Engineering Design & Documentation

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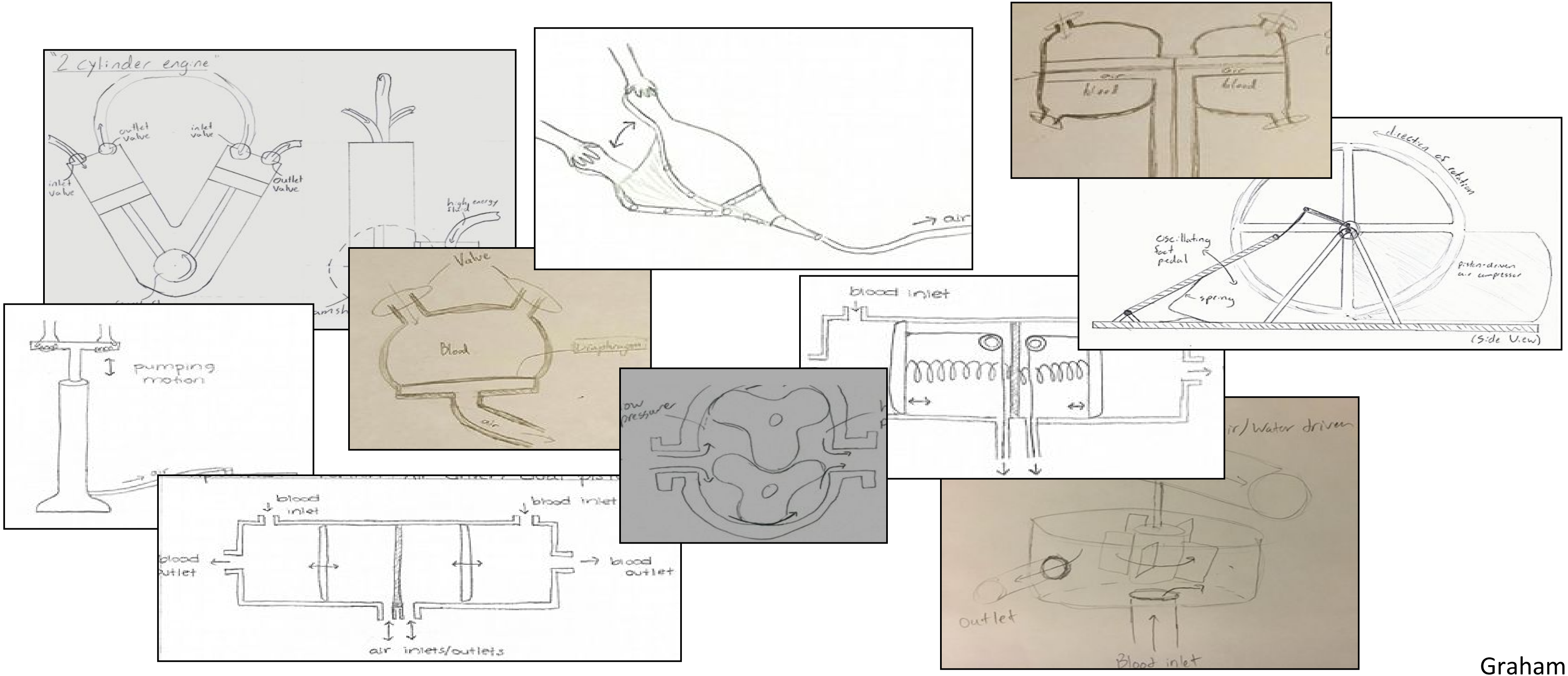
At the start of the project, we had too many design options to be effective.



Graham

A decision matrix was created for each of the designs that advance[illegible]inary round of

Driver Decision Matrix

Criteria	Weight	oot pedal w/ flywheel		Bike pump		t lever arm	Bellows	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Weighted Score	Raw Score	Weighted Score
output	21.0%	4	0.84	5	1.05	0.84	5	1.05
energy efficiency	11.7%	5	0.58	4	0.47	0.47	2	0.23
needs conversion	0.0%	2	0.00	5	0.00	0.00	5	0.00
precision of man.	18.7%	4	0.75	1	0.19	0.56	5	0.93
manufacturability	9.3%	3	0.28	1	0.09	0.37	4	0.37
complexity	4.7%	2	0.09	1	0.05	0.14	5	0.23
ease of use	14.0%	4	0.56	2	0.28	0.42	1	0.14
assembly	2.3%	2	0.05	5	0.12	0.09	5	0.12
durability	9.3%	3	0.28	2	0.19	0.37	2	0.19
size	2.8%	2	0.06	4	0.11	0.11	3	0.08
weight	4.7%	1	0.05	3	0.14	0.14	5	0.23
cost	1.4%	2	0.03	1	0.01	0.04	4	0.06
% Awesomeness (sum)	100.0%		71.3%		53.9%	71.3%		72.9%

Driver Decision Matrix

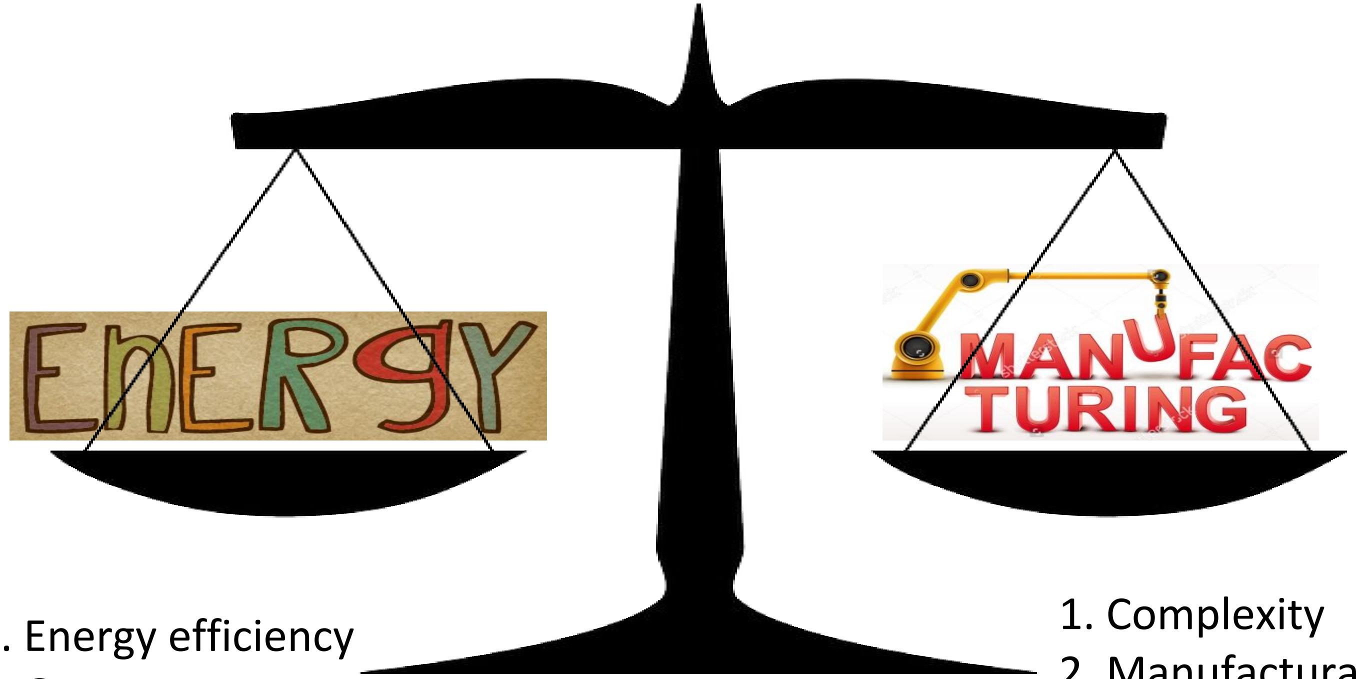
Criteria	Weight
output	21.0%
energy efficiency	11.7%
needs conversion	0.0%
precision of man.	18.7%
manufacturability	9.3%
complexity	4.7%
ease of use	14.0%
assembly	2.3%
durability	9.3%
size	2.8%
weight	4.7%
cost	1.4%
% Awesomeness (sum)	100.0%

Implantable Portion

Criteria	Weight	Air driven dual piston		Circular Expansive Diaphragm		ircular C						Center-to-Side Fan Pump		Center Fan Pump	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Sc						Raw Score	Weighted Score	Raw Score	Weighted Score
output	20.20%	5	1.010	3	0.606	3						4	0.808	3	0.606
Output speed	16.16%	3	0.485	[illegible]	0.323	2						3	0.485	3	0.485
energy efficiency	16.16%	5	0.808	4	0.646	5						2	0.323	2	0.323
durability	8.08%	2	0.162	1	0.081	3						4	0.323	3	0.242
precision of man.	14.14%	2	0.283	4	0.566	4						4	0.566	3	0.424
complexity (risk factor)	12.12%	3	0.364	2	0.242	4						3	0.364	3	0.364
manufacturability	10.10%	4	0.404	4	0.404	5						3	0.303	3	0.303
ease of seal	2.02%	2	0.040	5	0.101	4	0.081	5	0.101	4	0.081	3	0.061	2	0.040
cost	1.01%	3	0.030	4	0.040	5	0.051	4	0.040	5	0.051	3	0.030	3	0.030
size	2.02%	4	0.081	4	0.081	5	0.101	4	0.081	5	0.101	5	0.101	5	0.101
% Awesomeness (sum)			71.72%		60.20%		73.33%		68.28%		81.82%		65.25%		56.36%

Graham

Energy and manufacturability were taken to be the two biggest concerns with the project.

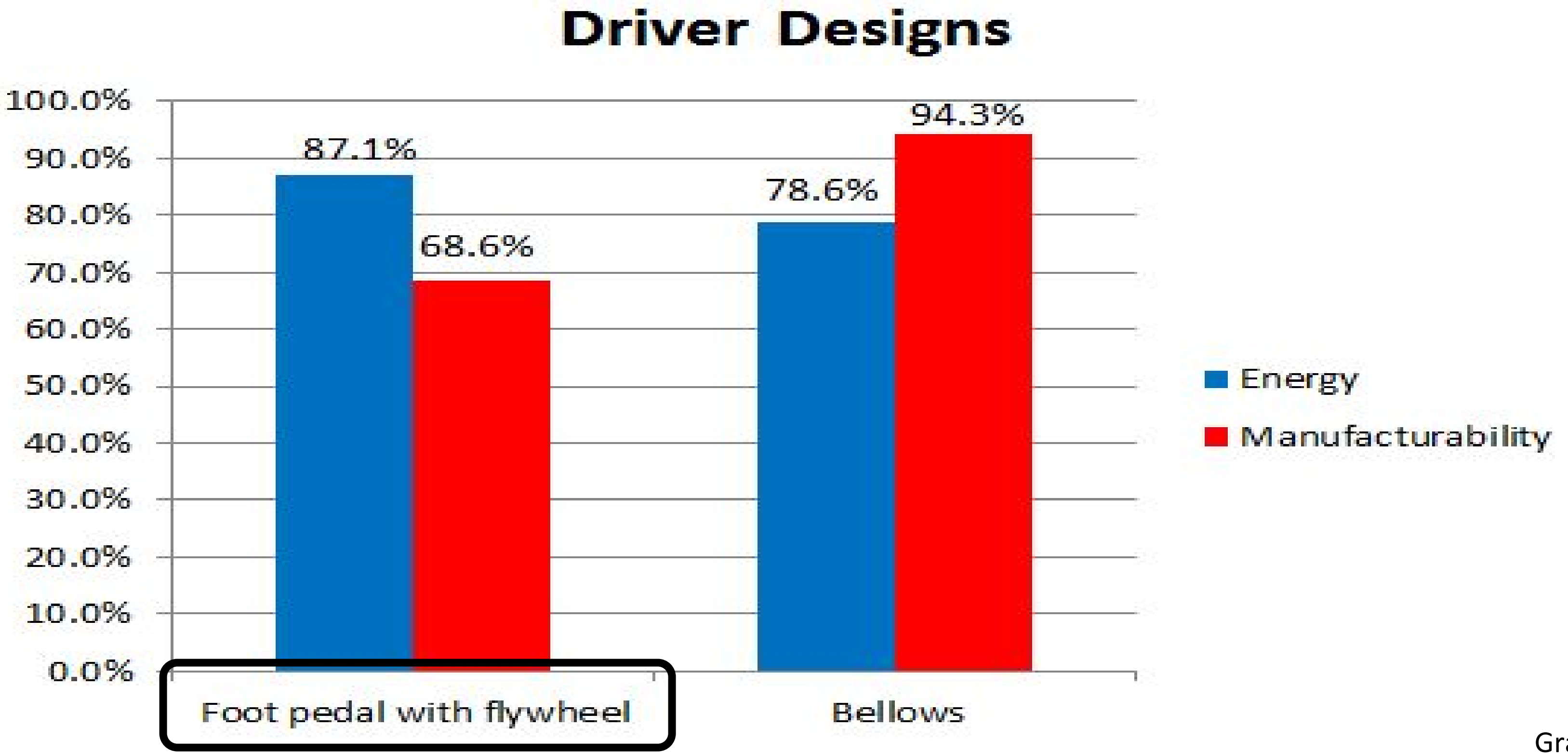


1. Energy efficiency
2. Output

1. Complexity
2. Manufacturability
3. Precision of manufacturing

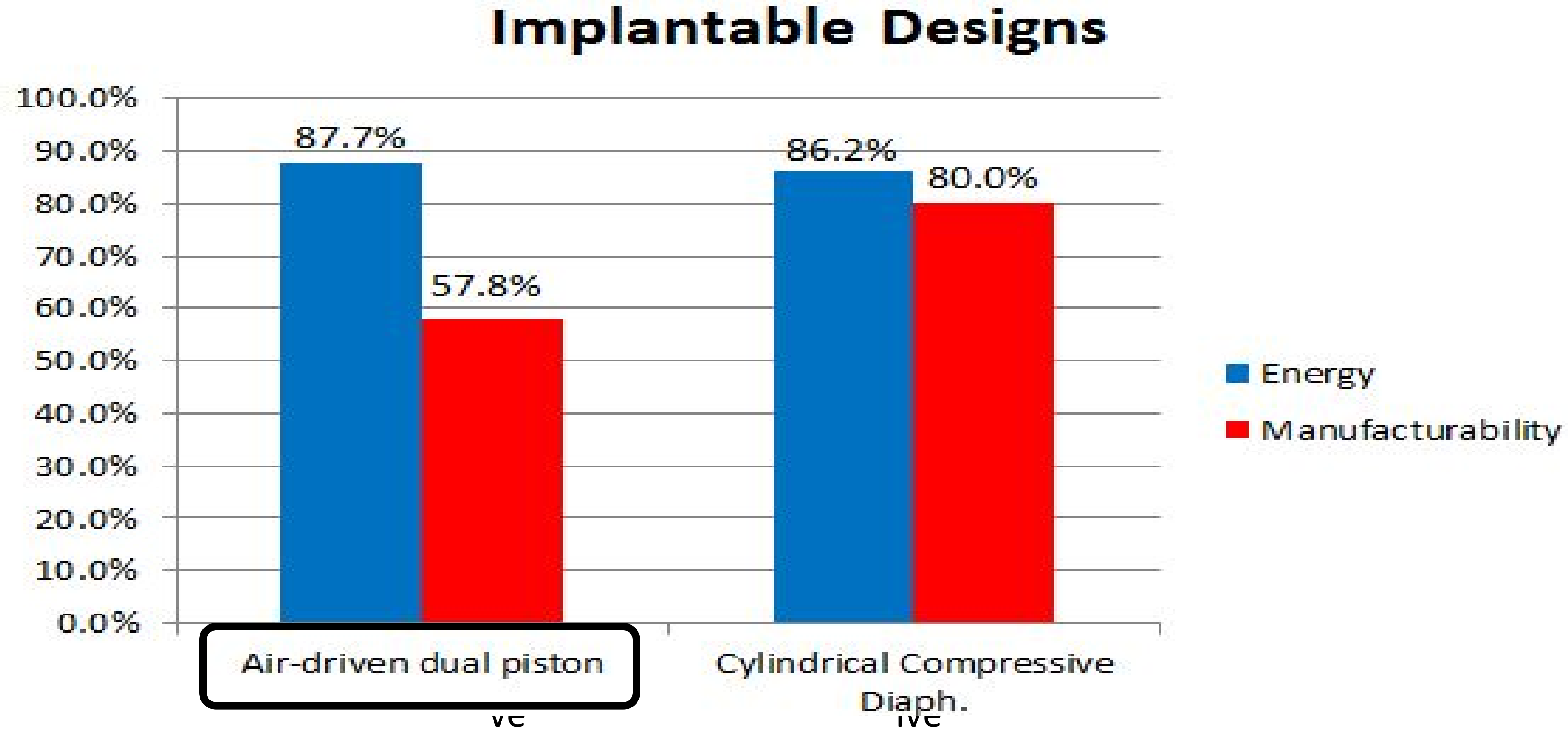
Graham

Since no one design was a clear winner, we sought to differentiate even more.



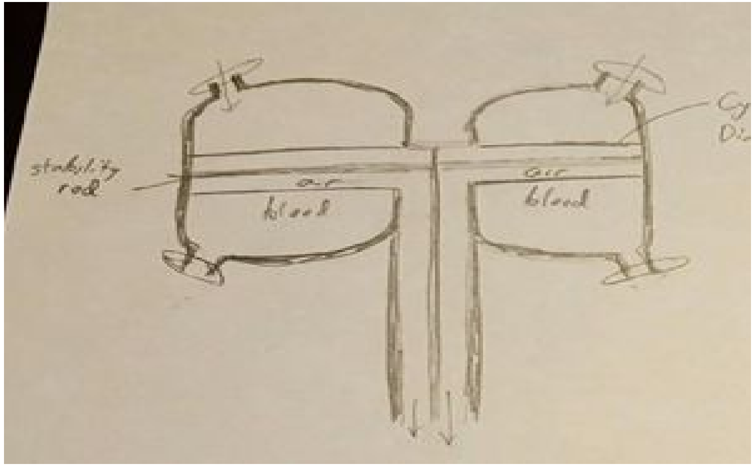
Graham

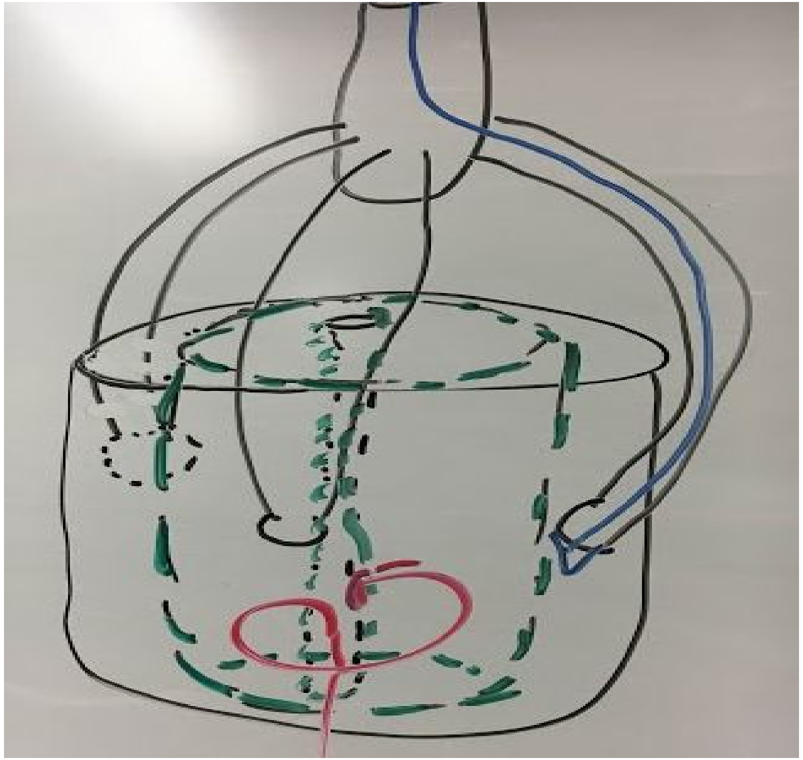
This process was also completed for the internal portion designs.



Graham

The cylindrical compressive diaphragm was not chosen due to unanticipated complexity.

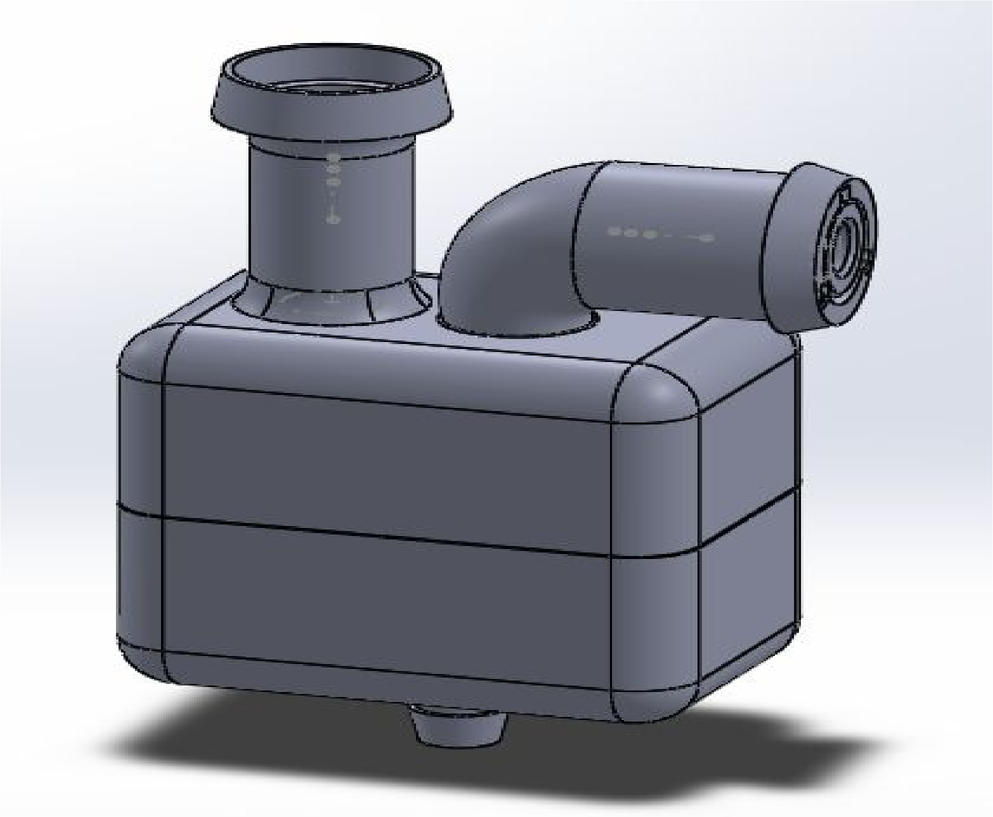




Pressure differential in transient flow (dV/dt)

Graham

The final design for the internal portion is shown below.



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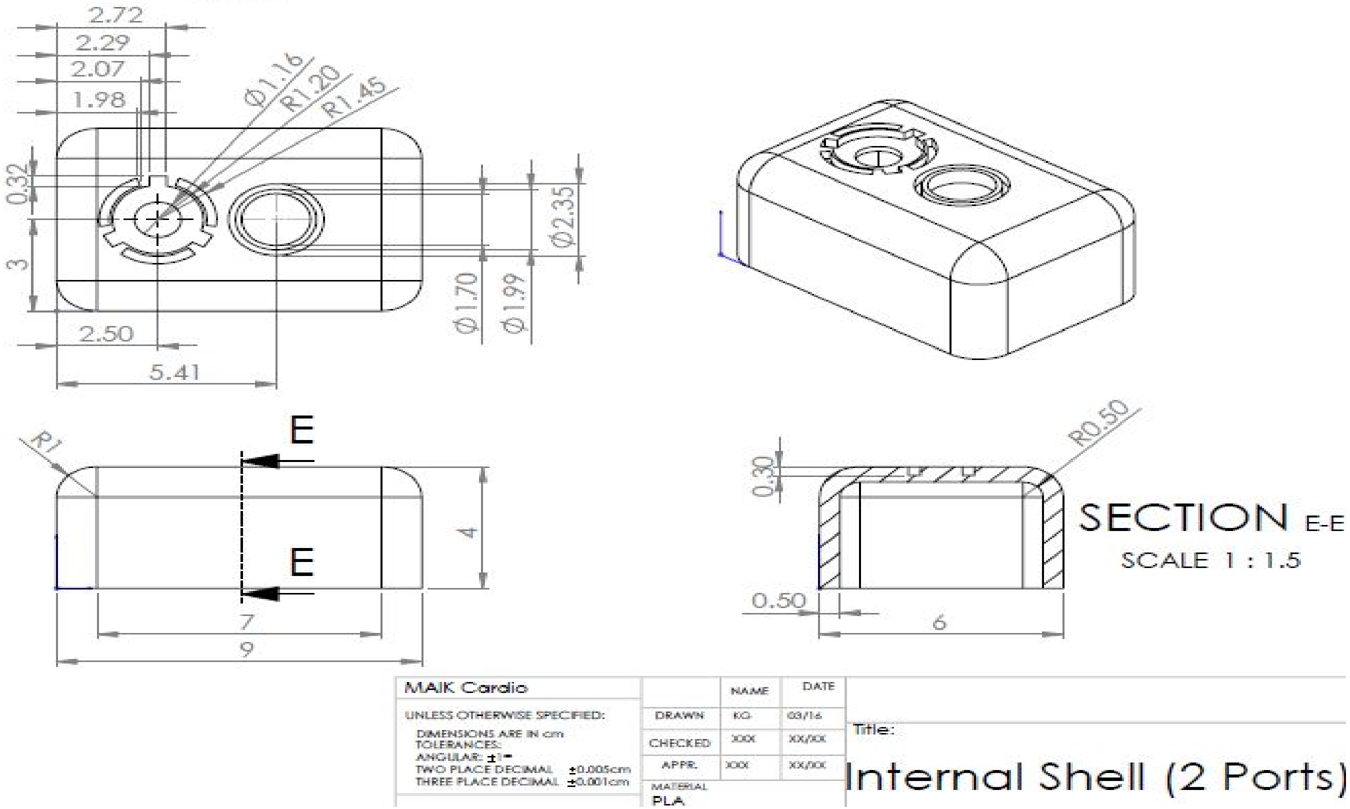
The internal portion was designed to have a volume of ~220 cc.



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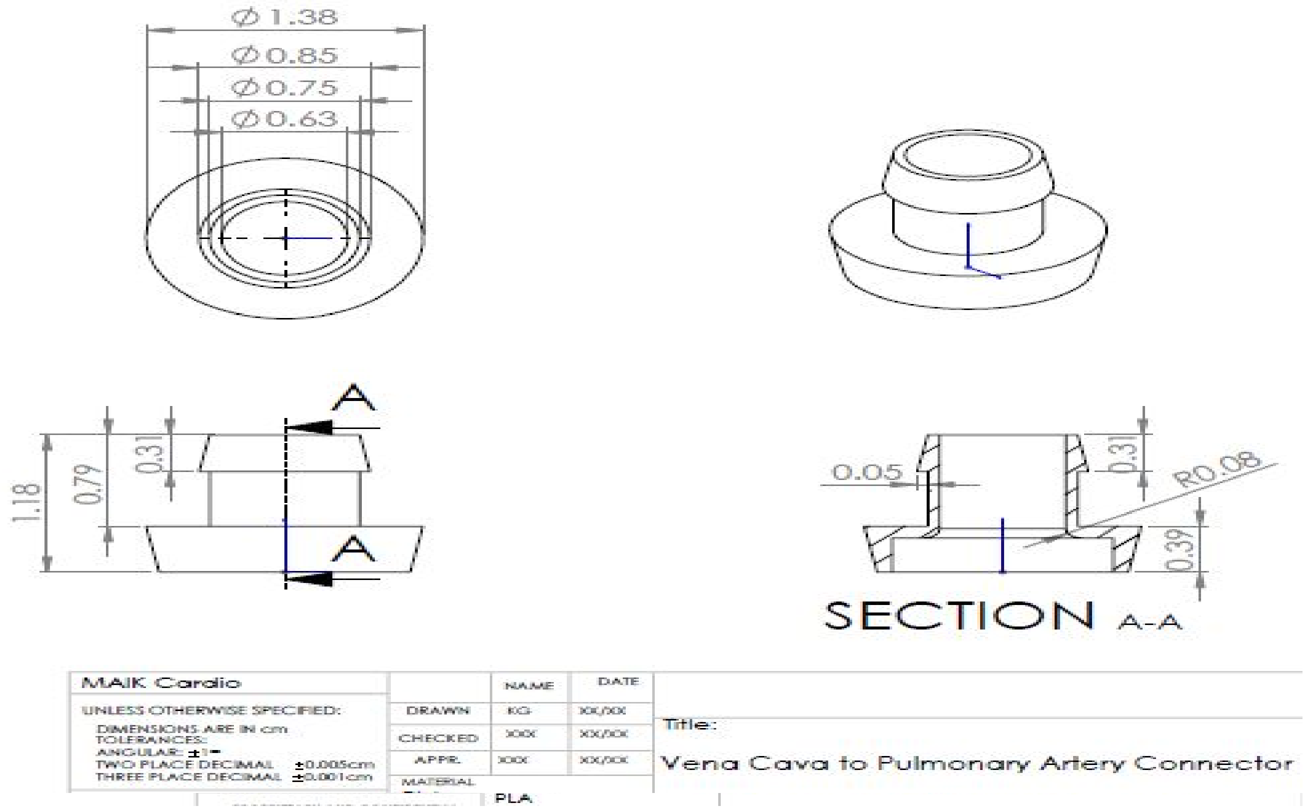
The internal portion also had to fit within anatomical specifications.



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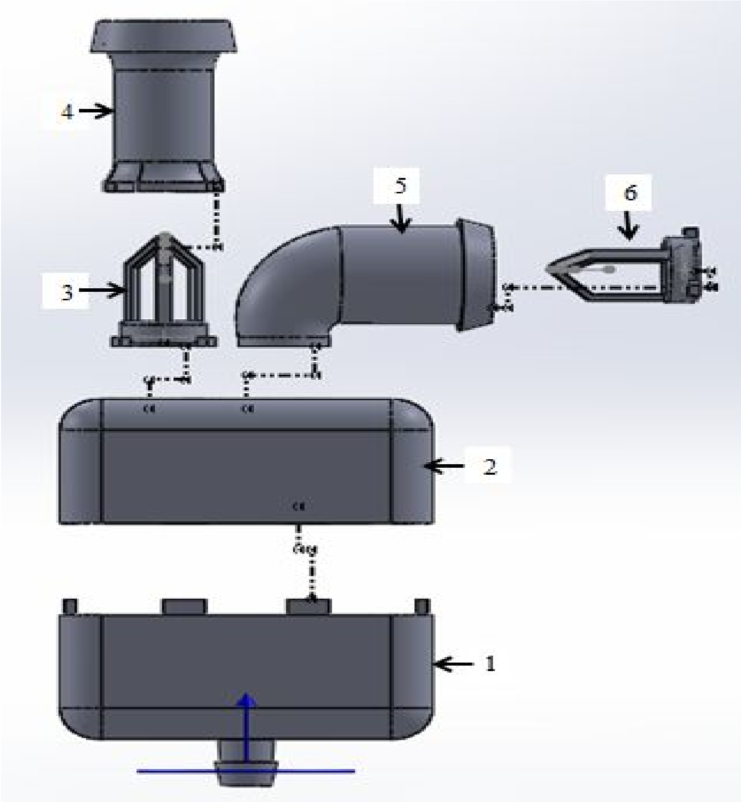
This figure shows the different components of the internal portion.



Parts List

1. Internal Shell (1 port)
2. Internal Shell (2 ports)
3. Ball in Cage Valve*
4. Aorta Connector
5. Pulmonary Vein Connector
6. Ball in Cage Valve*

Not pictured:
-Diaphragm
-Vena cava/pulmonary artery connector

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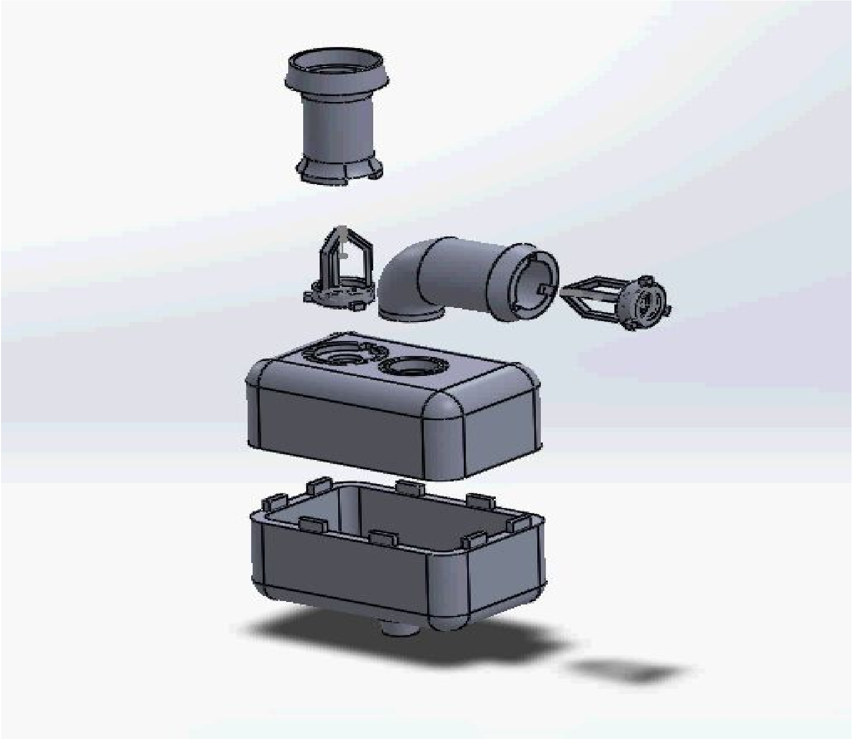
This animation shows how the internal portion is assembled.



Graham

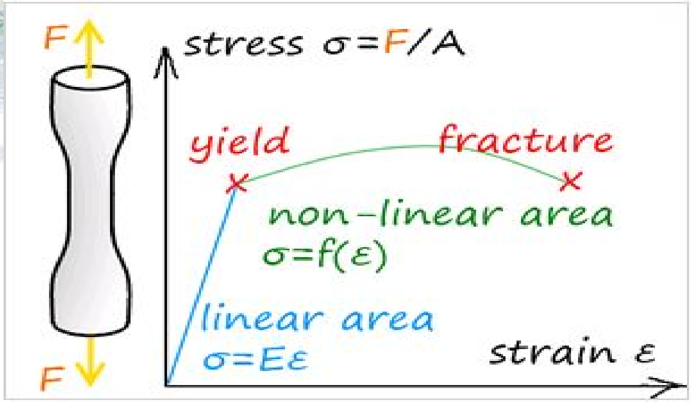
Different materials and adhesives were used in assembling the project.

Hot glue, caulk (sealant), heat, and acetone were used to bond parts together

Graham

Future adaptations/models would be made with different materials.

This would allow the device to meet sterilization and biocompatibility standards.



This would also solve issues with material strength and durability.

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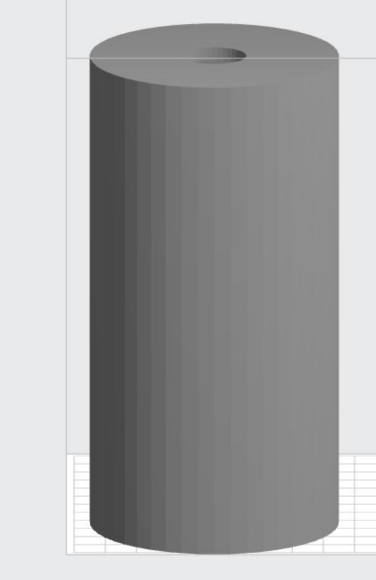
Future models would be tested for effects in live animals.

Graham

Potential valves were tested in shakedown using Relative Resistance and Percentage Flow.



Test 2:

Testing:

rR=(no valve flow)/(valve flow)

%Flow=(valve $flow_{open}$ - valve $flow_{closed}$) / (valve $flow_{open}$)

Where:

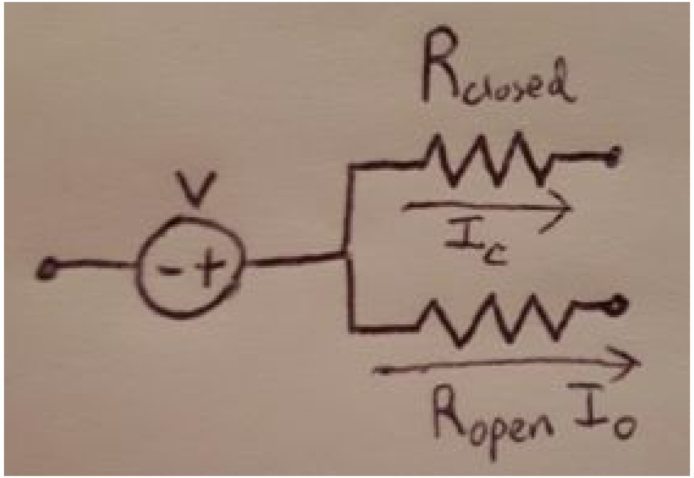
rR: Relative Resistance (units given as Goodwins [Go], the KAIM company standard resistance unit)

no valve flow: flow through the hole without the resistance of the valve

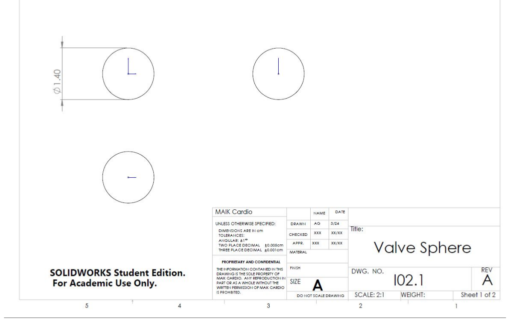
valve flow: flow through the hole with the valve inserted (orientation of open or closed is denoted by a subscript)

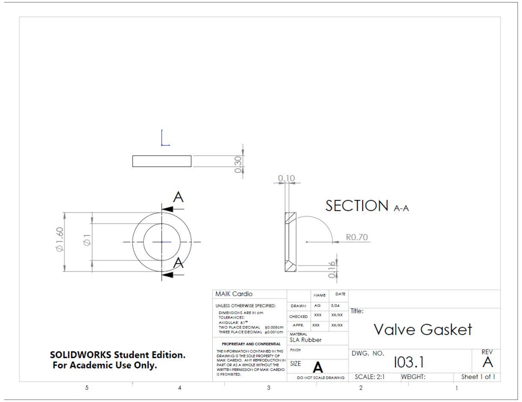
Percentage flow was deemed the most important factor, given the expected flow behavior.

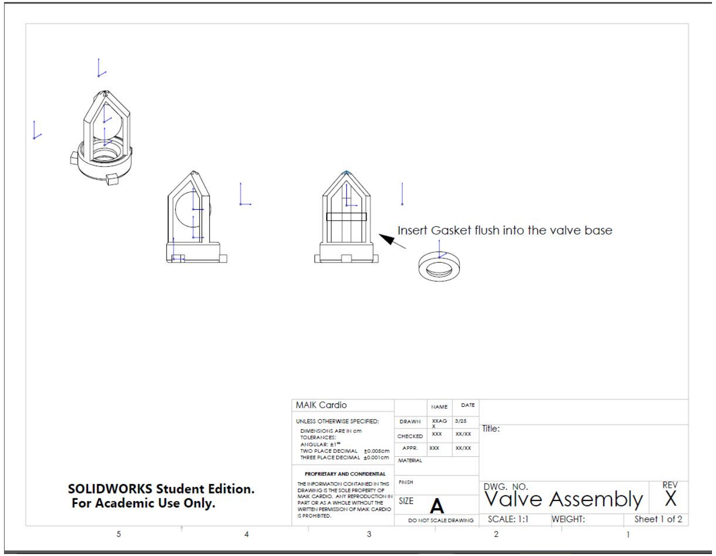
Type of valve	Relative Resistance (open) [Goodwins]	Relative Resistance (Closed) [Goodwins]	Percentage Flow
Tilt Valve (ABS all) [manual switch]	5.41	37.7	85.70%
Tilt Valve (ABS all) [auto switch]	8.46	------	77.60%
Tilt Valve (ABS shell, SLA rubber tilt flap) [manual switch]	4.06	20.6	13.30%
Tilt Valve (ABS shell, SLA rubber tilt flap) [auto switch]	17.6	------	80.00%
Ball in Cage (PLA shell, SLA hard ball, SLA rubber gasket)	3.28	47.1	93.00%
Ball in Cage (ABS shell, ABS ball, SLA rubber gasket)	2.84	66	95.70%
Duck Bill (SLA rubber)	47.1	220	78.60%

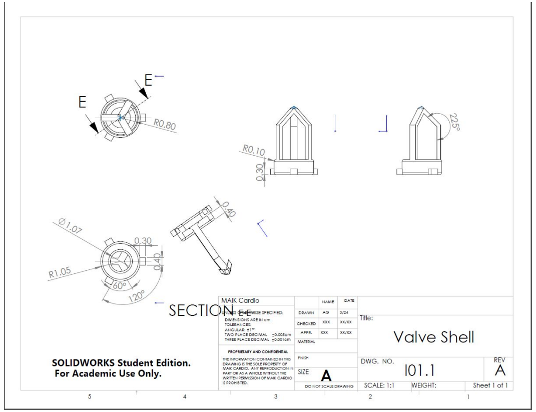


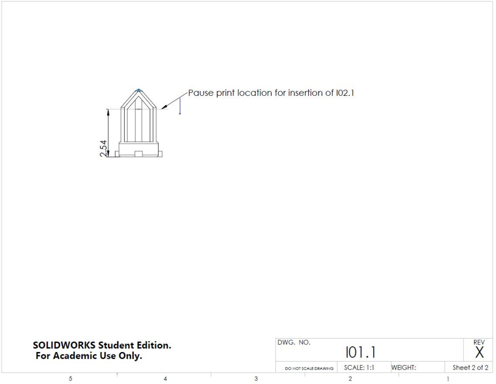
The valve was designed for maximum flow open and minimum flow closed.





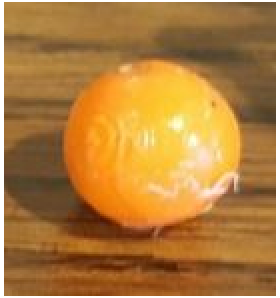




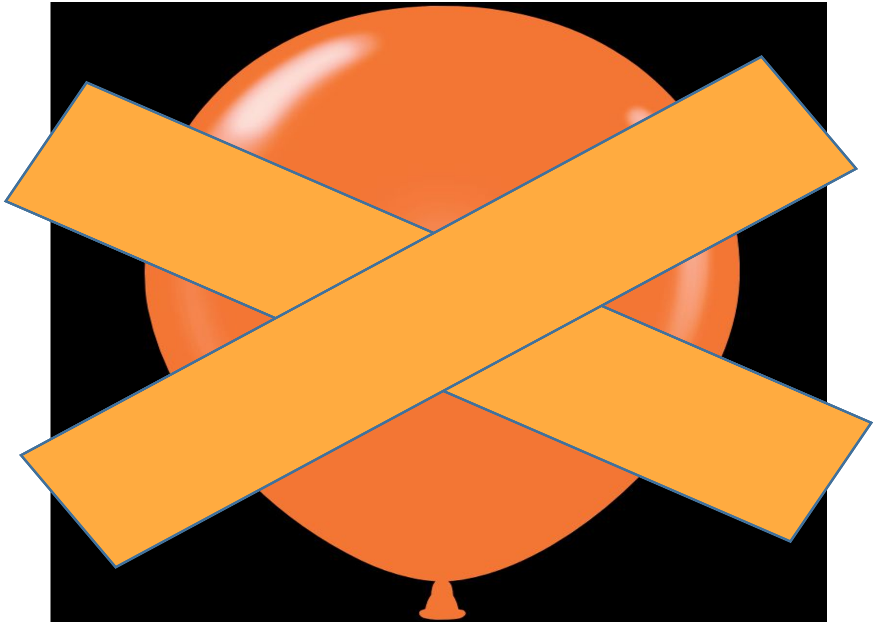


Though ABS showed higher flow, we chose PLA due to the preference of the manufacturer to maintain good relations.

It was realized the PLA balls float, so they were replaced with hard SLA balls.



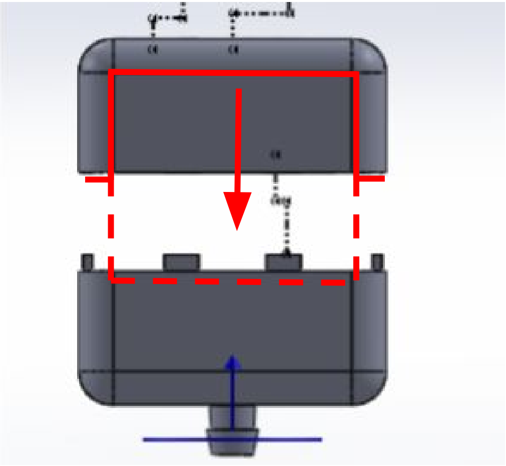
The diaphragm design sought to avoid reliance on elasticity of materials.



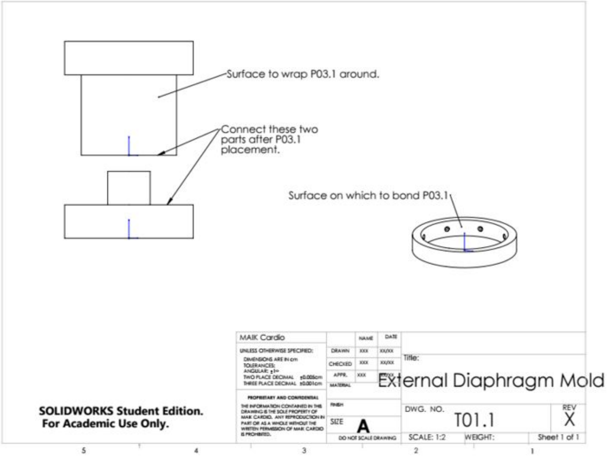
Shakedown for the diaphragm consisted of various bonding tests and a basic diaphragm construction attempt.

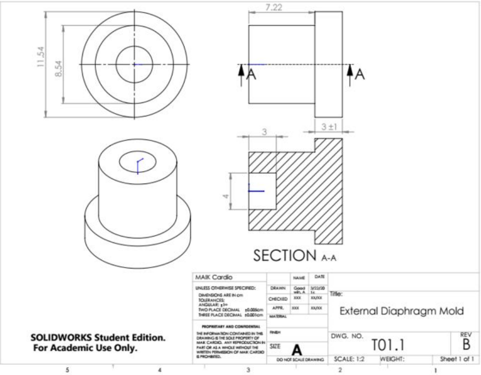
It was determined that a good seal could be created with Polyethylene and bonding issues could be designed around.

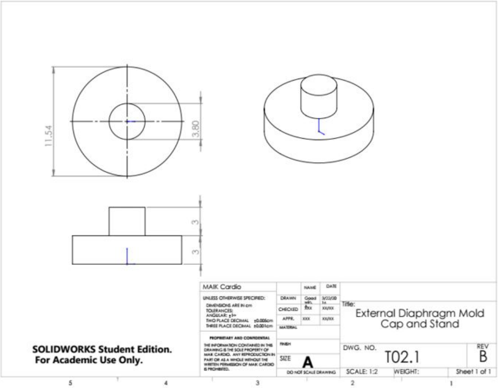
It was determined from shakedown and examination of our selected material that a diaphragm could be designed with its peak and trough having equally low tension.

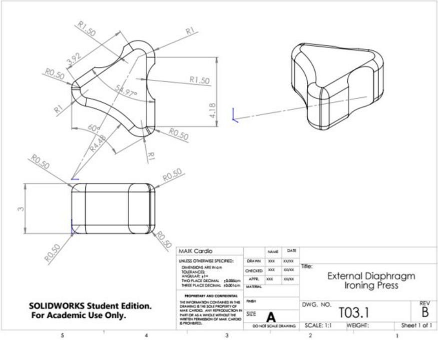


This shakedown led to a diaphragm construction plan requiring various tooling pieces.

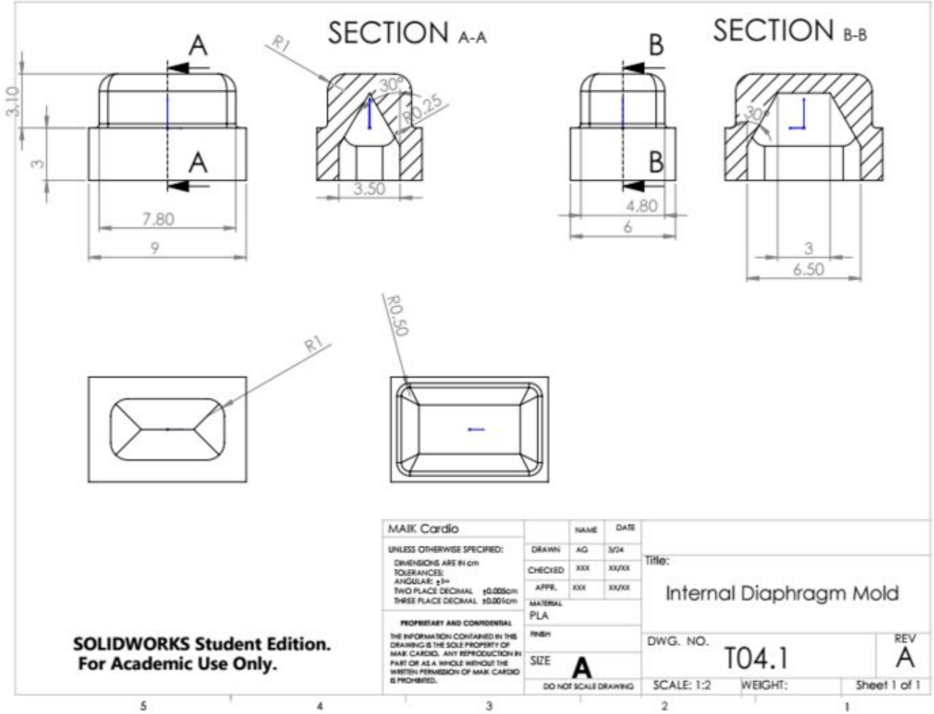


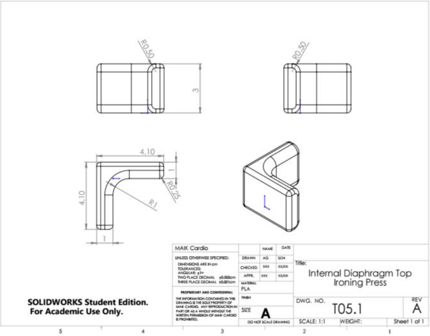


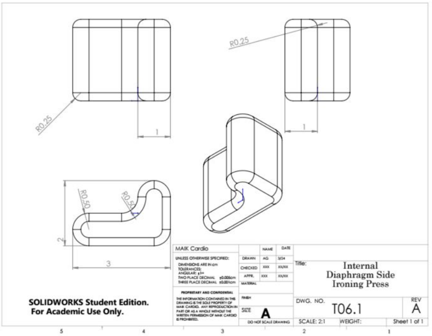




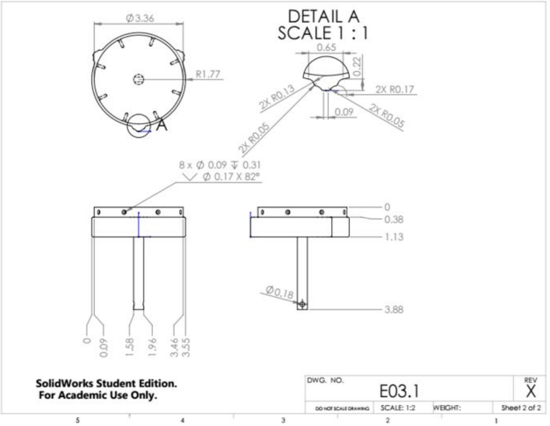
The internal diaphragm was created with one mold piece and two "ironing" presses.

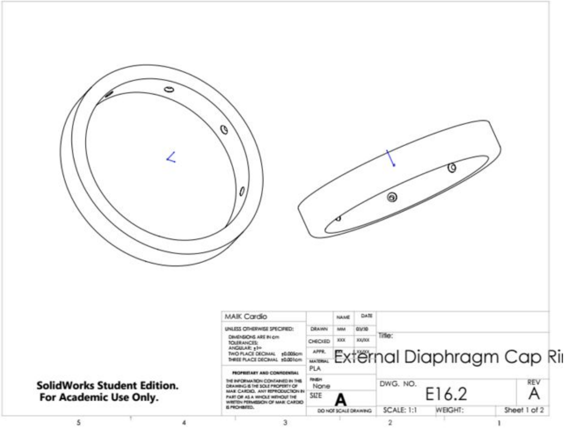




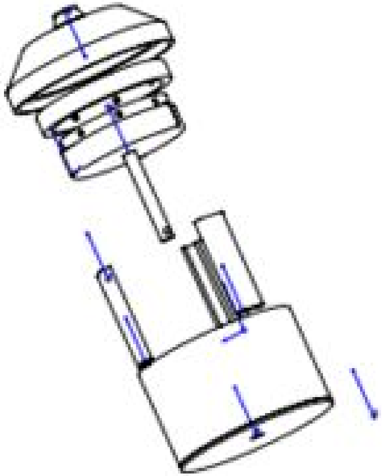


The external piston driven diaphragm would be attached to a cylinder and the piston itself.

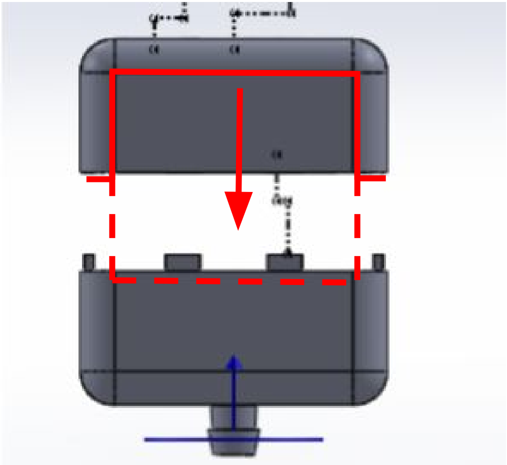


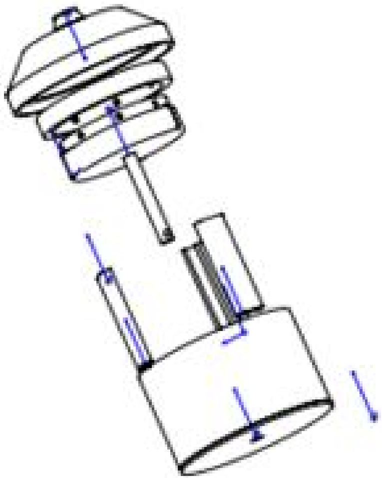


The completed diaphragm would attach at the ring to the piston cap.

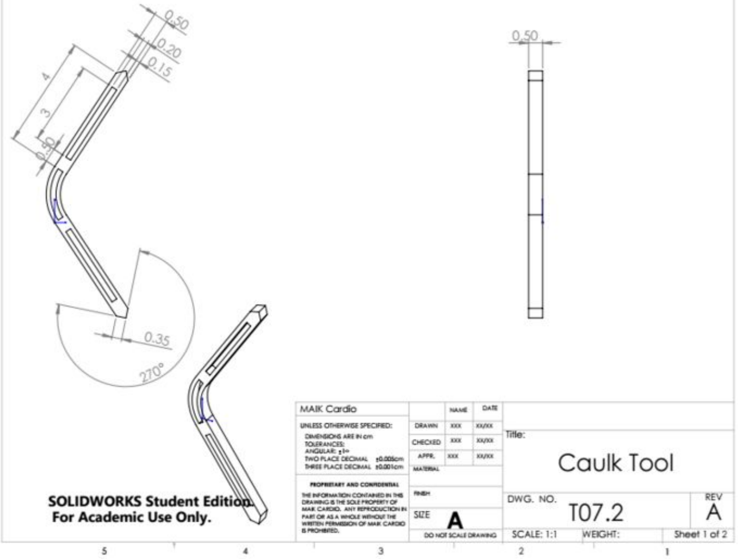


The volume moved by the external (driving) portion had to be less than the volume possibly moved by the internal.

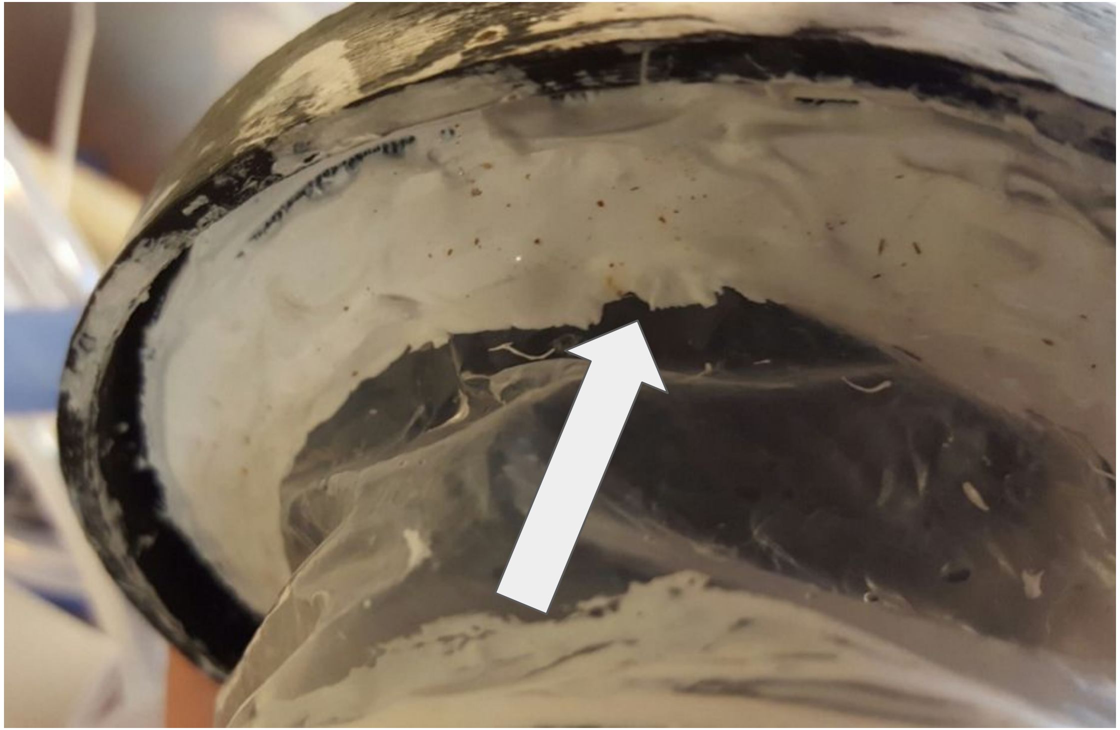




Caulking in both cases was assisted by this tooling part designed for flexure to apply caulk in difficult to reach places.

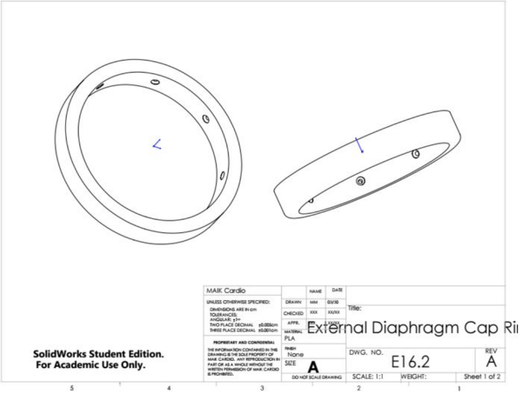


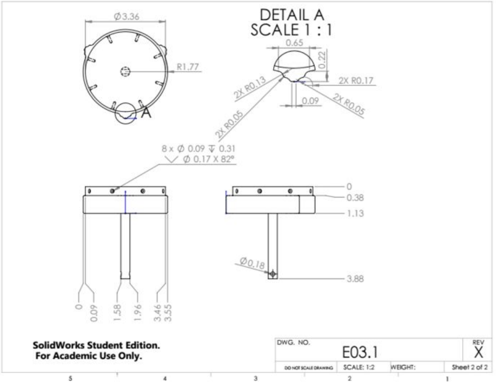
The primary limiting failure on our assembly was the ring connection on the external diaphragm.

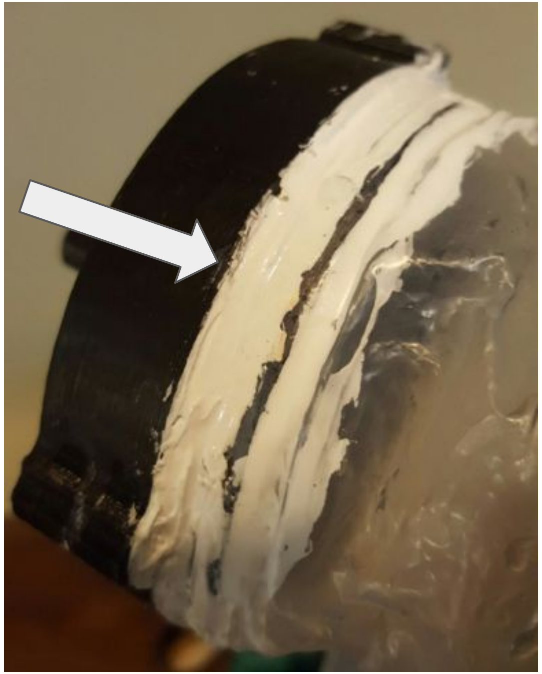


This was an avoidable material failure, however a solution is feasible.

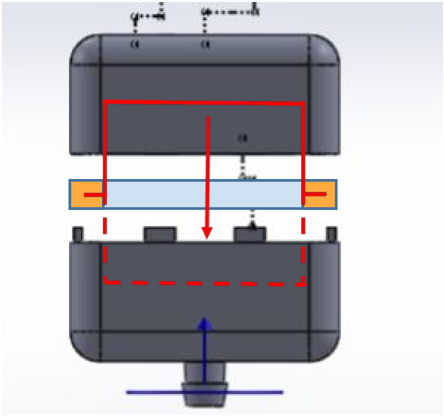
The proposed redesign: mimic the compressive bond and seal already on the piston side of the external diaphragm.



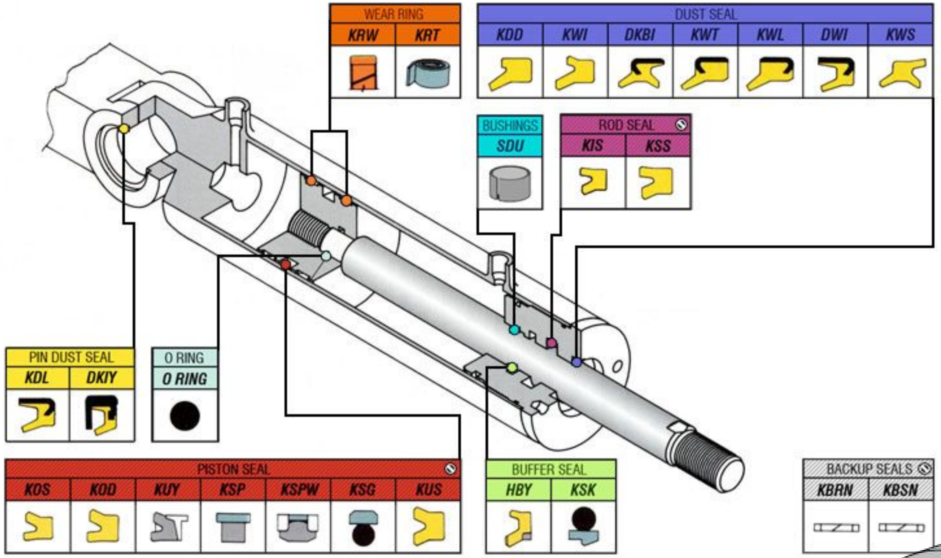




Though the internal diaphragm did not fail, it is suspected there may have been a small leak between the chambers. Thus a similar redesign would be sought there as well.



The piston research required a redesign of the internal portion

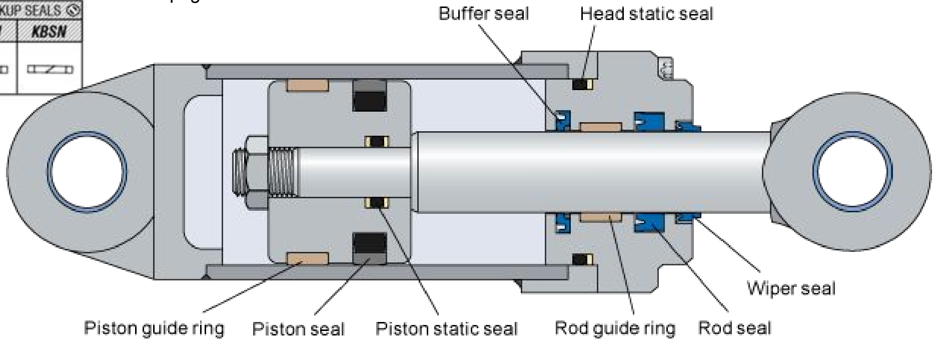


http://bimoseals.com/OLDCylinder_Proposal_v2.jpg

Not easy to replace old gaskets once in the body

Gaskets would lose a lot of energy due to friction

http://www.skf.com/binary/30-146081/1111%200020%20-%2012393%20w%20-%20EN_tcm_12-146081.png

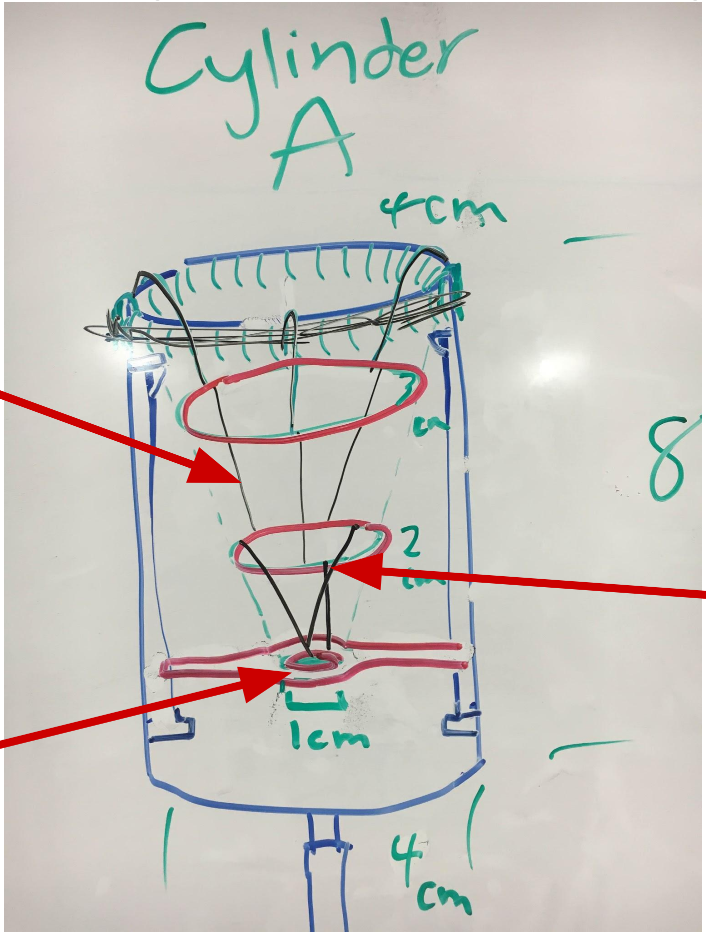


Murphy

The first internal portion was a piston system

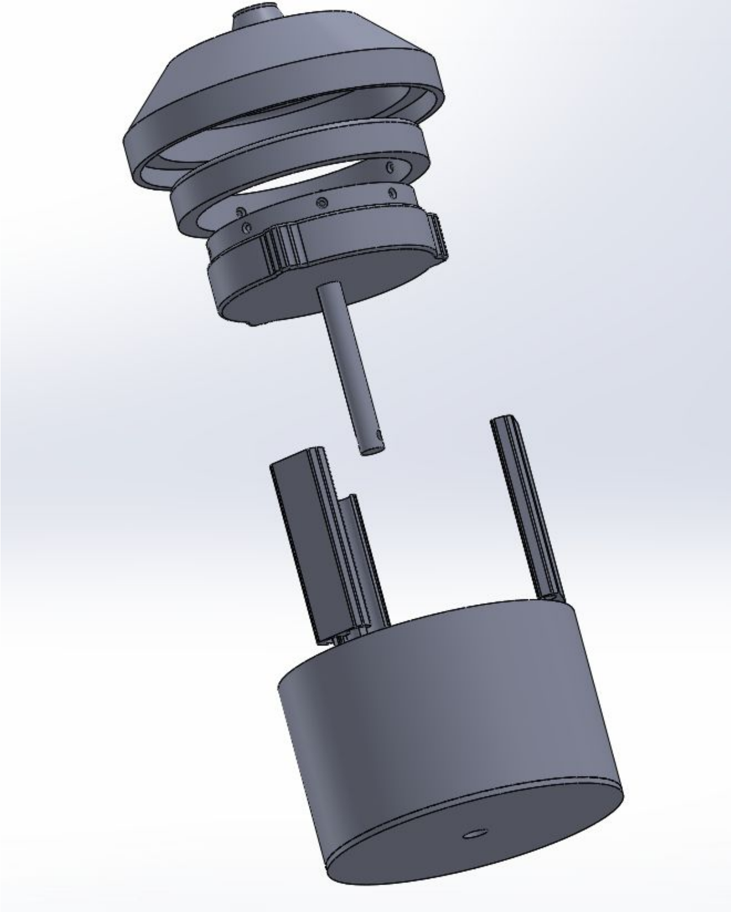
Rubber bands to prevent the bag from catching on guides or piston

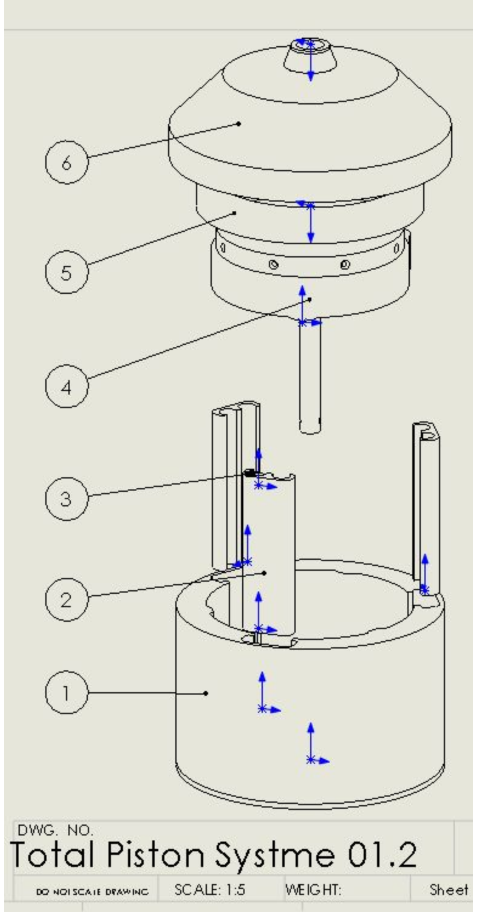
The end of the bag attached to the end of the piston



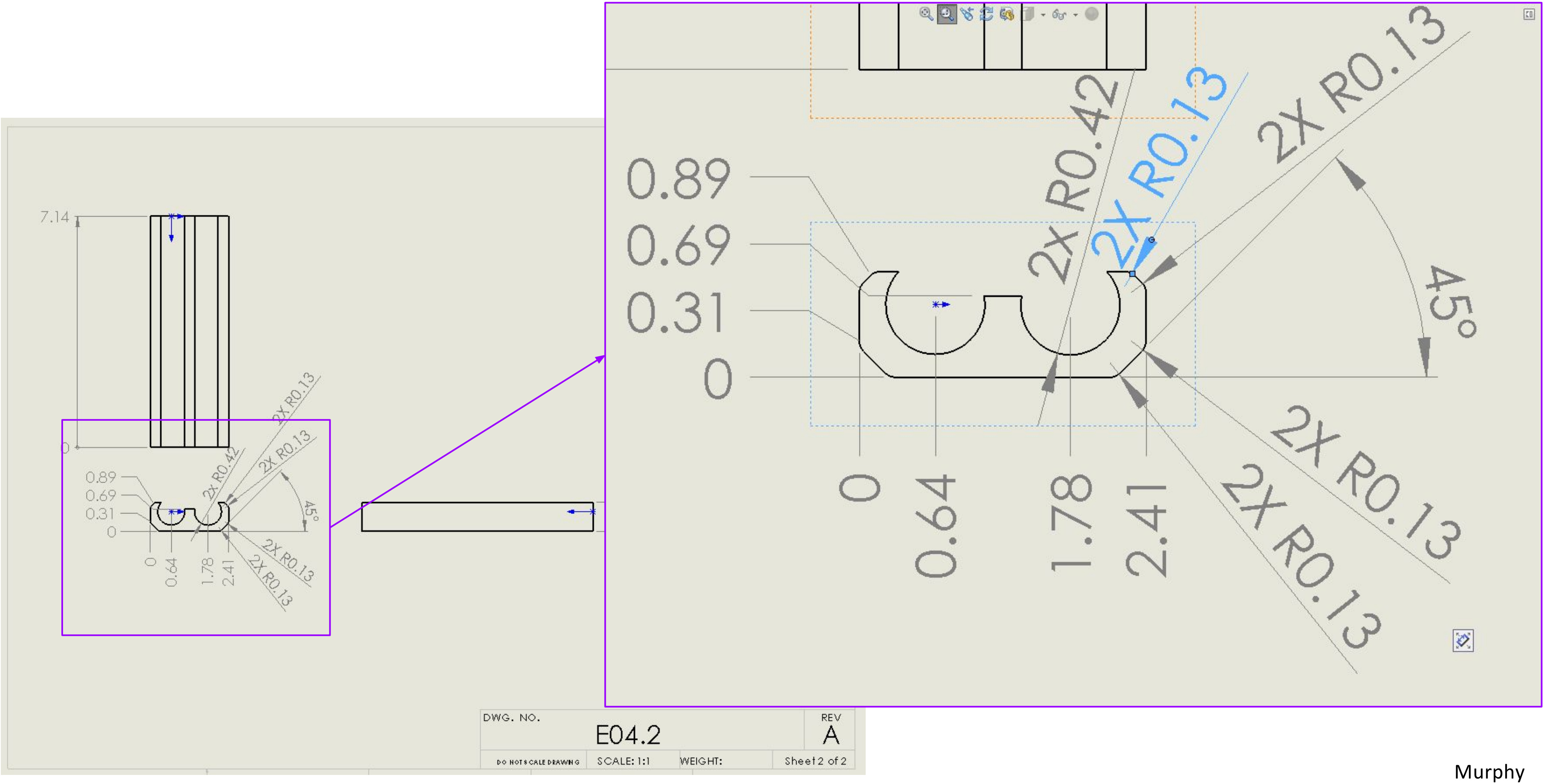
Plastics rings for the rubber bands to attach and serve the same purpose

The complete assembly of the external driver piston



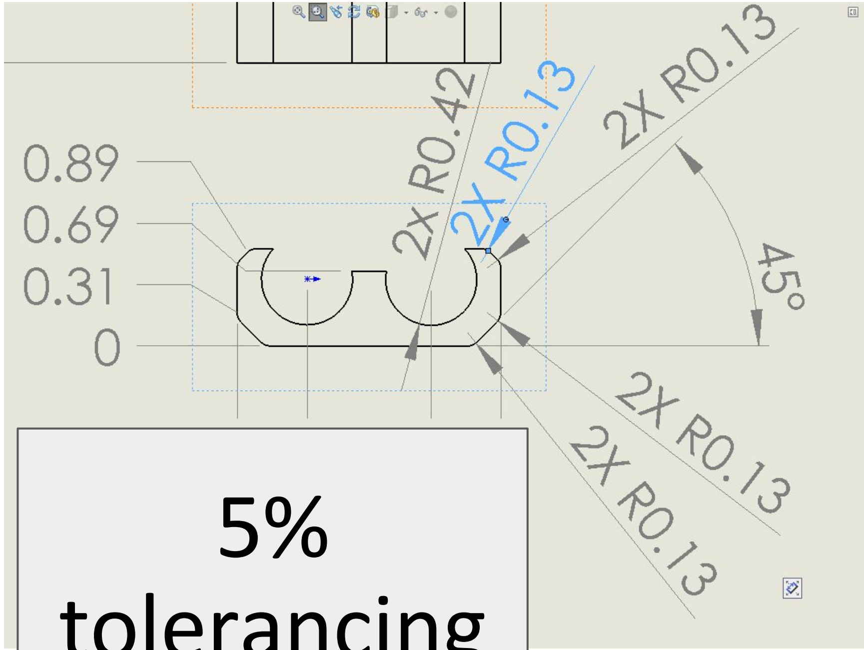


Murphy

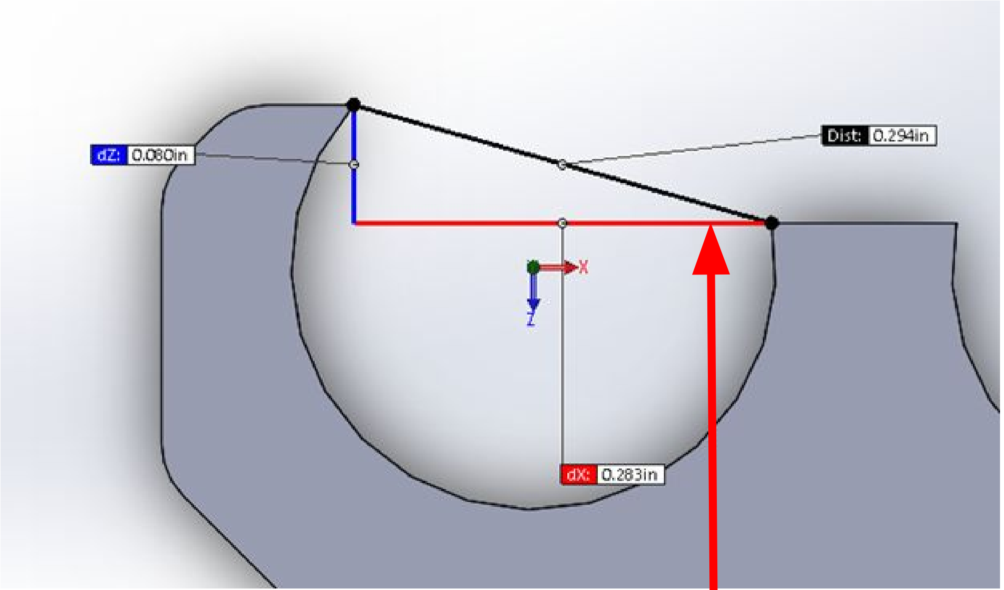

7.14
0
0.89
0.69
0.31
0
0
0.64
1.78
2.41
2X R0.42
2X R0.13
2X R0.13
45°
2X R0.13
2X R0.13
DWG. NO.
E04.2
REV
A
DO NOT SCALE DRAWING
SCALE: 1:1
WEIGHT:
Sheet 2 of 2

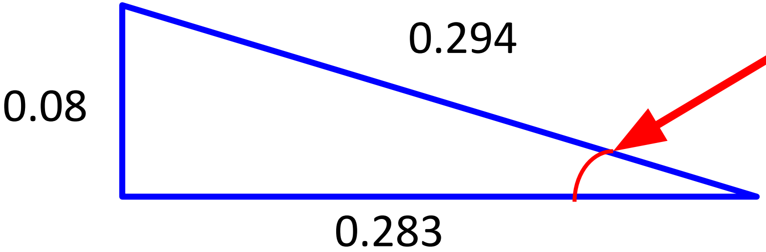
Murphy

The ball bearings depended on the tolerancing of the clip



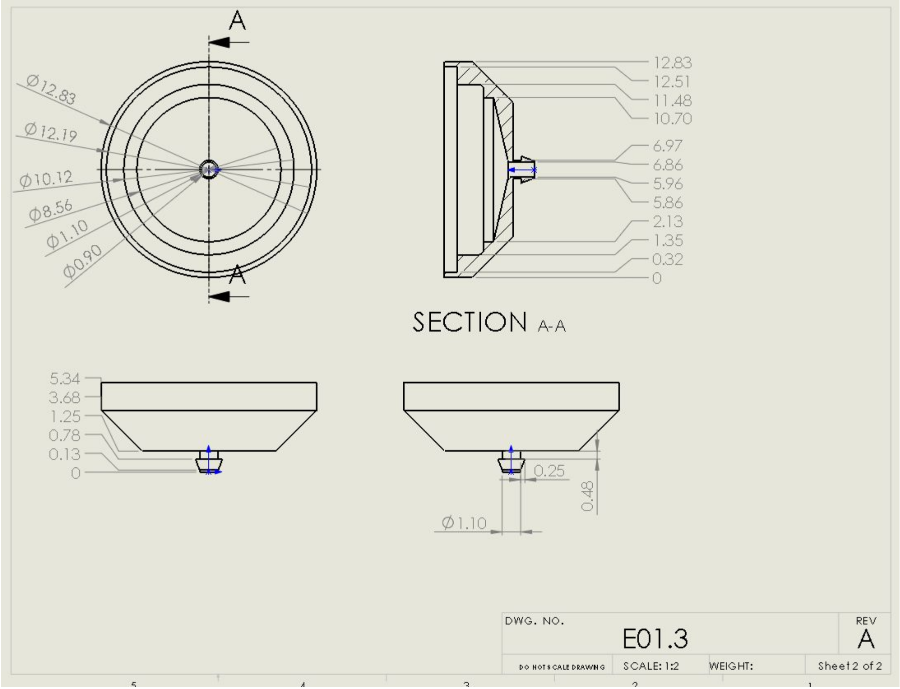
5% tolerancing for ball bearings

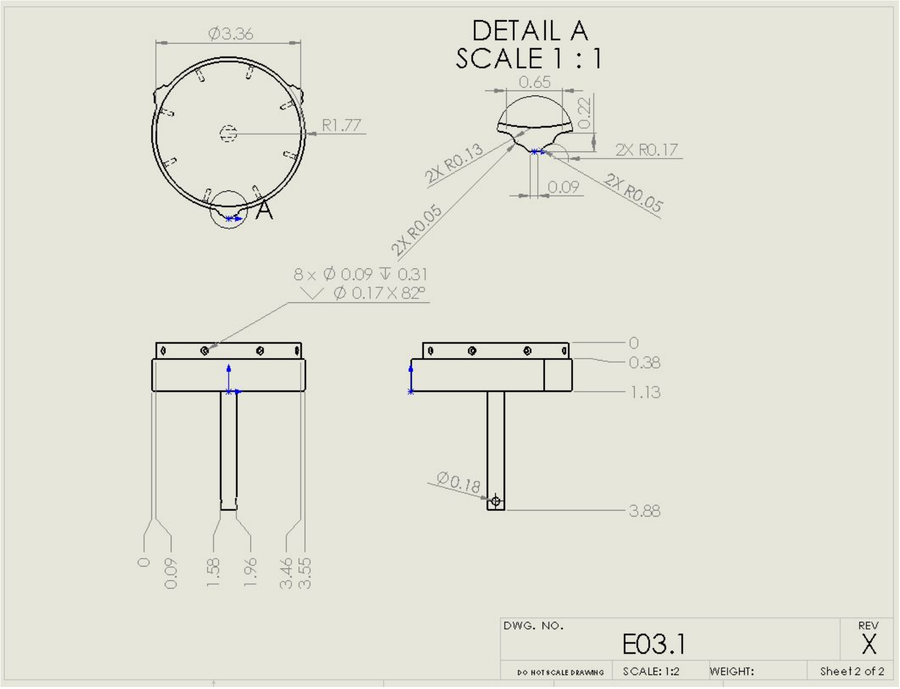




The angle should be ~15 degrees

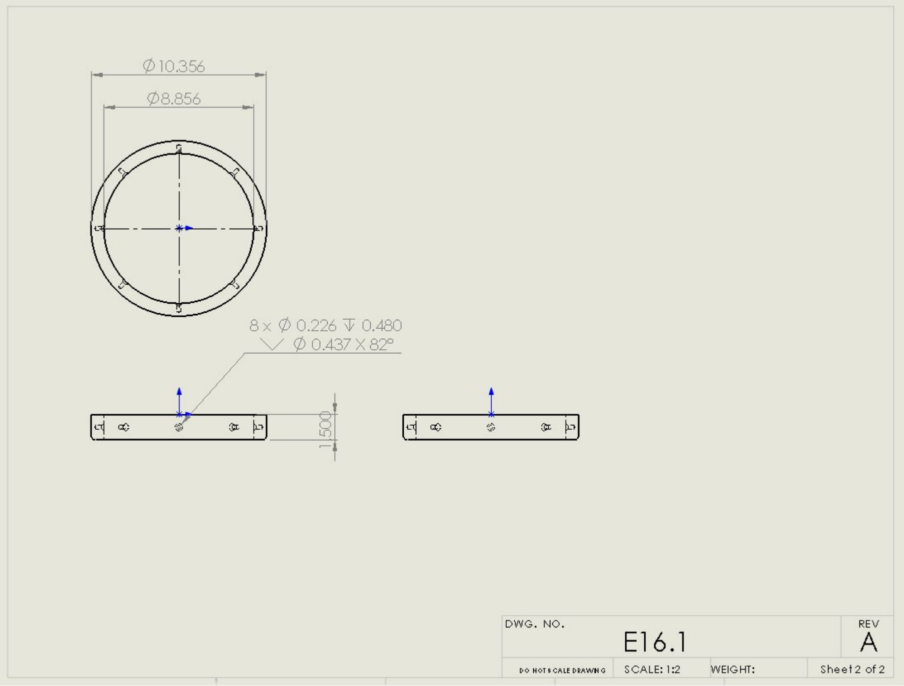
1-2.5% tolerance with post processing produce better parts

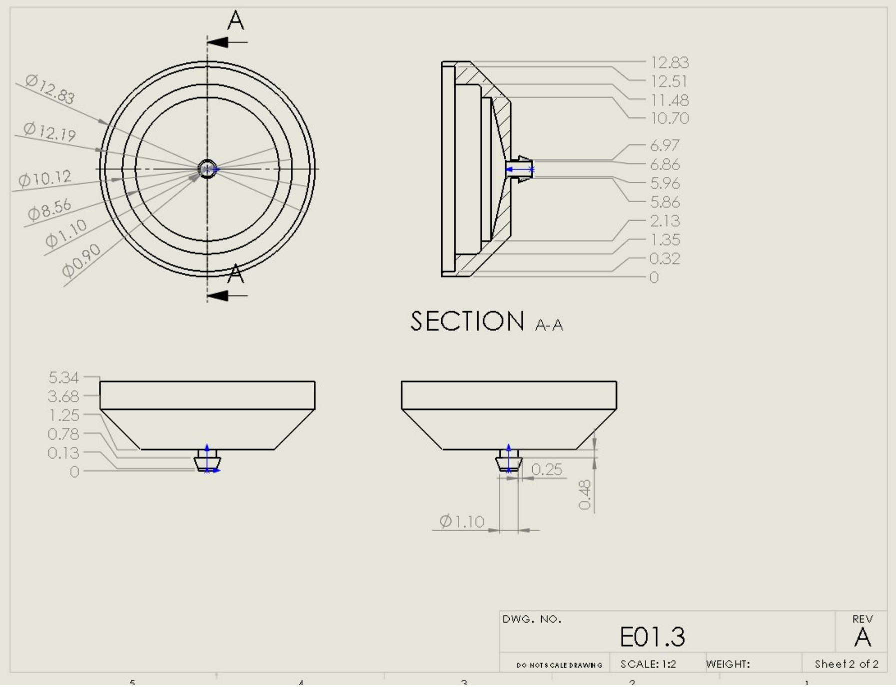




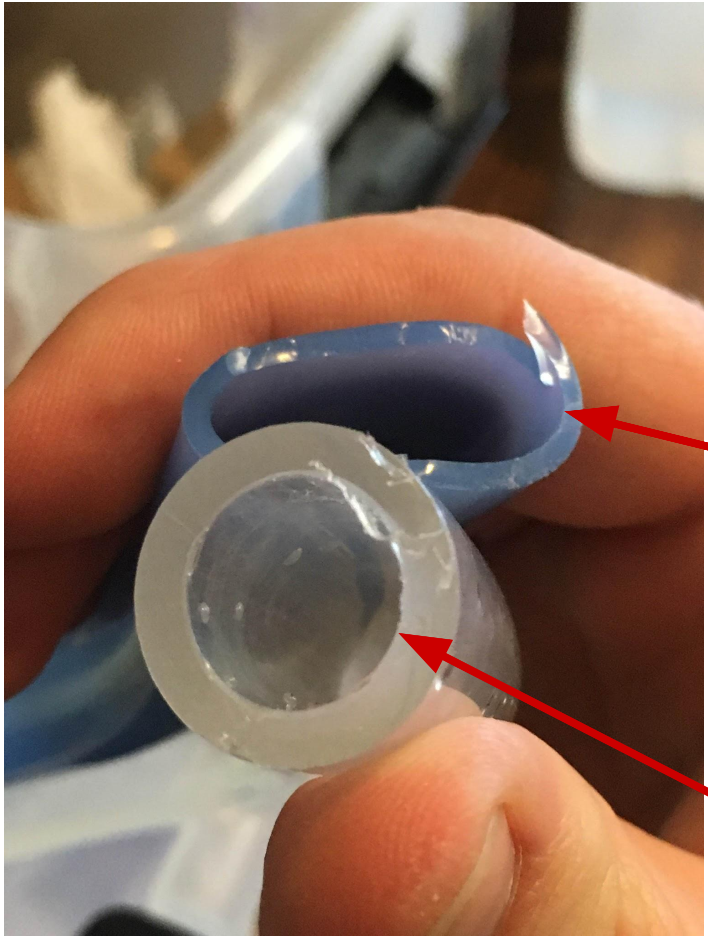
Murphy

Smaller parts (under ½ in) the tolerance should be like 0-2.5 percent.





Murphy

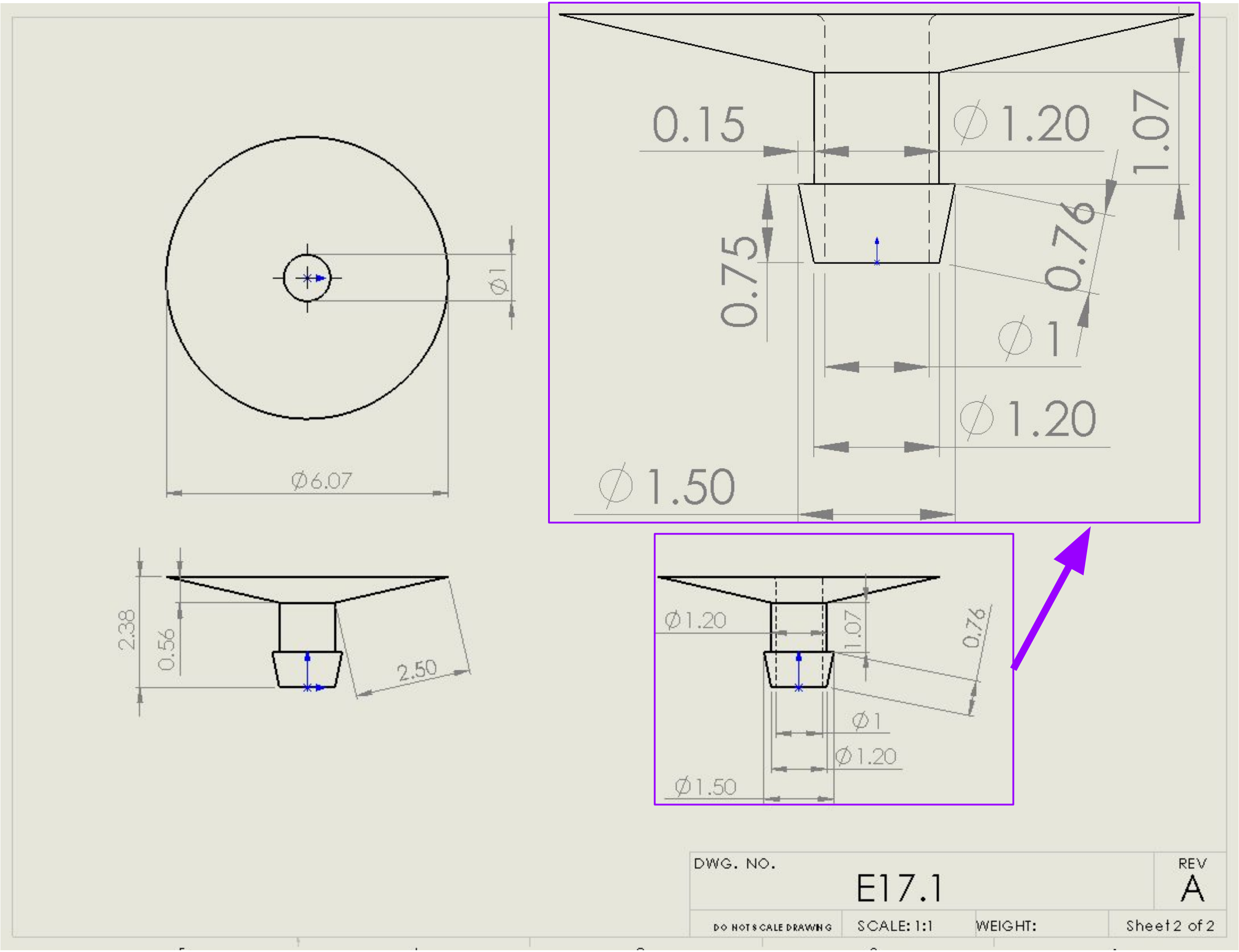


The flexibility of the tube influencing the barb connection

Soft Tube:
The OD of barb nozzle matched the ID of the tube

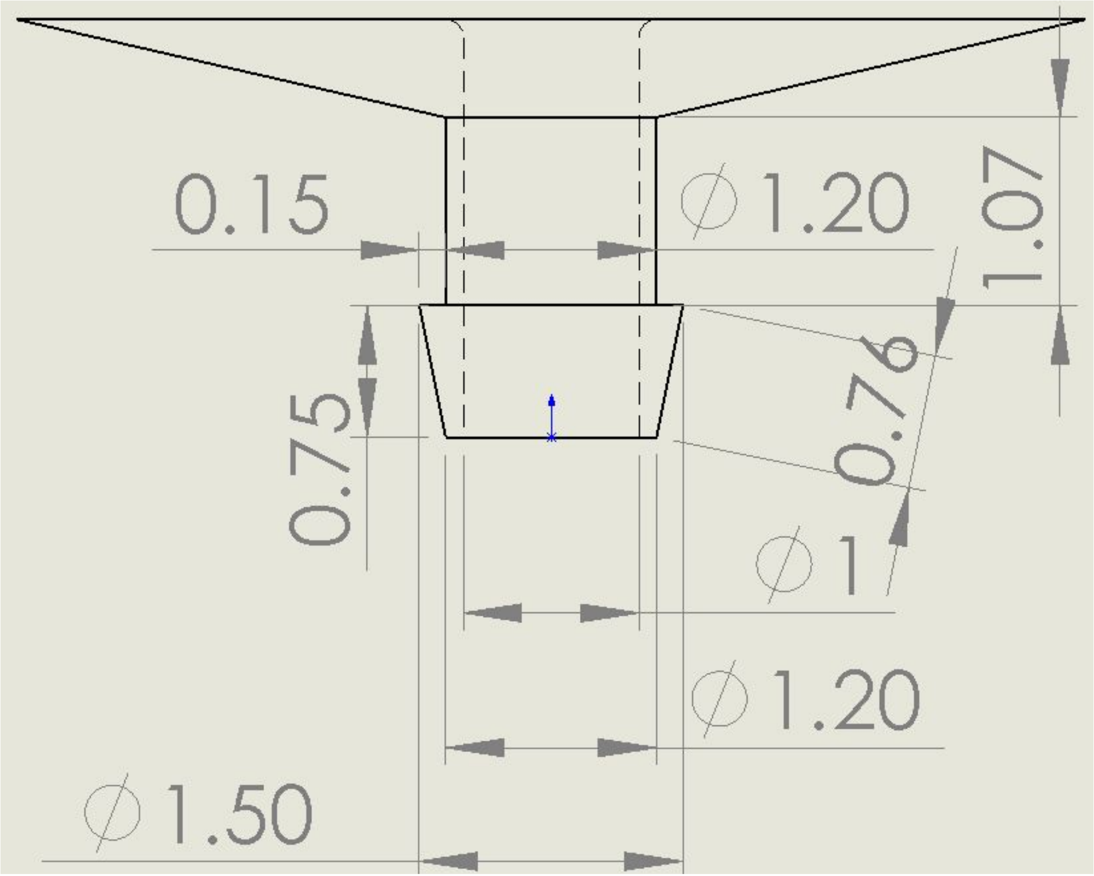
Firm Tube:
The centroid of barb triangle matched the ID of the tube

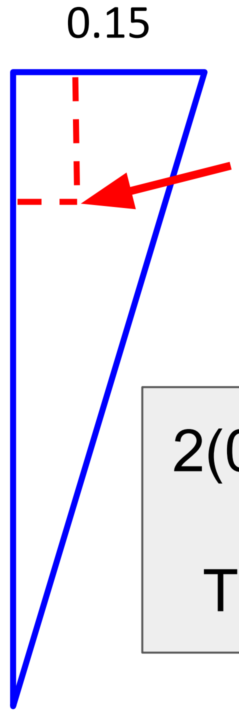
Murphy


Ø1
Ø6.07
2.38
0.56
2.50
0.15
Ø1.20
1.07
0.75
0.76
Ø1
Ø1.20
Ø1.50
DWG. NO.
E17.1
REV
A
DO NOT SCALE DRAWING
SCALE: 1:1
WEIGHT:
Sheet 2 of 2

Murphy

The centroid of barb roughly equals tube's ID



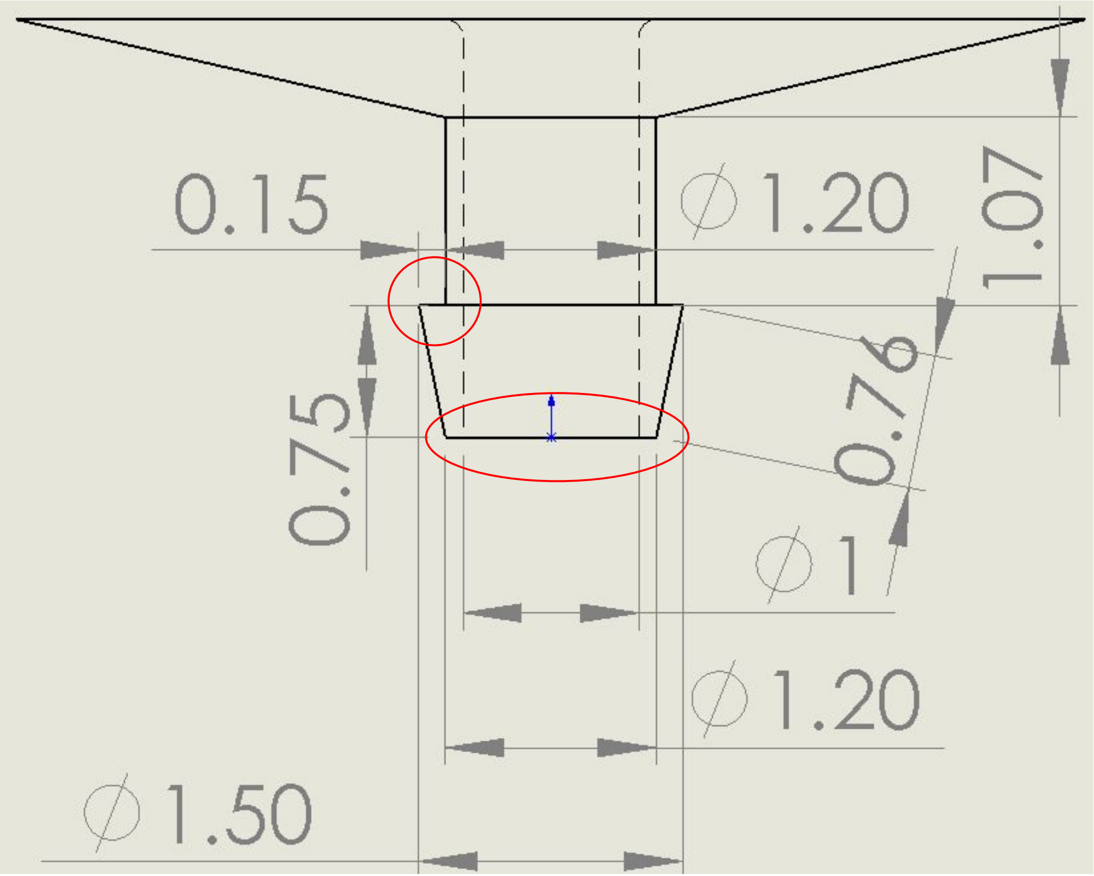


2(0.05)+1.2 = 1.3

Tube ID = 1.27

Murphy

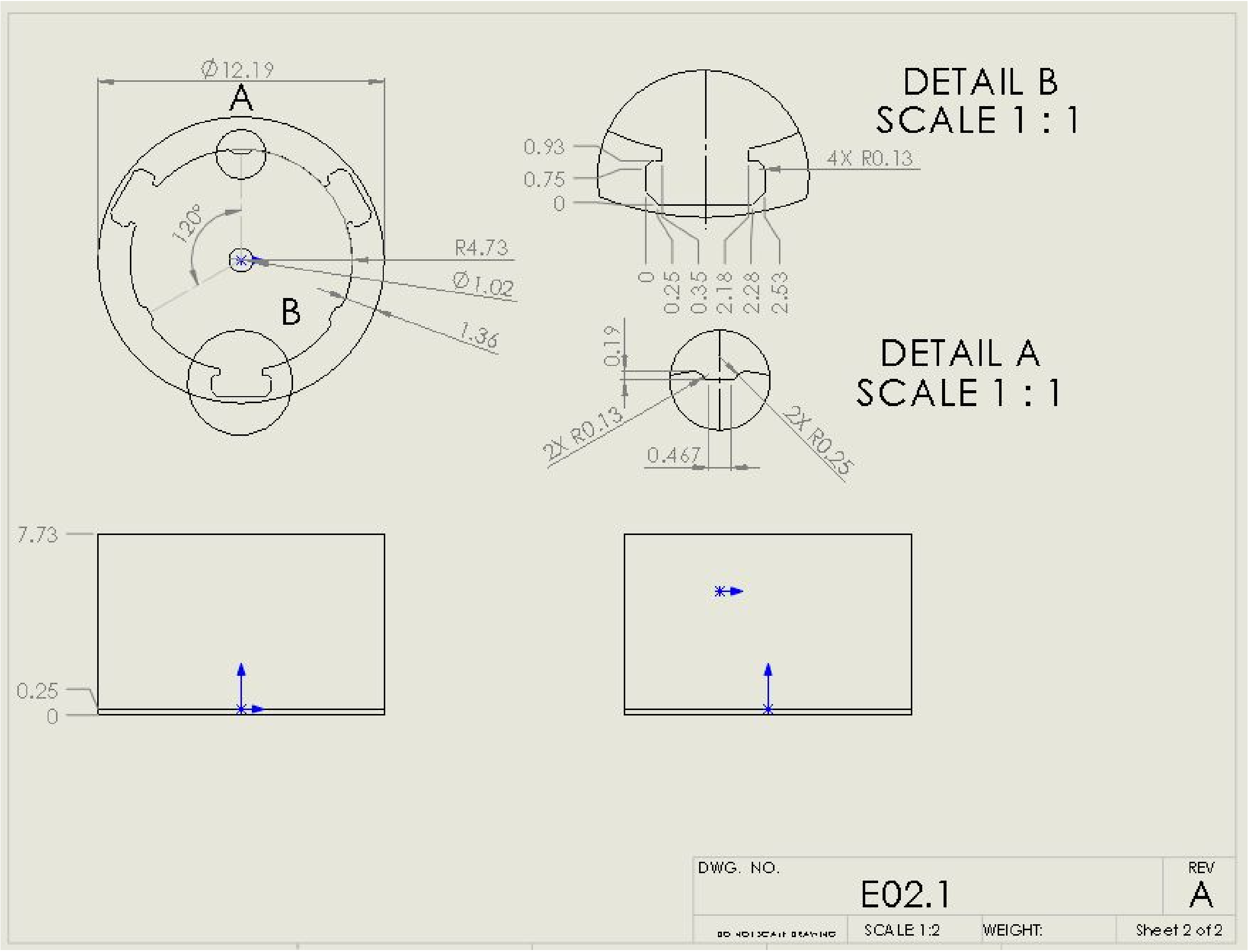
The barb horz. OD is about 1/10 of the outer nozzle OD



Murphy

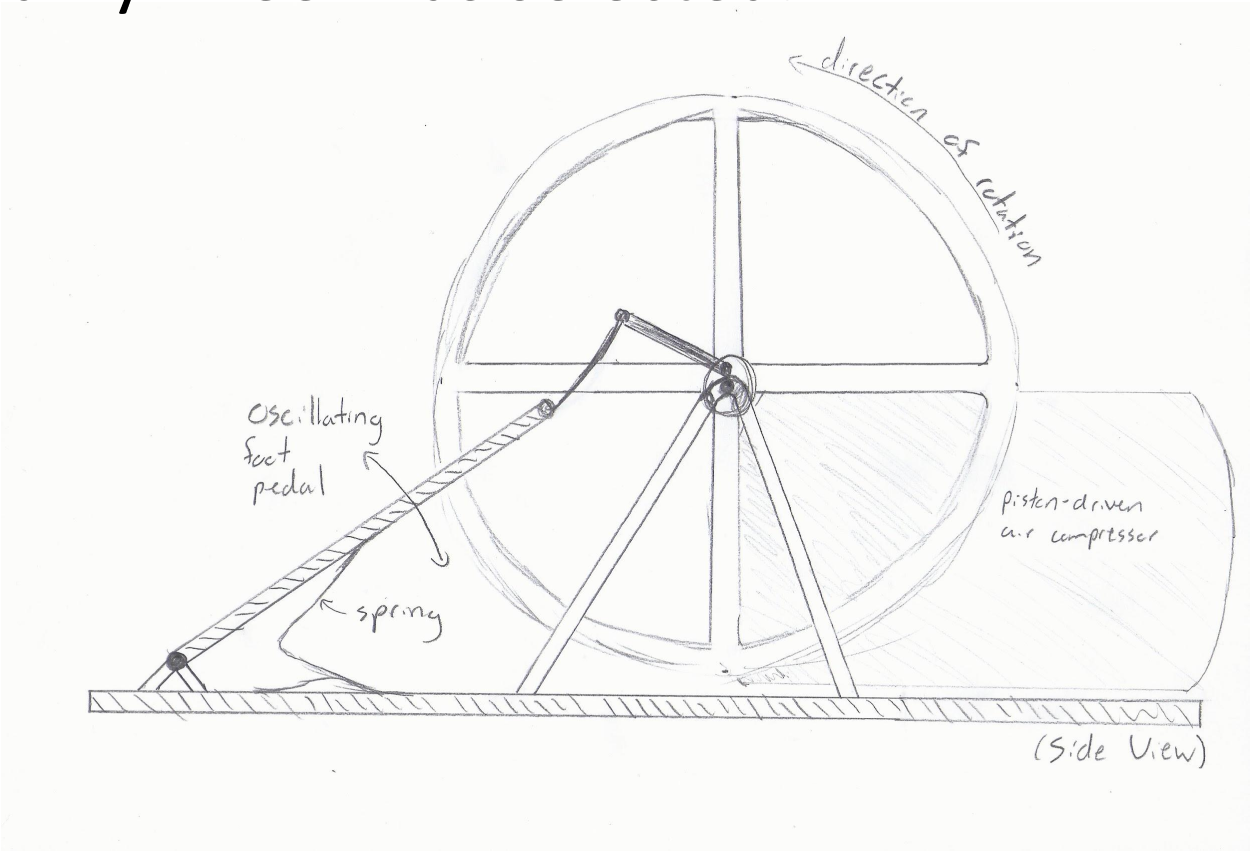
One redesign would be to use stainless steel ball bearings.

Another redesign would increase the shaft’s infill percentage and fillet the edge where it meets the piston head.



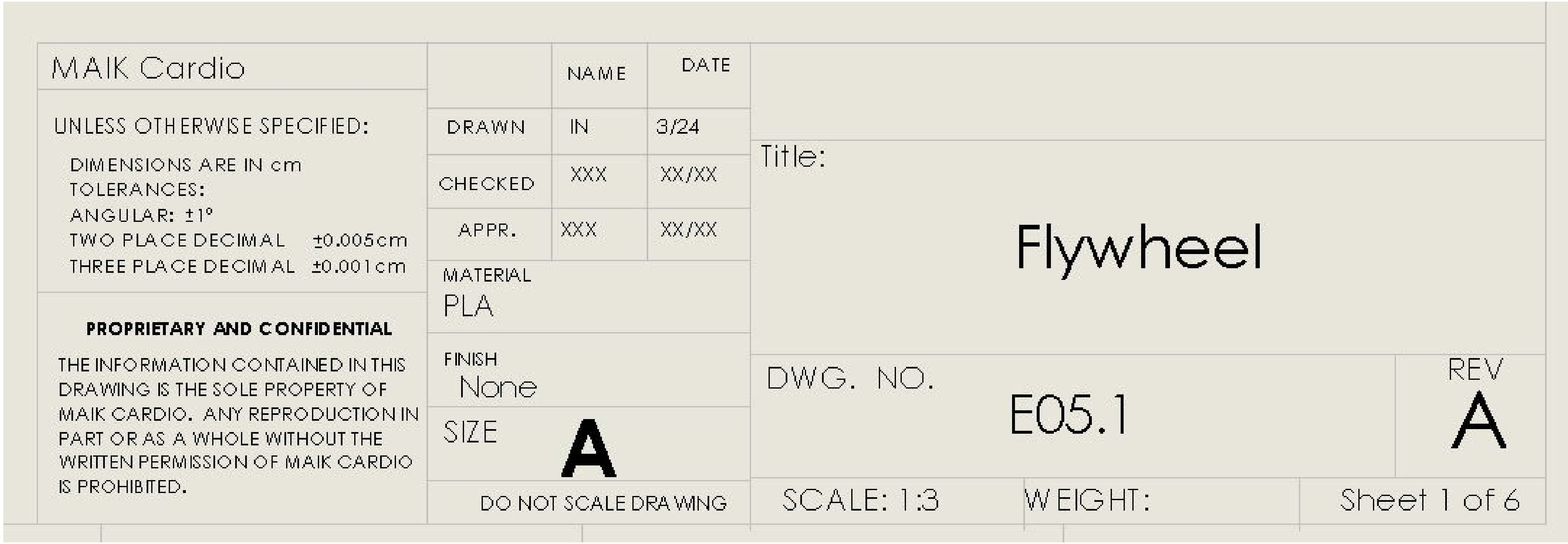
In addition, integrate the bearing clip into the piston casing.

After the design selection process, a foot pedal powered flywheel was selected.

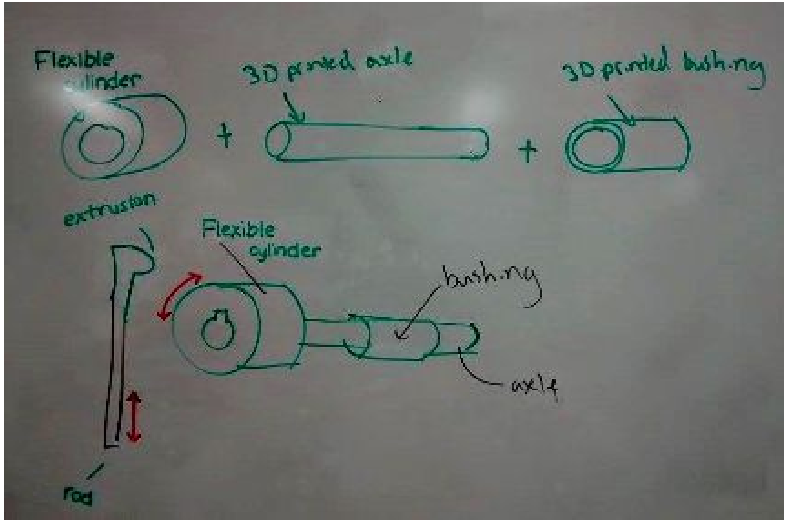


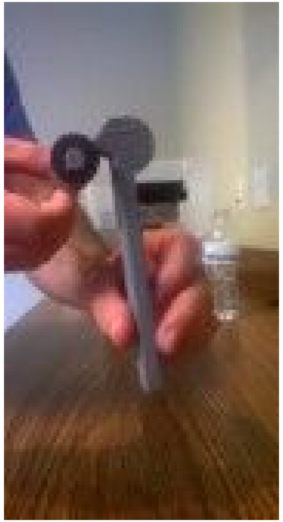
Need

All of our drawings were done to this template and numbering system to maintain continuity and organization.



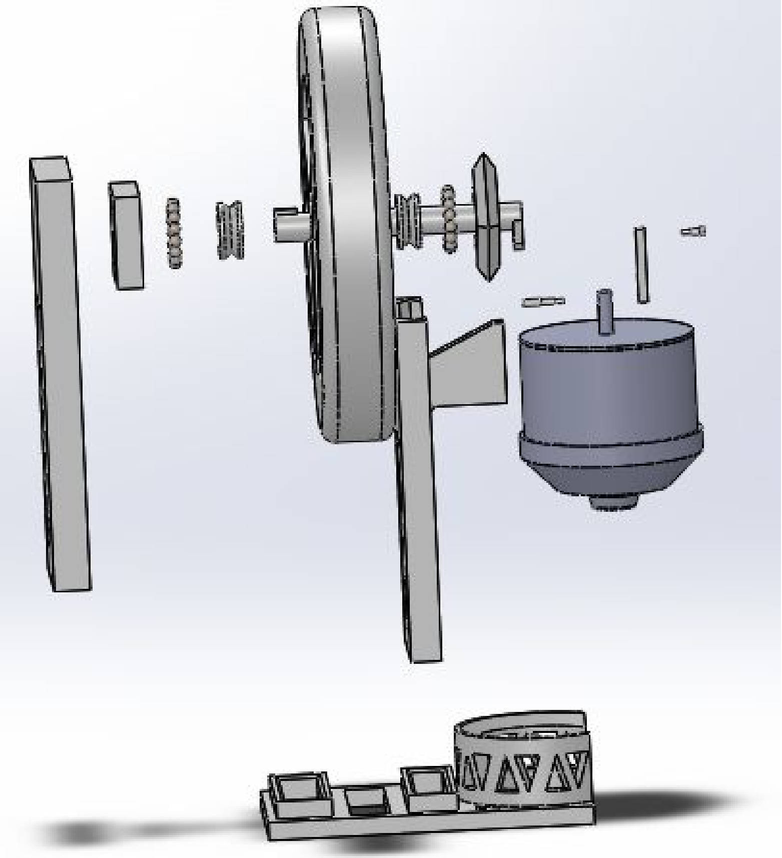
The connection between the foot pedal and the flywheel axle was tested during shakedown.

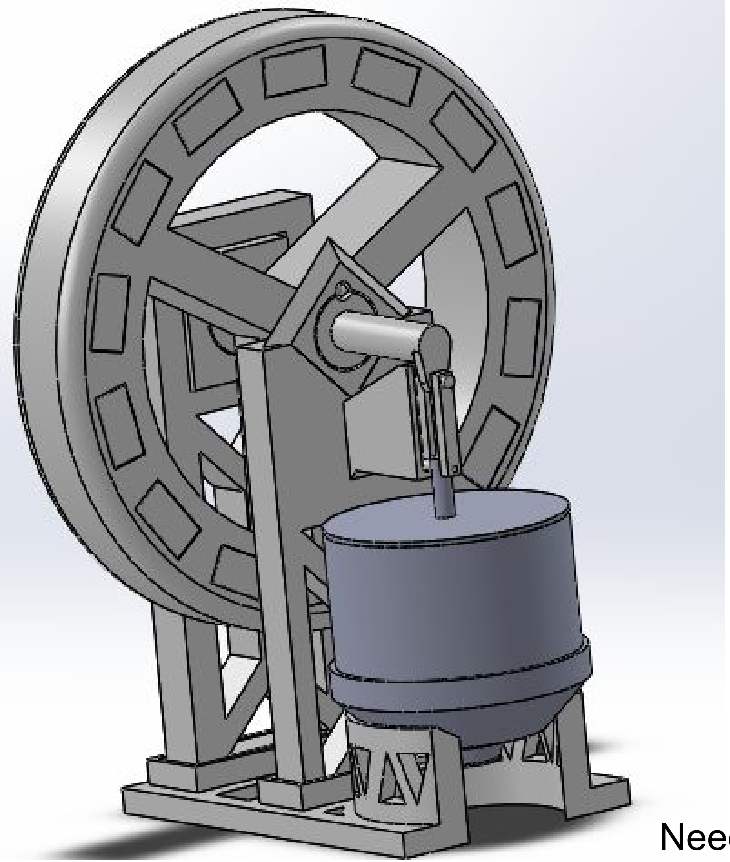




Need

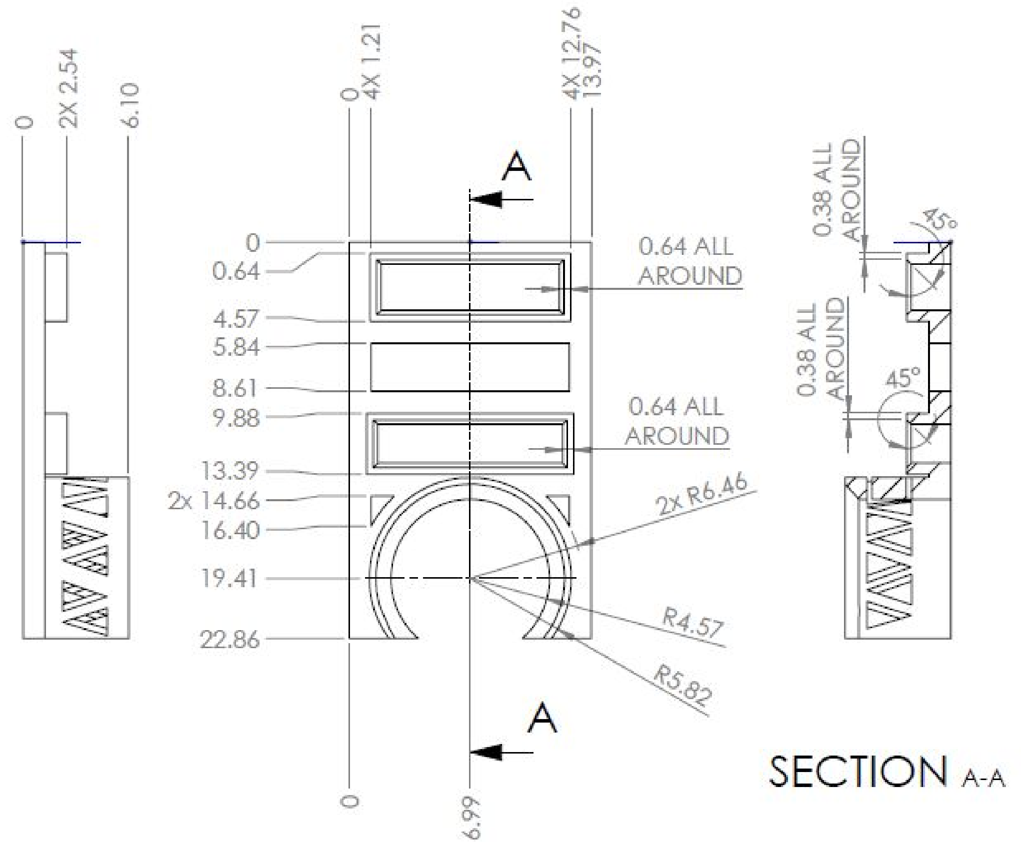
Based on the volume of the external piston, the flywheel apparatus was finalized.





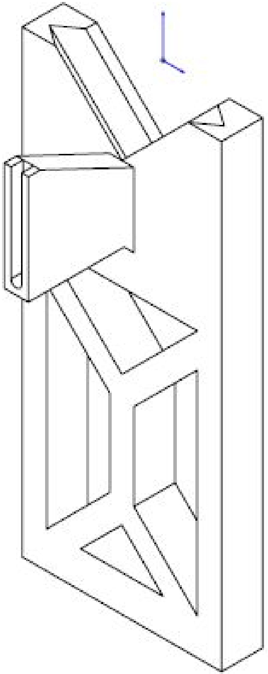
Need

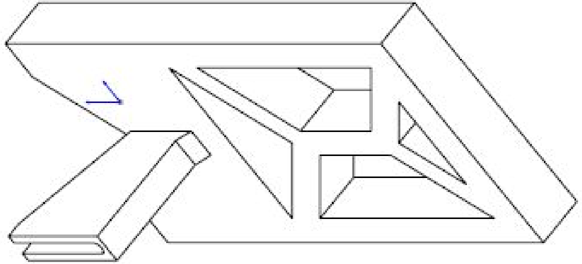
External Dimensions



DWG. NO.	Base Plate		REV A
DO NOT SCALE DRAWING	SCALE: 1:3	WEIGHT:	Sheet 2 of 3

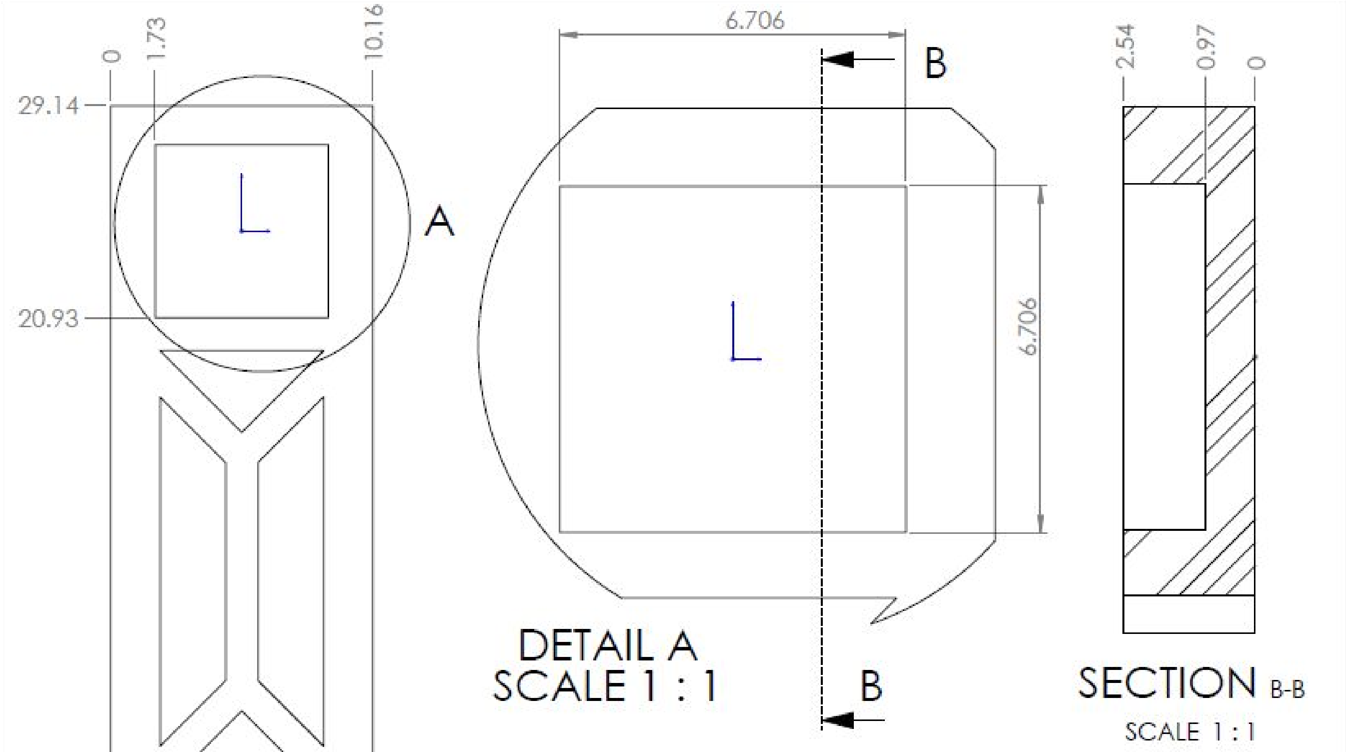
Need





MAIK Cardio		NAME	DATE	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN cm TOLERANCES: ANGULAR: ±1° TWO PLACE DECIMAL ±0.005cm THREE PLACE DECIMAL ±0.001cm	DRAWN	IN	03/16	Title:
	CHECKED	XXX	XX/XX	Front Support
	APPR.	XXX	XX/XX	
	MATERIAL PLA			
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF MAIK CARDIO. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF MAIK CARDIO IS PROHIBITED.	FINISH NONE			DWG. NO. E10.1 REV A
	SIZE A			
	DO NOT SCALE DRAWING			SCALE: 1:2 WEIGHT: Sheet 1 of 4

Need



MAIK Cardio		NAME	DATE	
UNLESS OTHERWISE SPECIFIED:	DRAWN	IN	3/24	Title:
DIMENSIONS ARE IN cm TOLERANCES: ANGULAR: ±1° TWO PLACE DECIMAL ±0.005cm THREE PLACE DECIMAL ±0.001cm	CHECKED	XXX	XX/XX	Main Support
	APPR.	XXX	XX/XX	
PROPRIETARY AND CONFIDENTIAL	MATERIAL PLA			
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF MAIK CARDIO. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF MAIK CARDIO IS PROHIBITED.	FINISH NONE			DWG. NO. E11.1 REV A
	SIZE A			
	DO NOT SCALE DRAWING			SCALE: 1:2 WEIGHT: Sheet 1 of 2

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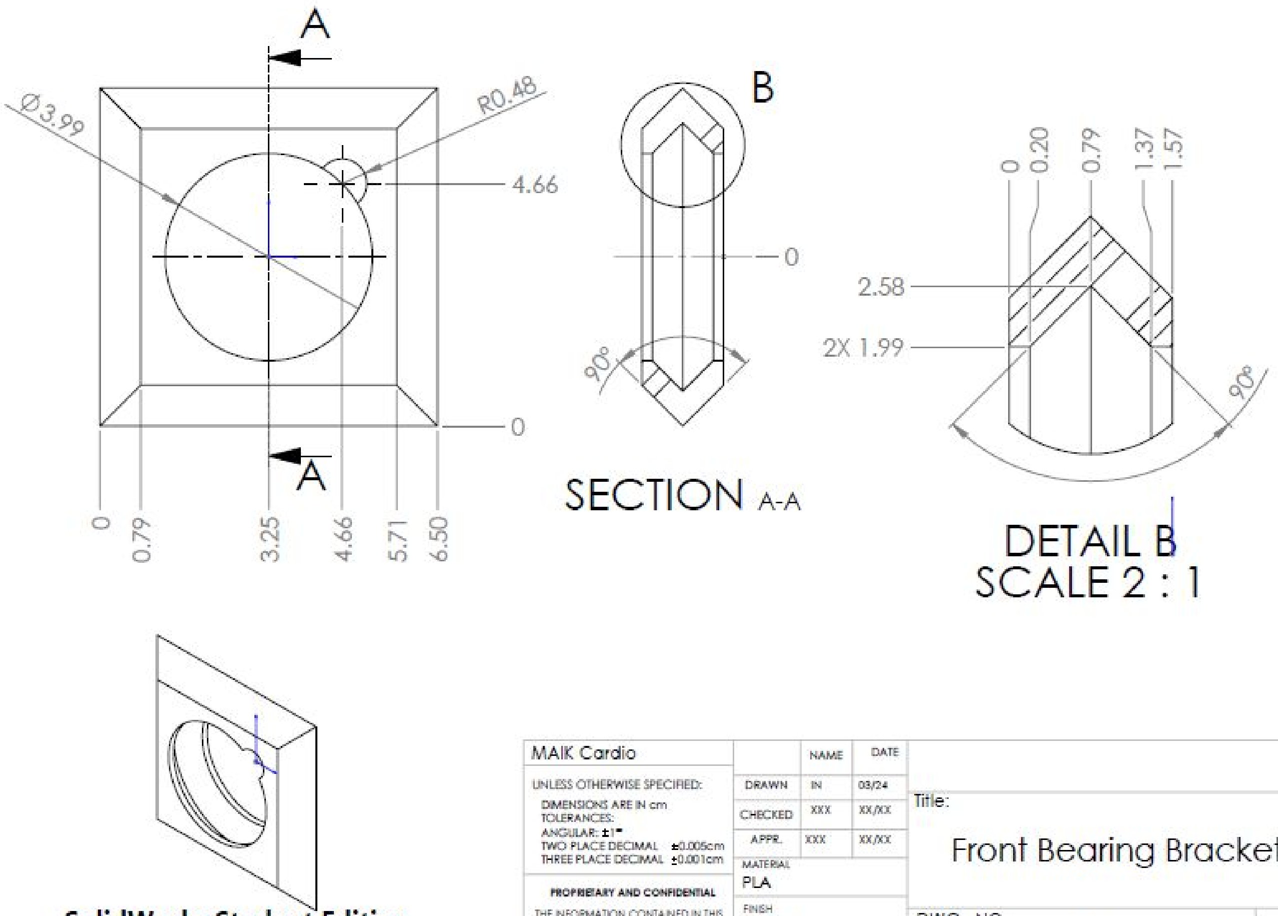
5 4 3 2 1

Need



MAIK Cardio

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN cm
TOLERANCES:
ANGULAR: ±1°
TWO PLACE DECIMAL ±0.005cm
THREE PLACE DECIMAL ±0.001cm

	NAME	DATE
DRAWN	IN	03/24
CHECKED	XXX	XX/XX
APPR.	XXX	XX/XX

MATERIAL: PLA

FINISH: NONE

SIZE: A

DO NOT SCALE DRAWING

Title: Front Bearing Bracket

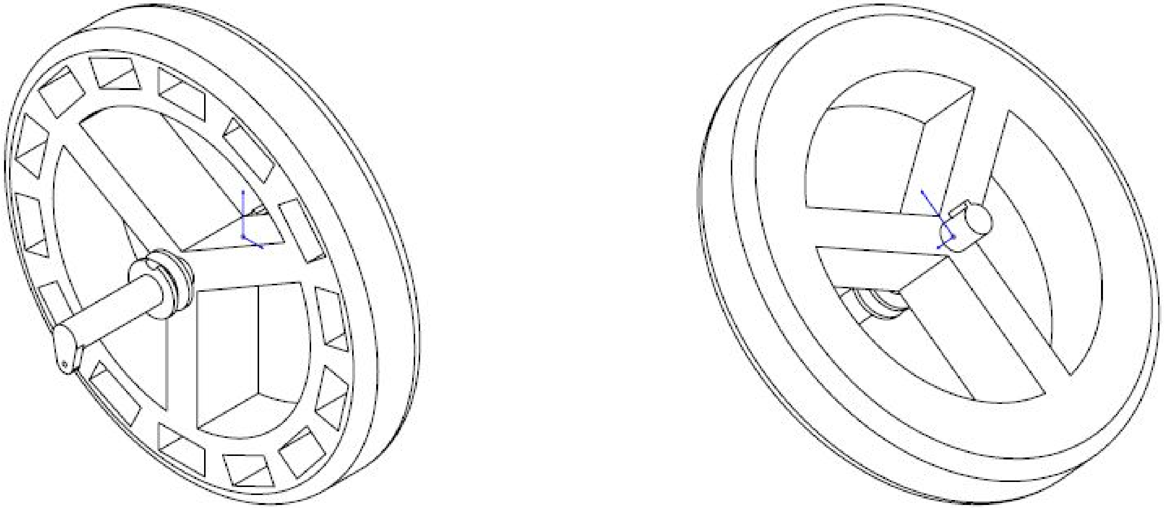
DWG. NO. E07.2

REV A

SCALE: 1:1 WEIGHT: Sheet 1 of 1

5 4 3 2 1

Need



MAIK Cardio		NAME	DATE
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN cm TOLERANCES: ANGULAR: ±1° TWO PLACE DECIMAL ±0.005cm THREE PLACE DECIMAL ±0.001cm	DRAWN	IN	3/24
	CHECKED	XXX	XX/XX
	APPR.	XXX	XX/XX
	MATERIAL PLA		
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF MAIK CARDIO. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF MAIK CARDIO IS PROHIBITED.	FINISH None		
	SIZE A		
	DO NOT SCALE DRAWING		

Title: Flywheel

DWG. NO. E05.1

REV A

SCALE: 1:3 | WEIGHT: | Sheet 1 of 6

5 4 3 2 1

Need

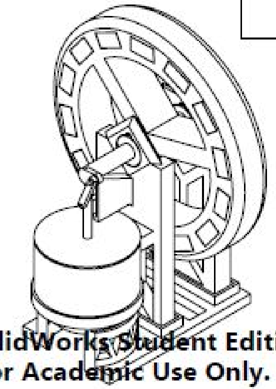
The flywheel posed a number of unique challenges in prototyping.

$$4\,Fe + 3\,O_2 \rightarrow 2\,Fe_2O_3$$

The density of iron (III) oxide is ρ=5.24 g/cm^3
while the density of pure iron is ρ=7.87 g/cm^3.

Need

ITEM NO.	PART NUMBER	DESCRIPTION	Angled Cylender/QTY.
1	E05.1	Flywheel	1
2	E06.1	Base Plate	1
3	E07.2	Front Bearing Bracket	1
4	E08.2	Square Bearing Bracket	1
5	E09.2	Inner Bearing Bracket	1
6	E10.1	Front Support	1
7	E11.1	Main Support	1
8	E12.1	Short Pin	1
9	E13.1	Long Pin	1
10	E14.1	Upper Linkage	1
11	E15.1	Pocket Lid	14
12	P01.1	5/16in Steel Ball Bearing	30
13	Total Piston System	External Pistion	1



MAIK Cardio

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN cm
TOLERANCES:
ANGULAR: ±1°
TWO PLACE DECIMAL ±0.005cm
THREE PLACE DECIMAL ±0.001cm

	NAME	DATE
DRAWN	IN	3/24
CHECKED	XXX	XX/XX
APPR.	XXX	XX/XX

MATERIAL N/A

FINISH N/A

SIZE A

Title: External Portion

DWG. NO. External portion-1.0

REV A

DO NOT SCALE DRAWING

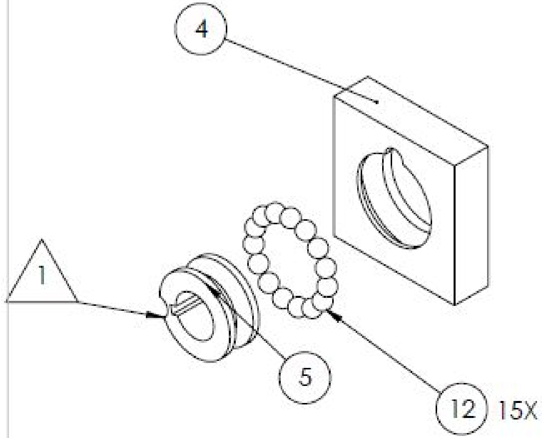
SCALE: 1:6 WEIGHT: Sheet 1 of 6

5 4 3 2 1

Need

Bearing Bracket Assembly

1. Use circular cutout to insert ball bearings into grove.
2. Check for ANSI Class I fit between the shaft and the inner surface of the bearing.



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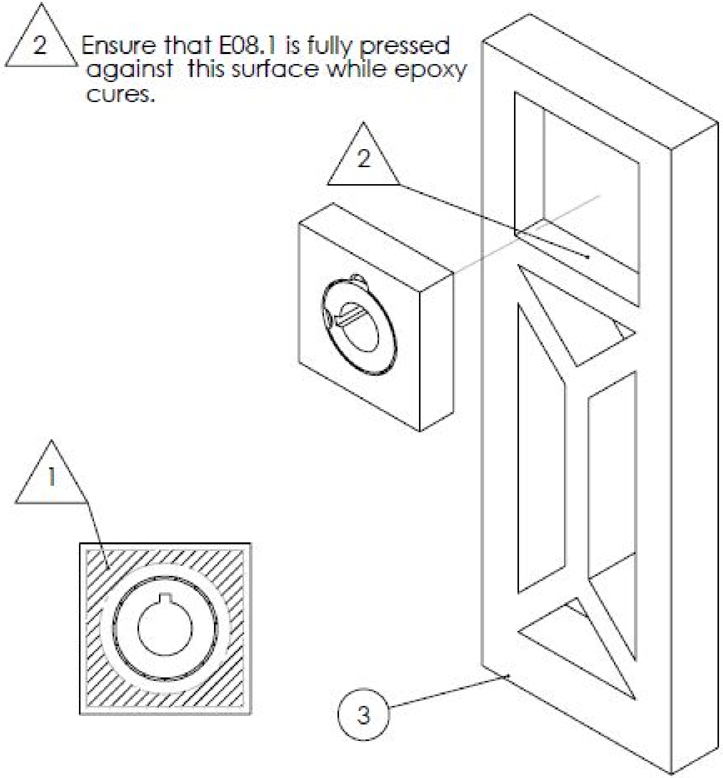
Bearing Bracket Attachment

1. Apply 5 minute epoxy to shaded areas.
2. Ensure that E08.1 is fully pressed against this surface while epoxy cures.



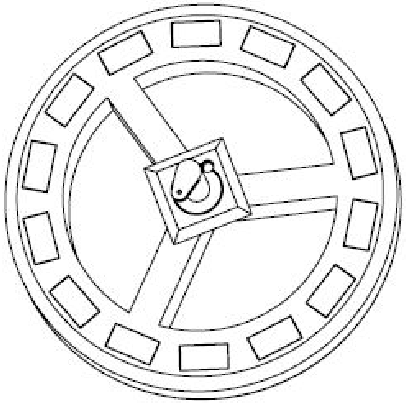
DWG. NO.	External Portion		REV A
DO NOT SCALE DRAWING	SCALE: 1:2	WEIGHT:	Sheet 2 of 6

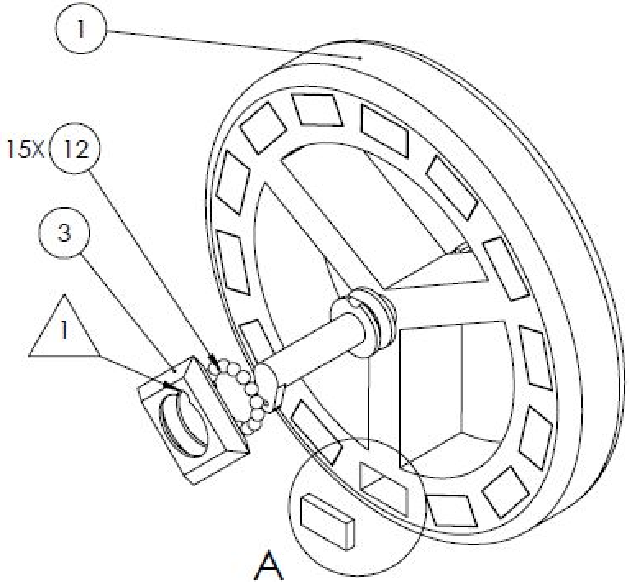
5 4 3 2 1

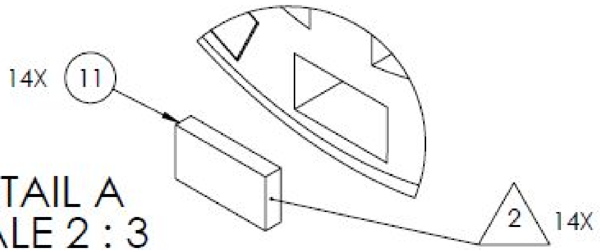
Need

Flywheel Assembly

1. Use circular cutout to insert ball bearings into grove.
2. Seal pockets with E15.1 and 5 minute epoxy applied to the outer edges of E15.1.







DETAIL A
SCALE 2 : 3

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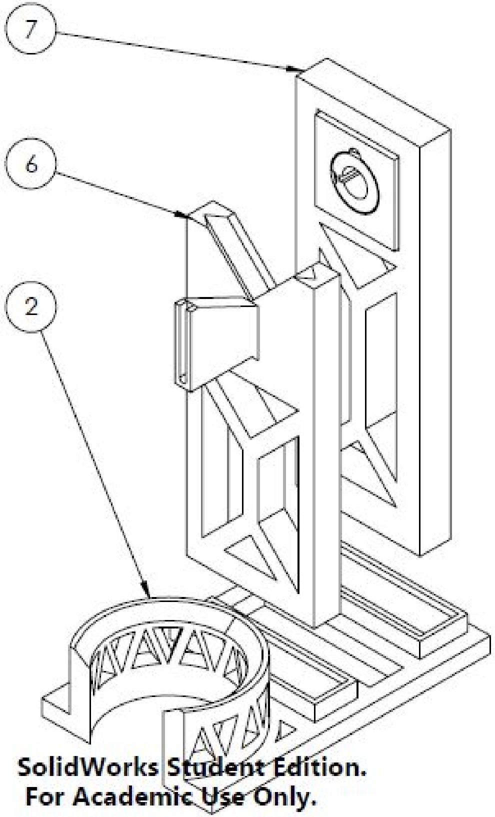
DWG. NO.	External Portion	REV A
DO NOT SCALE DRAWING	SCALE: 1:3	WEIGHT:	Sheet 3 of 6

5 4 3 2 1

Need

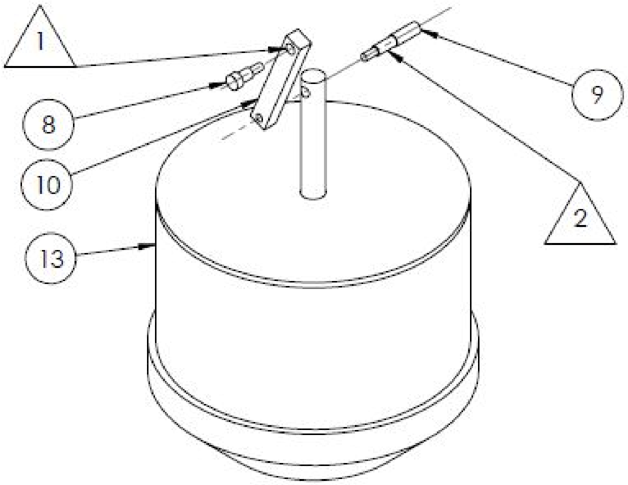
Base Assembly

Insert E10.1 and E11.1 into the raised slots on E06.2. The fit should be no closer than ANSI Class I.



Piston Linkage Assembly

1. Insert E12.1 into the upper hole in E14.1. Check to ensure that the fit is no tighter than ANSI Class II.
2. Insert E13.1 into the lower hole in E14.1 such that the shaft passes through the hole in E03.1. Check to ensure that the fit is no tighter than ANSI Class II.



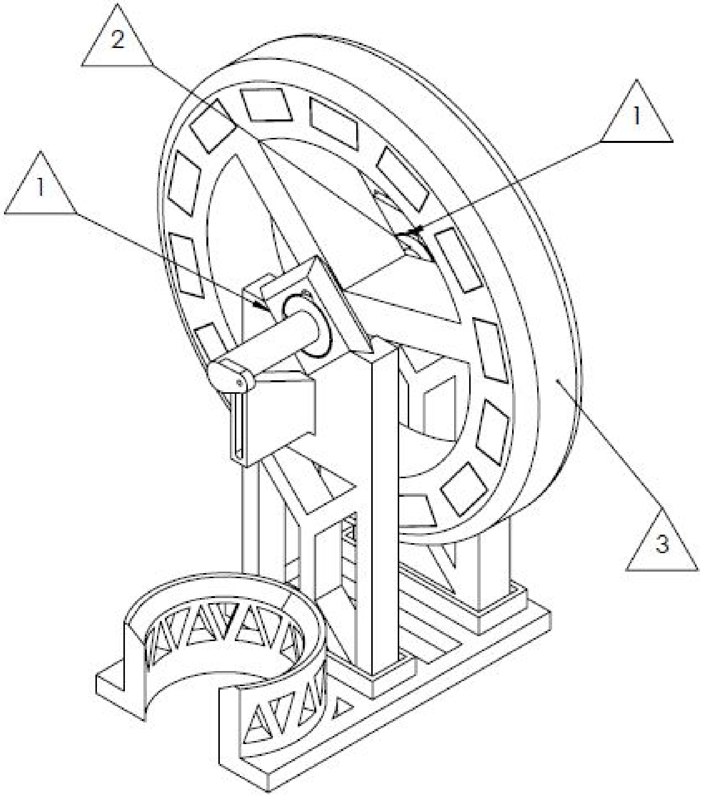
DWG. NO.	External Portion	REV A
DO NOT SCALE DRAWING	SCALE: 1:3	WEIGHT:	Sheet 4 of 6

Need

5 4 3 2 1

Flywheel Installation

1. Place Flywheel shaft into E09.1 and set E07.1 into the groove in 10.1.
2. Check the fit between the shaft of E05.1 and E09.1. It should be no looser than ANSI Class I.
3. Spin E05.1 for 30 seconds. It should rotate flreely.Apply lubrication to bearings if needed.



DWG. NO.	External Portion	REV A
DO NOT SCALE DRAWING	SCALE: 1:3	WEIGHT:

Sheet 5 of 6

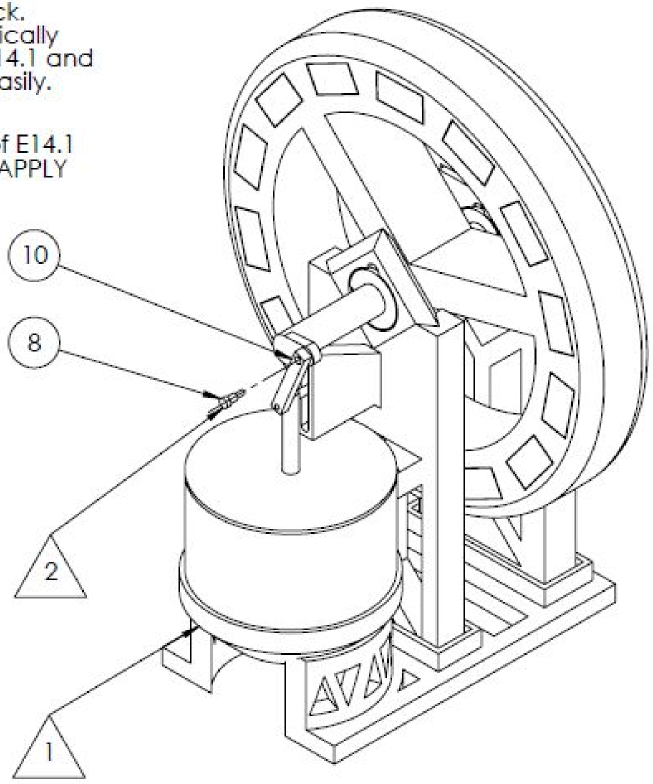
5 4 3 2 1

Need

Piston Installation

△1 Place Total External PIston on rack. Ensure that it is seated concentrically by checking the alignment of E14.1 and E05.1. The holes should line up easily. DO NOT APPLY ADHESIVE.

△2 Insert E12.1 into the upper hole of E14.1 and the hole on E05.1. DO NOT APPLY ADHESIVE.



DWG. NO. External Portion			REV A
DO NOT SCALE DRAWING	SCALE: 1:3	WEIGHT:	Sheet 6 of 6

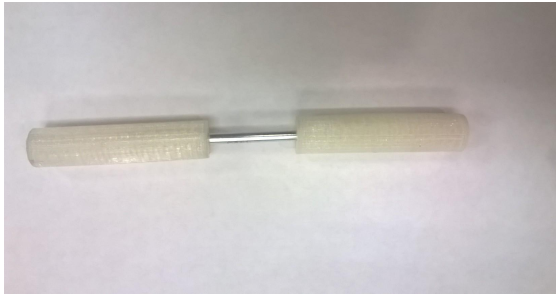
5 4 3 2 1

Need

Several clearance issues had to be addressed after the parts were printed.

Need

The original linkage design proved to be too much for PLA plastic so other solutions were explored.



Need

In spite of some tolerancing problems and sealing issues, we successfully pumped 0.8L of water in 40 seconds. This comes out to 1.2L/min.