MECH 4860 – Final Design Report

Design of a Primary Test Calibration System for Price Industries' Testing Department

Team #4 – The Price is Right
Project Advisor: Dr. Meghan Guyot
Date of Submission: December 4th, 2019

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Dr. Labossiere
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Dear Dr. Paul Labossiere,

Enclosed in this document is team number 4’s final design report submitted on Thursday, December 4th, 2019. This report is to propose a final design for a Primary Test Calibration System for Price Industries. In this report you will find the defined design problem including all client needs, constraints and specifications for the final design. An overview of the final design including all design features is described. This report also includes all preliminary engineering drawings, a list of sourced parts and vendors, a bill of materials, and all simulation results and calculations.

As a team, we would like to thank our faculty advisor Dr. Meghan Guyot for her technical support and feedback throughout the design. Please feel free to contact our team manager, Andrew Saygnavong at , with any questions, comments, or concerns about our report.

Kind regards,

Lynn Le

Andrew Saygnavong

Kamalpreet Singh

Bingsheng Xi

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Mr. Victor
Lab Leader

Winnipeg, Manitoba, Canada

Dear Mr. Andrew Victor

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As a team, we would like to thank both you and Mr. Bang Dinh for all your help throughout the design. Please feel free to contact our team manager, Andrew Saygnavong at , with any questions, comments, or concerns about our report.

Kind regards,

Lynn Le

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Kamalpreet Singh

Bingsheng Xi

Executive Summary

Price Industries is an international manufacturer of commercial air circulation products headquartered in Winnipeg, Manitoba, Canada. These products come in all forms such diffusers, noise dampers, and fan coils. One of the best testing facilities at Price Industries is also located in Winnipeg, Manitoba: The Price Research Center North. This facility contains various testing rooms and systems for all sorts of air distribution products. The overall objective of this project is to design a primary test calibration system that can calibrate the flow rate meters attached to each test rig to eliminate the need to outsource the flow rate meter calibrations.

The final design of the primary test calibration system uses the displacement of a piston through a hydraulic cylinder to measure the volumetric flow rate with a high accuracy ultrasonic sensor. Actuating valves controlled through a microcontroller sequentially open and close valves to allow for fluid to flow into the tank. A total of four electronic actuating valve control which portion of the fluid can enter and exit the tank. As fluid flows into one end of the tank, the piston will be moved, and the displacement is measured through an ultrasonic sensor. The ultrasonic sensor is placed on a plate at the end of the piston rod outside of the tank to measure the distance between the sensor and sensor lid. Through the use of both temperature and pressure sensors, the microcontroller will be able to determine when the system has reached a steady state to begin calibrations, as well as control the actuating valves to allow fluid to move the piston back in the other direction. The microcontroller takes the readings from all the sensors and calculates the flow rate of the system and outputs the results.

The primary test calibration system is 62.2” x 28.4” x 26.0” in size and is able to accommodate fluid flow ranging from 1 Gal/min to 60 Gal/min with an accuracy within 0.116%. The total cost of the design is $11,800 and the total weight of the design is 389lbs.

In this report, the entire design process can be found along with a full detailed design description. Additionally, included in this report is a bill of materials, a cost breakdown, preliminary engineering drawings, computational fluid dynamics analysis and a full design CAD model.

Table of Contents

List of Figures

List of Tables

1. Introduction

This section provides the background of the client and the design problem. From there, the project is defined along with the specifications of the project such as the customer needs and metrics. After defining all the target specifications, a brief summary of the design methodology is explained.

1.1 Background

Price Industries is a manufacturer of commercial air distribution products that was founded in Winnipeg, MB in 1949. Since then, the company has grown internationally and has widen their scope of products to all forms of air circulations. This ranges from designing and manufacturing air circulation systems for critical environments to everyday office space. Located at Price Industries' headquarters, in Winnipeg, is one of their best testing facilities, the Price Research Center North. At this facility, there are numerous testing rooms and systems for all sorts of air distribution products. Some examples of the rooms in this facility are the flow visualization room which allows visualization of the effect of a diffuser and the fan coil testing chambers, where water is ran through the systems for testing.

1.2 Problem Background

At this facility, there are numerous test rigs that are used to test the various products Price Industries manufactures. Attached to each of these test rigs are flow rate meters to measure the flow of fluid through each test rig and test piece. To ensure that these flow rate meters are consistently accurate, these flow rate meters must be calibrated yearly according to regulations. Currently, Price Industries removes these flow rate meters from their existing test rigs and outsources the calibration process to another company. This results in these test rigs being out of commission, which associates with long lead times and costs. Additionally, the flow rate meters are not easily accessible and removing them can be inconvenient. An example of a test rig can be seen in Figure 1 with the flow rate meters highlighted in red. These flow rate meters are two meters high and in between numerous obstacles. This can be seen in Figure 2.

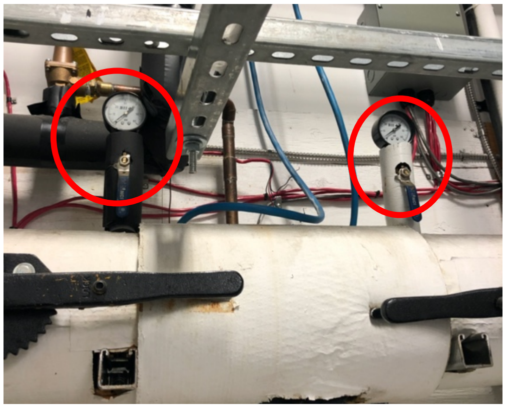


Figure 1: Test rig flow rate meters

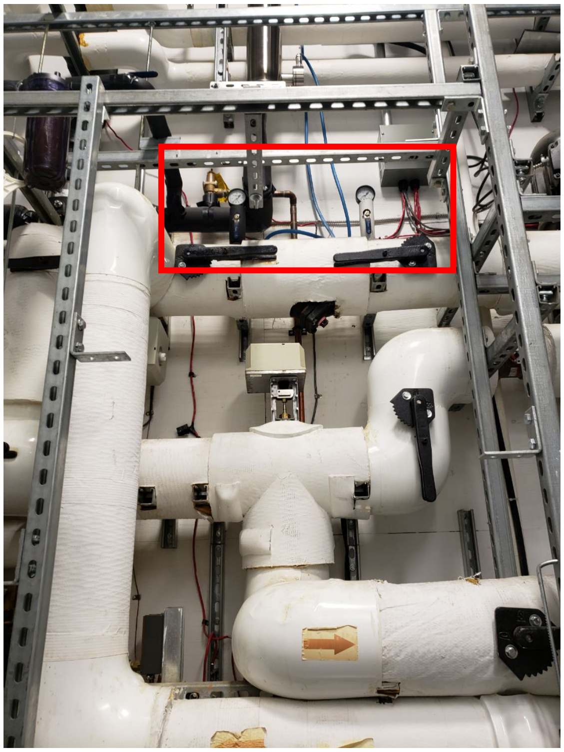


Figure 2: Position of flow rate meters

1.3 Problem Statement

The purpose of this project is to deliver a primary calibration system design for Price Industries to have the flow meters calibrated in-house. This design must function by using the bucket test principle as the method for measuring the flow rate of the water in the system. The bucket test principle is a method that states that the flow rate of a fluid can be determined by measuring the time it takes to fill a known volume or reach a known weight. The accuracy of the system also must be within 1%. The output of this system consists of a calibration report with the temperature, pressure, and multiple measurements of flow rates ranging from 1 gal/min to 60 gal/min. The water flow process shown in Figure 3, illustrates how the design will be integrated into Price Industries' current systems.

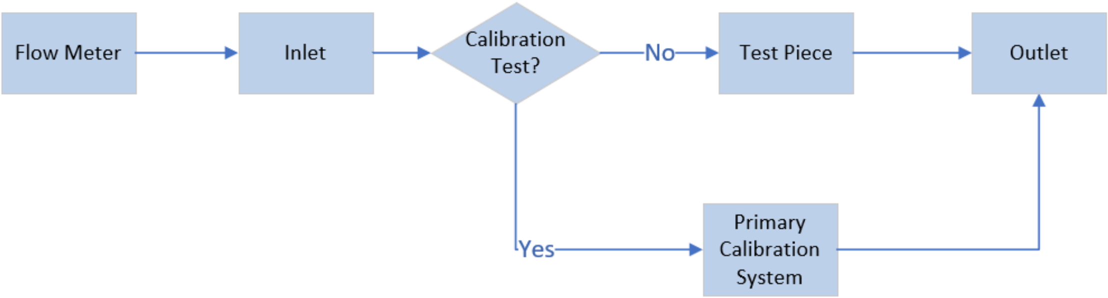


Figure 3: Water flow process flow chart

As a part of Price Industries' test room system, there is a pump located outside the room that pumps the water into the room through an input pipe. This pump will control the flow rate in the system. The water would go to the test piece and then out of the room through the outlet pipe. Our design will connect in between the inlet and the test piece and will connect back to the system at the outlet. Since the diameters and position of the inlet and outlet vary in each of the test rooms, the connection between the calibration station design and Price Industries' inlet and outlet is not part of the scope for this project. Another aspect of the project that is out of the scope is designing the control system to calculate the flow rates. One of the rooms with the inlet and outlet pipes can be seen in Figure 4.

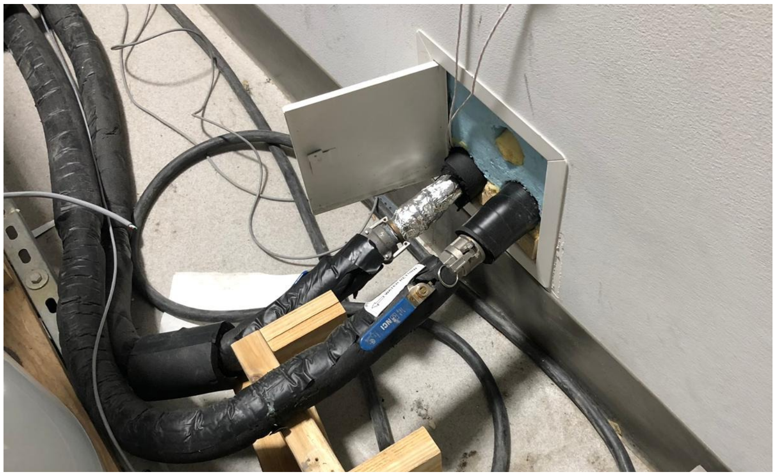


Figure 4: Inlet and outlet of a testing station

At the completion of this project, the following deliverables in the final design report will include:

- The CAD model of final design
- The preliminary engineering drawings
- The bill of materials
- The supporting analysis and calculations

1.4 Target Specification

For this design, Price Industries specified criteria based on how they would store and operate this system. This includes the mobility, the weight and the physical size of the system. These criteria along with the design specifications and operations considerations can be seen in TABLE I.

TABLE I: TARGET SPECIFICATIONS

Specification #	Metric	Units	Marginal Value	Ideal Value
1	System error	%	1	0.75
2	Maximum flow rate	gal/min	60	80
3	Minimum flow rate	gal/min	1	0.5
4	Maximum Overall weight	lbs.	500	400
5	Maximum Overall size	in	91”x94”	80”x80”
6	Change in fluid density	lb/ft^3	0.622	0
7	Usage of Bucket Test Principle	Pass/Fail	Pass	Pass
8	Outputs calibration report	Pass/Fail	Pass	Pass
9	Budget of design	$	10 000	7500
10	Ease of manufacturability	$	5000	4000
11	Ease of sourcing parts	Days	30	14
12	Ease of setting up test	Minutes	20	10

These target specifications are described further in Appendix A. From the target specifications, there are resulting constraints. In addition to these, there are constraints resulting from the course, such as team members and timeline. All these constraints can be seen in TABLE II.

TABLE II: PROJECT CONSTRAINTS

#	Constraint	Value
1	Project timeline	14 Weeks
2	Maximum Design size	94”x91”
3	Total maximum weight	500lbs
5	Design principle	Bucket Test Principle
7	Budget	$10,000
8	Design team size	4

1.5 Methodology

After defining the project specification, the team started the concept generation and development process. The concept generation phase began with internal and external designs for the tank and how the water would flow through the system. A total of 10 design concepts were generated and through concept scoring and weighting, this began to narrow down the selected number of concepts. The final design concept chosen was the Piston Design. A description of the concept generation and selection process can be found in Appendix A. During the final development of the overall design, several concepts were considered, analyzed and optimized from the original Piston Design.

A source for error from the piston is the effect of friction and the pressure difference from the gravity acting on the piston. To eliminate the effects of friction on the pressure losses, the piston design concept was turned horizontally, allowing both sides of the piston to have consistent pressure. The second optimization that was implemented was allowing the piston rod to move outside of the tank. This removed the need to have a submersible sensor inside the tank.

2. Final Design

The final design for the primary test calibration system is a hydraulic piston cylinder that displaces water to measure the volumetric flow rate with a high accuracy ultrasonic position sensor. This design consists of a piping system, containing electronic actuating valves, connected to a cylindrical tank. The final primary calibration system design can be seen in Figure 5.

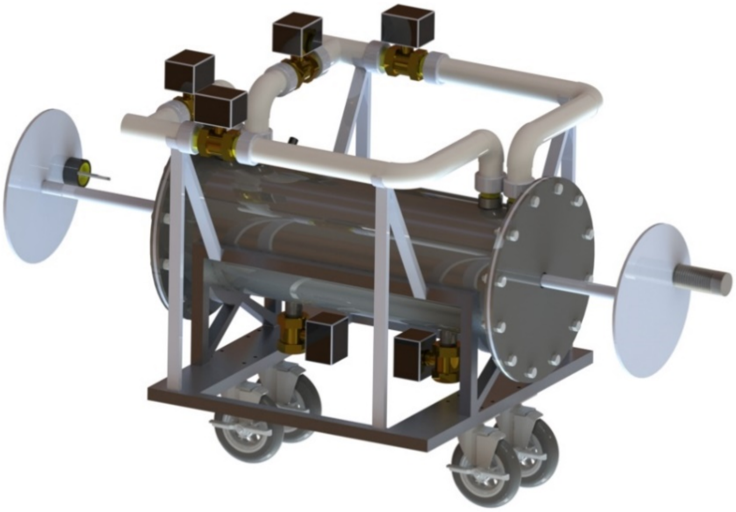


Figure 5: Final primary calibration system

The actuating valves are controlled through a microcontroller and are sequentially opened and closed. Within the cylindrical tank is a piston, with a rod welded on each side. As water flows through the piping system into the inlet of the tank, water pushes the piston horizontally inside the cylindrical tank from one end to the other. The same amount of water is flowing out of the other side of the tank. At each end of the piston rods, there is a plate with an ultrasonic sensor. The plate and sensor move with the piston and measures the time and displacement relative to the lid of the tank. At each inlet and outlet, a pressure and temperature sensor are placed. These sensors measure the pressure and temperature of the fluid at the respective inlet and outlet. Once the piston hits the stops and the position sensor output is within the stop range, the microcontroller will open and close the combination of valves to allow the piston to be pushed back in the other direction. In addition to this, once the pressure sensor reaches a certain pressure, this will also cause the valves to open. The calculations of the system specifications are calculated in Appendix B: Calculations. The microcontroller calculates the flow rate from the positional data measured from the ultrasonic sensor and outputs a calibration report accordingly. Each component of the overall design is further discussed in the following sections.

2.1 Sensors

In the system, there will be multiple types of sensors measuring different inputs. These inputs will all be connected to a microcontroller. The microcontroller will have to be able to process all the sensor inputs and create a calibration report with the flow rate for multiple flow rate ranges, the temperature and the system pressure. The chosen microprocessor is the Arduino DUE. The main reason for this choice is that it has it has a range of input voltages to accommodate for the various sensors in the system. This microcontroller also has a USB port to connect to a computer for easy programming. This can also act as an output, where it copies over data from the sensor to a USB drive. The designing and development of the microcontroller is out of the scope of this project.

2.1.1 Pressure Sensor

The requirement for both pressure and temperature sensors are that they both must be waterproof and attachable to the inside of the piping and tank. Additional criteria for these sensors are that they must be small enough to fit inside the tank, must have high accuracy and they must be inexpensive. From the sensors the team considered, the sensor chosen for pressure measurement for this application is a throw-in type liquid level transmitter. The prominent feature of this sensor is its high accuracy of 0.5% while also meeting the other requirements of being waterproof and able to fit inside the tank. The main use for this sensor is to measure the depth of the water. Though, the sensor measures the depth of water by sensing the pressure at the sensor point and converts this information into corresponding current signals. These signals are then transferred to the output of the sensor and can be transferred into an input port of a microcontroller. For measuring water level, the current signals can be converted to water depth, but in our application, it will be converted to pressure. Figure 6 shows the pressure sensor that will be used in the design.

Figure 6: Pressure sensor [1]

2.1.3 Temperature Sensor

The temperature sensor has the same decision criteria as the pressure sensor, high accuracy, waterproof and able to fit inside tank. The temperature sensor chosen for this application is the DS18B20 - Waterproof Temperature Sensor. From a list of commonly used sensors, this sensor is the second highest in terms of its accuracy of ±0.5°C, but it has the lowest cost. The most accurate sensor on the list has an accuracy of ±0.3°C, but it has a very high cost. For this application, the temperature is being measured to ensure that the environment is stable. The change in temperature does not affect the density of the fluid until the temperature is near freezing or 50°. From this, we determined that the accuracy of ±0.5°C was suitable for our application. The temperature sensor can be seen in Figure 7.

[redacted]

Figure 7: Temperature sensor [2]

2.1.4 Position Sensor

The last type of sensor in the system is the position sensor. This sensor is responsible for determining the flow rate of the system. The most important feature of this sensor is its accuracy. For the types of position sensors, the team considered infrared, hall effect, rotary potentiometer, linear variable differential transducer and ultrasonic. A more detailed selection process can be seen in Appendix C1: Sensor Selection.

From these sensors, the team has chosen to move forward with the ultrasonic sensor because of its high accuracy as well as its simplicity. From the ultrasonic sensors considered, the team has chosen the RPS-412A sensor from Migatron Corp. This sensor can achieve a 0.05% accuracy, the highest of all sensors considered. This can be seen in Figure 8.

[redacted]

Figure 8: Ultrasonic position sensor [3]

2.2 Piping

Polypropylene (PP) was the chosen material for the piping system in the design. This is because a distributor was found locally that distributes PP piping systems that also includes a threaded PP to brass adapters needed to assemble the overall design. The distributor used is called WD Industrial Group that distributes a product line called Niron PP piping systems. From this product line, the primary calibration system requires a total of five feet of 1 ½” PP pipe, two 1 ½” PP socket fusion tees, six 1 ½” PP socket fusion 90° elbows, 12 - 1 ½” NPT male threaded socket fusion brass adapter, and one PP welding socket to female brass outlet.

The design team considered that the effects of piping may influence the flow rate due to frictional forces. As such, the design team considered various materials of piping for the final design. Some considerations that the design team had were friction losses, cost, availability, and ease of implementation. The most common piping materials used are copper, steel, polyvinyl chloride (PVC), and polypropylene. Thus, a criteria comparison was done to weight each criterion accordingly and a weighted decision matrix was created. From this decision matrix, the best piping material rated was PVC and PP. This decision matrix can be found in Appendix C.

2.3 Valves

A key feature to the overall design concept is the actuating of specific valves with relation to one another. To do so, the design requires electronically actuated valves that can be completely turned on or off. The sourced electronic ball valve was a Deelat Motorized 2 Way Ball Valve. The criteria used for sourcing an electronically actuated valve was that it needed to be able to fully turn on and off with the sequencing of the microcontroller. Thus, the electronic ball valves were sourced from Deelat Industrial Products for the overall design. Figure 9 illustrates an example of the connection between piping, the pipe adapter, the actuating valve, and a tee fitting.

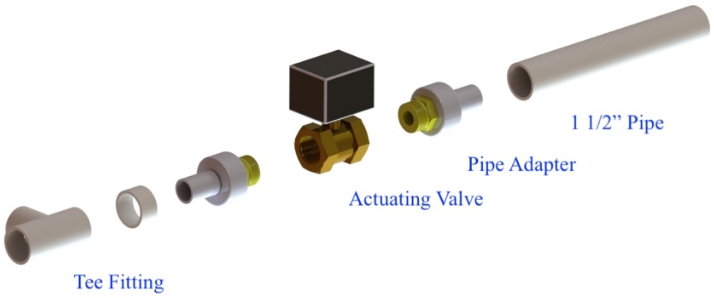


Figure 9: Pipe fitting connection

2.4 Tank Design

The tank is the largest component of the calibration system. The tank is made out of 316 Stainless Steel and has a diameter of 10 inches and a length of 29 inches. The measurable length set in the tank is 16 inches, which allows for the maximum flow rate of 60 gal/min to have a continuous testing period of five seconds. The piston is stopped 6.5 inches from the ends of the tank by a sleeve welded onto the lid. This 6.5 in is to allow for the placement of the inlet and outlet valves, as well as the temperature and pressure sensor. The inlets and outlets are located at the top of the tank to negate any potential pressure losses due to gravity.

Since the calibration station is filled with water, the seals used in the design are an integral part of the overall design as they prevent water from leaking out the tank and through the piston. The calculations to determine the O-ring groove are shown in the Appendix B.2 and B.5. The friction between the piston and the tank, as well as between the rod and the lids, are important factors that affect the accuracy of the calibration results. Thus, a wear ring can be used to additionally reduce the friction force experienced. The wear rings selected are made of Teflon which has a friction coefficient of 0.04 with a steel tank. This friction value has a minimal effect on the system, and therefore, it is neglected in analysis. The wear ring also supports the stabilization of piston and rod to avoid pitch motion during the calibration test. The last sealing feature are the wipers at the end of the tank. This keep the water inside the tank and any debris outside the tank. These seals can be seen on the piston in Figure 10.

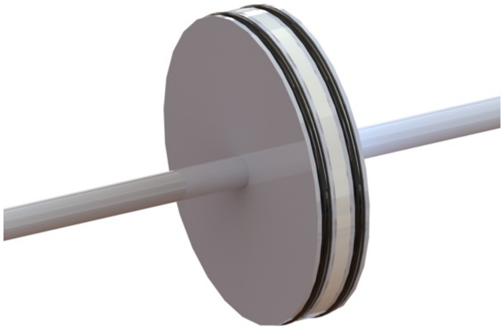


Figure 10: Piston with O-ring, wear ring and another O-ring.

Considering maintenance, the lids designed to be removable. The lids are bolted through a flange on both ends of the cylindrical shell of the tank. The hardware that attaches the lids to the tank are easily accessible for possible maintenance. Between the lid and the flange of the tank exists a rubber gasket that will prevent any potential water from leaking through. An exploded view of the lid and tank assembly can be seen in Figure 11.

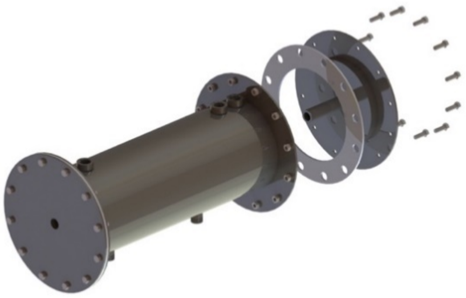


Figure 11: Tank lid connection

2.5 Design Function Procedure

This section gives a detailed explanation of how the mechanical system will function alongside the electronics to create the required calibration report for each calibration test. The calibration report will be computed through a microcontroller through processing readings from the sensors in the system. The calibration report will consist of the calculated flow rate, temperature readings and the pressure readings in the tank. A microcontroller will also be used to actuate the valves in the system. There is a total of six sensors in the overall design: two temperature sensors, two pressure sensors, and two ultrasonic sensors. Located at both the input and outputs of the calibration system are one temperature sensor and one pressure sensor.

Generally, the first step in the electronic sequencing is to allow the microcontroller to read each sensor. Once the pressure sensors detect a constant pressure between the inlet and the outlet, a new calibration test will begin as the system has reached a steady state. The ultrasonic sensor is attached to a thin plate at the end of the piston rod. As the piston rod is displaced, the ultrasonic sensor records the time it takes to reach a set distance from the sensor to the lid of the tank. When the piston reaches the stop, the system resets and the flow changes to the other side of the piston, pushing the piston to its original position. The system and the measuring distance can be seen in Figure 12.

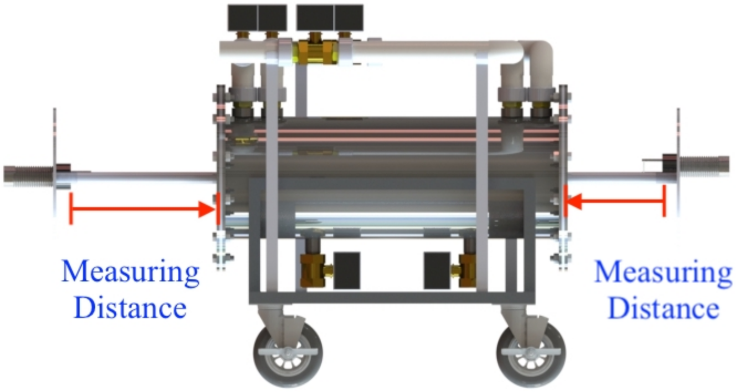


Figure 12: Sensor measuring distance

At the start of the test, the pump will be pumping water into the system. The flow will go through the flow meter at price and read a flow rate. The water then enters the calibration system. At the beginning of the calibration, the inlet and outlet on both sides of the piston will be opened to allow the fluid flow to continuously flow through the system and fill up the whole tank. After the system detects equal pressure in both sections, the left input will close so all the water will be flowing into the right side. At this point, the right output will be closed so the only output is on the right side. This allows the water to push the piston all the way to the left, the starting position of the calibration test. Figure 13 illustrates the sequencing of the valves where open valves are coloured green and closed valves are coloured red.

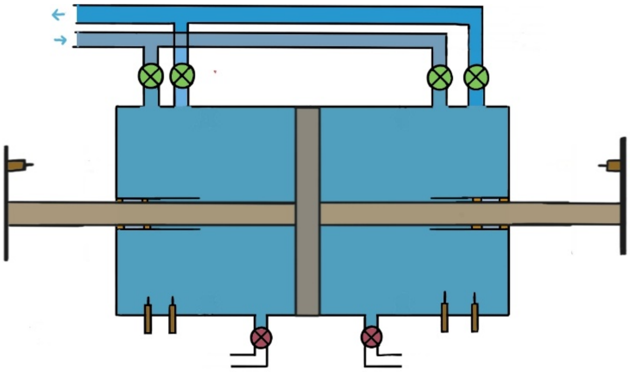


Figure 13: Initial stabilization with all inlets and outlets open

One inlet and one outlet from opposite ends will always be kept open after the initial stabilization to allow the fluid to flow into one section of the tank and out the other. The piston, as shown in Figure 14, will be pushed toward the other end of the cylindrical tank. As soon as the microcontroller actuates the valves, it signals the start of a calibration test.

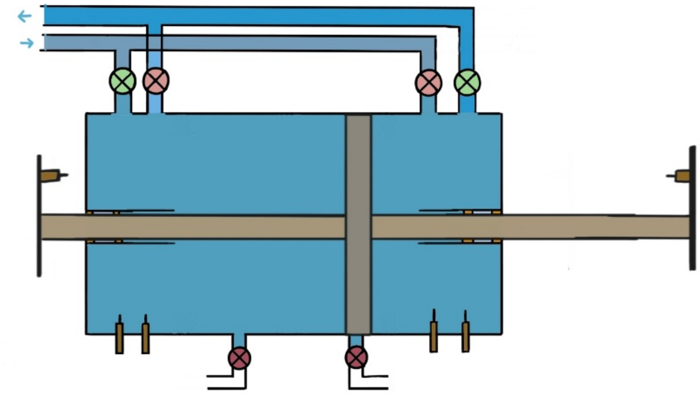


Figure 14: Calibration process with fluid flowing right to left

Once the piston has reached the stop on the opposite end of the tank, the microcontroller will signal for the other inlet and outlet valve to open, that is, the inlet valve close to piston and outlet valve far away from piston, In addition, the initially opened valves will be closed resulting in the piston to move in the other direction, as shown in Figure 15. This process will be repeated continuously to calibrate the flow meters at different flow rates. The microcontroller will start the calculations when the displacement from the ultrasonic sensors become precise within a set value. This value will have to be set through prototype testing since it depends on the initial fluid dynamics upon actuating the valves.

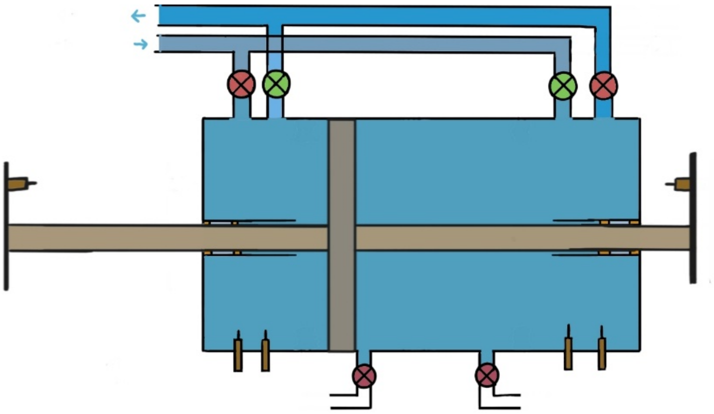


Figure 15: Calibration process with fluid flowing left to right

During each test, the ultrasonic sensor continuously transmits its readings into the microcontroller where it will record each reading and calculate the flow rate. The piston continues back and forth until the numbers of flow rates calculated have reached a satisfactory amount set by the operator. Once the flow rate has been consistently measured, another flow rate can be calibrated, and the process is repeated beginning with the stabilization of the fluid flow. The microcontroller also takes inputs from the pressure sensors and when the pressure inside any section of the tank increase more than allowable pressure in the tank, the respective drain valve opens to release the pressure.

2.7 Bill of Materials

A summary of the bill of materials can be seen in TABLE III. This bill of materials tabulates each component of the design, the vendor and part number, the quantity required, the cost per quantity, and totals the overall design.

TABLE III: BILL OF MATERIALS SUMMARY

Component	**Total Cost**
Piping	$1033
Valves	$1087
Fabrication	$4839
Electrical	$4378
Miscellaneous	$565
Total	**$11802**

For the fabrication of the tank, the total cost accounts for the material and an estimated manufacturing cost associated with it. There are numerous machine shops that are able to manufacture this design, if provided the materials, including, Wallin Industries, Metal Tech Industries, and Anything Custom.

For various components of the design, quotes were required to obtain a cost. The various quotes obtained for these components can be seen in Appendix D. This cost is above the budget requirement but can be reduced to be within the budget by removing one ultrasonic sensor. The use of two ultrasonic sensor is to increase the confidence in the calibration measurements. However, the requirement of accuracy will still be met by the use of one sensor.

2.8 Design Specifications

Several calculations were performed to compute the pressure in the tank, pressure losses, weight of the calibrations station, etc. TABLE IV shows the list of various parameters of the design and its values. Calculations for the design specifications can be seen in Appendix B.

TABLE IV: DESIGN SPECIFICATIONS

Parameters	Values
Static head Loss	0.8429 m or 8.2537 kPa
Maximum friction Loss due to Piping	1.9735 m or 19.325 kPa
Maximum Total Pressure Loss	2.8161 m or 27.5797 kPa
Overall Weight	389 lbs. or 176.45 kg
Overall Inaccuracy	0.116%

By knowing the maximum total pressure loss in the calibration system, it can be determined if any future or existing test rig can be used with the system. Pumps connected to each test rig must require a pump with a high pump capacity to overcome these losses. With a low overall inaccuracy, the results of the calibration system can be confidently calculated, and an accurate calibration of each flow rate meter can be conducted.

3. Recommendations and Considerations

With the completion of the primary calibration test system, the design team has determined several recommendations and future considerations to the design. This includes adding a booster pump, isolating the design when operated, the accommodation for future test rigs and reducing the costs while manufacturing the system.

The design of the primary calibration system was to accommodate the various test rigs that currently exist at Price Industries. In the future, Price Industries may create new test rigs that are unable to accommodate the primary calibration system due to additional pressure losses. Before using the primary calibration system with these new test rigs, ensure that the pump capacity is high enough to overcome the pressure losses of the system. If the pump capacity is not reached, the design team recommends that a booster pump may be added to the existing design if the pump used for a specific test rig is not sufficient to maintain the flow rate through the calibration system. As each test rig system is unique to the testing apparatus, the pump used for each as well varies. Thus, there is a possibility that pumps with smaller capacities will be unable to accommodate pressure losses of the design and hence be unable to operate the system.

An additional recommendation by the design team is the isolation of the calibration system while it is operational. This is a barrier to protect the operator from any possible risks from the dynamic system. As the calibration system is being operated, the piston rod and plate are reciprocating back and forth numerous times. This could potentially lead to someone being hit by the piston rod and plate. Thus, by isolating the design when being operated, the risk of injury would be eliminated.

As for the budget, some recommendations to reduce the cost consist of using existing carts and modifying the frame to accommodate the calibration system instead of custom manufacturing the whole cart. Another recommendation is to use hydraulic off-the-shelf tanks with bolted or threaded lids instead of custom manufacturing the tank. High strength plastics can also be used for this application to reduce costs and weight.

4. Conclusion

This design problem was presented to our team to find a solution to prevent the need for Price Industries to outsource the calibration of their flow rates meters to another company. This design accomplishes this problem by measuring the velocity of a piston inside a cylindrical tank with an ultrasonic sensor placed on a plate at the end of the piston rod. The overall design can be seen in Figure 16.

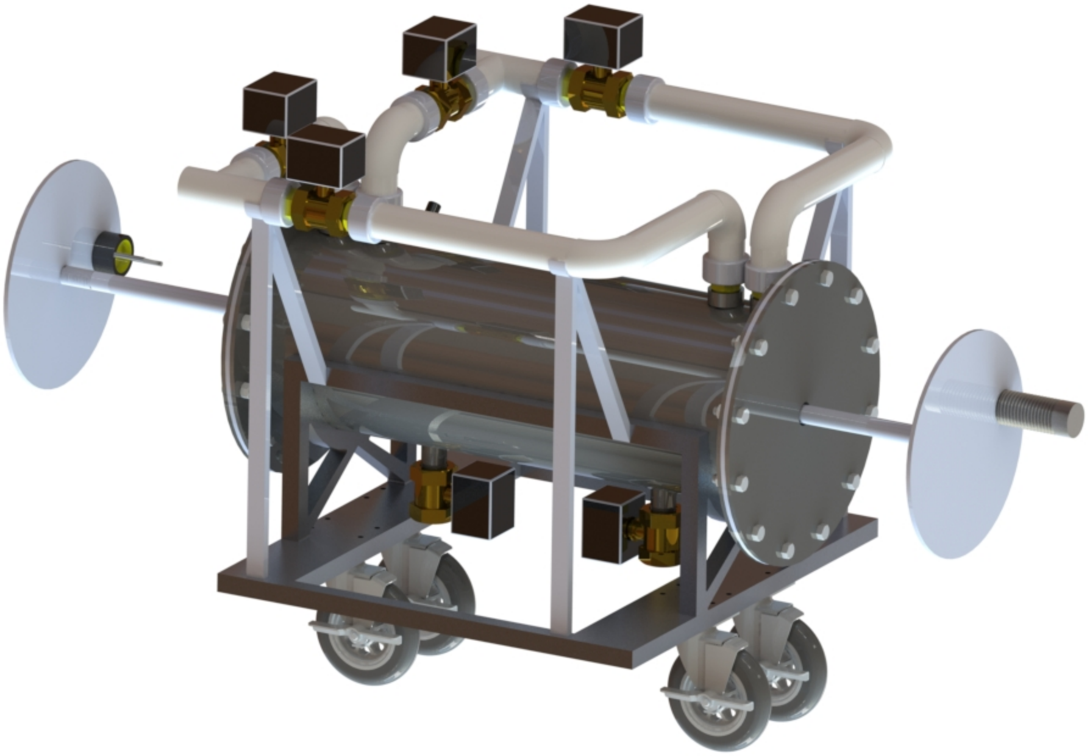


Figure 16: Primary test calibration system

The design is based on the bucket test principle such that it measures the flow rate by the measuring the change in volume per unit time. Pressure losses due to calibration station are considered to determine the required pump capacity. The maximum pressure losses due to static head and friction in the design is computed to be 2.8161 m or 27.5787 kPa. With these values, the current pumps in the test rooms are theoretically compatible with the calibration system, though testing is still needed to identify any other loses.

The cylindrical tank sits on an aluminum cart to allow for the calibration system to be easily maneuvered. The total weight of the design is estimated to be approximately 389 lbs. This estimation takes into consideration the weight of water filled inside the tank as well.

The height of the station is 28.35" and the length and width of the station are 62.2" and 25.98", respectively. The overall inaccuracy of the calibration station is found to be 0.11585%. These calculations can again all be found in Appendix B.

The total cost of the calibration station is estimated to be $11800. This total cost covers the design and fabrication of the tank, piston, and cart, as well as all other accessories such as sensors, piping, actuating valves, and microcontroller. The overall cost of the design may be reduced to $9710.76 with the use of only one ultrasonic sensor.

The Primary test calibration station fulfils all the requirements of the design and is within the constraints listed by Price Industries.

References

[1] DFRobot, "Gravity: Analog Water Pressure Sensor," [Online]. Available: https://www.dfrobot.com/product-1675.html. [Accessed 13 November 2019].

[2] Sparkfun, "Temperature Sensor - Water Proof," [Online]. Available: https://www.sparkfun.com/products/11050. [Accessed 13 November 2019].

[3] Migatron Corp., "RPS-412A," 2015. [Online]. Available: https://www.migatron.com/high-accuracy-sensor/. [Accessed 13 November 2019].

Appendix A: Concept Development/Selection Detail

This Appendix is to further detail the concept development and selection process of the overall design. To achieve the final design, a list of metrics that the design must contain was created. This is then followed with a list of generated concepts, both internally and externally, being created. Each of the design concepts were then scored based off the list of metrics found in Section 1.4. From this, a short list of four design concepts was created. Finally, from this short list of criteria, a weighted decision matrix with an expanded list of criteria was used to determine the final design concept.

List of Figures

List of Tables

A.1: Target Specification Justification

1. Maximum Weight

The overall design concept must be able to function in various Price Industries' testing areas and accommodate multiple different test rigs. Based on the working environment at Price Industries, the design must be easily movable by two to three people. The overall design must not exceed 500 lbs such that two or three people are able to maneuver the test station to each testing area.

2. Maximum Size

Due to the constant transportation of the calibration test station, the design will need to pass through various doors with a standard door size of 94" tall and 91" width. This will allow the calibration station to be used with multiple testing rigs that are in various areas of the facility.

3. Maximum Inaccuracy

The new calibration test system for Price Industries will measure the flow rate that is supplied from a test rig. A major criterion of the calibration station is that the design must be accurate within 1% of the true flow rate. This will be calculated through the part manufacturer's accuracies.

4. Bucket Test Principle

As required by Price Industries, the design principle of calibration system must be based on the Bucket Test Principle. This principle is used to ensure the overall design measures the mass of the fluid and the time for the mass to reach a certain level, whether volume or mass. From this information, the flow rate can be determined.

5. Fluid Properties

During the operation of the calibration station, the fluid properties must remain constant to ensure accuracy of measured flow rate. These properties include the density, pressure and temperature of the working fluid.

6. Accommodates Flow Rates

As previously mentioned, the calibration station will be used with various test rigs at Price Industries. Thus, the calibration station must accommodate a flow rate range of 1-60 gal/min.

7. Cost

The budget set by Price Industries is $10,000. The components that make up the system must be under this amount.

8. Ease of Manufacturing

When selecting the overall design concept, it is important to consider the overall manufacturability of the design. Thus, when selecting a design concept, it is important that parts for the overall design are easily accessible, machinable, and easily assembled.

9. Ease of Mobility

As size and weight are existing criterion, ease of mobility as well must be considered. Without the consideration of size and weight, the calibration station must be easily moved to and from various testing areas.

10. Potential Leakage

During the process of concept selection, the life of usage must also be considered. This includes the possibility of leakage of the overall design. The potential of leakage in the design will be considered a root cause of many other potential issues in the calibration station.

11. Maintenance

With the overall design, the maintenance of the calibration station must also be considered. This includes how often the calibration station needs to be maintained as well as how difficult it is to access common components to be replaced in the system.

12. Part Accessibility

The parts that make up the overall design must be easily accessible. This means that not only is the part easily sourced, but the replacements parts can be easily ordered.

13. Set Up Time

As the calibration station will be used for various test rigs and for the future, the overall set up time of the design is considered. This indicates the necessary time to set up the calibration station between each testing from start to finish.

A.2 Concept Development

To generate a list of concept designs, the design team used both internal and external methods. This resulted in eight internal concepts and two external concepts being created through a combination of generation techniques such as brainstorming, looking at existing patents, and the SCAMPER technique. This list of 10 concepts and a brief description can be seen in Table AI – Table AX.

TABLE AI: DAMPING WALL TANK CONCEPT DESCRIPTION

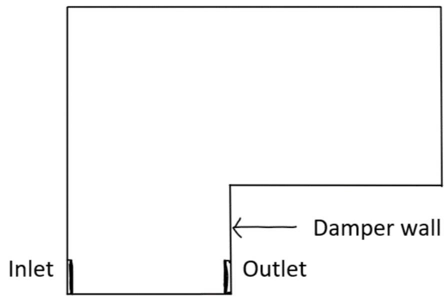
1. Damping Wall Tank	
Design Description	Schematic
This design consists of an inlet and an outlet at the bottom of the tank. The rest of tank is a closed system. The tank is narrower at the bottom and is wider for the top half section. The tank has a damper wall opposite to the inlet. The damper wall and the change in the cross-section help achieve stable level flow faster. Lastly, the outlet is closed while measurements are taken and is opened after calibration.	

TABLE AII: PISTON TANK CONCEPT DESCRIPTION

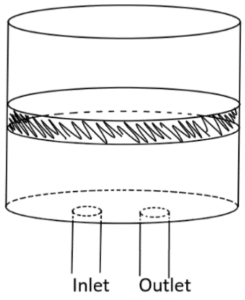
2. Piston Tank	
Design Description	Schematic
This design consists of a cylindrical tank with both inlet and outlet located at the bottom of the tank. The tank is closed from the top by a piston. The piston slides evenly up and down freely except when the water flows in. When the fluid flows in, it lifts the piston lying at the bottom of the tank. The piston triggers sensors along the walls of the tank and stops at the top of the tank after all measurements have been taken. The increase in the pressure in the tank opens the outlet.	

TABLE AIII: FUNNEL TANK CONCEPT DESCRIPTION

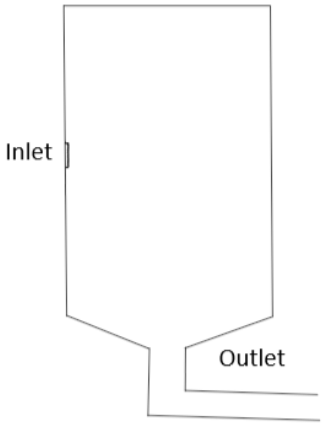
3. Funnel Tank	
Design Description	Schematic
The funnel shaped tank has the inlet at the top of the tank along the side and outlet at the bottom. The outlet is closed at the beginning of the calibration. Fluid flows in the from the inlet and tank fills while sensors are activated, and measurements are taken. Once the measurements are taken, the outlet opens and all the fluid in the tank flows out of the tank.	

TABLE AIV: SIMPLE CYLINDRICAL TANK CONCEPT DESCRIPTION

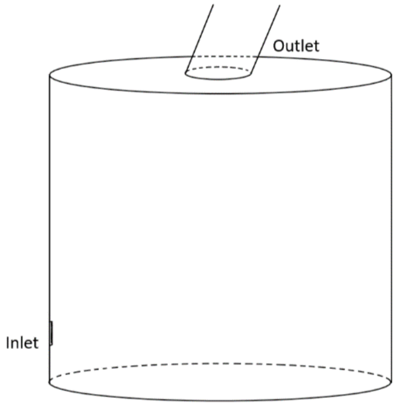
4. Simple Cylindrical Tank	
Design Description	Schematic
The simple cylindrical tank has an inlet at the bottom along the side of the tank and an outlet at the top of the tank. The tank has a baffle in the middle to reduce the turbulence and stabilize the fluid. Water flows in the tank from the bottom inlet and sensors are activated while fluid rises. After the measurements are taken, fluid flows out of the outlet at the top of the tank.	

TABLE AV: LONG VERTICAL TUBE CONCEPT DESCRIPTION

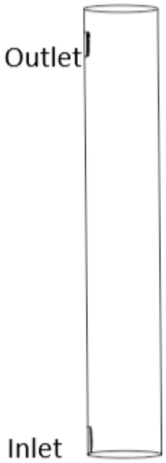
5. Long Vertical Tube	
Design Description	Schematic
This design consists of a long vertical tube with an inlet at the bottom and an outlet at the top. Water flows in through the inlet and sensors are activated as the water rises in the tube. Measurements are taken and water flows out of the outlet.	

TABLE AVI: T-LINK CONNECTOR

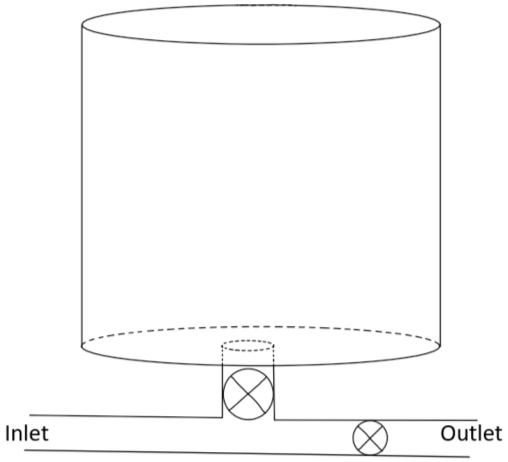
6. T-Link Connector	
Design Description	Schematic
The design consists of a closed cylindrical tank connected in a T-connection with the flow in the test rigs. The inlet is at the bottom of the tank. Fluid is directed into the tank by opening the inlet to the tank and closing the outlet to the test rig. Once the measurements are taken, the inlet to the tank is closed and the outlet is opened such that flow from the test rig is returned to test rig without any interference of the calibration station.	

TABLE AVII: CURVED PATH CONCEPT DESCRIPTION

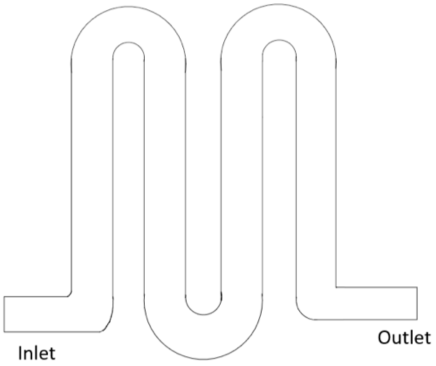
7. Curved Path	
Design Description	Schematic
The curved path design consists of water flowing in from an inlet at the bottom of the curved pipe path. The design has several vertical sections of pipe where the sensors are placed to perform measurements. After the measurements are taken, the fluid flows out the design through the outlet at the end of the curved pipe path.	

TABLE AVIII: WATER WHEEL CONCEPT DESCRIPTION

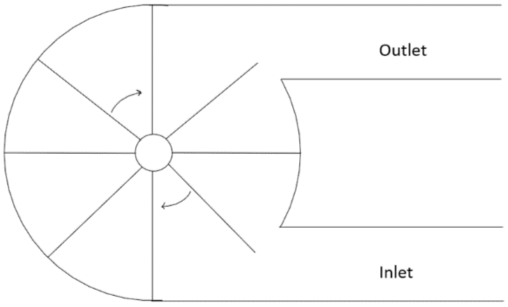
8. Water Wheel	
Design Description	Schematic
The design consists of a closed water wheel with an inlet and an outlet. The wheel consists of several sections or pockets created by the blades of the wheel. The blades are designed such that when the water comes in, the wheel rotates. With the known volume of each pocket, the time between each pocket is measured and flow rate can be calculated. Water flows out of the outlet at the same flow rate as inlet.	

TABLE AIX: TURBINE FLOW METER CONCEPT DESCRIPTION

9. Turbine Flow Meter	
Design Description	Schematic
The turbine flow meter consists of a turbine which rotates because of the flow rate of the fluid. The turbine has a rotor and light reflective blades. When water flows in, the rotor rotates the blades and light sensors senses the speed of rotation of blades. The speed of the rotation is proportional to the volumetric flow rate of the fluid. [1]	[redacted]

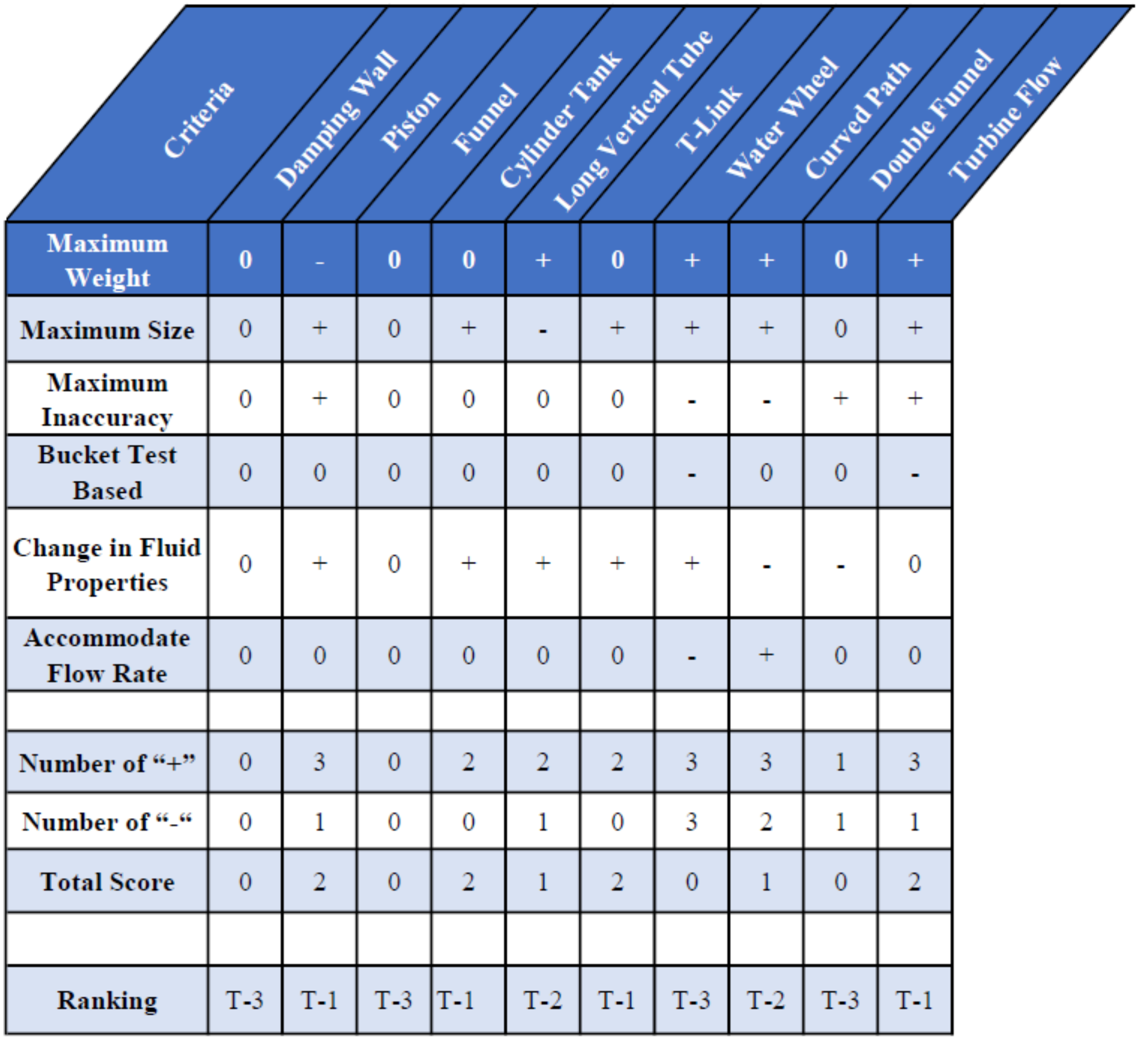
TABLE AX: DOUBLE FUNNEL CONCEPT DESCRIPTION

10. Double Funnel	
Design Description	Schematic
The double funnel design consists of a funnel like structure at the top and bottom of the tank. A neck with a scale is installed at the top of the tank. A known volume of fluid is added in the tank and weighted to ensure correct measurement of volume. The expansion and compression of the fluid is considered by incorporating temperature measurements using thermocouples and calibration is performed accordingly. [2]	[redacted]

A.3 Concept Screening

From these design concepts, a short list was created by evaluating each concept with each criterion from TABLE I. The results of the concept scoring can be seen in TABLE AXI.

TABLE AXI: PRELIMINARY CONCEPT SCREENING



Criteria	Damping Wall	Piston	Funnel	Cylinder Tank	Long Vertical Tube	T-Link	Water Wheel	Curved Path	Double Funnel	Turbine Flow
Maximum Weight	0	-	0	0	+	0	+	+	0	+
Maximum Size	0	+	0	+	-	+	+	+	0	+
Maximum Inaccuracy	0	+	0	0	0	0	-	-	+	+
Bucket Test Based	0	0	0	0	0	0	-	0	0	-
Change in Fluid Properties	0	+	0	+	+	+	+	-	-	0
Accommodate Flow Rate	0	0	0	0	0	0	-	+	0	0
Number of “+”	0	3	0	2	2	2	3	3	1	3
Number of “-“	0	1	0	0	1	0	3	2	1	1
Total Score	0	2	0	2	1	2	0	1	0	2
Ranking	T-3	T-1	T-3	T-1	T-2	T-1	T-3	T-2	T-3	T-1

For the final design concept screening, the design team used a weighted decision matrix. Before doing so, each criterion was weighted based on the importance the criteria carried. To do so, this each criterion was compared to one another and weighted accordingly. The results of the criteria comparison and scoring can be seen in TABLE AXII.

TABLE AXII: CRITERIA COMPARISON TABLE

		Max. Weight	Max. Size	Max. Inaccuracy	Bucket Test	Fluid Properties	Accommodates	Cost	Ease of	Ease of Mobility	Aesthetically	Potential Leakage	Maintenance	Part Accessibility	Set Up Time	
Criteria	ID	A	B	C	D	E	F	G	H	I	J	K	L	M	N	Score
Max. Weight	A		B	C	D	E	F	A	A	I	A	K	A	A	A	6
Max. Size	B			C	D	E	F	B	B	I	B	K	B	B	B	7
Max. Inaccuracy	C				C	E	C	C	C	C	C	C	C	C	C	12
Bucket Test Principle	D					E	D	D	D	D	D	D	D	D	D	11
Fluid Properties	E						E	E	E	E	E	E	E	E	E	13
Accommodates Flow Rates	F							F	F	F	F	F	F	F	F	10
Cost	G								G	I	G	K	L	G	N	3
Ease of Manufacturing	H									I	H	K	L	H	N	2
Ease of Mobility	I										I	K	I	I	I	8
Aesthetically Pleasing	J											K	L	M	N	0
Potential Leakage	K												K	K	K	9
Maintenance	L													L	N	4
Part Accessibility	M														N	1
Set Up Time	N															5

Finally, with the weighted criteria, a final design concept weighted decision matrix was created. This can be found below in TABLE AXIII.

TABLE AXIII: FINAL CONCEPT WEIGHTING

		Piston		Cylinder		T-Link		Turbine Flow	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Max. Weight	7%	1	0.07	2	0.14	2	0.14	3	0.21
Max. Size	8%	3	0.24	2	0.16	2	0.16	3	0.24
Max. Inaccuracy	13%	3	0.39	2	0.26	2	0.26	3	0.39
Bucket Test Principle	12%	3	0.36	3	0.36	3	0.36	1	0.12
Fluid Properties	14%	3	0.42	3	0.42	3	0.42	3	0.42
Accommodates Flow Rates	11%	3	0.33	3	0.33	3	0.33	3	0.33
Cost	3%	1	0.03	3	0.09	2	0.06	1	0.03
Ease of Manufacturing	2%	1	0.02	3	0.06	2	0.04	1	0.02
Ease of Mobility	9%	3	0.27	2	0.18	2	0.18	3	0.27
Aesthetically Pleasing	0%	3	0	2	0	2	0	2	0
Potential Leakage	10%	1	0.1	3	0.3	2	0.2	2	0.2
Maintenance	4%	1	0.04	3	0.12	2	0.08	1	0.04
Part Accessibility	1%	1	0.01	3	0.03	3	0.03	1	0.01
Set Up Time	5%	3	0.15	1	0.05	1	0.05	2	0.1
Total	100%	2.43		2.5		2.31		2.38	

From this final weighted decision matrix, it can be seen that the top two design concepts were the Cylinder Design and the Piston Design. As both design concepts scored very closely, the design team consulted with Price Industries and came to a conclusion to proceed with the Piston Design.

A.3 Design Optimization

The initial piston concept did not allow for continuous calibrations at different flow rates. Since the increase in volume was used to measure the flow rate, volume could not be increased and decreased repeatedly because of requirement of continuous flow rate at the outlet with the initial concept. Hence, a tank design with two sections, as shown in Figure A1, was proposed containing an inlet in one section and an outlet in the other section.

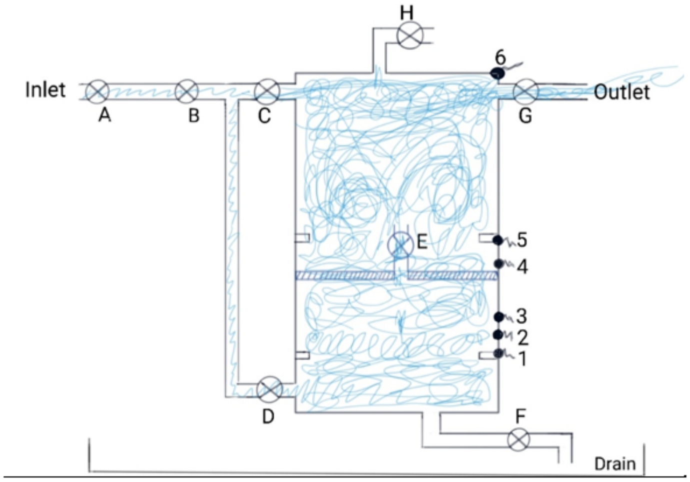


Figure A1: Front view two section tank design

This allowed for the continuous measurement of flow rate without any change in the total volume of the fluid in the tank. However, some of the issues with this design was that the measurements were taken along certain vertical displacement of the piston. The hydrostatic pressure on the piston varied at the bottom position of the tank compared to the top of the tank. This would result in different friction losses and pressure in the tank during calibrations leading to inaccuracies. This issue was resolved by proposing a horizontal cylindrical tank instead of vertical i.e. the piston would move horizontally. This iteration of the piston design can be seen in **Error! Reference source not found.**. The design involved fluid flowing into one section of the tank and exiting from other section and vice versa. The back and forth displacement of the piston would provide the required flow rate. The optimized design, now, does not have the issue concerning different friction and pressures at different segments of calibration. In addition, another issue that arose was that the level of the piston may not be consistent in the tank and get stuck in the tank or not be parallel to the side walls of the tank. A rod was added to the both sides of the piston and was additionally stabilized by using linear bearings on the side walls. This design concept is illustrated in Figure A2.

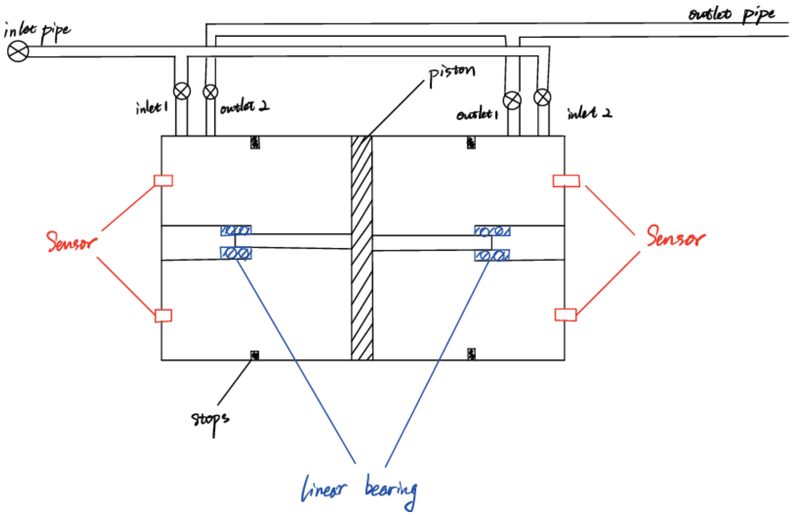


Figure A2: Horizontal Tank Design

Since the position or displacement sensor is required to measure the position of piston in the tank, submersible sensors not ideal as they were large, costly and less accurate. In order to optimize and reduce the overall size, cost and inaccuracy of the design, the rod was made able to move out of the tank by sealing each rod with O-rings at the two ends of the tank. Although, the seals added a minimal amount of friction to the motion of the rod, the solution led to the use of a more accurate and cheaper sensor to measure the position of the rod and hence the piston. These changes resulted in the optimized, smaller, accurate, and more economic final design.

References

[1] J. C. Owen and D. R. DeMaagd, "Turbine Flow meter". United States of America Patent 3217539, 7 April 1961.

[2] N. M. System, "Good Practice Guide - Calibration of Flow meters," [Online]. [Accessed 14 October 2019].

Appendix B: Calculations

This appendix demonstrates the computational analysis of the final design regarding the pressure losses, flow rate, inaccuracy, size, weight of the design, etc. Several calculations were performed to ensure that the design fulfils all the requirements of the designs and is within the design constraints. Detailed calculations are shown for various parameters of the design as follows.

List of Figures

List of Tables

B.1. Tank Design

This section consists of the calculations to size the tank, piston, shaft, lids and other components of the design. The sizing is determined by considering the critical parts of the design that needed to be sourced. The size of tank had been predetermined to be a standard pipe to reduce the extra cost of customized tank machining. O-rings around the piston and rod are some of the important dimensions which influenced the size of piston and the tank.

B.1.1. Diameter of Tank

The maximum volumetric flow rate of the design is 60 GPM, which can be convert to 231 cubic inches per second for the calibration station. By setting the calibration length to 16 in, the time calculated to finish the calibration at the maximum volume flow rate is 5 seconds. The diameter of the tank can be calculated by the equation (B.1), (B,2) and (B.3).

$$Volume\ of\ water = 231\frac{in^3}{s} * 5s = \ 1155\ in^3 \tag{B.1}$$

$$Area\ of\ tank = \frac{Volume\ of\ water}{Calibration\ length} = \frac{1155}{16} = 72.1875\ in^2 \tag{B.2}$$

$$Diameter\ of\ tank = \sqrt{\frac{4}{\pi} * Area\ of\ tank} = \sqrt{\frac{4}{\pi} * 72.1875} = 9.58707\ in \tag{B.3}$$

As the result of these calculation, the diameter of the tank is equal to 9.58707in. To easily source a tank of this size, the diameter selected was rounded to a standard size of 10 in.

B.1.2 Tank Length

To determine the required length of the tank, the sensor range, size of inlet and outlet pipes, and the clearance for the piston must be considered.

$$Sensor's\ range\ of\ measurements, R = 40\ cm$$

$$Size\ of\ inlet\ and\ outlet\ pipes, D_{pipe} = 1.61" = 4.0894\ cm$$

$$Clearance\ required\ between\ inlet, outlet\ and\ piston\ stops, C = 8\ cm$$

Considering, inlets, outlets and clearance on both sides of the piston,

$$Required\ minimum\ length\ of\ Tank, L_{tank} = R + 2\left(2\left(D_{pipe}\right) + C\right) \qquad \text{(B.4a)}$$

$$Minimun\ L_{tank} = 40 + 2(2(4.0894) + 8) = 72\ cm\ approx. \qquad \text{(B.4b)}$$

B.1.4. Maximum Pressure

The pressure inside the tank is due to the weight of fluid, velocity of fluid, potential energy. Additional pressure is exerted to overcome the friction between the seal rings and tank around piston and rod. Since it is very difficult to calculate the friction and the pressure losses due to friction, the amount of friction are expected to be very small; the pressure exerted to overcome friction is assumed negligible. Hence, according to Bernoulli's equation, [1]

$$P = \rho g h + \frac{1}{2}\rho v^2 \qquad \text{(B.5a)}$$

The dynamic pressure is defined by the velocity is same everywhere in the tank whereas the hydrostatic pressure increases with increase in the depth. Hence, maximum pressure is at the bottom of the tank. Therefore, maximum pressure in the tank is computed as follows.

$$P_{max} = \rho_{water} g h + \frac{1}{2}\rho_{water} v_{max}^2 \tag{B.5b}$$

By assuming the highest level of water is the top of the calibration station, at the top of the piping system, the maximum pressure can be calculated.

$$h = distance\ from\ bottom\ of\ tank\ to\ top\ of\ piping\ system$$

$$h = D_{tank} + Height\ of\ piping\ system \tag{B.6a}$$

$$h = 0.254 + 0.1765 = 0.4305\ m \tag{B.6b}$$

$$Maximum\ Velocity\ of\ flow, v_{max} = \frac{\dot{Q}_{max}}{A_{pipe}} = \frac{0.0037854}{0.0013128} = 2.8794\ m/s \tag{B.7}$$

Using these values for height and maximum velocity, Equation B.5b is used to calculate the maximum pressure in Equation B.8.

$$P_{max} = 998.0(9.81)(0.4305) + \frac{1}{2}(998.0)(2.8794)^2 \tag{B.8a}$$

$$P_{max} = 8.352\ kPa \tag{B.8b}$$

B.1.3. Tank Thickness

The thickness of the tank depends on a number of tank parameters such as allowable stress, corrosion and design pressure. The maximum pressure inside the tank, hence, is computed as follows. [2]

$$Tank\ material = 316\ Stainless\ Steel$$

$$Yield\ Stress, S = 290\ MPa$$

Assuming corrosion allowance of 1 mm,

$$Inside\ radius\ of\ tank, R_i = \frac{D_i}{2} + 1\ mm = \frac{0.254}{2} + 0.001 \qquad \text{(B.9)}$$
$$= 0.128\ m$$

Assuming joint efficiency of 1.0 i.e. [3]

$$E = 1.0$$

$$Design\ Maximum\ pressure, P_{max} = 8.352\ kPa = 8350\ Pa$$

$Required\ wall\ thickness,$ [4]

$$t_R = \frac{P.R_i}{S.E - 0.6(P)} \qquad \text{(B.10a)}$$

$$t_R = \frac{8352(0.128)}{290(10^6)(1.0) - 0.6(8352)} = 0.0036865\ mm \qquad \text{(B.10b)}$$

For ease of manufacturing, the tank thickness is taken to be 0.25” or 0.00635 m. Hence,

$$Tank\ thickness, t_{tank} = 0.00635\ m$$

B.1.3. Maximum Allowable Pressure

Given the thickness of tank, maximum allowable working pressure is computed as follows. [4]

$$Max. Allowable\ Pressure\ inside\ tank, P_{all} = \frac{S.E.t_c}{R_i + 0.6(t_c)} \tag{B.11}$$

Where, t_c is the corroded thickness. Thus,

$$t_c = t_{tank} - 0.001\ m = 0.00419\ m - 0.001\ m = 0.00319\ m \tag{B.12}$$

Considering safety factor of 2 and using Equation B.11, the maximum allowable pressure can be calculated as seen in Equation B.13.

$$S.F. = 2$$

$$P'_{all} = \frac{290(10^5)(1.0)(0.00319)}{0.128 + 0.6(0.00535)(S.F.)} = 0.352\ MPa \tag{B.13}$$

B.2. O-Rings around the piston

To ensure that the piston is sealed, the piston was designed to accommodate two O-rings and one wear ring. Using the O-rings and wear-rings sourced, calculations were performed to determine the groove size, piston size and tank diameter required while also considering the compression squeeze, stretch of O-rings and other factors such as extrusion gap. An example for standard O-rings of about 10” diameter was sourced from Hi-Tech Seals, distributor in Winnipeg. Dash 448 is the ISO 3061/AS-568 O-ring with nominal inner diameter of $9\frac{1}{2}''$ and cross-section (C/S) of ¼”. The dimensions are labelled in Figure B1.

[redacted]

Figure B1: O-Ring dimensions [5]

$$Actual\ Inner\ diameter, I.D._{448} = 9.475 \pm 0.055\ inches$$

$$Actual\ Cross - section, C/S_{448} = 0.275 \pm 0.006\ inches$$

Thus, the cross-section of O-ring is equal to 0.275". Figure B2 and TABLE BI show the dimension requirements for O-ring under reciprocating applications. The average values were used to design the size of piston and groove. The diameter of piston and groove can be calculated as 9.993in and 9.527 in separately. To obtain a tight fit between the O-ring and piston groove, the O-ring's inside diameter must stretch between 2% and 5% for dynamic applications. Hence, in the final design the stretch is assumed to be around 3% and the required piston's customized O-ring inner diameter is calculated to be 9.250". Thus, the customized piston O-ring has 9.25" inner diameter with ±0.055in tolerance and 0.275" cross-section with ±0.006" tolerance.

[redacted]

Figure B2: Piston groove dimensions [5]

TABLE BI: GROOVE DIMENSIONS FOR PISTON APPLICATIONS

O-Ring C/S	D Groove Depth	Compression Squeeze (%)	Compression Squeeze [inches]	E Diametrical Clearance [inches]	W Groove Width [+0.010/-0.000]	R Groove Radius [inches]
0.275	0.229-0.244	9-19	0.025-0.052	0-0.007	0.374	0.039
Average	0.2365	14	0.0385	0.0035	0.374	0.039

For piston applications, additional groove dimensions, shown in Figure B3, can be determined based on ISO 3601 and TABLE BII.

Figure B3: Additional groove dimensions [5]

TABLE BII: ADDITIONAL GROOVE DIMENSIONS FOR PISTON APPLICATIONS

O-Ring C/S [inches]	Wall Angle a	Break Edge B [inches]	Radius C [inches]	Chamber angle d	Chamber Length (e) [inches]
0.275	0^{0}	0.008	0.039	15^{0}	0.142

B.3. Wear-Rings around the piston

Wear rings, as shown in Figure B4, help keep the piston centered and allows for even wear and pressure distribution on the seals. WR 10000500 is the standard wear-ring size. This has a nominal outer diameter of 10.000”, width of 0.500” and cross-section of

0.125”. Following the instruction of Hercules 2017 seal catalog, the width of groove is equal to 0.515” and 0.11” depth of groove.

Figure B4: Wear ring model [5]

B.4. Piston Size

The piston model is shown in Figure B5. To consider the O-rings and wear rings, grooves on the piston have to be calculated and designed. This also dictates the piston width shown in Figure B6.

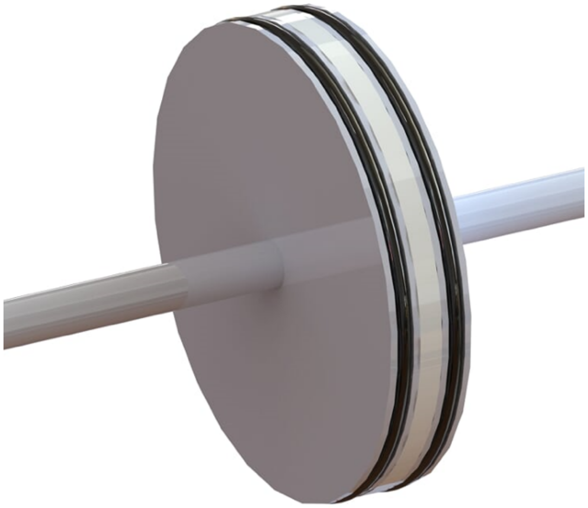


Figure B5: Piston model

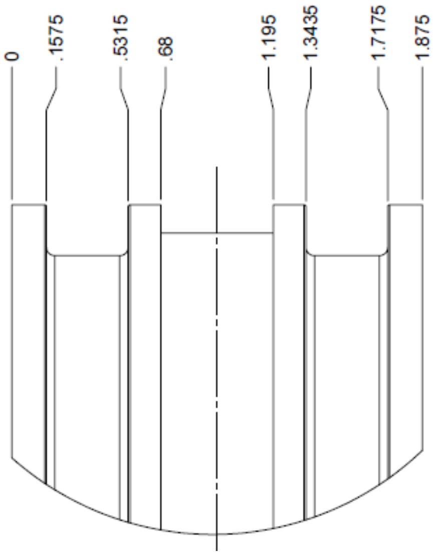


Figure B6: Piston groove dimensions

B.5. O-Rings at Rod Ends

The rod ends support the piston while the piston rod reciprocates back and forth while the calibration is performed. For this, O-rings are required to prevent the fluid from flowing out of the tank. An example is the ISO 3061/AS-568 O-ring with nominal inner diameter of 1"and cross-section (C/S) of 1/16".

$$Actual\ Inner\ diameter, I.D._{022} = 0.989 \pm 0.010\ inches$$

$$Actual\ Cross - section, C/S_{022} = 0.070 \pm 0.003\ inches$$

The diameter of the rod is 1" and the O-Ring must be stretched by 3% to ensure that it is secure within the piston. Thus, the inner diameter of the rod customized O-ring can be calculated as 0.966" with ± 0.008" tolerance and 0.07" cross-section with ±0.003" tolerance.

The rod diameter was selected to be one inch and hence the O-ring dimensions define the groove size in the tank lid. For reciprocating applications, according to ISO 3601, the groove dimensions, as shown in Figure B3, can be seen in TABLE BIII.

TABLE BIII: GROOVE DIMENSIONS FOR ROD APPLICATIONS

O-Ring C/S	D Groove Depth	Compression Squeeze (%)	Compression Squeeze [inches]	E Diametrical Clearance [inches]	W Groove Width [+0.010/-0.000]	R Groove Radius [inches]
0.070	0.056	20	0.014	0.004	0.110	0.012

For Rod applications, another groove dimensions, as shown in Figure B7, can be determined based on ISO 3601 as follows in TABLE BIV.

[redacted]

Figure B7: Groove dimensions for rod applications [5]

TABLE BIV: ADDITIONAL GROOVE DIMENSIONS FOR ROD APPLICATIONS

O-Ring C/S [inches]	Wall Angle a	Break Edge B [inches]	Radius C [inches]	Chamber angle d	Chamber Length (e) [inches]
0.275	0^0	0.008	0.039	15^0	0.142

B.6. Wipers at Rod Ends

To reduce any possible leakage from the rod, wipers are applied at the rod ends with equivalent ingression resistance to a sharp lip wiper. WD 1000 is a standard size wiper. With this, the groove size is defined in Figure B8 and TABLE BV.

Figure B8: Wiper groove dimensions [5]

TABLE BV: WIPER GROOVE DIMENSIONS

Part Number	(A) Rod diameter [inches]	(B) Groove Diameter [inches]	(C) Groove width [inches]	(D) Shoulder Diameter [inches]
WD 1000	1.000	1.372	0.187	1.245

B.7. Pressure Losses in the system

Pressure or head losses occur in the calibration system in a number of ways. This includes static head loss, friction losses in the piping system and the friction losses around the piston in the tank. Required calculations for different pressure or head losses is shown below.

B.7.1. Static head Loss

Static head losses are defined as the head or pressure losses due to the change in height. As the gravitational force is acting on the fluid, a required amount of force is needed to lift the fluid to a certain level which causes static head loss.

The total height of overall design defines the total static head loss. Hence,

$$Height\ of\ Cart = 31.09\ cm$$

$$Height\ of\ tank\ and\ piping = 53.20\ cm$$

$$Total\ height\ of\ the\ Calibration\ station = 84.29\ cm = 0.8429\ m$$

$$Static\ head\ loss, \Delta P_{static\ loss} = 0.8429\ m$$

Assuming ambient temperature and pressure, for water,

$$1\ m\ of\ Water = 9.792\ kPa\ of\ Static\ Pressure$$

$$Therefore, \qquad \Delta P_{static\ loss} = 8.2537\ kPa$$

B.7.2. Friction losses

Apart from the static head losses, friction plays an important role in causing pressure losses in the system. Friction is the force opposing the flow or motion and is dependent on the material roughness to which the flow is in contact with. Friction is present in all locations where there is contact between the fluid flow and the containing surface. Hence, friction losses are calculated considering various areas of the design such as friction losses in the piping system, around the piston, and around the shaft at the O-rings.

B.7.2.1. Friction loss around piston and rod

Friction is also experienced due to the sealing piston ring used to prevent fluid from flowing between sections of the pipe. However, the pump must also overcome the sliding friction caused by the piston ring. Both sealing O-rings and wear rings are made out of Teflon, which only has a 0.04 friction coefficient with steel. The friction force is small between piston and tank but the accurate friction force cannot be determined due to the manufacturing tolerance such as the magnitude of ellipticity or eccentricity of the tank and piston.

B.7.2.2. Friction losses in the pipe

The pipe has a certain roughness value which causes pressure losses when fluid comes in contact with the pipe inner surface. The longer the pipe and the larger the diameter results in a larger cross-sectional area which reduces the friction losses. Also, with increasing flow rates the friction losses also increase. The following calculations are performed based on the information taken from [1]. For the given length and size of the pipe, friction losses are computed as follows.

$$Total\ length\ of\ the\ pipe, L = 4ft = 1.2192\ m$$

$$Nominal\ diamter\ of\ the\ pipe, D_{nominal} = 1.5\ in = 0.0381m$$

$$Actual\ outer\ diameter, D_{outer} = 1.9\ in = \ 0.04826m$$

$$Actual\ inner\ diameter, D_{inner} = 1.61\ in = 0.040894m$$

$$Area\ of\ pipe\ crossection, A_{pipe} = \frac{\pi {D_{inner}}^2}{4} = \ 2.0358\ in^2 = 1.3128 * 10^{-3}\ m^2 \tag{B.14}$$

As flow rate increases, the friction loss increases. Hence, the following calculations considers maximum flow rate to calculate the maximum friction loss in the system.

$$Maximum\ flow\ rate, \dot{Q}_{max} = 60\ gpm = 0.0037854 \frac{m^3}{s}$$

$$Maximum\ Velocity\ of\ flow, v_{max} = \frac{\dot{Q}_{max}}{A_{pipe}} = \frac{0.0037854}{0.0013128} \quad \text{(B.15)}$$

$$= 2.8794\ m/s$$

Ambient temperature and pressure are assumed for the sample calculations purposes.

$$Temperature, T = 20^o\ C = 293.15\ K$$

$$Density\ of\ water\ at\ ambient\ temperature\ and\ pressure, \rho_{water} = 998.0\ \frac{Kg}{m^3}\ [5]$$

$$Kinematic\ viscosity, \vartheta_{water} = 0.0000010023 \frac{m^2}{s}\ [5]$$

Using the information from [1], Reynold's number can be calculated from Equation B.16.

$$Reynolds\ Number, Re = v_{max}. \frac{D_{inner}}{\vartheta_{water}} = 2.8794 * \frac{0.040894}{0.0000010023} \quad \text{(B.16)}$$

$$= 117480.2387$$

$$When\ the\ Reynolds\ Number\ is\ bigger\ than\ 4000, the\ Flow\ is\ Turbulent$$

Since the material for the pipe used is Polypropylene, the roughness value for the pipe material is as follows.

$$Roughness\ value, \in = 1.5 * 10^6\ m$$

The roughness factor k can be determined though the diameter of pipe and roughness value.

$$k = \frac{\in}{D_{inner}} = \frac{1.5 * 10^{6}}{0.040894} = 3.668 * 10^{-5} \tag{B.17}$$

The Friction Coefficient, f, is defined by the roughness of the pipe surface, diameter of pipe, and Reynolds number. There are number of theories and formulas to calculate friction factor. Some these theories are useful for range of Reynold number and other are valid for all kinds of flow. The equation used in these calculations to calculate friction coefficient is an approximation of Colebrook-White Relation. The Colebrook-White Relation equation is as follows.

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\in}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right) \tag{B.18}$$

Where, D_h is the inside diameter of the pipe.

The resulting friction factor is equal to 0.0217 for Poly-propylene schedule 40, 1.61 in actual diameter and 2.882214 m/s flow velocity.

After the determining friction factor, the value of f is equal to 0.01778. The results from this approximation complies with the Moody plot and hence are assumed to be the correct friction factor results. The friction factor for our design for maximum flow is calculated as follows. [1]

$$Loss\ Coefficient, K = \frac{fL}{D} = \frac{0.01778 * 1.2192}{0.040894} = 0.53009 \tag{B.19}$$

Friction head Loss is calculated using Darcy-Weisbach equation which is defined as follows.

$$H_{F,pipe} = K_{pipe}.\frac{v^{2}}{2g} \tag{B.20a}$$

Where, $H_{F,pipe}$ is the friction head loss for the pipe and g is the acceleration due to gravity and assumed to be 9.81 m/s2. Hence, the friction head loss due to pipe for the maximum flow rate is as follows.

$$H_{F,pipe,max} = K_{pipe}.\frac{v_{max}^2}{2g} = 0.53009 * \frac{2.8794^2}{2 * 9.81} = 0.224\, m \tag{B.20b}$$

$$or\ H_{F,pipe,max} = 2.1934\, kPa \tag{B.20c}$$

B.7.2.3. Friction loss in the fittings and valves

Components, such as fitting and valves, each affect the flow differently. The diversion and obstruction of flow in these fitting and valves cause pressure losses due to friction. The friction losses are computed as follows.

$$No. of\ valves, n_{valves} = 6$$

$K_{valve} =$ 0.06 [7]

$$K_{valves} = n_{valves}.K_{valve} \tag{B.21}$$

$$K_{valves} = 0.36$$

$$No. of\ T - fittings, n_T = 2$$

$K_{T-fitting} = 1.26$ [7]

$$K_{T-fittings} = n_T.K_{T-fitting} \tag{B.22}$$

$$K_{T-fittings} = 2.52$$

$$No.\,of\ elbows, n_{elbows} = 2$$

$K_{elbow} = 0.63$ [7]

$$K_{elbows} = n_{elbows}.\,K_{elbow} \qquad \text{(B.23)}$$

$$K_{elbows} = 1.26$$

The total friction losses due to fittings can be calculated by summing the frictional losses from each fitting.

$$K_{fittings} = K_{valves} + K_{T-fittings} + K_{elbows} \qquad \text{(B.24)}$$

$$K_{fittings} = 4.14$$

Hence, the friction head loss due to fittings for the maximum flow rate is as follows. [1]

$$H_{F,fittings,max} = K_{fittings}.\,\frac{v_{max}^2}{2g} = 4.14 * \frac{2.8794^2}{2 * 9.81} = 1.7495\ m \qquad \text{(B.25)}$$

$$or\ H_{F,fittings,max} = 17.131\ kPa$$

B.7.2.4. Total Friction Loss

The total friction loss is the sum of the friction losses due to the pipe, fittings, and piston seal. [1]

$$Total\ maximum\ friction\ loss, H_F = H_{F,fittings,max} + H_{F,pipe,max} \qquad \text{(B.26a)}$$

$$H_F = 1.7495 + 0.224 = 1.9735\ m\ or\ 19.3245\ kPa \qquad \text{(B.26b)}$$

B.7.2.5. System curve.

The following curve, shown in Figure B9, represents the head loss in the calibration station with increase in the flow rate. The pump must be able to perform at the required flow rate given these pressure losses at different flow rates.

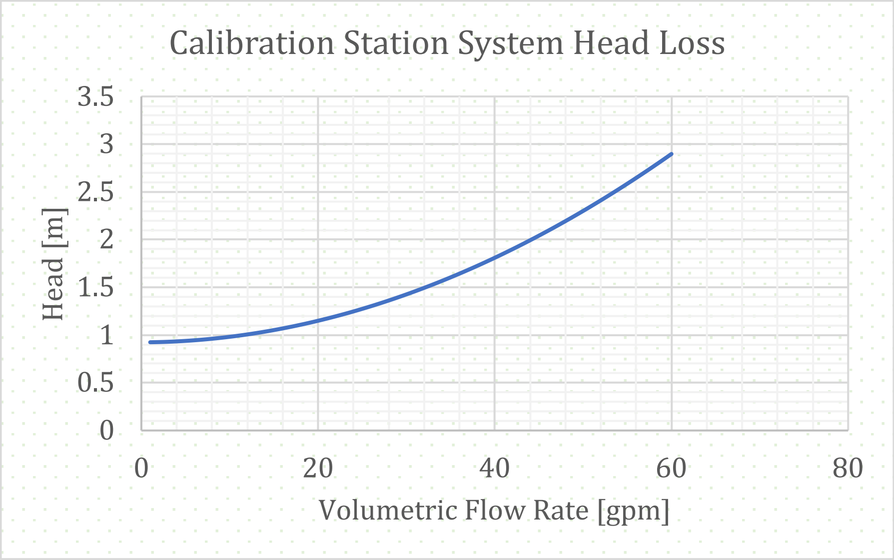


Figure B9: Calibration station system curve

B.8. Required pump capacity

The pump must be able to provide the required flow rate to overcome all the pressure losses such as static head loss and friction losses. For the calculation purposes, the pressure losses in the piping system and test rigs at Price Industries are not considered. In order to compute the total pump capacity, pressure losses in the calibration system can be considered. The following calculations accounts for the required pump capacity to operate the calibration station only. [1]

$$Total\ pressure\ losses\ in\ the\ design, \Delta P_{losses} = \Delta P_{static\ loss} + H_F \qquad \text{(B.27a)}$$

$$\Delta P_{losses} = 0.8429 + \ 1.9735 = 2.8164\ m \qquad \text{(B.27b)}$$

$$Required\ Pump\ Head, H = 2.8164\ m$$

$$Required\ Pump\ Power, P = \frac{\dot{Q}.H.g.\rho}{\eta} \tag{B.28a}$$

Where, η is the pump efficiency. Assuming the pump has 50% pump efficiency,

$$P = \frac{0.0037854 * 2.8164 * 9.81 * 998.2}{0.5} = 208.796\ W$$
$$= 0.2088\ kW \tag{B.28b}$$

Because the pump is not in the scope of project, the assumption of pump efficiency is made to be 50%. This is to ensure there is a safety factor in the calculations. From this calculation, the pump at Price Industries can withstand the calibration station. The lowest pump power in the test room is 0.5 kW.

B.9. Required Position Sensor Specifications

The position sensor is one of the most crucial parts of the design; the size of the tank and sensor specifications are interdependent. The position sensor must be able to measure the position of the piston and hence will have some limiting factors such as velocity of the piston, resolution, range of measurements and accuracy. Hence, the following calculations consider these factors to specify the required sensor.

$$v_{max} = 2.8794\ m/s$$

$$Number\ of\ measurements\ for\ one\ cycle, N = 2$$

$$Range\ of\ measurements = up\ to\ 40\ cm$$

The sensor must also be able to measure up to 50 cm. Also, the sensor should be able to operate against piston moving with maximum velocity of 2.8794 m/s.

Selected sensor:

$$Range\ of\ measurements = 20\ mm\ to\ 420\ mm$$

$$Resolution = 0.0127\ \mathrm{mm}$$

$$Inaccuracy = 0.05\%$$

Hence, the selected sensor has resolution of 0.0127 mm and maximum of inaccuracy of 0.05%.

B.10. Tank Size

The tank size is dependent on the sensor specifications, number of measurements need to be taken in a cycle, stabilization time and flow turbulence. The calculations to determine the possible dimensions of tank are as follows.

$$Calibration\ distance, C = 400\ mm$$

$$\text{Thickness of Piston}, T_{piston} = 47.3202\ mm$$

$$\text{Outer Diameter of Pipe}, OD_{pipe} = 48.26\ \mathrm{mm}$$

$$Minimum\ Length\ of\ Tank, L = C + T_{piston} + 4 * OD_{pipe} = 640.3602\ mm \tag{B.29}$$

$$Diameter\ of\ Tank, D = 254\ mm$$

Selected Tank Specifications:

$$L = 738.658\ mm$$

$$D = 254\text{ mm}$$

$$Thickness = 6.35\ mm$$

B.11. Density Variations

The change in temperature and pressure of fluid may cause change in the density or specific volume of the fluid. The following computation analysis justifies that there is not much change in the density of the water with change in pressure for given temperature. The equation also demonstrates how the density changes with change in the pressure and temperature.

At ambient temperature, $T_{ambient} = 20^0C,$

$$for\ Pressure = 2.339\ kPa$$

$$Density\ of\ water = \frac{1}{0.001002}\frac{Kg}{m^3} = 998.0\frac{Kg}{m^3}\ [5]$$

$$for\ Pressure = 500\ kPa$$

$$Density\ of\ water = \frac{1}{0.001002}\frac{Kg}{m^3} = 998.0\frac{Kg}{m^3}\ [5]$$

With change in pressure for a given ambient temperature, the density of water changes very little. If there is a change in temperature for a given pressure change, density values are as follows in TABLE BVI. [5]

TABLE BVI: DENSITY VARIATIONS

Stage	Temperature [°C]	Pressure [kPa]	Density $[\frac{Kg}{m^3}]$
1	0.01	0.6113	1000
2	20	2.339	998

3	40	500	992.06

$$\%Difference\ between\ Stage\ 1\ and\ 2 = \frac{1000 - 998}{1000}.100\% \quad \text{(B.30a)}$$
$$= 0.2\%$$

$$\%Difference\ between\ Stage\ 2\ and\ 3 = \frac{998 - 992.06}{998}.100\% \quad \text{(B.30b)}$$
$$= 0.596\ \%$$

$$\%Difference\ between\ Stage\ 1\ and\ 3 = \frac{1000 - 992.06}{1000}.100\% \quad \text{(B.30c)}$$
$$= 0.794\%$$

Therefore, with increase of 40 °C and 500 kPa, the change in density is only 0.794%. Thought, there are very low changes of those changes in temperature and pressure.

B.12. Volumetric flow rate

Our team designed a calibration system which measures the volumetric flow by measuring position of the piston at measured time. Hence, following calculations show the computation of the volumetric flow rate from the measure position of the piston and time.

$$Position\ 1 = P_1$$
$$Position\ 2 = P_2$$

$$Displacement, d = P_2 - P_1 = 400\ mm \quad \text{(B.31)}$$

$$Time\ taken\ between\ 1\ and\ 2 = T$$
$$Velocity\ of\ Piston, V_{piston} = \frac{d}{T} \quad \text{(B.32)}$$

$$Area\ of\ crosssection\ of\ Piston, A_{piston} = \frac{\pi {D^2}_{piston}}{4} = 0.05067\ m^2 \quad (B.33)$$

$$Volumetric\ flow\ rate, \dot{Q} = A_{piston}.V_{piston} \quad (B.34a)$$

B.13. Mass Flow rate

The calibration station must be able to calibrate volumetric flow meters and mass flow meters such as a Coriolis flow meter installed in various test rigs at Price Industries. Since the calibration station is volume-time based, the mass flow area needs to be computed by considering the density of the fluid around the piston at the time of calibration. Required calculations to compute mass flow rate are shown below.

$$Mass\ flow\ rate, \dot{m} = \rho.\dot{Q} = 998.0 * \ \dot{Q} \quad (B.35)$$

B.14. Accuracy of the design

One objective of the project is to design a calibration station to calibrate the flow meters with maximum inaccuracy of 1%. Hence, the accuracy of the design is an important factor to consider and ensure that the design does not have inaccuracy of more than 1%. This section demonstrates the calculations of the accuracy of the design.

B.14.1. Accuracy of Position Sensor

The position sensor is the most important sensor since it measures the position of the piston and calculates the volumetric flow rate.

$$Inaccuracy\ of\ Position\ sensor, \alpha_{pos} = 0.05\%$$

B.14.2. Accuracy of temperature sensor and its impact

The temperature change may cause a change in density of fluid which, if not taken in account, may result in incorrect calculations of the mass flow rate. Hence, the inaccuracy in temperature sensor needs to be considered while computing total inaccuracy of the calibration station.

$$Inaccuracy\ of\ temperature\ sensor, \alpha_{temp} = 0.5℃$$

0.5 °C can change the density by 0.02%.

B.14.3. Accuracy of pressure sensors

The pressure sensors measure the pressure which, similarly, effects the density of the fluid and hence the inaccuracy of pressure sensor, also, is part of the total inaccuracy of the design.

$$Inaccuracy\ of\ Pressure\ sensor, \alpha_{press} = 0.5\%$$

Setting 101.3 kPa as standard pressure, 0.5% inaccuracy can cause 0.007% of density changing.

B.14.4. Total System Inaccuracy

As discussed, the total inaccuracy of the calibrations station in calibrating flow meters is the sum of the inaccuracies of all the sensors in the system and the inaccuracy cause by the change in mass flow rate observed in the CFD study. Therefore, the total inaccuracy of the calibration station us computed as follows.

$$Total\ Inaccuracy, \alpha = \alpha_{pos} + \alpha_{temp} + \alpha_{press} + \alpha_{CFD} \tag{B.36a}$$

$$\alpha = 0.05 + 0.02 + 0.007 + 0.03885 = 0.11585\% \qquad \text{(B.36b)}$$

B.15. Overall Size and Weight

Some of constraints on the design are that the overall size of the calibration station must be with 94” X 91” and the weight of the station must not exceed 500lbs. This section justifies that the calibration station is within constraints via following calculations.

B.15.1. Overall Size

$$\text{Distance between two end of sensor}, L_s = 1582.28\, mm$$

$$Diamter\ of\ tank, D_{tank} = 266.7\ mm$$

$$Length\ of\ cart, L_{cart} = 624.359\ mm$$

$$Width\ of\ Cart, W_{cart} = 660.4\ mm$$

$$Height\ of\ Cart, H_{cart} = 282.0178\ mm$$

$$Height\ of\ piping\ above, H_{pipe} = 167.962\ mm$$

$$Overall\ height\ of\ design:$$

$$H_{design} = H_{cart} + H_{pipe} + D_{tank} = 716.680\ mm \qquad \text{(B.37)}$$

$$Overall\ length\ of\ design, L_{design} = L_s = 1582.28\ mm$$

$$Overall\ width\ of\ design, W_{design} = W_{cart} = 660.4\ mm$$

B.15.2. Overall Weight

Weight of calibration system and cart: $W_{cc} = 309\ lbs$

Weight of water: $W_w = 80\ lbs$

Total Weight: $\mathrm{W} = W_{cc} + W_w = 389\ lbs$

(B.38)

The total weight of calibration system is 389 lbs. This meets the design needs of the max weight being 500 lbs. Thus, the weight of design satisfies the criteria of weight.

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Appendix C: Material/Vendor Selection

This Appendix details the material and vendor selection for each component of the overall design. This includes the decision matrices for each component's material and vendor selection. In this section includes the selection process for the sensors, the piping, the actuating valves, and the tank design.

List of Tables

C1: Sensors Selection

For the type of sensors, a list was generated of possible choices that may potentially work with the final design. The types of sensors considered were ultrasound, infrared, linear variable displacement transducer, hall effect and a rotary potentiometer. These are all scored against each other on a decision matrix seen in Table C1 with accuracy, size, range, cost and ease of implementation as the metrics.

The first step the team proceeded with in sensor selection as to define the criteria for choosing a type of sensor. The initial criteria that the sensor must have are defined by our project needs. The project needs that apply to sensor selection is that the full-scale system must not have a lower accuracy than 1%. Therefore, the sensor may have an accuracy to 1% at the most, though it is more beneficial to have a high accuracy to account for the inaccuracies of the other parts of the system. Other factors for sensor selection are that the sensor must fit inside the current tank and must be able to measure the full length of the piston movement. Though, the smaller the sensor and the larger the range, the better. The team also considered two other metrics that are defined by the project goals which is to minimize the cost of the system and the complexity of the system. The metrics that represents this is the cost and the ease of manufacture. All the metrics for the selection process can be seen in TABLE CI. These metrics were then weighted against each other to define the weight for them. These metrics and weights are the added to the weighted decision matrix to select a type of sensor. The weighted decision matrix be seen in TABLE CII.**Error! Reference source not found.**

TABLE CI: SENSOR CRITERIA WEIGHTING

		Accuracy	Size	Range	Ease of Manufacturing	Cost	
Criteria	ID	A	B	C	D	E	Score
Accuracy	A		A	A	A	A	4
Size	B			C	D	B	1
Range	C				D	E	1
Ease of Manufacturability	D					D	3
Cost	E						1

The application of the types of sensor considered with the system is described as follows.

Linear variable differential transducer

This transducer functions by sensing the change in movement of its core using out of phase coils and the induced voltage in them. The disadvantage to this is that the core has to be mechanically linked to the moving object. Because of this, the length of the core has to be at least the movable distance of the piston, which is 40 cm.

Ultrasonic Sensor

This ultrasonic sensor functions by measuring the time it takes to send and receive ultrasonic waves from an object. The disadvantage to this sensor is that any solid object will affect the results of the measurement. Though, from the three sensors, this is the most accurate.

Infrared Sensor

This sensor functions by sending infrared waves and receiving the waves back and calculating the time between the displacements. This sensor can work through clear parts since it takes a solid object to reflect the wave back.

Hall effect sensor

For this type of system, there will be magnets attached to the piston rod and the hall effect sensor mounted on a stable part of the tank, such as the rod support. When the piston moves, the hall effect clocks when it senses a magnet. The distances between the magnets is known and so the velocity of the piston can be calculated with the times the sensor clocked it at.

Rotary potentiometer

In this system, the rotary potentiometer functions with a rack and pinion design. A rotary potentiometer measures the angle displacement. It does this through a mechanical connection between the rotary object and the shaft located on the potentiometer. For the rack and pinion system, the accuracy will depend on the size of the pinion as well as the rotary potentiometer itself. The disadvantage to this sensor is the complexity it adds to the system. The rod of the piston must have 40 cm a rack attached to it and the pinion must be relatively large for high accuracy.

TABLE CII: SENSOR WEIGHTED DECISION MATRIX

Metric	Weight	Ultrasonic		Infrared		LVDT		Hall Effect		Rotary position transmitter	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Accuracy	0.4	5	2	3	1.2	4	1.6	2	0.8	5	2
Size	0.1	4	0.4	4	0.4	2	0.2	4	0.4	2	0.2
Range	0.1	4	0.4	4	0.4	2	0.2	5	0.5	5	0.5
Cost	0.3	3	0.9	3	0.9	3	0.9	5	1.5	3	0.9
Ease of Manufacturing	0.1	4	0.4	4	0.4	2	0.2	3	0.3	2	0.2
Total	1		4.1		3.3		3.1		3.5		3.8

From the weighted decision matrix, the type of sensor with the highest score is the ultrasonic sensor. With this, the team decided to move forward and select an ultrasonic sensor for measuring the movement of the piston.

C2: Piping Selection

To select a proper piping material, the first step was to create a list of criteria that each piping material would be selected upon. The criterion that the design team chose was the friction each material would contain, the cost of the material, the availability of the material, how compatible the material would be to the overall design, the weight of the material, and finally, the overall strength of the material. The criteria weighting can be seen in TABLE CIII.

TABLE CIII: PIPING CRITERIA WEIGHTING

		Friction	Cost	Availability	Compatibility	Weight	Strength	
Criteria	ID	A	B	C	D	E	F	Score
Friction	A		A	A	A	A	F	4
Cost	B			B	B	B	B	4
Availability	C				D	C	C	2
Compatibility	D					D	D	3
Weight	E						E	1
Strength	F							1

From this criteria weighting, a given weight can be given to each criterion. From TABLE CIV, the weights of each criterion can be found as well as the scoring for each piping material.

TABLE CIV: PIPING MATERIAL SCORING

		Copper		Steel		PVC		PP	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Friction	26.67%	1	0.2667	2	0.5334	3	0.8001	3	0.8001
Cost	26.67%	1	0.2667	2	0.5334	3	0.8001	3	0.8001
Availability	13.33%	1	0.1333	1	0.1333	3	0.3999	3	0.3999
Compatibility	20%	3	0.6	2	0.4	2	0.4	2	0.4
Weight	6.67%	1	0.0667	2	0.1333	3	0.2001	3	0.2001
Strength	6.67%	2	0.1334	3	0.2001	1	0.0667	1	0.0667
Total	100%	1.4668		1.9335		2.6669		2.6669	

From this decision matrix, it can be seen that the two highest scoring piping materials are PVC and PP.

During the researching phase of the piping material selection, it was discovered that both PVC and PP were readily available. A concern was that the piping and the valve must be easily fitted to one another. As the valve selected was made of brass, an adapter was required to connect the plastic piping material to the brass fitting. Such an adapter was difficult to source for PVC but a local distributor was found for PP. All the piping requirements for the overall design can be seen in TABLE CV.

TABLE CV: SOURCED PIPING MATERIAL

Item #	Material Description	Qty.	Price/Qty	Total Cost
1	1 1/2" PP Piping	5 Ft	$7.13/ft	$142.50
2	1 1/2" Socket Fusion PP Tee	2	$8.70	$17.40
3	1 1/2" Socket Fusion 90° Elbow	6	$14.44	$86.63
4	1 1/2" NPT Male Threaded Socket Fusion Brass Adapter	12	$48.75	$585.00
5	1 ½" to ½" NPT Male Threaded Fusion Socket Brass Adapter	1	$11.25	$11.25

C3: Valve Selection

To select an appropriate valve for the overall design, the design team listed the required criteria for sourcing the part. There were very few criteria that the team deemed necessary for the selection. The criteria are being that the valve must be able to turn completely on or off through a microcontroller and that the valve was to be as low in cost as possible. There were many potential sources for such a valve and the design team chose the cheapest option which was found to be a 1 ½" Motorized Ball Valve from Deelat Industrial Products.

C4: Tank Material Selection

When selecting a material for the tank, there were many criterions that the design team felt must be met. This list of criterion includes, the friction the tank would have with the piston, the cost of the material, the availability of the material, the manufacturability of the material, the weight of the material, and lastly, the strength of the material. The criteria weighting for the tank material can be seen TABLE CVI.

TABLE CVI: TANK CRITERIA WEIGHTING

		Friction	Cost	Availability	Manufacturability	Weight	Strength	
Criteria	ID	A	B	C	D	E	F	Score
Friction	A		B	C	D	E	F	0
Cost	B			B	D	B	B	4
Availability	C				D	E	C	2
Manufacturability	D					D	D	5
Weight	E						E	3
Strength	F							1

From this criteria weighting, each criterion was given a weight. The weights of each criterion along with the scoring for each tank material can be seen in TABLE CVII.

TABLE CVII: TANK WEIGHTED DECISION MATRIX

		Copper		Stainless Steel		PVC		Aluminum	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Cost	26.67 %	1	0.2667	2	0.5334	3	0.8001	2	0.5334
Availability	13.33 %	1	0.1333	2	0.2667	2	0.2667	3	0.3999
Manufacturability	33.33 %	2	0.6666	3	0.9999	1	0.3333	1	0.3333
Weight	20%	1	0.2	1	0.2	3	0.6	2	0.4
Strength	6.67%	2	0.1334	3	0.2001	1	0.0667	1	0.0667
Total	100%	1.4		2.2001		2.0665		1.733	

As seen from TABLE CVII, the top scored tank material was stainless steel. Thus, the design team proceeded to source potential manufacturers of a custom cylindrical steel tank.

Appendix D: Bill of Materials and Quotes

This Appendix details the bill of materials of the overall design along with all the quotes received by the design team. The bill of materials includes the quantity of each material, the vendor used for the material, the cost per unit, and the total cost of the material. The overall bill of materials can be seen in TABLE D1.

TABLE D1: OVERALL BILL OF MATERIALS

Piping Material						
Item #	Material Description	Vendor	Part #	Qty.	Price/Qty	Total Cost
1	1 ½” PP Piping	Niron	27TNIRCL5073	20 ft	$7.13/ft	$142.50
2	1 1/2” Socket Fusion PP Tee	Niron	27NG50	2	$7.13	$17.40
3	1 1/2” Socket Fusion 90° Elbow	Niron	27NT50	6	$14.44	$86.63
4	1 ½” NPT Male Threaded Socket Fusion Brass Adapter	Niron	27NRFM1140114NPT	12	$48.75	$585.00
5	1 ½” to ½” NPT Male Threaded Fusion Socklet Brass Adapter	Niron	27NGSF124050NPTL	1	$11.25	$11.25
6	1/8” Bleed Valves	Acklands Grainger	WWG14F304	1	$30.43	$30.43
7	Brass Adaptor 1/2” to 3/8”	Acklands Grainger	FAR120DC	1	$4.24	$4.24
8	Brass Adaptor 3/8” to 1/8”	Acklands Grainger	FAR120CA	1	$3.44	$3.44
9	1 ½” Male NPT Stainless Steel Bushing Adapter	McMaster Carr	4464K158	2	$18.69	$37.38

10	1 ½” Female NPT Stainless Steel Bushing Adapter	McMaster Carr	4464K175	4	$28.50	$114.00
					Overall Cost	$1032.27
Valves						
Item #	Material Description			Qty.	Price/Qty	Total Cost
1	1 ½” Motorized Ball Valve	Deelat	D1774304	6	$181.15	$1086.89
					Overall Cost	$1086.89
Fabrication						
Item #	Material Description	Vendor	Part #	Qty.	Price/Qty	Total Cost
1	Tank Fabrication*	Unified Alloys	N/A	1	$1339	$1339
2	Piston Fabrication	Wallin	N/A	1	$2000	$2000
3	Cart Fabrication	Wallin	N/A	1	$1500	$1500
					Overall Cost	$4839
Electrical						
Item #	Material Description	Vendor	Part #	Qty.	Price/Qty	Total Cost
1	Arduino Microcontroller	DFRobot	DFR0220	1	$56.00	$56.00
2	Ultrasonic Sensor	Migatron Corp	RPS-412A	2	$2090.00	$4180.00
3	Pressure Sensor	DF Robot	SEN0257	2	$8.90	$17.80
4	Temperature Sensor	SparkFun	DS18B20	2	$11.95	$23.90
					Overall Cost	$4277.70

Miscellaneous						
Item #	Material Description	Vendor	Part #	Qty.	Price/Qty	Total Cost
1	½”-20 Hex Bolt	McMaster Carr	92620A746	3	$7.80/Pkg	$23.70
2	½”-20 Hex Nut	McMaster Carr	95462A525	1	$16.67/Pkg	$16.67
3	Rubber Wheels	McMaster Carr	4941T140	4	$50.33	$201.32
4	Sealing Gasket	Hi-Tech Seals	N/A	2	$61.00	$122.00
5	O-Rings (Piston)	Hi-Tech Seals	N/A	2	$8.16	$16.32
6	O-Rings (Rod)	Hi-Tech Seals	N/A	2	$60.00	$120.00
7	Wear Rings (Piston)	Hi-Tech Seals	WR10000500BRZ	1	$48.00	$48.00
8	Wear Rings (Rod)	Hi-Tech Seals	WR1125500BRZ	2	$6.00	$12.00
9	Wiper	Hi-Tech Seals	WD1000	2	$4.00	$8.00
					Overall Cost	$565.01
					TOTAL	$11800.76

The cost of the tank and cart are an estimated cost calculated by the design team based off the cost of material and manufacturing costs. After speaking with local machine and welding shops, the average manufacturing cost per hour is $95/hr. This cost was used to calculate the overall cost of manufacturing and can be seen below.

$$Tank\ Cost = Material\ Cost + Manufacturing\ Hours * Manfacturing\ Cost$$

$$Tank\ Cost = \$389 + 10\ hrs * \frac{\$95}{hr} = \$1339$$

All of the formal quotes that was received for the primary calibration system can be seen in the following pages.

DEELAT
INDUSTRIAL PRODUCTS

ADDRESS
Suite 908, 906 12th Avenue SW
Calgary, AB, Canada
T2R1K7

CONTACT INFO
Email: sales@deelat.ca
Direct Line: 1 (888) 667-5776
Fax: 1 (403) 454-9338

Order Reference	2101328

INVOICE

#IN2101328

Order Date	11/19/2019 10:48:45

Please confirm your order details below

SKU#	PRODUCT / REFERENCE	UNIT PRICE (TAX EXCL.)	QTY	TOTAL (TAX EXCL.)
D1774304	Motorized Ball Valve (Electric) - 2-Way AC - 1 1/2", 3.5N.m, 110 V - On/Off	$158.99	6	$953.94

BILLING ADDRESS:

Andrew Saygnava
University of Manitoba Faculty of Engineering
75 Chancellor Circle, E2 -290
Engineering & Information Technology Complex
University of Manitoba
Winnipeg, Manitoba
Canada R3T 5V6

Phone: 204-451-3733
Saygnava@myumanitoba.ca

SHIPPING ADDRESS:

Andrew Saygnava
University of Manitoba Faculty of Engineering
75 Chancellor Circle, E2 -290
Engineering & Information Technology Complex
University of Manitoba
Winnipeg, Manitoba
Canada R3T 5V6

Sub Total:	$953.94
Shipping Cost:	$26.99
Volume Discount	-$19.08
GST/PST 13% (MB):	$125.04
Total Due:	**$1,086.89**

Unpaid Click here to pay invoice

VISA MasterCard AMERICAN EXPRESS DISCOVER NETWORK PayPal BANK WIRE

You will receive $16.30 Deelat Dollars (store credit) once payment is made.

Please send us a bank wire with the following information:

Amount:
$1,086.89

Name of account owner:
Boon Trading Canada (2018) Ltd.

Bank Address:
347 - 58th Avenue SE, Calgary AB, T2H 0P3 CANADA;

Include these details:

Bank Name: HSBC Bank Canada
Swift Code: HKBCCATT
Institution: 016
Transit: 10880
Account Number: 174846-002

DO NOT FORGET TO INSERT YOUR ORDER REFERENCE 2101328 IN THE SUBJECT OF YOUR BANK WIRE.

If your payment method is cheque, please send all cheques to:

Suite 908, 906 12th Avenue SW
Calgary, AB, Canada T2R1K7

Terms: Payment should be made within 30 days by cheque or bank wire transfer. We will ship as soon as your payment is confirmed.

www.deelat.com

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NIRON CLIMA QUOTE

WD Industrial Group
1036 Waverley Street
Winnipeg, MB R3T 0P3
Phone: 204-896-1333

DATE	**02/122019**
QUOTE #	
JOB #	
PROJECT #	
PROJECT NAME	

CUSTOMER

COMPANY

TERMS AND CONDITIONS

- The parts and corresponding quantities quoted are offered to the customer for information only. It is the responsibility of the contractor to select the correct type and quanitity of Niron parts. WD Industrial Group is not reponsible for the accuracy of the quoted items
- Pirce quoted is specific to this project only. Future prices might vary
- Net price quoted. Does not include applicable taxes and/or shipping

NOTES

NIRON CLIMA QUOTE

WD Industrial Group
1036 Waverley Street
Winnipeg, MB R3T 0P3
Phone: 204-896-1333
Fax: 204-896-6969

Notes:
- Piping System

LINE	PART NO.	DESCRIPTION	NOTES	Q.TY	U.M.	PRICED RESERVED TO YOU	TOTAL NET PRICE
1	27TNIRCL5073	1½" SDR 7,3 Niron Clima PP-RCT Fiber Glass Pipe Multilayer 20 FT		20	FT	$ 7.13	$ 142.50
2	27NG50	1½" 90° Elbow - Socket Fusion		2	PCS	$ 8.70	$ 17.40
3	27NT50	1½" Tee - Socket Fusion		6	PCS	$ 14.44	$ 86.63
4	27NRFM1140114NPT	1¼" x 1¼" Male Threaded Adapter w/NPT & Lead Free Brass - Butt		12	PCS	$ 48.75	$ 585.00
5	27NGSF124050NPTL	½" x 1¼"-1½" Female Threaded Welding Saddles w/NPT & Lead		1	PCS	$ 11.25	$ 11.25
		-			-	-	-
		-			-	-	-
		-			-	-	-
		-			-	-	$ 842.78
		-			-	-	-
		-			-	-	-
		-			-	-	-

UNIFIEDALLOYS®
Unified Alloys (British Columbia), a general partnership
26835 Gloucester Way Langley BC Canada V4W 3Y3
t. 604.607.6750 f. 604.607.6751 e. bc@unifiedalloys.com
www.unifiedalloys.com

SALES QUOTATION

CUSTOMER REFERENCE	PAGE	DATE	
	1	12/02/2019	VQ-267392

QUOTATION TO
BRYCE INDUSTRIES
CASH SALES

ATTN: KAMAL
PH#: 250.287.3542
FAX:

ITEM	PRODUCT CODE	DESCRIPTION	QUANTITY	UOM	UNIT PRICE	EXTENDED AMOUNT
		WELDED STAINLESS STEEL PIPE, ANNEALED & PICKLED TO ASTM A312				
1	10S10304LWP	10" SCH 10S A/SA312-TP304/L (10.75"OD X .165W)	4.00	FT	39.75	$159.00
2	CUT	CUTTING CHARGE			30.00	$30.00

THANK YOU FOR THE INQUIRY

FCA (INCOTERMS 2010): UNIFIED ALLOYS (LGY) WAREHOUSE
DEL: 1 DAY
PRICE VALID FOR 10 DAYS
TAXES EXTRA (HST, GST, PST)
PAYMENT NET 30 DAYS AFTER INVOICE DATE
ALL PRODUCTS LISTED ARE SUBJECT TO PRIOR SALE
ALL PARTIAL ORDER AWARDS SUBJECT TO REVIEW FOR ACCEPTANCE
ALL ORDERS SUBJECT TO UNIFIED ALLOYS (BC) STANDARD TERMS & CONDITIONS.
A COPY IS AVAILABLE UPON REQUEST OR ONLINE AT www.unifiedalloys.com/TC-En.pdf

BEST REGARDS,
BLAKE BLESSE

.00

TOTAL ⇨ $189.00

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Appendix E: CFD Simulation Results

This Appendix details the Computational Fluid Dynamic (CFD) study for the design of the primary test calibration system. This CFD study was conducted to solve for the fluid velocity and pressure at the inlet and outlets of the tank. Additionally, this CFD study was conducted to ensure that the pressures at the inlet and outlet remined equal through the calibration process.

To begin this CFD study, the volumetric fluid flow rate was set to the maximum flow rate, given by the project requirements, of 60 Gal/min. For this CFD study, a few adjustments were made to simplify the study. These adjustments were that the stops and the lid of the tank were taken out such that only the tank and piston were considered in the study. Another adjustment made was that the piston was restricted to only move 40cm which is what the design already indicated.

Figure E1 illustrates the initial movement of fluid entering the tank. At this moment, the velocity at the inlet and outlet are similar in value. As the study continues forward with time, it can be observed that the velocity remains constant at the inlet and outlet. Figure E2 and Figure E3 show the progression of the calibration process by moving the piston. These figures also confirm that the velocity at the inlet and outlet are equal. The average velocity at the inlet and outlet is 2.8790 m/s and 2.8801 m/s respectively. This is a percent difference of 0.038%

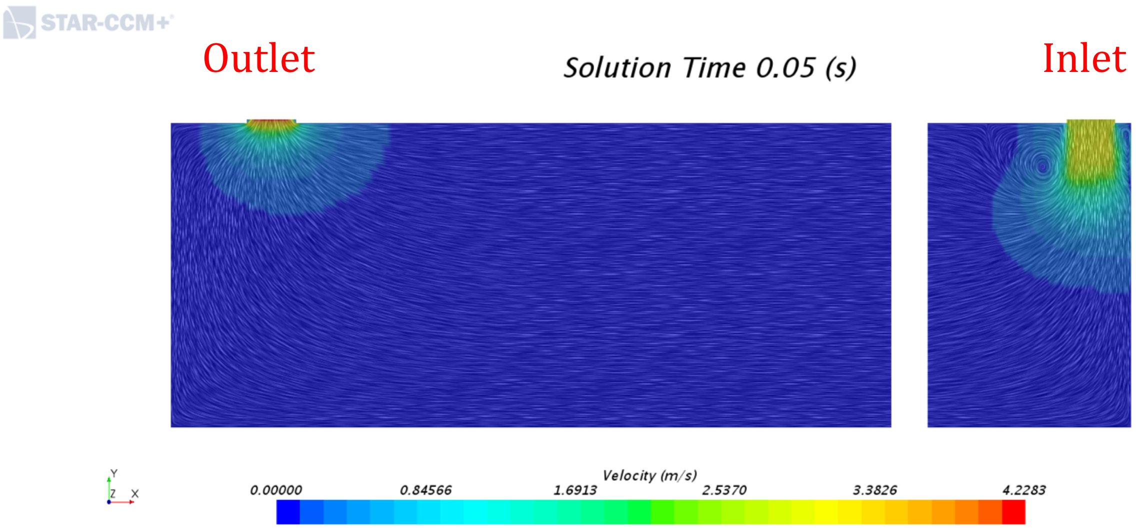


Figure E1: Initial CFD results

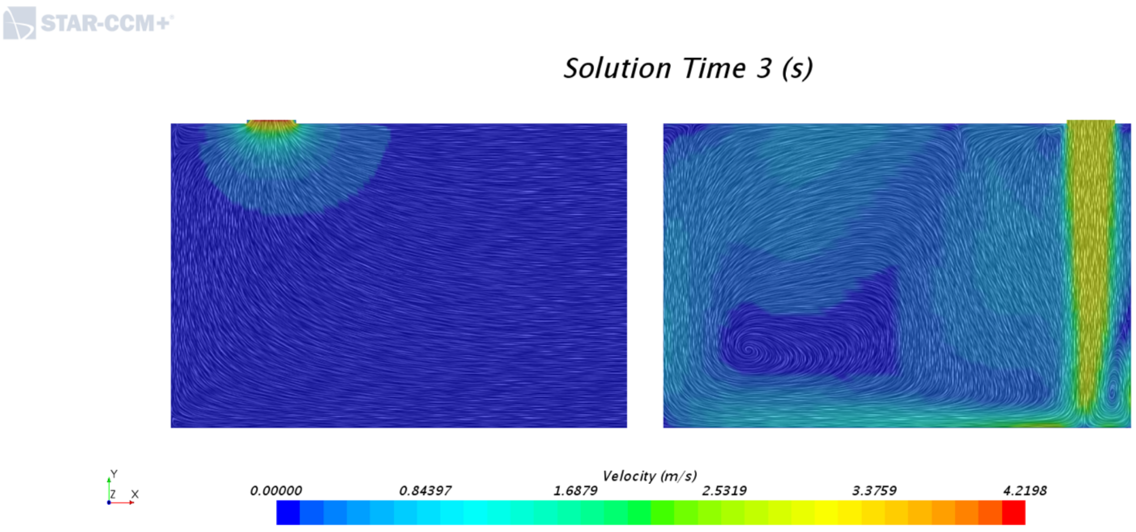


Figure E2: CFD results at 3 seconds

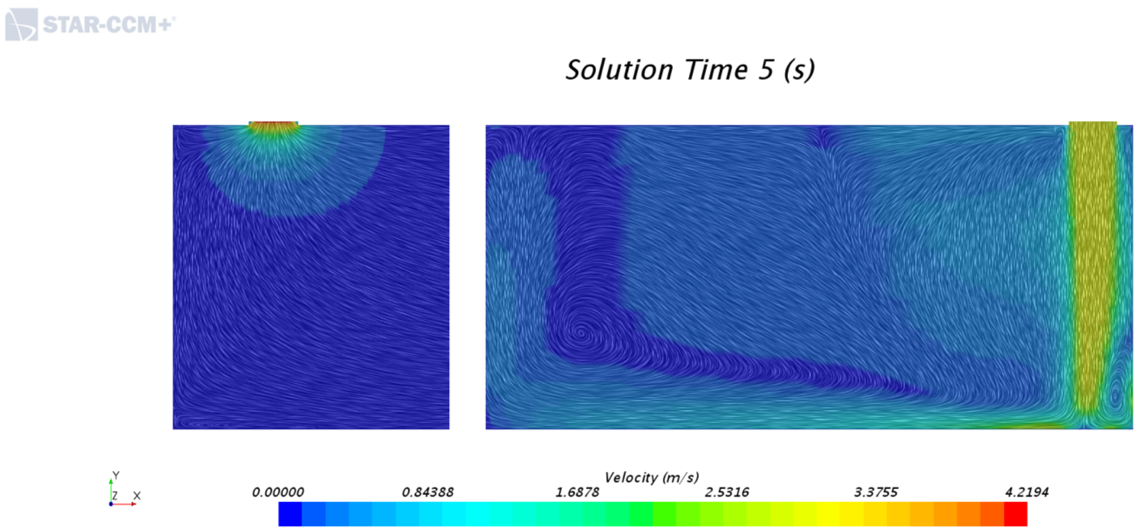


Figure E3: CFD results at 5 seconds

From this CFD study, the mass flow rate was measured throughout the entire calibration process. These measurements were plotted over time and can be seen in Figure E4.

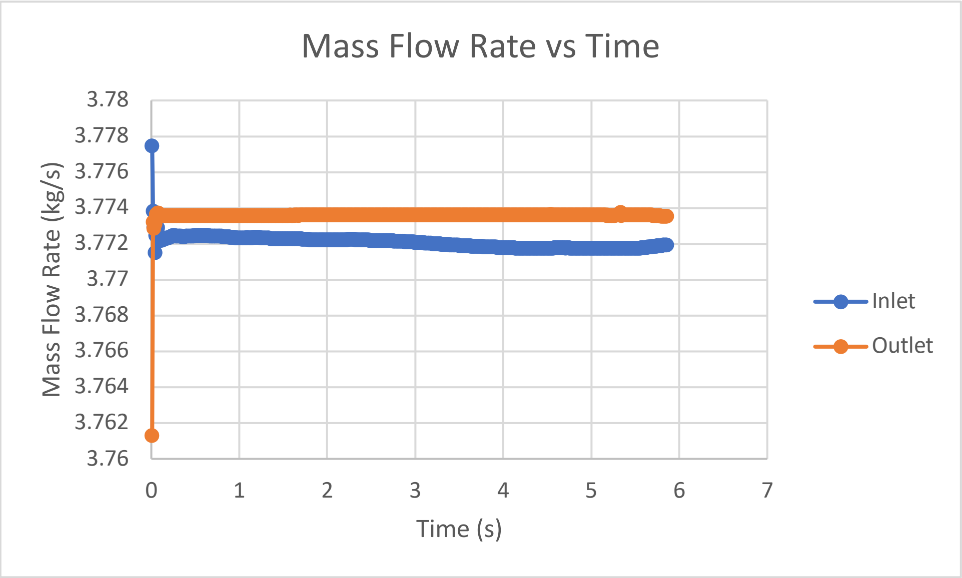


Figure E4: Mass flow rate plot

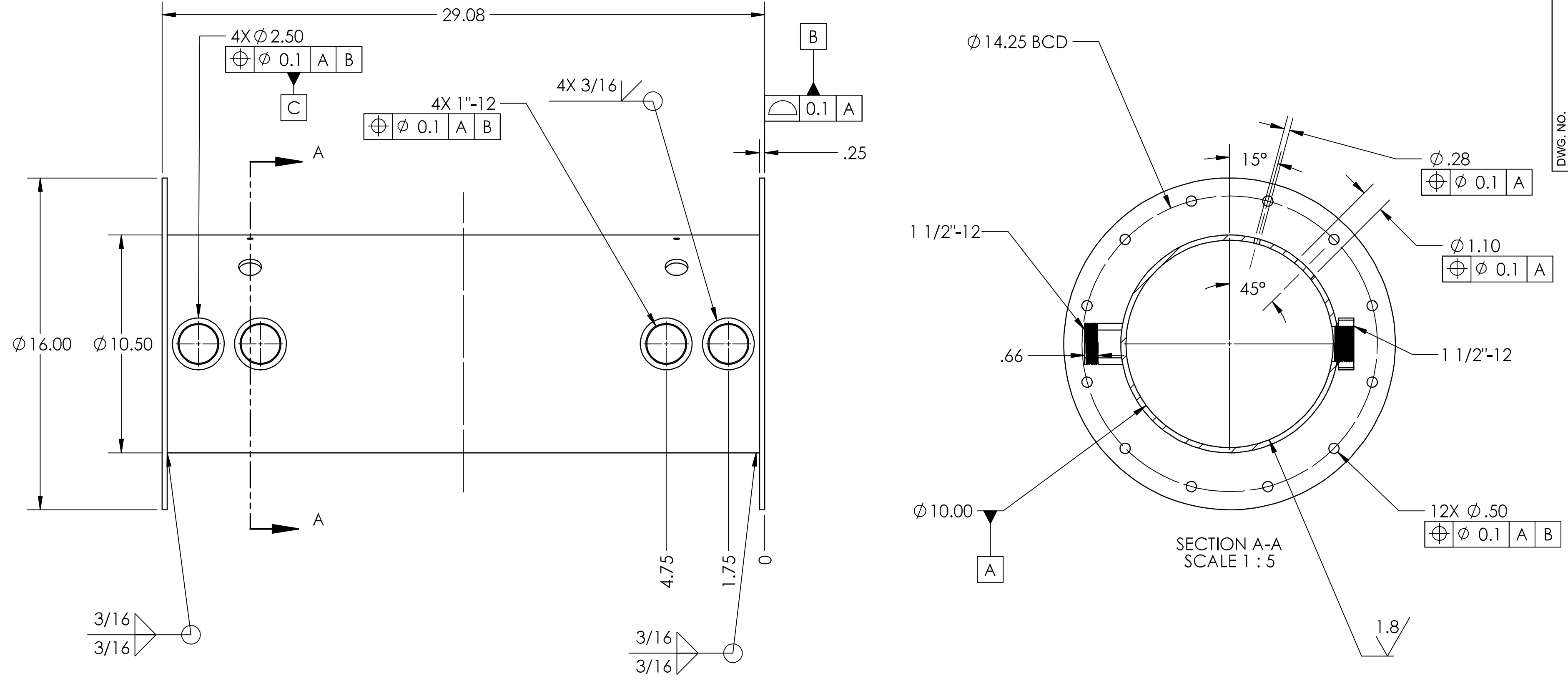
This plot indicates that the mass flow rate at the inlet and outlet are very close in value. The average mass flow for the inlet and outlet are 3.7721 kg/s and 3.7736 kg/s respectively. This results in a percent difference of 0.0397% and is assumed to be equal.

The average inaccuracies from these calculations is 0.03885%. This value is added to the system's total inaccuracies. The total inaccuracy including the CFD results is equal to 0.11585%.

Appendix F: Engineering Drawings

This Appendix contains the preliminary engineering drawings for the various parts of the overall design.

DWG. NO. Tank REV 0



REV	DATE Y/M/D	DESCRIPTION		
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
0	19/11/24	PRELIMINARY DRAFT	DWN NAME #	A. SAYGNAVONG
			CKD NAME #	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

GENERAL TOLERANCE
⌓ 0.005 A B C

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR INTERNAL THREADS AT ∅MINOR

CHAMFERS N/A
FILLETS N/A
BREAK SHARP R0.05±0.02 X 45° ±2°
SHARP N/A

MATERIAL 316 SS

FINISH CHROME 3.2

DO NOT SCALE DRAWING

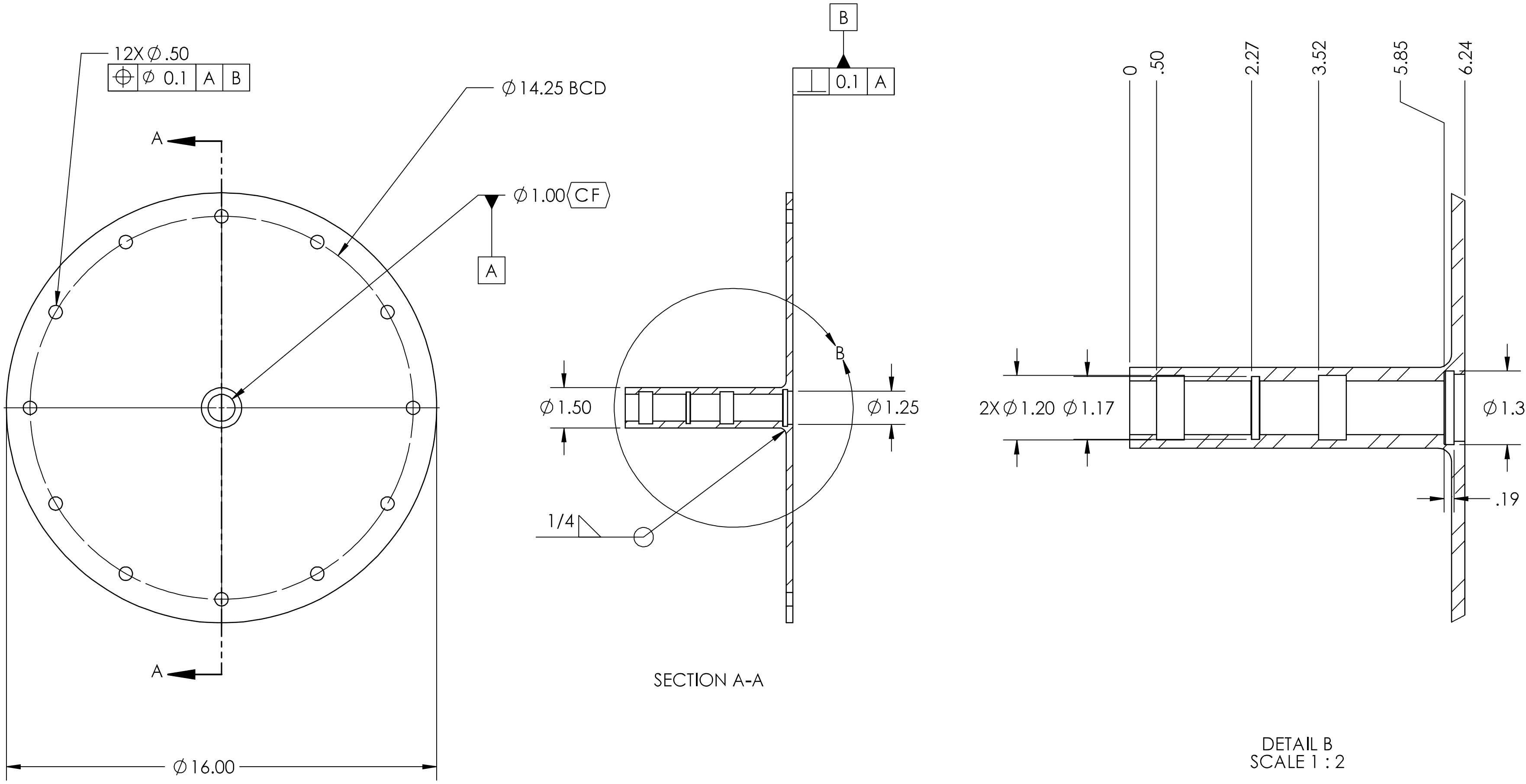
UNIVERSITY OF MANITOBA
MECH 4860 Engineering Design

TITLE:
TEAM #4: THE PRICE IS RIGHT
UNIVERSITY OF MANITOBA
FACULTY OF ENGINEERING

SIZE **B**
DWG. NO. Tank
REV 0

SCALE: 1:5
WEIGHT: N/A
SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



REV	DATE Y/M/D	DESCRIPTION		
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
B	19/11/27	REMOVED 10" STEP	DWN NAME #	A.SAYGNAVONG
			CKD NAME #	
A	19/11/24	PRELIMINARY DRAFT	DWN NAME #	A.SAYGNAVONG
			CKD NAME #	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
⌓ 0.005 | A | B

THREADED FEATURES EXTERNAL THREADS AT ØMAJOR
INTERNAL THREADS AT ØMINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS N/A
FILLETS 0.008 ± 0.001
BREAK SHARP R0.05 ± 0.02
SHARP N/A

MATERIAL
316 SS

FINISH N/A
???

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN

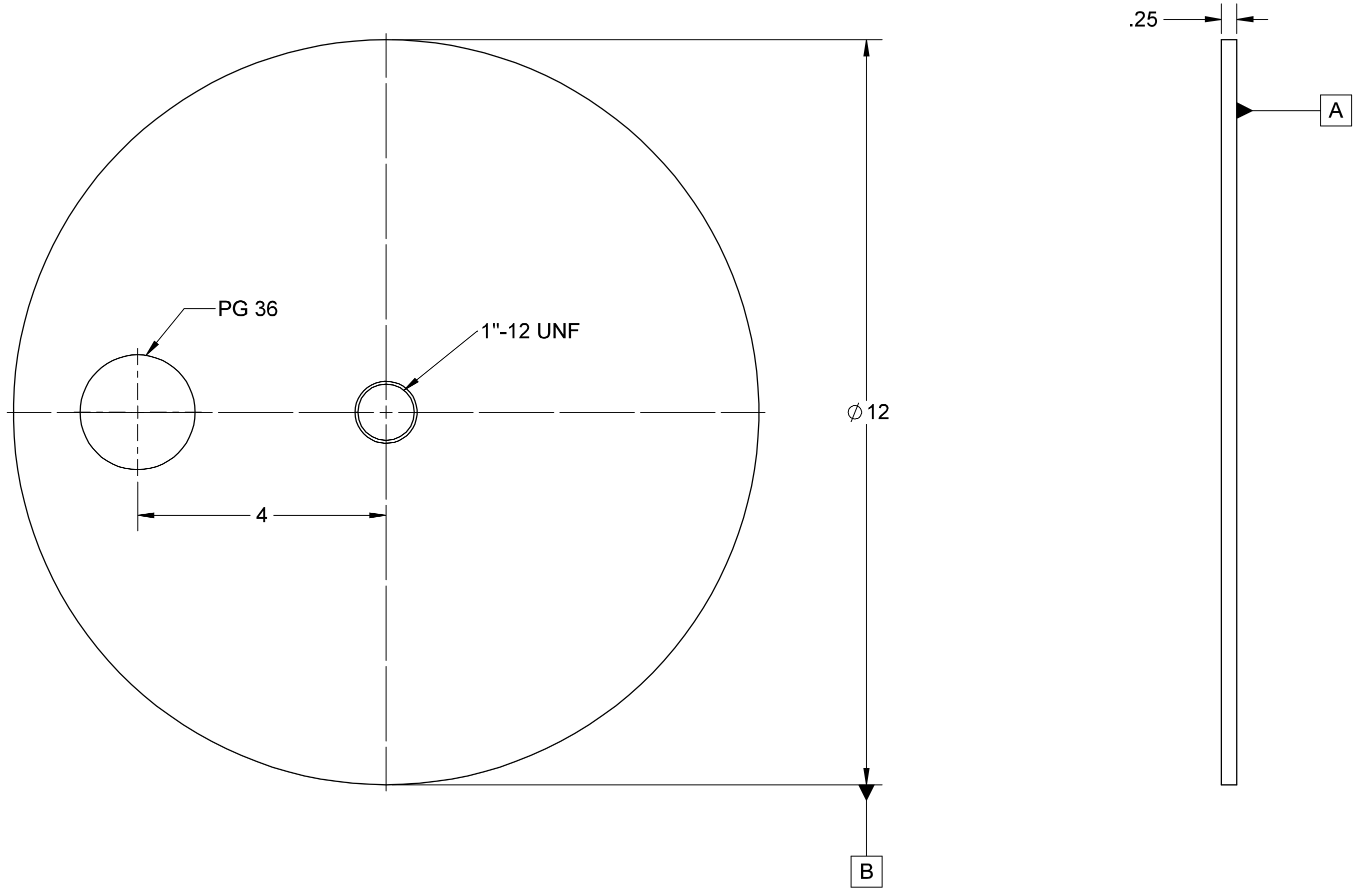
TITLE:
TEAM #4: THE PRICE IS RIGHT
UNIVERSITY OF MANITOBA
FACULTY OF MECHANICAL ENGINEERING

SIZE	DWG. NO.	REV
B	Tank Lid V2	1

SCALE: 1:4 | WEIGHT: N/A | SHEET 1 OF 1

DWG. NO. Tank Lid V2 REV 1

DWG. NO. Tank Plate REV 0



REV	DATE Y/M/D	DESCRIPTION		
			DWN CKD	
			DWN CKD	
			DWN CKD	
			DWN CKD	
0	19/11/26	PRELIMINARY DRAWING	DWN CKD	L.LE

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

GENERAL TOLERANCE ⌓ 0.05 | A | B

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

MATERIAL AL 6061

FINISH 3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA — MECH 4860 ENGINEERING DESIGN

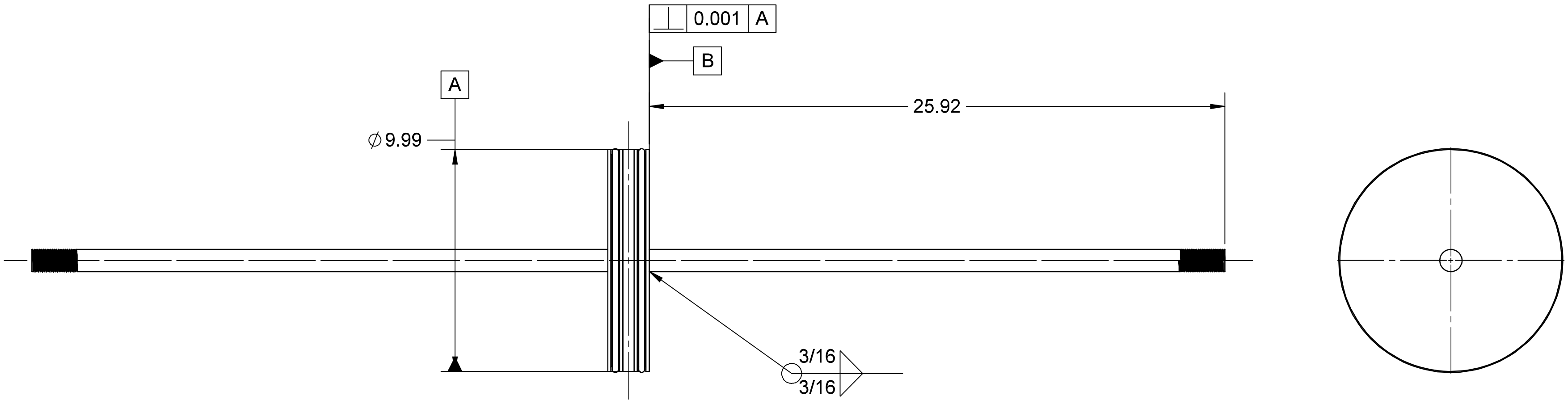
TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
TANK PLATE

SIZE B | DWG. NO. Tank Plate | REV 0

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

DWG. NO. Piston Assembly REV 0



ITEM NO.	PART NUMBER	QTY.
1	PISTON - PLATE	1
2	PISTON - ROD	1

REV	DATE Y/M/D	DESCRIPTION		
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
0	19/11/28	PRELIMINARY DRAWING	DWN NAME # CKD NAME #	L.LE

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE ⌓ 0.005

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

MATERIAL AL 6061 T6

FINISH 3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
PISTON ASSEMBLY

SIZE B

DWG. NO. Piston Assembly

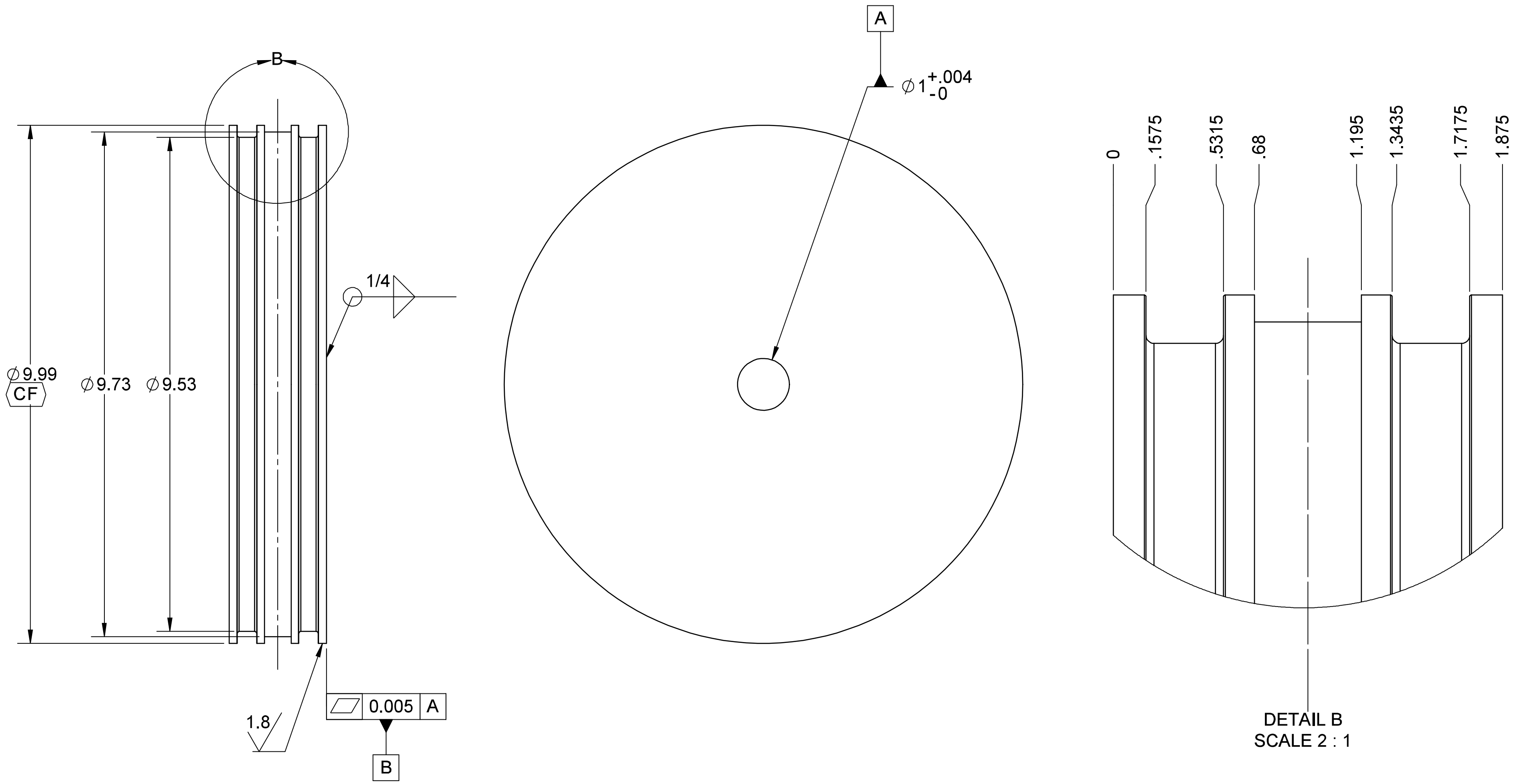
REV 0

SCALE: 1:5

WEIGHT:

SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



DETAIL B
SCALE 2 : 1

REV	DATE Y/M/D	DESCRIPTION		
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	19/11/24	PRELIMINARY DRAFT	DWN	LL
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
0.01 | A | B

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS N/A
FILLETS R0.04 ±.004
BREAK SHARP N/A
SHARP R0.05 ± 0.02

MATERIAL
316 SS

FINISH
3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860: ENGINEERING DESIGN

TITLE:
TEAM #4: THE PRICE IS RIGHT
UNIVERSITY OF MANITOBA
FACULTY OF MECHANICAL ENGINEERING

SIZE B | DWG. NO. Piston | REV 0

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

DWG. NO. Piston REV 0

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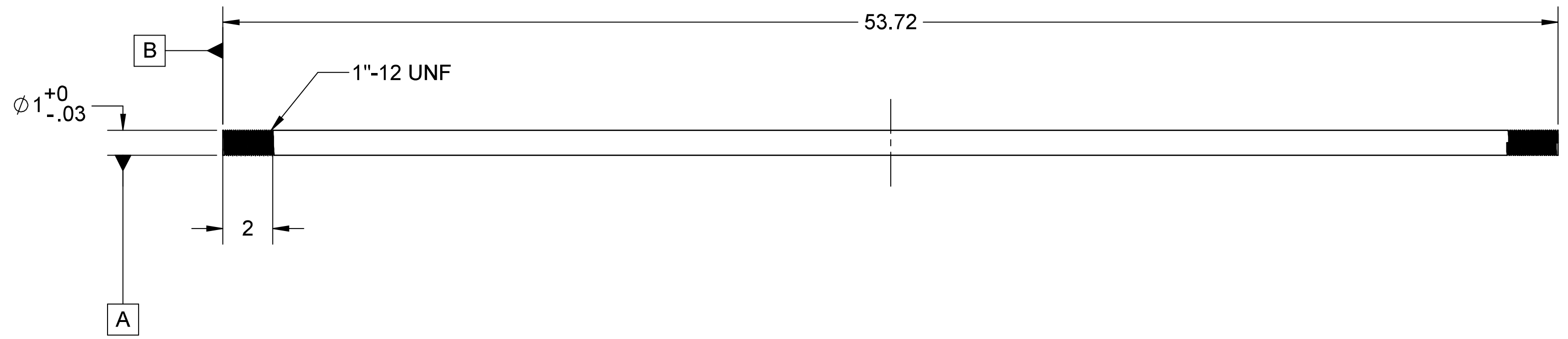


REV	DATE Y/M/D	DESCRIPTION		
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
			DWN NAME #	
			CKD NAME #	
0	19/11/26	PRELIMINARY DRAWING	DWN NAME #	L.LE
			CKD NAME #	

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE

⌓	0.05	A	B

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS	N/A
FILLETS	N/A
BREAK SHARP	N/A
SHARP	N/A

MATERIAL
AL 6061

FINISH
3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

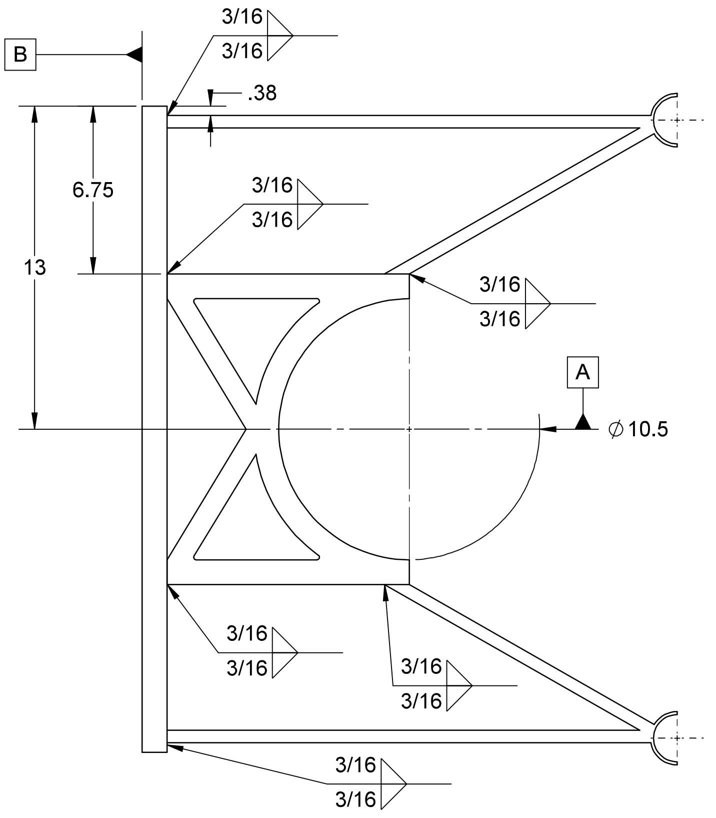
TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
Piston - Rod

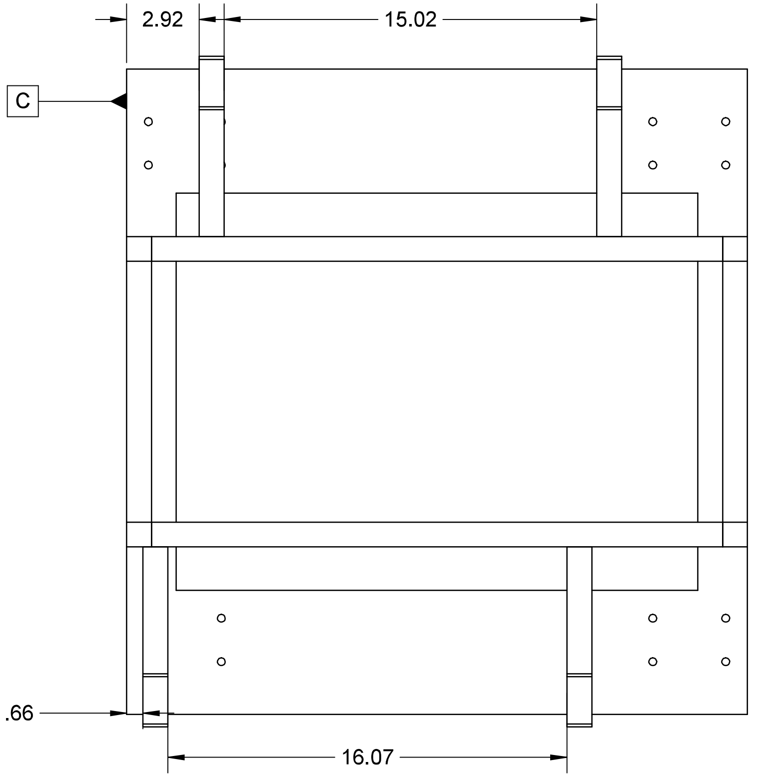
SIZE B
DWG. NO. Piston- rod
REV 0

SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

DWG. NO. Piston- rod
REV 0

SOLIDWORKS Educational Product. For Instructional Use Only.





ITEM NO.	PART NUMBER	QTY.
1	Cart - Bottom	1
2	Cart - Side	2
3	Cart - Bar	2
4	Pipe Arm	4

REV	DATE Y/M/D	DESCRIPTION		
A	19/11/26	PRELIMINARY DRAWING	DWN CKD	L.LE

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
⌓ 0.05 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS N/A
FILLETS R0.1 ±.05
BREAK SHARP N/A
SHARP R0.05 ±0.02

MATERIAL AL 6061

FINISH 3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN

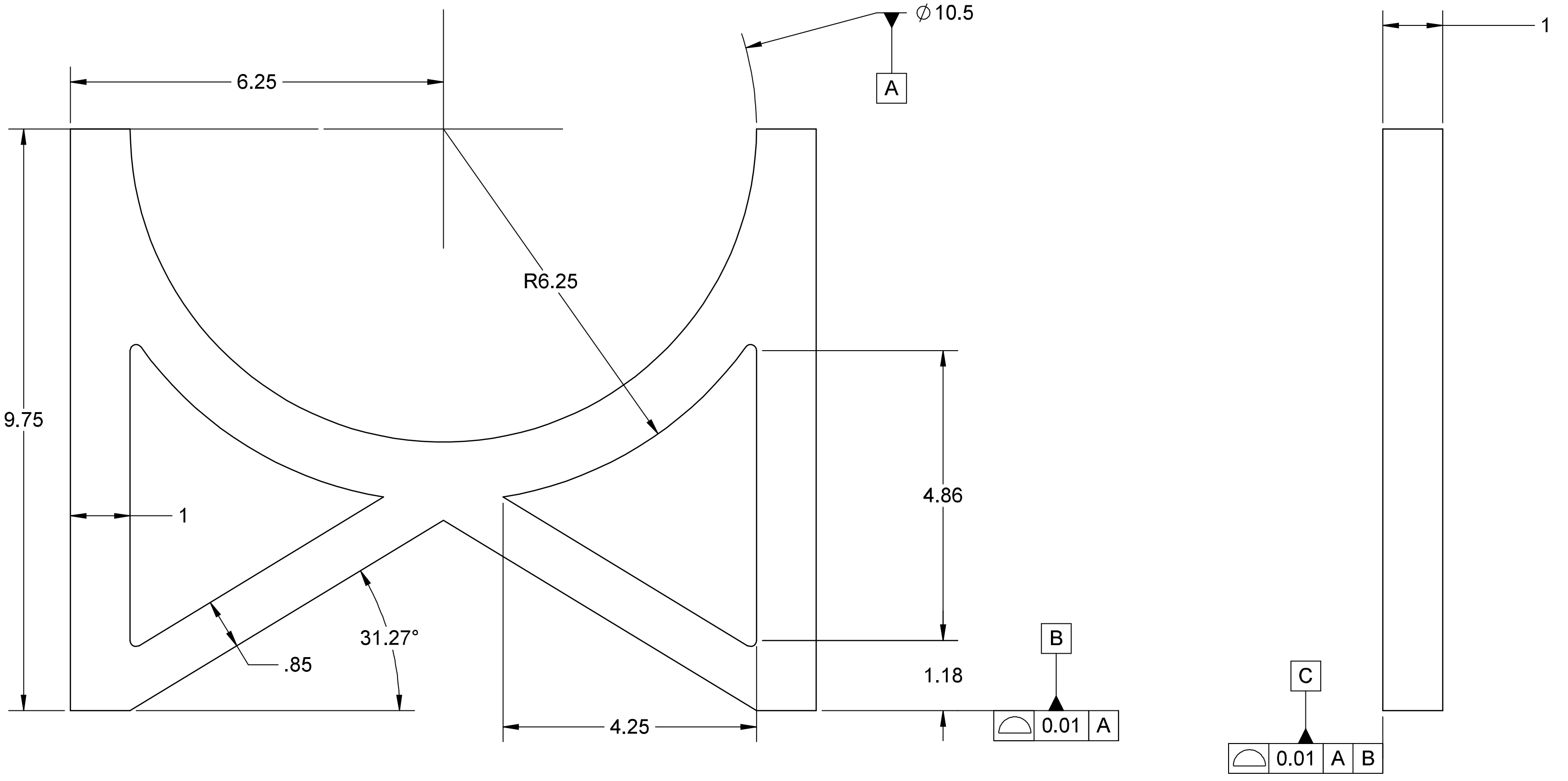
TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
CARTASSEMBLY

SIZE B
DWG. NO. Cart V2
REV

SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

DWG. NO. Cart V2
REV

SOLIDWORKS Educational Product. For Instructional Use Only.



REV	DATE Y/M/D	DESCRIPTION		
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			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	19/11/26	PRELIMINARY DRAWING	DWN	L.LE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

GENERAL TOLERANCE ⌓ 0.05 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

CHAMFERS N/A
FILLETS R.1 ±.05
BREAK SHARP N/A
SHARP R0.05 0.02

MATERIAL
6061 Al

FINISH
3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA MECH 4860 ENGINEERING DESIGN

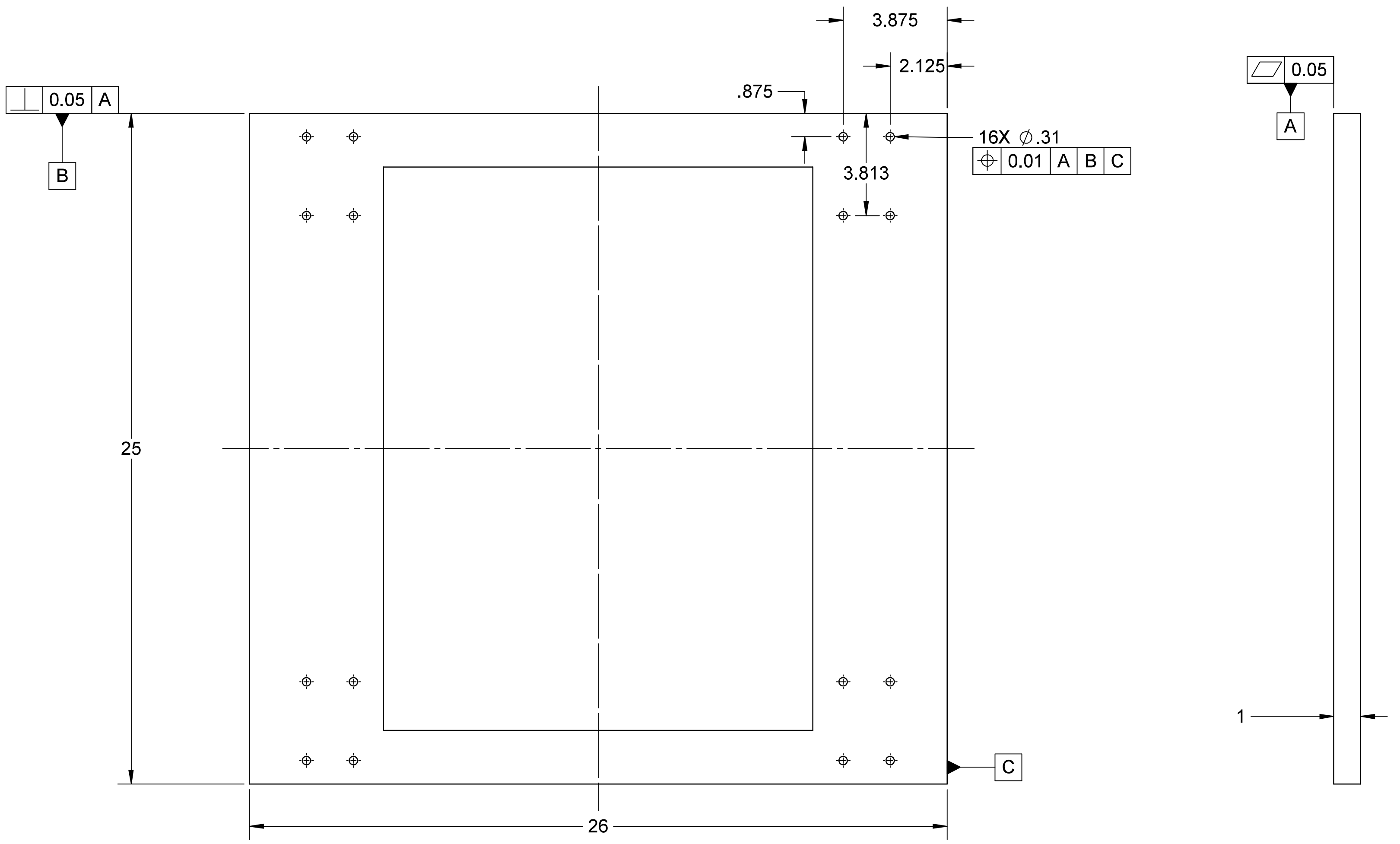
TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
CART- SIDE

SIZE B
DWG. NO. Cart - Side
REV 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

DWG. NO. Cart - Side REV 0

SOLIDWORKS Educational Product. For Instructional Use Only.



REV

DWG. NO.

Cart - Bottom

REV	DATE Y/M/D	DESCRIPTION		
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
			DWN NAME # CKD NAME #	
A	19/11/26	PRELIMINARY DRAWING	DWN NAME # CKD NAME #	L.LE

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
⌓ 0.01 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS N/A
FILLETS R0.04 ±.004
BREAK SHARP N/A
SHARP R0.05 0.02

MATERIAL
TBD

FINISH
3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
CART- BOTTOM

SIZE **B**

DWG. NO.
Cart - Bottom

REV

SCALE: 1:4

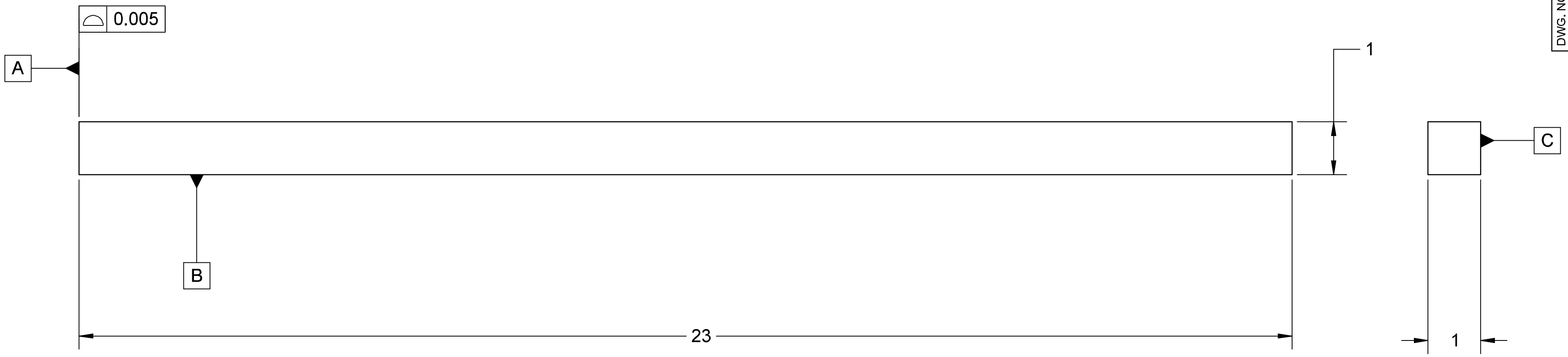
WEIGHT:

SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

REV 0

DWG. NO. Cart - Bar



REV	DATE Y/M/D	DESCRIPTION		
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			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	19/11/28	PRELIMINARY DRAWING	DWN	L.LE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

GENERAL TOLERANCE ⌓ 0.01

THREADED FEATURES EXTERNAL THREADS AT ØMAJOR
INTERNAL THREADS AT ØMINOR

CHAMFERS	N/A
FILLETS	N/A
BREAK SHARP	N/A
SHARP	N/A

MATERIAL
AL 6061 T6

FINISH
3.6

DO NOT SCALE DRAWING

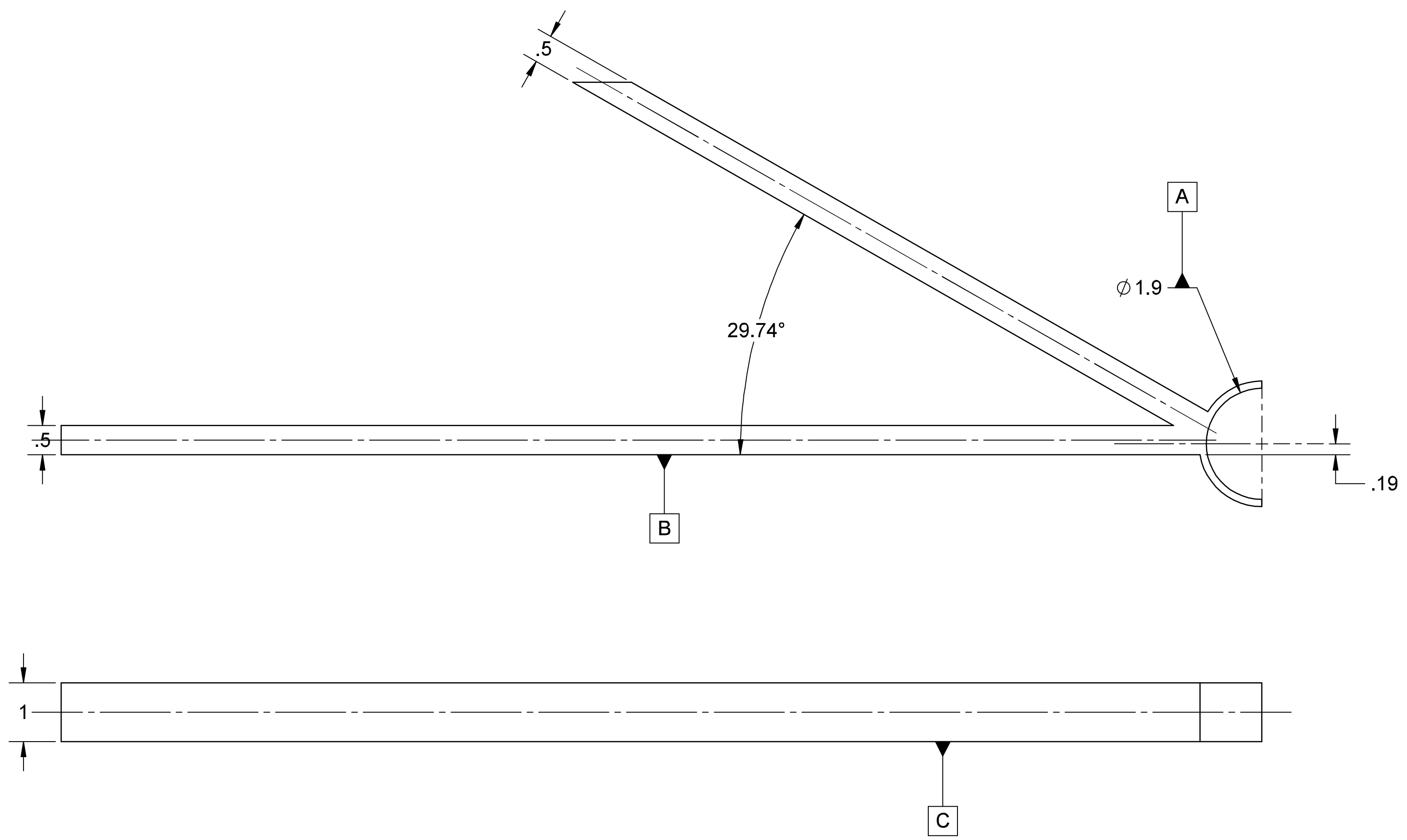
UNIVERSITY OF MANITOBA MECH 4860 ENGINEERING DESIGN

TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
CART BAR

SIZE **B** DWG. NO. Cart - Bar REV 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



REV	DATE Y/M/D	DESCRIPTION		
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			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	19/11/28	PRELIMINARY DRAWING	DWN	L.LE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE

⌓	0.01	A	B	C

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR
INTERNAL THREADS AT ∅MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS	N/A
FILLETS	N/A
BREAK SHARP	N/A
SHARP	N/A

MATERIAL
AL 6061 T6

FINISH
3.6

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA
MECH 4860 ENGINEERING DESIGN

TITLE:
TEAM #4: THE PRICE IS RIGHT
PRIMARY CALIBRATION SYSTEM
PISTON ASSEMBLY

SIZE B
DWG. NO. Pipe Arm
REV 0

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

DWG. NO. Pipe Arm
REV 0

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