Advanced Mechanical Design, University of Rochester
Final Design Report
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NEAR ZERO LEAK / LOW FRICTION ROTARY COOLANT VALVE

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ABSTRACT

The objective of this senior design project is to improve sealing to reduce internal valve leakage across output ports of a rotary style 3-way / 2-position coolant control valve without significantly increasing motor actuation torque. An existing design, as well as requirements and specifications, were provided as a starting point by G.W. Lisk, a worldwide supplier of valves, solenoids, LVDT sensors, and other precision components for various military and commercial industrial applications. Throughout the semester, the team came up with several different design concepts. Through the use of a Pugh matrix and concept selection criteria, two designs were selected for further design optimization and testing. The team created CAD of the two designs in order to conduct various computer-based analyses. The two designs were manufactured and assembled into prototypes. A test plan was formulated for both on-campus testing done by the students in order to measure leakage and actuation torque and for official testing at Lisk facilities. The on-campus testing found a leakage reduction to less than 10% of the baseline leakage and an acceptable actuation torque for both designs. These initial testing results were further confirmed by official testing at the G.W Lisk facilities.

PROBLEM DEFINITION

Global warming is causing climate change around the world. A reduction in the emission of greenhouse gasses is necessary to mitigate the effects that rising temperatures are having on human and ecosystem welfare. Fossil fuel use in the transportation sector contributes to greenhouse gas emission. Transitioning vehicles to electric means of locomotion helps reduce the impact the transportation sector has on the climate crisis. Electric vehicles contain cooling systems that regulate the temperature of batteries during operation. A 3 way / 2 position motor-operated rotary coolant valve developed by G.W. Lisk is inherent to the cooling system. The valve directs flow at different times to the batteries and a bypass system. Currently the baseline design contains internal leakage across the outlet ports of the valve. Improving the current design by minimizing leakage without significantly increasing actuation torque will increase the efficiency of electric vehicles and help to replace gasoline powered vehicles with electric vehicles.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

The primary deliverables for this project, as specified by G.W. Lisk, include multiple design concepts with concept selection criteria, computer aided design (CAD) of the design proposal(s), prototype hardware demonstration, and a final report providing measured leak rates across ports, design effect on pressure drops between the inlet port and the two outlet ports, and estimated leak rate over time in service. A flowchart of the primary deliverables can be seen in the Work Breakdown Structure (WBS) in Annex A. Annex B shows the Critical Path Management (CPM). Activities included in the CPM include all steps necessary for completion of the project in regards to both the requirements of G.W. Lisk and the instructor of this course.

The requirements and specifications for the project are listed below. Following the requirements and the specifications are descriptions of how each specification will be verified.

Requirements:

1. The valve must connect to a motor that can provide actuation torque.
2. The valve must have one inlet and two outlet ports. The outlets must be 180 degrees opposed. The inlet must be 90 degrees opposed from each outlet.
3. The valve assembly must be able to provide a pathway for the coolant (50/50 glycol and water mixture).
4. The valve must be made of a non-ferrous material that is compatible with a 50/50 water glycol mixture.
5. The mounting hole configuration must remain intact to the current layout.
6. There must be no evidence of exterior leakage past exterior leakage surfaces.

Specifications:

1. The pressure drop must be maintained within 5% of 50 kPa.
2. The inlet and outlet pipe diameters must be within +/- 0.2 of 25 mm.
3. The leakage must be reduced to at least 10% of the baseline leakage rate of 1.4 L/min.
4. The total actuation torque must not exceed 1.2 Nm (If a higher torque is required to achieve internal leakage requirement, defense of rationale will be required for acceptance).
5. The valve must be able to rotate in a 90 degree (± 2 degrees) range between the inlet and outlets.

6. The valve must be able to support a working temperature range of -40 to 125 ˚C without structural failure due to thermal stresses.

Verification of specifications:

1. Increase the inlet pressure until the flow across the valve is sufficient and measure the pressure drop.
2. Inspection
3. Close one outlet port and drive the pressure across the inlet and open outlet. Measure leakage in the closed port.
4. Measure the breakaway torque when pressure is driven across the inlet and an outlet. The torque required to move the gate under this condition is the breakaway torque.
5. Inspection
6. Thermal endurance test (if possible) or CFD (if possible)

CONCEPTS

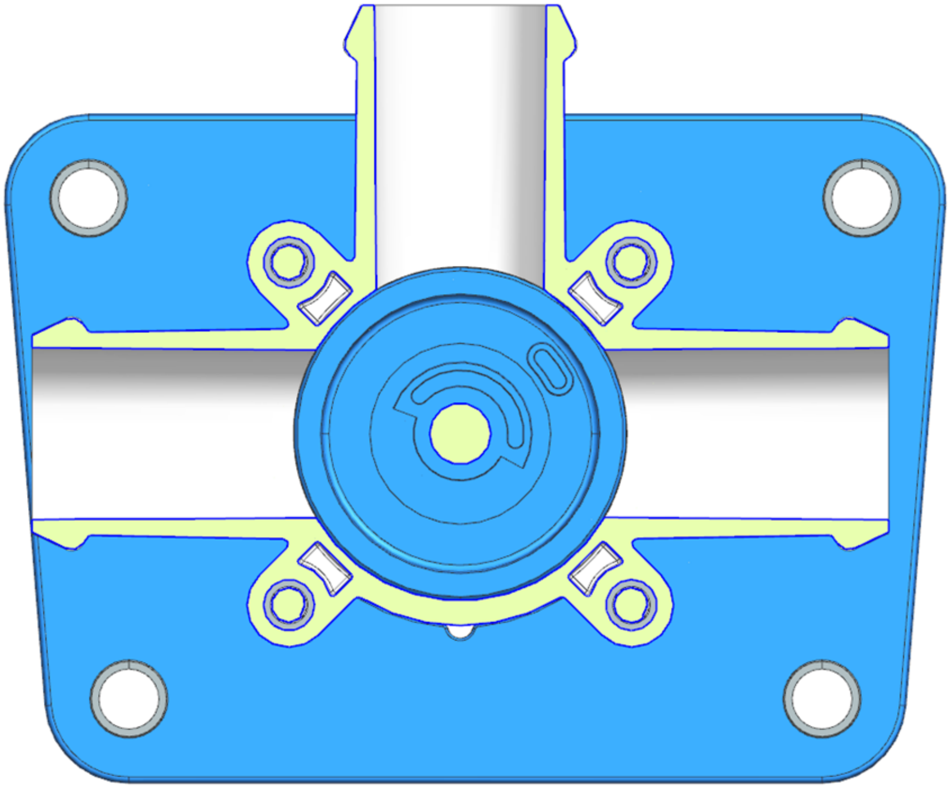
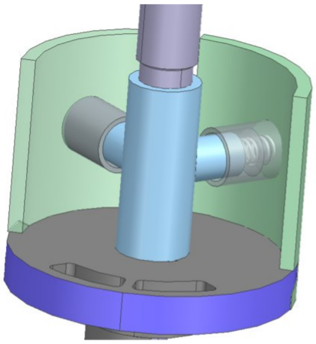
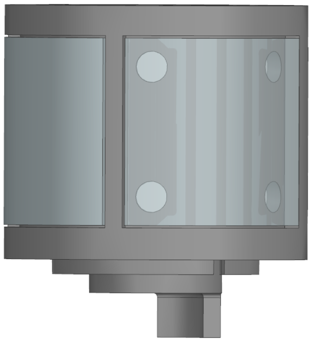
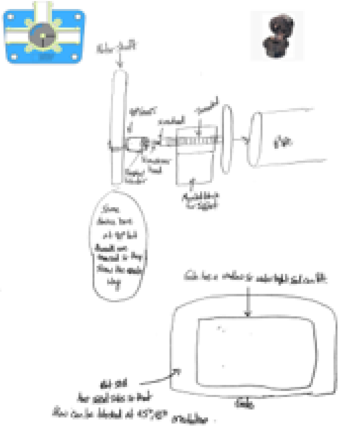


Figure 1. Top down cross-sectional view of the outer valve housing supplied by Lisk

Figure 1 above shows a top down cross-sectional view of the outer valve housing supplied by Lisk. The inlet is the pipe that extends from the top of the image and the two outlets are the pipes that extend to the left and the right of the image. Different gate concepts were designed by the team to spin inside of the outer value housing to block the desired outlet with minimal leakage. Table 1 below shows the final three gate designs that the team created. Larger sketches and images of the designs can be found in Figures 13-15 of Annex C.

Table 1. Final Design Concepts

Design Number	Sketch/Image	Description
1		A press fit on the shaft extends compression springs to keep two flaps in place against the outer valve housing. When in front of an outlet the pressure differential forms a seal between the flap and rim of the outlet pipe.
2		The design contains a gate with two cavities that each hold a flap. When in front of an outlet the pressure differential pushes the flap towards the outlet to create a seal between the flap and rim of the outlet pipe.
3		Gear and screw system that employs Bevel gears, an extender, a screwdriver head, and a screw to extend a blockage towards the outlet. Another system with the same components is located 90 degrees clockwise from the original with screw threads that are reversed. As the motor shaft rotates, one blockage moves towards an outlet pipe while the other blockage moves away from the other outlet. Vice versa occurs when the motor shaft rotates the opposite way.

To evaluate the final concepts in Table 1, the team formulated a Pugh matrix (see Table 2 below) to rank the designs. The details of the Pugh matrix evaluations are seen below. Rankings range from 1 to 5 where 1 is the worst and 5 is the best.

Evaluation criteria:

- Time to Manufacture
- Ability to stop leakage (Functionality)
- Actuation Torque - A small actuation torque is more desirable than a large actuation torque
- Design Simplicity
- Cost
- Ease of Material Selection – How easy is it to find materials for the components in the design?
- Durability
- Ease of Assembly
- Thermal Design – How well can the design withstand changes in temperatures?

Multipliers were placed on certain criteria to signify greater importance:

Time to Manufacture: Multiplier = 4

- The limited timeframe assigned to this project hinders the team's ability to execute certain manufacturing techniques resulting in more simplistic and easier-to-manufacture designs.

Ability to stop leakage (Functionality): Multiplier = 5

- The main objective of the project is to reduce the leakage rate to at least 10% of the baseline 1.4 L/min. If a concept does not fulfill this specification it is not successful. Therefore, the team agreed to assign the ability to stop leakage as having the most weight in the Pugh Matrix.

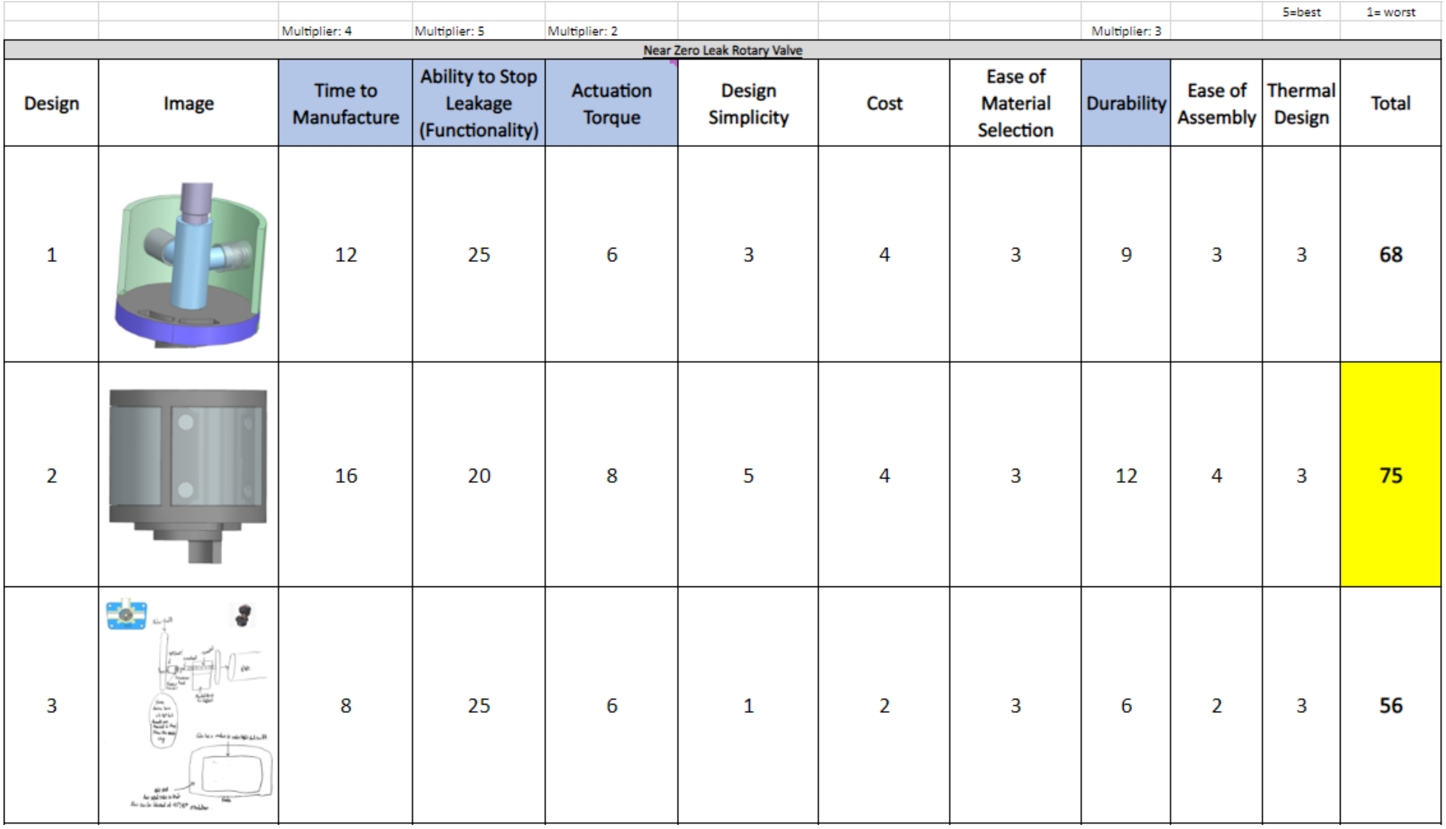
Actuation Torque: Multiplier = 2

- Project sponsors would prefer to keep the actuation torque of the control valve at 1.2 Nm as this would allow the current motor setup to be kept in usage.

Durability: Multiplier = 3

- Concepts need to be long-lasting as there will be constant pressure from the coolant flow applied to the hardware components.

Table 2. Pugh Matrix of Final Design Concepts with Grading Criteria



										5=best	1= worst
		Multiplier: 4	Multiplier: 5	Multiplier: 2				Multiplier: 3			
Near Zero Leak Rotary Valve											
Design	**Image**	**Time to Manufacture**	**Ability to Stop Leakage (Functionality)**	**Actuation Torque**	**Design Simplicity**	**Cost**	**Ease of Material Selection**	**Durability**	**Ease of Assembly**	**Thermal Design**	**Total**
1		12	25	6	3	4	3	9	3	3	**68**
2		16	20	8	5	4	3	12	4	3	**75**
3		8	25	6	1	2	3	6	2	3	**56**

Results of the Pugh matrix:

The design with the greatest total points in the Pugh matrix was Design 2. The team agreed with this result as Design 2 is a simple and practical design. However, the team also felt that Design 1 and 3 would be better at stopping leakage. After discussion, Design 3 was eliminated from consideration for manufacture because of its complicated design and estimated long construction time. Design 1 was determined to be more reasonable to manufacture although it would likely take more time, material, contain more complicated components, and increase actuation torque more than Design 2. Ultimately, the team decided to pursue Design 1 and 2 for manufacturing and testing while noting the tradeoffs between the two designs. Two sets of flaps would be constructed for both designs made from the material Ultra High Molecular Weight Polyethylene (UHMWPE) with thicknesses of 3/32” and 1/16”.

Bill of material and part drawings for Design 1 and 2 can be found in Figures 16 through 23 of Annex D.

MECHANICAL ANALYSIS

This section will detail mechanical analysis performed specifically for Design 1 and 2 as well as mechanical analysis performed generally for both designs. The conclusion of each analysis and the effect of the conclusion on the design will also be stated.

Design 1:

Tolerance Analysis: Press Fit Between YPAN26_0C0032A and VY2-5217:

In Design 1, the shaft is press fit (locational tolerance fit) into part ypan26_0c0032A in order to achieve sufficient torque transmission. The drawings for both parts are shown in Figures 2 and 3 below. The tolerance analysis is demonstrated in Eqn. (1-4) below:

Press fit indicates H7/p6 [1]:
$D =$ basic size of hole, $d =$ basic size of shaft, δ_u = upper deviation, δ_l = lower deviation, δ_F = fundamental deviation,

For hole diameter:

$$D_{max} = D + \Delta D \tag{1}$$

$$D_{min} = D \tag{2}$$

$$\Delta D = 0.0006in,\ D_{min} = D = 0.3646in$$

$$D_{max} = 0.3646 + 0.0006 = 0.3652in$$

For shaft diameter:

$$d_{min} = d + \delta_F \tag{3}$$

$$d_{max} = d + \delta_F + \Delta d \tag{4}$$

$$\Delta d = 0.0004in,\ \delta_F = 0.0006in$$

$$d_{min} = d + \delta_F = 0.3646 + 0.0006 = 0.3652in$$

$$d_{max} = d + \delta_F + \Delta d = 0.3656in$$

The dimensions of the press fit part are created based on the results of the above calculations.

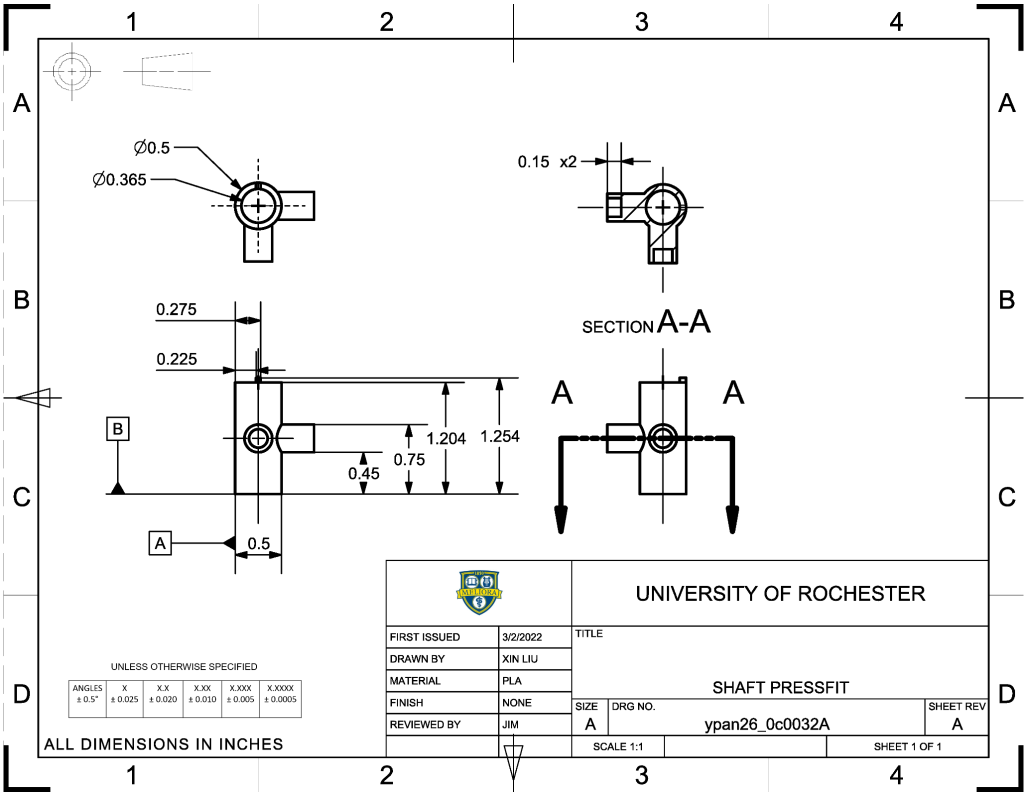


Figure 2. Drawing of Design 1's press-fit component

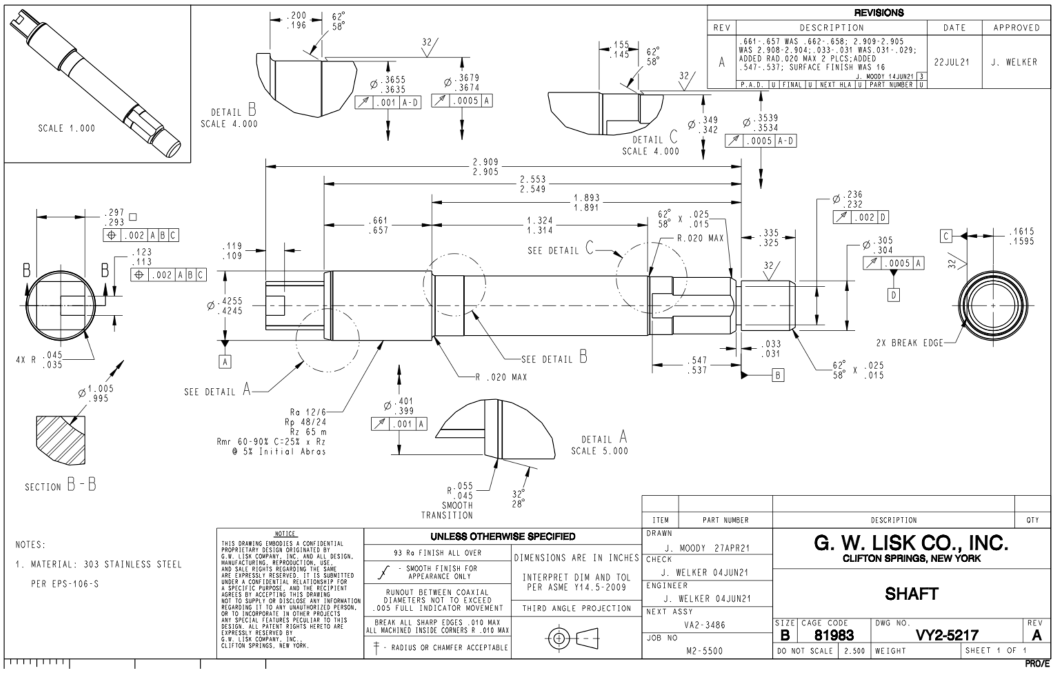


Figure 3. G.W. Lisk drawing of shaft component

Computer-Based Analysis: Flap Notch Interface Between YPAN26_0C0031A and YPAN26_0C0034A:

Figure 4 below shows the results of structural FEA on the flap notches in Design 1. The top left corner shows an exaggerated simulation of the flap and gate when the load is applied. The top right and bottom left corners are two different perspectives of the flap to display the locations of stress concentrations. The bottom right corner shows the stress profile on the protrusions on the gate. The purpose of this simulation is to verify that the maximum stress in this region will not cause the UHMWPE material to fail.

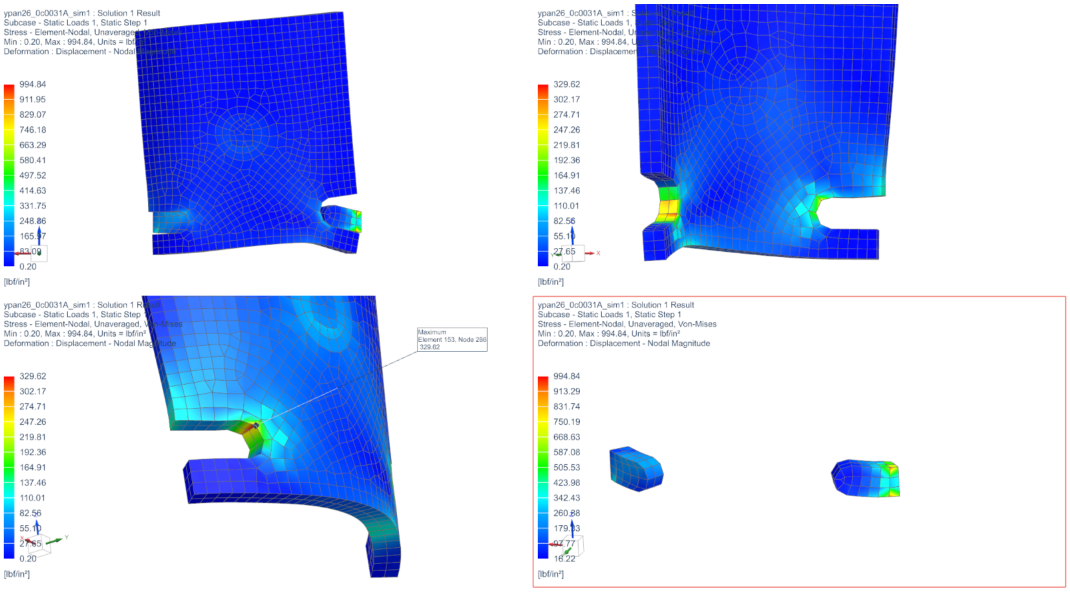


Figure 4. Stress analysis on Design 1's notches

Flap material: UHMWPE (Young's Modulus = 624 MPa) [2]
Mesh type: CHEXA(8)
Mesh size: 0.05in
Constraints: Cylindrical constraint in radial direction on outer surface of the flap; Contact surface with fixed gate protrusions
Load: friction force of 12.6N
Static friction coefficient between contact surfaces: 0.3

Friction between the flap and valve housing is assumed to be the main source of load. Equations (5-8) below show the process of calculating the friction force. P = Pressure, A = Area, F = Force, k = Spring Constant, d = Spring Displacement, f_f = Force of Friction.

$$F_{N,pressure} = PA \tag{5}$$

$$P = 80kPa,\ A = \pi r_{port}^2 = \pi(0.5)^2 = 0.785in^2 = 0.000507m^2,\ F_{N,pressure} = PA = 80,000 \times 0.000507 = 40.5N$$

$$F_{N,spring} = k * d_{compress} \tag{6}$$

$$k = 6.08lb_f/in,\ d_{compress} = 0.5 - 0.44 = 0.06in,\ F_{N,spring} = k * d_{compress} = 6.08 \times 0.06 = 0.3648lb_f = 1.62N$$

$$F_{N,total} = F_{N,spring} + F_{N,pressure} \tag{7}$$

$$F_{N,\,total} = F_{N,\,spring} + F_{N,\,pressure} = 40.5N + 1.62N = 42.12N$$

Assuming the coefficient of friction between the flap and valve housing is 0.3, then:

$$f_f = \mu \times F_{N,\,total} \tag{8}$$

$$f_f = 0.3 \times F_{N,\,total} = 0.3 \times 42.12 = 12.6N$$

Therefore, this friction force is the applied load used in the simulation to calculate maximum stress present in the flap geometry. A contact surface constraint is placed between the notches on the flap and the protrusions (shown in the bottom right of Figure 4) on the gate, essentially preventing the flap from tilting “left or right.” A cylindrical constraint in the radial direction is placed on the outer surface of the flap, essentially preventing the flap from sliding “in or out.” The results show that the maximum stress occurs at the edges where the two surfaces interact, which is expected. The maximum stress of interest on the flap is 330 psi and the ultimate tensile strength of UHMWPE is 3550 psi, which gives a factor of safety greater than 10. Therefore, the design of the flap is validated and does not need modification for stress failure.

Fundamental Mechanical Analysis:

Static actuation torque can be calculated based on Equations (5-8) of the force of friction between the working flap and valve housing. The theoretical actuation torque value is the product of the friction force between the working flap and the valve housing and the radius of the gate. This calculation can be seen below in Eqn. (9):

$$\tau_{actuation} = r_{gate} f \tag{9}$$

$$\tau_{actuation} = 0.025 \times 12.6 = 0.315\, Nm$$

Since this value is less than 0.4 Nm (the difference between the existing setup and the maximum 1.2 Nm of actuation torque allowed) it confirms the feasibility of Design 1.

Computer-Based Analysis: Contact Pressure Between YPAN26_0C0032A and Rim of Outlet Pipe:

UHMWPE flaps with 3/32” and 1/16” thicknesses are compared for use in Design 1. A consistent legend scale is used for easy color comparison between figures.

YPAN26_0C0032A UHMWPE 3/32” Flaps:

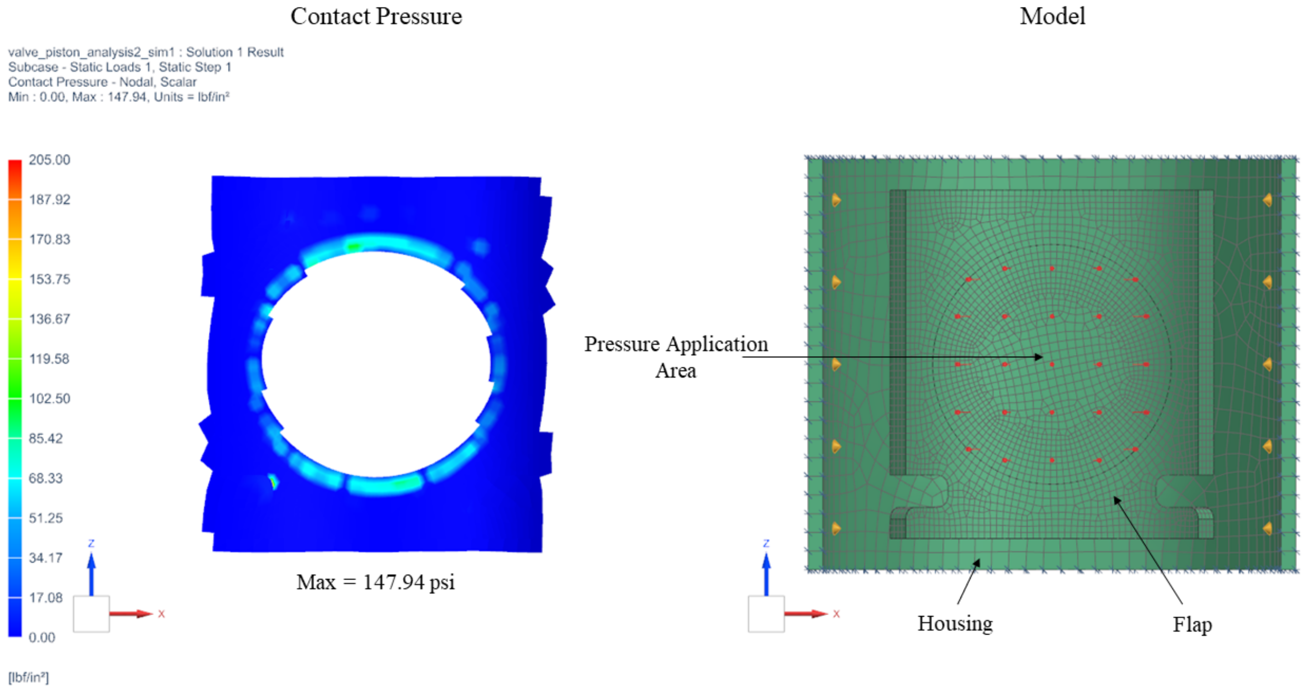


Figure 5. Contact pressure simulation on Design 1’s 3/32” flaps

Flap material: UHMWPE (Young’s Modulus = 624 MPa) [2]
Housing material: Fortron 1140L4 PPS (Young’s Modulus = 14,700 MPa) [3]
Mesh type: CHEXA(8)
Mesh size (0.03” for flap and 0.08” for housing)
Gap between flap and housing contact surfaces: 0.0013”
Constraints: Housing fixed on outer edge faces, contact surface set between valve housing and flap
Load: 80kPa pressure on a circular area present on the flap that is slightly larger than the outlet pipe area
Static friction coefficient between contact surfaces: 0.2

YPAN26_0C0032A UHMWPE 1/16" Flaps:

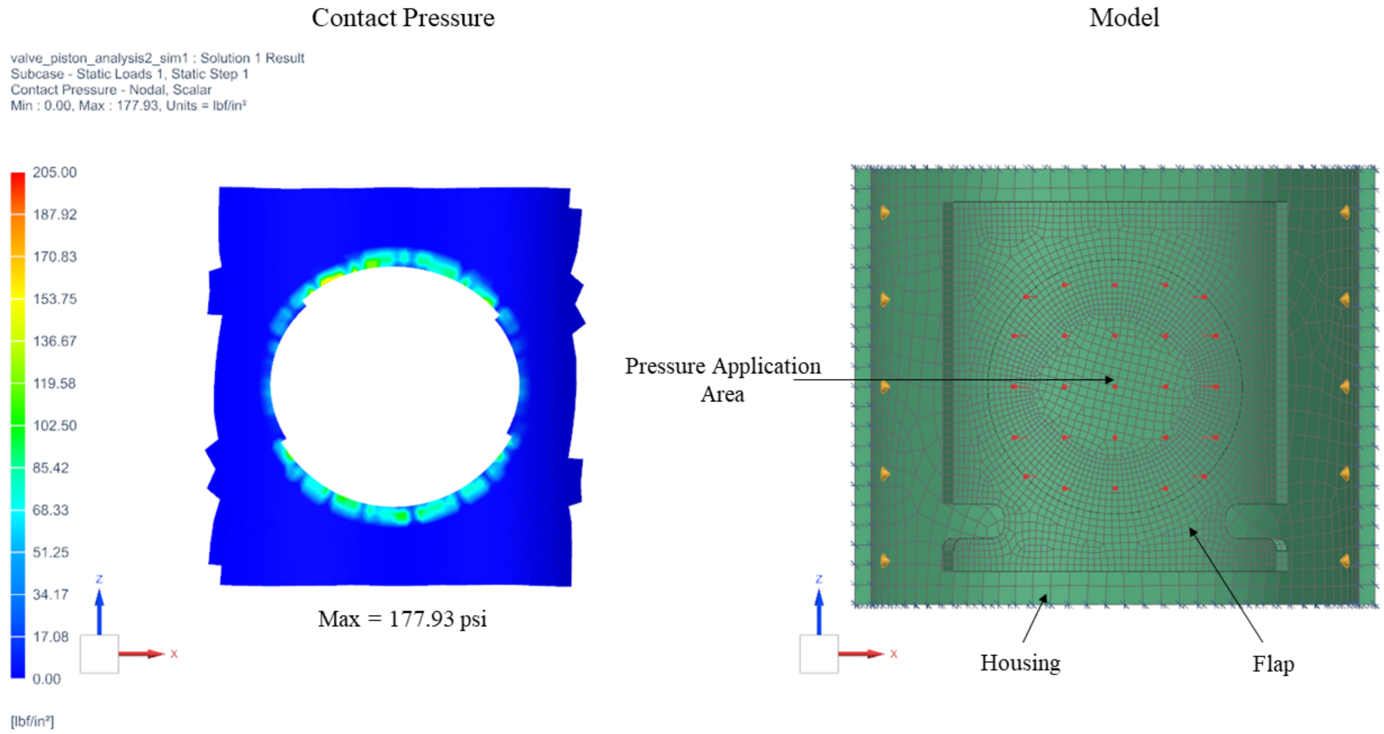


Figure 6. Contact pressure simulation on Design 1's 1/16" flaps

Flap material: UHMWPE (Young's Modulus = 624 MPa) [2]
Housing material: Fortron 1140L4 PPS (Young's Modulus = 14,700 MPa) [3]
Mesh type: CHEXA(8)
Mesh size (0.03" for flap and 0.08" for housing)
Gap between flap and housing contact surfaces: 0.0013"
Constraints: Housing fixed on outer edge faces, contact surface set between valve housing and flap
Load: 80kPa pressure on a circular area present on the flap that is slightly larger than the outlet pipe area
Static friction coefficient between contact surfaces: 0.2

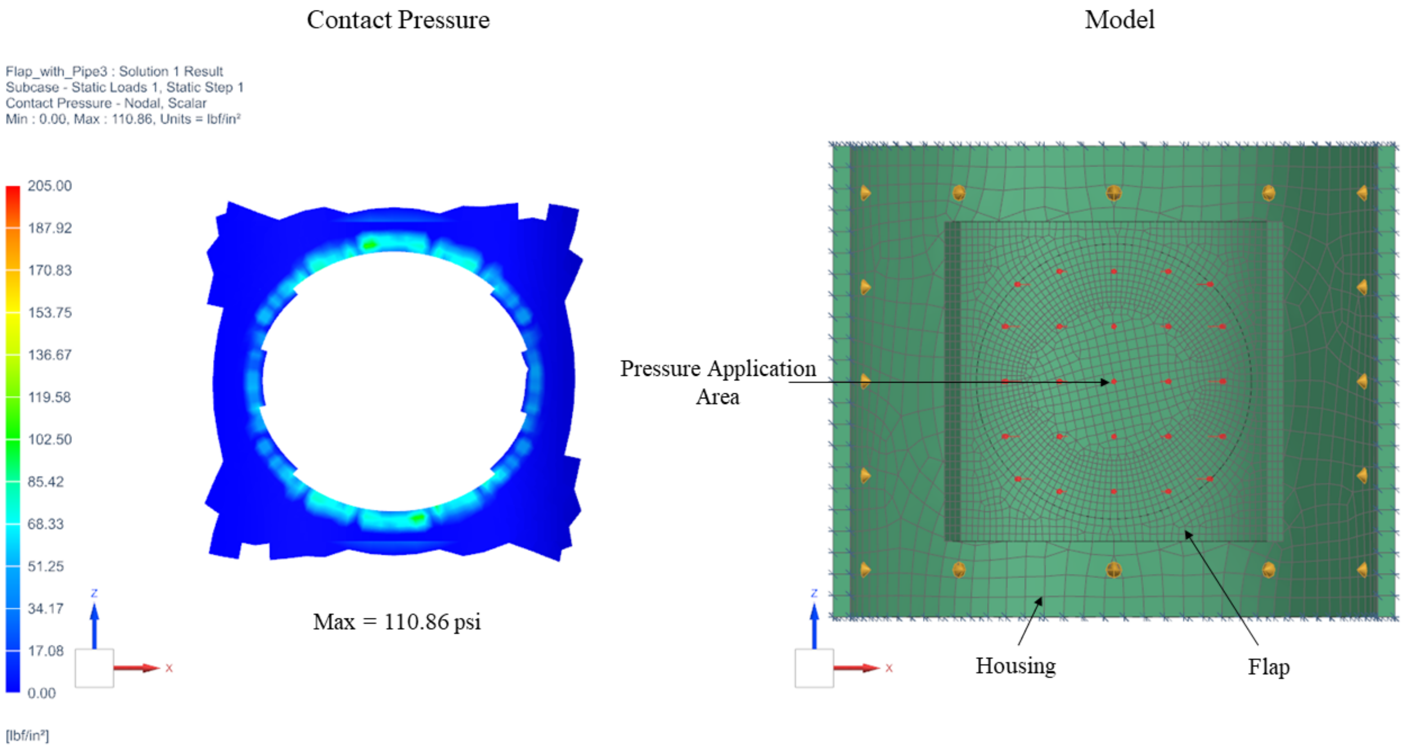
For Design 1 the team expects the pressure differential between the inlet and outlet to cause the flap to slightly deform and create a seal in conjunction with the compression spring when in front of the outlet. To test this idea the team created the simulations above to analyze the contact pressure around the rim of the outlet. Figure 5 above shows the results of contact analysis between 3/32" flaps and the valve housing, while Figure 6 shows the same with 1/16" flaps. As seen in the simulations, the 3/32" thick flap has better distributed contact pressure around the outlet than the 1/16" flap. However, the 1/16" flap has larger contact pressures around the outlet than the 3/32" flap. An ideal design would have an evenly distributed high pressure contact profile for the best seal. As a result of the tradeoff between the 1/16" and 3/32" flaps, the team decided to test both flap thicknesses in Design 1.

<u>Design 2:</u>

Computer-Based Analysis: Contact Pressure Between PSCHAEFE_0C0030A and Rim of Outlet Pipe:

UHMWPE flaps with 3/32” and 1/16” thicknesses are compared for use in Design 2. A consistent legend scale is used for easy color comparison between figures.

PSCHAEFE_0C0030A UHMWPE 3/32” Flaps:


Contact Pressure

Model

Figure 7. Contact pressure simulation on Design 2’s 3/32” flaps

Flap material: UHMWPE (Young’s Modulus = 624 MPa) [2]
Housing material: Fortron 1140L4 PPS (Young’s Modulus = 14,700 MPa) [3]
Mesh type: CHEXA(8)
Mesh size (0.03” for flap and 0.08” for housing)
Gap between flap and housing contact surfaces: 0.0013”
Constraints: Housing fixed on outer edge faces, contact surface set between valve housing and flap
Load: 80kPa pressure on a circular area present on the flap that is slightly larger than the outlet pipe area
Static friction coefficient between contact surfaces: 0.2

PSCHAEFE_0C0030A UHMWPE 1/16" Flaps:

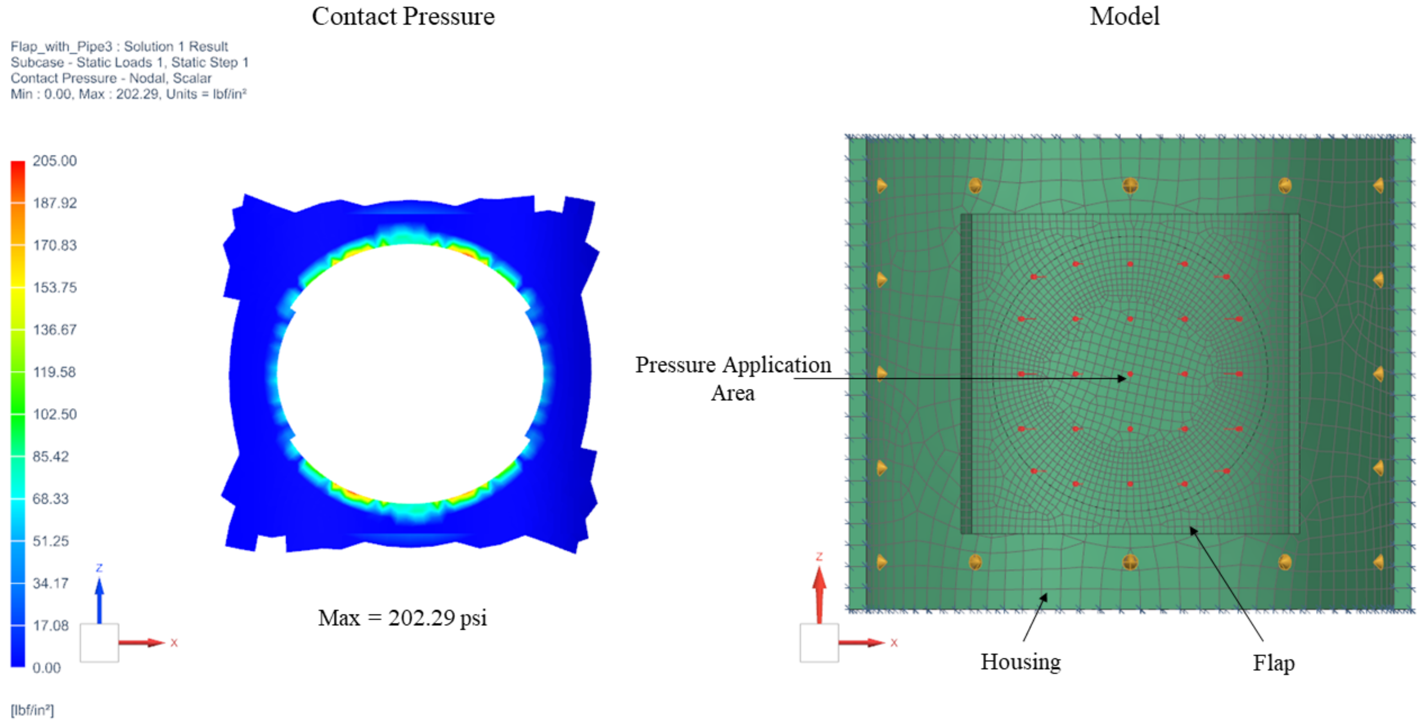


Figure 8. Contact pressure simulation on Design 2's 1/16" flaps

Flap material: UHMWPE (Young's Modulus = 624 MPa) [2]
Housing material: Fortron 1140L4 PPS (Young's Modulus = 14,700 MPa) [3]
Mesh type: CHEXA(8)
Mesh size (0.03" for flap and 0.08" for housing)
Gap between flap and housing contact surfaces: 0.0013"
Constraints: Housing fixed on outer edge faces, contact surface set between the valve housing and flap
Load: 80kPa pressure on a circular area present on the flap that is slightly larger than the outlet pipe area
Static friction coefficient between contact surfaces: 0.2

For Design 2, like Design 1, the team expects the pressure differential between the inlet and outlet to cause the flap to slightly deform and create a seal when in front of the outlet. To test this idea the team again created simulations to analyze the contact pressure around the rim of the outlet. Figure 7 above shows the results of contact analysis between 3/32"flaps and the valve housing, while Figure 6 shows the same with 1/16" flaps. As seen in the simulations, both the 3/32" and 1/16" flaps have evenly distributed contact pressure around the outlet. However, the 1/16" flap has larger contact pressures around the outlet than the 3/32" flap. The team decided to incorporate both flap thicknesses into Design 2 for testing, but noted that the 1/16" flap would likely have less leakage.

Calculations for both designs:

Computer Based Analysis: Fluid Flow Through Valve and Pressure at Outlet

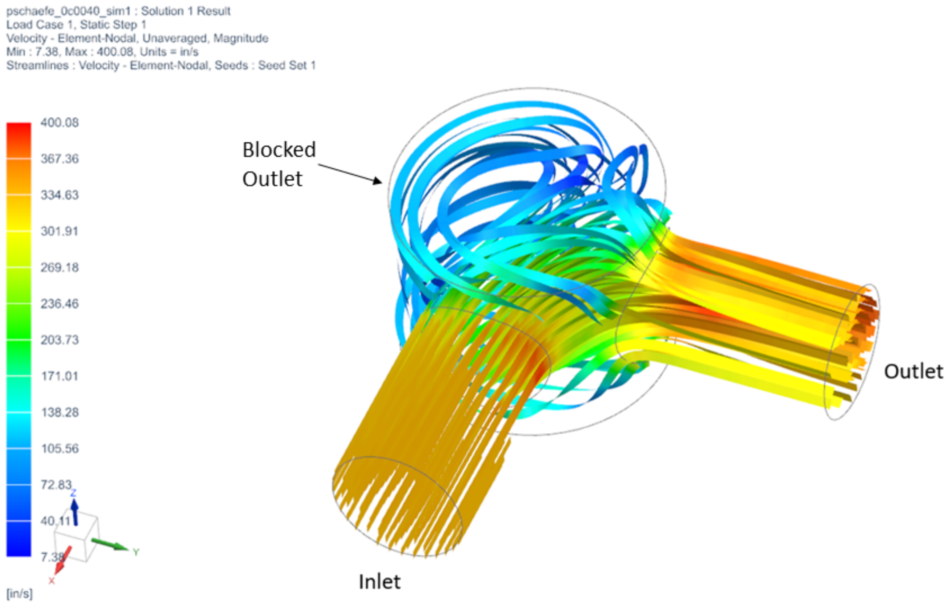


Figure 9. Fluid flow through valve housing with one outlet blocked

Fluid: Water
Mesh type: 3D TET4
Mesh element size: 0.1”
Constraints: Inlet Pressure = 80 kPa, Outlet Pressure = 0 kPa
Assumes one outlet is blocked

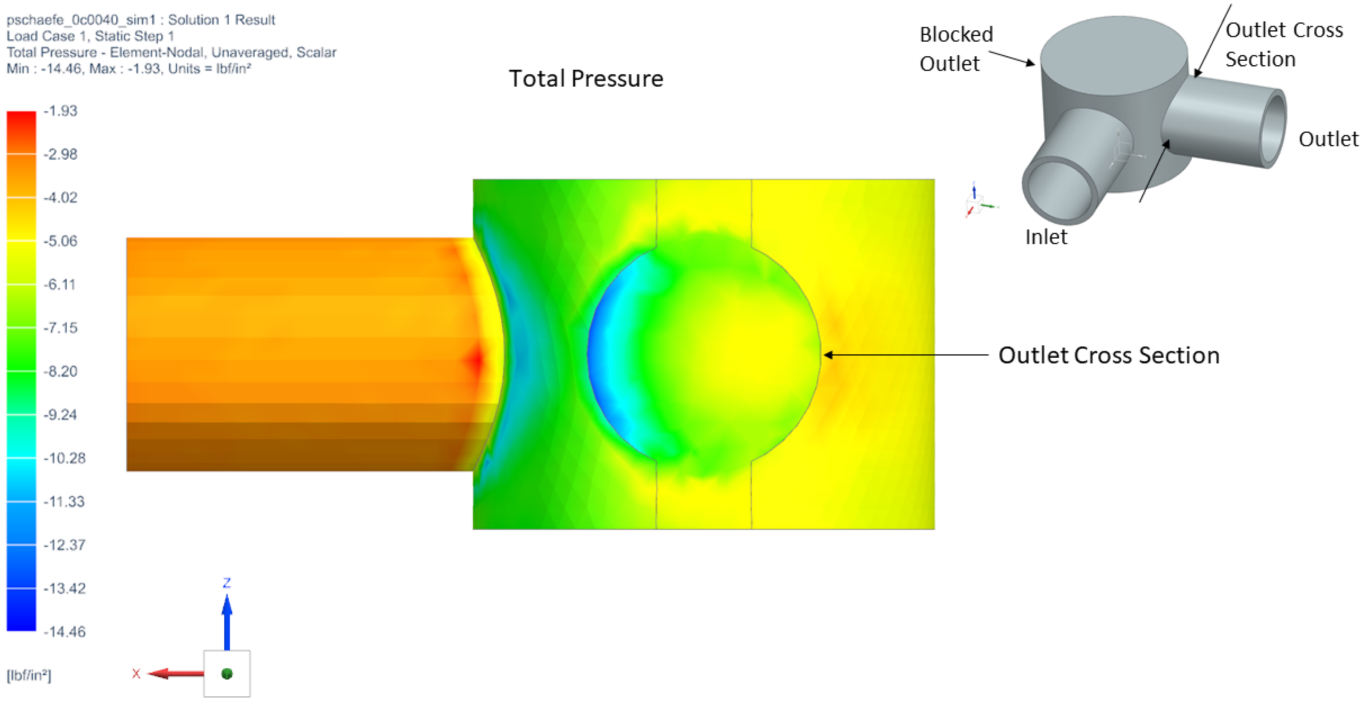


Figure 10. Total pressure at outlet where flaps in Design 1 and Design 2 are located

Fluid: Water
Mesh type: 3D TET4
Mesh element size: 0.1”
Constraints: Inlet Pressure = 80 kPa = 11.6 psi, Outlet Pressure = 0 kPa = 0 psi
Assumes one outlet is blocked

As seen in Figure 9, the team used computational fluid dynamics to visualize flow through the valve when one outlet is blocked. The team also used the simulation to analyze the pressure profile in the valve body. Since the team was not equipped to measure the pressure drop between the inlet and outlet ports during the preliminary testing, this simulation result gave insight into a theoretical pressure drop value. As indicated in Figure 10, the inlet pressure (marked with orange) is approximately 6 psi or 40 kPa higher than that at the open outlet (marked with teal and green). Although this value is within 20% of the 50 kPa requirement, it is important to note that this simulation does not necessarily represent the actual results. The simulation is largely idealized (assuming zero-leakage at the closed port and ignoring the gate components) and needs to be verified by testing data from Lisk. If more time was given, the team could improve the simulation’s accuracy by calibrating against the testing results.

The simulation can also be used to view the cross section of total pressure where a flap in Design 1 or 2 would be located as seen in Figure 10. This was mostly exploratory and did not influence Design 1 or 2. However, the team concluded that at the outlet of the valve where the flaps would be located the pressure is less on the side closest to the inlet and greater on the opposite side. This is disadvantageous to the flaps because the side of the flap that experiences less pressure will not seal as properly as the other side and may lead to leakage. The team concluded that future work may take place to redesign the interior of the valve to create a more even distribution at the location of the flaps for a better seal.

Other Analysis to Consider: Fatigue

Due to time constraints, only qualitative fatigue analysis is estimated. For both designs, the fatigue created by pressure cycles on the flap should be considered. As coolant enters the valve, the flaps are pushed against the housing. Pressure causes the flaps to deform around the rim of the valve outlet which over time subjects the flaps to relatively high-cycle fatigue. In addition, the rotary motion of the valve causes wear on the flaps due to friction between the flaps and valve housing. Fatigue and wear will stiffen the UHMWPE flaps and create undesirable deformations. As a result, the flaps will no longer align flush with the inner circumference of the valve housing. This will negatively affect the flap's sealing ability and increase the valve's leakage over time.

MANUFACTURING

Gate - 3D printing / Injection molding; Flaps - Mill and bending

The principal material decision for Design 1 and 2 was determining the material for the flaps. The team decided on Ultra High Molecular Weight Polyethylene (UHMWPE). It was selected for the flaps because it is compliant in nature, compatible with a 50/50 glycol water based coolant, and has a very slippery friction rating [4]. UHMWPE is also a low cost material meaning that large quantities of various thicknesses and shapes can be purchased for testing without significant impact on the team's budget.

The UHMWPE flaps were purchased from McMaster in sheets of 5ft, with varying thicknesses. The manufacturing of the flaps was completed in two stages, milling and bending. The first stage, milling, consisted of the team cutting two notches on either side of the flaps. The notches were finished by sanding with sandpaper to meet the proper tolerances to fit with the gate. The second stage consisted of bending the flaps to the same curvature of the valve housing's internal diameter to create a seal. The flaps were clamped using pipe clamps to a mandrel with a radius slightly less than that of the valve housing's internal diameter. The mandrel with the flaps was placed into a furnace at 130 ℃, the softening temperature of UHMWPE, for 30 minutes. The flaps were then taken off the mandrel, bent back by hand to the correct radius, and sanded to meet the correct tolerances.

Components including Design 1's press fit, gate, and spring caps, and Design 2's gate were all 3D-printed with Polylactic Acid (PLA) due to their organic shape. The team considered machining the components from round stock but decided that machining would be time consuming, costly, and waste material. Ideally, the team would have injection molded these parts for the best tolerances but mold design is time consuming, expensive, and outside the scope of one semester of work.

The team did, however, contemplate considerations for how the gates for Design 1 and 2 would be injection molded. The location for the injection mold gate would depend on the stress induced by the components. It should be placed so that areas of high stress do not experience weld lines and air traps that would weaken the structure. Injection molding would also reduce surface flaws present in both prototype 3D-printed gates that had to be sanded down and post processed with acetone. Finer surface tolerances from injection molding would further reduce the overall actuation torque needed to rotate the designs in the valve housing and would allow for a cleaner interface between the gates and the UHMWPE flaps. UHMWPE does not follow the conventional style of injection molding for manufacture due to its high molecular weight. It rather uses compression molding that involves using heat and hydraulic pressure to force the polymer powder into a mold [5]. With more time the team would have further explored this possibility.

If the designs were scaled to 1000 then 3D printing would not be an option for manufacturing as 3D printing is time consuming and, as mentioned, produces many flaws. The processes of injection molding for the 3D-printed parts and compression molding for the flaps would be the most ideal methods in this circumstance as they would decrease cost, decrease time to manufacture, and produce better tolerances.

Tables 3 & 4 below show the estimated manufacturing costs and the development time costs for the project.

Table 3. Manufacturing Costs

Purchases	**Cost**
Hardware	$175
Shop Time	$0
Hanne Hartveit (manufacturing time)	$3,016
Xin Liu (manufacturing time)	$2,650
Harris Mawardi (manufacturing time)	$2,983
Yixin Pan (manufacturing time)	$3,016
Peter Schaefer (manufacturing time)	$4,116
Total Cost	**$15,956**

Table 4. Development Time Costs

Development Time	**Cost**
Hanne Hartveit	$6,034
Xin Liu	$5,300
Harris Mawardi	$5,967
Yixin Pan	$6,034
Peter Schaefer	$8,234
Total Cost	**$31,569**

TEST PLAN AND RESULTS

On-campus testing done by the students was done in order to compare the leakage and actuation torque of Design 1 and 2 to that of the current existing model from Lisk. A sketch of the testing setup is shown below in Figure 11:

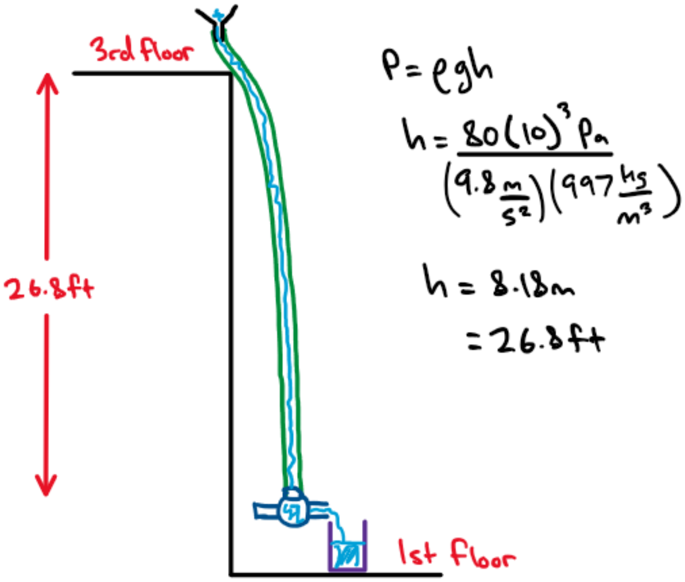


Figure 11. Experimental schematic to develop 80kPa pressure differential

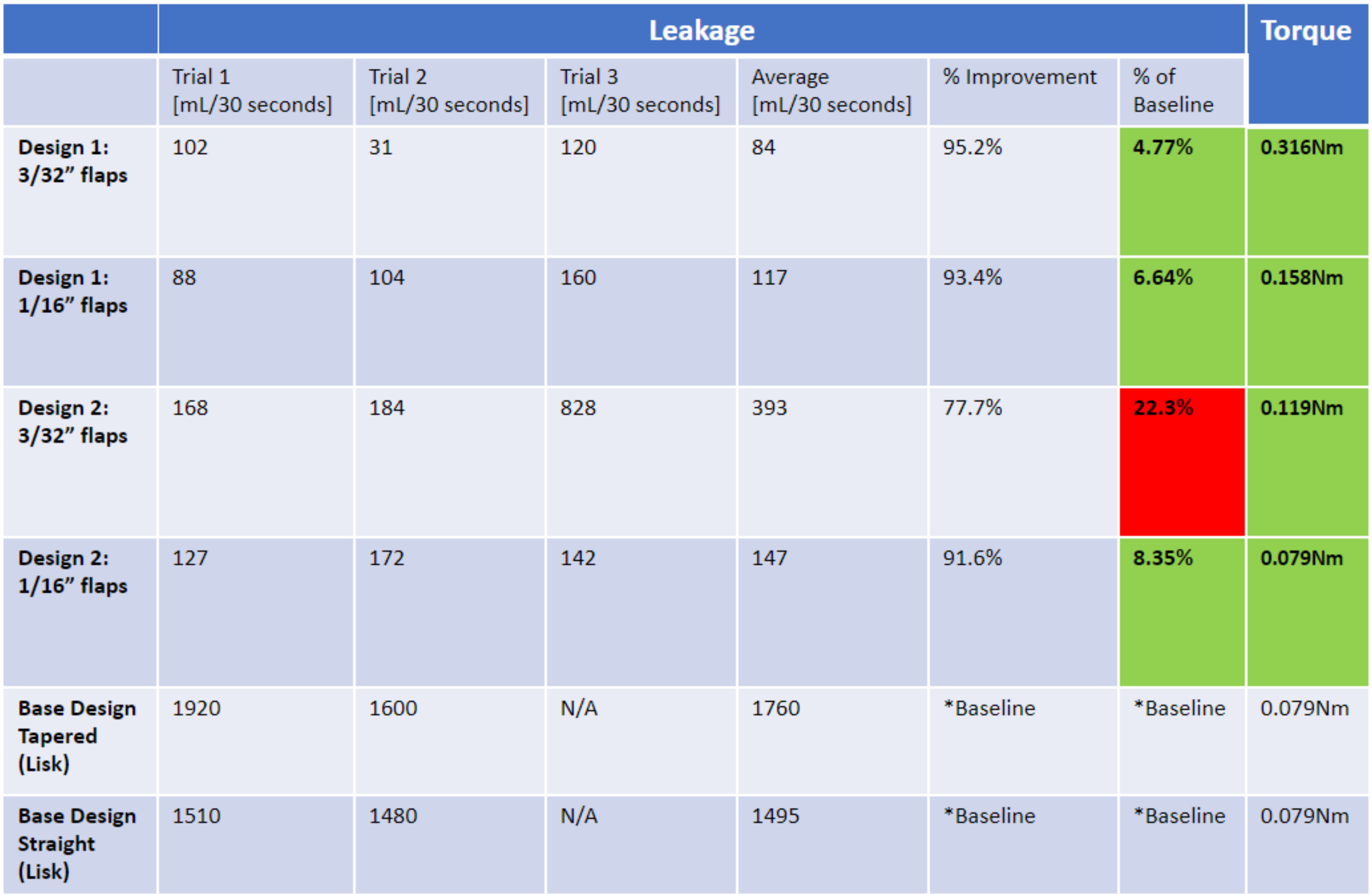
The purpose of the 26.8 ft water column is to create a pressure differential of 80kPa (see calculation in Figure 11) as specified by the sponsor. To complete the test, part of the team held a garden hose filled with water on the 3rd floor of the Rettner building at the University of Rochester and the other part of the team measured the valve leakage on the 1st floor. One of the outlet ports was plugged with a metal cylinder (shown on the left side of the valve in Figure 12 below) while the other was left open to be sealed by Design 1 or 2 (shown on the right side of the valve in Figure 12). The inlet port (shown in the middle of Figure 12) is connected to a ball valve and then to the garden hose (not pictured).

Figure 12. Experimental hose and valve assembly

A 1-liter graduated cylinder was placed at the open outlet to collect any leakage. Once the team was ready, one team member switched open the ball valve and another started a timer for 30 seconds. The team members on the 3rd floor maintained the water column height by refilling the garden hose with the water jugs. After the leakage testing was completed, a team member measured the actuation torque of the valve with a torque wrench. At the end of the testing trial, the ball valve was closed, and the leakage in the graduated cylinder was measured and recorded. The same procedure was repeated so that the leakage was measured 3 times for each design. The average of the trials was calculated and compared to the leakage of the Lisk baseline designs.

The results are shown below in Table 5. Note that Design 1 with both flap thicknesses and Design 2 with the 1/16" flap thickness pass the leakage and operating torque specifications from Lisk.

Table 5. UofR Leakage & Torque Experimental Results



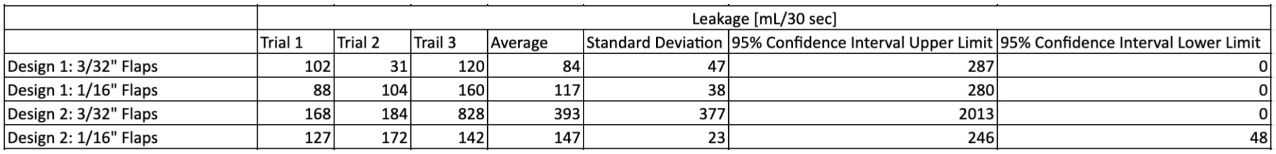
	Leakage						Torque
	Trial 1 [mL/30 seconds]	Trial 2 [mL/30 seconds]	Trial 3 [mL/30 seconds]	Average [mL/30 seconds]	% Improvement	% of Baseline	
Design 1: 3/32" flaps	102	31	120	84	95.2%	**4.77%**	**0.316Nm**
Design 1: 1/16" flaps	88	104	160	117	93.4%	**6.64%**	**0.158Nm**
Design 2: 3/32" flaps	168	184	828	393	77.7%	**22.3%**	**0.119Nm**
Design 2: 1/16" flaps	127	172	142	147	91.6%	**8.35%**	**0.079Nm**
Base Design Tapered (Lisk)	1920	1600	N/A	1760	*Baseline	*Baseline	0.079Nm
Base Design Straight (Lisk)	1510	1480	N/A	1495	*Baseline	*Baseline	0.079Nm

Table 5. Considerations:
**Lisk desires a leakage that is 10% or less of their baseline design*
**Lisk allows 0.4 N*m of additional torque from gate*
**Green indicates specification passed, red indicates specification failed*
**% of Baseline was calculated using the average leakage for Base Design Tapered (Lisk)*
**All trials used 100% water for leakage testing instead of 50/50 glycol and water*

There were few modifications to the requirements for testing. First, water was used for this initial testing instead of coolant (50% water and 50% glycol solution) for simplicity and safety. The valve is designed for coolant but water was approved to be used as a substitute by the sponsor because of their similar viscosities. Second, the 80 kPa pressure differential was only roughly achieved while testing. Resistance, leakage in the hose connections, and flow rate aren't accounted for in the pressure calculation. Such simplifications were discussed with the sponsor and were deemed appropriate for initial testing.

Since the initial testing measures leakage over only 30 seconds and has only three trials for each design, the sample size isn't big enough to make conclusions with high confidence. As shown in Table 6 below, the 95% confidence interval is too large to conclude if Design 1 and 2 did improve over the baseline designs. In order to improve the statistical significance of the results, more trials would need to be conducted.

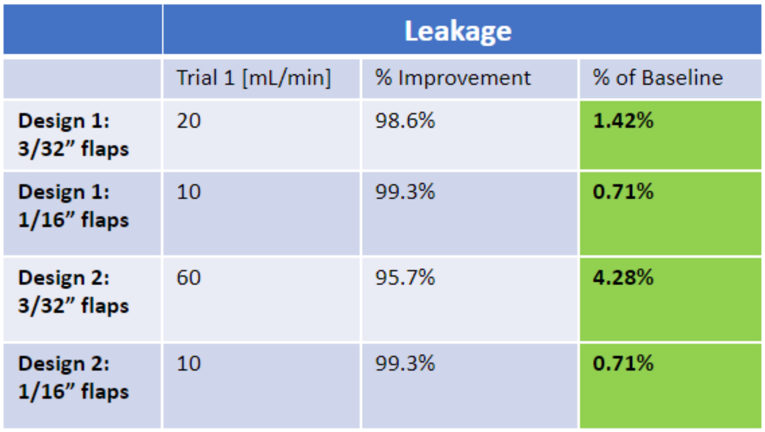
Table 6.



	Leakage [mL/30 sec]						
	Trial 1	Trial 2	Trail 3	Average	Standard Deviation	95% Confidence Interval Upper Limit	95% Confidence Interval Lower Limit
Design 1: 3/32" Flaps	102	31	120	84	47	287	0
Design 1: 1/16" Flaps	88	104	160	117	38	280	0
Design 2: 3/32" Flaps	168	184	828	393	377	2013	0
Design 2: 1/16" Flaps	127	172	142	147	23	246	48

For more rigorous testing, the valve hardware was sent to the G.W. Lisk testing facility. The proper coolant solution, 50% water and 50% glycol, was used along with the 80 kPa pressure differential between inlet and outlet. The results of this testing can be seen below in Table 7. Note that both flap thicknesses for Design 1 and 2 pass the leakage specification defined by Lisk.

Table 7. G.W. Lisk Leakage Experimental Results



	Leakage		
	Trial 1 [mL/min]	% Improvement	% of Baseline
Design 1: 3/32" flaps	20	98.6%	**1.42%**
Design 1: 1/16" flaps	10	99.3%	**0.71%**
Design 2: 3/32" flaps	60	95.7%	**4.28%**
Design 2: 1/16" flaps	10	99.3%	**0.71%**

Table 7. Considerations:
**Lisk desires a leakage that is 10% or less of their baseline design*
**Green indicates specification passed, red indicates specification failed*
**% of Baseline was calculated using the Lisk specification of 1400 mL/min*
**All trials used a 50/50 glycol and water coolant solution*

The remaining specifications defined by the team and Lisk outside of leakage and torque are mostly inherent to the outer housing supplied by Lisk. Therefore, they are also assumed to be met.

INTELLECTUAL PROPERTY

Design 1 and 2 have potential to be patentable, however it is simply an improvement of the existing G.W. Lisk design. The G.W. Lisk low friction rotary coolant valve is currently not patented so the team does not expect a patent to be filed. There are other existing automotive coolant control valves that are patented and similar in nature to the G.W. Lisk design. A similar concept is the patented *Control valve with improved sealing for a fluid circulation system* W02004061342A1 [6] which is cited by an additional 25 patents for a multitude of well established companies. The patent was published by inventors Frédéric Vacca and Mathieu Chanfreau on 07-22-2004. The "rotary valve" idea is for a better sealed control valve that has an inlet and at least two outlets in homologous cylindrical housing where a member is capable of rotating about an axis to distribute fluid between outlets. A few companies working in this sector include Mitsubishi Electric Corporation, Nordson Corporation, and Valeo Systemes Thermiques.

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

Coolant valves are an inherent part of cooling systems used in electric vehicles, serving the purpose of controlling the battery's temperature. Decreasing the internal valve leakage of such cooling systems allows them to operate more efficiently. Increased efficiency, in turn, tends to lead to decreased cost, which would make electric vehicles more attractive in the transportation market. A higher usage of electric vehicles would allow for movement away from diesel powered vehicles, an important step in reducing the effects the transportation sector has on global warming. Replacing gas vehicles with electric vehicles also creates better air quality, thus improving public health.

Injection molding is widely used to create plastic parts, and is used by Lisk to manufacture plastic valves. A study has found that the most significant measure of the environmental impact of injection molding of high-density polyethylene parts is electricity consumption [7]. Knowing this, electricity consumption can be used as a selection criteria when selecting an injection molding machine. The study mentions that in the future, it would be beneficial to analyze how the electricity consumption of an injection molding machine can be optimized. The study also mentions that it would be beneficial to assess the effects of various materials on electricity consumption. Both are relevant to this project.

RECOMMENDATIONS FOR FUTURE WORK

The project made a lot of progress as planned in the schedule. Nonetheless, there are optimizations that can be done if more time is provided. More compliant materials could be tested as flaps such as high-density polyethylene (HDPE). Due to time constraints, only UHMWPE was used for current designs. The current curvature and thickness of the flap pieces could also be improved to create a better seal with the outlet. If more time was given, the team could look into injection molding for the gates and compression molding for the flaps to create better tolerances for the seal. The team could also study and test the fatigue of the flaps and gate. A quantitative estimate for the lifetime of the valve would be beneficial in creating maintenance schedules for valve replacement. In addition, the internal housing of the valve could be modified with more time to create an even pressure distribution across the flap for a better seal. CFD analysis could be optimized based on the testing results and a more realistic model could be created.

CONCLUSION

This project was a memorable learning experience for the team. We have learned what it takes to work as a cohesive team in a limited amount of time. It has encapsulated all that we have learned in our four years of being undergraduate students in a semester-long project. The support that we received from both our mentors at G.W. Lisk and faculty at the University of Rochester have helped propel us through the challenges of the project. Looking back we are proud of what we have accomplished with the time given. We believe the project was a success and has helped us become better engineers and teammates. One of the greatest takeaways the team realized during this experience was how valuable time is. If given more time, the team could have made even more improvements to the designs. As Dan Meath once said, "Time is what makes or breaks ideas."

ACKNOWLEDGMENTS

This project was supported by G.W. Lisk Co Inc. We thank our mentors from G.W. Lisk Co Inc, Dan Meath, Troy Rutherford, and Trevor Crandell for all the insight and assistance they provided from years of industry experience.

We are also grateful to members from the University of Rochester, including Christopher Muir, Chris Pratt, Jim Alkins, Marc Haddad, and F. Douglas Kelley, for the continuous support and critique they provided in their areas of expertise. This project would not have been possible without them.

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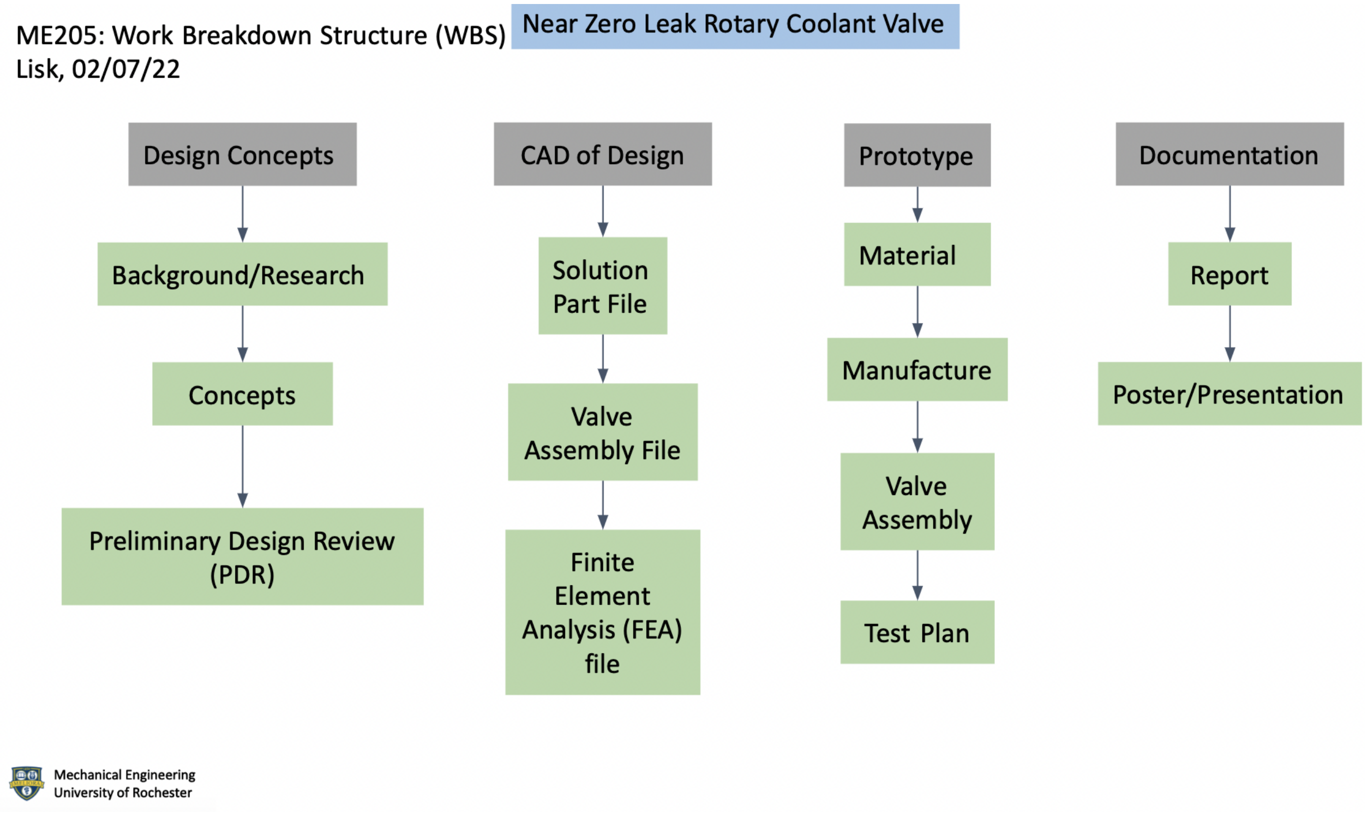
[6] Google, 2022, from https://patents.google.com/patent/WO2004061342A1/en?oq=low+friction+rotary+coolant+valve

[7] Elduque, A., Elduque, D., Javierre, C., Fernandez, A., Santolaria, J., 2015, “Environmental impact analysis of the injection molding process: analysis of the processing of high-denisity polyethylene parts”, Journal of Cleaner Production, **108**(part A), pp. 80-89.

APPENDIX

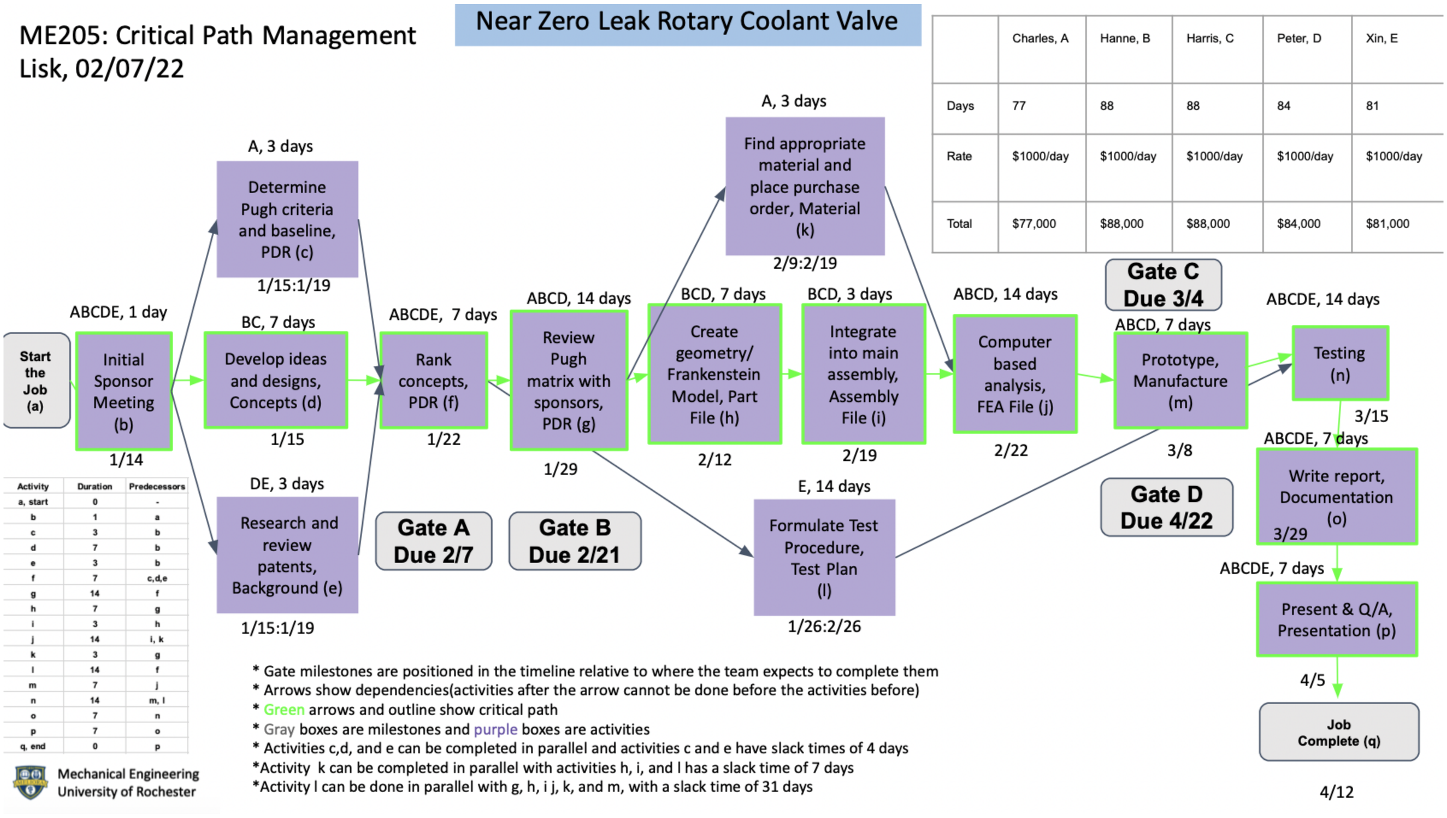
ANNEX A

WORK BREAKDOWN STRUCTURE (WBS)



ANNEX B

CRITICAL PATH MANAGEMENT (CPM)



ME205: Critical Path Management
Lisk, 02/07/22

Near Zero Leak Rotary Coolant Valve

	Charles, A	Hanne, B	Harris, C	Peter, D	Xin, E
Days	77	88	88	84	81
Rate	$1000/day	$1000/day	$1000/day	$1000/day	$1000/day
Total	$77,000	$88,000	$88,000	$84,000	$81,000

Activity	Duration	Predecessors
a, start	0	-
b	1	a
c	3	b
d	7	b
e	3	b
f	7	c,d,e
g	14	f
h	7	g
i	3	h
j	14	i, k
k	3	g
l	14	f
m	7	j
n	14	m, l
o	7	n
p	7	o
q, end	0	p

- * Gate milestones are positioned in the timeline relative to where the team expects to complete them
- * Arrows show dependencies(activities after the arrow cannot be done before the activities before)
- * Green arrows and outline show critical path
- * Gray boxes are milestones and purple boxes are activities
- * Activities c,d, and e can be completed in parallel and activities c and e have slack times of 4 days
- *Activity k can be completed in parallel with activities h, i, and l has a slack time of 7 days
- *Activity l can be done in parallel with g, h, i j, k, and m, with a slack time of 31 days

Mechanical Engineering
University of Rochester

ANNEX C

FINAL DESIGN CONCEPTS

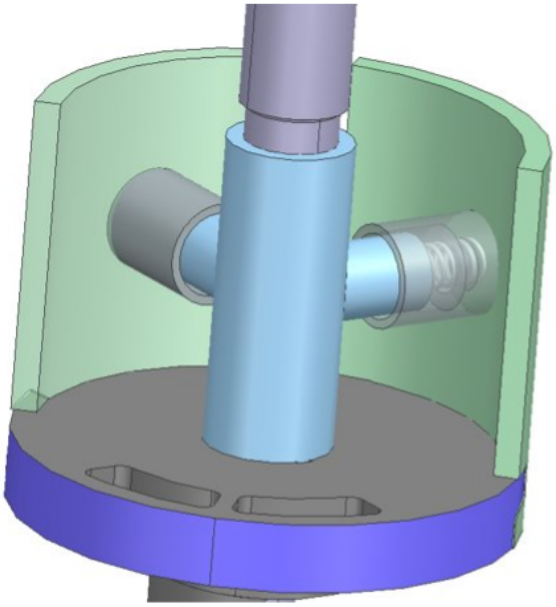


Figure 13. Design 1

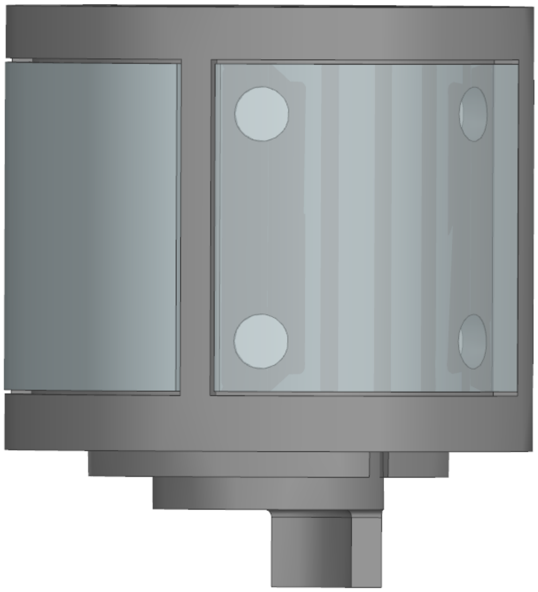


Figure 14. Design 2

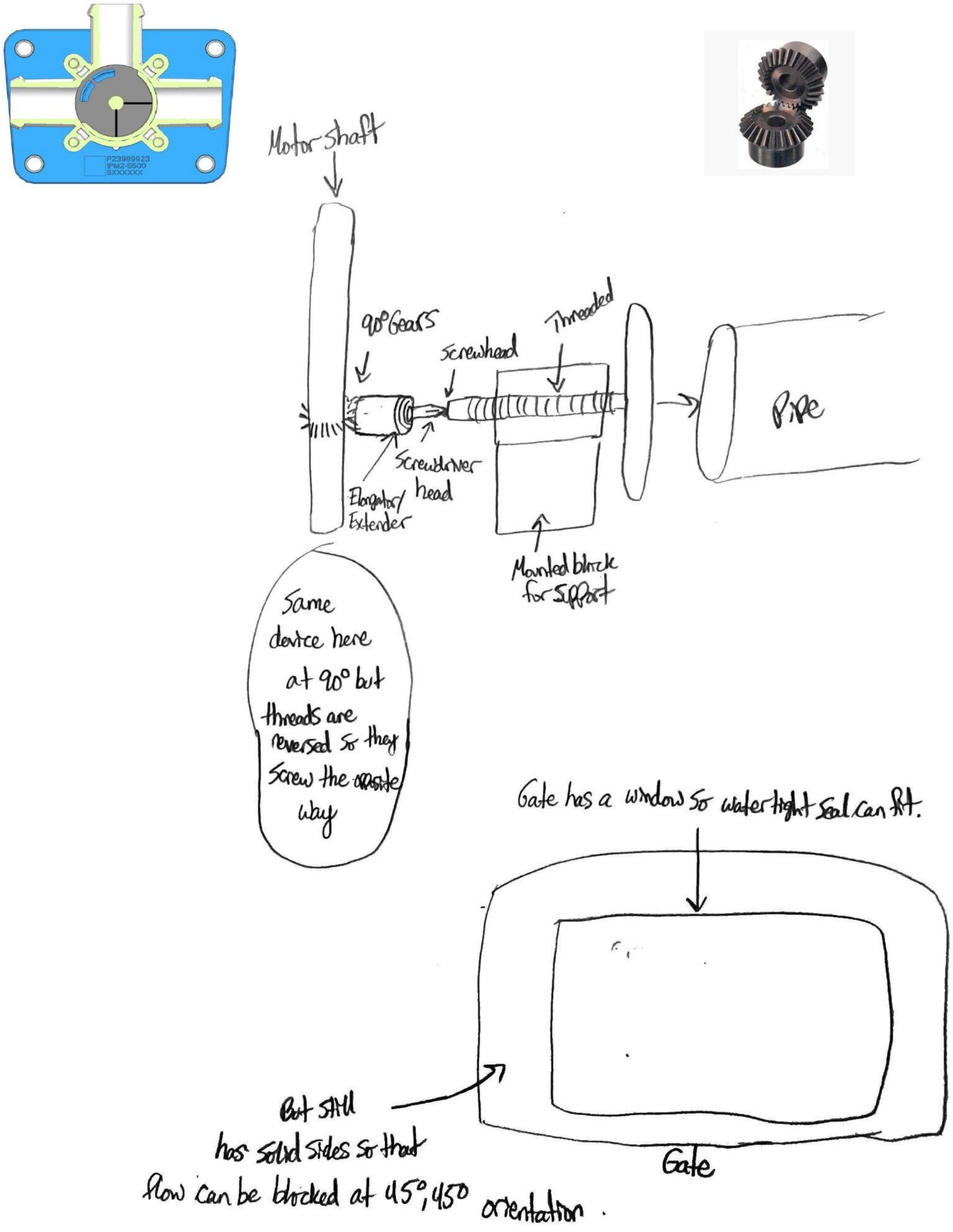
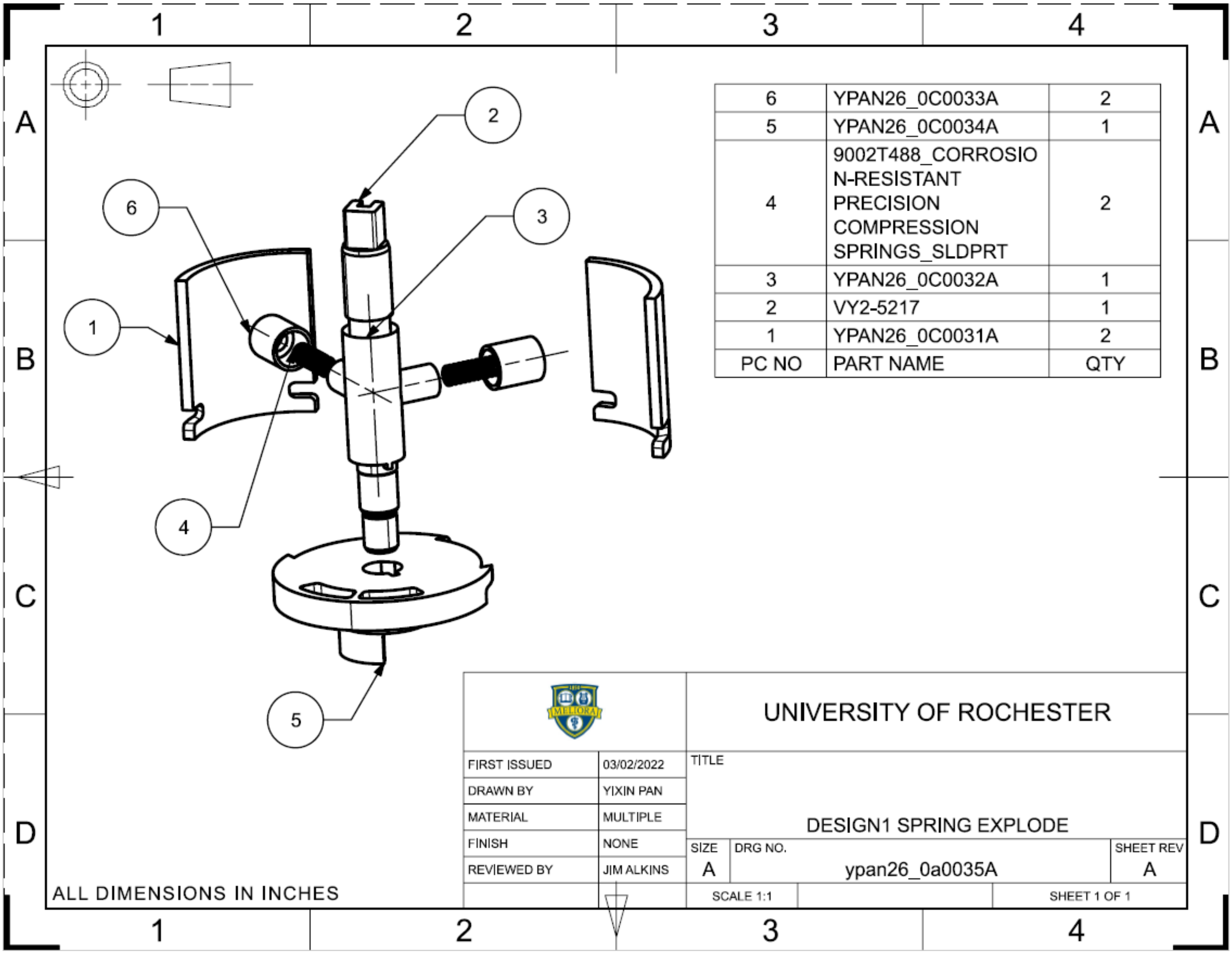


Figure 15. Design 3

ANNEX D

DRAWINGS



PC NO	PART NAME	QTY
6	YPAN26_0C0033A	2
5	YPAN26_0C0034A	1
4	9002T488_CORROSION-RESISTANT PRECISION COMPRESSION SPRINGS_SLDPRT	2
3	YPAN26_0C0032A	1
2	VY2-5217	1
1	YPAN26_0C0031A	2

UNIVERSITY OF ROCHESTER

FIRST ISSUED	03/02/2022
DRAWN BY	YIXIN PAN
MATERIAL	MULTIPLE
FINISH	NONE
REVIEWED BY	JIM ALKINS

TITLE
DESIGN1 SPRING EXPLODE

SIZE	DRG NO.	SHEET REV
A	ypan26_0a0035A	A

SCALE 1:1
SHEET 1 OF 1

Figure 16. Design 1 Assembly

Colloquial terms for each part:
1: Flaps
2: Shaft
3: Press fit component
4: Springs
5: Gate base
6: Spring caps

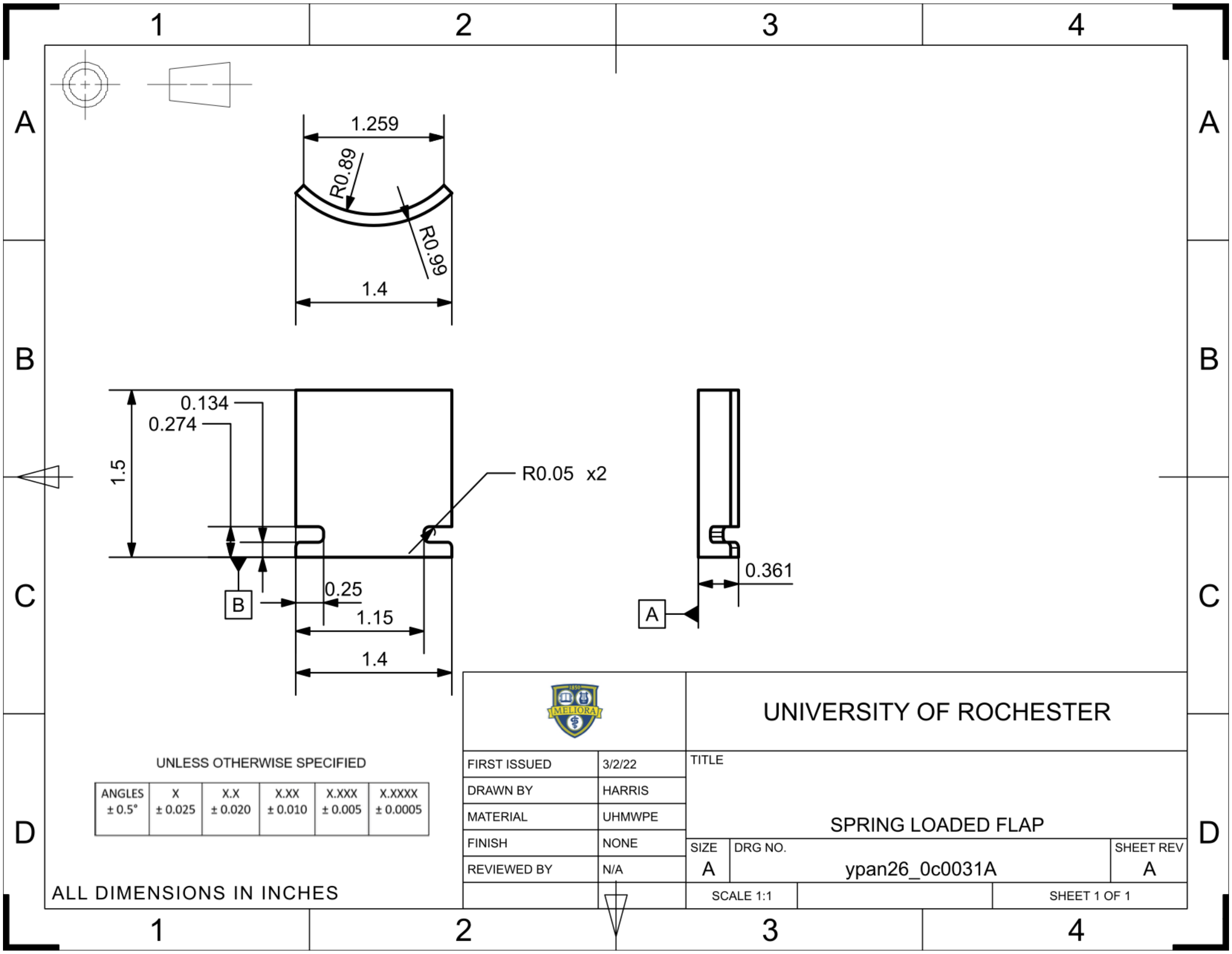


Figure 17. Design 1 UHMWPE Flap

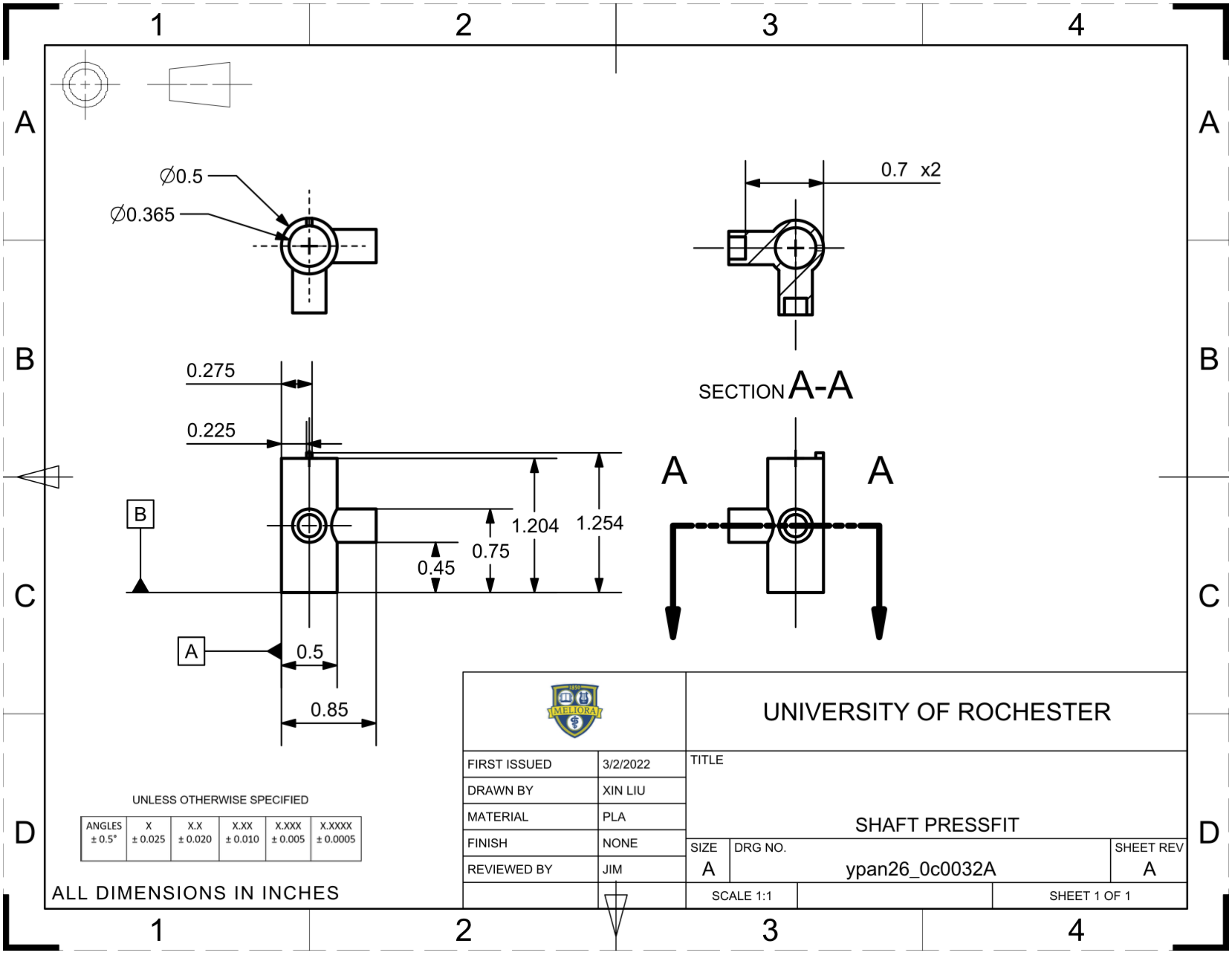


Figure 18. Design 1 Press-Fit Sleeve

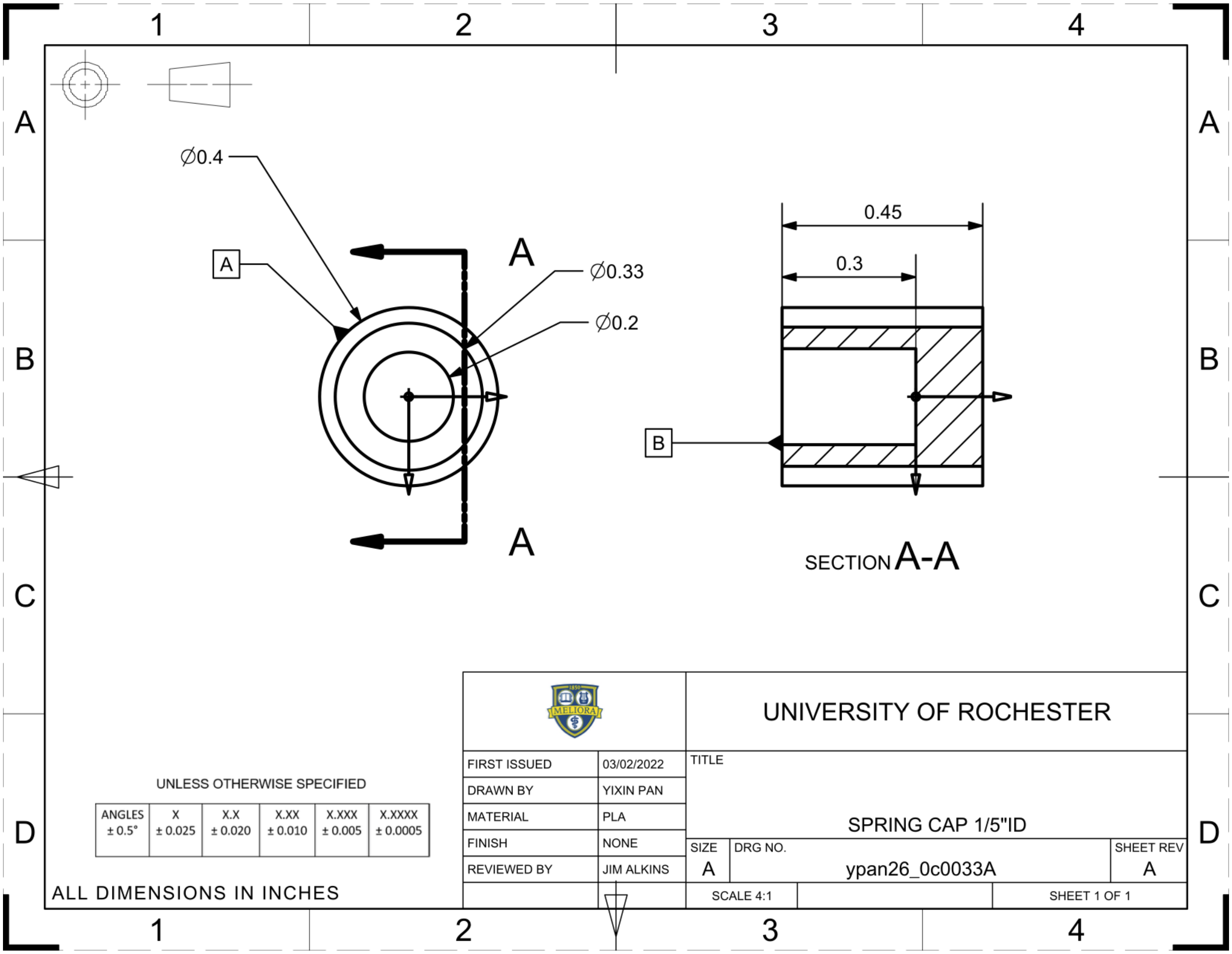


Figure 19. Design 1 Spring Cap

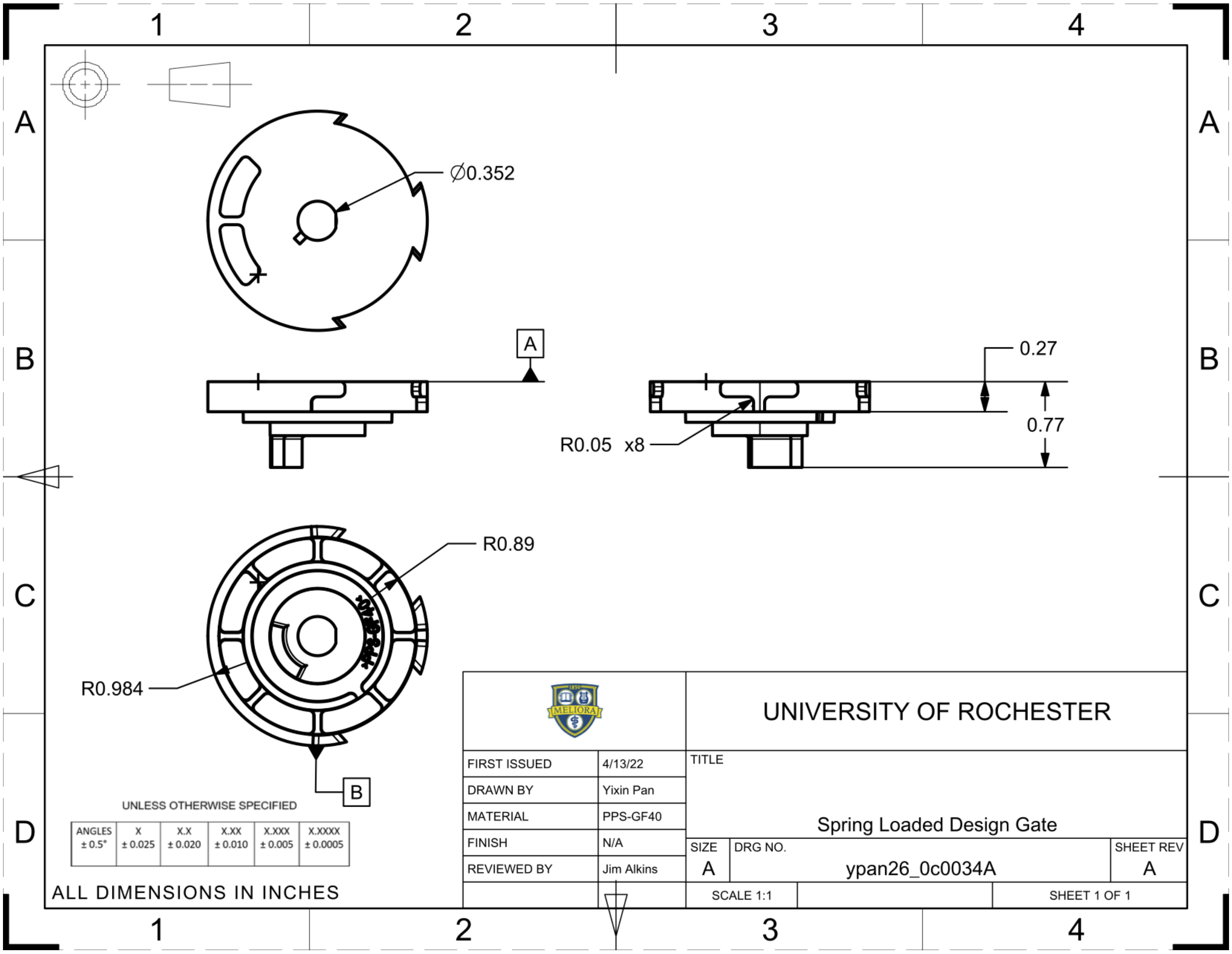
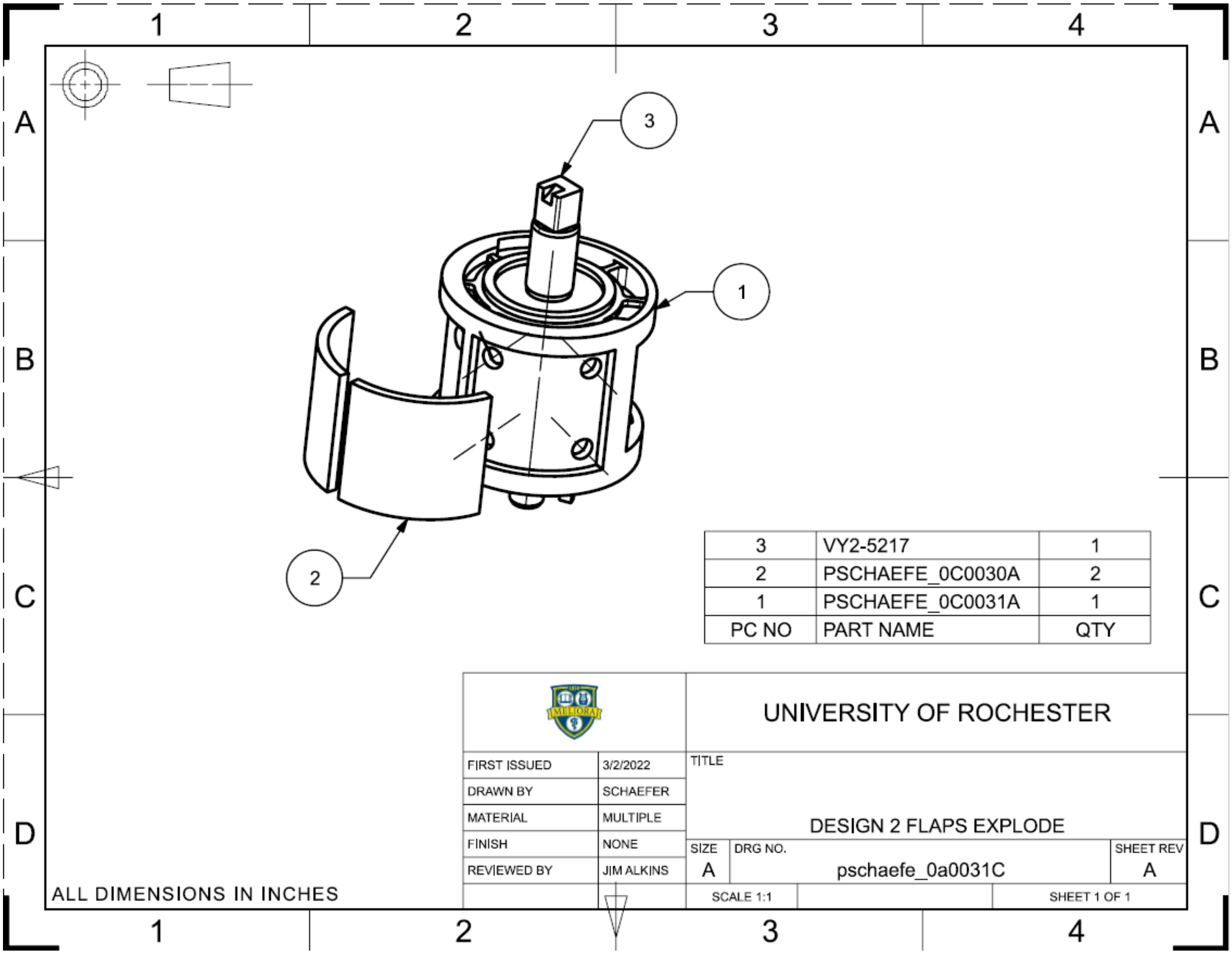


Figure 20. Design 1 Gate Base



PC NO	PART NAME	QTY
3	VY2-5217	1
2	PSCHAEFE_0C0030A	2
1	PSCHAEFE_0C0031A	1

UNIVERSITY OF ROCHESTER

FIRST ISSUED	3/2/2022
DRAWN BY	SCHAEFER
MATERIAL	MULTIPLE
FINISH	NONE
REVIEWED BY	JIM ALKINS

TITLE: DESIGN 2 FLAPS EXPLODE

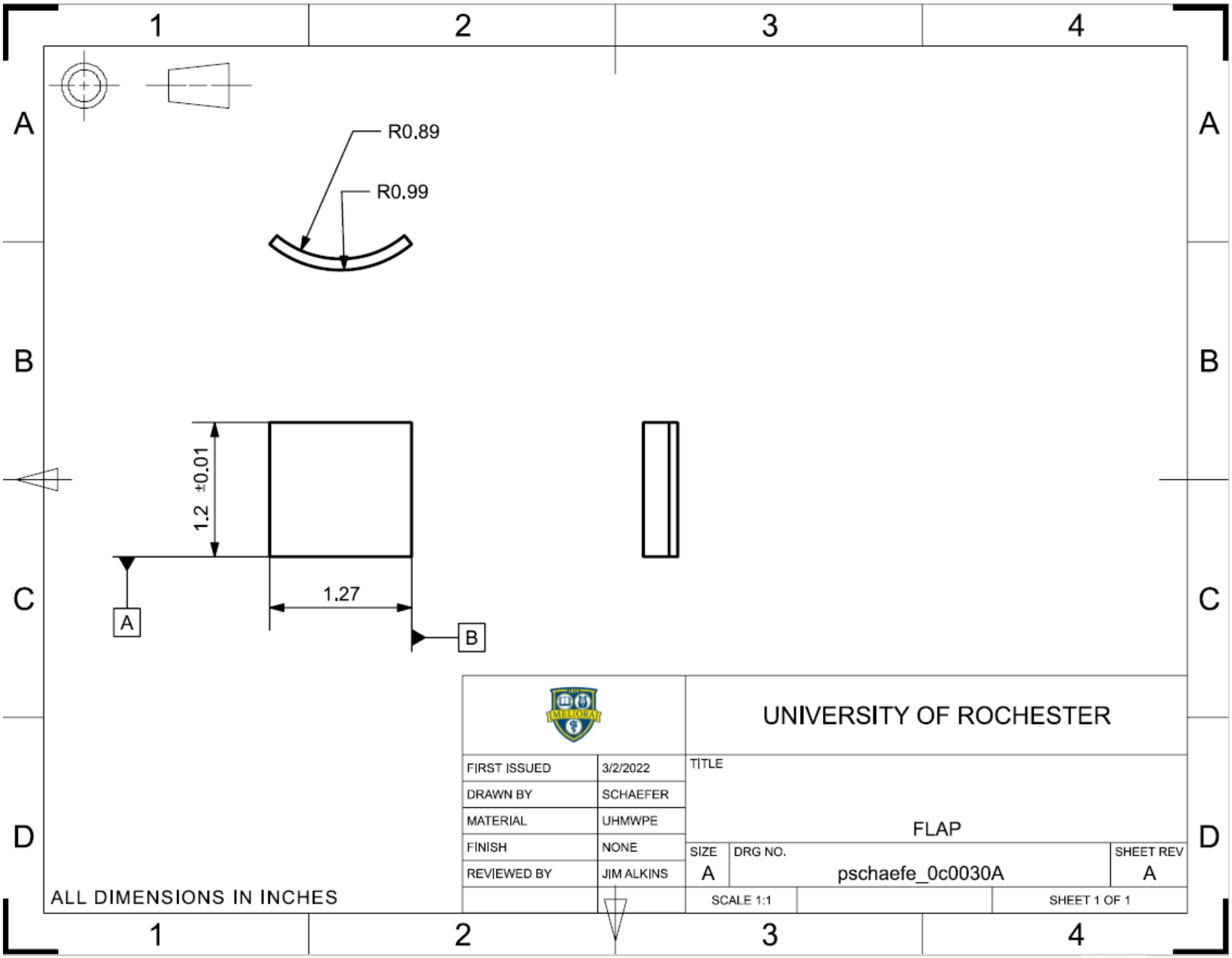
SIZE	DRG NO.	SHEET REV
A	pschaefe_0a0031C	A

SCALE 1:1

SHEET 1 OF 1

Figure 21. Design 2 Assembly

Colloquial terms for each part:
1: Gate
2: Flaps
3: Shaft



		UNIVERSITY OF ROCHESTER	
FIRST ISSUED	3/2/2022	TITLE FLAP	
DRAWN BY	SCHAEFER		
MATERIAL	UHMWPE		
FINISH	NONE	SIZE A	DRG NO. pschaefe_0c0030A
REVIEWED BY	JIM ALKINS	SHEET REV A	
		SCALE 1:1	SHEET 1 OF 1

Figure 22. Design 2 UHMWPE Flap

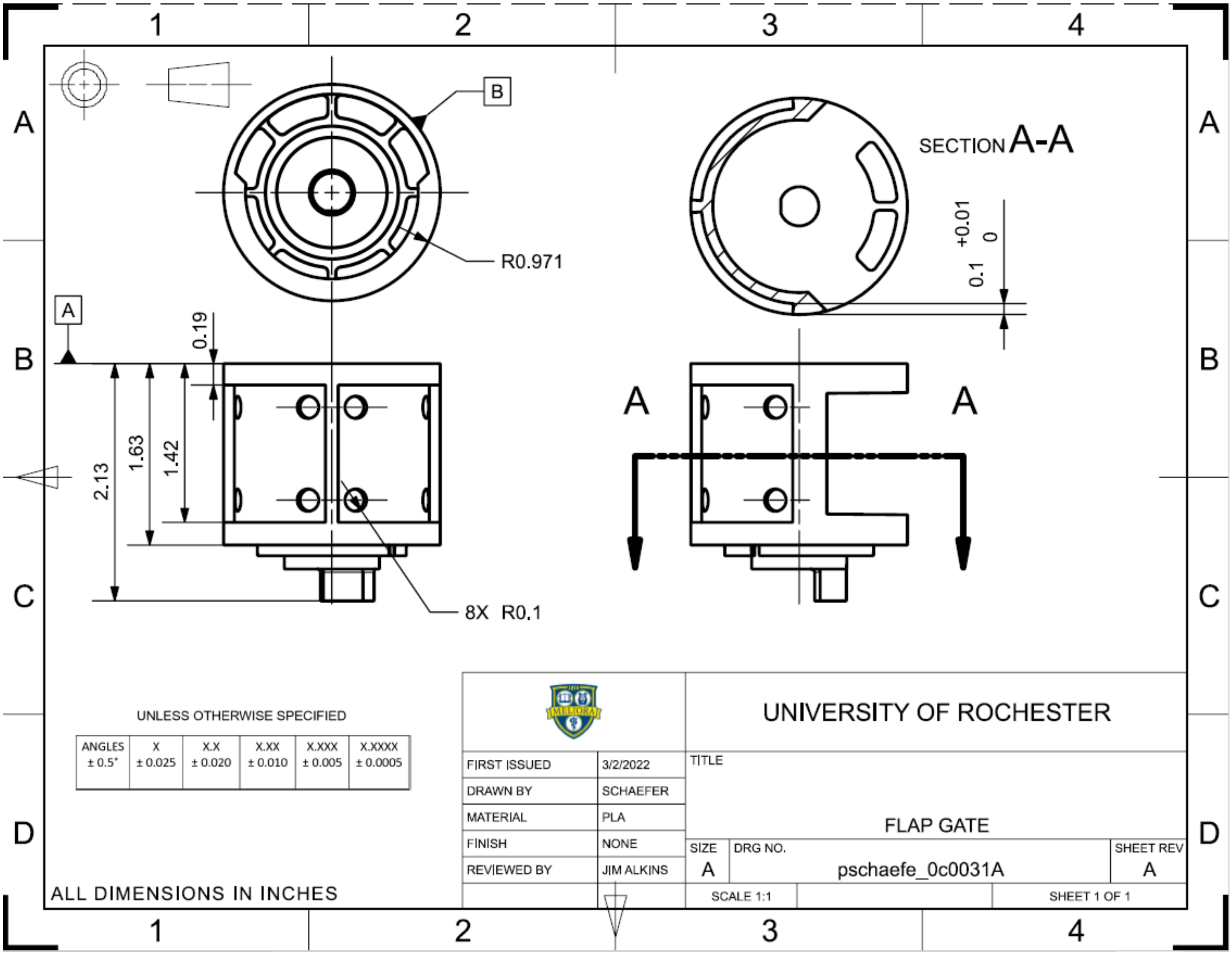


Figure 23. Design 2 Gate

PEER REVIEW

SECTION	WRITER	REVIEWER 1	REVIEWER 2
ABSTRACT	HANNE HARTVEIT	ALL	ALL
PROBLEM DEFINITION	ALL	ALL	ALL
REQ/SPEC/DELIVERABLES	ALL	ALL	ALL
CONCEPTS	PETER SCHAEFER	ALL	ALL
ANALYSIS	ALL	ALL	ALL
MANUFACTURING	HARRIS MAWARDI	ALL	ALL
TEST PLAN	YIXIN PAN	ALL	ALL
IP	HARRIS MAWARDI	ALL	ALL
SOCIETAL/ENVIRONMENTAL	HANNE HARTVEIT	ALL	ALL
FUTURE WORK	XIN LIU	ALL	ALL
APPENDIX	ALL	ALL	ALL

*The team read the FDR out loud together on Zoom.