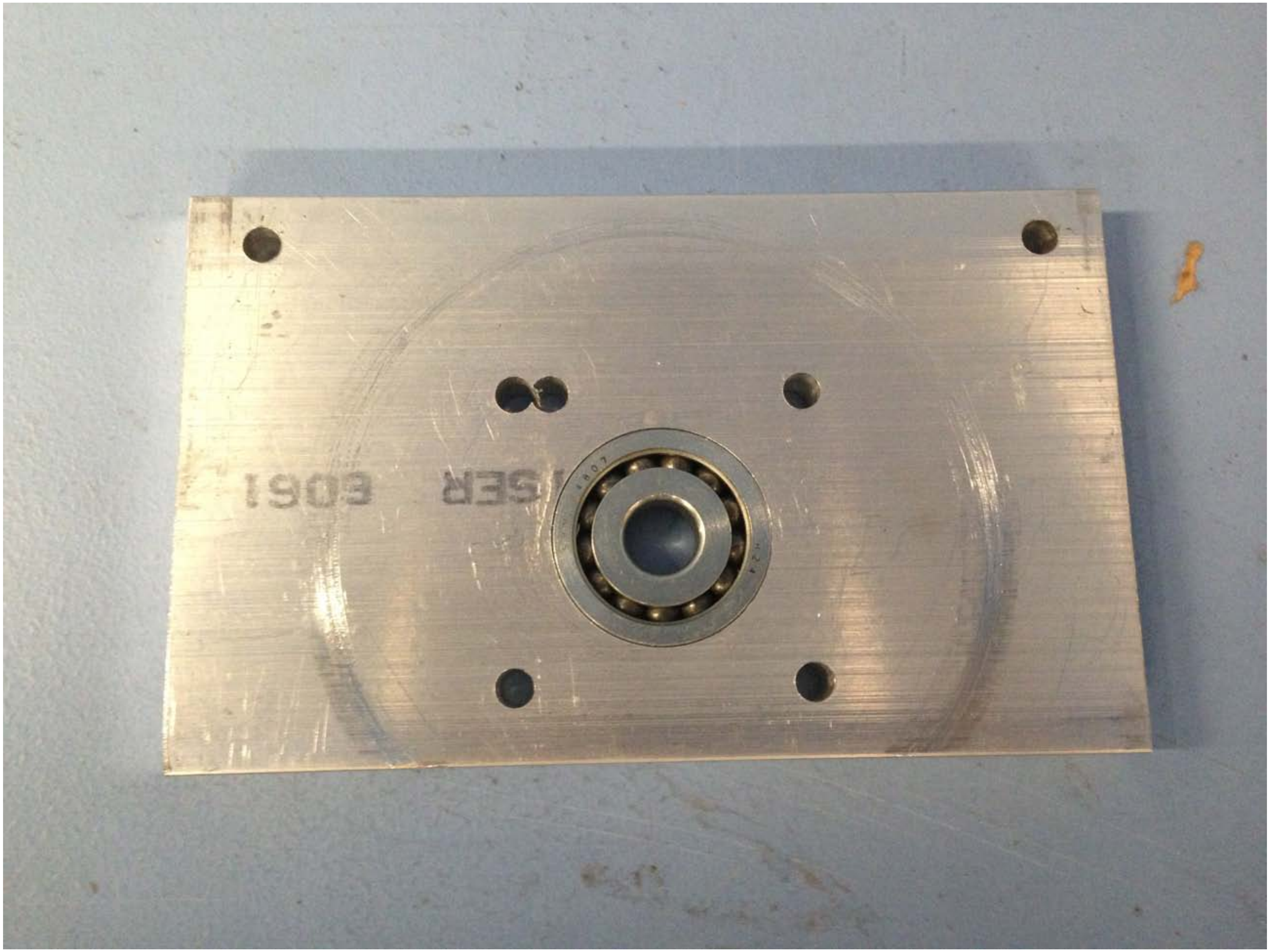


Fig 4.13. *Back Plate*. Note the ball bearing fitted into place by Joe. Nothing could take that thing out of there. Nothing. Well, maybe something, but why would you want to take it out? It looks so good in. The inner upper left corner double-hole was a mistake. Do not copy us. Follow the assembly.

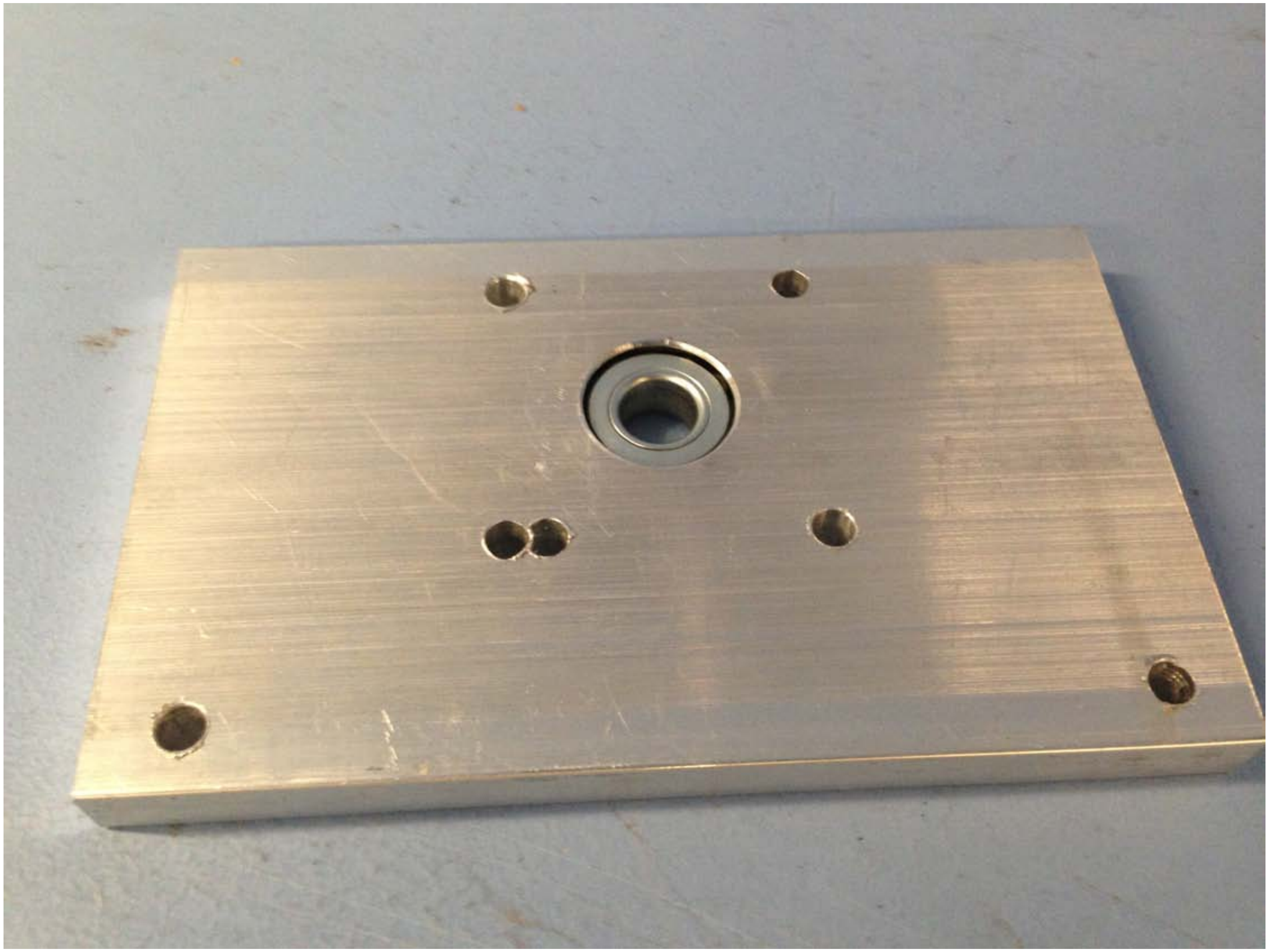
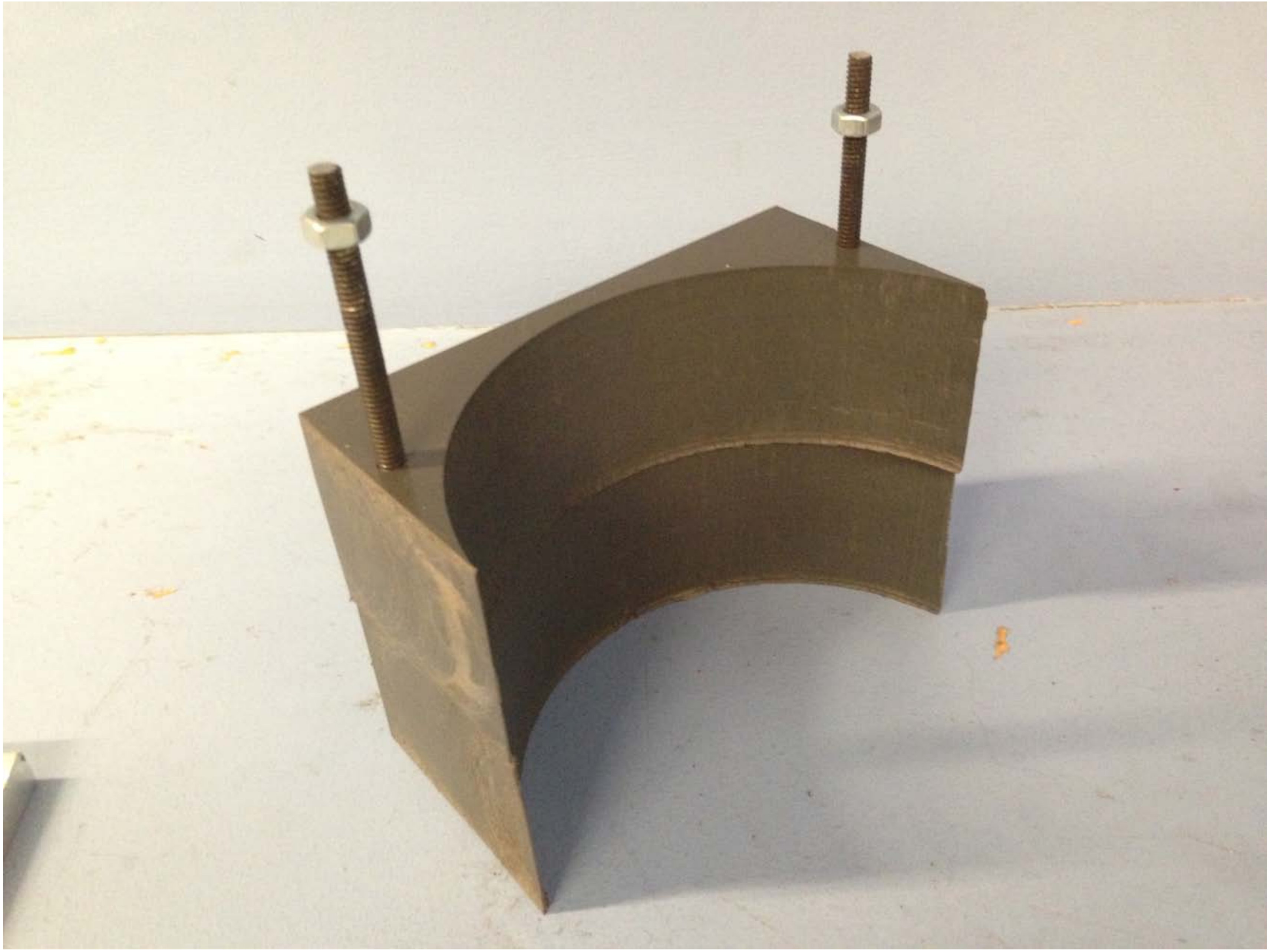
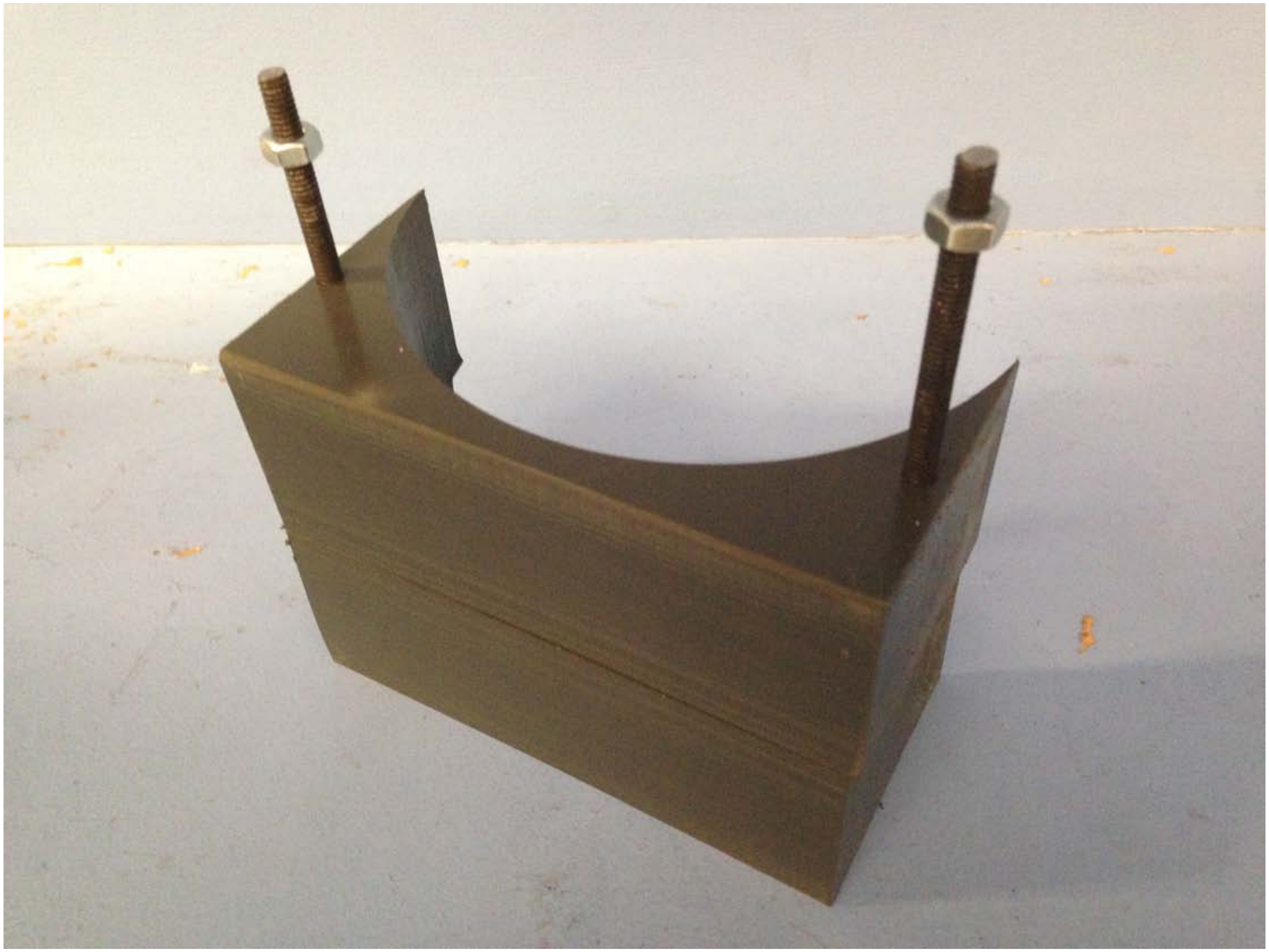
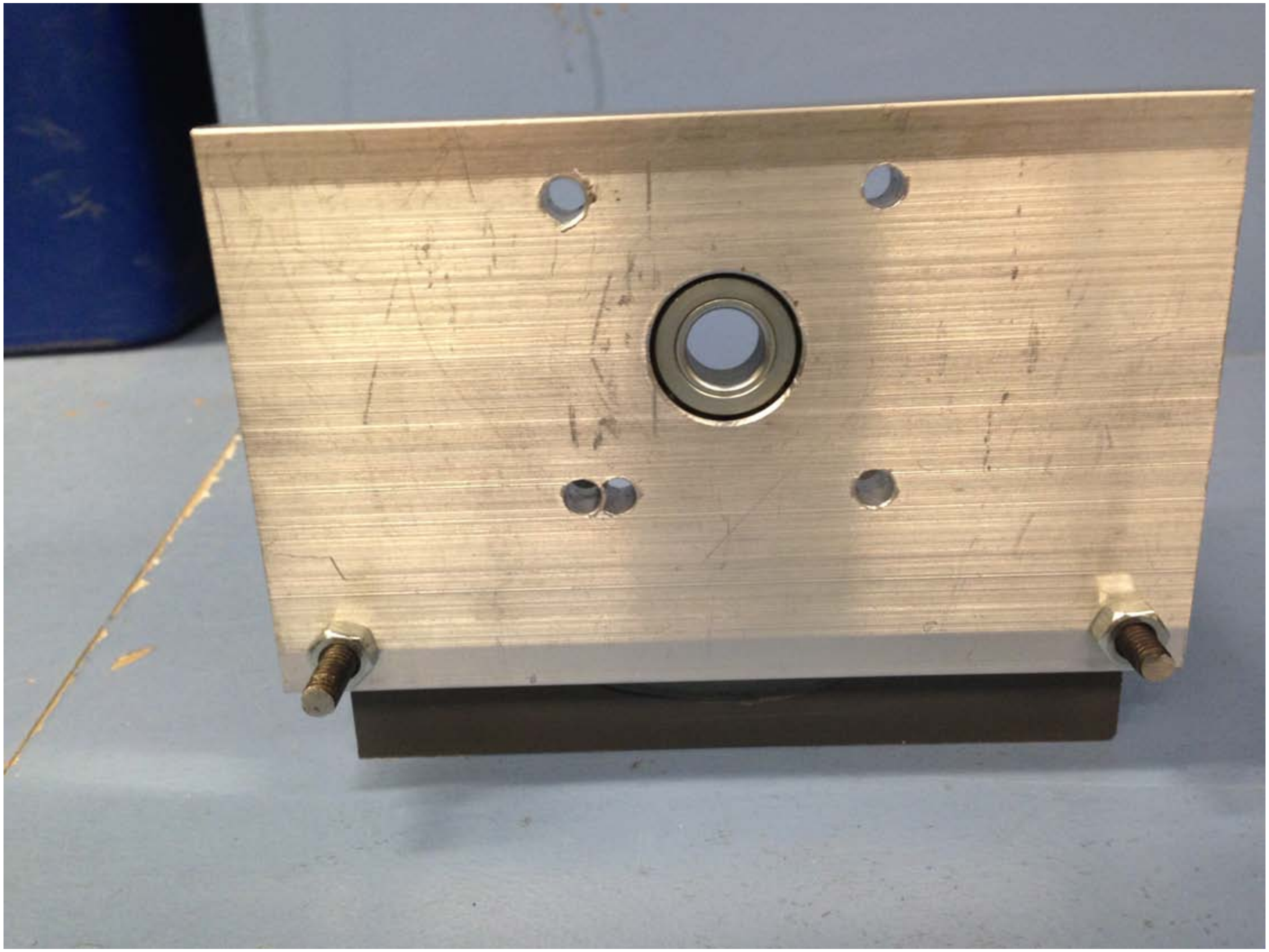


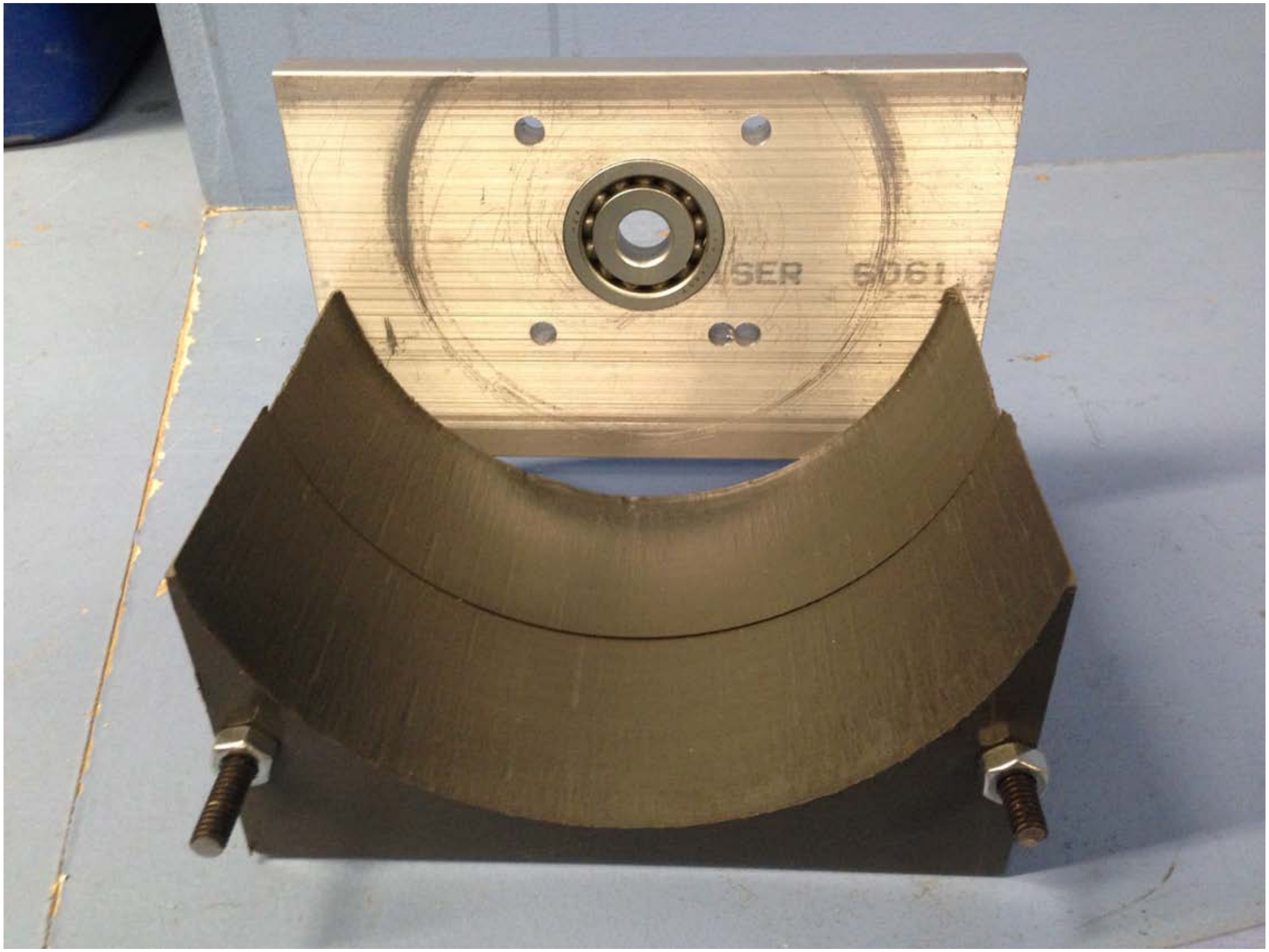
Fig 4.16. *Threaded Rod*. An example of a threaded rod. Note the food stain on the upper right.

Fig. 4.17. *Polyurethane Tubing*. Here is the terrible Polyurethane tubing that proved too stiff to be used with our peristaltic pump. Unfortunately, no picture of the heaven-sent Tygon tubing was taken.





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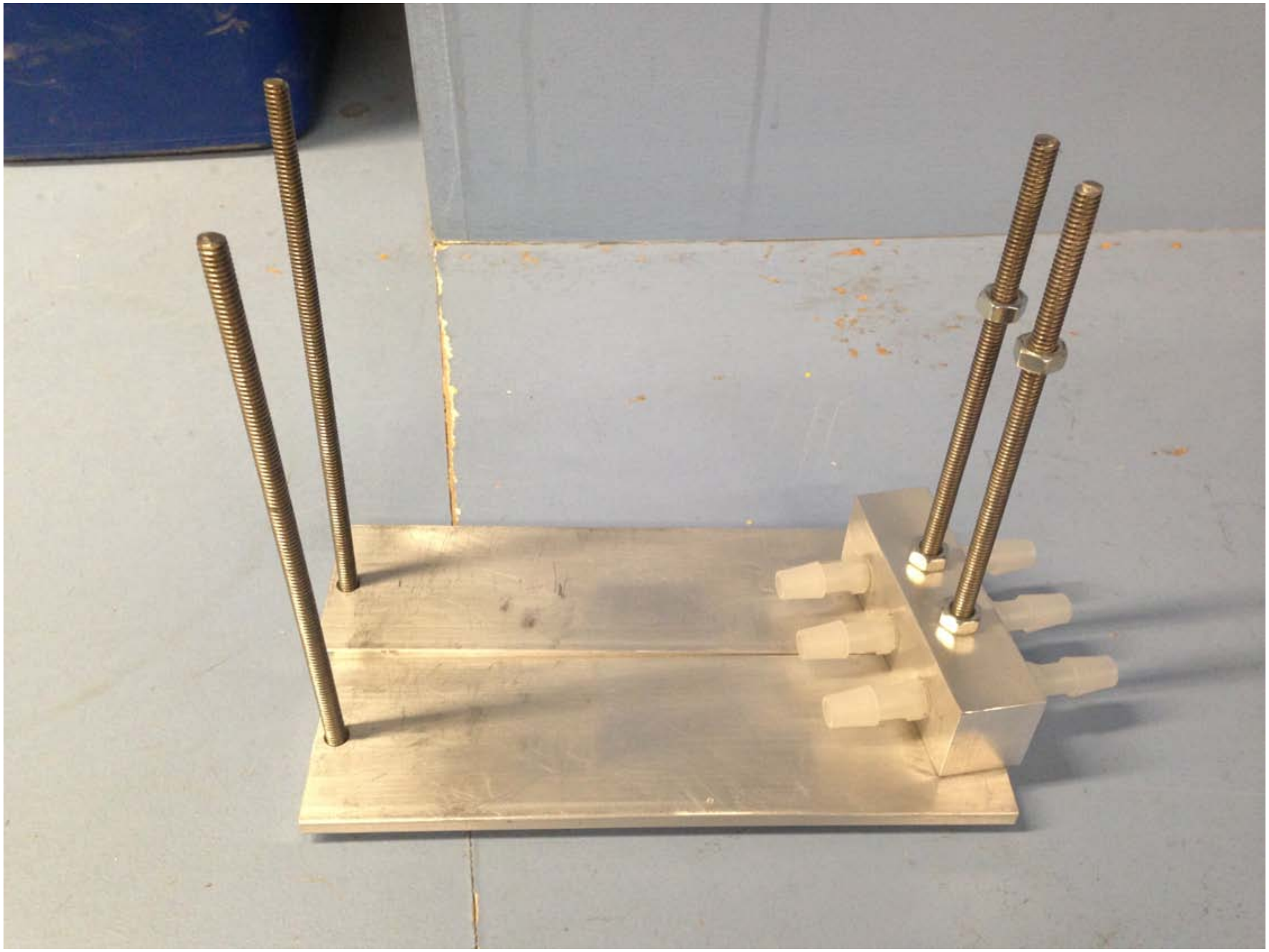
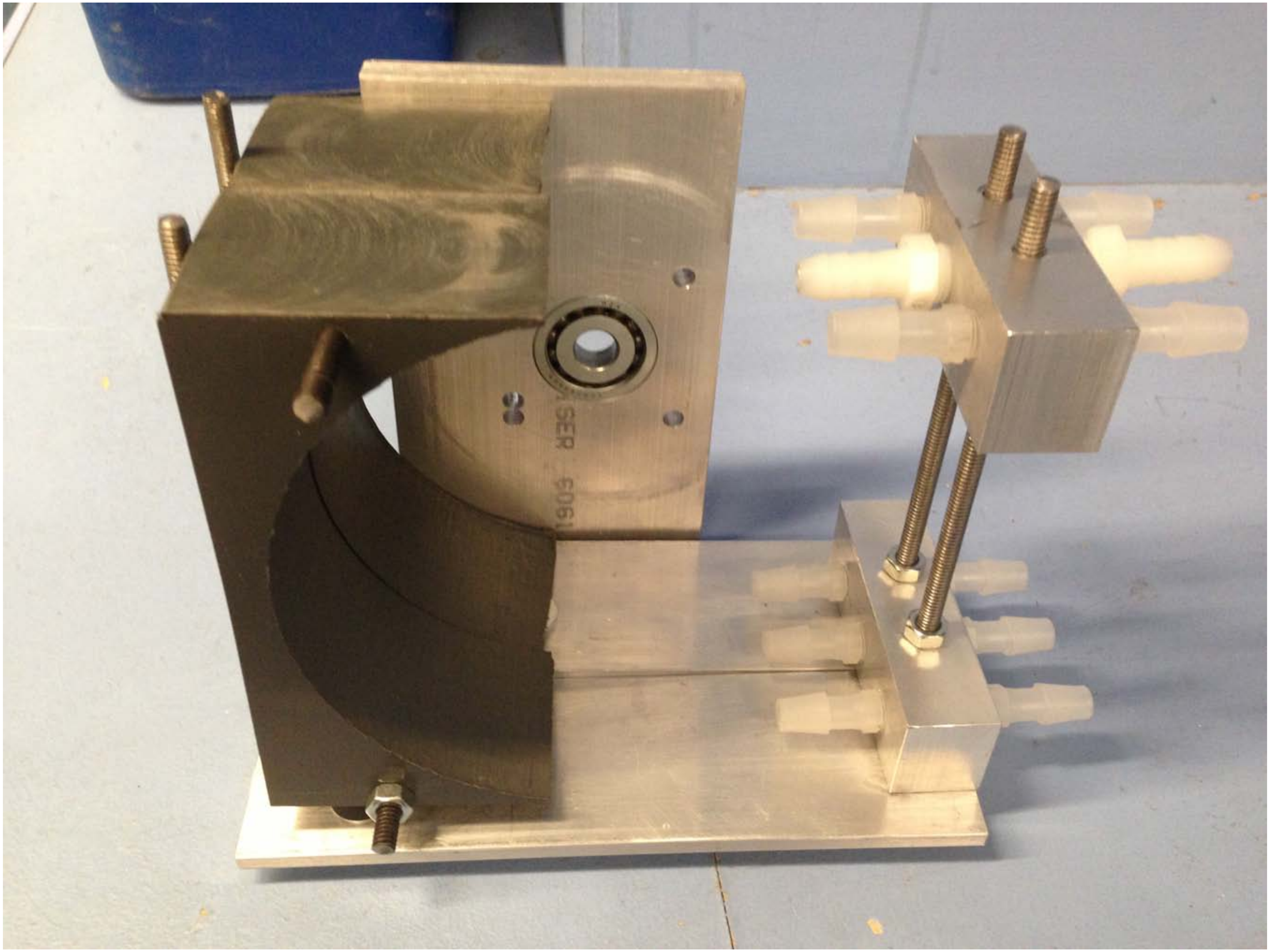
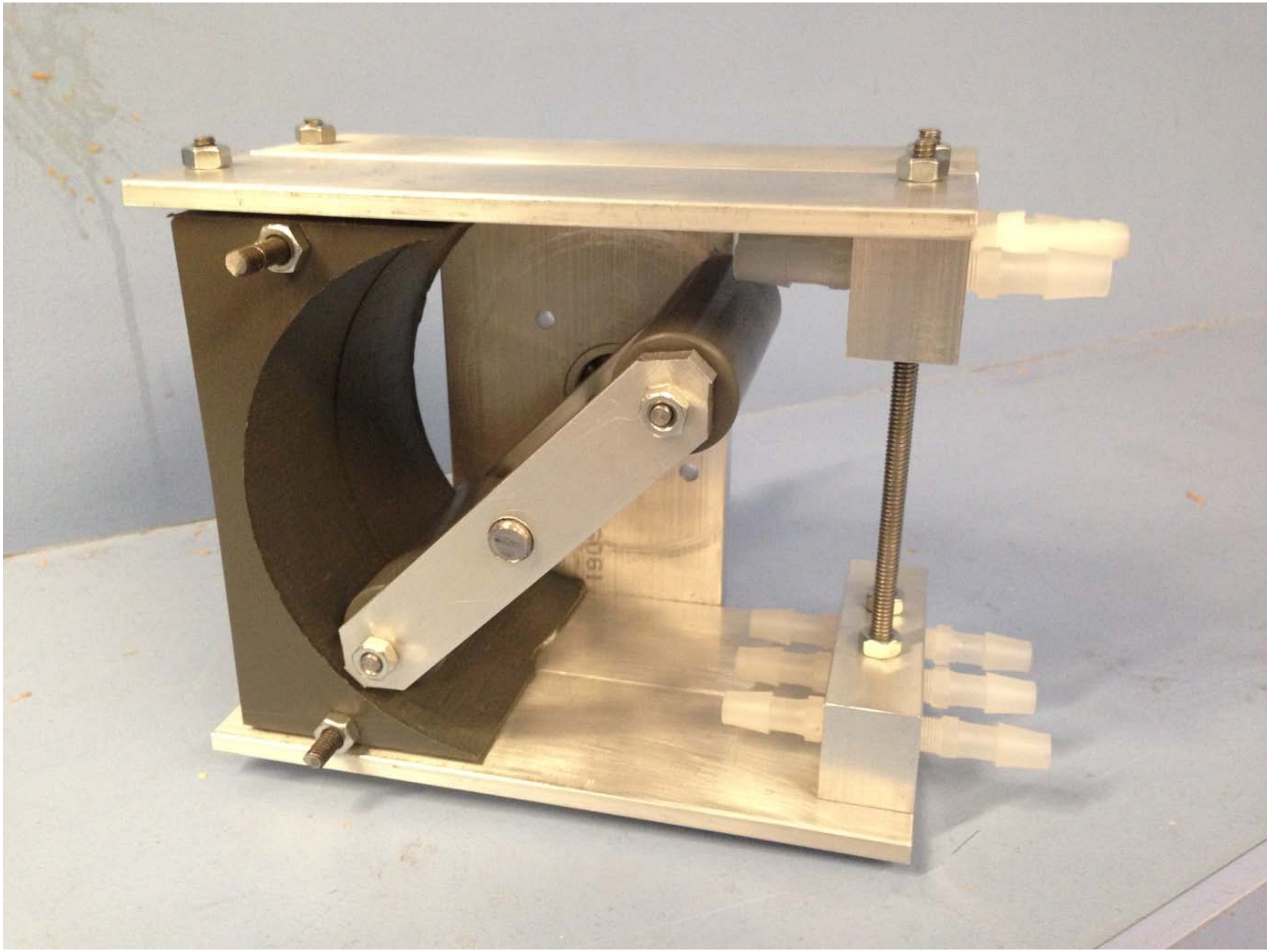


Fig. 4.23. *Starting to Assemble the Pump*. Note the location of the nuts on the threaded rods on the right. This is to keep the Fitting Jigs up where they are supposed to be. You will see how they just hang there in the next figure.





Phase 5: Presentation & Marketing

Total Work Hours

Table 5.1. *Total Work Hours*. This table shows how many total and individual hours every person had working on the pump.

	Engineering Hours	Total machining hours	Standard Work Week	Overtime Machining Hours
Rebecca	30.5	8		0
Anjit	33.8	15.5		6.375
Jesse	33.5	13.75		4.625
Herman	25	6		0
Saajan	31.5	5.5		0
Tim	22	6		0
Total	**176.3**	**54.75**	**9.125**	**11**

Environmental Energy Costs

Table 5.2. Environmental Energy Costs. This table shows how much our pump costs environment wise. In other words, it shows how eco-friendly our pump is. And although it might seem quite high, it actually is not. Since the pump only works on wind, it will be in general a lot more eco-friendly in the long run as it does not consume electricity produced by carbon emitting generators.

Material	Total Volume (Cubic Centimeters)	Total Mass (kg)	Energy Cost (MJ / KG)	Energy Cost	Carbon Cost (KG CO2 / KG)	Carbon Cost
AISI 1012 Steel	82.7	0.651	56.7	**39.9**	6.15	**4**
6061 T6 Alumimum	649.1	1.752	155	**271.6**	8.24	**14.4**
Delrin	557.8	0.786	123.8	**97.3**	2.5	**2**
PVC Tygon	65.4	0.077	77.2	**5.9**	2.41	**0.2**
Nylon	22.6	0.029	138.6	**4**	2.5	**0.1**
Total	1377.6	3.295		**418.7**		**20.7**

Total Costing of Pump

Table 5.3-5.4. *Total Costing of Pump*. Below are two tables. The first shows how much the pump costs in terms of Labor Units and the second shows the total cost of the Prototype. Of course, if our pump were to be mass-produced, the cost of an individual pump would go way down, down to 165 dollars or so.

Type	Labor Units		Parts
Holes	18		Support Plates, Back Arches, Rotary Arms, Fitting Jigs
Threads	21		Rotary Arms, Roller Shafts, Input Shaft, Fitting Jig
Mill Turn Flat	8		Support Plates, Rotary Arms, Fitting Jigs
Curved Surfaces	20		Back Arches
Cuts	18		Threaded Rods, Support Plates, Rotary Arms
Hand Finished Surfaces	28		Support Plates, Fitting Jigs, Rotary Arms
Total Labor Units		Total Cost	
113		**$135.60**	

Prototype Manufacturing Hours	Material Cost (dollars)	Total Prototype Cost (dollars)
65.75	29.99	23815.99

User Manual

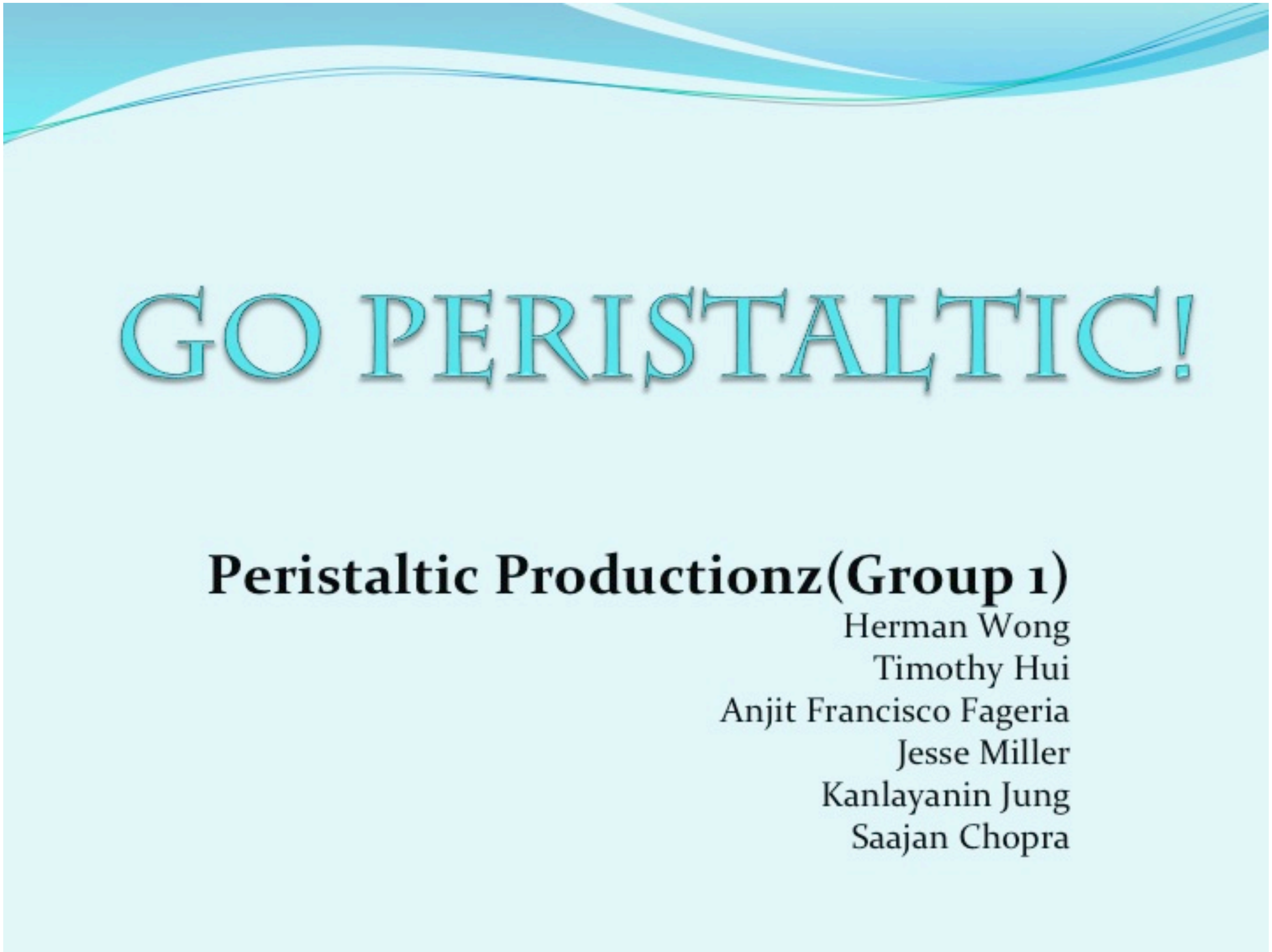
See the Link below for the User Manual:
https://cornell.box.com/s/ls3xh6jw42e2buak9pml

Product Development Report

See the link below for the Product Development Report:
https://cornell.box.com/s/xwqj6hnlfqk5tnqyrsb8

Marketing Presentation

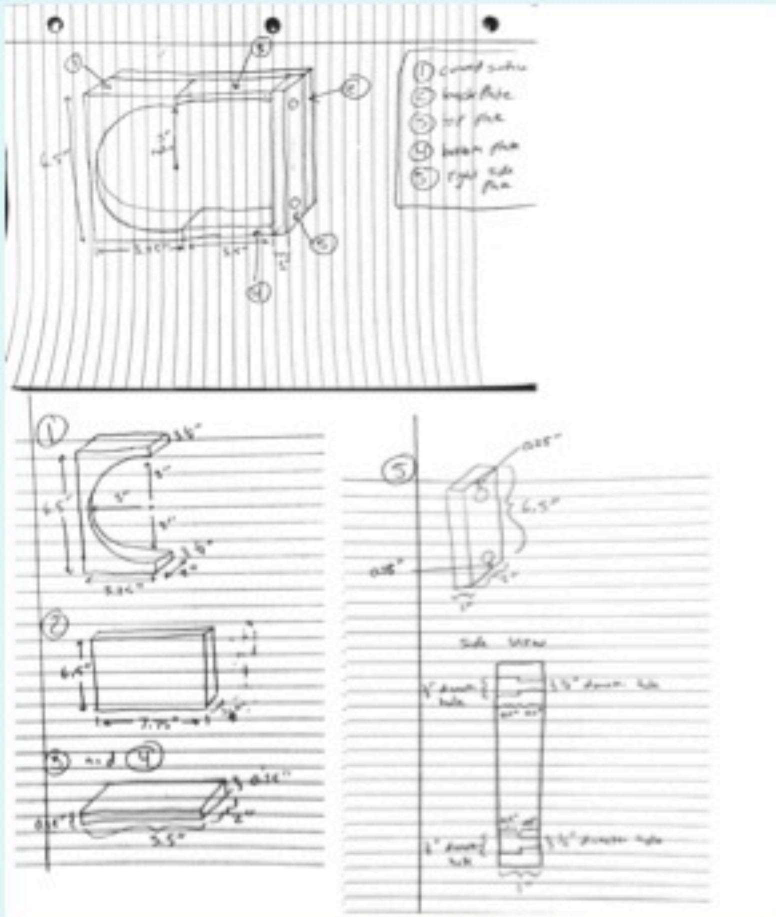
Figs. 5.1 – 5.16. *Marketing Presentation*. Below are the slides for the Marketing Presentation.



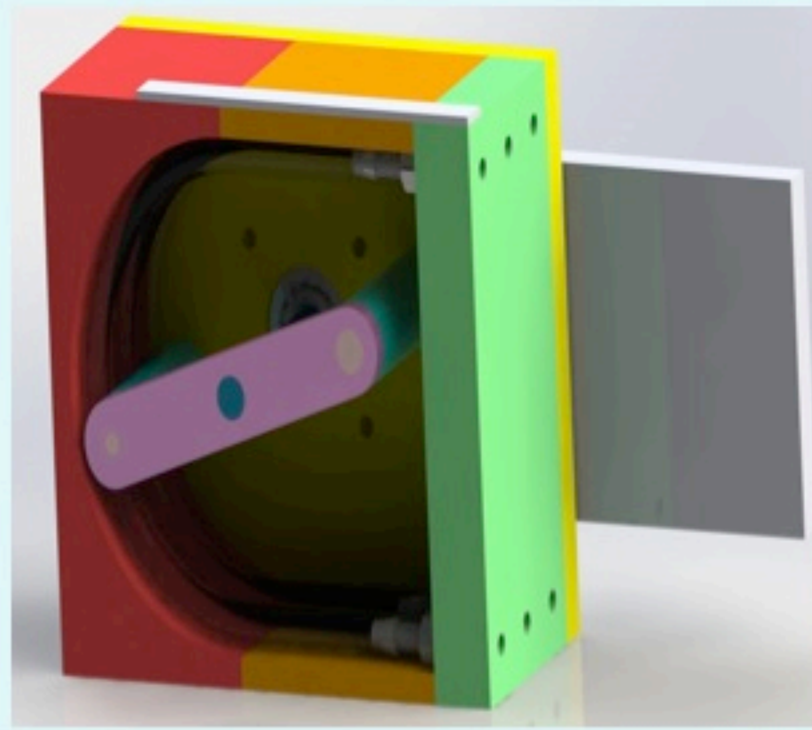
Customer Needs Satisfied

- Is able to attach to a windmill
- Securely stands on a 7"x7" platform
- Pumps water at rate of at least 1 L/min
- Pumps water to a height of 1.5 meters
- Attaches to a faceplate provided by the consumer
- Fits in a 14"x14"x14" space

Our Development Process

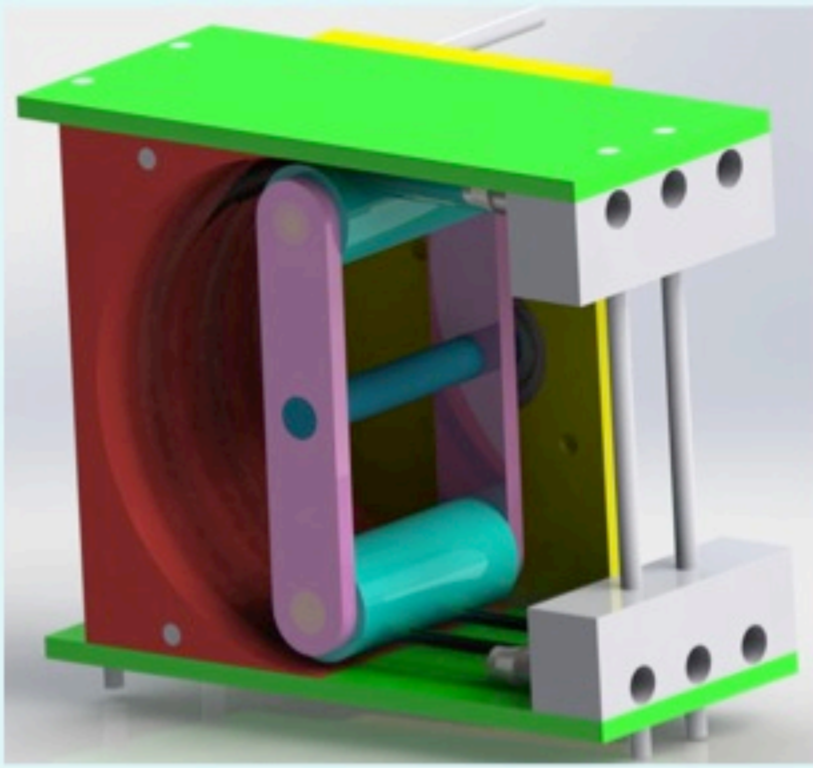


Initial Design Hand Drawings

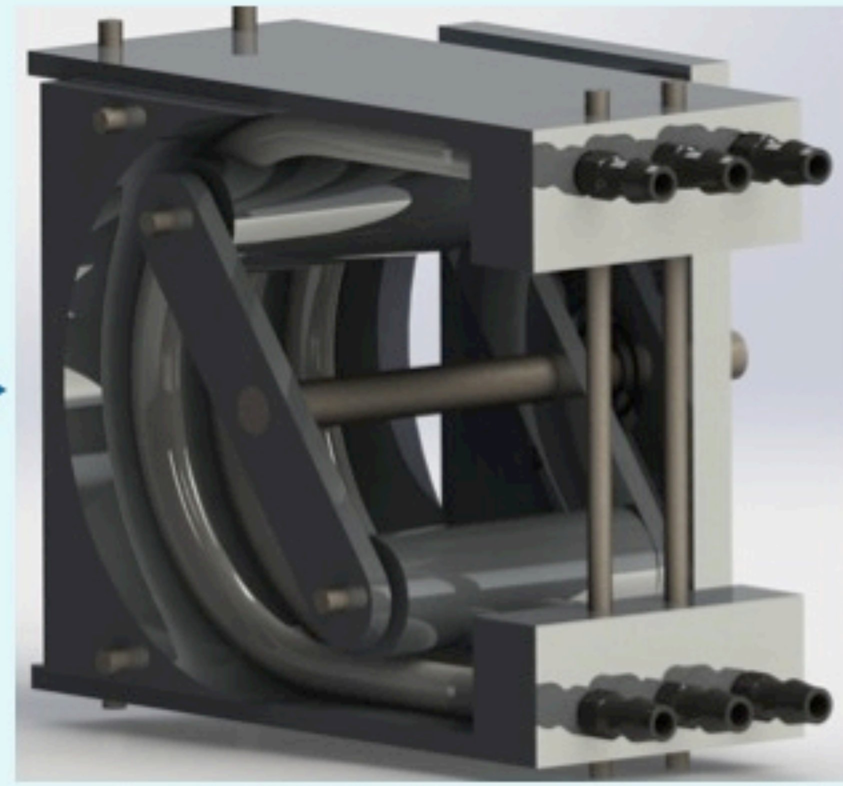


Design Version 1 Render

Our Development Process (Cont.)

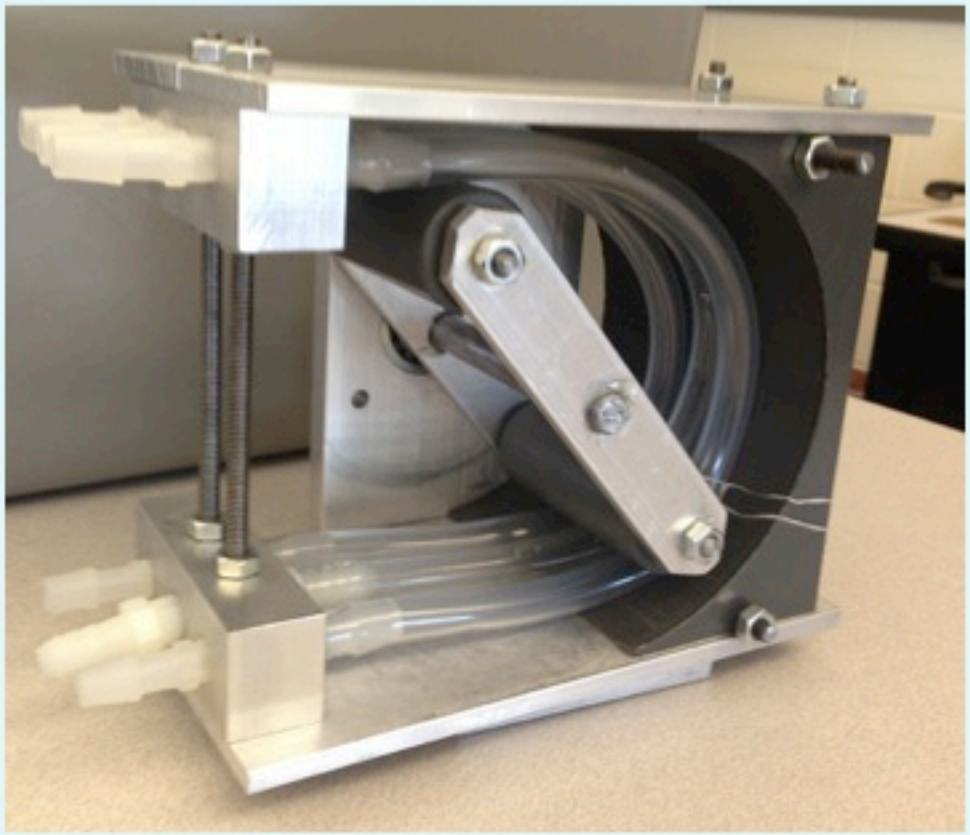


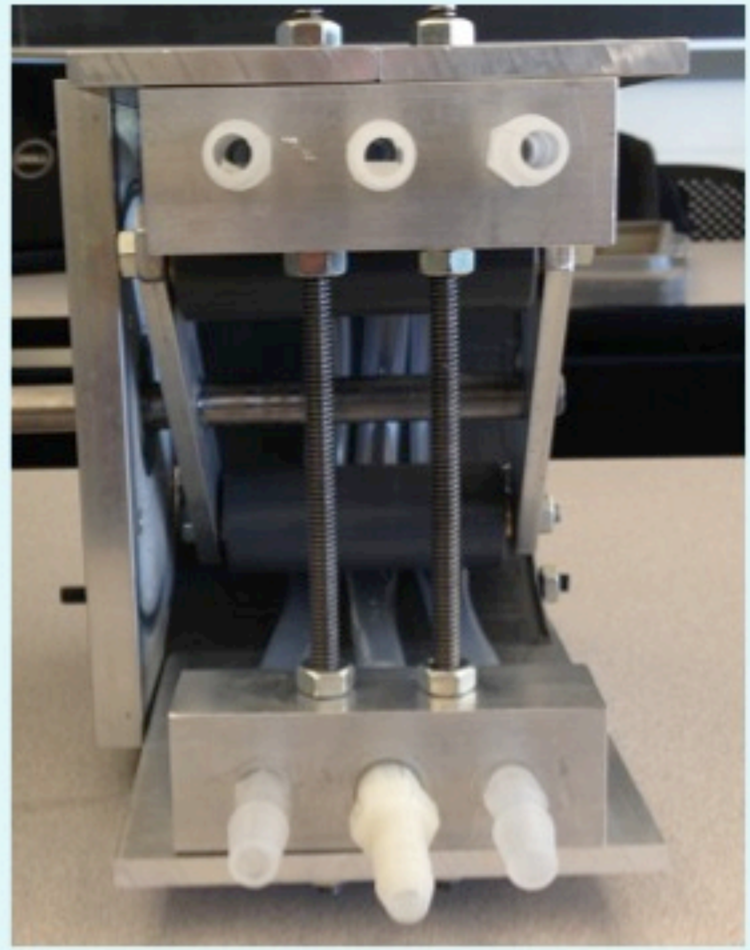
Design Version 2 Render



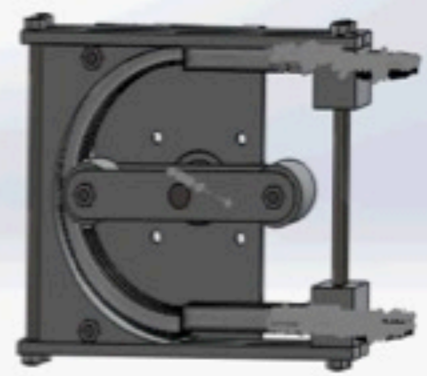
Design Version 3
(Final) Render

Final Product Photos





See how it works!



Wind Pump Specifications

Length = 9.1”

Width = 5.5”

Height = 7”

Weight = 6.97lbs

Power and Pump Rate

-Power Output at 4.23 Watts

-Assumed 20% Efficiency of our Pump

→Pumps 3.5 Liters per Minute

Cost of Parts

Vendor	Item Name/Description	Part/Order #	Quantity	Unit Price	Total
McMaster Carr	Ultra-Soft Clear Tygon PVC Tubing 3/8" ID, 1/2" OD, 1/16" Wall Thickness	5894K37	3.583	$2.87	$10.28
McMaster Carr	Chemical-Resistant Polypro Barbed Fitting High-Temp, Straight, 3/8" Tube ID X 1/8 Male Pipe	5121K411	1.2	$4.46	$5.35
McMaster Carr	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	6383K45	1	$5.88	$5.88
Emerson	1/2" Steel Rod (per foot) 1012 Steel		0.63	$1.65	$1.03
Emerson	1/4 - 20 threaded rod (per foot)		2.33	1.41	$3.29
Emerson	1/4 - 20 unthreaded rod (per foot)		0.75	$1.41	$1.06
Emerson	1/4 - 20 threaded rod (per foot)		0.92	$1.41	$1.29
Emerson	Bolts		20	$0.07	$1.40
Emerson	Washers		4	$0.04	$0.16
	Epoxy		0.043	$5.75	$0.25
					Total:
					$29.99

Cost of Labor

Type	Labor Units	Parts
Holes	18	Support Plates, Back Arches, Rotary Arms, Fitting Jigs
Threads	21	Rotary Arms, Roller Shafts, Input Shaft, Fitting Jig
Mill Turn Flat	8	Support Plates, Rotary Arms, Fitting Jigs
Curved Surfaces	20	Back Arches
Cuts	18	Threaded Rods, Support Plates, Rotary Arms
Hand Finished Surfaces	28	Support Plates, Fitting Jigs, Rotary Arms
	Total Labor Units	Total Cost
	113	$135.60


Total Cost
-Total Prototype Cost:
23,815.99 dollars.
-Product Cost per pump (1 sold):
23,951.59 dollars.
-Product Cost per pump (1000 sold):
159.41 dollars!

Energy and Carbon Cost

Material	Total Volume (Cubic Centimeters)	Total Mass (kg)	Energy Cost (MJ / KG)	Energy Cost	Carbon Cost (KG CO2 / KG)	Carbon Cost
AISI 1012 Steel	82.7	0.651	56.7	**39.9**	6.15	**4**
6061 T6 Alumimum	649.1	1.752	155	**271.6**	8.24	**14.4**
Delrin	557.8	0.786	123.8	**97.3**	2.5	**2**
PVC Tygon	65.4	0.077	77.2	**5.9**	2.41	**0.2**
Nylon	22.6	0.029	138.6	**4**	2.5	**0.1**
Total	1377.6	3.295		**418.7**		**20.7**

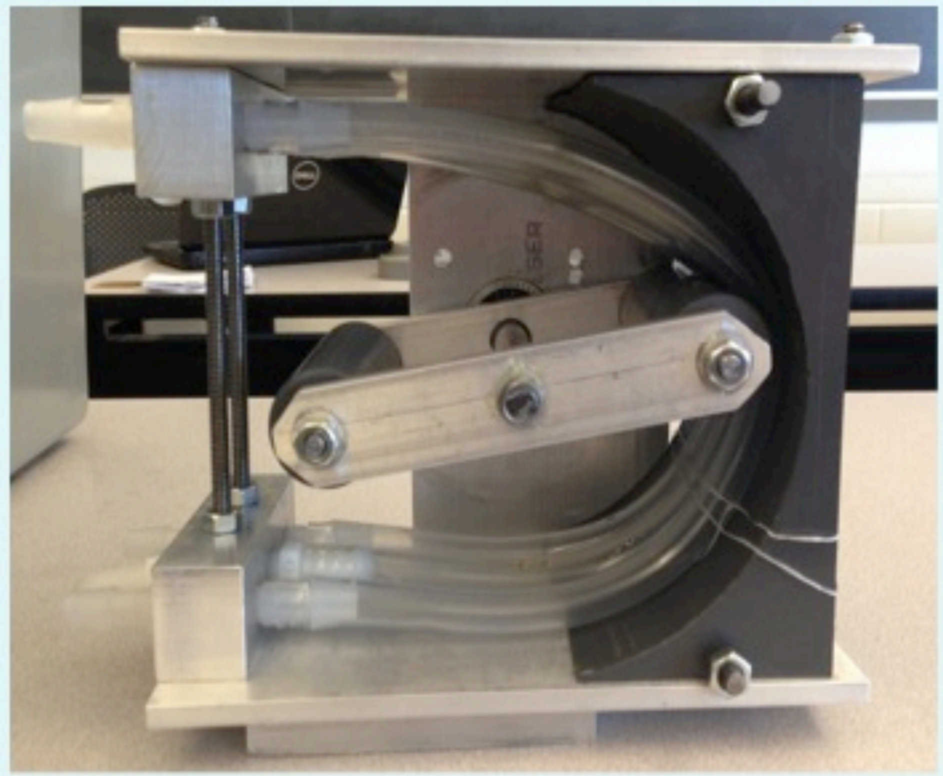
Strengths

- Low maintenance costs
- No slip
- Dry running and self-priming
- Abrasion Resistant
- High Suction Lift

A Quick Test Run...

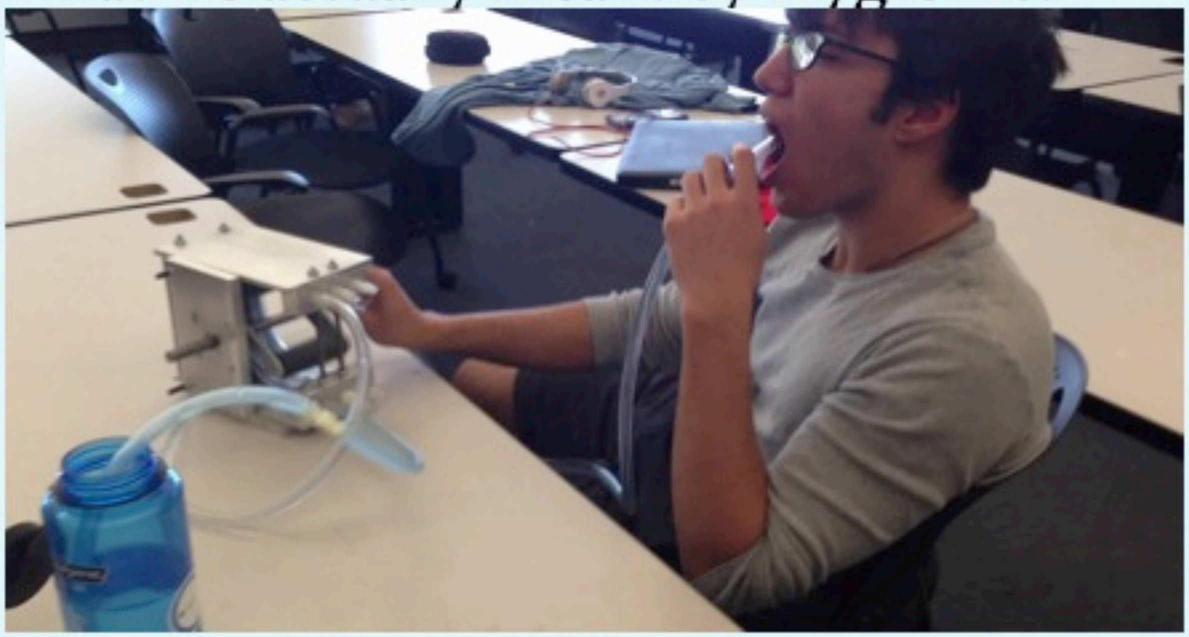
Why Pick this Pump?

- Versatility
  - Hygienic
  - Reversible
  - Solids Handling
  - Accurate Dosing
- Gentle Pumping Action
- Ease of Use/Maintenance



And if that Didn't Convince You…

This is what we actually meant by **Hygienic**:



Completely sanitary for all types of liquids…

(Like root beer!)

Phase 6: Iteration

We did it!!

Below is a copy of our technical report on our peristaltic pump, showing how the testing went and what changes we could make to our pump in order to improve it. Here is a link to our actual Technical Report: https://cornell.box.com/s/pvwls4ghla86ft6b5ffa

Test Run Images and Video

Click on the link below to see a video of our pump working during Testing!: https://cornell.box.com/s/16h2xajes8ukmlrk0lfr

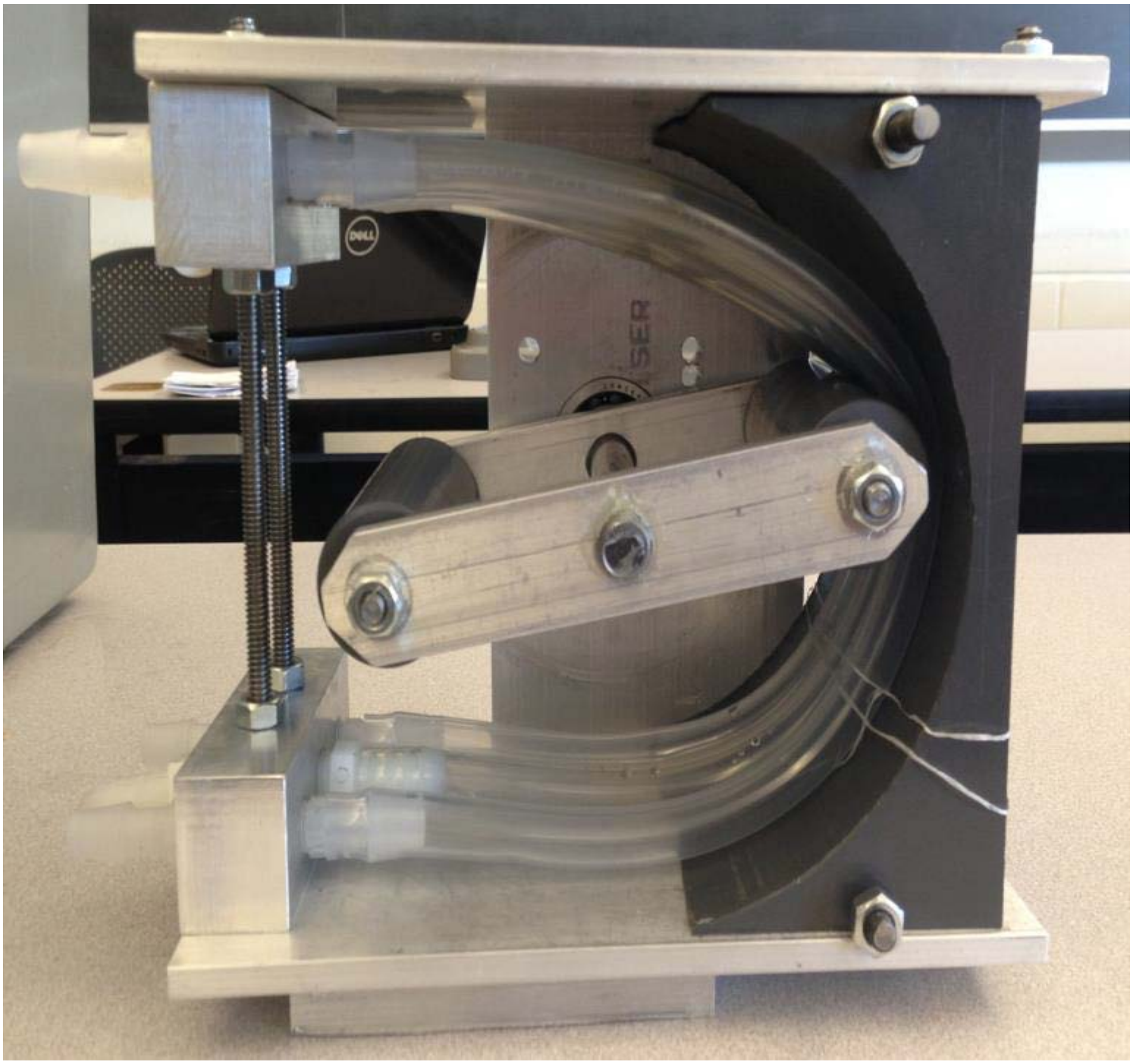


Fig 6.1. *Ready For Testing!* This is our pump ready for its testing today!

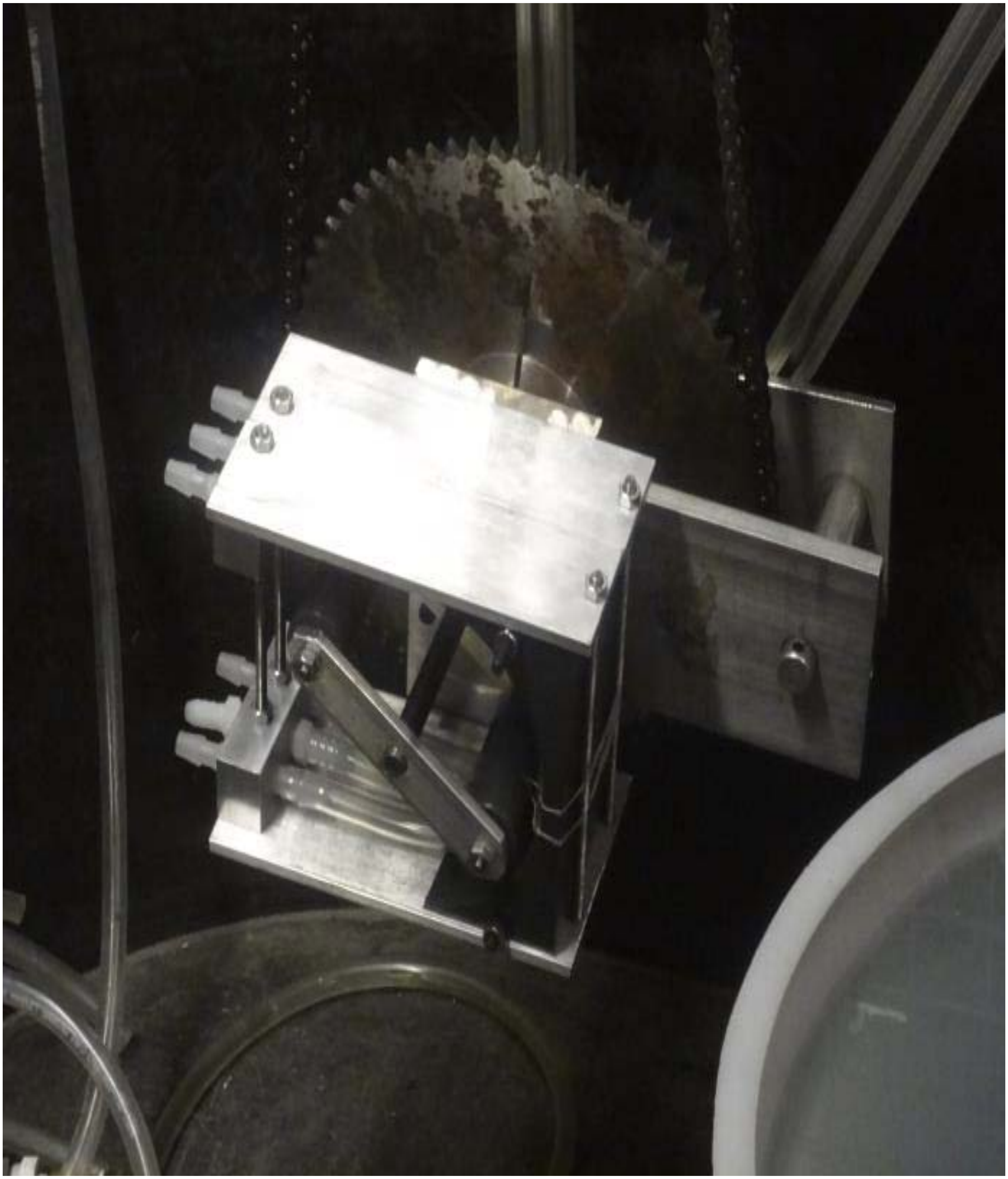


Fig 6.2. *Almost There*. Our pump attached to the faceplate and gear, getting ready for the moment of truth.

Fig 6.2. *Testing Facility*. Our pump attached to the faceplate and gear, getting ready for the moment of truth. From here you can see the whole testing room.

Evaluation

First Run:

- **Setup:** For our first run, the pump was set up in the standard configuration. All three Tygon tubes were attached to the pump in order to maximize volume flow rate. The nuts were also tightened to prevent the parts from rattling or shifting positions while the pump ran. From previous test runs of the pump, it was discovered that the tubes tended to shift away from the rollers as the pump ran. To solve this problem effectively and inexpensively, dental floss was wrapped around the tubing preventing it from shifting position.
- **Results:** The first run was successful, having a flow rate of **1.5 liters per minute** and pumping the water up a height of **1.5 meters.** This flow rate surpassed the requirement of 1 liter per minute. The dental floss used to hold the tubes in place did its job successfully. Virtually no leakage occurred and basically all the water was pumped into the measuring container. One noticeable flaw in the run was the time the pump took to extract the water from the bucket and into the body of the pump. It took about 40 seconds for the pump the draw the water in. However, once the water had entered the pump body, the flow rate increased considerably and it only took 15 seconds for the water to reach the required 1.5 meter height. The flow of the water was very steady, as opposed to some other pump designs (such as piston pumps) that pump the water in bursts.

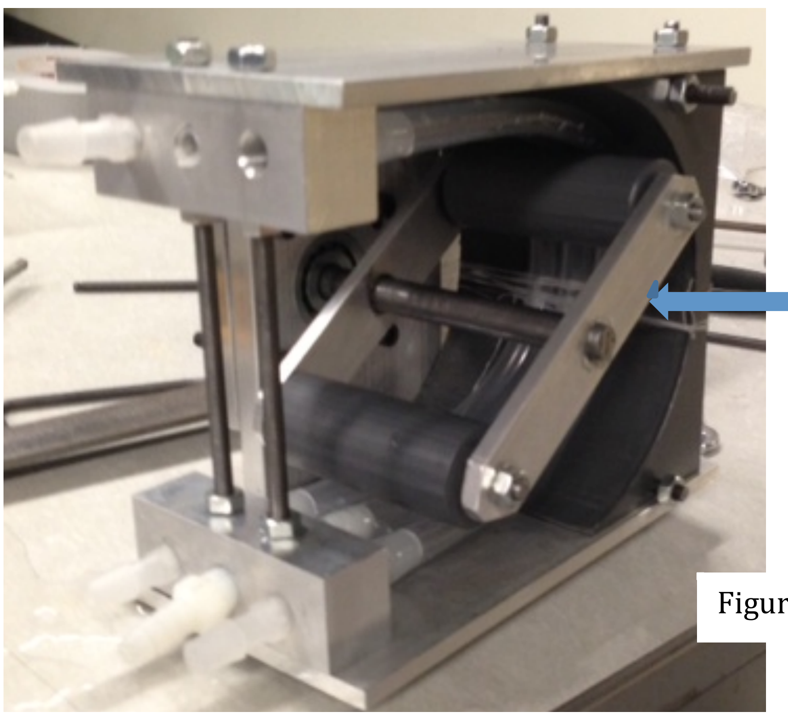


Figure 1

Second Run:

- **Setup:** For the second run, a single adjustment was made for the purpose of increasing flow rate. A 1.2 mm stack of paper sheets covered in blue tape was inserted behind the curved tubes, as seen in Figure 2. The purpose of these sheets was to decrease the radius of curvature of the Delrin semicircle that the Tygon tubes were compressed against. In earlier tests, it was found that the rollers did not seem to apply adequate pressure on the tubes when compressing it against the Delrin semicircle. By decreasing the radius, the rollers were able to apply more pressure to the tubes thus increasing the flow rate. Another difference between the first run is that the water was already in the tubes from the previous test. Since the water was already in the tubes, pump would be able to start pumping a lot faster.

- **Results:** As expected, the water began pumping sooner since the water was already in the tubes. The effect of the paper padding was also very noticeable. The water flowed at a faster rate as a result of the increased pressure on the tubes. For this round, the water flowed at a rate of **4 liters per minute**, over 2.5 times more than the previous trial. Unfortunately, the paper padding slid out its position slightly only 10 seconds after it started rolling. Had the paper padding been more securely fastened to the pump, it is possible that the flow rate could have surpassed 4 liters per minute. Just like the previous round, there was almost no leakage and the flow rate was steady. Another interesting observation is that our analysis predicted a flow rate of 3.5 liters per minute. This prediction was based upon an approximation of 20% efficiency. The actual flow rate compared to the predicted flow rate was quite close, indicating that our analysis was accurate. In fact, it is possible that our pump was more than 20% efficient since the actual flow rate exceeded the predicted flow rate by 0.5 liters per minute.

Figure 2

Revisions and Improvements To the Windpump

While our pump did fantastically, this pump could have had some revisions and improvements in order to make it work more effectively than it did today:

1. Firstly, it was difficult to keep the machining as accurate as possible, especially for the Delrin back arch piece. Because we had to use a rotary table rather than more accurate methods such as CNCing, the circle made might have been a few millimeters off of the values that were specified in the part drawings. This could have made the roller piece, which was a bit easier and hence more accurate to machine, a bit off in the way that it was supposed to push up against the Tygon tubes and the Delrin, and this would therefore ruin the airtight seal and let the water slip back in the pump. This actually occurred in the pump's testing as can be seen in the videos and recordings made, as one can see that it took a rather long while for the water to be pushed up into the peristaltic pump, which means that it took a while for the rollers to squeeze out enough air to make the water want to fill the empty space. This means that there potentially existed a leak in the tubing, and the only real potential problematic area was the Delrin arch, because the Aluminum top and bottom supports were be adjusted to be higher or lower in order to make the seal as tight as possible. Of course, it is extremely difficult to machine anything as accurately as

possible, but any process that would increase our accuracy would benefit this pump, its ability to create an airtight seal, and thus benefit the customer.

A potential improvement and solution to this could be making slots in the rotary arm that would allow the rollers to be adjusted back or forth as necessary so that it could create more or less pressure on the tubes as required. However, this pump had its rollers epoxied so any changes now are practically impossible.

Another potential solution to this problem is lining the Delrin with enough tape or material to make the seal as airtight as possible. As can be seen from the recordings, on the second try of testing, a blue-taped sheet of paper of only 1.2mm thickness (as can be seen in Fig 2) was inserted to line the Delrin arch, and this already created much of a difference. The pump improved its water pushing capabilities from 1.5 L/min to 4 L/min, and this was even done with that sheet of paper slipping out of place. So, something as simple as lining an inaccurately machined Delrin arch with a sheet of paper improved the pumping capacity 2.6 times.

2. Secondly, another necessary revision would be to create some way to successfully contain all the inner tubes so that they do not move out of position and lose the airtight seal capabilities that they have when they are in place. This happened quite a bit, especially before testing, and a solution was tying the tubes with dental floss—something small enough to prevent any disruption of the pump's functionality but strong enough to keep the tubes in place—but of course, this is not a very professional solution per say. Perhaps, if some sort of slot or adhesive were used on the back of the Tygon tubes, this improvement could be made.

3. Thirdly, a revision to be made is definitely in the pieces that the tube fittings were attached to. The threading in the holes that would accommodate the tube fittings was at times fantastic, but other times atrocious, making it incredibly difficult to insert the fittings at times and even making them crooked and letting them leak. Also, making all tube fittings equal would allow for easier usability and replacement of parts later on, although the different fitting had to be used because of costing issues.

4. Fourthly and finally, another revision would be adding zip-ties or some sort of tube fitting fasteners in order to ensure the tubes stay on the fittings and to reduce any potential leakage as well.

Final Summary Slide

See the link below for a link to our final summary slide:
https://cornell.box.com/s/ds1j6d9xhcpr8z3uzu06

FIN!