



UNIVERSITY  
OF MANITOBA

Phase III: Final Report

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## Automated Fixture for Leak Detection Scanning

MECH 4860 – Engineering Design

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## Executive Summary

Price Industries designs and manufactures components for heating, ventilation and air conditioning systems. One series of products they manufacture is the Price LFDC / LFDCSS Series Laminar Flow Diffusers with replaceable high-efficiency filters. The laminar flow diffusers provide filtered air to environments where air quality is important, such as hospitals and clean rooms. The diffusers are manufactured from sheet metal, and each diffuser has various seams and joints that are tack welded and caulked. To ensure that the diffusers function as intended, each unit must undergo an aerosol challenge test to detect any leaks. The aerosol challenge test involves pressurizing the diffuser with air infused with oil particles and using a photometer to detect if the oil-infused air is escaping through any of the seams or joints. The current process involves a worker with a handheld device manually passing the device's nozzle over the seams. The objective of our project was to design a fixture that can automatically scan each seam and joint as well as alerting the worker to a detected leak, with minimal human interaction. We were also tasked with designing the documentation system for documenting the location of leaks detected that can be tied into the barcode scanning system. After considering the constraints, limitations, customer needs and target specifications, we generated a variety of concepts. We analyze the concepts with decision matrices and determined the best concept for each component of the design. After determining the best concepts, we began the final design process.

We designed a test fixture which meets all the requirements determined. Our test fixture is comprised of a manually adjustable frame, four leadscrews with guide rails, and four nozzle carriages that run along the lead screws. The adjustable frame allows the test fixture to accommodate multiple diffuser sizes. Leadscrews run along each side of the test fixture and are driven by mounted stepper motors. The leadscrews and guide rails are used to move the nozzle carriages along each side of the diffuser to scan the seams. The nozzle carriages are comprised of a simple C shaped frame where the nozzles, valves, and a small stepper motor are mounted. The valves allow us to control which nozzle is pulling air at any time, and the stepper motor allows for adjustability of the vertical nozzle to scan the corner, vertical seams.

Along with the design report, we have provided Price with CAD models, part drawings, spec sheets for purchased parts, and operational methodology for the test fixture. The overall cost of our design is estimated at \$8,804.52 CAD, which is within the allowable budget of \$20,000.

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## 1.0 Introduction

The purpose of the final report is to discuss the process of taking the final designs generated and analysed in the concept development phase and create the physical model for the test frame, as well as the bill of materials and logic flow diagram required for our project to be complete. In this report, we took the resulting ideas from our concept development report and created the model for the test fixture in Solidworks. We also created the flow chart for the documentation system to keep track of the test results. Part of this process involved creating a CAD model of the existing test rig, designing and creating the CAD model for our test frame, sourcing and implementing off the shelf components for the parts we decided not to design ourselves and combining them all into an assembly that demonstrates the functionality of the test fixture. Our final design consists of a manually adjustable frame. The frame can be adjusted and locked into various positions to accommodate a variety of sizes of diffusers. Mounted to the frame are four acme leadscrews that drive the motion of the carriages, which hold the components required to detect and indicate leaks, along the seams that must be tested. In the following sections we provide an overview of the company, a summary of the constraints, limitations, and target specifications, as well as an in depth explanation of our final design.

### 1.1 Background

Price Industries is a manufacturer of air distribution and HVAC products. The company employs a team of engineers to design, test, and manufacture a wide variety of air handling equipment for hospitals, schools, and commercial buildings. The Winnipeg division produces all the critical environment products for Price Industries in North America, including the HEPA filtered air diffusers. The HEPA filtered air diffusers are a critical component of cleanroom facilities found in hospitals, sensitive component manufacturing facilities, and laboratory settings. Figure 1 shows the HEPA filtered laminar air flow diffuser.

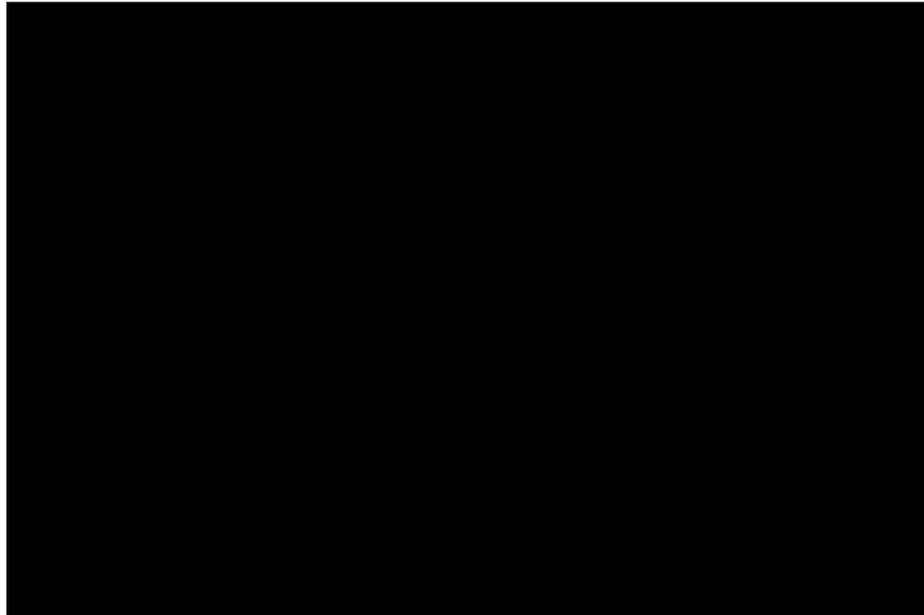


Figure 1: HEPA filtered laminar air flow diffuser [1].

The HEPA filter removes particulate contaminants from the air before it is distributed through the room. To ensure that the diffusers function as required, the HEPA filtered air diffusers undergo an Aerosol Challenge test to detect any leaking seals in the sheet metal joints. The Aerosol Challenge test detects leaks by pressurizing the diffuser plenum with air that has been aerosolized with oil particles and using a photometer to detect any oil particles that leak through faulty welds or improper seals. Figure 2 shows the diffuser in the test rig.



Figure 2: The test rig and HEPA filter diffuser assembly [2].

The current process involves a worker manually moving the photometer at a specified rate and specified distance from the seals along all seals to be tested. When a unit passes the leak test, a sticker is placed on the unit to identify that the unit has passed. There is no documentation process in place to track leaks that are detected. Price has decided that the current method can be improved through automation of the test process as well as by implementing a system for documenting the results of each test. These improvements will increase the consistency of the testing method, efficiency of the process and free up the worker for other tasks.

## 1.2 Problem Statement

The current manual scanning is only effective if the worker performing the test is diligent in following the test procedure, and the leaks detected are not documented. An example of the current test procedure in action can be seen in Figure 3.



Figure 3: Manual leak scanning procedure using handheld sniffer [3].

Automating the process would increase the consistency and effectiveness of the test. Our task is to complete a detailed design and 3D model of a robotic automation scanner which will test all required seams at the proper speed and in a pre-programmed sequence. Leaks will be marked physically on the diffuser and documented electronically. If a unit passes the test without leaks, it will be electronically serialized for quality assurance, with this process tying into the current barcode label that is on each diffuser.

### 1.3 Project Objectives

Our team will produce a detailed 3D CAD model of a robotic fixture that will be able to scan all required seams at the specified speed automatically, mark leaking areas and trigger the printing of the approval sticker when there are no leaks, without need for worker intervention apart from starting the procedure. Along with the model, a bill of materials will be included which will list all parts required to build the fixture. We will also provide a comprehensive method and bill of materials for the leak documentation, labelling and electronic record keeping system which will tie into the barcode system and provide a test history associated with each diffuser tested.

### 1.4 Constraints and Limitations

During the project definition phase, we first had to consider the constraints and limitations for our project. We defined the constraints as follows: size, cost, time, codes and safety standards, equipment, and level of automation. We determined that time and cost were the major constraints. We must complete all deliverables by December 8<sup>th</sup>, and the design must fall within the budget of \$20,000 that the client has set for this project. Based on the time constraint, after a discussion with the client we determined we will only be required to provide the mechanical design and bill of materials for the leak scanning fixture, as well as a logical block diagram for the documentation process. A working prototype will be considered above and beyond the requirements. An example of the expectations for the logical block diagram are shown in Figure 4.

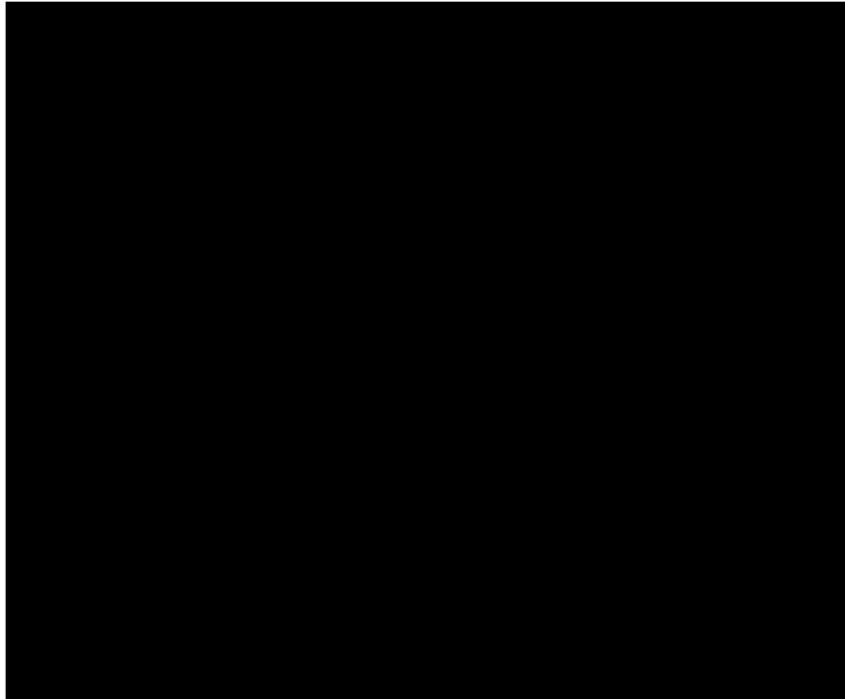


Figure 4: Logical block diagram for library book return and borrowing [4].

A complete summary of the constraints and limitations is provided in TABLE I.

TABLE I: LIST OF CONSTRAINTS AND LIMITATIONS

Constraint/Limitation	Summary
<b>Codes and Safety Legislation</b>	CSA Z432 and Price Testing Standard
<b>Size</b>	Test fixture can not increase the footprint of the test rig by more than 2 feet in any direction.
<b>Cost</b>	Less than or equal to \$20,000 CAD
<b>Time</b>	Time permits only mechanical design and logical block diagram for software coding
<b>Equipment</b>	Existing ATI “Sniffer” must be used for detection
<b>Level of Automation</b>	The device is to be 100% automated except for the loading and unloading of the diffuser.

## 1.5 Target Specifications

Before we could begin the conceptual design phase, we had to produce a list of target specifications. The list of target specifications represents the client's requirements for our design. We first collected a list of customer needs, then created a list of metrics to evaluate the needs of the design. Each need is linked to one or more metrics, after which a set of target specifications was established.

### 1.5.1 Customer Needs

After our discussion with the client, we determined a list of customer needs shown in TABLE II.

**TABLE II: LIST OF CUSTOMER NEEDS WITH RELATIVE IMPORTANCE**

NEED #	NEED	IMPORTANCE
1	The design accommodates scanning of a product barcode	5
2	The fixture scans and detects for leaks along all joints of the air diffuser	5
3	The fixture accommodates two product sizes	5
4	The fixture has a provision for marking and identifying locations of leaks	5
5	The system stores leak information, pass/fail status and links this information to the product serial number	4
6	The system prints a label for diffusers that have passed the test	5
7	The system will not allow a label to be printed for diffusers that have failed the test	5
8	The system does not interfere with other objects in the surrounding area	3
9	The system is easy to maintain	3
10	The system is reliable	3

TABLE II: LIST OF CUSTOMER NEEDS WITH RELATIVE IMPORTANCE (CONTINUED)

NEED #	NEED	IMPORTANCE
11	The system requires minimal human interaction	4
12	The fixture allows diffusers to be quickly and easily installed	3

Each need was given a rating of importance from 1 to 5, 5 signifying high importance and 1 low importance.

### 1.5.2 Performance Metrics

Once the customer's needs were established, we established a series of metrics. Metrics are a way of evaluating the customer needs and are rated in terms of relative importance from 1 to 5. Each metric is assigned a unit and a marginal and ideal value. TABLE III summarizes the metrics used to evaluate the customer needs.

TABLE III: LIST OF METRICS WITH MARGINAL AND IDEAL VALUES

METRIC #	NEED #	METRIC	IMPORTANCE	UNITS	MARGINAL VALUE	IDEAL VALUE
1	1	The design accommodates scanning of a product barcode	5	Type	Human	Automated
2	2	The fixture scans and detects for leaks along all joints of the air diffuser	5	Y/N	Yes	Yes
3	3	The fixture accommodates two product sizes	5	Y/N	Yes	Yes
4	4	The fixture has a provision for marking and identifying locations of leaks	5	Y/N	Yes	Yes
5	5	The system stores leak information, pass/fail status and links this information to the product serial number	4	Y/N	Yes	Yes
6	6	The system prints a label for diffusers that have passed the test	5	Y/N	Yes	Yes

TABLE III: LIST OF METRICS WITH MARGINAL AND IDEAL VALUES (CONTINUED)

METRIC #	NEED #	METRIC	IMPORTANCE	UNITS	MARGINAL VALUE	IDEAL VALUE
7	7	The system will not allow a label to be printed for diffusers that have failed the test	5	Y/N	Yes	Yes
8	8	Total design footprint	3	ft x ft	6' x 4'	4' x 3'
9	9	Amount of time required per week to maintain	3	min	<30	0
10	10	Amount of downtime per month	3	Hours	<2	0
11	11	Human operations required from start to finish of test	4	List	<3	1
12	12	Amount of time required to change diffuser sizes	3	min	<5	<1

### 1.5.3 Target Specifications

After creating a list of customer needs and a list of metrics, each need was linked to one or more metrics. We evaluated each of the customer needs based on our ideal and marginal metric values and created a list of target specifications. TABLE IV summarizes our target specifications.

TABLE IV: LIST OF TARGET SPECIFICATIONS

METRIC #	METRIC	UNIT	TARGET SPECIFICATION
1	The design accommodates scanning of a product barcode	Type	Human
2	The fixture scans and detects for leaks along all joints of the air diffuser	Y/N	Yes
3	The fixture accommodates two product sizes	Y/N	Yes
4	The fixture has a provision for marking and identifying locations of leaks	Y/N	Yes

TABLE IV: LIST OF TARGET SPECIFICATIONS (CONTINUED)

METRIC #	METRIC	UNIT	TARGET SPECIFICATION
5	The system stores leak information, pass/fail status and links this information to the product serial number	Y/N	Yes
6	The system prints a label for diffusers that have passed the test	Y/N	Yes
7	The system will not allow a label to be printed for diffusers that have failed the test	Y/N	Yes
8	Total design footprint	ft x ft	6' x 4'
9	Amount of time required per week to maintain	min	0
10	Amount of downtime per month	Hours	0
11	Human operations required from start to finish of test	List	<3
12	Amount of time required to change diffuser sizes	min	<5

After considering the customer needs, creating a list of metrics, and determining the target specifications of our design, we moved to phase II of our project, the concept definition phase.

## 2.0 Final Concept

Based on the results of our concept scoring matrix, found in Appendix A, we have determined that the best concept to continue developing for the movement and detection system is the individual jackscrew design with the C-style detector arm. This concept outscored the continuous rail with C-style detector arm as well as the six-axis robot arm.

For the leak identification portion of the design, the results from our concept analysis indicate that the best concept to continue developing are the LED indicators. This concept outscored the pneumatic stamping system as well as physically stopping the machine and manually applying a mark to the air diffuser.

When combined, our final concept will include:

1. Jackscrew movement system (individual jackscrews for each side of the diffuser)
2. Four air hose branches coming off the main ATI photometric scanner (one to each carriage assembly)
3. C-style detector arm with three air nozzles on each arm
4. LED indicators positioned on the carriages that identify where the leak was detected. The worker will then manually mark the location of the leak.

A visual summary of the final concept can be seen in Figure 5.

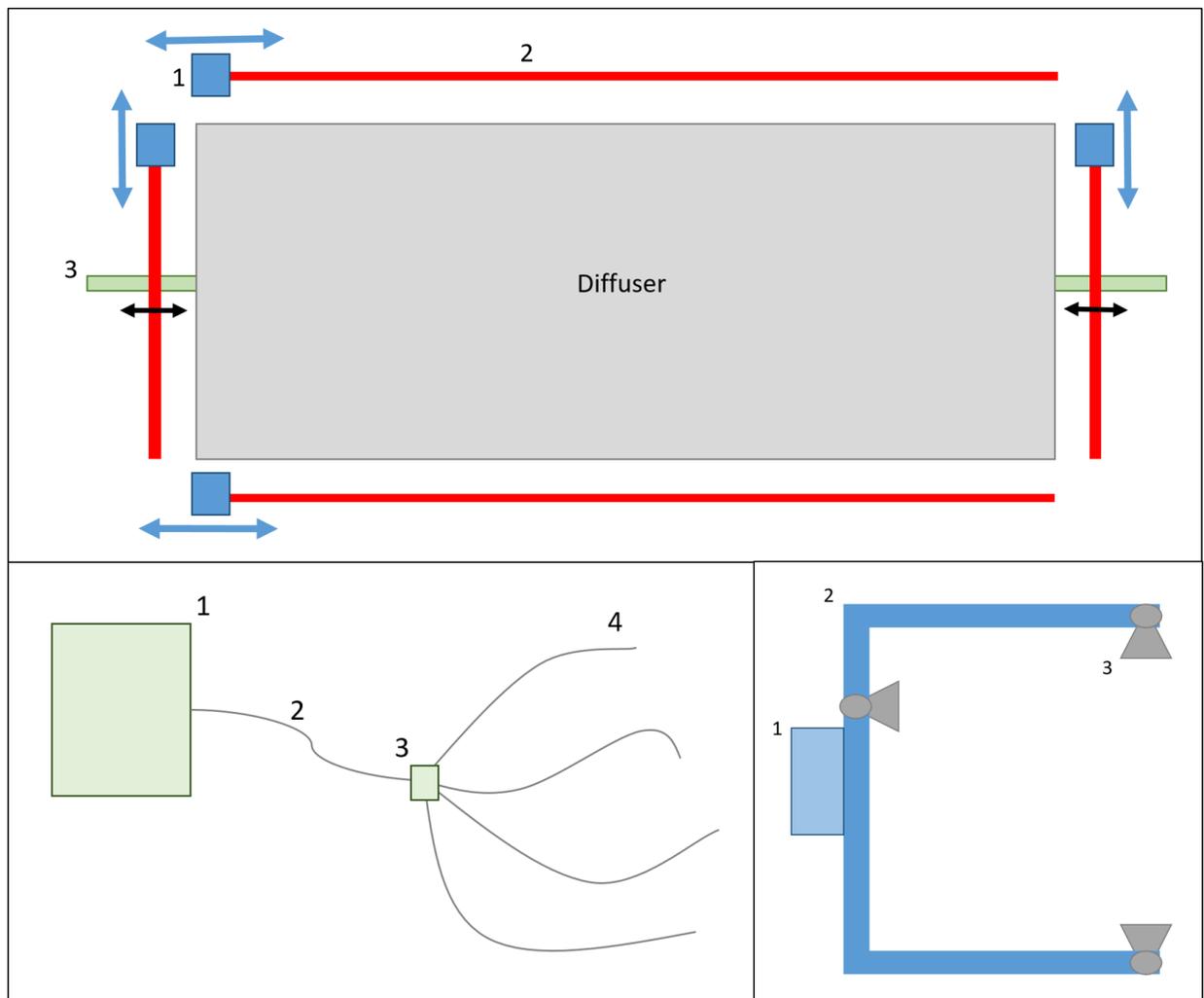


Figure 5: A visual summary of the final concept including jackscrew movement method (top), the required four air hose branches (bottom left), and C-shape detector arm with three air nozzles (bottom right).

### 3.0 Details of Design

After selecting the final concept, we began the design phase. Our concept generation, analysis and selection phase gave us a general idea to pursue and with the design phase we expanded upon and fleshed out the selected idea. To create the design, we split the concept into multiple tasks. The first task involved creating a CAD model of the testing rig as it exists currently. We need the test rig model to build our design around. The test rig model had to be accurate so that our test fixture could be designed properly. The next task was to design a frame to support the leadscrew and framework for the moving, functioning parts. After we designed the base frame we created the total assembly with all the off the shelf components and custom fabricated components.

#### 3.1 Test Rig and Diffusers

We modeled the existing test rig based on measurements taken of the test rig at Price's facilities. When designing the model, we omitted certain elements from the actual test rig that we deemed unnecessary to consider for our design purposes. The actual rig is shown in Figure 2 and the modeled rig can be seen in Figure 6.



Figure 6: Model of test rig.

We modeled the diffusers based on the technical drawings provided by Price Industries. Four models were created based on the four most commonly produced diffusers. The different

diffusers are referred to by their dimensions. The dimensions are 24"x24"x6.5", 24"x24"x9.5", 48"x24"x6.5" and 48"x24"x9.5". The 48"x24"x6.5" diffuser is shown in Figure 7.

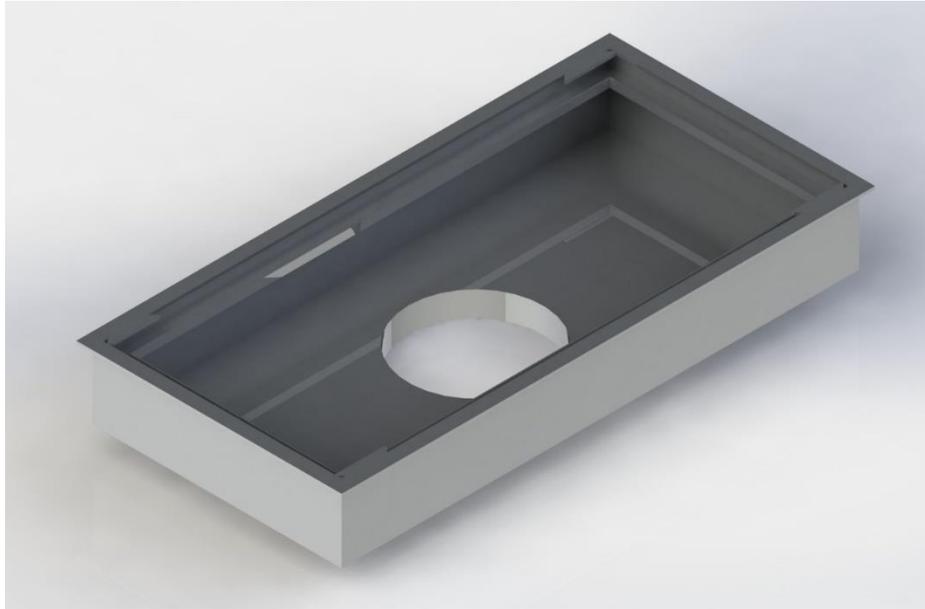


Figure 7: 48"x24"x6.5" Diffuser

### 3.2 Automated Fixture for Leak Detection Scanning

The final test fixture design is shown in Figure 8. Our automated fixture for leak detection scanning can theoretically scan all leaks and seams required by the client. In the following section, we will explain in detail the sub assemblies, how they function and our reasoning behind the components we selected.

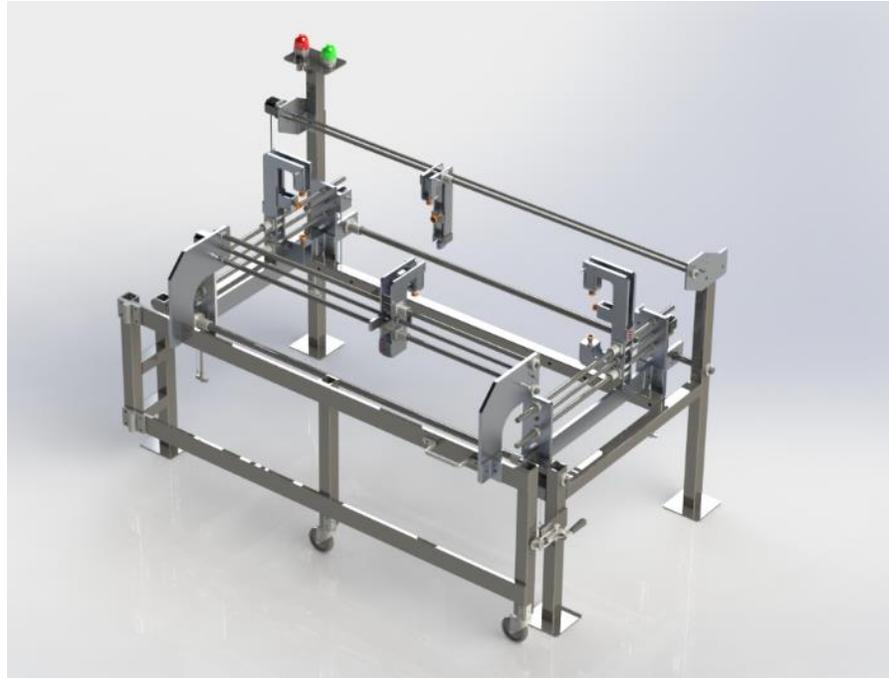


Figure 8: Automated Fixture for Leak Detection Scanning.

### 3.2.1 Gate and Frame Assembly

The gate and frame assembly provides support to the automated fixture and allows for the front of the fixture to open, which provides access for the worker for inserting and removing the diffuser. Figure 9 shows the gate and frame assembly.

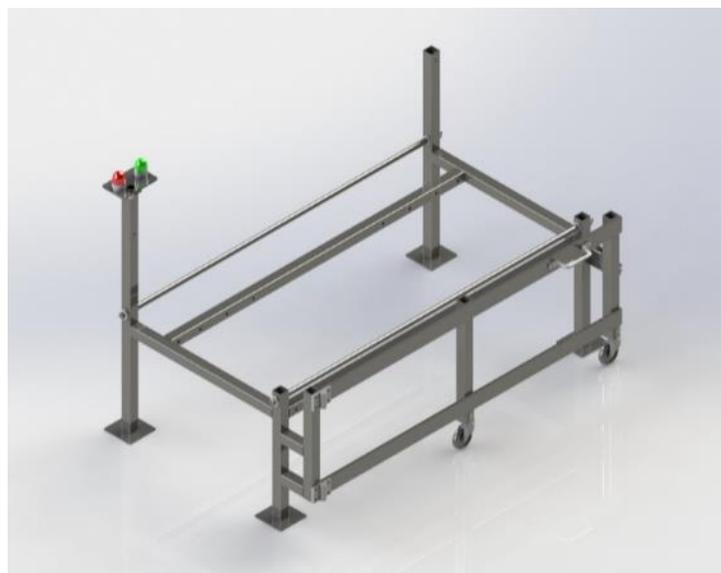


Figure 9: Gate and Frame Assembly.

The gate uses a toggle clamp to lock the mechanism, preventing the gate from opening during the test process. One of the most important features of the frame assembly are the rails that allow for adjusting the fixture to accommodate a variety of diffuser sizes. This functionality will be explained in more detail in later sections. Mounted to one of the back vertical posts is a platform. Mounted to the platform are a green beacon, red beacon and audible alarm speaker. The purpose of the beacons is to provide a clear visual indication of whether the diffuser passed the test or whether a leak was detected during the test. The green beacon will be on if the test was passed, and the red beacon will be on if the test was failed. The audible alarm speaker will sound whenever a leak is detected, signifying to the worker that the leak location must be marked on the diffuser. In the next section, we will explain how the side carriage rail assemblies function, and how they interact with the rails on the frame to allow for adjusting the size of the fixture.

### 3.2.2 Carriage Rail Assemblies

The carriage rail assemblies provide the motion to the scanning carriages. A feature unique to the side carriage rail assemblies is the ability to adjust the width of the fixture to accommodate various diffusers sizes. Figure 10 shows the side carriage rail assembly from the right side of the fixture.

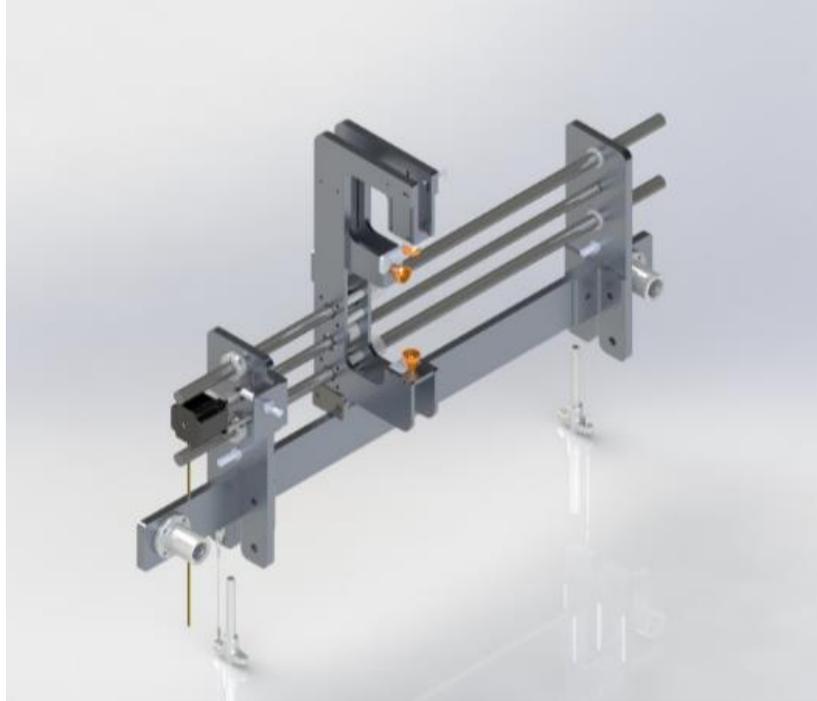


Figure 10: Right Side Carriage Rail Assembly.

The front, side and rear carriage rails all provide motion to the carriages using an acme leadscrew connected to a stepper motor. The stepper motor will be programmed to turn the acme leadscrew at the rate required to move the carriage 2 inches per second, which is the required scanning speed. The use of proximity induction sensors allows the carriage to sense when it approaches the ends of the rail, signaling the motor to stop turning, reverse direction or simply to prevent collisions. Details of the logic controlling the motors will be discussed in the section Logic Flow Diagrams. One of the unique features of the side carriage rail assemblies is that it can be moved along a set of guide rails on the frame of the fixture and locked at various positions. The worker can manually adjust the width of the fixture to accommodate the size of diffuser being tested. In the next section, the functionality of the carriages will be explained.

### 3.2.3 Scanning Carriage Assemblies

We designed three different models of the scanning carriages to accommodate the different scanning requirements of the sides, front and back of the diffuser. The carriages are shown in Figure 11, Figure 12, and Figure 13.

The front carriage design, shown in Figure 11, required two nozzles. The nozzle on the vertical portion of the carriage was designed to be adjustable to scan the vertical seam at the front

corners of the diffuser. We achieved this functionality by mounting the nozzle to a small leadscrew which is driven by a small servo motor. The top nozzle can be manually adjusted by pulling the spring-loaded plunger and moving the nozzle to one of two locking positions. This adjustability allows the carriage to scan both the 6.5" high and 9.5" high diffuser sizes. The carriage itself travels along a leadscrew using an acme leadscrew and bearing. Low friction bearings are used to allow the carriage to move along the guide rail smoothly and with no binding.



Figure 11: Front carriage.

The side carriage design, shown in Figure 12, required three nozzles to accommodate scanning the top plenum seal, the seam along the side of the diffuser, and the seam along the bottom edge of the diffuser. Like the front carriage, the top nozzle was designed to be adjustable to accommodate both the 6.5" high and 9.5" high diffuser models. The side nozzle is also required to adjust to accommodate the 2 heights of diffusers, and we achieved this by attaching it to the same adjustment mechanism that the top nozzle uses. The bottom nozzle is fixed and does not require adjustability.



Figure 12: Side carriage.

The rear carriage required two nozzles and the functional requirements were identical to the front carriage. The carriage required two nozzles, with a servo-driven vertical nozzle and adjustable top nozzle. The same design was used to achieve the adjustability, with a lead screw and servo motor for the vertical nozzle, and a manually adjustable top nozzle. The unique requirement for the rear carriage was that the carriage itself must fit through the narrow spacing at the back of the test rig. This was a unique challenge and required a more compact design and smaller components.



Figure 13: Back carriage.

### 3.3 Scanner Flow Control

An aspect of the final design is to design a pneumatic system that can interface between our robotic fixture and the existing ATI particulate scanner at Price Industries. Since our mechanical design includes multiple nozzles, the design will need to include a series of manifolds and valves that connect the nozzles back to the ATI scanner. The ATI scanner has a  $\frac{1}{4}$ " push-to-connect tubing port acting as an inlet for downstream flow during the DOP test. The pneumatic system will feature a four-port manifold that outputs to the ATI scanner, with each of the four ports connecting to each branch of the robotic fixture. Additionally, since each of the four sides will have multiple nozzles, each branch will need to have its own manifold and valves. A schematic of the entire pneumatic system can be seen in Figure 14.

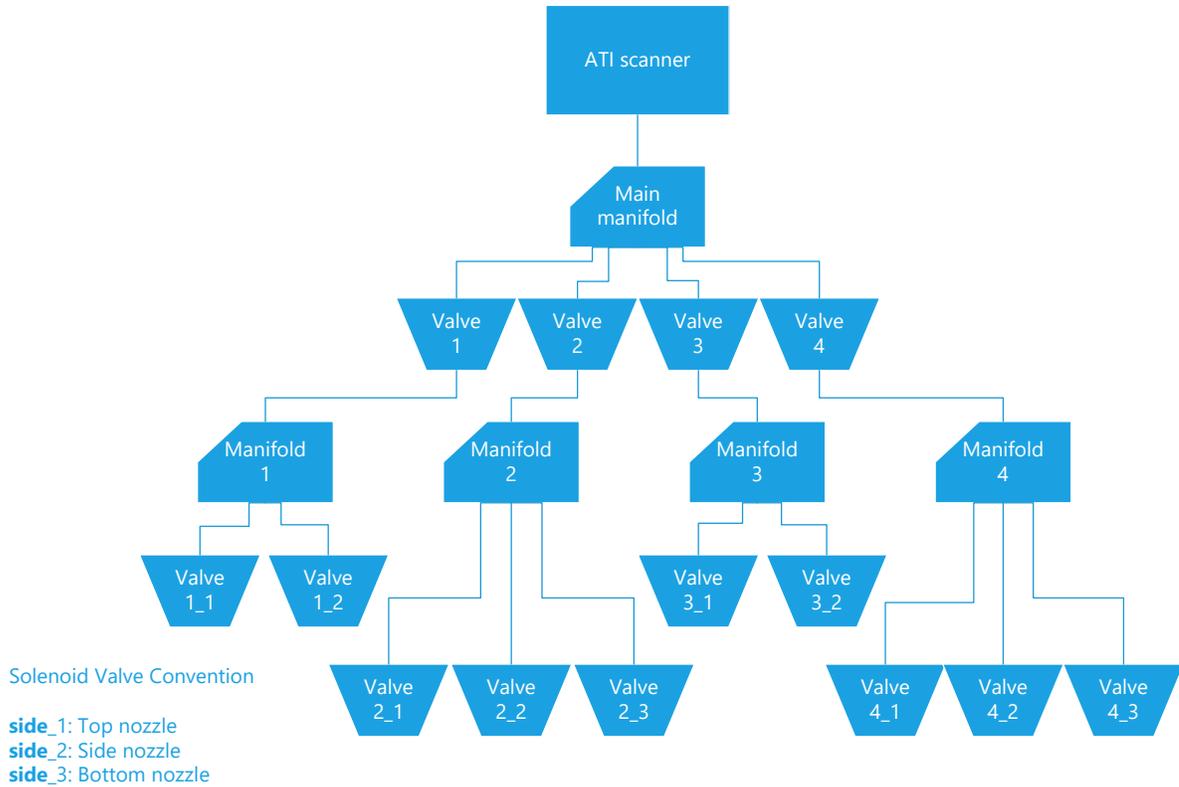


Figure 14: Schematic showing the routing of the pneumatic lines.

Since the entire fixture is to be automated, it has been decided to use electronically actuated solenoid valves in the design such as the ones shown in Figure 15.

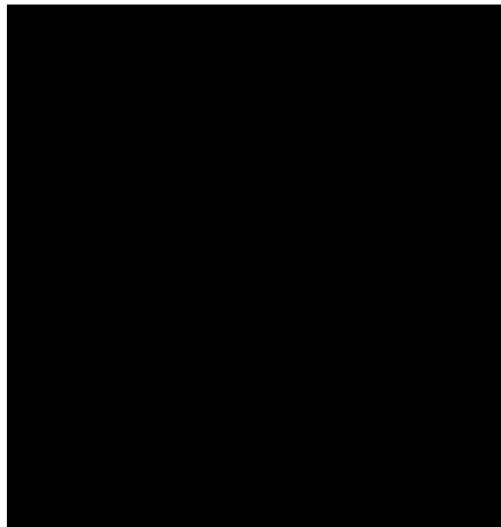


Figure 15: Electronically actuated solenoid valves used in the pneumatic system design.

The specified solenoid valves include a 1/4"-18 NPT female thread on both inlet and outlet ports. A total of 14 solenoids will be needed for the design. Four will be needed for each branch, in addition to two solenoids for each of the long sides and three solenoids for each of the short sides. The four-port manifold used in the design is shown in Figure 16.



Figure 16: Four-port manifold used in the pneumatic system.

The manifold includes a female 3/8"-18 NPT inlet and four female 1/4"-18 NPT outlets. A three-port manifold must be used for the carriages on the short side which have three nozzles each. Two-port manifolds must be used for the carriages on the long sides of the air diffuser that have two nozzles each. Both three-port and two-port manifolds include 3/8"-18 NPT inlets and 1/4"-18 NPT outlets. The three-port manifolds can be seen in Figure 17 and the two-port manifold can be seen in Figure 18.

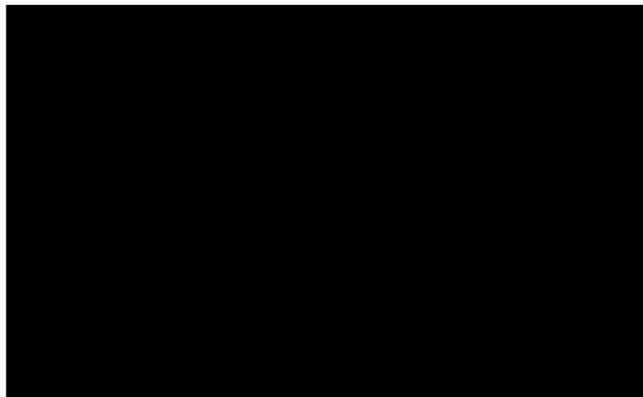


Figure 17: Three-port manifold used in the pneumatic system.

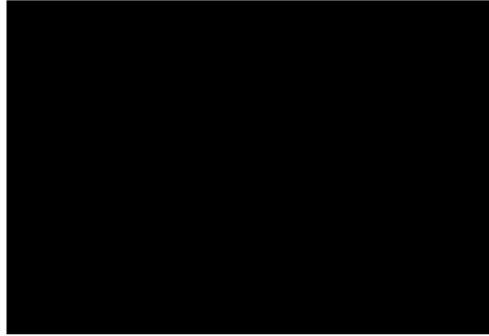


Figure 18: Two-port manifold used in the pneumatic system.

From Figure 14, we see that the ATI scanner will input into the four-port manifold. This will be accomplished using  $\frac{1}{4}$ " PVC tubing. One end will connect to the downstream port of the ATI scanner, while the other end will have a tube-to-male thread adapter that connects to the  $\frac{3}{8}$ " NPT input of the four-port manifold. Four male  $\frac{1}{4}$ " NPT to male  $\frac{1}{4}$ " NPT adapters will be used to connect the outlets of the four-port manifold to the four branch solenoid valves. Male  $\frac{1}{4}$ " NPT to male  $\frac{3}{8}$ " NPT adapters will then be used to connect the four solenoid valves to the inputs of the individual branch manifolds. An additional ten male  $\frac{1}{4}$ " NPT to male  $\frac{1}{4}$ " NPT adapters will be used to connect the outlets of the individual branch manifolds to the individual branch solenoids and ten male thread-to-tube adapters will connect the solenoid valves to ten individual lengths of PVC tubing that will connect to the ten nozzles shown in Figure 19. Ten tube-to-female thread adapters paired with ten  $\frac{1}{4}$ " NPT male thread to Loc-Line nozzle adapters connect the PVC tubing to the nozzles. A detailed breakdown and bill of materials for the pneumatic system can be found in the BOM and Cost section of the report.

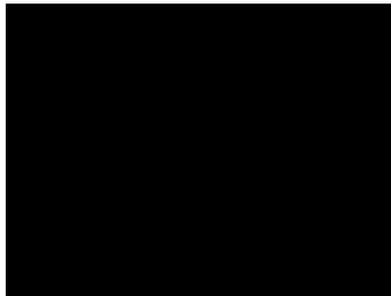


Figure 19: Nozzles used in the pneumatic design.

### 3.4 Electrical System and Logic Flow Diagram

As part of our automated design, a logical flow diagram must be developed for the software portion of the design. The electrical side of the project will require a PLC, two 15 slot I/O cards, four stepper motors to drive the four carriages, a power source and stepper drivers for the stepper motors, two servos for the vertical ball screws, eight proximity sensors, ten LEDs for indicating which nozzle is detecting a leak, a pair of red and green beacon lights used to indicate the status of the test, as well as an audible alarm. A detailed bill of materials for the electrical system is included in the BOM and Cost section of the report. Price Industries may use their discretion to alter, add or remove any components specified in the electrical system bill of materials.

The general overview of the leak detection system includes the four stepper motors driving the individual carriages along the sides of the diffuser using the nozzles to check for leaks along each seam. Proximity sensors are used to stop the stepper motors from driving the carriages once the carriages reach the end of their travel distance. Figure 20 shows a schematic diagram of the stepper motor and proximity sensor arrangement used in the final design along with a convention labelling each side of the diffuser from 1 to 4. Proximity sensors labelled as 'A' refer to proximity sensors that are near the motor on their respective sides, while sensors labelled as 'B' refer to sensors located on the opposite side of the motor. The variable names for the stepper motors and the proximity sensors to be used in the code are also included in Figure 20.

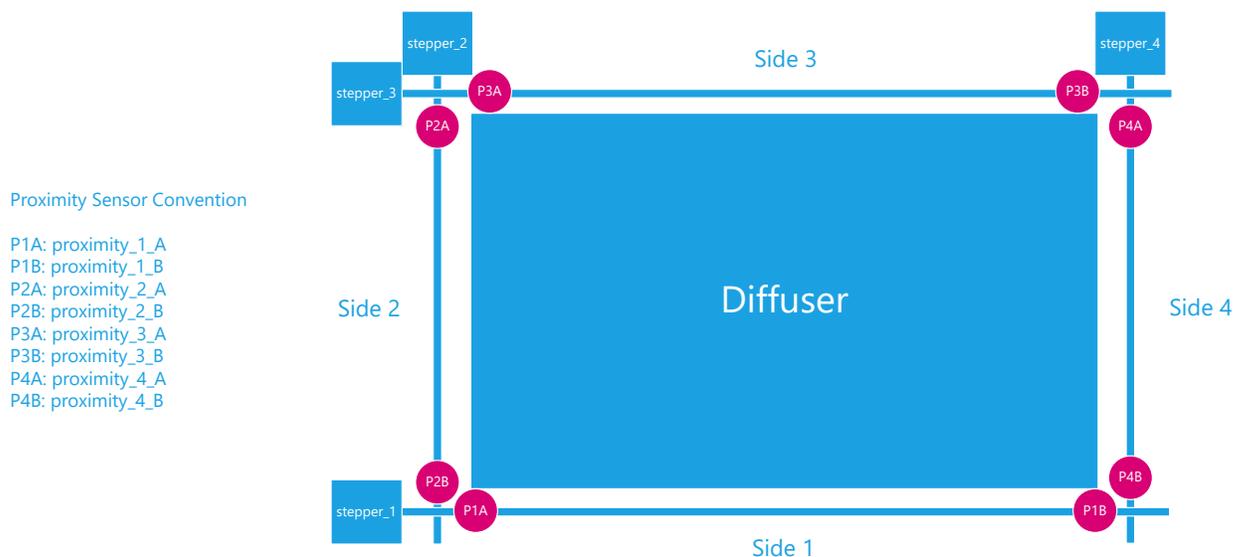


Figure 20: Schematic diagram showing stepper motor variable names as well as proximity sensor variable names.

The logical flow diagram for top-level code is shown in Figure 21.

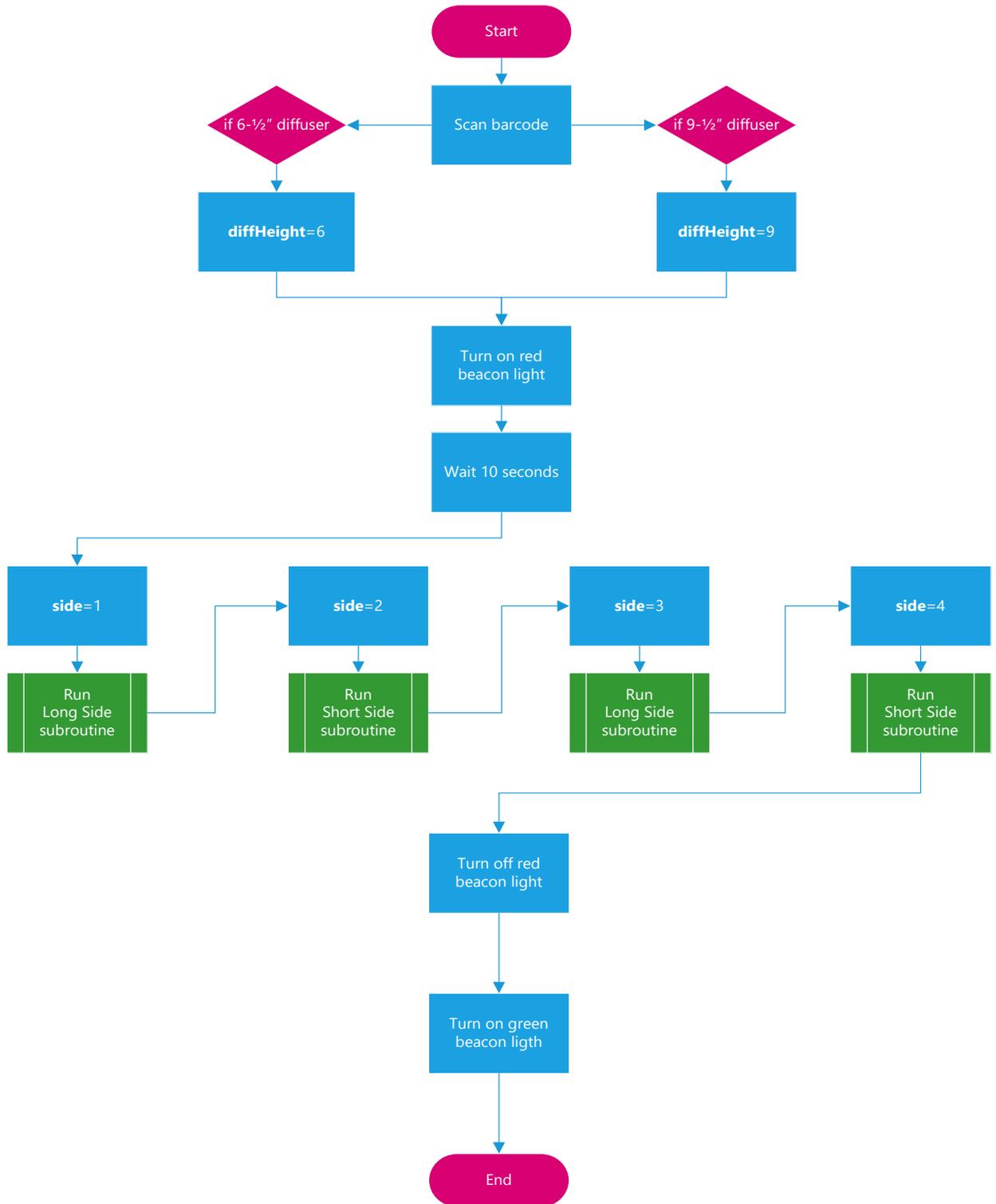
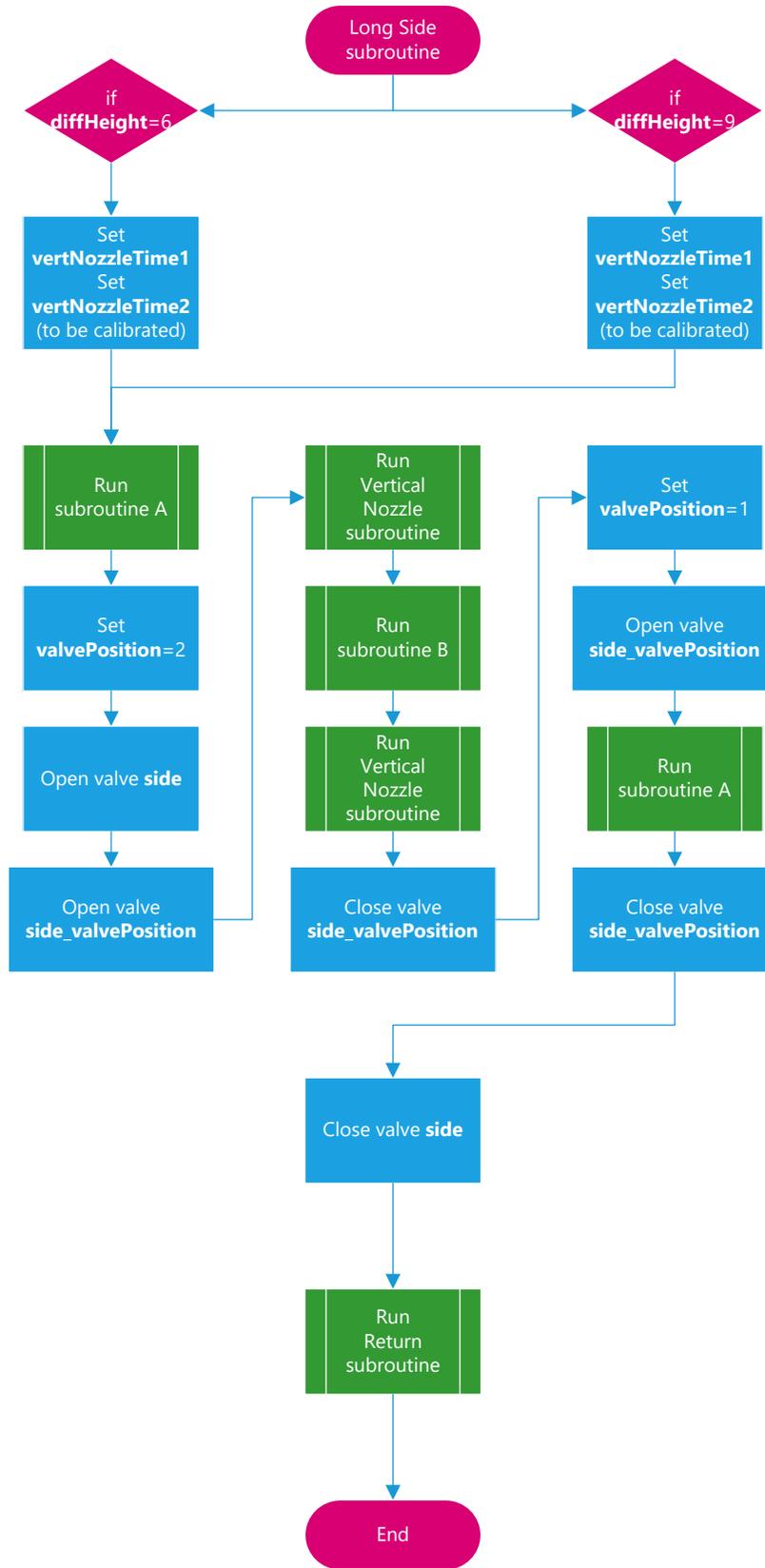


Figure 21: Logical flow chart for the top-level code.

The program starts with the operator scanning the product barcode. The PLC then determines whether the serial number corresponds to a 9-1/2" high diffuser or a 6-1/2" high diffuser and sets the **diffHeight** variable accordingly. The red beacon light is then turned on to signify that the test is in progress. Ten seconds elapse to ensure that the operator has time to leave the area before the test starts. The PLC sets the **side** variable to 1 and runs the Long Side subroutine, which is a subroutine for detecting leaks along the long side of the diffuser. Once the Long Side subroutine is complete, the PLC sets the **side** variable to 2 and runs the Short Side subroutine, which is a subroutine for detecting leaks along the short end of the diffuser. The process is repeated for **side** 3 and 4. It is at this point the red beacon is turned off and the green beacon is turned on to signify that the test is complete. A detailed breakdown of the Long Side subroutine can be observed in Figure 22.



If at any point, **scanner=1**, run the Interrupt subroutine before continuing with the flowchart

Figure 22: Logical flow chart for the Long Side subroutine

The Long Side subroutine takes the **diffHeight** variable and sets the **vertNozzleTime1** and **vertNozzleTime2** variables to appropriate values that will allow the servo motors to drive the vertical nozzles up and down the entire length of the vertical seams of the diffuser in the Vertical Nozzle subroutine. Once the variables have been set, subroutine A is run which brings the carriage towards the motor until the 'A' side proximity sensor tells the stepper to stop turning. This is the carriage's starting position. A new variable **valvePosition** is set to 2, which indicates the solenoid valve controlling the side nozzle. A detailed naming convention for the solenoid valves was shown in Figure 14. The valves corresponding to the **side** of the diffuser and the **valvePosition** of the diffuser are then opened and the Vertical Nozzle subroutine is run. Subroutine B is then run which drives the carriage towards the opposite end of the motor towards proximity sensor 'B'. This detects for leaks along the side seam of the diffuser. Once the carriage is stopped when it reaches proximity sensor 'B', the Vertical Nozzle subroutine is run again. The valve corresponding to the **valvePosition** variable (the side nozzle valve) is closed and the **valvePosition** variable is set to 1, which indicates the solenoid valve controlling the top nozzle. The corresponding valve is opened and subroutine A is run again, driving the carriage towards the motor while detecting for leaks along the top seam. All valves are then closed and the Return subroutine is run which brings the carriage back to the midpoint of the leadscrew in order to prevent interference with the other carriages. If at any point, the scanner detects a leak (**scanner** = 1), the Interrupt subroutine is run before the rest of the subroutine is followed. Figure 23 shows a detailed flowchart for the Short Side subroutine.

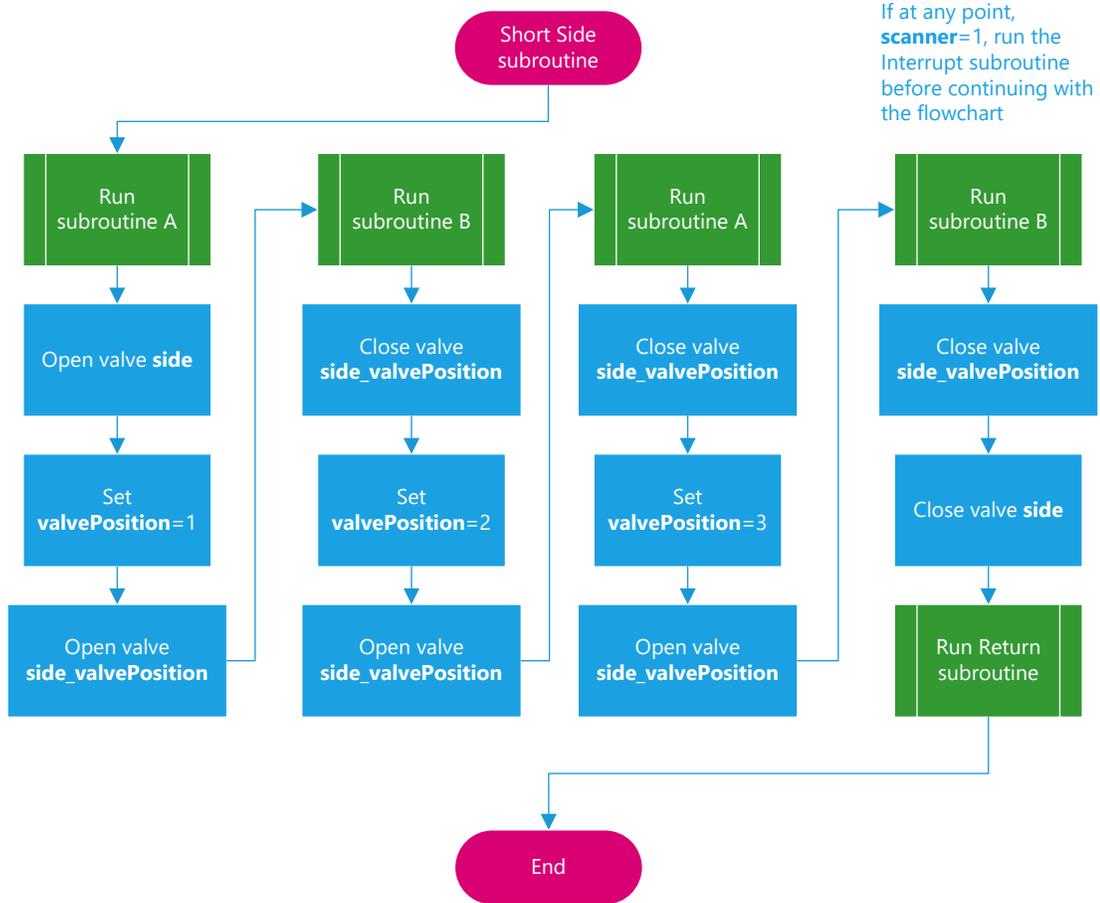


Figure 23: Logical flow chart for the Short Side subroutine.

The Short Side subroutine is coded similarly to the Long Side subroutine apart from a Vertical Nozzle subroutine and the addition of a third bottom nozzle. Subroutines A and B required for turning the stepper motors and driving the carriages are shown in Figure 24.

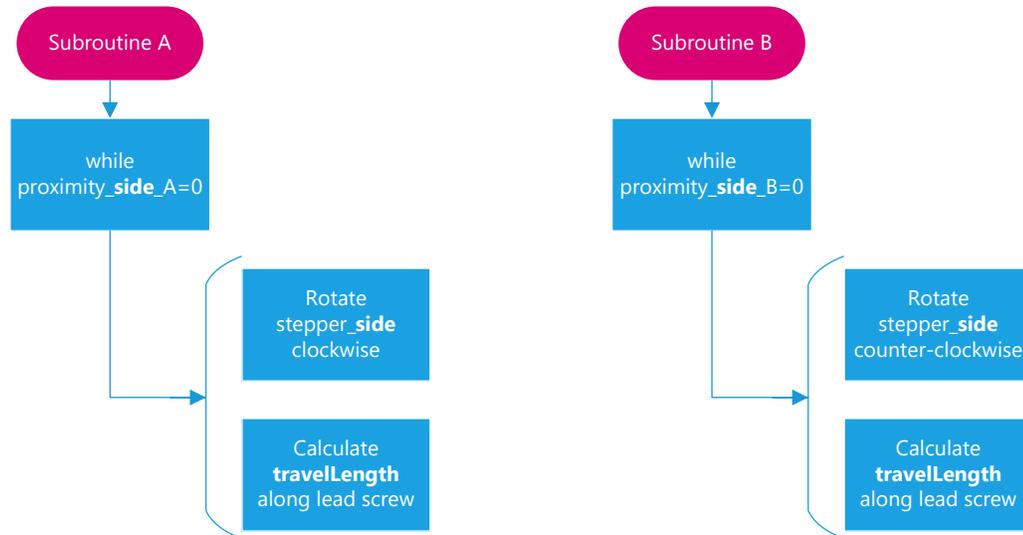


Figure 24: Logical flow chart for subroutines A and B.

Subroutine A includes a while loop that turns the stepper motor clockwise and drive the carriage towards the stepper motor until the proximity sensor 'A' is activated. The length that the carriage travels is also calculated using the number of pulses sent to the stepper and the linear travel per rotation of the lead screw and stored in the **travelLength** variable, which will be used to record the location of leaks in the leak documentation system. Subroutine B is identical to subroutine A except that the stepper is turned counter-clockwise instead of clockwise. The Vertical Nozzle subroutine is shown in Figure 25.



Figure 25: Logical flow chart for the Vertical Nozzle subroutine.

The Vertical Nozzle subroutine turns the servo driving the vertical nozzle for a specified time **vertNozzleTime1**, to get the vertical nozzle to the top of the vertical seam. The servo then turns in the opposite direction for **vertNozzleTime1 + vertNozzleTime2** seconds to bring the nozzle to the bottom of the vertical seam. The servo then drive the vertical nozzle back up to the neutral point by turning for **vertNozzleTime2** seconds. The Return subroutine is shown in Figure 26.

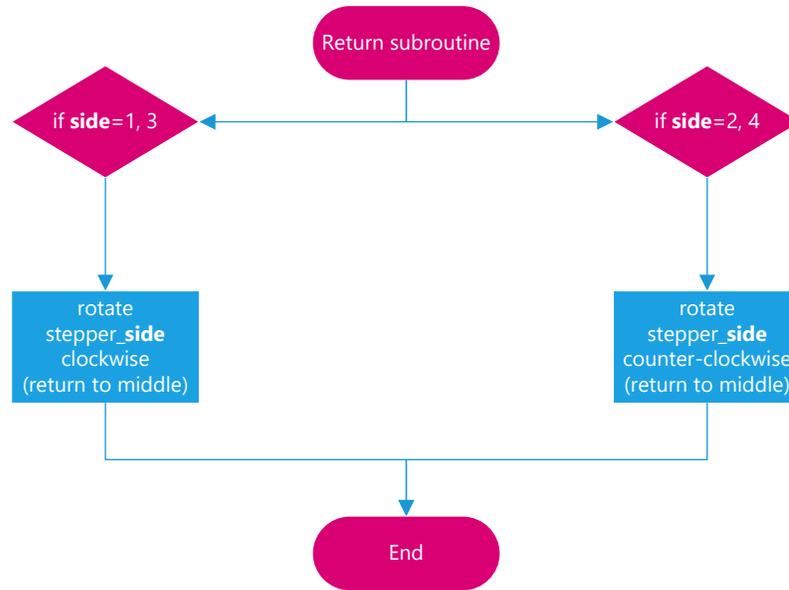


Figure 26: Logical flow chart for the return subroutine.

The Return subroutine simply returns the carriages to the midpoint of their leadscrews. For the long sides (sides 1 and 3), the steppers must rotate a certain number of steps clockwise, while for the short sides (sides 2 and 4), the steppers must rotate a certain number of steps counter-clockwise. The Interrupt subroutine is shown in Figure 27.

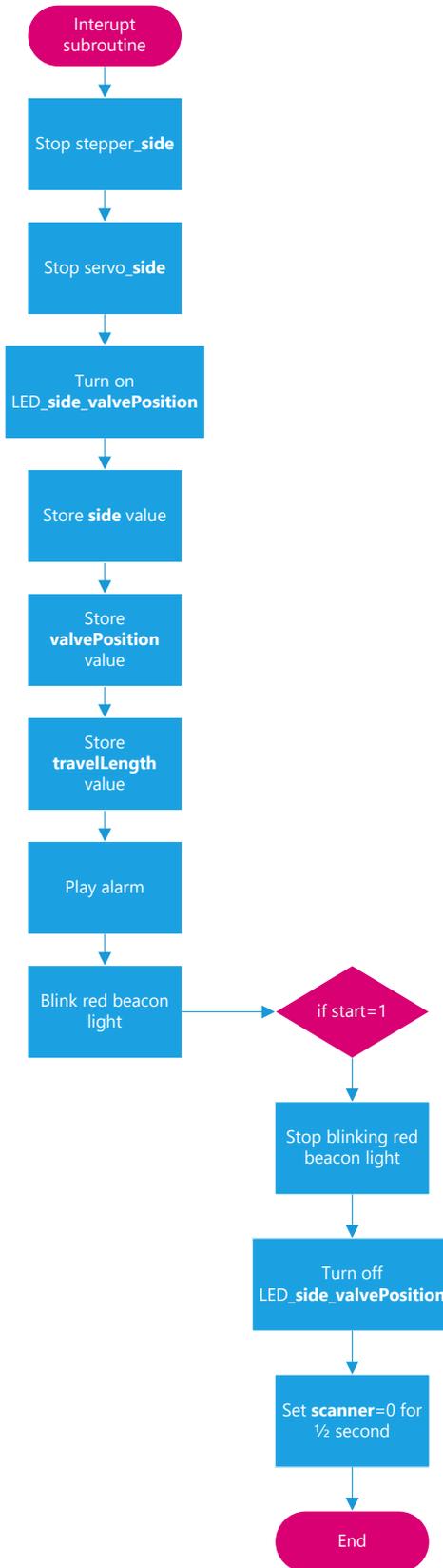


Figure 27: Logical flow chart for the Interrupt subroutine.

The Interrupt subroutine is run anytime a leak is detected (**scanner** = 1) before PLC follows the rest of the program. When the Interrupt subroutine is run, the stepper and servo (if applicable) stop rotating. The corresponding LED is turned on indicating which nozzle is detecting a leak. The **side**, **valvePosition**, and **travellength** values are stored and linked to the product serial number documenting the location of the leak on the unit. An alarm sounds and the red beacon light is flashed informing the operator that a leak has been detected. The system sits idle until the operator can come and mark off the location of the leak with a marker. When the operator presses the start button on the interface, the program continues. The blinking red beacon light is stopped, the LED indicating the location of a leak is turned off, and the **scanner** variable is set to 0 for ½ second. It is set to 0 for this length of time in order to prevent a double detection of the same leak. Now that the **scanner** variable is set to 0, and the Interrupt subroutine is completed, the rest of the program may execute.

### 3.5 BOM and Cost

A cost analysis was conducted for the detailed design. Prices of each item as well as the quantities needed are listed in the in Appendix C. Prices of items listed were obtained from actual suppliers which were in Winnipeg or deliver products to Winnipeg. The cost of raw materials for fabricated parts was estimated to be 50 dollars per part. The total cost is estimated to be \$8804.52 Canadian dollars before tax. For the full bill of materials see Appendix C.

## 4.0 Conclusion

The objective of this project was to design an automated fixture that can scan and detect for leaks along all seams of Price Industries four most common laminar flow air diffusers. A typical air diffuser leak detection test includes pressurizing the diffuser chamber with air infused with an oil particulate. A photometric scanning probe is then manually moved along each seam of the diffuser to see if any oil particulate escapes from the diffuser chamber. Our design includes four lead screw assemblies positioned along each side of the air diffuser. The left and right lead screw assemblies can be manually adjusted inward and outward to accommodate different diffuser widths such as the 4' diffuser, 3' diffuser and the 2' diffuser. On each lead screw assembly, carriages are mounted which house multiple air nozzles that are used to detect for leaks along each seam. Each air nozzle is connected to a hose and all the hoses run through a series of manifolds and electronically actuated solenoid valves before outletting to the ATI particulate scanner, which draws a 1 cfm vacuum. Only one nozzle can be connected to the ATI scanner at any one time meaning only one seam can be detected at a time. Stepper motors control the rotation of the leadscrews and the linear motion of the carriages. This is how the nozzles can detect for leaks along the entire length of a seam. When a leak is detected, the whole assembly stops and the operator must mark off the location of the leak before resuming the automated scanning process. The position of the leak is also documented and linked to the unit serial number for future reference. The entire scanning, detection and documentation systems have been automated which is what the original project objectives specified. This automated system will provide a net benefit to the client by providing and more reliable, repeatable and accurate process for detecting leaks in their laminar flow air diffusers. The automated documentation system also provides an accurate and reliable reference of leak locations for all produced units for quality assurance.

## 5.0 References

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## Appendix A

### Concept Development

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## A.1 Introduction

The concept development section contains the results from the concept generation and analysis phase of the project. The concepts generated were weighted against each other using selected criteria. The results of the comparison resulted in 3 main concepts. We then chose one of those concepts after further comparison of the ideas. This section provides a detailed explanation of the entire concept generate and analysis process.

## A.2 External Research

An extensive external search was conducted to aid in the concept generation and selection phase of the project. This external search consisted of performing a patent search, researching competitor products, consulting standards, and talking with the client and equipment operators.

### A.2.1 Codes and Standards

We found two standards that relate to our project. The first standard, ISO 14664 relates to integrity testing of HEPA filters. The second, CSA Z432-94, is a standard that outlines the safeguarding of machinery. Both these standards will need to be consulted for our final design.

ISO 14664, entitled *Cleanrooms and associated controlled environments*, attempts to standardize the air quality of clean rooms and other controlled environments. Most of these types of environments are protected from foreign particulates by HEPA filters. The standard is broken down into eight sections:

- 1.) a classification for air cleanliness
- 2.) specifications for testing and monitoring
- 3.) test methods
- 4.) design, construction and start-up
- 5.) operations
- 6.) vocabulary
- 7.) separative devices (clean air hoods, glove boxes, isolators and mini-environments)
- 8.) classification of airborne molecular contamination [1].

We are particularly interested in subsection 3, as it relates to the testing of HEPA filters. The standard outlines two main ways in which HEPA filters and their corresponding enclosures may be tested. One of these ways is through a DOP test (dispersed oil particulate test). The DOP test involves mixing oil particulates into an air flow and passing the flow through a HEPA filter assembly. Downstream of the filter, a vacuum nozzle pulls air into an aerosol photometer that determines the

concentration of oil particulates based on scattered light. This is the test method that our client, Price Industries, uses for the HEPA filtered air diffusers. The filter and surrounding enclosure is said to pass the test if the downstream concentration of oil particulate is less than 0.01% of the upstream concentration.

CSA Z432-94, entitled *Safeguarding of Machinery*, is an Occupational Health and Safety standard that contains “minimum requirements for protecting persons from the hazards associated with machinery” [2]. The standard provides a classification of mechanical hazards, machine design, classification and selection of safeguards, as well as information on guard design, ergonomics, inspection procedures, maintenance procedures, and warning signs and labels. Our final design must conform to this standard.

### A.2.2 Patent Search

A thorough patent search was necessary to perform before our brainstorming and concept generation stage. This search provided us with a few initial ideas for our brainstorming sessions and ensured that we were not infringing on any existing patents. Our search was completed using the Canadian Patents Database, which contains over 2 million patents, as well as Google Patents, which has a database of over 7 million patents from around the world. Search terms were confined to “air diffuser, air diffuser leak detection, leak detection, leak detection apparatus, automated leak detection of gaskets, automated leak detection, HVAC leak detection, photometric sniffer, photometer test method, filter testers, HEPA filter leak detection, HEPA filter frame leak detection.”

The HEPA filter DOP test method outlined in ISO 14664 is a standard test and has been performed since the 1950s [1]. Through our patent search, we found one manufacturer who specializes in making devices and equipment relating to aerosol testing of HEPA filters. Air Techniques International (ATI), whose parent company is Hamilton Associates Inc., manufactures photometers, aerosol generators and automated filter testers. Hamilton Associates Inc. holds a patent on one of these automated filter leak testers as outlined in US patent 7694548. The device is shown in Figure A-1.

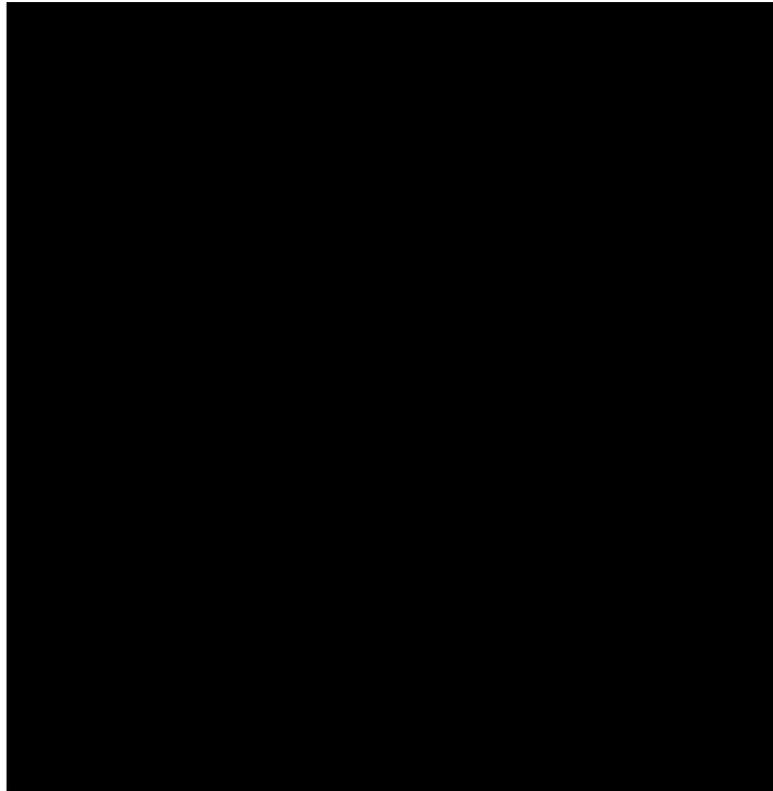


Figure A-1: Automated leak detection apparatus for filters as outlined in US patent 7694548 [3].

This patent was the only one we could find that relates to the automated leak detection of HEPA filters. The device has a small chuck assembly where a filter, respiratory cartridge, filter media or other protective device may be placed and subjected to an airflow concentrated with oil particulate (aerosol challenge). Downstream of the object to be tested, a vacuum pump pulls the air through a photometer where the concentration of challenge is measured. All of this is done automatically. If the concentration is above a certain threshold, the object fails the leak test.

The scope of our project is to use a photometer supplied by ATI to perform a photometric leak detection test (as described in the above patent) on the air diffusers manufactured by our client. While we will be using this photometric test technology in our final design, the above patent has no bearing on the scope of our project and there is no concern with infringing on any patents. The above patent describes an automated leak detection process on small pieces of filter material or respiratory cartridges. The scope of our project is to design an automated test fixture that can use

ATI's photometric leak detection technology to detect leaks along the seams of our client's air diffusers. The purpose of our project is not related to the claims outlined in the patent.

Further patent searches did not yield any further results. A search of our client's competitors' patents did not result in any similar devices to what we will be designing. Our project is meant for internal use in a very specific application and will not infringe upon any other existing patented technologies.

### A.2.3 Client Meetings

Another external source used in the concept generation process was meeting with our client and seeing the current scanning process. When viewing the current scanning method, we made valuable observations that helped us in the concept generation process. We observed:

1. The difficulties in accommodating different product sizes.

This observation made us realize that accessibility was going to be an important design criterion and that any potential design should not negatively impact the current level of accessibility that the operators have when removing the air diffusers.

2. The limited space near the back of the test rig.

Any potential design must be compact enough to fit between the air diffuser and the back of the test rig. As shown on the following page in Figure A-2., there is only 4" of clearance between the back of the air diffuser and the pneumatic cylinders that press the gasket plate onto the air diffuser.



Figure A-2: Clearance around the back of the air diffuser and the test rig [4].

### 3. The inconsistencies in the detection of leaks.

When a leak is present, oftentimes the leaking air will diffuse into the surrounding area and the photometric test device will detect the particulate at a location further away than the location of the actual leak. In the case of an improper gasket seal between the gasket plate and the knife edge of the air diffuser, a significant amount of particulate may escape the air diffuser chamber and give several false positives. This could prove to be an obstacle in any automated design and would have to be considered during our concept generation phase.

### 4. The cumbersome nature of the tubing attached to photometric sniffing device.

The current method of scanning requires the operator to walk around the air diffuser with the photometric device, which causes the tubing to wrap around the test rig and cause potential trip hazards. When generating concepts, we must be mindful of the amount of tubing we are introducing and ensuring that the movement of the automated fixture does not cause tubing to get wrapped around the test rig.

Through discussion with our client, we were also able to generate a few ideas to include in our concept generation stage. These ideas included

- Implementing a continuous rail system around the air diffuser that a carriage could ride on.
- Using angular positioning air nozzles.
- Using three nozzles to detect three seams along one side of the air diffuser at once.

### A.3 Concept Generation

For our internal search, we used individual and group methods for developing an effective concept for the client. The generation of concepts involves taking the customer needs and target specifications to produce ideas that can potentially address the problem at hand. In our team's case, this is the desire for the automation of the leak detection scanning for the HEPA filter diffuser at Price Industries. The general process for concept development is described by Figure A-3.

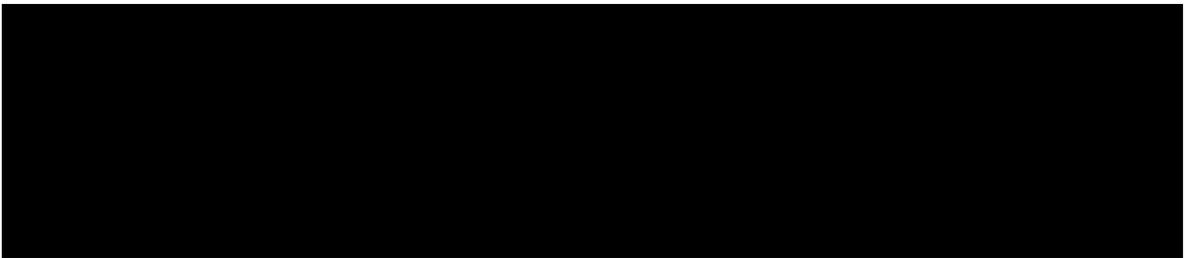


Figure A-3: The general process flow for producing concepts to address the problem at hand, which will then be analyzed to determine the best potential solution [5].

Based upon Figure A-3, the input of customer needs and target specs will drive a concept generation phase that will center on the client. This is an important facet to our method of determining a concept to address the issue, as the customer's satisfaction will be the number one priority.

For the internal search our team will use micro phases to progress towards complete concepts. The first step is to individually brainstorm concepts based upon the customer needs and target specifications. We discussed important requirements and limitations involved with the problem to clarify any misconceptions about the problem. Once the clarification meeting is complete, individual brainstorming was done, allowing for team members to think about the problem.

Following the individual brainstorming step, TRIZ and the method of contradictions was used to move the concept development phase forward. The main reason for utilizing this tool is to provide a way to gain different perspectives on the problem at hand. TRIZ provides a different view point

on the problem by providing solutions to improving one component and preserving another. TRIZ will then produce a suggested solution from the input. The solutions are not clear-cut or specific but provide a pathway for a new idea. In our project, the level of automation was typically chosen as the aspect to improve, while various other categories were chosen to be preserved. The group used this as a primer for a formal team brainstorming session [6].

For the group brainstorming session, the Production Preparation Process method, or 3P method, popularized by Sensei Nakao and the Shingijutsu consultants, was chosen since it provides the most payback. The 3P method provides an organized process in developing ideas and concepts by systematically breaking the problem down and encouraging all participants to bring forward ideas [7]. The 3P method is discussed further in the next section.

### A.3.1 Production Preparation Process (3P)

Typically, the 3P method is utilized for processes in manufacturing and assembly lines, but the process is very effective at breaking down problems of all nature. 3P is effective since it allows for the problem to be broken down into small sub components and then producing several concepts for each of those sub components. To utilize 3P effectively, understanding the philosophy underlying this method is of the utmost importance. The 3P method is based upon sixteen catchphrases, which characterize effective mindsets for brainstorming, with client and efficiency in mind [8].

The catchphrase ‘Spiral upwards to jidoka,’ is very important for the problem in this project. Jidoka, is the Toyota Production systems term for adding human judgment to automated devices [9]. For the automated leak detection scanner, the device must interact with the diffuser like a human by physically marking the locations of leaks and documenting them. The concept that is developed may produce this result by following Jidoka’s four steps closely [8].

The four steps are as follows:

1. Detect the abnormality
2. Stop the machine /operation / line
3. Correct / fix the current condition

#### 4. Seek permanent solution by examining the root cause

Keeping Jidoka in mind for the brainstorming will aid in the development in an automated leak detection scanner that can address all four steps.

Now that the philosophy behind the 3P method is established, the steps to brainstorm concepts is systematic. First, any problem that is being solved is addressing a way to improve a process. In the case of the automated leak detection scanner, the process is the scanning of the HEPA filter diffuser. The process was visually observed to gain an understanding of what the problem is and the associated limitations. The second step was to break the problem down into components involved in the process and potential solution utilizing automation. This was done to simplify the problem and to conduct the seven ways method of brainstorming in 3P. Following the deconstruction of the problem, seven methods were brainstormed as a group to solve each component. From these brainstormed concepts the group ranked the top three concepts for each sub problem and a concept combination table was produced to create permutations of solutions for the automated leak detection scanner [7]. It should be noted that the solutions produced are not limited to the final solution of the problem at hand. Any ideas that were inspired from the process in the end can be used if it deemed valid by the group. The subsequent sections will discuss the steps taken in the 3P process by our team.

##### A.3.1.1 Process at a Glance

To start the 3P process, a process at a glance is done as a group to get an understanding of the process at hand. This is important since the generating of concepts cannot be effective unless it is done with a purpose. If concepts were generated without a thorough understanding of the manual leak detection, the concepts would be arbitrary and not have any context. The impact of having no context for generated ideas increases the risk of completely missing the client's needs. Conducting the process at a glance allows everyone involved with the 3P to be acquainted with the manual leak detection process at Price Industries. Therefore, this first step is very important to allow for efficient and effective brainstorming session during the seven ways brainstorming method.

The current process for leak detection of the HEPA filter diffuser involves the calibration of the ATI photometer and ensuring it functions effectively. Following this, the diffuser to be tested is indexed to the test rig and then pressurized with the test rig's clamping device. The operator ensures no

leaks are present by using the ATI Photometer to check for indications of catastrophic leaks near the gasket. Once this diffuser is properly indexed, the operator then makes passes along the weld and sealant seams of the diffuser to ensure no leaks in those locations. If a leak is detected, the operator removes the diffuser and then fixes the defect. After the repair of the leaks, the process is repeated until no leaks are detected. After the diffuser being tested passes the inspection, a sticker and barcode are placed on the part indicating it is ready for customer use. The process cycle is depicted in Figure A-4.

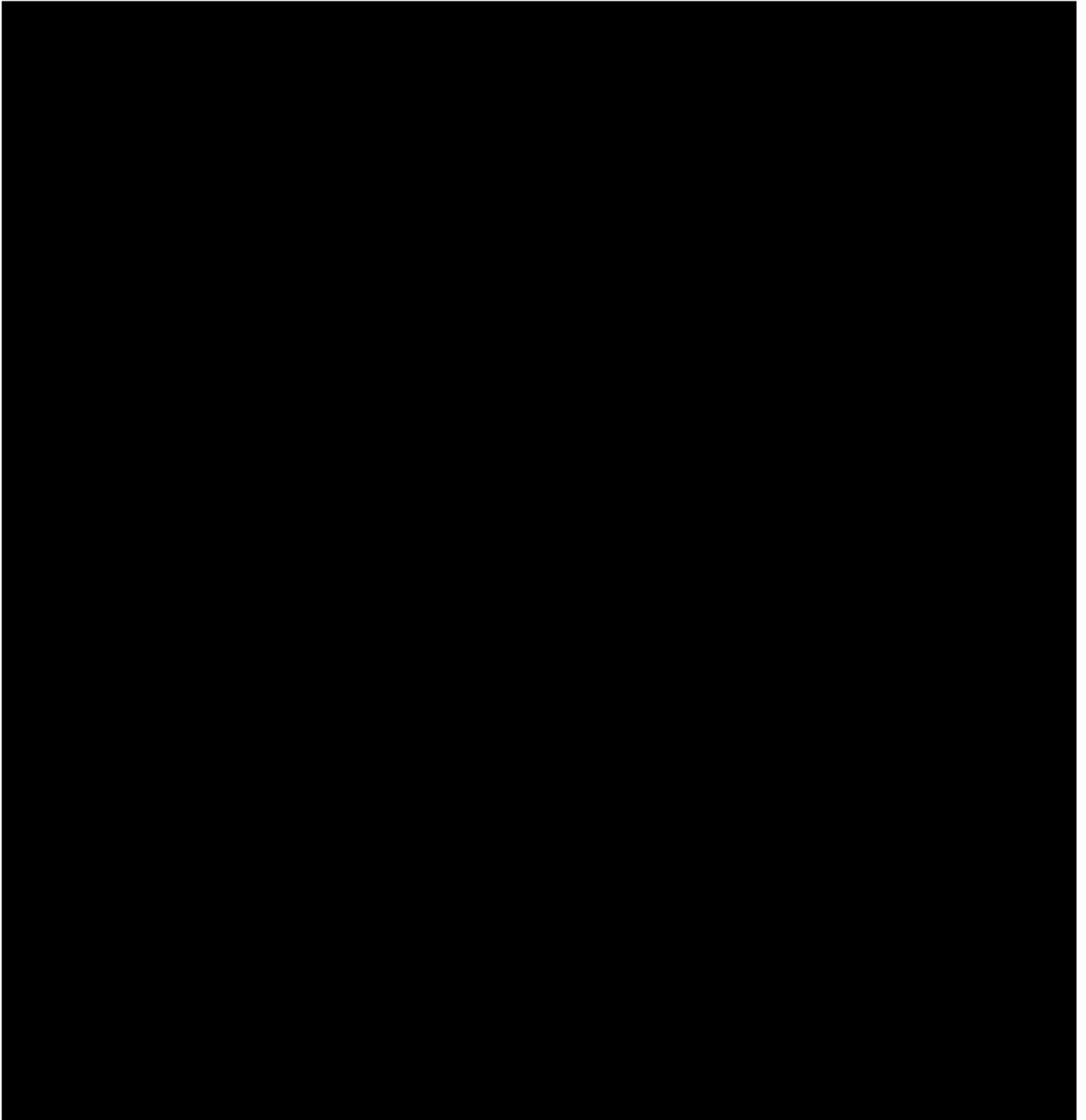


Figure A-4: The process at a glance for the manual leak detection of the HEPA filter diffuser [10].

### A.3.1.2 Seven Ways Brainstorming

The seven ways component of the 3P process is a way of breaking the problem down into subsection and components to simplify the problem. The breakdown could be sub-components to a piece of equipment to be developed or sequential steps in a process. The next step is to brainstorm seven concepts for each of the components the group has divided the problem into. The method helps with creativity by getting obvious solutions out of the way to allow for creativity. After seven concepts are created, the top three concepts are picked out for each component. Usually, the top three concepts would be rapidly prototyped, but due to time limits and context of the automated HEPA filter leak detection device, we created a concept combination table.

To start the seven ways brainstorming process the group broke the problem down in small subcomponents. The main problem is the desire to have an automated HEPA filter leak detection fixture. Our group will break this problem down into two sections: the detection and the leak identification. The detection of a leak involves the automated movement around the diffuser, the device used to detect a leak, and adjustability of size for various diffuser products. The leak identification process involves having a method of determine the location of the leak, a method for documentation of the leaks, and printing a barcode for the diffuser. The figure below provides a visual for the project breakdown of the automated leak detection fixture for the seven ways brainstorming method.

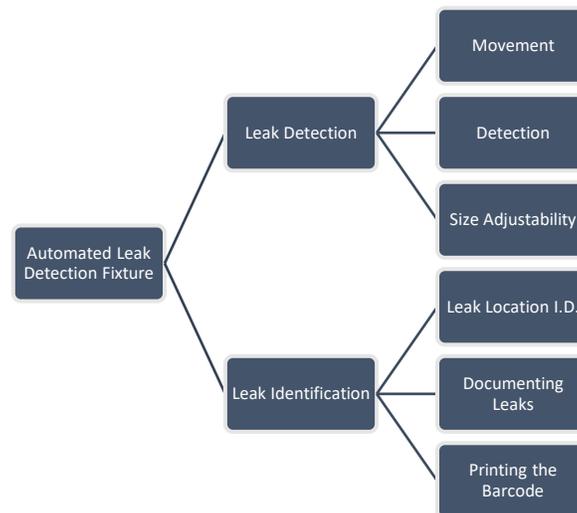


Figure A-5: The breakdown structure of the automated leak detection fixture problem for the seven ways brainstorming method.

Following the breakdown of the automated leak detection fixture, the seven ways method is conducted producing over forty-two different concepts to address each sub component of the problem. The concepts generated are summarized in TABLE A-I below.

**TABLE A-I: THE SEVEN WAYS RESULTS FOR EACH OF THE COMPONENTS FOR THE PROJECT**

Description	1	2	3	4	5	6	7
Movement	Robotic arm	CNC type	4 individual jackscrews	conveyor belt	continuous rail	chain/sprocket/belt	linear actuation
Detection	current sniffer	vacuum hoses	multiple hoses	infrared camera	soapy water	injecting dye/smoke	feel by hand/sound/pressure sensor
Size Adjustability	rack and pinion	jack screw	multiple path programs	different fixtures for each size	pneumatic/hydraulic cylinders and spring	chain/sprocket/belt	amount of linear actuation
Leak Location ID	pneumatic cylinder	electric solenoid	LEDs along path	stopping machine	audible alarm	electronic map/data	shooting magnets
Documenting Leaks	3D model	coordinate system	2D model (T/S/B)	hand documented	automated checklist	photo/video	punch card
Printing Barcode	laser scribe	print label	ink stamp	waterjet/ plasma	slag	ink/laser print onto diffuser	punch stamp

TABLE A-I shows all the concepts produced. The subsequent sub-sections explain each concept and resulting top three ranking of each section that is chosen for the concept combination tree.

### Movement

The movement subsection is to determine a method of moving the detection device around the HEPA filter diffuser. This is critical to our design as the client wants absolute detection automation. The first concept that the group came up with was a robotic arm that would be programmed to move around the HEPA filter diffuser. This is a common automation device and readily available from vendors. A sketch is shown in Figure A-6.

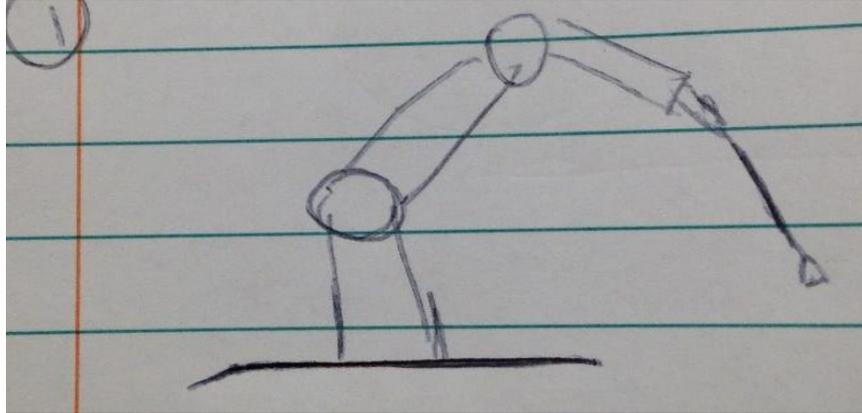


Figure A-6: A sketch of the robotic arm concept [11].

The next idea produced by the group was to create a CNC gantry with a sniffer head to detect leaks on the HEPA filter diffuser. This concept would provide 5 degrees of freedom, since it would move front to back, side to side, up and down, and the detector head would rotate for axis to the sides of the diffuser. Figure A-7 shows a rough schematic of the concept.

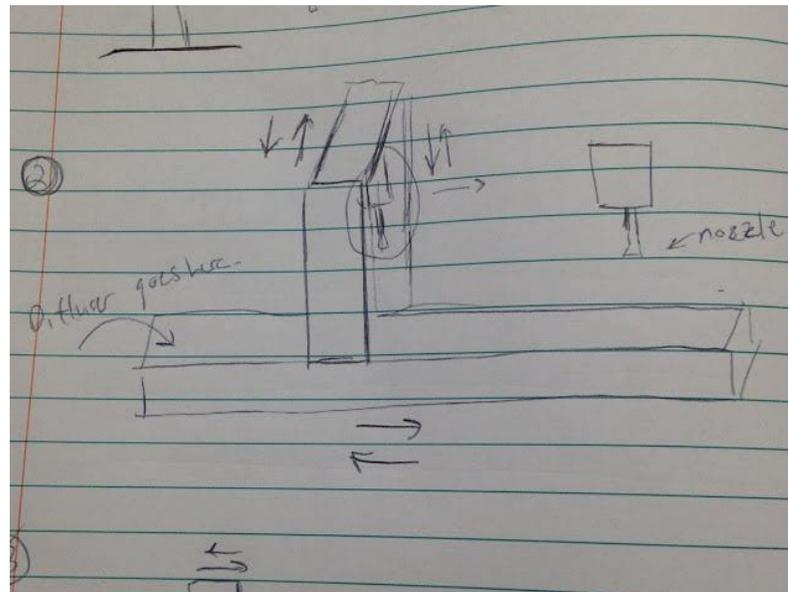


Figure A-7: The CNC movement concept. The detection head would move on a gantry to get 5 degrees of freedom [12].

The third idea would have movement of the detection device actuated by lead screws and mounted carriages. There would be four separate sides that would act on their own and function in sequence.

That is, once one side finishes the next side begins to actuate and detect for leaks. This would continue until all four sides are scanned. Figure A-8 provides a rough sketch of this method.

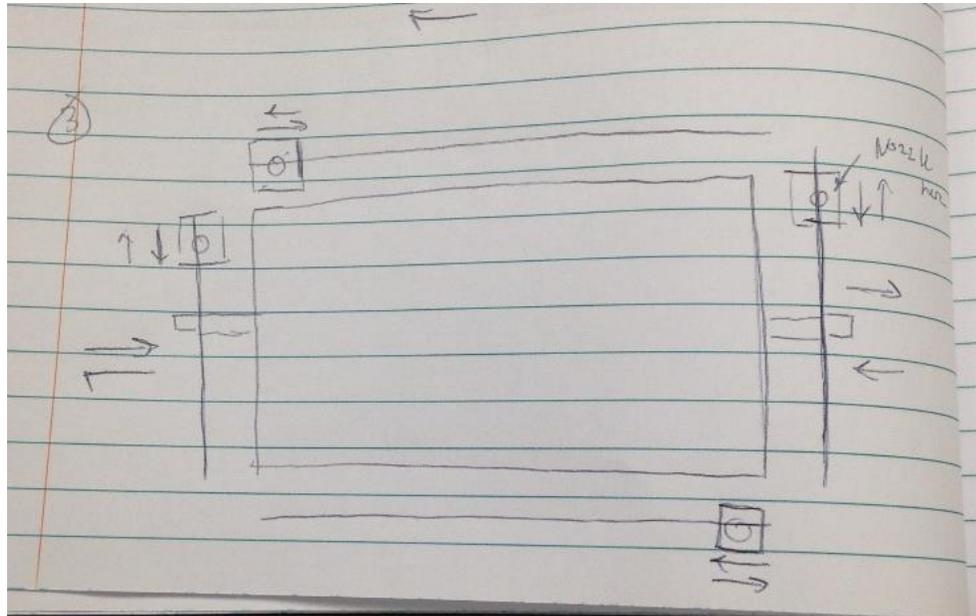


Figure A-8: The lead screw method of actuation around the HEPA filter diffuser [13].

The next proposed method is the use of a conveyor belt to move the detection device around the diffuser. The conveyor belts would be positioned on each side of the diffuser, with four separate detectors. Figure A-9 shows the conveyor belt concept.

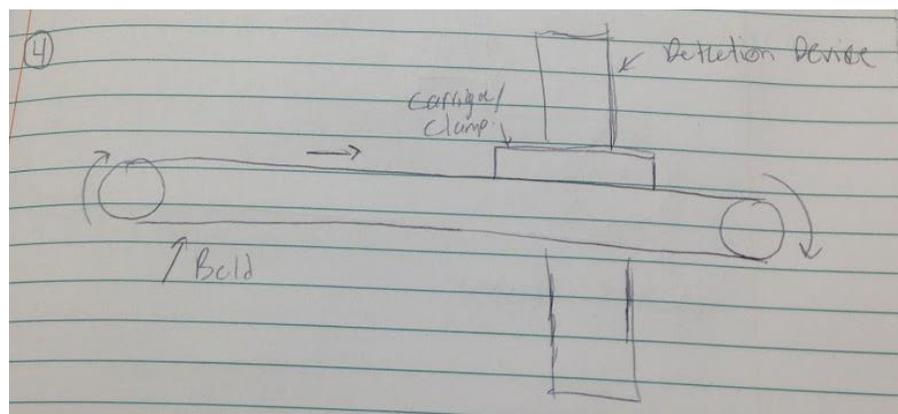


Figure A-9: The conveyor belt method of actuating the detector device around the diffuser. The conveyor belt would have synchronized servos and heavy duty robotic belt [14].

The fifth movement concept involves a continuous rail that would have a carriage move around the diffuser while it detects leaks on the diffuser. This concept would involve having different rails for each diffuser dimension. Figure A-10 provides a sketch of this concept.

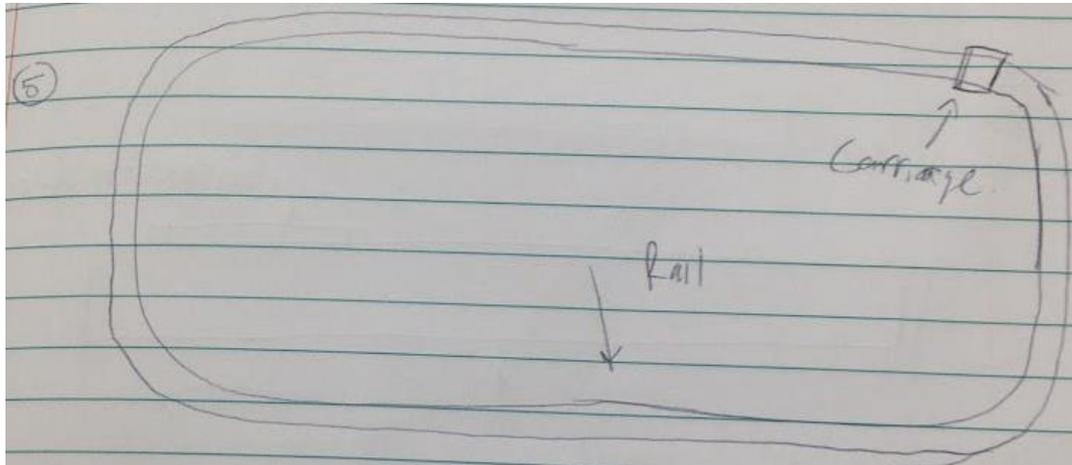


Figure A-10: The continuous rail concept that would have a carriage actuate around the rail. This concept would require various rails for different diffuser sizes [15].

The sixth movement concept involves utilizing a chain and sprocket to move the detection device around the diffuser and leak detection points. Chains are reliable and effective methods of transmitting rotational power into linear power. This method would also need four separate arrangements for each side of the diffuser. Figure A-11 below demonstrates this concept.

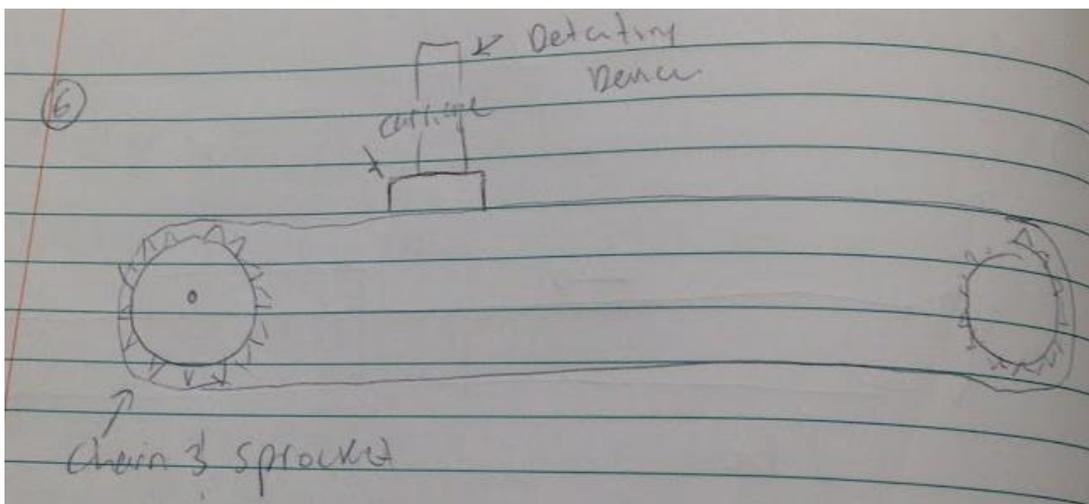


Figure A-11: The chain and sprocket concept of movement around the diffuser [16].

The final movement concept proposes the use of linear actuators to move the detection devices around the diffuser. Again, this would involve an actuator for every side of the diffuser. The linear actuator that would best be suited for this method would be the slider track type linear actuator. Figure A-12 shows this concept.

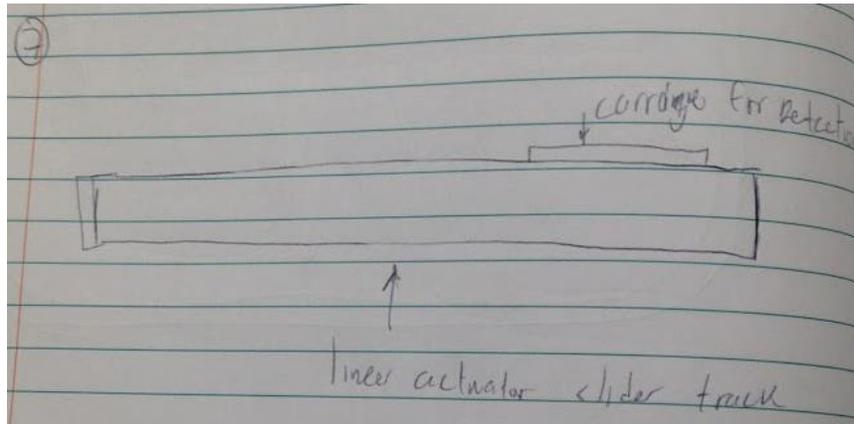


Figure A-12: The linear actuator method of moving the detection device around the diffuser [17].

In TABLE A-II, the concepts described were ranked based upon their performance against the process criteria indicated. The process criteria are determined to be best descriptors of performance for the methods of movement. The criteria in TABLE A-II are also utilized for the other sub components of the project. The criteria are as follows: cost, interaction, simplicity to implement, simplicity after implementation, known process technology, impact of maintenance, off the shelf components, quick changeover, and “roots and vines”. Cost is a metric for the level of expense associated with each method or concept. Interaction is a criterion for how much interaction the operator will have with the product during the automated detection process, essentially how much touch time is involved. Simplicity to implement and simplicity after implementation are associated metrics in that a concept should be simple to implement, but should require minimal upkeep or maintenance for function during the concepts lifetime. These two criteria are a trade-off that need to be balanced. The criteria for known process technology is a descriptor of whether the technology is common or not. This makes a difference since a common technology will be easy to implement and cost effective. Impact of maintenance is another criterion that evaluates how the concept performs after implementation. The maintenance requirements should not be complicated. Complicated maintenance procedures would increase down-time. The criteria for off the shelf components involves easily purchasable components for the device chosen.

This criterion is important since it will reduce cost, maintenance time if replacement components are needed, and ease of assembly when being built and implemented. Having quick change over criterion, revolves around the thought that the automated device should allow the installation of the diffusers and removal as well. It should not obstruct the user from preparing the diffusers to be inspected. Finally, the last criterion, roots and vines is a term describing a concept that has fewer pinch points, trip hazards, or obstructions. This criterion is the safety component of ranking the concepts, as this is very important in the work setting. These criteria developed by the team apply to all the sub components in the seven ways.

The criterion described are used to evaluate the various methods of moving the detector around the diffuser. TABLE A-II shows the result of the four lead/jack screws, continuous rail and linear actuation were the top three concepts for movement.

TABLE A-II: THE RANKING OF THE CONCEPT DEVELOPED UTILIZED THE SEVEN WAYS BRAINSTORMING METHOD

Movement								
Process Criteria	Alternatives							Comments
	1	2	3	4	5	6	7	
Cost	7	5	3	1	6	2	4	1 - Cheapest, 7 - most expensive
Interaction	1	2	2	2	2	2	2	1- least interaction, 7 - most interaction
Simplicity to implement	1	7	2	4	3	4	4	
simplicity after implementation	1	1	1	1	1	1	1	
Known process technology	1	3	2	6	3	6	3	
Impact of Maintenance	7	6	1	4	1	5	3	1 - low, 7 - high
off the shelf components	6	6	5	1	2	4	1	1 - highly available, 7 - least available
quick changeover	1	3	3	3	2	3	3	1 - quickest, 7 - slowest
roots or vines	1	7	3	3	2	3	3	
Sum of scores	26	40	22	25	22	30	24	

### Detection

The next component of the automated leak detection fixture is detection. Detection involves a method of picking up leaks on the diffuser. This component is critical as it is the interface between the ATI photometer and the diffuser for detecting the leak. It is the leak detection device for the fixture. The first concept that is considered is incorporating the current 'sniffer' or suction gun that the operator uses for inspection. This method is depicted in Figure A-13.

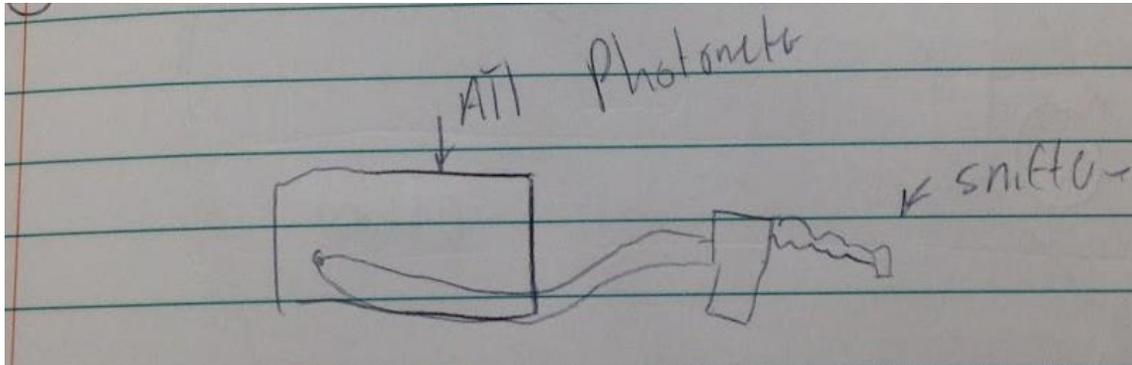


Figure A-13: The ATI Photometer with the current 'sniffer' as a method for leak detection [18].

The next concept for leak detection involves utilizing numerous vacuum hoses situated near leak points. The hoses would be cycled through, turned on or off, using an automated valve to detect a leak. This method is simple but would occupy a lot of space and would need a housing to organize the hoses. The benefit to this method is that it would not require any moving parts around the device. This concept is shown below in

Figure A-14.

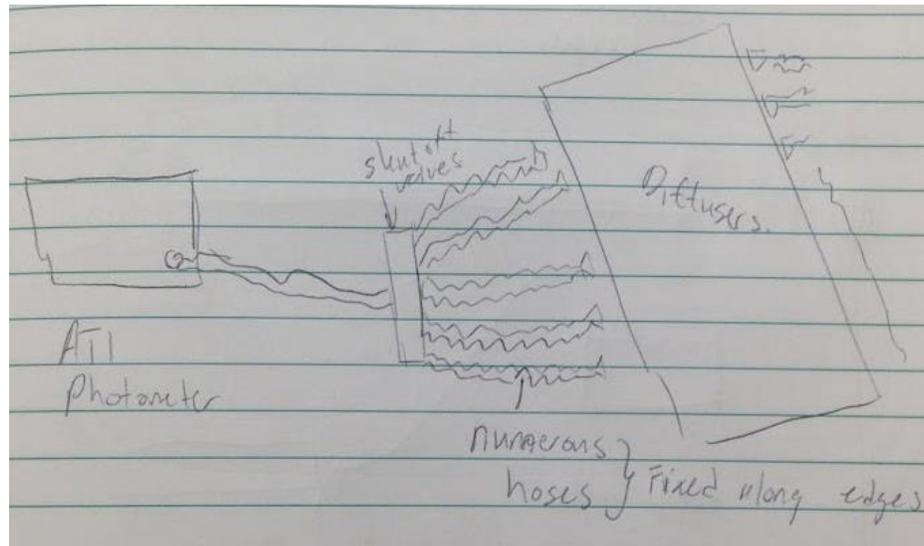


Figure A-14: The concept utilizing multiple vacuum hoses connected to the ATI Photometer [19].

The next concept involves four hoses branching off the ATI Photometer. Each hose would be associated with one side of the diffuser and would be mounted to a carriage to scan all the potential leak locations. Since the ATI Photometer needs a specified airflow to pick up particulate a leak, an automated splitter valve would be required. This concept is depicted in Figure A-15.

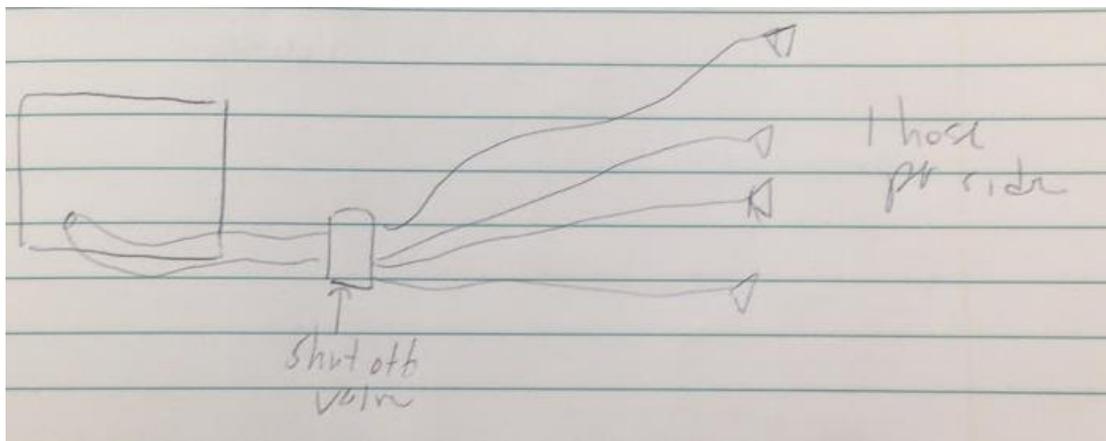


Figure A-15: The four-branch hose configuration with an automated splitter indicated to shut off valves and maintain air flow [20].

The fourth concept that the group developed for detection involved the use of infrared scanning. Infrared scanning can be used to pick up thermal profile changes in the vicinities of a body. If a leak were occurring on the diffuser, an infrared scanner would be able to show this right away using the difference between ambient air temperature and the particulate flow used to pressurize the diffuser. The concept is depicted in Figure A-16.

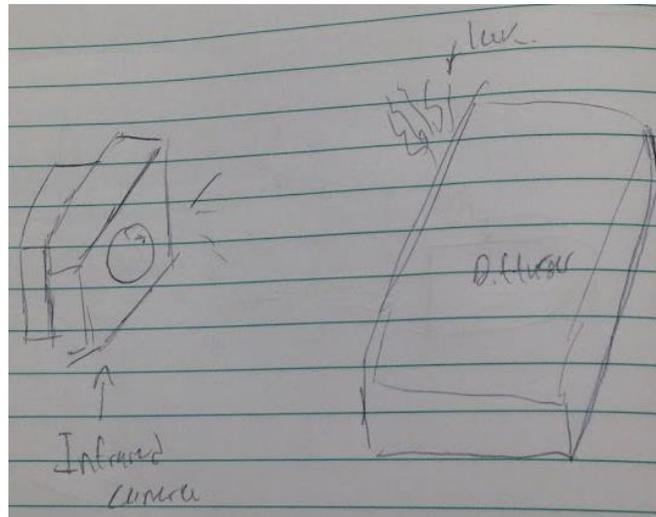


Figure A-16: A concept that would utilize an infrared scanner to detect leaks on the diffuser [21].

The next three concepts generated were determined to not meet our design requirements. In Figure A-17, a concept is shown that would use soapy water applied at the diffuser seams. The leaks would show much like a bike tire that contains an air leak dipped in water.

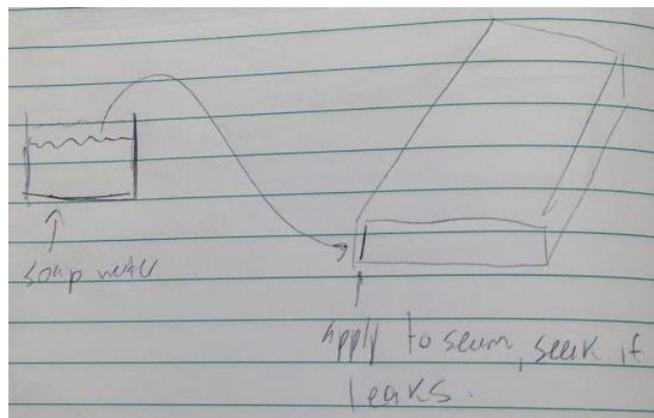


Figure A-17: The concept using soapy water to detect leaks on diffuser. The soapy water would bubble up at seams that leaks are present [22].

Figure A-18 depicts a concept that would inject colored smoke into the particulate flow that pressurizes the diffuser. The colored smoke would then leak out of any improperly applied seals and welds.

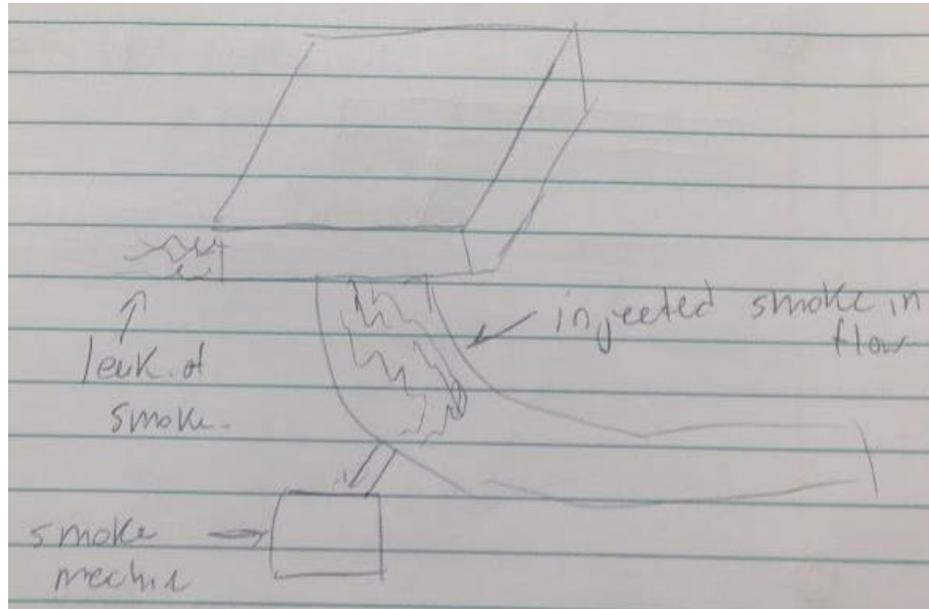


Figure A-18: The concept utilizing colored injected smoke into the down stream particulate flow. The colored smoke would leak out improperly sealed and welded seams [23].

The final concept, shown in Figure A-19, for detection of leaks involves the use of pressure detection either by feel or pressure change sensor to detect a leak. These would be attached to a detector arm that would scan each diffuser seam. The drawback to this is the amount of particulate leaking cannot be determined.

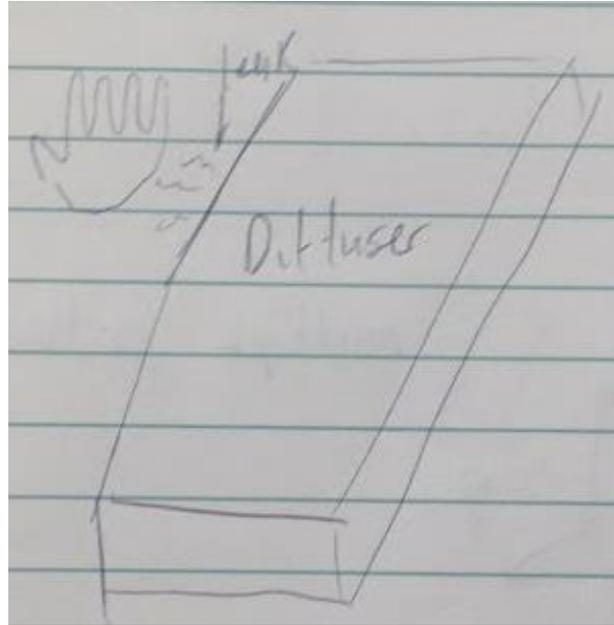


Figure A-19: The detection method that would use pressure to detect leaks on the diffuser. Any pressure above ambient would give off a leak reading [24].

After creating the seven concepts for leak detection, we chose to only look at the first three concepts. This was done because of the client's need for automated detection and a method that would not be invasive or potentially damage the part. Additionally, the client and ISO standard specified the use of the ATI Photometer as the tool to detect the level of contamination in the air surrounding a HEPA filter diffuser. TABLE A-III on the following page shows the rankings of the three concepts for comparison.

TABLE A-III: THE RANKING TABLE FOR LEAK DETECTION METHODS

Detection								
Process Criteria	Alternatives							Comments
	1	2	3	4	5	6	7	
Cost	1	2	3					1 - Cheapest, 7 - most expensive
Interaction	1	1	1					
Simplicity to implement	2	1	2					
simplicity after implementation	1	1	1					
Known process technology	1	1	3					
Maintenance	2	1	2					
off the shelf components	1	2	3					
quick changeover	1	1	1					
roots or vines	1	1	2					
Sum of scores	11	11	18					

A-30

### Size Adjustability

The next sub component for the leak detection portion of the automated leak detection fixture is size adjustability. This component addresses the issue of the fixture being able to scan the different diffuser dimensions that Price Industries provides for sale. The diffusers all have a two-foot width, but the length may vary up to four feet. With this variability in length considered, the adjustability would require the fixture to change its length by the press of a button. In this sub-section the methods developed by the group to address this issue are presented.

The first two concepts function on a very similar principle, as sides of the fixture would move back and forth using a rack and pinion, shown in Figure A-20, or a lead/jack screw, shown in Figure A-21.

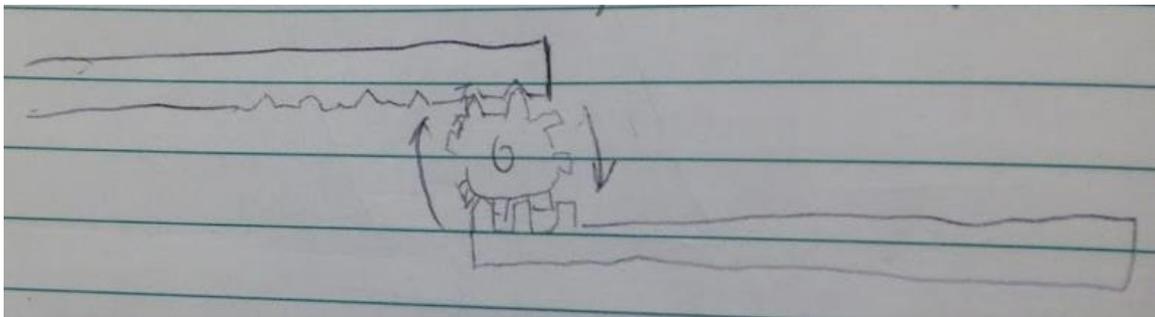


Figure A-20: A rack and pinion sketch for the method of adjusting the dimensions of the automated fixture [25].

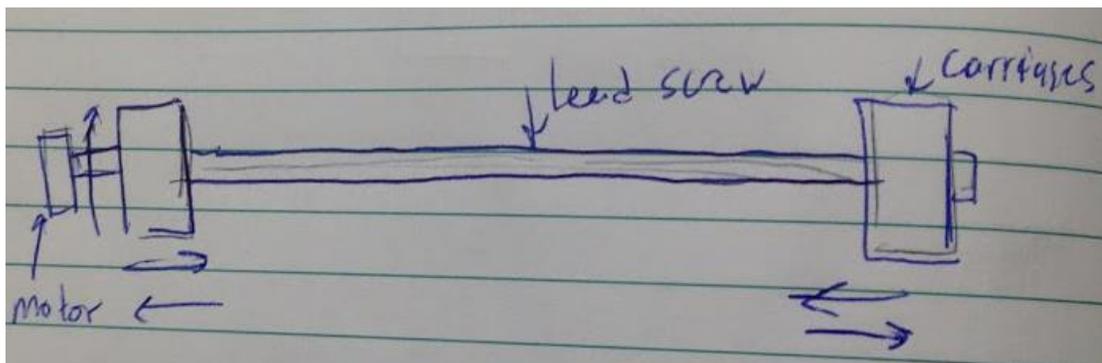


Figure A-21: A lead/jack screw sketch for the method of adjusting the dimensions of the automated fixture [26].

The next concept developed is the use of multiple program paths that would correspond to different diffuser sizes. The user would have to specify which diffuser is being inspected for leaks. This method would be most applicable to a robotic arm or CNC type method of leak detection. Figure A-22 below shows this concept.

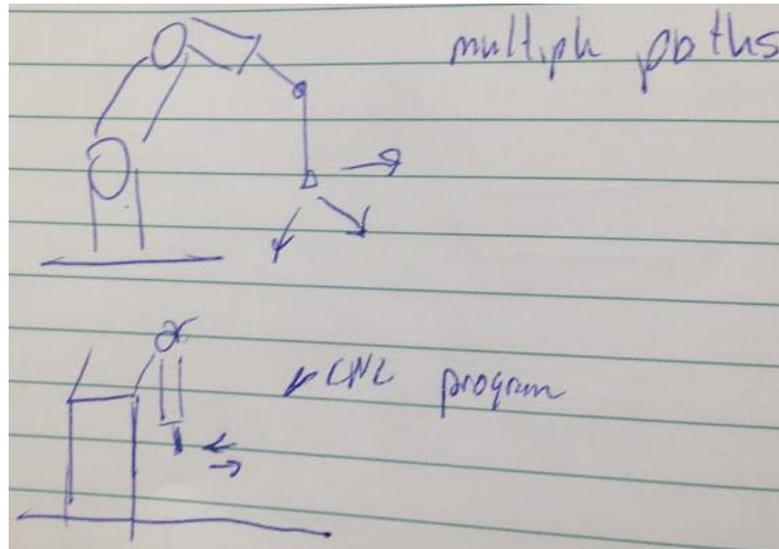


Figure A-22: Multiple program paths would be utilized or account for different diffuser sizes, the operator would simply specify to the machine which dimension the diffuser is [27].

The next concept, shown in Figure A-23, would have the rail system or guide system for a detection device to be changed every time a differently dimensioned diffuser were inspected. This would have the operator change the fixture manually and there for a longer change over time, but reliability in terms of adjustability would be present.

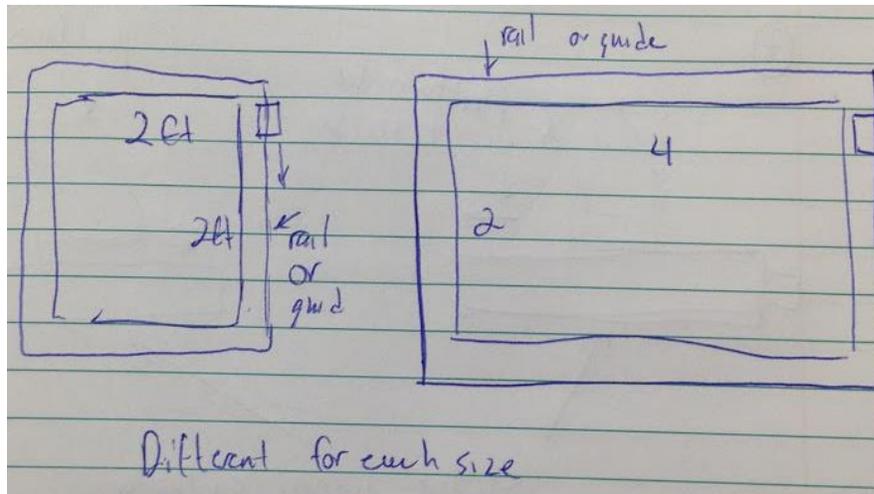


Figure A-23: Differently dimensioned rails or guides for a leak detection system that would be changed for different diffuser dimensions [28].

In Figure A-24, Figure A-25, and Figure A-26 the method of adjusting the automated fixture is similar to the first two methods. The concept in Figure A-24 uses a pneumatic or hydraulic cylinder to adjust the width to accommodate different diffuser dimensions.

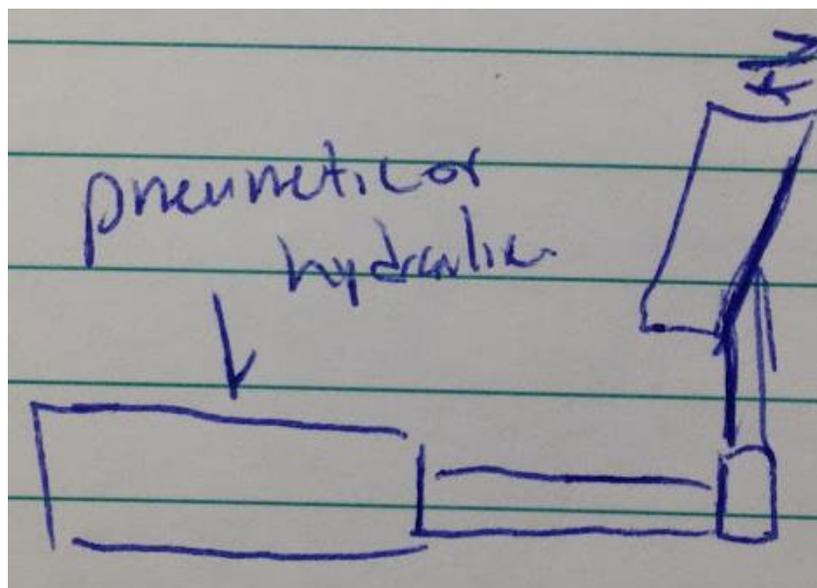


Figure A-24: A concept that utilizes a pneumatic or hydraulic cylinder to change the dimensions of the automated fixtures sides in order to accommodate Price Industries product range [29].

Figure A-25 shows a concept that would use a chain and sprocket system to narrow or widen the automated leak detection fixture.

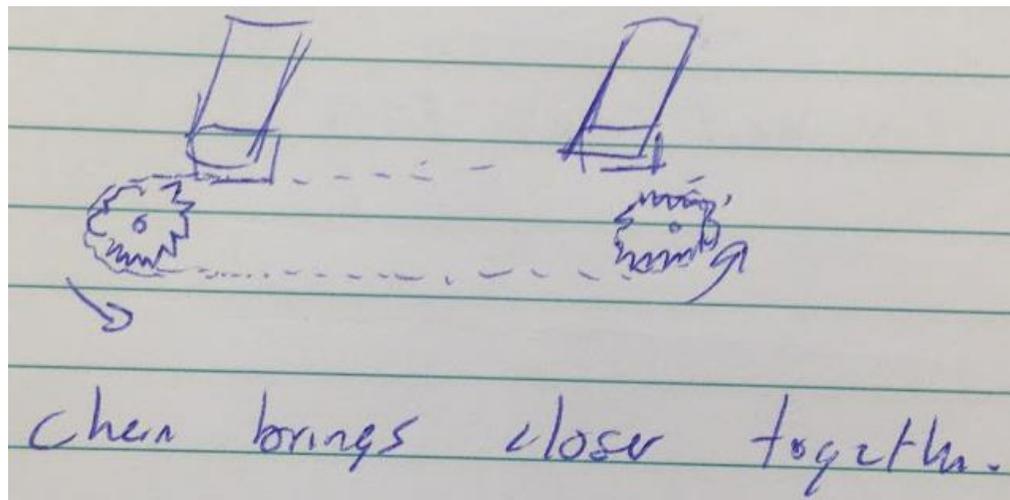


Figure A-25: A concept that would use a chain and sprocket to change the dimensions of the automated fixtures sides in order to accommodate Price Industries product range [30].

Finally, the last concept for adjustability, shown in Figure A-26, would use linearly actuating slider tracks to adjust the automate leak detection fixture for different diffuser dimensions.

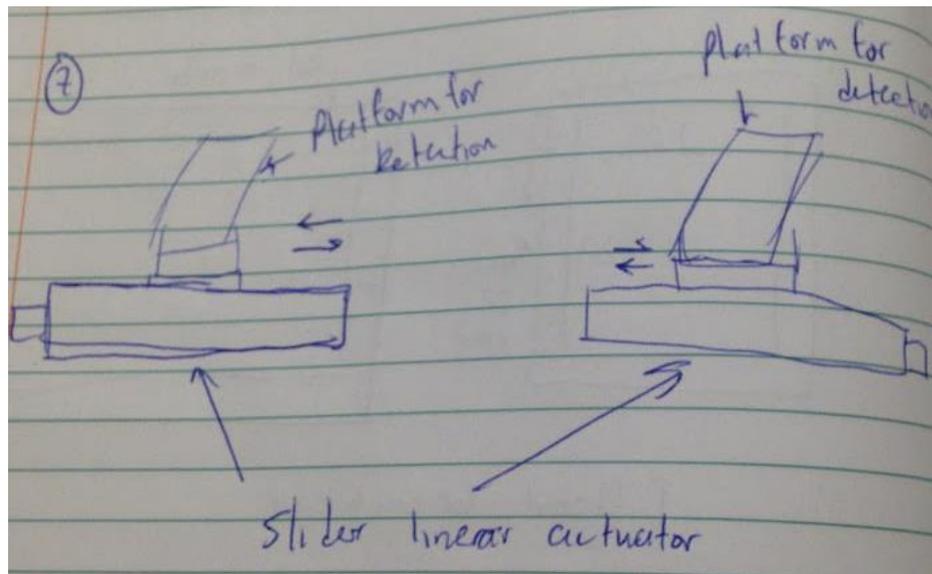


Figure A-26: A concept uses a linearly actuating slider track to change the dimensions of the automated fixtures sides in order to accommodate Price Industries product range [31].

After brainstorming the many concepts for size adjustability, the concepts were ranked for each of criteria established previously in the movement section. From this exercise, the top three results were determined to be the rack and pinion, the differently sized rails or fixtures, and the lead/jack screws. The results from the ranking are shown in TABLE A-IV on the following page.

TABLE A-IV: THE RANKING RESULTS FOR THE SIZE ADJUSTABILITY CONCEPTS

Size Adjustability								
Process Criteria	Alternatives							Comments
	1	2	3	4	5	6	7	
Cost	4	4	1	5	3	4	2	1 - Cheapest, 7 - most expensive
Interaction	2	2	1	3	2	2	2	
Simplicity to implement	2	2	7	6	2	2	1	
simplicity after implementation	2	2	1	7	2	2	2	
Known process technology	1	6	5	5	1	4	1	
Maintenance	3	7	1	3	3	6	1	
off the shelf components	4	6	5	6	1	1	1	
quick changeover	4	2	1	7	4	4	2	
roots or vines	2	2	1	2	2	2	2	
Sum of Scores	24	33	23	44	20	27	14	

### Leak Location Identification

The leak location identification involves marking off the leak on the diffuser for the operator to know where a faulty seal is. This is an important a vast improvement over the current operation as there is no mark for where a leak is, the standard is to simply remove the diffuser every time a leak is detected. This process is slow and inefficient since it relies on the operator to know exactly where the leak is. To address this issue, a leak identification method would prove useful and save time as the operator could repair leaks after they occur or see where exactly a leak is.

The first two concepts produced by the group are very similar. Both involve using a stamp and an actuator to press the mark onto the diffuser where a leak is. The difference between the two is the use of pneumatic cylinder in Figure A-27 and an electric solenoid Figure A-28.

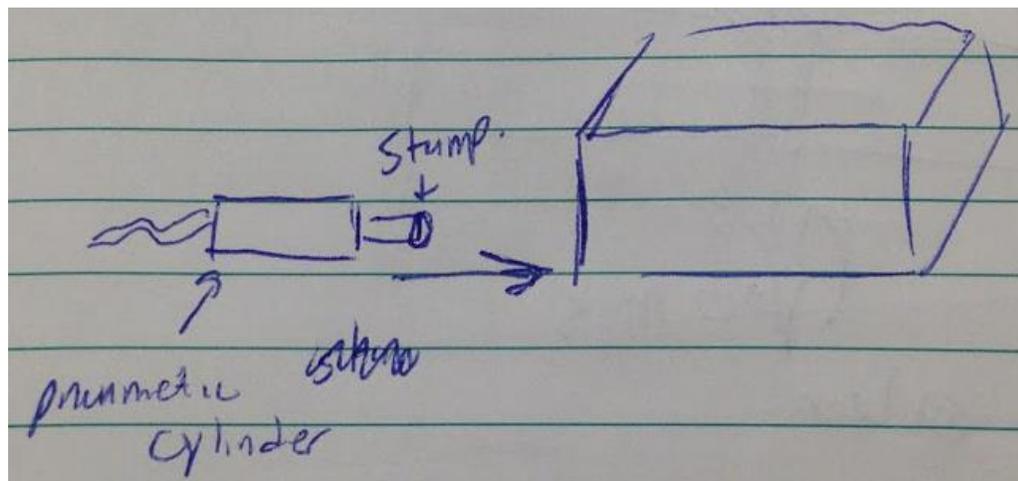


Figure A-27: Using a pneumatic cylinder to stamp the diffuser to indicate a leak [32].

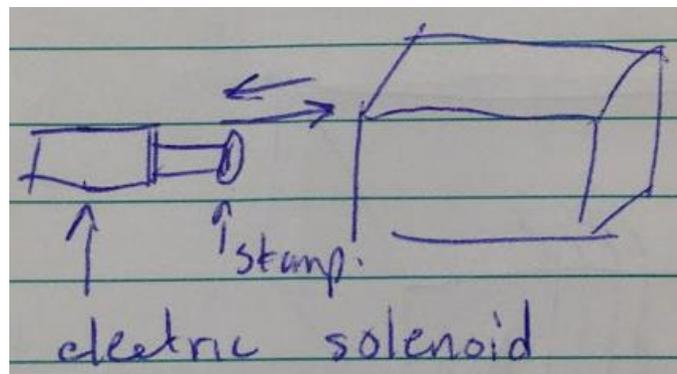


Figure A-28: Using a solenoid cylinder to stamp the diffuser to indicate a leak [33].

The next concept, shown in Figure A-29 below, uses a strip with tightly spaced LED's that will light up where a leak is. The LED's will be in three rows for the top, side, and bottom seam of the diffuser. The corresponding LED would light up at the location and indicate whether the leak is on the top, side, or bottom. These LED's would stay lit until the fixture completes its passes of the diffuser and the operator would then manually mark the leaks off.

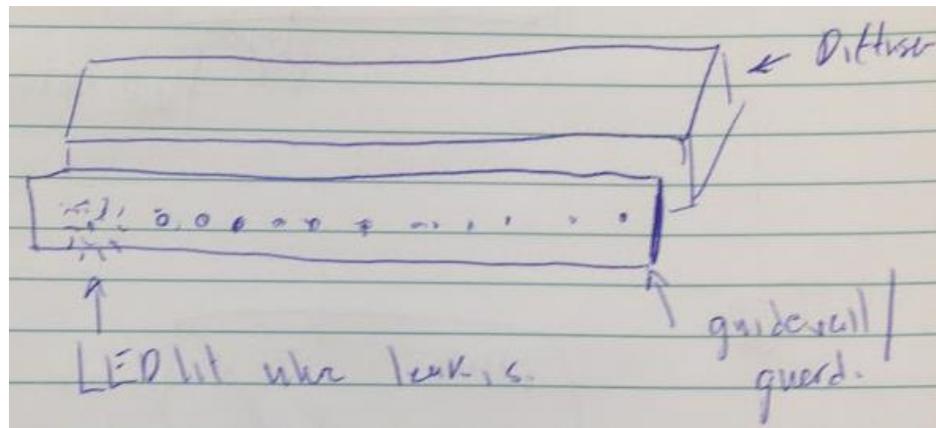


Figure A-29: The LED strip concept for locating a leak on the diffuser. The LED would light where the detector senses a leak [34].

The next concepts, shown in Figure A-30 and Figure A-31, involve stopping the automate leak detection fixture every time it detects a leak. For Figure A-30, once the automated leak detection fixture is halted, the operator would mark off the product where the leak is located. This method would also have an LED on the leak detection device indicating if the leak were on the top, side, or bottom seam of the diffuser to aid the operator. The operator would mark off all leaks as the fixture stops and would then remove the diffuser to repair after the fixture has completed the inspection. For the method depicted in Figure A-31, the leak detection fixture would stop and sound an alarm every time a leak is detected. The operator would then also mark the leak off, and then the automated device would continue its inspection.

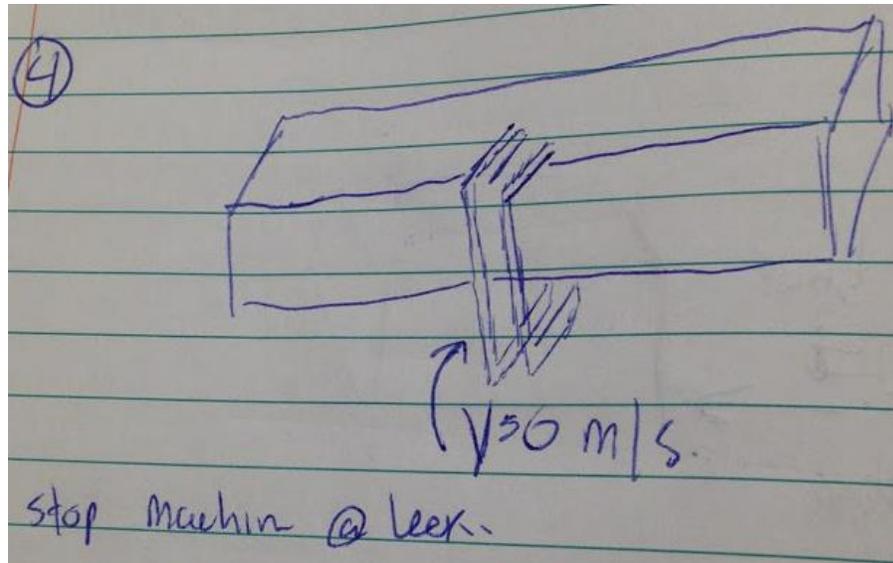


Figure A-30: The method of identifying leaks by stopping the fixture. The operator would then mark off the location of leak for later when the repair is to be done [35].

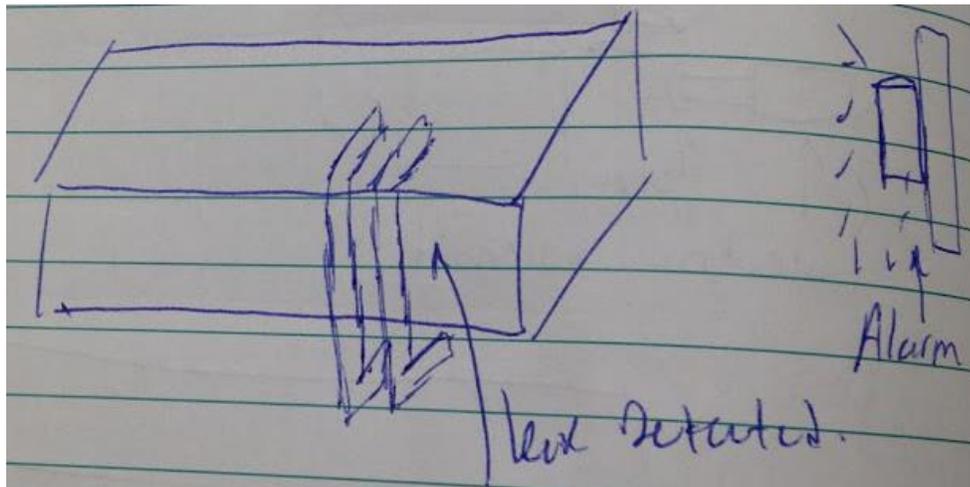


Figure A-31: This method depicts the detection device stopping and sounding an alarm every time a leak detected. The operator would then proceed to mark the leak off [36].

The next two concepts are both unique from the previously discussed methods for leak identification. In Figure A-32, a method that would plot the detected leaks on a computer screen would be shown. The output would be shown at the end of inspection process for the operator to look at and manually mark off leaks on the diffuser.

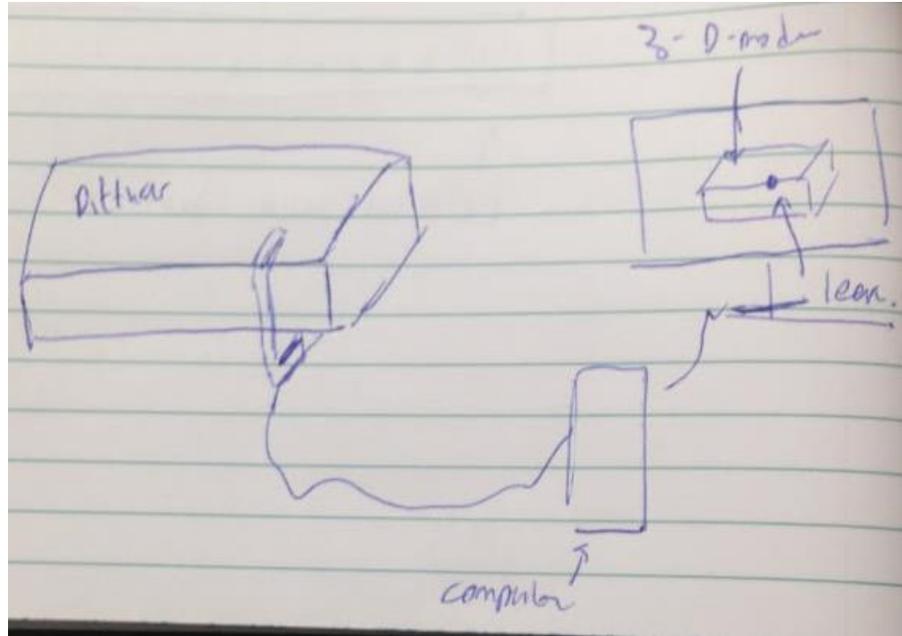


Figure A-32: The method of identifying leaks by displaying them on a 3-D model [37].

The next concept for leak identification is shown in Figure A-33, this method would use magnets that would be released at locations where leaks are. A magazine would be present for the top, side, and bottom seams. When a leak is detected, a shunt in the tube would lift and release the magnet to stick onto the sheet metal diffuser.

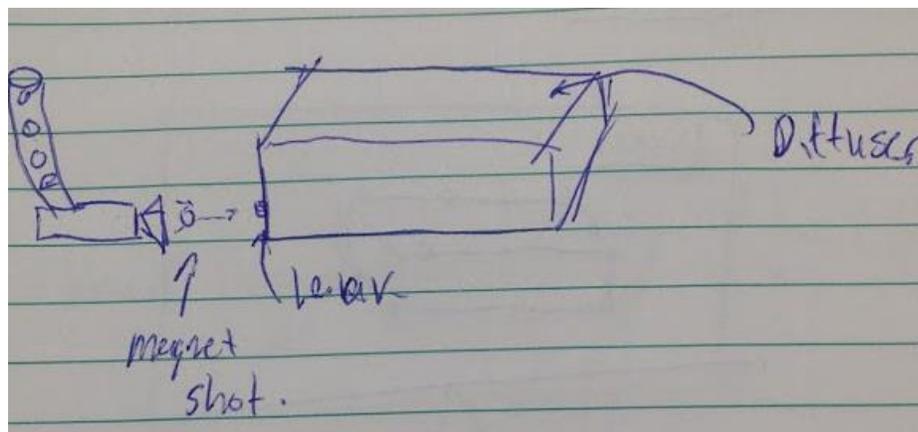


Figure A-33: The method of documenting leaks by attaching a magnet to the diffuser. A shunt in the magnet gun would and release a magnet once the leak is detected [38].

Following the concept generation, we placed the concepts into the evaluation matrix with the previously stated criterion and ranked them accordingly. The results of the ranks are shown in TABLE A-V. The rankings yielded the pneumatic cylinder, electric solenoid and stopping the machine for leak identification as the top three concepts.

TABLE A-V: THE RANKING RESULTS FOR THE SEVEN DIFFERENT LEAK IDENTIFICATION CONCEPTS

Process Criteria	Leak Location ID							Comments
	Alternatives							
	1	2	3	4	5	6	7	
Cost	6	6	3	1	2	3	5	
Interaction	1	1	5	7	5	3	3	
Simplicity to implement	6	6	3	1	2	3	3	
simplicity after implementation	1	1	5	6	5	3	3	
Known process technology	1	1	5	1	4	5	5	
Autonomous maintenance	4	1	7	1	4	1	4	
off the shelf components	1	1	6	1	1	7	5	
roots or vines	3	3	7	1	2	3	3	
Sum of Scores	23	20	41	19	25	28	31	

A-42

### Documenting Leaks

The next component in the leak identification portion of the project involves documenting the detected leaks. The documentation will revolve around locating and stating whether the leak was successfully repaired. The benefit to having a documented history of leaks for the HEPA filter diffusers is that when a defect occurs in the field it can be traced back to a root cause. Additionally, since these diffusers are utilized in critical control environments, such as medical and clean room applications, a high degree of precision and attention to quality is highly valued by the consumers of the product. This attention to quality assures the customer the product is reliable and will function as stated. From the 3P exercise, seven alternatives were determined by the group as potential solutions.

All the concepts produced in the seven ways exercise revolve around having a co-ordinate system to locate and trace back leaks. In fact, all but one concept will utilize a co-ordinate system as an essentially principle for documentation. The first three concepts will utilize a computer model and paperless documentation of leaks. All the information will be stored on a database, which will have the specific diffusers barcode associated with a product history for quality. Figure A-34, will utilize a 3-D model with the points of leaks indicated on the model with co-ordinates. A 3-D method of documenting leaks would be effective in providing a visual aid as to where the leak is located on the diffuser in question.

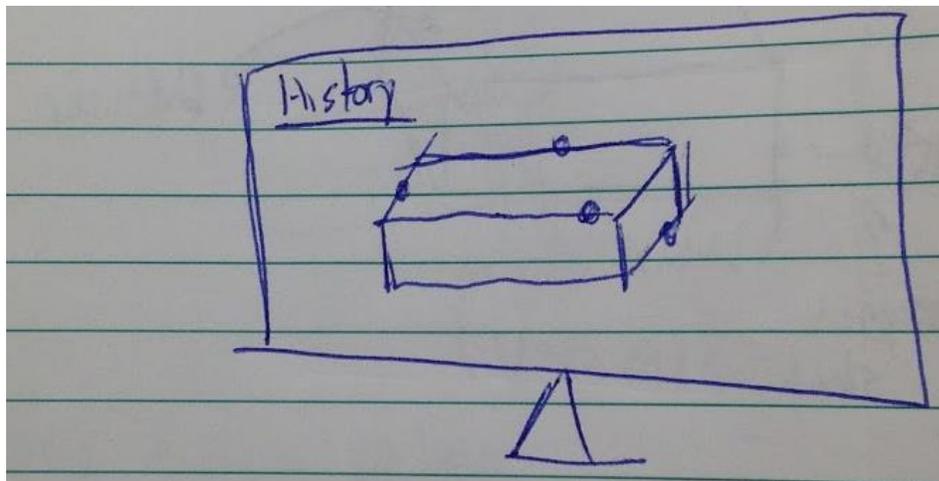
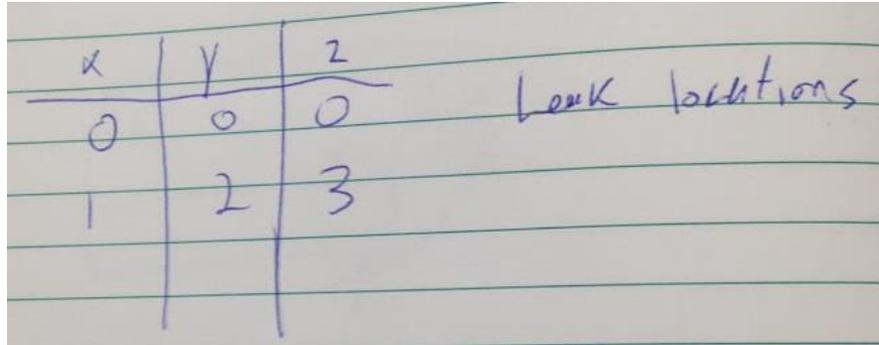


Figure A-34: A method of documenting leaks utilizing a 3-D visual model with co-ordinates and historical leak information [39].

The next concept, Figure A-35, takes a different route in that it does not utilize a visual aid and only stores co-ordinates of leaks based upon the dimensions of the diffuser. This would be stored a table of points, co-ordinates and general information regarding the leak.



X	Y	Z
0	0	0
1	2	3

Leak locations

Figure A-35: A method of documenting leaks simply using co-ordinates of the leaks based on diffuser dimensions. The table that would be produced would also contain historical leak information [40].

The method for leak documentation shown in Figure A-36 would utilize a 2-D model as a visual aid and function much like the concept in Figure A-34.

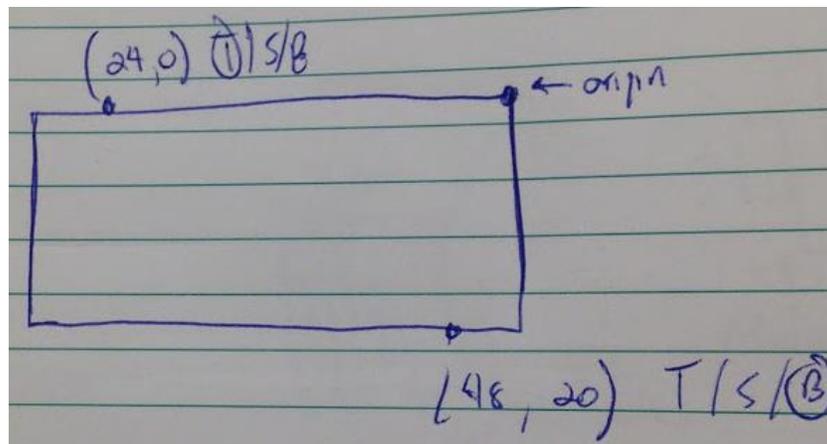


Figure A-36: A method of documenting leaks utilizing a 2-D visual model with co-ordinates and historical leak information [41].

The next two concepts discussed are both generated list of leaks with co-ordinates. These lists would either be hand documented by the operator or automatically printed by a computer once

the automated leak detection fixture completes the inspection process on the diffuser. Figure A-37 and Figure A-38 depict these concepts.

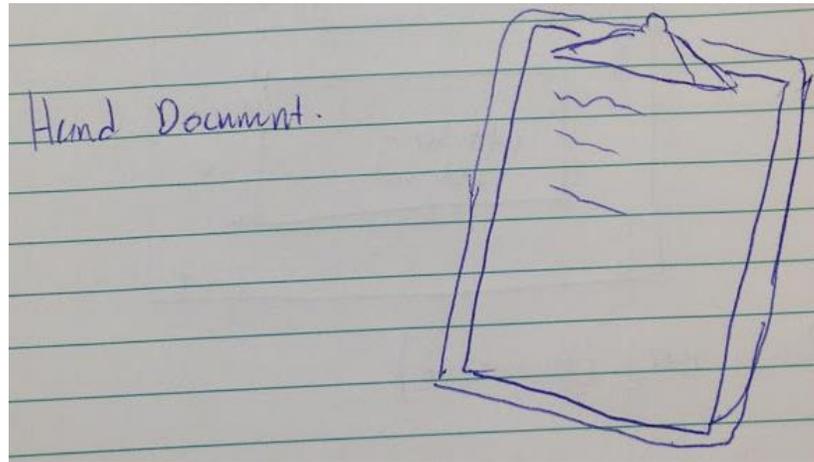


Figure A-37: A hand written document that the operator would use to indicate leak location and history. This document would then be transferred to a computer database or stored in a physical filing area [42].

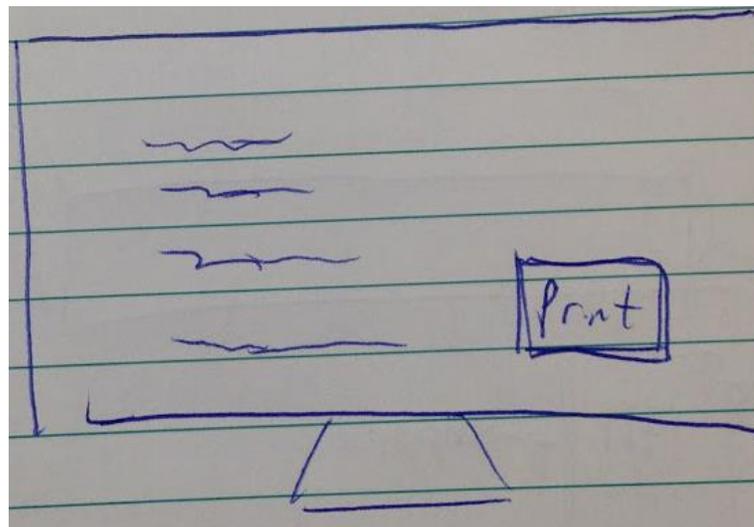


Figure A-38: An automated leak location print off list that would be produced by a computer once the automated leak detection fixture completes the diffuser inspection. This would be stored physically in a database or transferred to an electronic one [43].

The final two concepts are presented in Figure A-39 and Figure A-40. The concept shown in Figure A-39 for documentation of leaks involves videotaping or taking pictures of the leaks. The pictures or videos would be stored in the electronic database for later reference.

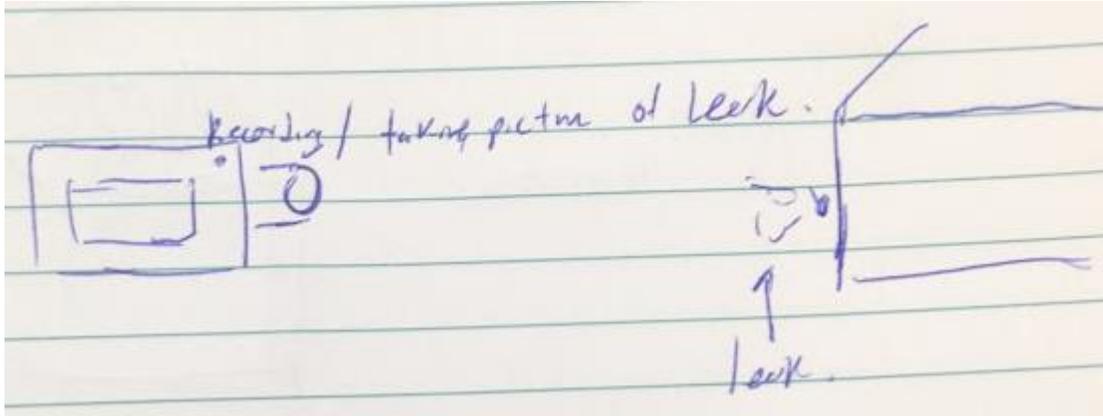


Figure A-39: A videotaping method for documenting leak locations and history of the diffuser [44].

The method shown in Figure A-40 involves using punch card that would have a 2-D schematic with equally spaced co-ordinates for leak locations and a punch category for top, side, or bottom seams. A machine of some sort would punch the card and indicate where the leak is. This punch would be stored physically.

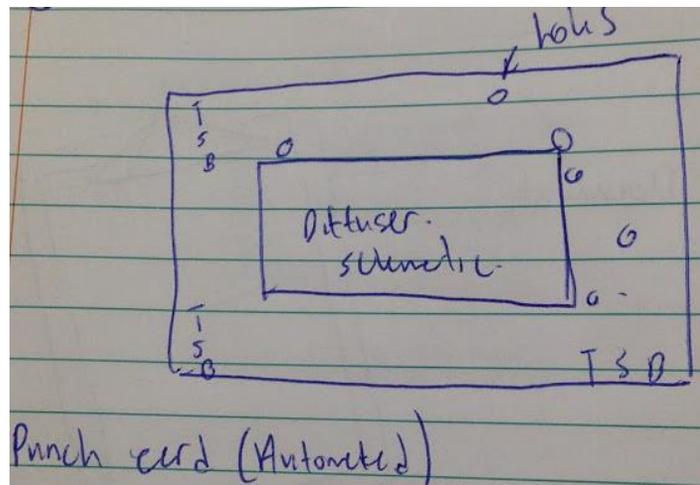


Figure A-40: A punch card method of storing the history of leaks on diffusers. Punch locations would be co-ordinates and indicate which the seam the leak occurred on [45].

Following the determination of seven concepts for leak documentation, each was ranked against the selected criteria as shown in TABLE A-VI. The final three concepts that our group will focus on for the final concept development phase will be the electronic co-ordinate system, the 2-D model, and the automated checklist that will be printed off once the detection has finished its inspection.

TABLE A-VI: THE RANKINGS FOR METHODS OF LEAK DOCUMENTATION

Documenting Leaks								
Process Criteria	Alternatives							Comments
	1	2	3	4	5	6	7	
Cost	2	2	2	1	2	7	2	
Interaction	1	1	1	7	1	1	1	
Simplicity to implement	7	2	2	1	2	6	5	
simplicity after implementation	4	1	4	1	1	4	4	
Known process technology	7	2	4	1	2	4	4	
Autonomous maintenance	1	1	1	5	1	6	6	
off the shelf components	7	1	4	1	1	5	5	
quick changeover	1	1	1	6	1	5	6	
roots or vines	1	1	1	6	1	5	6	
Sum of Scores	31	12	20	29	12	43	39	

A-48

### Printing Barcode

Printing the barcode for the HEPA filter diffuser is the final sub-component for the leak identification component. This sub-component simply needs to produce a barcode for the diffuser once it has passed all leak inspection testing. All the methods the team came up with revolved a barcode being stamped, printed, scribed onto the diffuser by some method. Figure A-41 shows a method which uses a laser to inscribe the barcode directly onto the diffuser.

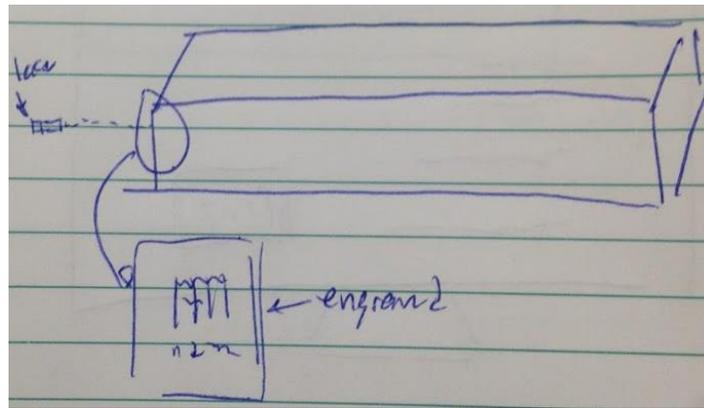


Figure A-41: A laser would inscribe the barcode onto the diffuser once it has passed the leak detection test. This would occur after the automated fixture has completed its inspection [46].

The method shown in Figure A-42 involves printing a barcode sticker and applying it to the diffuser.

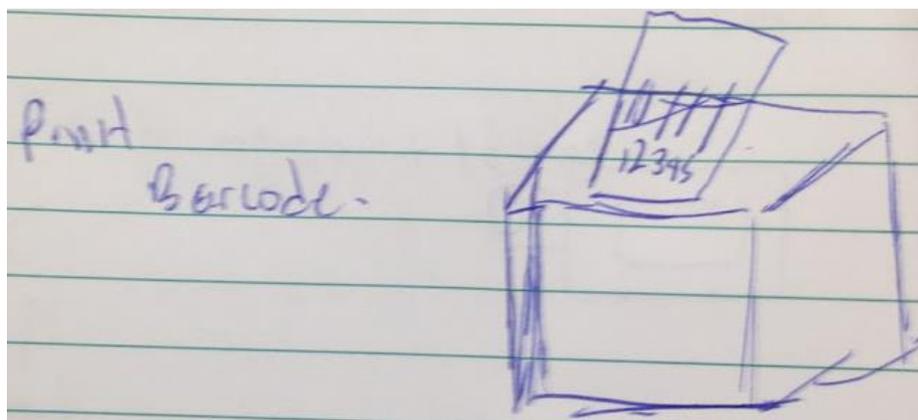


Figure A-42: A barcode sticker would be printed off after the diffuser passes the leak inspection by the automated fixture. The operator would then proceed to place the sticker on the diffuser [47].

Figure A-43 shows how an ink stamp could be used to apply the barcode to the diffuser.

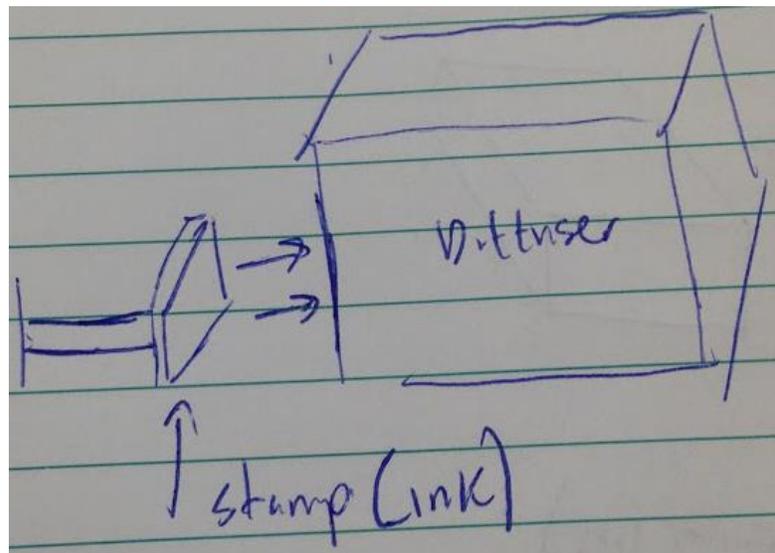


Figure A-43: This method of barcode application would use an ink stamp that would function on an actuator of some sort to place a barcode on the diffuser. Again, upon successful pass of the inspection this will occur [48].

Figure A-44 shows how a water jet or plasma cutter could be used to inscribe a barcode. It would be difficult to control the depth of the inscription using these methods.

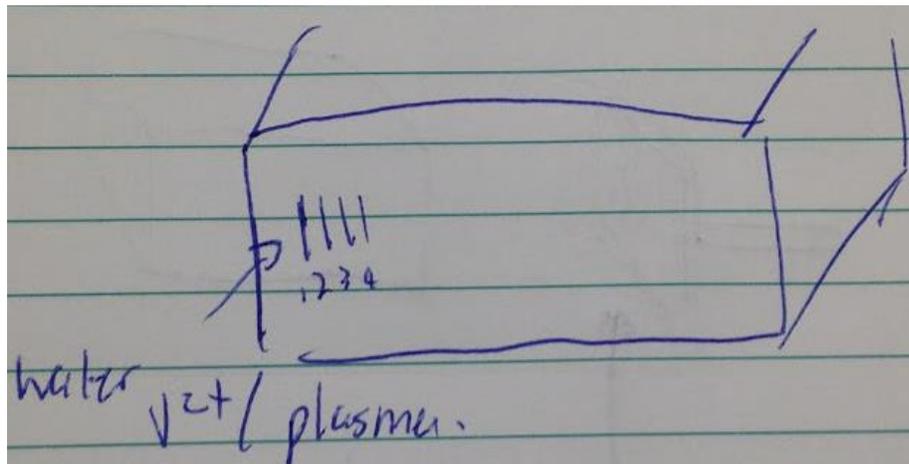


Figure A-44: A water jet or plasma cutter would lightly braze the surface of the HEPA filter diffuser with a barcode. This would require some actuation devices and safe guards [49].

The method shown in Figure A-45 uses a welding gun to apply the barcode as a weld bead.

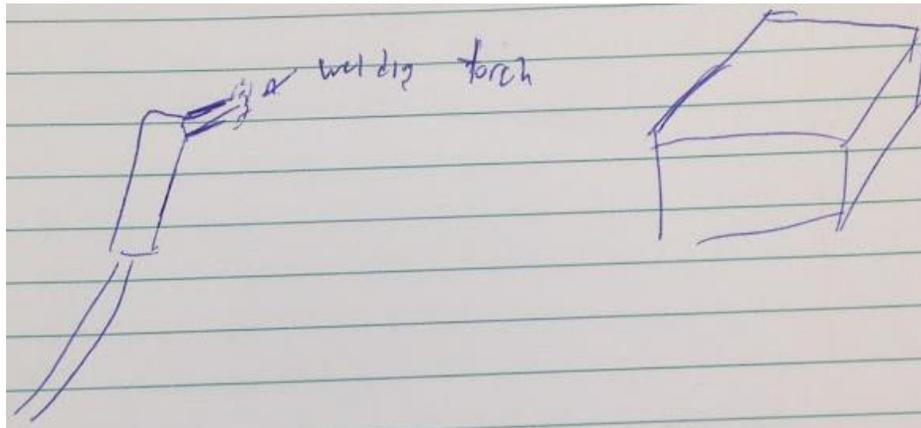


Figure A-45: An automated gun would place a weld bead, or slag, on the diffuser to produce a barcode on a successfully inspected diffuser [50].

Figure A-46 shows how an ink jet printer could print the barcode directly onto the diffuser.

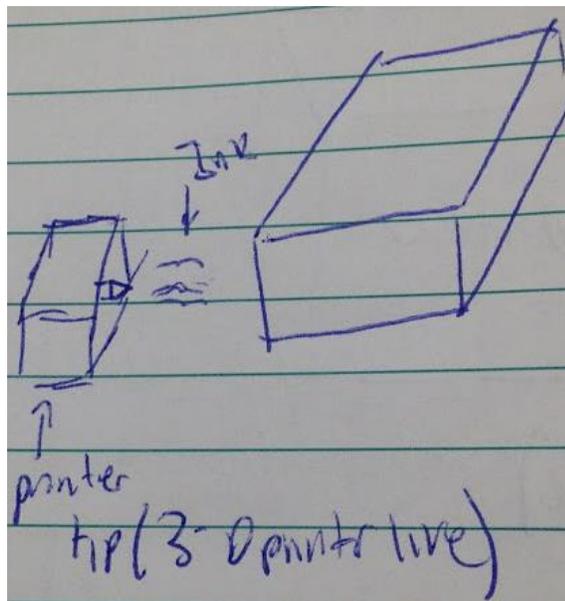


Figure A-46: A printer head would directly laser print a barcode onto the diffuser. This would be applied after successful inspection. This would function much like a 3-D printer head [51].

Figure A-47 shows how a die stamp could be used to stamp the barcode into the sheet metal of the diffuser.

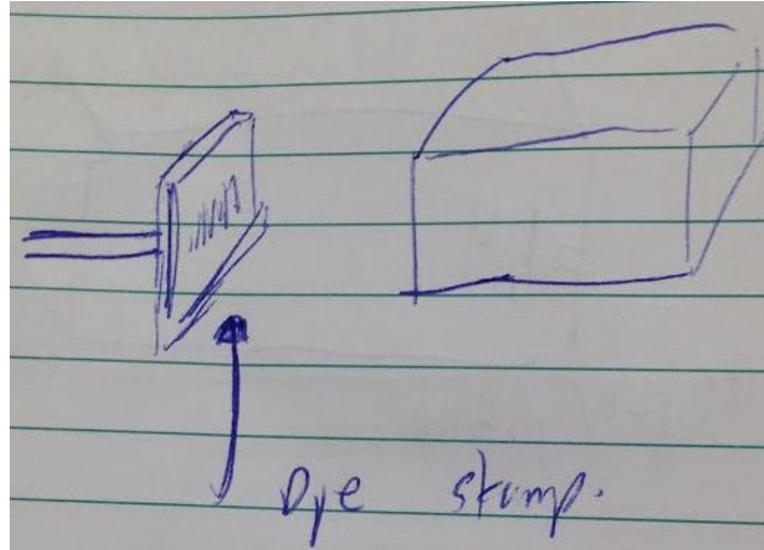


Figure A-47: The final concept produced by the team would use a die stamp to apply a barcode. This would utilize physical deformation of the diffuser sheet metal to implant a barcode [52].

Following the brainstorming of these concepts, they were placed into a ranking matrix against the selected criterion to see determine the top three concepts. These top three concepts would be the final step in the concept combination table, which will be discussed in the next section. The results of the rankings yields the best methods for barcode application to be printing a barcode sticker, stamping the barcode onto the diffuser, and directly printing the barcode onto the diffuser. The results of the ranking can be observed in TABLE A-VII on the following page.

TABLE A-VII: THE RANKINGS OF THE DIFFERENT BRAINSTORMED METHODS FOR BARCODE APPLICATION

Printing Barcode								
Process Criteria	Alternatives							Comments
	1	2	3	4	5	6	7	
Cost	6	1	2	6	5	3	3	
Interaction	1	1	1	1	1	1	1	
Simplicity to implement	6	1	2	6	4	3	3	
simplicity after implementation	6	1	2	6	4	3	3	
Known process technology	6	1	2	6	4	3	3	
Autonomous maintenance	6	1	2	6	4	3	3	
off the shelf components	6	1	2	6	4	3	3	
quick changeover	2	1	6	2	2	2	6	
roots or vines	6	1	2	6	4	3	3	
Sum of Scores	45	9	21	45	32	24	28	

A-53

### A.3.2 Preliminary Concepts

From the 7 ways matrix ranking, we could reduce the number of ideas in each project branch from seven to three. The top three ideas in each project branch are summarized in Figure A-48.

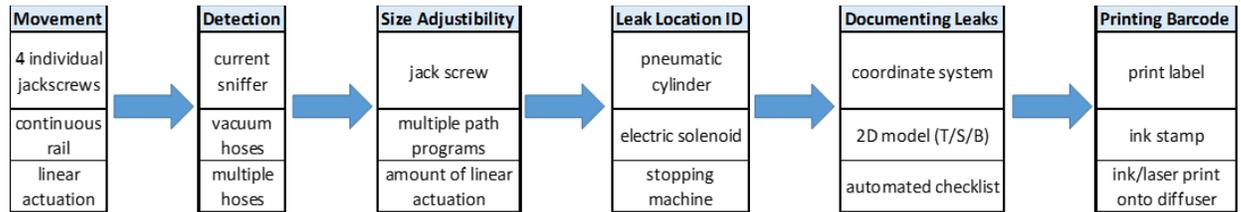


Figure A-48: Top three ideas in each project branch.

The main obstacle of our project is determining a way to traverse around the perimeter of the air diffuser and devising a way to detect leaks along the seams of the air diffuser. Consequently, most of our effort during concept generation went into the mechanical aspect of the design (movement and detection). Based on the top three ideas in the movement, detection, and size adjustability branch, we were able to generate the following concepts.

Figure A-49 shows a four-individual jackscrew movement device.

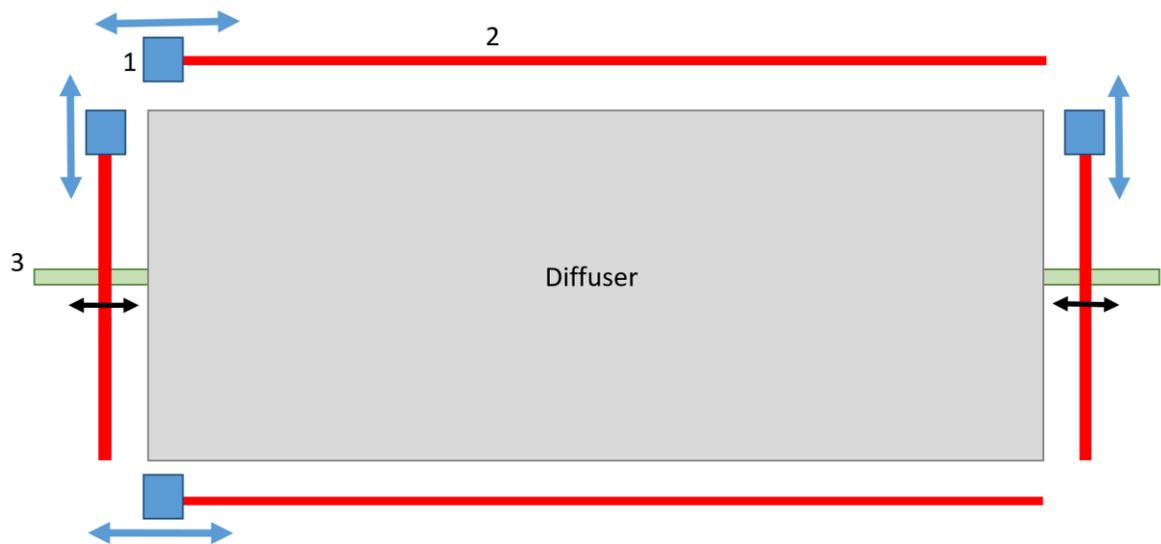


Figure A-49: Four individual jackscrew movement concept [53].

A carriage (Item 1) that contains one or more vacuum nozzles for leak detection rides on a jackscrew (Item 2) that is turned by a motor. There is a carriage and jackscrew situated on each of the four

sides of the diffuser. As the motors turn the jackscrews, the carriages move along the length of the diffuser and the vacuum nozzles are able to detect along all seams of the air diffuser. For size adjustability, a separate motor runs an auxiliary jackscrew (Item 3) that brings the two jackscrews on the sides of the air diffuser closer together. The nature of the device will mean that there will need to be four individual air hoses running to each of the four carriages, as shown in Figure A-50.

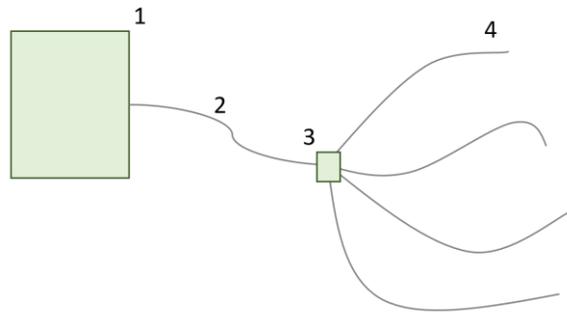


Figure A-50: ATI photometric scanner four branch configuration [54].

In Figure A-50, the main air hose (Item 2) runs from the ATI scanner (Item 1) to a shutoff valve (Item 3). Four air hose branches (Items 4) then run from the shut off valve to each of the four carriages.

Another way to navigate around the perimeter of the air diffuser is using a continuous rail device, as shown in Figure A-51.

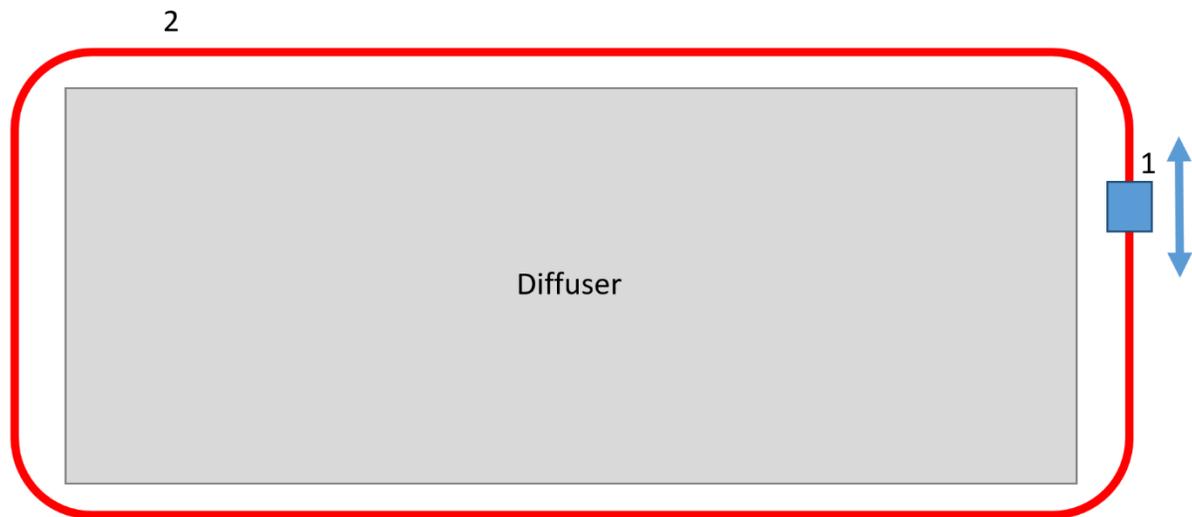


Figure A-51: Continuous rail movement concept [55].

In Figure A-51, a carriage (Item 1) runs along a continuous rail (Item 2) along all sides of the air diffuser. The carriage moves through the means of a chain and sprocket. One or more air nozzles are positioned on the carriage and take care of leak detection. In terms of size adjustability, a separate rail track would need to be manufactured for each product size.

In terms of the carriage device that contains the air nozzles, we developed two concepts, which are shown in Figure A-52 and Figure A-53, respectively.

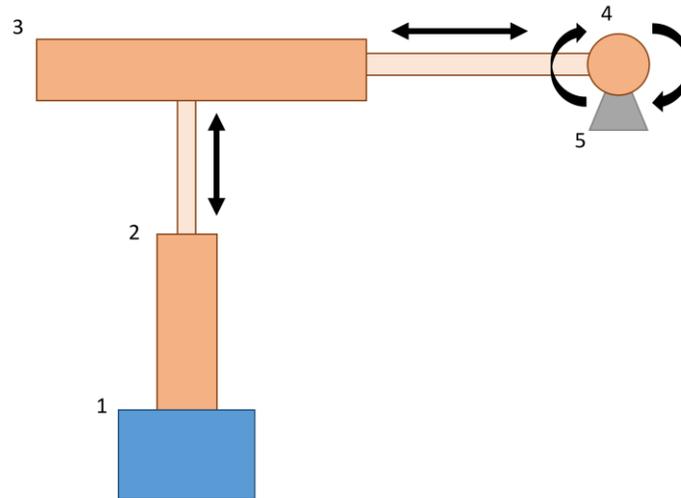


Figure A-52: Linear actuated detection arm concept [56].

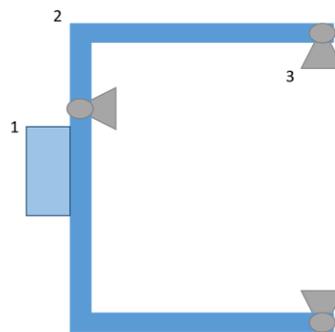


Figure A-53: C-style detection arm concept with multiple air nozzles [57].

In Figure A-52, the carriage (Item 1) is positioned on the continuous rail or jackscrew. The air nozzle (Item 5) can rotate 180° by way of a servo motor (Item 4). A linear actuator (Item 3) is able to move the air nozzle towards or away from the air diffuser, while another linear actuator (Item 2) is able to move the air nozzle up and down.

In Figure A-53, three air nozzles (Item 3) are positioned on a C-shaped assembly (Item 2) that wraps around the top, side, and bottom of the air diffuser. A carriage (Item 1) is attached to the C-shape assembly and rides on the continuous rail or jackscrew.

A standalone concept, entitled the CNC gantry, is shown in Figure A-54.

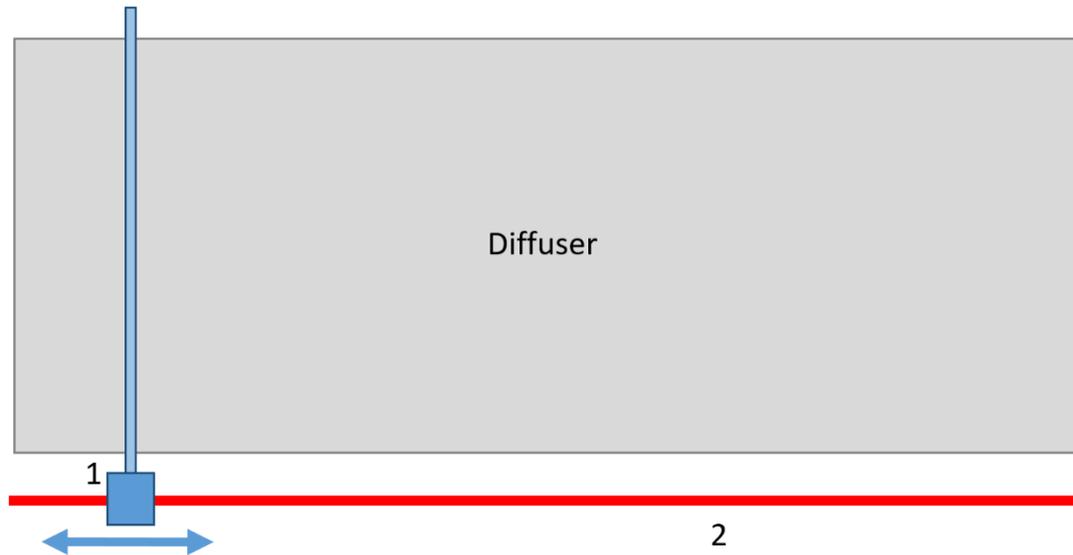


Figure A-54: CNC gantry movement concept [58].

The CNC gantry concept consists of a carriage (Item 1) that rides along a straight section of rail or jackscrew (Item 2). A side profile showing how the CNC gantry operates is shown in Figure A-55.

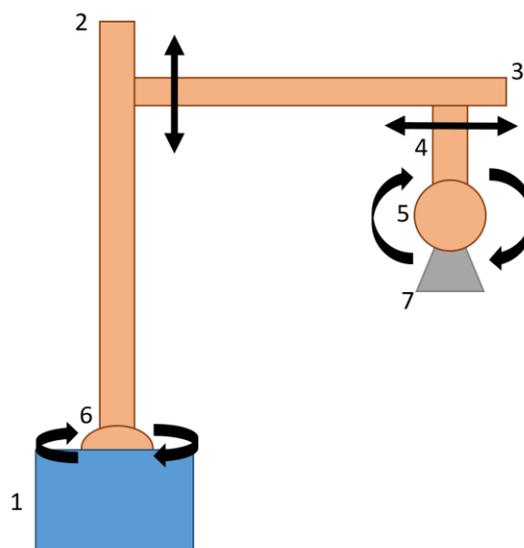


Figure A-55: CNC gantry concept side profile [59].

In Figure A-55, Item 1 is the carriage that rides along the straight section of rail or jackscrew. The air nozzle (Item 7) can be rotated 180° using a servo motor (Item 5) and can run back and forth along a track (Item 3). The horizontal track can also move up and down by running along a vertical track (Item 2). The whole assembly can rotate about the axis of the vertical track using another servo motor (Item 6). This would give the device all the required degrees of freedom to detect along all seams of the air diffuser.

A final concept that we envisioned using was a 6-axis robotic arm like the one shown in Figure A-56.



Figure A-56: Robotic arm concept [60].

The robotic arm would be positioned near one of the corners of the air diffuser and would contain either the ATI sniffing gun or a vacuum hose in its hand. Its six degrees of freedom would then be able to traverse all the seams of the air diffuser looking for leaks.

The CNC gantry concept as well as the robotic arm concept are standalone ideas. The continuous rail concept and the jackscrew movement concept can be paired with either the linear actuated detector arm or the C-style detector arm. This gives us six final concepts that are summarized below:

1. Jackscrew movement (Figure A-49) with linear actuated detection arm (Figure A-52).
2. Jackscrew movement (Figure A-49) with C-style detection arm (Figure A-53).
3. Continuous rail movement (Figure A-51) with linear actuated detection arm (Figure A-52).
4. Continuous rail movement (Figure A-51) with C-style detection arm (Figure A-53).
5. CNC gantry (Figure A-54, Figure A-55).
6. Robotic arm (Figure A-56).

## A.4 Concept Analysis and Selection

As explained in section 3.0 concept generation, we will consider the concept analysis and selection of the movement and detection, and the documentation system separately.

### A.4.1 Movement and Detection

Once we finished generating our main concepts and ideas we moved onto the analysis and selection stage where we compared all the concepts generated and selected the three best concepts. We chose to give the robot arm concept special consideration because of how versatile and effective it could potentially be for our application.

#### A.4.1.1 Concept Analysis

After the initial concept generation phase, we came up with six concepts. The concepts were the continuous curved rail with either the dual actuator detection head or the c-style triple detection head, the 6-lead screw array with either four dual actuator detection heads or four c-style triple detection heads, the CNC gantry style and finally the six-axis robot arm. The first step in reducing these concepts to the three best concepts was to apply the Pugh method of comparing each concept to the current method. We came up with five criteria to compare the concepts with the current method: number of passes required, accessibility, flexibility, time savings, and reliability. The number of passes criteria compares how many times the detection head must traverse the diffuser to scan all seams. Accessibility is defined as how easily the operator can insert and remove the diffuser to and from the test rig. Flexibility is a measure of whether the automated fixture can accommodate multiple diffuser sizes, as well as how easily the fixture can be changed between sizes. Time savings rates each concept on whether the concept will reduce or increase the time required to scan each diffuser. Reliability is the criteria which rates the concepts reliability, which we defined as fewer false positives and false negatives. The TABLE A-VIII summarizes the results of our Pugh chart.

TABLE A-VIII: MOVEMENT AND DETECTION PUGH CHART

	<u>Concepts</u>						<u>Reference</u>
<u>Selection Criteria</u>	curved rail (C-style)	curved rail (dual actuators)	6-leadscrews (C-style)	6-leadscrews (dual actuators)	CNC	Robot	Current method
# of passes required	+	0	+	0	0	0	0
Accessability	0	0	-	-	-	0	0
Flexibility	-	-	0	0	0	0	0
time savings	+	+	+	+	+	+	0
Reliability	+	+	+	+	+	+	0
Pluses	3	2	3	2	2	2	
Minuses	1	1	1	1	1	0	
Sames	1	2	1	2	2	3	
Score	2	1	2	1	1	2	

As shown in the Pugh chart, we have three concepts which stand out above the rest. The three concepts are the curved, continuous rail and the 6-leadscrew configuration each with the C-style triple detection device, and the six-axis robot arm. We expanded upon our criteria to include a cost comparison, number of moving components, fixture footprint, safety, purchasable off the shelf components vs specialty components and programming difficulty. A cost analysis was performed to provide an estimate of how much each concept would cost to implement. We considered the number of moving components because we determined that fewer moving components would reduce the chances of any individual component failing. We also determined that safety is an important factor because we want our fixture to be inherently safe with minimal extra safeguarding required. We also want the fixture to be built using as many purchasable off the shelf components as possible for ease of maintenance and repair should any component break down. We also want the fixture to be easy to interface with and program without the need for a high-level understanding of programming. The device footprint was also considered since we are limited to an additional

two-foot radius around the current test rig. We rated each criterion against each other to determine an appropriate weighting score for each criterion. The TABLE A-IX summarizes the results of our criteria weighting.

TABLE A-IX: CRITERIA IMPORTANCE WEIGHTING MATRIX

	a	b	c	d	e	f	g	h	j	k	
	<b>Cost</b>	<b># of moving components</b>	<b>least # of passes required</b>	<b>Footprint</b>	<b>Accesibility</b>	<b>Flexibility</b>	<b>Safety</b>	<b>purchasable vs special components</b>	<b>Reliability/Accuracy of detection</b>	<b>Difficulty to program</b>	
a	<b>Cost</b>	b	c	a	e	f	g	a	j	a	
b	<b># of moving components</b>		b	b	e	b	g	b	j	b	
c	<b># of passes required</b>			d	e	c	g	h	j	k	
d	<b>Footprint</b>				e	d	g	h	j	k	
e	<b>Accesibility</b>					e	g	e	j	e	
f	<b>Flexibility</b>						g	h	j	f	
g	<b>Safety</b>							g	g	g	
h	<b>purchasable vs special components</b>								j	h	
j	<b>Reliability/accuracy of detection</b>									j	
k	<b>Difficulty to program</b>										
	<b>Total Hits</b>	3	6	2	2	7	2	9	4	8	2
	<b>Weight</b>	0.07	0.13	0.04	0.04	0.16	0.04	0.20	0.09	0.18	0.04

We created a criterion weighting matrix with all our determined criteria. We then discussed as a group to decide how the criteria ranked against each other.

We determined that the most important factor to consider was the safety of the device. We need the fixture to be safe to operate, or if it isn't safe then their must be safeguarding designed to mitigate any hazards. Optimally, our final design will be inherently safe and will not require extra safeguarding however if we determine that the best concept requires extra safeguarding then we will implement it into our design. Secondly, we want our device to be reliable. For the scanning fixture to be reliable it must not give any false negatives. A false negative is where the diffuser is leaking however the scanning fixture does not indicate that there is a leak. We also want to

minimize false positives, where the scanning fixture detects a leak where there is none. False positives are not ideal but acceptable in small amounts. False negatives are unacceptable and thus we must design our fixture to prevent these results. The third most important criterion is accessibility. Our fixture must be easy to remove, move out of the way, or not obstruct the worker when the worker is installing the diffuser in the rig, or removing the diffuser from the rig. The goal of our design is to increase the efficiency of the test process and therefore we do not want to increase the amount of work required to install and remove the diffuser. The next two most important criteria were the number of moving components and the purchasable off the shelf vs specialty components. Both these criteria affect the overall durability of the system. Fewer moving components means less wear, and off the shelf components are more easily replaced. The least important criteria were the cost, flexibility, difficulty to program and the footprint. Cost was weighted lower because the client provided a large enough budget that we felt we had the freedom to explore more expensive concepts without cost overruns. Footprint and flexibility were weighted the least when compared to the other criteria.

#### A.4.1.2 Cost Analysis

The budget limit provided by the client for this project is \$20,000. A rough cost estimation was conducted for the best 3 concepts.

##### Curved Rail Cost Estimation

To roughly estimate the cost of this concept, prices of each item are listed in the TABLE A-X on the following page as well as the quantities needed. The movement system mainly consists of two independent curved rails to scan two different sizes of diffusers; each rail uses a chain and 4 sprockets to move the C-shape leaking detector along the rails, parts for assembling and supporting the system are also needed. Prices of most items listed were reasonably estimated by comparing prices of several similar products from actual suppliers which either locate in or deliver products to Winnipeg. For items that can be manufactured and provided by ourselves, such as C-shape assembly and fasteners, the costs were estimated based on experiences of group members and general knowledge. The suppliers from whom we obtained product information are listed in the table too.

A factor of 2 was multiplied to prices of both rails, because of the relatively wide price range for different curved rail manufactures, which may result the prices of rails to be double of the original estimations; A factor of 1.25 was also multiplied to the subtotal cost for the same reason. As result showed, the rough cost is \$9401.75.

TABLE A-X: COST BREAKDOWN FOR CURVED RAIL CONFIGURATION

Item	Unit price	Quantity	Subtotal	Factor	Total	Potential Supplier/Manufactures
Rail (per mm)	0.45	3657.6	1645.92	2	3291.84	McMaster Carr [61]
Rail (per mm)	0.45	2438.4	1097.28	2	2194.56	McMaster Carr [61]
Carriage	200	2	400	1	400	McMaster Carr [61]
Sprockets	20	8	160	1	160	Fastenal [62]
Chain (per ft)	3	30	90	1	90	Fastenal [63]
Motor	500	1	500	1	500	McMaster Carr [64]
Valves	65	3	195	1	195	Automationdirect [65]
Tubes (per 100 ft)	20	1	20	1	20	Home Depot [66]
Actuators/lead screw	20	1	20	1	20	Home Depot [66]
Misc. Stock/Machining/Fasteners	200	1	200	1	200	N/A
PLC	200	1	200	1	200	Arduino [67]
C-shape assembly	250	1	250	1	250	N/A
SUBTOTAL					7521.4	
FACTOR					1.25	
TOTAL					9401.75	

#### 6-Leadscrew Cost Estimation

The 6-leadscrew array concept requires 6 independent slider bars as the movement system for scanning two different sizes of products. Following the same method of estimating the cost of curved rails, TABLE A-XI was made demonstrating prices for each item and the total cost estimation, only a factor of 1.25 was multiplied to the subtotal cost since there are no rails in this design. As the result shows, the total rough cost of this design will be \$4820.

TABLE A-XI: COST BREAKDOWN FOR 6-LEADSCREW CONFIGURATION

Item	Unit price	Quantity	Subtotal	Potential Supplier/Manufactures
Jack Screw	121.6	6	730	McMaster Carr [68]
Stepper Motor	100	6	600	Robotshop [69]
Slider Bar	1	6	6	McMaster Carr [68]
Valves	65	14	910	Automationdirect [65]
PLC	200	1	200	Arduino [67]
Rod	35	6	210	McMaster Carr [70]
Tube (per 100 ft)	20	1	20	Home Depot [66]
Nozzle	10	10	100	McMaster Carr [71]
Actuator	20	4	80	Home Depot [66]
C-shape assembly	250	4	1000	N/A
SUBTOTAL			3856	
FACTOR			1.25	
TOTAL			4820	

## Six-Axis Robot Arm Cost Estimation

This concept mainly consists of a 6-axis robotic arm as the movement system, and the C-shape leaking detector. The estimated cost is 8087.5 dollars and is summarized in TABLE A-XII

TABLE A-XII: COST ESTIMATION FOR SIX-AXIS ROBOT ARM CONFIGURATION

Item	Unit price	Quantity	Subtotal	Potential Supplier/Manufactures
6-Axis Robotic Arm	6000	1	6000	Denso Robotics [72]
C-shape assembly	250	1	250	N/A
Actuator	20	1	20	Home Depot [66]
PLC	200	1	200	Arduino [67]
SUBTOTAL			6470	
FACTOR			1.25	
TOTAL			8087.5	

#### A.4.1.3 Concept Selection

After we determined the weighting of each criteria, we then rated our three main concepts on the criteria. We gave each concept a score from one to five based on how well it met each criterion. The rating was then multiplied by the weight of the criteria and a total scored was calculated. The results of this process are summarized in the TABLE A-XIII.

TABLE A-XIII: WEIGHTED SCORING MATRIX RESULTS FOR MOVEMENT AND LEAK DETECTION

	Weight	Curved Rail (C-style)		Leadscrews (C-style)		Six-Axis Robot Arm	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	0.07	3	0.20	4	0.27	3	0.20
# of moving components	0.13	4	0.53	2	0.27	3	0.40
# of passes required	0.04	4	0.18	4	0.18	2	0.09
Footprint	0.04	4	0.18	4	0.18	1	0.04
Accessibility	0.16	3	0.47	3	0.47	4	0.62
Flexibility	0.04	2	0.09	4	0.18	4	0.18
Safety	0.20	3	0.60	5	1.00	1	0.20
purchasable vs special components	0.09	3	0.27	5	0.44	4	0.36
Reliability/accuracy of detection	0.18	3	0.53	3	0.53	5	0.89
Difficulty to program	0.04	4	0.18	3	0.13	1	0.04
		Score	3.22	Score	3.64	Score	3.02

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Our rating on accessibility, flexibility, safety, difficulty to program and reliability were subjective. We felt that we did not have the concepts concretely defined enough to provide objective scores. The number of passes required was scored based on more objective grounds. The basic function of each concept provided us with how many passes would be required. Through the course of our cost analysis we determined the number of moving components, as well as the number of off the shelf components vs specialty components. The footprint was determined based on our initial designs for each concept and scored accordingly.

Based on our analysis we determined that the best concept to explore would be the 6-leadscrew configuration.

#### A.4.2 Leak Documentation System

Apart from the movement and detection system, our design will also need to include a method in which to identify and mark off the location of leaks. From our initial concept generation, we needed to select a final concept to develop. The way we selected our final concept was by taking a handful of the better ideas and screening them using a Pugh chart, followed by the development of a criteria importance weighting matrix, and then finally scoring the concepts in a scoring matrix.

##### A.4.2.1 Concept Analysis

From our initial concept generation phase for the leak identification portion of the design, we chose four concepts to further screen. These concepts include 1.) stopping the machine and having the operator mark of the leak location manually, 2.) a pneumatic stamping system, 3.) using magnetic indicators, and 4.) using LEDs to show the location of leaks. These four concepts were chosen for further screening because they represent a broad spectrum of potential designs. Each one of the four concepts are unique and very different from one another.

A list of criteria was generated to screen the four concepts against the current method of leak scanning. These criteria include 1.) cost, 2.) reliability, 3.) roots and vines, 4.) time savings, 5.) storage of leak history, and 6.) indicator of leak. The cost criterion is intended to indicate whether a concept will be significantly more costly to implement than the current process. The reliability criterion refers to the accuracy and repeatability of marking off the location of leaks. Roots and vines is a criterion that refers to the number of additional components that would need to be added to the design in order to implement the idea. Time savings refers to the time required to mark off

all the leak locations on one diffuser. Storage of leak history refers to the ability of the system to record and document the history of leaks for each individual air diffuser unit. Indicator of leak refers to the quality of the indication on the air diffuser compared to the current process. TABLE A-XIV is our Pugh chart for screening our leak identification concepts.

TABLE A-XIV: LEAK IDENTIFICATION PUGH CHART

<b>Selection Criteria</b>	<b>Concepts</b>				<b>Reference</b>
	<b>Stop Machine w/ user mark off</b>	<b>Pneumatic Stamper mark off</b>	<b>Magnetic indicators</b>	<b>LED on rails to show location of leak</b>	<b>Current method</b>
<b>Cost</b>	0	+	+	0	0
<b>Reliability</b>	+	+	-	+	0
<b>Roots and Vines</b>	0	-	-	0	0
<b>Time Savings</b>	+	+	+	+	0
<b>Storage of leak history</b>	+	+	+	+	0
<b>Indicator of leak</b>	0	+	+	+	0
<b>Pluses</b>	3	5	4	4	
<b>Minuses</b>	0	1	2	0	
<b>Sames</b>	3	0	0	2	
<b>Score</b>	<b>3</b>	<b>4</b>	<b>2</b>	<b>4</b>	

From the above Pugh chart, we see that the highest scoring concepts include the LED indicators, the pneumatic stamping device, and physically stopping the machine to have the operator mark off the individual locations. We decided that the top three concepts would move past the concept screening stage and into the concept scoring matrix.

In order to evaluate the three concepts in a scoring matrix, a set of criteria was developed as well as a set of weights to apply to each criterion. The criteria that we decided to include in concept

scoring matrix include: relative cost, number of moving components, number of pinch point and trip hazards, number of purchasable versus special components, time saved, reliability and accuracy of detection, effective leak location mapping, and difficulty to program. TABLE A-XV shows our criteria weighting for the leak identification portion of the design.

**TABLE A-XV: CRITERIA IMPORTANCE WEIGHTING MATRIX FOR LEAK DETECTION SYSTEM**

		a	b	c	d	e	f	g	h
		<b>Cost</b>	<b># of moving components</b>	<b>Pinch Points/Trip Hazards</b>	<b>purchasable vs special components</b>	<b>Time Saved</b>	<b>Reliability/Accuracy of detection</b>	<b>Effective Leak Location Mapping</b>	<b>Difficulty to program</b>
a	<b>Cost</b>		a	c	a	e	f	g	a
b	<b># of moving components</b>			c	b	e	f	g	b
c	<b>Pinch points/trip hazards</b>				c	c	c	c	c
d	<b>Purchasable vs special components</b>					e	f	g	h
e	<b>Time Saved</b>						f	g	e
f	<b>Reliability/accuracy of Identification</b>							f	f
g	<b>Effective Leak Location Mapping</b>								g
h	<b>Difficulty to program</b>								
<b>Total Hits</b>		3	2	7	0	4	6	5	1
<b>Weight</b>		0.11	0.07	0.25	0.00	0.14	0.21	0.18	0.04

The relative importance of each criteria with respect to one another is clearly shown in TABLE A-XV. The most important criteria was the number of potential pinch points and trip hazards. As mentioned in the previous criteria weighting matrix, we want our design to be as safe as possible. The next most important criteria was the reliability and accuracy of detecting leaks. Again, we do

not want to have false negatives during our testing procedure, as this would severely undermine the client's needs of our device. The third most important criteria was effective leak location mapping. This refers to the relative ease in which the leak identification system can interface with a documentation system that records the location of each leak for each air diffuser unit. The remaining criteria, in order of importance are: time savings, cost, number of moving components, and difficulty to program. The amount of purchasable versus special components ended up having a zero-weight associated with it, as it was not found to be more important than any of the other seven criteria.

#### A.4.2.2 Concept Selection

Once a weight was applied to each of the criteria, we could score each of the three concepts in a scoring matrix. Each concept was given a subjective rating from 1 to 5 for each of the 8 criteria and the results are shown in TABLE A-XVI on the following page.

TABLE A-XVI: WEIGHTED SCORING MATRIX RESULTS FOR LEAK IDENTIFICATION SYSTEM

	Weight	<u>Stop Machine w/ user mark off</u>		<u>Pneumatic Stamper mark off</u>		<u>LED on rails to show location of leak</u>	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
<b>Cost</b>	0.11	5	0.54	3	0.32	5	0.54
<b># of moving components</b>	0.07	5	0.36	2	0.14	5	0.36
<b>Pinch points/trip hazards</b>	0.25	3	0.75	2	0.50	3	0.75
<b>Purchasable vs special components</b>	0.00	5	0.00	3	0.00	4	0.00
<b>Time Saved</b>	0.14	3	0.43	5	0.71	4	0.57
<b>Reliability/accuracy of Identification</b>	0.21	4	0.86	3	0.64	4	0.86
<b>Effective Leak Location Mapping</b>	0.18	4	0.71	4	0.71	4	0.71
<b>Difficulty to program</b>	0.04	4	0.14	3	0.11	4	0.14
		<b>Score</b>	<b>3.79</b>	<b>Score</b>	<b>3.14</b>	<b>Score</b>	<b>3.93</b>

The TABLE A-XVI shows that based on the above criteria and weights, that the LED identification system is the preferred choice, followed by the stopping of the machine, and then the pneumatic stamping system. With the last of the design concepts narrowed down, we determined which designs we would follow in the following section.

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## Appendix B

### Technical Calculations

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## B.1 Stress Analysis

The design for the Automated Leak Detection fixture required a stress analysis for the support rails and ACME lead screws. The reason for this that the rods support the scanning fixtures over an extended span and deflection over the length of these members is of concern. Below in Figure B-1 the automated leak detection fixture is shown. The areas of concern are the front, side, and back rails.

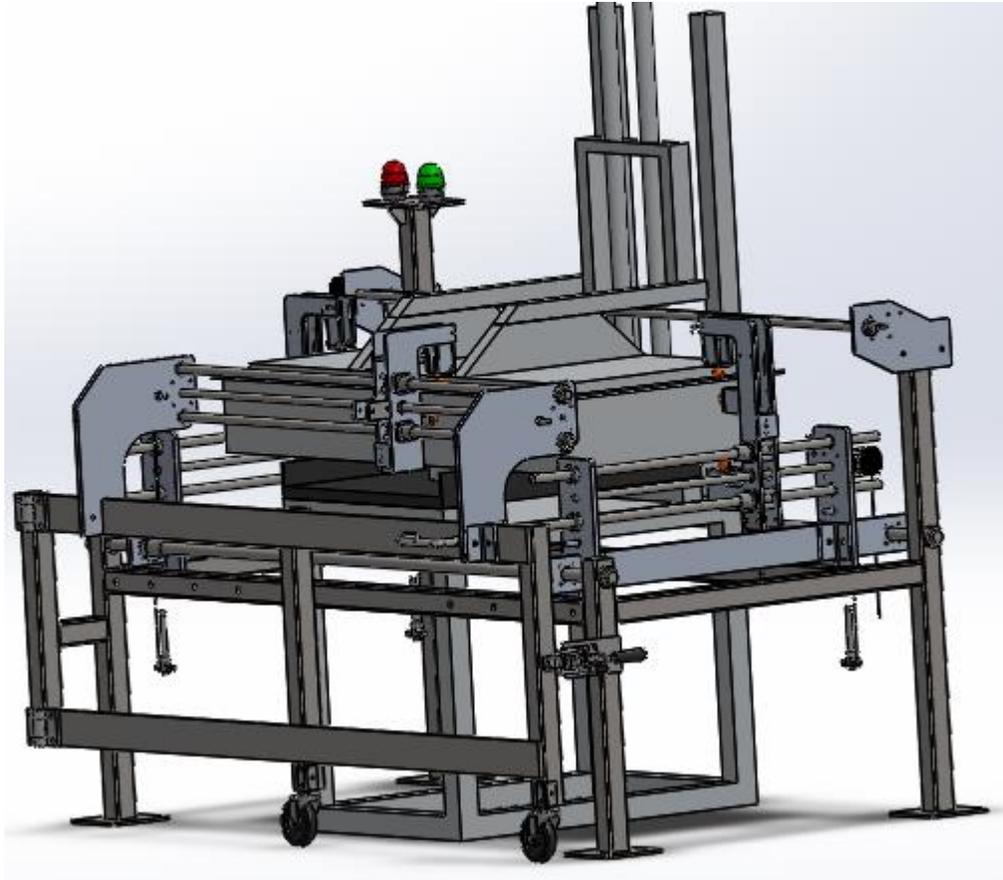


Figure B-1: The Automated Leak Detection Fixture.

To begin the analysis some assumptions were made. The analysis utilizes the method of superposition for statically indeterminate structures, along with the screw and rails modeled as solid steel rods. This method was deemed acceptable as it allows for a simplification of the analysis, while providing adequate results to ensure and detail the behaviour of the support rail and ACME screw assemblies. The next consideration is that no significant impact load will occur on the Automated Leak Detection Fixture. Impact loads would be unforeseen in the test lab environment and the likelihood of such a condition is very low. The stress will instead look at the load being

carried by the screws and rail, the scanning fixtures. Additionally, the worst-case scenario of an operator wrenching on the scanning fixture assemblies will be assessed to determine how much load could be withstood.

To begin the analysis, the side rail assembly will be assessed. For an approximation, the rods will be assumed to be connected by a flat plate with load “P” applied at the top most portion of the scanning fixture. It should be noted all measurements will be taken from the bottom of the scanning fixture. In Figure B-2 and Figure B-3 the scanning fixture being analyzed is shown, along with a free body diagram from the normal view to the front face of fixture. The forces in Figure B-3 depict the forces from the wrenching and self-weight of the fixture. It should be noted that the sign convention in Figure B-3 is the same for all stress analysis unless otherwise stated.

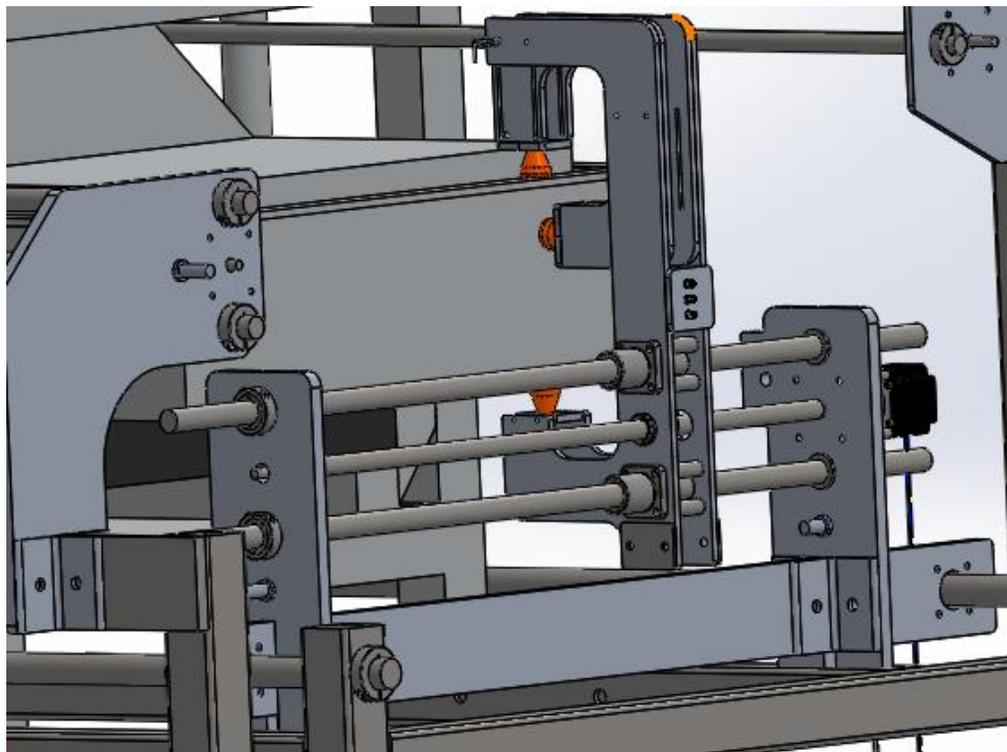


Figure B-2: The side scanning fixture for the Automated Leak Detection Fixture.

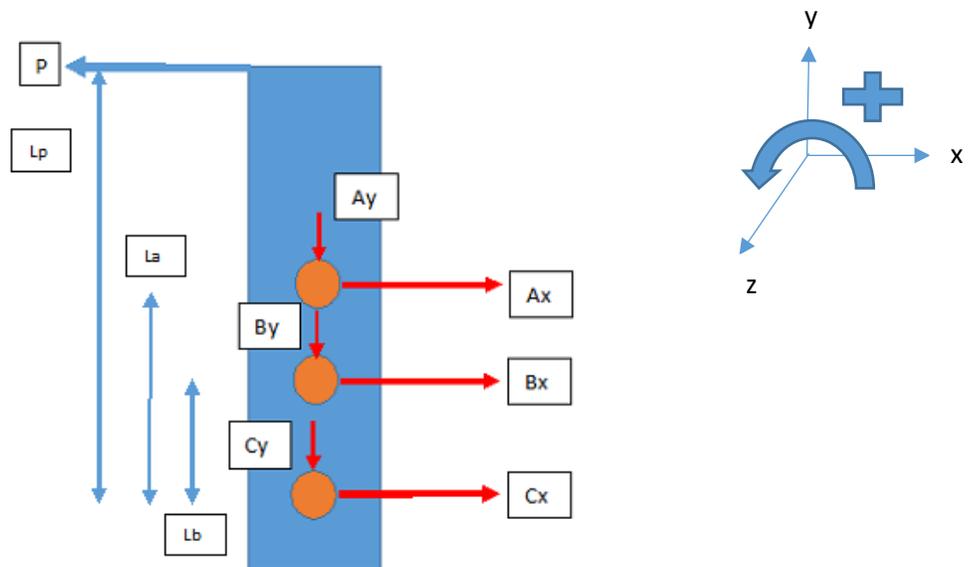


Figure B-3: The Free body diagram of the scanning fixture from wrenching (x components) and self-weight (y components).

TABLE B-1 summarizes some values that will be utilized to conduct the analysis on the flat plate scanning fixture and rod assemblies, referring to Figure B-3 for length values and symbols.

TABLE B-1: SUMMARY OF KEY VALUES FOR THE STRESS ANALYSIS OF THE SIDE SCANNING ASSEMBLY RAIL

Variable	Value	Unit of Measurement
P	250	[N]
Length to P	0.20844	[m]
Length to A	0.09645	[m]
Length to B	0.04713	[m]
Length to C	0	[m]
Young's modulus steel	200	GPa
Young's Modulus Aluminum	70	GPa

The first analysis will look at forcible wrenching. This analysis will look at the scanning fixture and then resolve the forces understanding that the deflection at the rod locations would be equal to the scanning fixture at those points. Since the structure is statically indeterminate, the first step is to render reaction "Bx" as redundant and separating the scenario into two simply supported beam

problems, depicted in Figure B-4 and Figure B-5. The deflection from both problems are determined then combined to obtain the gross effect of the loads on the scanning fixture from wrenching. The next step would be to equate the deflection at point B to the deflection at rod B at the center point.

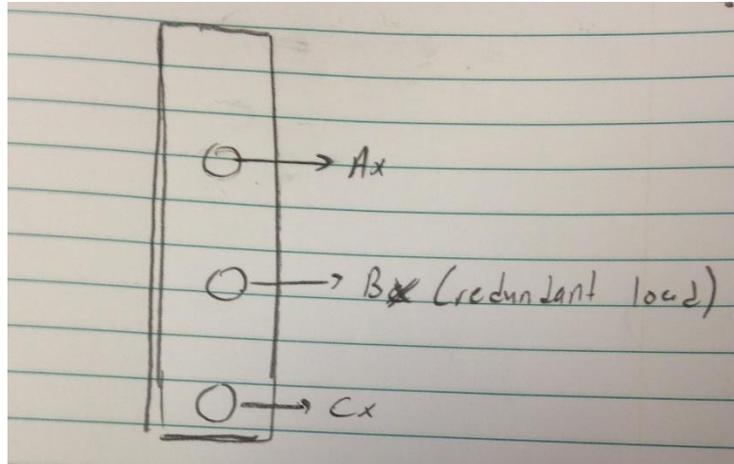


Figure B-4: The free body diagram for Rod B rendered redundant.

Referring to Figure B-4, it is apparent that the problem may be approximated as a simply supported beam on pins. The equation to describe maximum deflection, which will be at point B, is as follows:

$$x_B = \frac{B_x L^3}{48 * E * I}$$

Where  $B_x$  is the reaction at B, L is the distance from point C to A, E is the stiffness of 6061 Aluminum, and I is the area moment of inertia of the approximated scanning fixture plates.

The next analysis refers to Figure B-5 below, approximating the scanning fixture plate as a simply supported beam with a load P at the end.

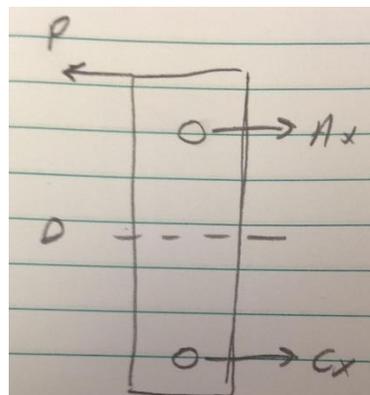


Figure B-5: The free body diagram for the load applied at point P.

The method of statics is used to resolve the forces at A and C by taking the moment about point C and A

$$\sum M_A = 0$$

$$0 = P * .20844 + C_x * .09645$$

$$C_x = -P * \frac{.11199}{.09645}$$

$$\sum M_C = 0$$

$$0 = P * 380.1 + A_x * 103.82$$

$$A_x = -P * \frac{.20844}{.09645}$$

Next the deflection for this scenario is required, to apply super position and obtain the resultant deflection at point B. The member is cut at point D, as indicated in Figure B-5, the free body diagram is created. The free body diagram at the cut at point D is shown below in Figure B-6.

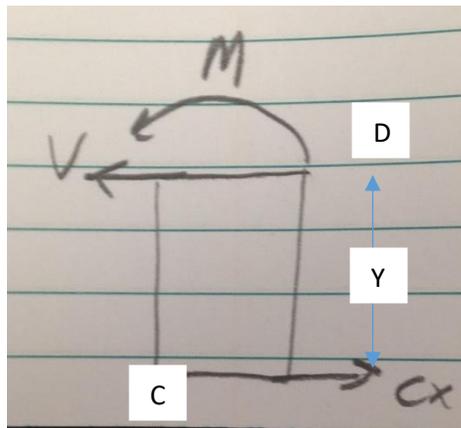


Figure B-6: The free body diagram of the cut at cross section D for the simply supported beam of the decomposition of Scanning fixture plate.

Solving for the moment at point D.

$$\sum M_D = 0$$

$$0 = M + C_x * y$$

$$M = -C_x * y$$

Understanding that moment is equivalent to the following equation:

$$\frac{EI d^2 x}{d^2 y} = M = -C_x * y$$

Integrating twice the two following equations are yielded.

$$\text{First Integration: } \frac{EI dx}{dy} = \frac{-C_x y^2}{2} + C_1$$

$$\text{Second Integration: } EI x = \frac{-C_x y^3}{6} + C_1 y + C_2$$

At  $x = 0$  the boundary conditions are:  $y = 0$

Substituting the boundary conditions into the second integration.

$$\therefore C_2 = 0$$

At  $x = L_{CA}$  the boundary conditions are:  $y = 0$

Substituting into the second integration, this yields after rearrangement:

$$C_1 = \frac{1}{6} * C_x * L_{CA}$$

Where  $L_{CA}$  is the distance from point C to A on the flat plate. Substituting this result into the second integration yields.

$$x_B = \frac{1}{EI} * \left( -\frac{1}{6} * C_x * y^3 + \frac{1}{6} * C_x * L_{CA}^2 * y \right)$$

Now finally applying the principle of superposition and understanding the deflection at point B is equal to the deflection of rod due to the reaction from the load P, it is written:

$$x_B = B_x * \frac{L^3}{48 * E * I} + \frac{1}{EI} * \left( -\frac{1}{6} * C_x * y^3 + \frac{1}{6} * C_x * L_{CA}^2 * y \right) \quad \text{eq 1}$$

The next step is to solve for the deflection on rod B due to the reaction load  $B_x$ . The free body diagram of rod B may be observed in the Figure B-7 below, which assumes the rod is supported by fixed supports at the end plates.

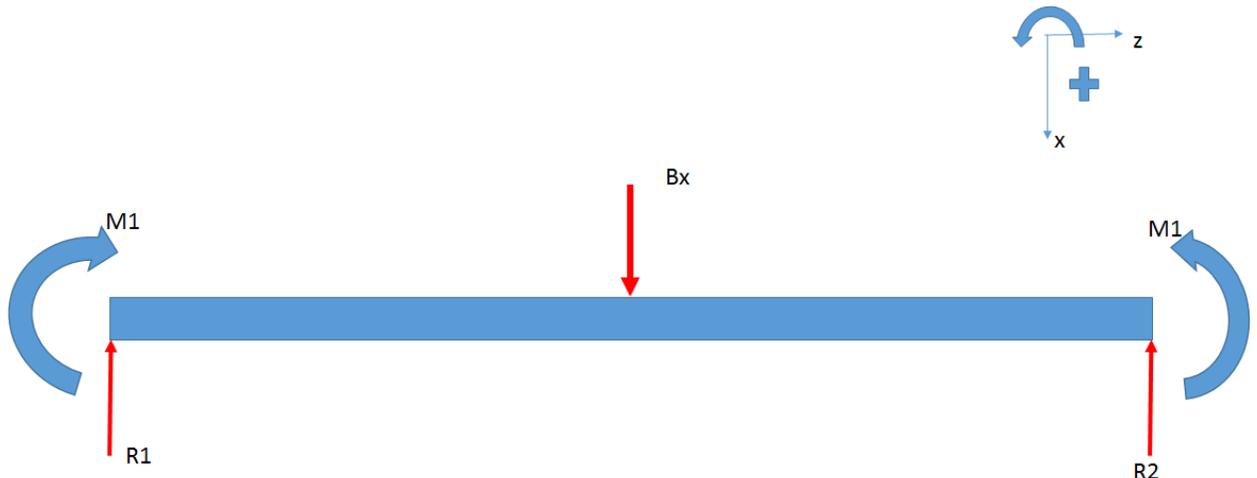


Figure B-7: The free body diagram of Rod B with Reaction Force  $B_x$ .

The rod is statically indeterminate so the principle of super position is applied to simplify the analysis to resolve the reactions. The three subsequent figures together describe the load condition adequately.

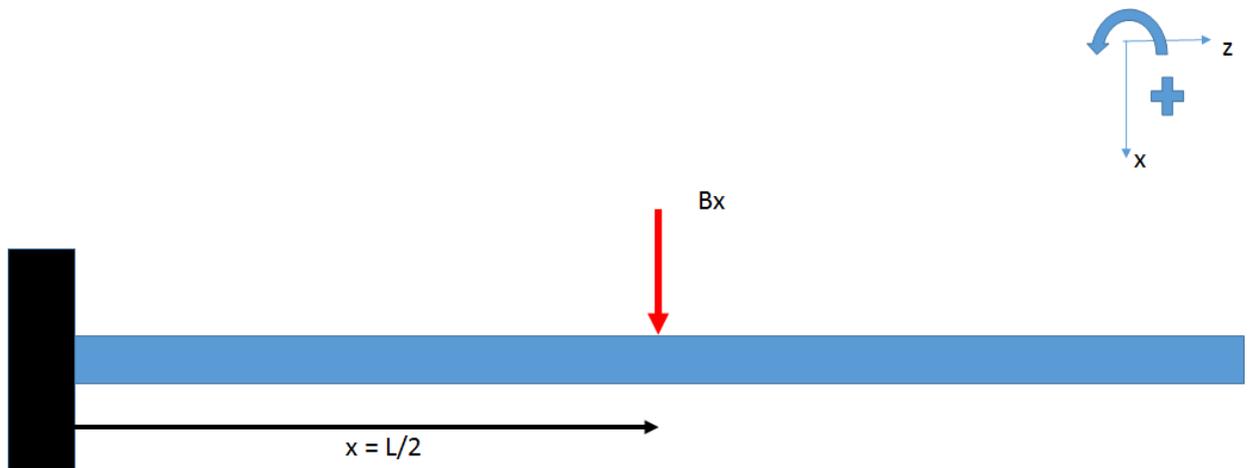


Figure B-8: The decomposed Rod B with the load  $B_x$  being analyzed individually.

For Figure B-8, the slope and deflection at support/end  $R_2$  may be described by:

$$\text{Slope of Deflection } \theta_x = \theta_{R2} = -B_x * \frac{z^2}{2EI}$$

$$\text{Deflection in the } x - \text{direction } x_{R2} = -B_x * \frac{z^3}{3EI} - B_x * \frac{z^2}{2EI}$$



Figure B-9: The decomposed Rod B with the reaction moment at fixed support analyzed.

For 9, the slope and deflection at support/end  $R_2$  may be described by:

$$\text{Slope of Deflection } \theta_x = \theta_{M2} = M_2 * \frac{L}{EI}$$

$$\text{Deflection in the } x - \text{direction } x_{M2} = M_2 * \frac{L * z}{2EI}$$

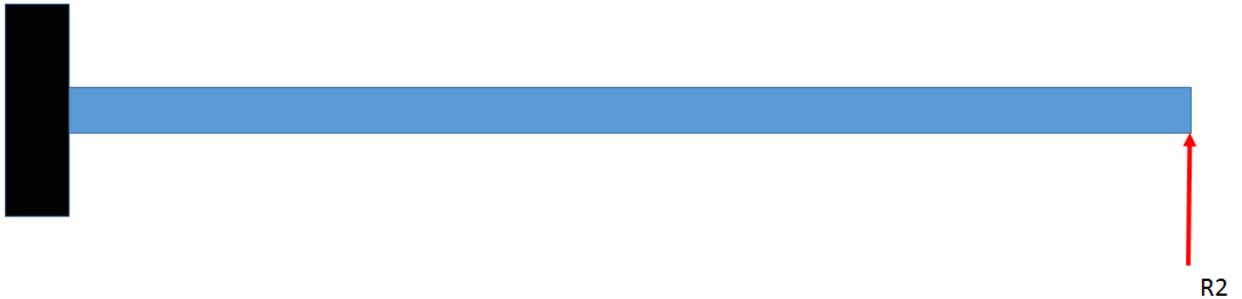
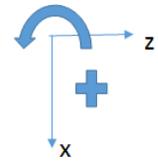


Figure B-10: The decomposed Rod B with the reaction at fixed support 2 being analyzed.

For 10, the slope and deflection at support/end  $R_2$  may be described by:

$$\text{Slope of Deflection } \theta_x = \theta_{R2} = R_2 * \frac{L^2}{2EI}$$

$$\text{Deflection in the } x - \text{direction } x_{R2} = R_2 * \frac{L^2 * z}{3EI}$$

The resultant deflection and slope at support  $R_2$  may be determined now by combing all three scenarios into one equation.

$$x_{R2} = R_2 * \frac{L^2 * z}{3EI} + M_2 * \frac{L * z}{2EI} - B_x * \frac{z^3}{3EI} - B_x * \frac{z^2}{2EI}$$

$$\theta_{R2} = R_2 * \frac{L^2}{2EI} + M_2 * \frac{L}{EI} - B_x * \frac{z^2}{2EI}$$

at  $x = L$   $\theta_{R2} = 0$ ,  $x_{R2} = 0$

$\therefore$

$$0 = R_2 * \frac{L^2 * z}{3EI} + M_2 * \frac{L * z}{2EI} - B_x * \frac{a^3}{3EI} - B_x * \frac{a * b}{2EI}$$

$$0 = R_2 * \frac{L^2}{2EI} + M_2 * \frac{L}{EI} - B_x * \frac{z^2}{2EI}$$

Substituting and rearranging.

$$R_2 = B_x * \frac{4z^3}{L^3}$$

$$M_2 = -B_x * \frac{z^3}{L^2}$$

This result is the same for all rods in the assembly in terms of reactions at supports. For the deflection at point B the method of super position is utilized again with the difference being in scenario depicted in Figure B-8. The point of interest is point B so the equation for deflection becomes:

$$x_{Bx} = -B_x * \frac{z^3}{3EI}$$

The resultant deflection at B then becomes:

$$x_{Bx} = B_x * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - B_x * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI} - B_x * \frac{z^3}{3EI} \quad \text{eq. 2}$$

Equating eq 1 and eq 2 the following result is obtained.

$$\begin{aligned} & B_x * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - B_x * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI} - B_x * \frac{z^3}{3EI} \\ &= B_x * \frac{L^3}{48 * E * I} + \frac{1}{EI} * \left( -\frac{1}{6} * C_x * y^3 + \frac{1}{6} * C_x * L_{CA}^2 * y \right) \end{aligned}$$

The variables z, L, E<sub>st</sub>, E<sub>Al</sub>, I<sub>R</sub>, I<sub>C</sub>, y, L<sub>ca</sub>, C<sub>x</sub> are summarized below in TABLE B-II for a load of P = 250 N, which was decided upon as the max wrenching load per NASA [1].

TABLE B-II: SUMMARY OF VARIABLE TO RESOLVE FORCE B<sub>x</sub>

Variable	Value	Unit
z	0.664	[m]
L	1.328	[m]
Est	200000000000	[Pa]
Eal	700000000000	[Pa]
Ir	1.29294E-08	[m <sup>4</sup> ]
Ic	1.97547E-07	[m <sup>4</sup> ]
y	0.04713	[m]
Cx	-665.286072	[N]
Lca	0.09645	[m]

Therefore, after substitution and rearrangement of the equation the force B<sub>x</sub> is resolved as follows:

$$B_x = -0.0000569 \approx 0 \text{ N which is expected since the Rod B centers the assembly}$$

The next step is to analyze the rod for a y-deflection due to the scanning fixture and the self-weight of the supporting rod. Referring to Figure B-3, we see that the load is applied downward on all the three rods. The rods also have the same supporting conditions as in the wrenching deflection. Therefore, the deflection equations will be the same, aside from the load applied. The equations for the deflections in the y-direction are summarized as follows:

$$y_A = A_y * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - A_y * z^2 * \frac{b}{L^2} * \frac{L * z}{2EI} - A_y * \frac{z^3}{3EI}$$

$$y_B = B_y * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - B_y * z^2 * \frac{b}{L^2} * \frac{L * z}{2EI} - B_y * \frac{z^3}{3EI}$$

$$y_C = C_y * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - C_y * z^2 * \frac{b}{L^2} * \frac{L * z}{2EI} - C_y * \frac{z^3}{3EI}$$

Looking at the equations it should be realized that the Young's modulus, dimensions, and moment of inertia are all the same. Additionally, the deflections are all equal since they are constrained by

the scanning assembly. Therefore, all the loads are equal and the weight is distributed evenly between the rods.

$$y_A = y_B = y_C$$

$$A_y = B_y = C_y$$

The load applied in the y-direction for the side scanning fixture is the center of gravity for the steel rod across the span and the weight due to the scanning fixture. The weights are summarized below in TABLE B-III.

TABLE B-III: THE SUMMARY OF WEIGHT ON THE THREE RODS WITH WEIGHT PER ROD

Weight		Units
Rod	29.89116	[N]
Side Scanning Fixture	5.5	[N]
Weight/Rod	35.39116	[N]

From this the deflection for a rod may be calculated using the previous deflection equation described. The equation for rod C is shown below for reference.

$$y_C = C_y * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI} - C_y * z^2 * \frac{b}{L^2} * \frac{L * z}{2EI} - C_y * \frac{z^3}{3EI}$$

The variables are summarized below in TABLE B-IV.

TABLE B-IV: THE SUMMARY OF VARIABLE USED IN THE DEFLECTION FOR A ROD

Variable	Value	Unit
z	0.664	[m]
L	1.328	[m]
Est	200000000000	[Pa]
Ir	1.29294E-08	[m^4]
Cy	-35.39	[N]

From the prescribed variable, the deflection may be calculated, using the equation for Rod C.

$$y_C = -0.0006436 \text{ m}$$

From the described process the deflections and forces are summarized below for each of the scanning fixture assemblies with three rods for a wrenching load of 250 N and weight of the scanning fixture acting the y-direction.

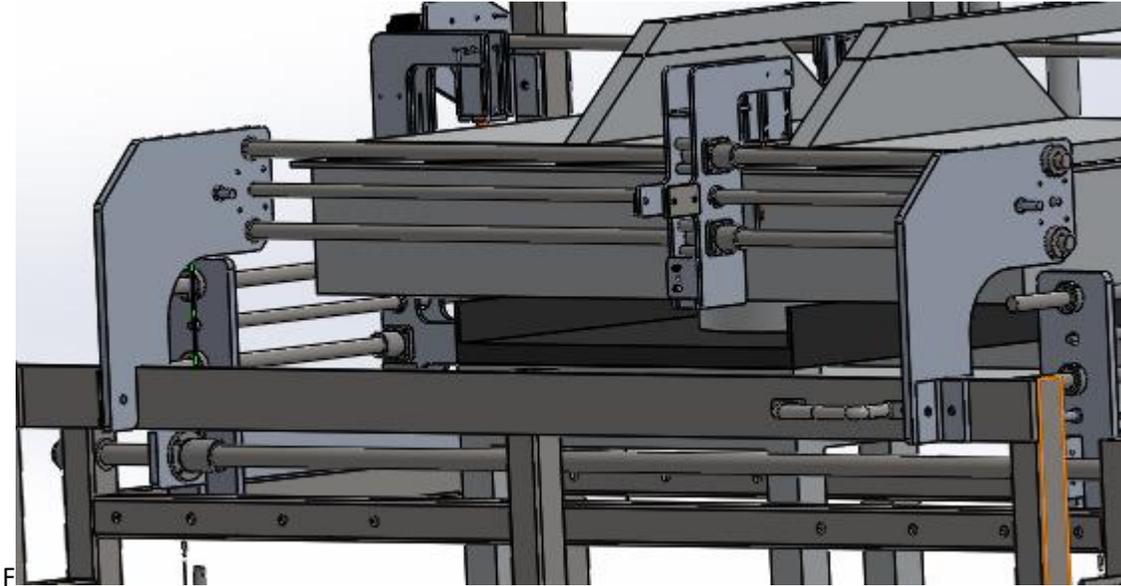
TABLE B-V: THE SUMMARY OF REACTION AND LOADS ON THE SCANNING FIXTURE

Results From Initial Redundant Loading			Sense of load
P	250	[N]	Left
Length to P	0.20844	[m]	
Length to A	0.09645	[m]	
Length to B	0.04713	[m]	
Length to C	0	[m]	
Rc	-665.286072	[N]	Left on Scanner
Ra	540.2799378	[N]	Right on Scanner
Bx side	-5.69787E-05		left
Rc side	2.68354E-06		
Bx	-0.047097185	[N]	Left on Scanner
Ax	540.3029517	[N]	Right on Scanner
Cx	-290.2558545	[N]	Left on Scanner

TABLE B-VI: THE SUMMARY OF DEFLECTIONS FOR THE RODS IN THE SIDE ASSEMBLIES

Sides		
Rod A		
Material Stiffness	2E+11	[Pa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Ax	-540.3029517	[N]
Load Ay	-35.39	[N]
Length A	1.328	[m]
Load app point	0.664	[m]
Length from Load to Rxn	0.664	[m]
Deflection in X	-0.036235895	[m]
Deflection in Y	-0.00064357	[m]
Sides		
Rod B		
Material Stiffness	2E+11	[GPa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Bx	0.047097185	[N]
Load By	-35.39	[N]
Length B	1.328	[m]
Load app point	0.664	[m]
Length from Load to Rxn	0.664	[m]
Deflection in X	3.15861E-06	[m]
Deflection in Y	-0.00064357	[m]
Sides		
Rod C		
Material Stiffness	2E+11	[GPa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Cx	290.2558545	[N]
Load Cy	-35.39	[N]
Length C	1.328	[m]
Load app point	0.664	[m]
Length from Load to Rxn	0.664	[m]
Deflection in X	0.019466266	[m]
Deflection in Y	-0.00064357	[m]

For the front scanning fixture a similar analysis was conducted since it had the same fixed supports on the ends of the support rods. The front scanning fixture contains differing dimensions and self-weight loads, which are reflected in the analysis summary. The front scanning fixture is shown below Figure B-11.



*Figure B-11: A view of the front scanning fixture of the Automated Leak Detection Fixture.*

The stress analysis is summarized in the subsequent tables for the front scanning fixture.

TABLE B-VII: THE SUMMARY OF REACTION AND LOADS ON THE FRONT SCANNING FIXTURE

Results From Initial Redundant Loading			Sense of load
P	250	[N]	Left
Length to P	0.3801	[m]	
Length to A	0.10382	[m]	
Length to B	0.05108	[m]	
Length to C	0	[m]	
Rc	-665.286072	[N]	Left on Scanner
Ra	915.286072	[N]	Right on Scanner
Bx side	-7.8276E-05		left
Rc side	3.35533E-06		
Bx	-0.04286538	[N]	Left on Scanner
Ax	915.307162	[N]	Right on Scanner
Cx	-665.264297	[N]	Left on Scanner

TABLE B-VIII: THE SUMMARY OF DEFLECTIONS FOR THE RODS IN THE FRONT ASSEMBLIES

Sides		
Rod A		
Material Stiffness	2E+11	[Pa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Ax	-915.307162	[N]
Load Ay	-5.50	[N]
Length A	0.9398	[m]
Load app point	0.4699	[m]
Length from Load to Rxn	0.4699	[m]
Deflection in X	-0.000201357	[m]
Deflection in Y	-0.000464683	[m]

Sides		
Rod B		
Material Stiffness	2E+11	[Pa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Bx	0.042865381	[N]
Load By	-5.50	[N]
Length B	0.9398	[m]
Load app point	0.4699	[m]
Length from Load to Rxn	0.4699	[m]
Deflection in X	9.4299E-09	[m]
Deflection in Y	-0.000464683	[m]
Sides		
Rod C		
Material Stiffness	2E+11	[Pa]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]
Load Cx	665.2642967	[N]
Load Cy	-5.50	[N]
Length C	0.9398	[m]
Load app point	0.4699	[m]
Length from Load to Rxn	0.4699	[m]
Deflection in X	0.000146351	[m]
Deflection in Y	-0.000464683	[m]

For the rear assembly analysis, the wrenching deflection was neglected because it was not a means of load application being located at the very back of the fixture. Therefore, for the back scanning fixture the self-weight deflection was only considered. The rear assembly analysis is shown below in Figure B-12.

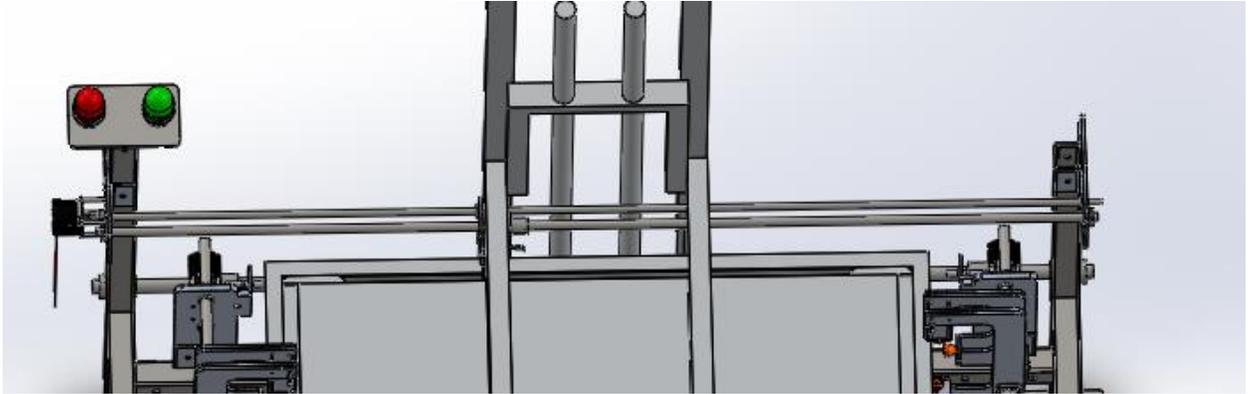


Figure B-12: The rear scanning fixture viewed from the top of the scanning assembly.

The vertical load applied to the two rods from the scanning fixture acts as depicted in Figure B-13.

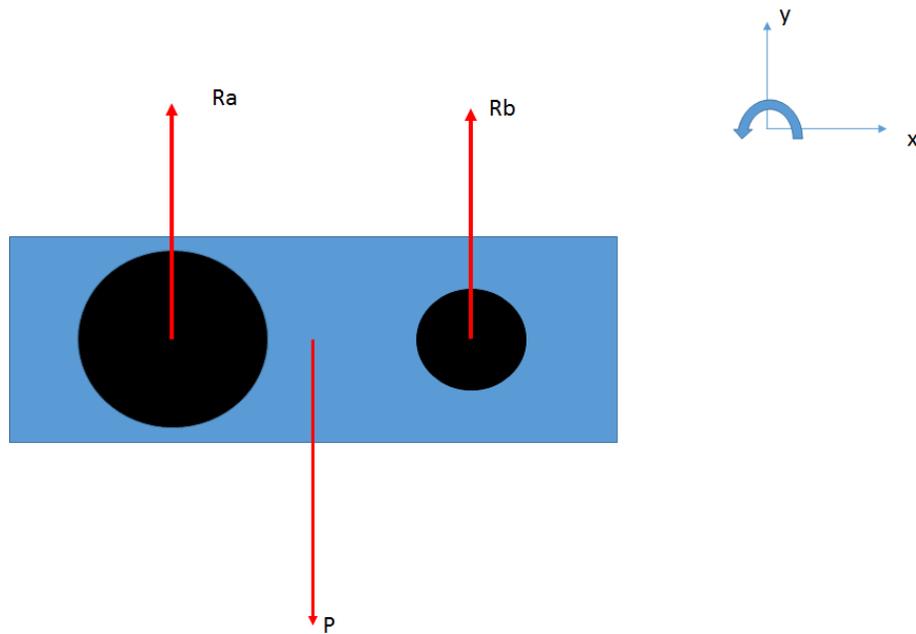


Figure B-13: The free body diagram of the self-weight on the support rods and acme screws.

$$\sum F_y = 0$$

$$-P + R_a + R_b = 0$$

Since both rods are constrained together they deflect the same amount due to the load, but because the support rail has a higher inertia it supports a higher amount of the load. To prove this the deflections of the fixed support rods are calculated using the following equations.

$$y_A = R_A * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI_A} - R_A * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI_A} - R_A * \frac{z^3}{3EI_A}$$

$$y_B = R_B * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI_B} - R_B * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI_B} - R_B * \frac{z^3}{3EI_B}$$

Where  $z$  is the point of load application on the rod as shown below,  $L$  is length of the rod,  $E$  being the young's modulus of steel,  $I$  the moment of inertia of the rod geometry.  $A_y$  and  $B_y$  are the vertical reaction loads taken by the rods respectively.

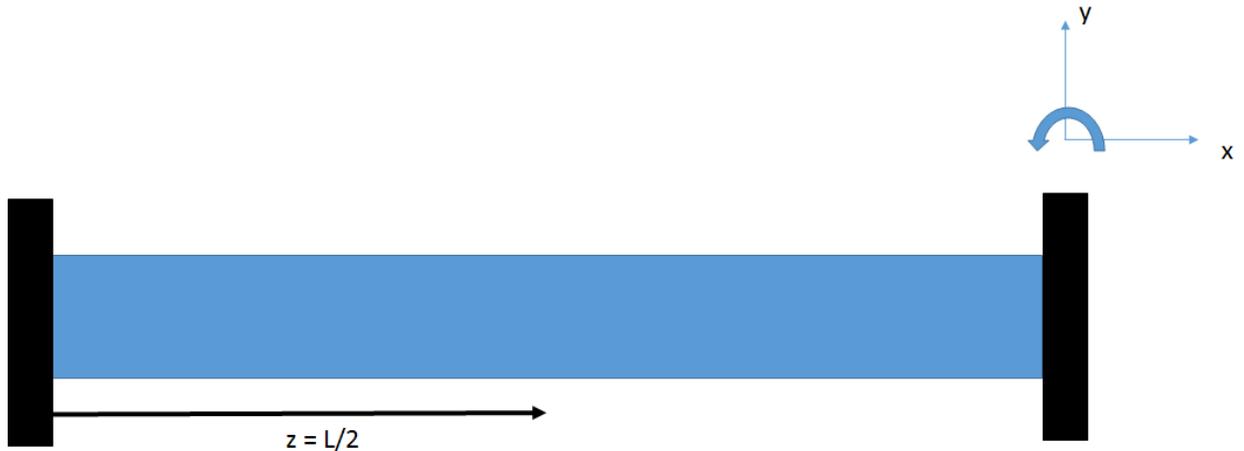


Figure B-14: A diagram of the support Rod or ACME screw for the rear scanning fixture.

For the back scanning fixture a hollow tube will be used for support and the ACME screw will be estimated as a solid cylinder. The moments of inertia may be calculated by the following equations.

$$I_A = \frac{\pi}{2} * (r_{Ao}^4 - r_{Ai}^4)$$

$$I_B = \frac{\pi}{2} * (r_{Bo}^4)$$

TABLE B-IX and TABLE B-X summarize the dimensions, mass, inertia, and self-weight from the rods.

TABLE B-IX: THE SUMMARY OF ROD A DIMENSIONS AND MASS

Steel Tube		Units
Diameter	0.01905	[m]
Wall Thickness	0.002413	[m]
Radius	0.009525	[m]
Mass Rod	1.805135671	[kg]
Load from Rod	17.70838093	[N]
Moment of Inertia	8.65283E-08	[m <sup>4</sup> ]

TABLE B-X: THE SUMMARY OF SCREW B DIMENSIONS AND MASS

Steel Screw		Units
Diameter	0.01905	[m]
Radius	0.009525	[m]
Mass Rod	4.079505081	[kg]
Load from Rod	40.01994485	[N]
Moment of Inertia	1.29294E-08	[m <sup>4</sup> ]

To determine how the load is distributed amongst the rods the deflections are equated using the previous stated equations.

$$\begin{aligned}
 & R_A * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI_A} - R_A * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI_A} - R_A * \frac{z^3}{3EI_A} \\
 = & R_B * \frac{4z^3}{L^3} * \frac{L^2 * z}{3EI_B} - R_B * z^2 * \frac{z}{L^2} * \frac{L * z}{2EI_B} - R_B * \frac{z^3}{3EI_B}
 \end{aligned}$$

Since all the loads are applied at the same location and both rods have the same length the preceding calculation may be simplified to the following.

$$\frac{R_A}{I_A} = \frac{R_B}{I_y}$$

$$.41R_A = R_B$$

This now can be substituted into the static equations to solve  $R_A$  and then  $R_B$  as follows.

$$-P + R_a + .41R_a = 0$$

$$P = 1.41R_a$$

Where P is the load from the rod and scanning fixture weight. The results from the analysis are summarized in the following tables.

TABLE B-XI: THE RESULTING LOADS FROM THE APPLIED SELF-WEIGHT OF THE ROD AND SCANNING FIXTURE.

Variable	Value	Unit
Load	11.032	[N]
Ay	8.574426	[N]
By	2.457574	[N]

TABLE B-XII: THE SUMMARY OF THE DEFLECTION CALCULATIONS FOR THE LOADING SCENARIO.

Sides		
Rod A		
Material Stiffness	200	[GPa]
Moment of Inertia	8.91073E-09	[m <sup>4</sup> ]
Load Ay	-8.57	[N]
Length A	1.778	[m]
Load app point	0.889	[m]
Length from Load to Rxn	0.889	[m]
Deflection in Y	-0.00063406	[m]
Sides		

Rod B		
Material Stiffness	200	[GPa]
Moment of Inertia	2.55396E-09	[m <sup>4</sup> ]
Load By	-2.46	[N]
Length B	1.778	[m]
Load app point	0.889	[m]
Length from Load to Rxn	0.889	[m]
Deflection in Y	-0.00063406	[m]

From the analysis on the rods and screws for the scanning fixtures, it is apparent that the self-weight deflections are minimal. The rods act up to the standard required, especially since the application is low tolerance and simply needs to make a pass to detect the leak. The wrenching load is a low likelihood occurrence but should be analyzed to see what the behaviour to see if the device will have a life after the applied wrenching load. With the analysis completed the design performs satisfactorily.

## B.2 Stepper and ACME Screw Analysis

The method of actuation requires the use of stepper motors and ACME lead screws. Each side of the Automated Leak Detection Fixture will have these. The summary of key dimensions and information is summarized in TABLE B-XIII below.

TABLE B-XIII: A SUMMARY OF LEAD SCREW DIMENSIONS AND KEY FEATURES

Location	Diameter, $D_m$ [in]	Lead [in]	Length [in]	Load [lbs]	n
Side	0.75	0.5	32	3.71	8
Front	0.75	0.5	52	3.71	8
Back	0.625	0.25	64	2.48	8
Pressure Angle	14.5	[Degrees]			

For clarification n is the number of threads and lead is how much distance is travelled per revolution.

For the analysis of lead screws stress analysis and critical speed calculations are required. The following equations describe the process to determine the values of stress and critical speed.

Shear stress can be determined from the following equations:

$$\tau = \frac{F}{A_s}$$

Where F is the load and  $A_s$  is the shear calculated by the following formula:

$$\text{Shear Area} = A_s = \pi * D_{\text{minor}} * (.5 + n \tan(14.5)) * (D_p - D_{\text{minor}})$$

Where  $D_p$  is pitch diameter and  $D_{\text{minor}}$  is minor diameter expressed as follows:

$$D_p = D_m - .5P$$

$$D_{\text{minor}} = D_m - P$$

Where pitch, P is:

$$P = \frac{1}{n}$$

TABLE B-XIV provides a summary of calculated ACME screw geometries.

TABLE B-XIV: THE CALCULATED ACME SCREW GEOMETRIES

Side and Front		Back	
Major Diameter	0.75	Major Diameter	0.625
Pitch	0.125	Pitch	0.125
Pitch Diameter	0.6875	Pitch Diameter	0.5625
Minor Diameter	0.625	Minor Diameter	0.5

Tensile Stress can be determined using a similar means but determine the tensile area. The following calculations highlight this.

$$\sigma = \frac{F}{A_t}$$

Where  $A_t$  is the tensile area calculated by the following:

$$A_t = \pi * \left( \frac{D_p + D_{minor}}{4} \right)^2$$

For the given loads and geometries described in TABLE B-XIV, the tensile and shear areas are calculated and summarized in TABLE B-XV.

TABLE B-XV: THE SHEAR AND TENSILE AREAS CALCULATED FOR THE ACME SCREWS

	Shear Area [in <sup>2</sup> ]	Tensile Area [in <sup>2</sup> ]
Side	0.33	1.1
Front	0.33	1.1
Back	0.22	0.88

The calculated are then followed up in TABLE B-XVI below.

TABLE B-XVI: THE SUMMARY OF TENSILE AND SHEAR STRESSES ON THE ACME SCREWS

	Shear Stress [Psi]	Tensile Stress [Psi]
Side	10.96	3.35
Front	10.96	3.35
Back	11.18	2.80

Since the allowable stress of the ACME screws is 64,000 Psi, and the values calculated are significantly smaller, the selected screws are sufficient [2]. Additionally, the general fatigue strength of 1020 Carbon Steel is 21 ksi, therefore the screw will most likely last the lifetime of the Automated Leak Detection Fixture [3]. It should be a note of caution that the lubrication and maintenance of the screws is important to ensure lengthy usage and minimal wear.

The next step in analysis for the ACME lead screws is to look at the critical speeds of rotation for the Lead Screws. This value is calculated and then compared to the expected rotation speed of the Automated Leak Detection fixture application to ensure that critical speeds are not exceeded. The calculation for critical speed is shown below.

$$n_c = \frac{4.76 * 10^6 * k_s * D_{minor}}{SF * L^2}$$

Where SF is the safety factor, Ks is the fixity factor at the ends of the screws for one end fixed and simply supported at the other, L is the length of the screw.

The values in the TABLE B-XVII summarizes the factors chosen.

TABLE B-XVII: THE SUMMARY OF FACTORS CHOSEN FOR THE CRITICAL SPEED ANALYSIS.

SF	1.25
Ks	1.55

The values of critical speed are summarized below in TABLE B-XVIII for each ACME screw.

TABLE B-XVIII: THE SUMMARY OF CRITICAL SPEED CALCULATIONS FOR THE ACME LEAD SCREWS

Location	Minor Diameter [in]	Length [in]	Critical Speed [RPM]
Side	0.625	32	3602.54
Front	0.625	52	1364.28
Back	0.5	64	720.51

To calculate RPM two variables are required the desired Scanning Fixture velocity and the lead of the selected ACME screw. The RPM is then calculated with the following equation:

$$n = \frac{V}{L} * 60 \frac{min}{sec}$$

Where V is desired Scanning feature velocity and L is the screw lead. For our application, the desired velocity is 2 in/sec and the lead depending on the ACME screw used. The values are summarized in TABLE B-XIX.

TABLE B-XIX: THE SUMMARY OF THE CALCULATED RPM FOR THE SCANNING FIXTURE.

Location	Velocity [in/sec]	Lead [in/rev]	n [RPM]	n<nc?
Side	2	0.5	240	YES
Front	2	0.5	240	YES
Back	2	0.25	480	YES

The next step is to source the proper stepper, in our case we decided to use Automation Direct as the supplier. Automation Direct also offers a method of calculating the required Torque to turn the ACME lead screw with the load. By determining this torque the proper stepper can be sourced. An additional, consideration is that a half-step configuration is desired for the stepper motor. This is a configuration when the stepper supplies partial power to poles of the stator to turn the rotor. By partial powering in sequence to turn the rotor, a smooth transition as higher speeds can be obtained. Although higher speed is achieved this comes at the expense of Torque the stepper can provide. Hence, a torque curve will be consulted with the selected, or most suitable stepper, to indicate where our system lies in relation to rated values. The following calculations that are conducted are following those provided by Automation Direct [Automation Direct].

The first step to determine the required Torque is to calculate the total inertia of the system which is determined by the following:

$$J_{Total} = J_{motor} + J_{gear} + \frac{J_{coupling} + J_{screw} + J_w}{i^2}$$

Where  $J_{total}$  is the total inertia,  $J_{motor}$  is the motor inertia,  $J_{gear}$  is the gear inertia,  $J_{coupling}$  is the coupling inertia,  $J_{screw}$  is the screw inertia, and  $J_w$  is the inertia due to the load, and  $i$  is the gear ratio of 1.

In our case the gear and coupling inertia is zero. The remaining inertias are calculated as follows:

$$J_w = \frac{W}{g * e} * \left( \frac{1}{(2 * \pi * P)^2} \right)$$

Where  $W$  is the load being carried,  $g$  is the gravity constant,  $e$  is the ACME screw efficiency of 0.4, and  $L$  is the ACME screw lead. These constants are summarized in the table below.

TABLE B-XX: THE SUMMARY OF THE CONSTANTS TO CALCULATE THE INERTIA DUE TO LOAD BEING CARRIED

Location	W [lbs]	Lead [in/rev]	efficiency of ACME	gravity constant [in/sec <sup>2</sup> ]
Side	3.71	0.5	0.4	386
Front	3.71	0.5	0.4	386
Back	2.48	0.25	0.4	386

The inertia due to the screw is calculated as follows:

$$J_{screw} = \frac{\pi * L * \rho * r^4}{2 * g}$$

Where  $\rho$  is the density of steel, 0.28 lb/in<sup>3</sup>.

The next inertia which is motor inertia is dependent on the motor, it is a small value so it will be ignored for torque requirement. However, the motor inertia is utilized to calculate the inertial ratio to ensure the motor is of adequate size for the system. The equations necessary to calculate the total inertia are established. The calculations for each ACME lead screw is summarized in the table below.

TABLE B-XXI: THE SUMMARY OF THE INERTIA CALCULATIONS FOR EACH ACME LEAD SCREW

Location	Jw [in-lb-sec <sup>2</sup> ]	J <sub>screw</sub> [in-lb-sec <sup>2</sup> ]	J <sub>total</sub> [in-lb-sec <sup>2</sup> ]
Side	0.00015	0.00072	0.00087
Front	0.00015	0.00117	0.00132
Back	0.0000254	0.00069	0.0007154

Now that the inertias are established the Torques are now calculated in regards to the Torque required to accelerate the load and the Torque required to run the machine. The equations for the acceleration and running torque are presented subsequently.

$$T_{acceleration} = J_{total} * \frac{V}{\Delta t} * .1$$

Where  $V$  is the load velocity, in this case the scanning fixture, and  $\Delta t$  is the change time to accelerate the load. For the analysis of the Automated Leak Detection Fixture, the change in time

is taken as 1 second. Velocity, which was established previous, is 2 in/sec. Next the calculation for running Torque is presented.

$$T_{run} = \left( \frac{F_{total} * i}{2 * \pi * L} \right)$$

Where  $F_{Total}$  is the force due to the load on the ACME Lead screw, described below.

$$F_{Total} = F_{external} + F_{Friction} + F_{gravity}$$

Since no external load is applied,  $F_{ext}$  is taken as zero. The two forces  $F_{Friction}$  and  $F_{gravity}$  are calculated via the following two equations.

$$F_{Friction} = \mu W \cos\theta$$

$$F_{gravity} = W \sin\theta$$

In both cases  $\theta$  is zero and the coefficient of friction,  $\mu$ , with lubricated steel on steel contact is taken as .15 [Automation Direct]. Therefore the  $F_{Total}$  becomes:

$$F_{Total} = F_{Friction} = \mu W \cos\theta$$

Now that working equations to calculate Torque have been established, the calculations are completed and summarized in TABLE B-XXII.

TABLE B-XXII: THE CALCULATED TORQUE TO TURN THE ACME LEAD SCREW

Location	Friction Force [lbs]	Jtotal [in-lb-sec <sup>2</sup> ]	Acceleration Torque [lb-in]	Running Torque [lb-in]	Total Torque [lb-in]
Side	0.5565	0.0032	0.00064	0.708	0.7091
Front	0.5565	0.0036	0.00072	0.708	0.7092
Back	0.372	0.0072	0.00144	0.473	0.4750

Based on the calculated values the Torque curve for STP-MTR-23055 [4] is consulted since it matches the applications needs best. The shaded area on the Torque provided below indicated where the calculated values are in relation to the rated values. Our max pulses per second will be 3200 pps.

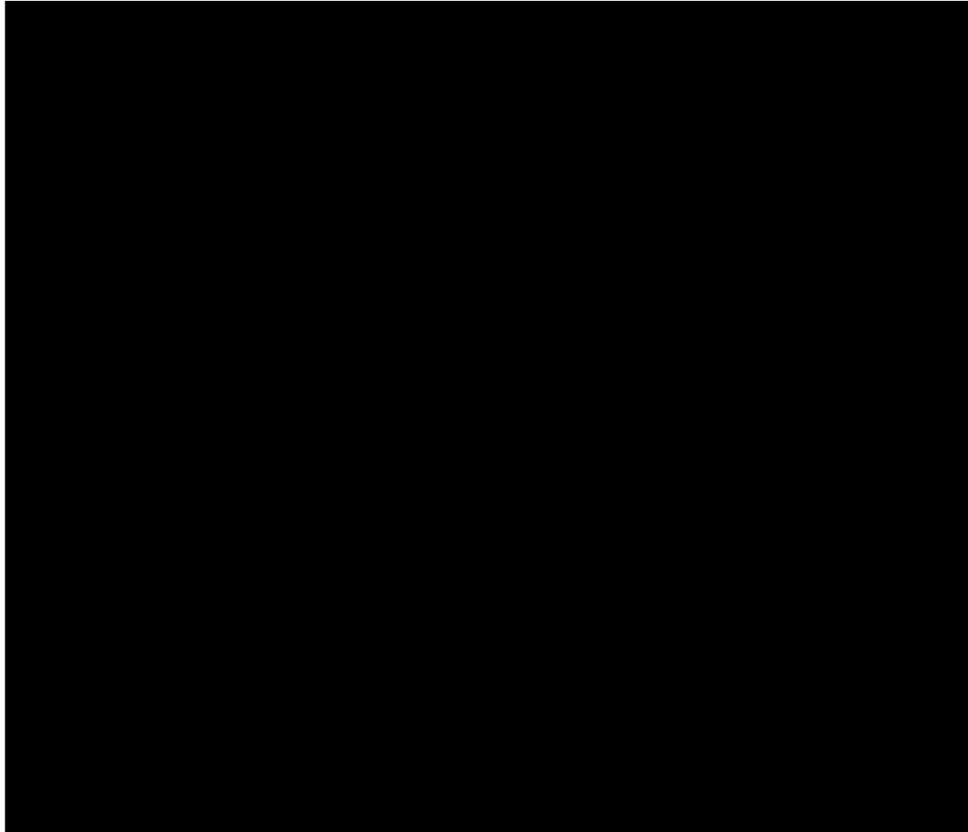


Figure B-15: Torque VS Speed for Stepper Motor [4]

For the inertial ratio, to determine if the motor is truly adequate for the Automated Leak Detection Fixture, we consult Automation Directs specified value for the STP-MTR-23055. The value yielded for motor inertia is .00024 lb-in-sec<sup>2</sup>. Taking the total inertia for a screw and dividing it by the motor inertia will yield the inertial ratio. The inertial ratio is recommended by Automation Direct to be less than 10. The calculation is as follows.

$$J_{ratio} = \frac{J_{Total}}{J_{motor}}$$

The ratios are summarized in TABLE B-XXIII below.

TABLE B-XXIII: THE SUMMARY OF THE INERTIAL RATIO FOR EACH ACME SCREW

Location	Jtotal [in-lb-sec <sup>2</sup> ]	Jmotot [in-lb-sec <sup>2</sup> ]	Inertial Ratio
Side	0.00087	0.00024	3.625
Front	0.00132	0.00024	5.5
Back	0.0007154	0.00024	2.980833333

From the TABLE B-XXIII, the values are all less than 10. Therefore the STP-MTR-23055 is an adequate stepper motor.

## B.3 References

- [1] NASA, "Human Performance Capabilities," 07 05 2008. [Online]. Available: [https://msis.jsc.nasa.gov/sections/section04.htm#\\_4.9\\_STRENGTH](https://msis.jsc.nasa.gov/sections/section04.htm#_4.9_STRENGTH). [Accessed 05 12 2016].
- [2] McMaster-Carr. (1901). "Precision Acme Threaded Rods & Nuts" [Online]. Available: <https://www.mcmaster.com/mvA/pdf/122/1147.pdf> [December 3, 2016].
- [3] R. L. Mott, Machine Elements In Mechanical Design 5th Edition, Upper Saddle River: Pearson, 2014.
- [4] Automation Direct. (1999). "Stepping Motor Drive" [Online]. Available: <https://www.automationdirect.com/static/specs/surestepdrive.pdf> [December 3, 2016].

## Appendix C

### Cost Analysis

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## C.1 Introduction

In this section, we have summarized our cost analysis and determined a final estimated cost for our design.

## C.2 Cost Analysis

A cost analysis was conducted for the detailed design. Prices of each item are listed in the TABLE C-1 as well as the quantities needed. Prices of items listed were obtained from actual suppliers which were in Winnipeg or deliver products to Winnipeg. The cost of raw materials for fabricated parts was estimated to be 50 dollars per part. The total cost is estimated to be \$8804.52 Canadian dollars before tax.

TABLE C-1 COST ANALYSIS

Item	Quantity	Price Per Unit (CND)	Supplier	Subtotal (CND)
1018 Carbon Steel Precision ACME Threaded Rod, 3/4"-8 Size, 1/2" Travel/Turn, 6' Long, Right-Hand Thread, 4 Starts	3	65.60	Mcmaster [1]	196.8
1018 Carbon Steel Precision ACME Threaded Rod, 5/8"-8 Size, 1/4" Travel/Turn, 6' Long, Right-Hand Thread, 2 Starts	1	78.14	Mcmaster [1]	78.14
Miniature Metric Ball Screw with Ball Nut, 8mm Screw Diameter, 2mm Travel/Turn, 250mm Length	2	248.79	Mcmaster [2]	492.74
Clamping Shaft Collar for 3/4" Diameter, Black-Oxide 1215 Carbon Steel	12	2.56	Mcmaster [3]	30.72
Clamping Shaft Collar for 5/8" Diameter, Black-Oxide 1215 Carbon Steel	2	2.11	Mcmaster [3]	4.22
Clamping Shaft Collar for 1" Diameter, Black-Oxide 1215 Carbon Steel	4	2.83	Mcmaster [3]	11.32
High-Load Oil-Embedded Flanged Sleeve Bearing for 3/4" Diameter, SAE 863 Bronze, 1/2" Length, 1-1/8" Flange OD	14	0.83	Mcmaster [4]	11.62
High-Load Oil-Embedded Flanged Sleeve Bearing for 1" Shaft Diameter, SAE 863 Iron-Copper Bronze, 3/4" Length	4	1.79	Mcmaster [4]	7.16
T-Handle Push-Button Quick-Release Pin with Lanyard, 1/2" Diameter, 3-1/4" Usable Length	4	40.76	Mcmaster [5]	163.04
Load-Rated Surface-Mount Hinge with Holes, 150 lb. Capacity/Pair, Primed Steel, 4" Wide	2	65.40	Mcmaster [6]	130.8
Angle Mount Caster, 4" x 31/32" Rubber Wheel, 110 lb Capacity	2	21.00	Mcmaster [7]	42
Flange-Mounted Linear Ball Bearing with Square Housing, 1-5/8" x 1-11/16" x 1-11/16" Overall	6	47.54	Mcmaster [8]	285.24

Item	Quantity	Price Per Unit (CND)	Supplier	Subtotal (CND)
Flange-Mounted Linear Ball Bearing with Square Housing, 5/8" Shaft Diameter, 1-1/2" x 1-1/2" x 1-1/2"	1	38.15	Mcmaster [8]	38.15
Bronze Precision ACME Round Nut, 3/4"-8 Size, 1/2" Travel/Turn, 4 Starts, Right-Hand Thread	3	54.63	Mcmaster [9]	163.89
Bronze Precision ACME Round Nut, 5/8"-8 Size, 1/4" Travel/Turn, 2 Starts, Right-Hand Thread	1	36.5	Mcmaster [9]	36.5
Formed Steel Pull Handle with Through Holes, Round Grip, Dull Finish, 8" Center to Center	1	7.35	Mcmaster [10]	7.35
Pull-Action Toggle Clamp, U-Bolt, 2000 lb. Maximum Holding Capacity, Steel	1	26.87	Mcmaster [11]	26.87
Aluminum Unthreaded Spacer, 1/2" OD, 1-1/2" Length, for 1/4" Screw Size	28	3.02	Mcmaster [12]	84.56
Ball Nut, 5/8" Diameter, 13/64" Lead, 778lb Load Cap, Square	1	31.85	Mcmaster [13]	31.85
Iglide G300, flange bushing	2	2.46	IGUS [14]	4.92
L-Handle Retractable Spring Plungers	4	9.03	Mcmaster [15]	36.12
1/2" to 1/4" Adapter – Pack of 20	1	60.22	Loc-line [16]	60.22
WERMA industrial signal beacon, permanent green LED, 58mm beacon diameter, 24 VAC/DC, IP65, base mount installation.	1	74.7	Automationdirect [17]	74.7
SureStep NEMA 23 stepper motor, single shaft, 166 oz-in holding torque, 2.8 amps/phase, 1.8 degrees / full step (200 steps/revolution), bipolar. 12-inch cable.	5	47.35	Automationdirec [18]	236.75
WERMA industrial signal beacon, permanent red LED, 58mm beacon diameter, 24 VAC/DC, IP65, base mount installation.	1	74.7	Automationdirect [17]	74.7
WERMA industrial signal beacon, permanent yellow incandescent, 57mm beacon diameter, 12-240 VAC/DC, IP65, base mount installation. Purchase 5 watt bulb separately.	10	7.34	Automationdirect [17]	73.4
WERMA audible alarm buzzer, piezoelectric, 80 dB at 10 cm, 2.4 kHz tone frequency, continuous tone, 115 VAC/DC, 22.5 mm panel mount, IP65.	1	42.52	Automationdirec [19]	42.52
Flange-Mounted Linear Ball Bearing with Round Housing, 1" Shaft Diameter, 2-1/4" x 2-1/2" x 2-1/2"	6	63.91	Mcmaster [8]	383.46
C1 Servo Spline to 1/4" Shaft Coupler	2	6.65	Servocity [20]	13.3
HS-5245MG Servo	2	66.46	Servocity [21]	132.92
High-Load Oil-Embedded Flanged Sleeve Bearing for 1/4" Shaft Diameter, SAE 863 Iron-Copper Bronze, 1/4" Length	2	0.49	Mcmaster [4]	0.98
Field wireable connector, M12 nut 4-pin female right-angle connection, accepts 4 to 6 mm diameter cable, 18 AWG, screw terminal connection, IP67.	8	9.29	Automationdirec [17]	74.32
Multipurpose Flanged Sleeve Bearing for 8 mm Shaft Diameter, 11 mm OD	8	3.32	Mcmaster [22]	26.56

Item	Quantity	Price Per Unit (CND)	Supplier	Subtotal (CND)
<b>Aluminum Unthreaded Spacer, 5/16" OD, 1-3/4" Length, for Number 10 Screw Size</b>	28	1.76	Mcmaster [12]	49.28
<b>Raw Materials (Part)</b>	40	50	NA	2000
<b>Brass Actuated On/Off Valve, Normally Closed, 120V AC, 1/4 NPT Female</b>	14	100.49	Mcmaster [23]	1406.86
<b>Black Anodized Aluminum Manifold, 4 Outlets on One Side, 3/8 Pipe Size Inlet</b>	1	18.36	Mcmaster [24]	18.36
<b>PIPE FITTINGS AND PORT ADAPTERS 1/4 FF-B</b>	14	4.39	Parker [25]	61.46
<b>PIPE FITTINGS AND PORT ADAPTERS 3/8X1/4 FF-B</b>	4	7.95	Parker [25]	31.8
<b>Push-to-Connect Tube Fitting for Air, Straight Adapter for 1/4" Tube OD x 1/4 NPT Male</b>	10	3.08	Mcmaster [26]	30.8
<b>Push-to-Connect Tube Fitting for Air, Straight Adapter for 1/4" Tube OD x 3/8 NPT Male</b>	1	3.95	Mcmaster [26]	3.95
<b>Push-to-Connect Tube Fitting for Air, Straight Adapter, 1/4" Tube OD x 1/4 NPT Female</b>	10	5.67	Mcmaster [26]	56.7
<b>Male Adapter, 1/4" Trade Size x 1/4 NPT, for Loc-Line Coolant Hose</b>	10	4.35	Mcmaster [27]	43.5
<b>Reducer, 1/2" x 1/4" Trade Size, Female x Male, for Loc-Line Coolant Hose</b>	10	5.46	Mcmaster [27]	54.6
<b>Black Anodized Aluminum Manifold, 3 Outlets on One Side, 3/8 Pipe Size Inlet</b>	2	18.15	Mcmaster [24]	36.3
<b>Black Anodized Aluminum Manifold, 2 Outlets on One Side, 3/8 Pipe Size Inlet</b>	2	15.62	Mcmaster [24]	31.24
<b>Productivity2000 I/O base, 15-slot, DIN rail or flush mount. Holds power supply, CPU and 15 I/O modules. Requires power supply.</b>	2	205.66	Automationdirect [28]	411.32
<b>Productivity2000 CPU module, 50 MB user memory, 4 x 10 character OLED display, (1) RS-232 (RJ12) port, (1) RS-485 (3-wire terminal block) port, (2) Ethernet (RJ45) port, (1) microB-USB port, (1) microSD card slot.</b>	1	338.35	Automationdirect [29]	338.35
<b>SureStep microstepping drive, 7.5A per phase, 24-65 VDC, 2-phase bipolar PWM output; step and direction control mode.</b>	4	118.09	Automationdirect [30]	472.36
<b>SureStep power supply, linear, dual output, 48 VDC at 5A unregulated, 5 VDC at 0.5A regulated, 240W, 1-phase, fused overcurrent protection, open frame housing.</b>	4	185.76	Automationdirect [30]	743.04
<b>Series 10 New 'E2 mini'</b>	10	12.87	Igus [31]	128.7
<b>Total</b>				8804.52

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## Appendix D

### Engineering Drawings

## Table of Contents

D.1 Introduction.....	3
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## D.1 Introduction

This appendix contains the assembly drawings for the automated fixture as well as the part drawings for custom fabricated parts.

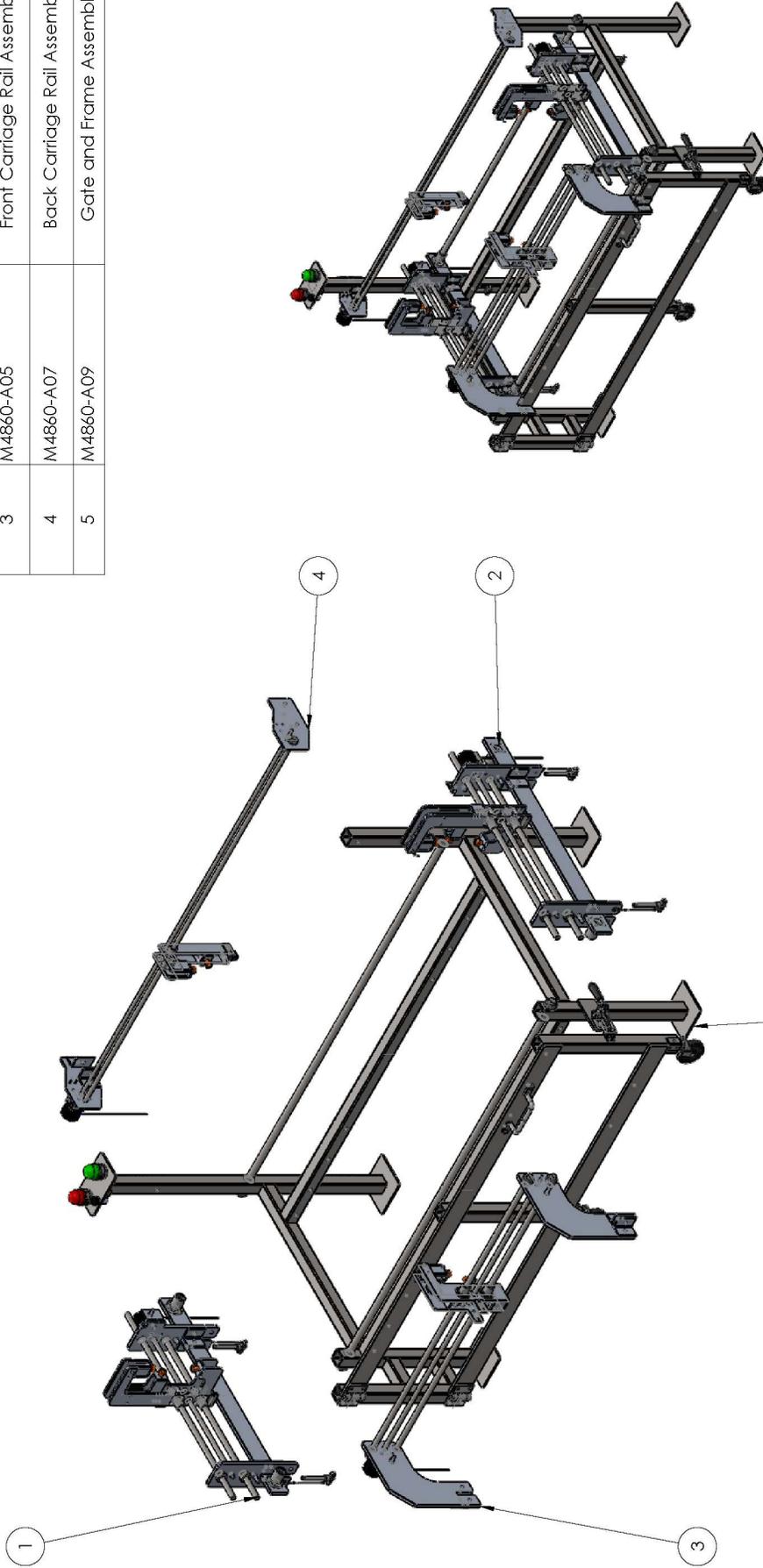
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2

3

4

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-A01	Left Side Carriage Rail Assembly	1
2	M4860-A03	Right Side Carriage Rail Assembly	1
3	M4860-A05	Front Carriage Rail Assembly	1
4	M4860-A07	Back Carriage Rail Assembly	1
5	M4860-A09	Gate and Frame Assembly	1



B

D-4

A

TITLE:

AUTOMATED FIXTURE FOR LEAK DETECTION SCANNING

NAME	JHAN	DATE	2016/12/03
CHECKED	CWATSON	DATE	2016/1/20/05

SIZE	DWG. NO.	REV
B	M4860-A00	0

SCALE: 1:20 WEIGHT: SHEET 1 OF 1

Automated Fixture for Leak Detection Scanning

INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994
UNLESS OTHERWISE SPECIFIED:	
DIMENSIONS ARE IN INCHES	
TOLERANCES	
ANGULAR: MACH: 0°30'	
TWO PLACE DECIMAL ±.01	
THREE PLACE DECIMAL ±.002	



MECH 4860 ENGINEERING DESIGN

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2

3

4

1

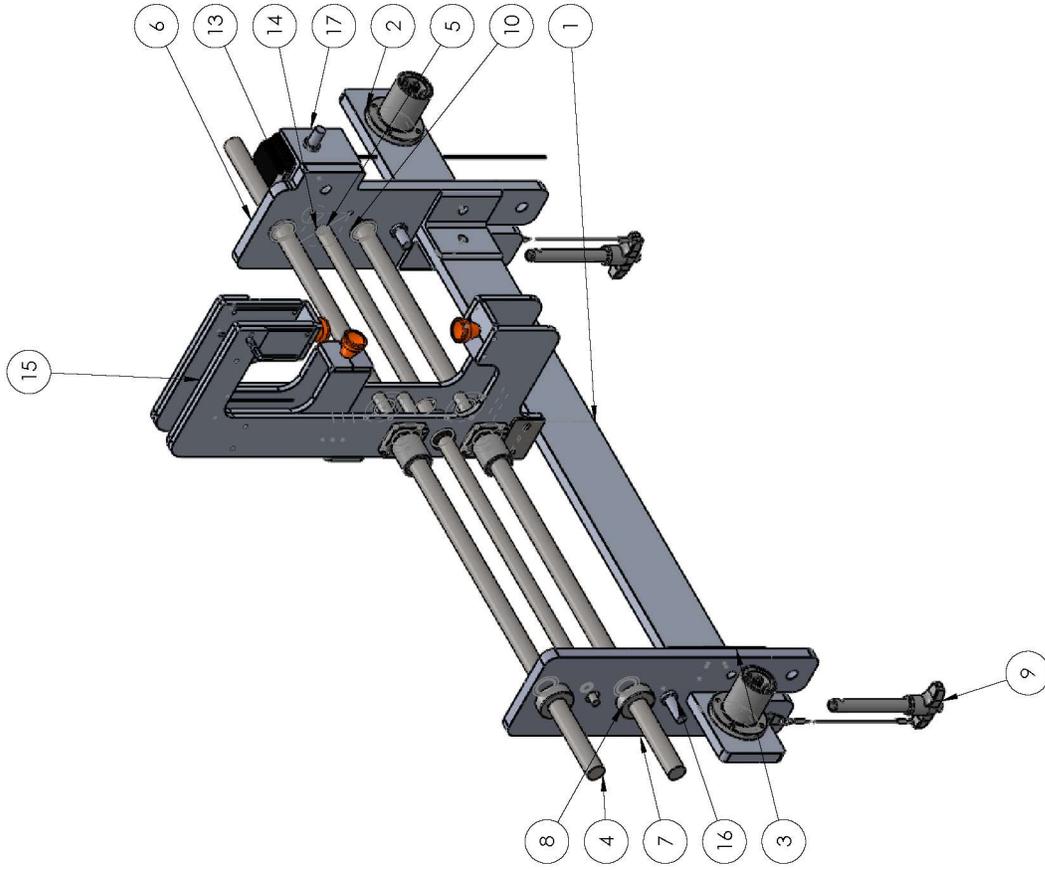
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3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-028	Side Rail Front Plate	1
2	6483K56	Flange-Mount Linear Ball Bearing	2
3	M4860-000	Angle Bracket 1	4
4	M4860-029	Side Rail Guide Bar	2
5	99030A600_1018 CARBON STEEL PRECISION ACME THREADED ROD side screw	Fast-Travel Precision Acme Threaded Rod	1
6	M4860-030	Side Rail Mounting Bracket 2	1
7	M4860-014	Side Rail Mounting Bracket 1	1
8	6435K16	One-Piece Clamp-On Shaft Collar	4
9	93750A718	Aluminum-Handle Push-Button Quick-Release Pin with lanyard	2
10	2938T53	High-Load Oil-Embedded Flanged Sleeve Bearing	4
11	92510A251	Unthreaded Spacer	4
12	U-CPDW19-L0_25-R8	Couplings - Disc for Servo Motors	1
13	STP-AMTR-23055	Stepper Motor	1
14	5448T2	Multipurpose Flanged Sleeve Bearing	2
15	M4860-A02	Left Side Carriage Assembly	1
16	PMW-OP-2H Proc Sensor	Inductive Proximity Sensor	3
17	M4860-033	Proc Sensor Angle Bracket	1



B

D-5

A



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**ENGINEERING**  
**DESIGN**



4

3

2

1

TITLE:

LEFT SIDE CARRIAGE RAIL ASSEMBLY

INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	CHECKED	NAME	DATE
		JHAN	CWATSON		2016/12/03
UNLESS OTHERWISE SPECIFIED:		MATERIAL			
DIMENSIONS ARE IN INCHES		FINISH			
TOLERANCES					
ANGULAR: MACH ±0°30'					
TWO PLACE DECIMAL ±.01					
THREE PLACE DECIMAL ±.002					
DO NOT SCALE DRAWING					

SIZE	DWG. NO.	REV
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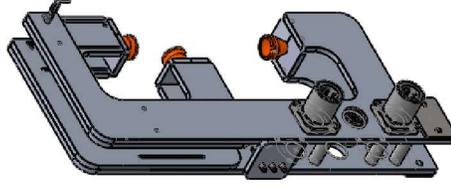
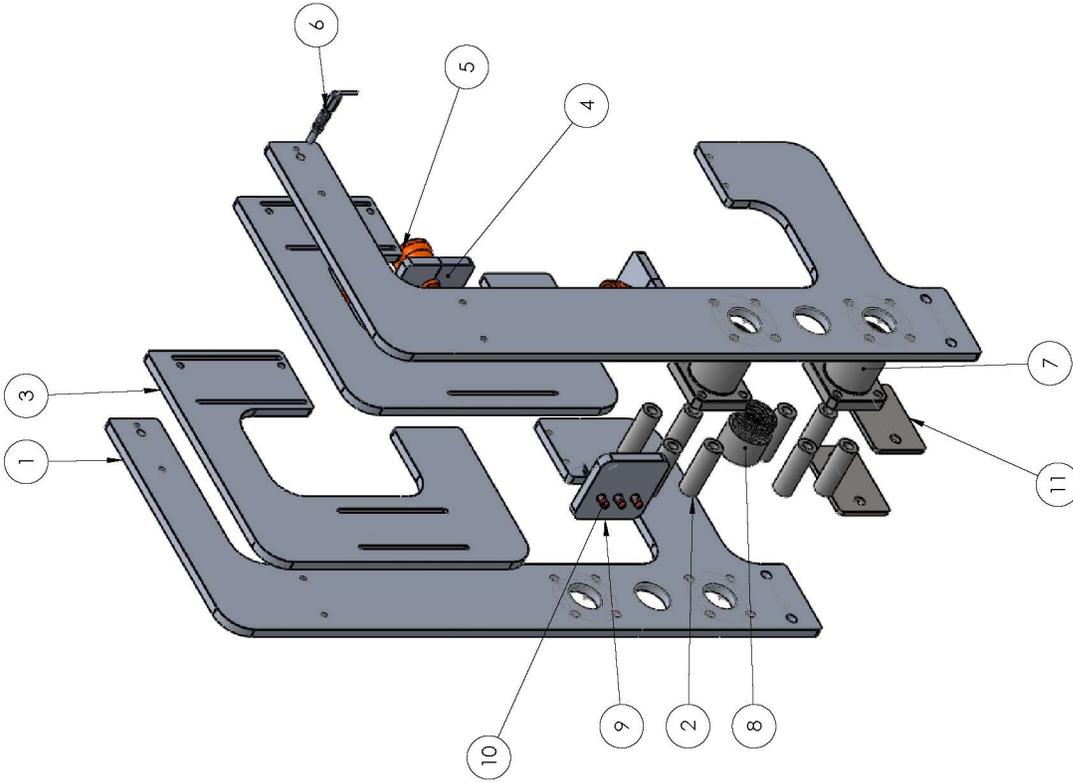
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3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-015	Left Carriage Plate	2
2	92510A771	Unthreaded Spacer	8
3	M4860-013	Left Carriage Adjustment Plate	2
4	M4860-008	Nozzle Retainer	6
5	User Library-loc-line 59869	Loc Line Nozzle	3
6	8498A76	Retractable Spring Plunger without Locking Nose	1
7	6483K65	Flange-Mount Linear Ball Bearing	2
8	95072A540	Fast-Travel Precision Acme Round Nut	1
9	M4860-009	LED Mounting Bracket	1
10	LED 5mm	Red LED	3
11	M4860-012	Proximity Sensor Detection Plates	2



B

D-6

A



**UNIVERSITY**  
OF  
**MANITOBA**

**MECH 4860**  
**ENGINEERING**  
**DESIGN**



PROJECTION

Automated Fixture for Leak Detection Scanning  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES  
 ANGULAR: MACH: 0°30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

DO NOT SCALE DRAWING

MATERIAL FINISH

SIZE DWG. NO. **B** M4860-A02  
 REV **0**

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

TITLE:

LEFT SIDE CARRIAGE ASSEMBLY

4

3

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1



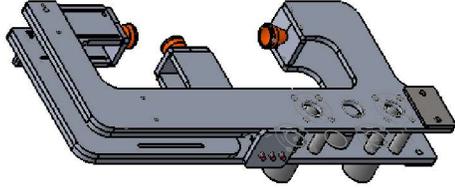
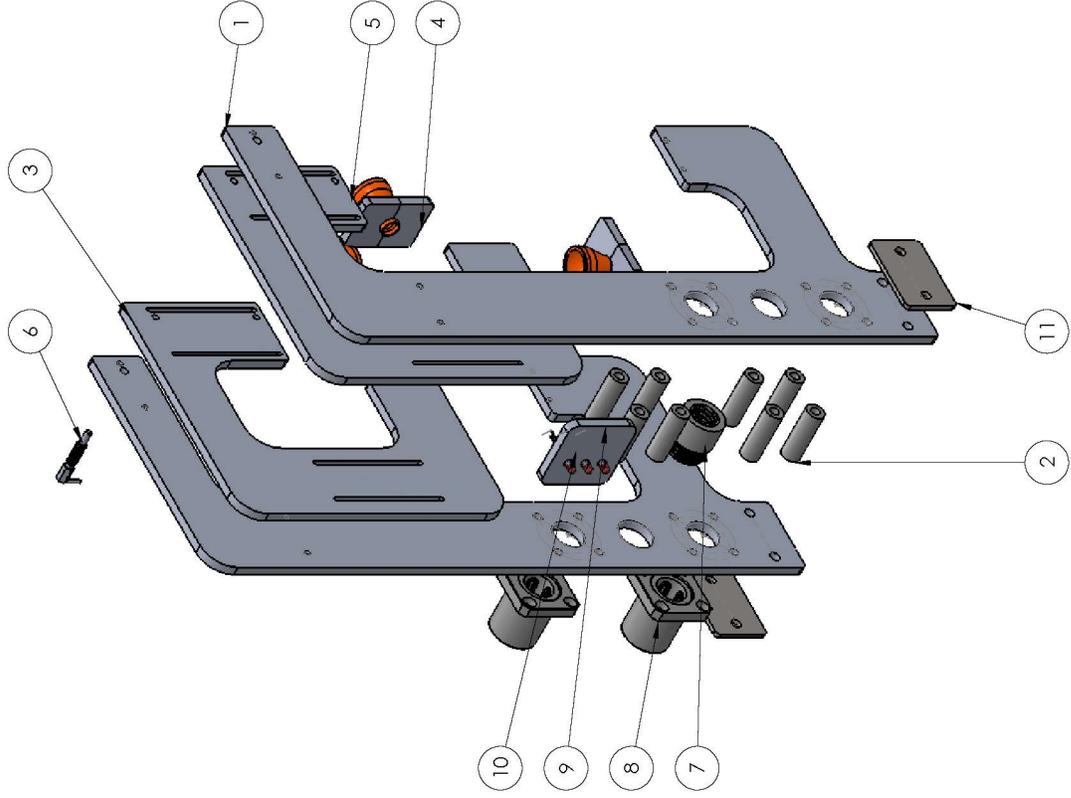
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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-015	Left Carriage Plate	2
2	92510A771	Unthreaded Spacer	8
3	M4860-013	Left Carriage Adjustment Plate	2
4	M4860-008	Nozzle Retainer	6
5	User Library-loc-line 59869	Loc Line Nozzle	3
6	8498A76	Retractable Spring Plunger without Locking Nose	1
7	95072A540	Fast-Travel Precision Acme Round Nut	1
8	6483K65	Flange-Mount Linear Ball Bearing	2
9	M4860-009	LED Mounting Bracket	1
10	LED 5mm	Red LED	3
11	M4860-012	Proximity Sensor Detection Plates	2



B

D-8

A



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**DESIGN**



MECH 4860  
 ENGINEERING  
 DESIGN

4

3

2

1

TITLE:

RIGHT SIDE CARRIAGE ASSEMBLY

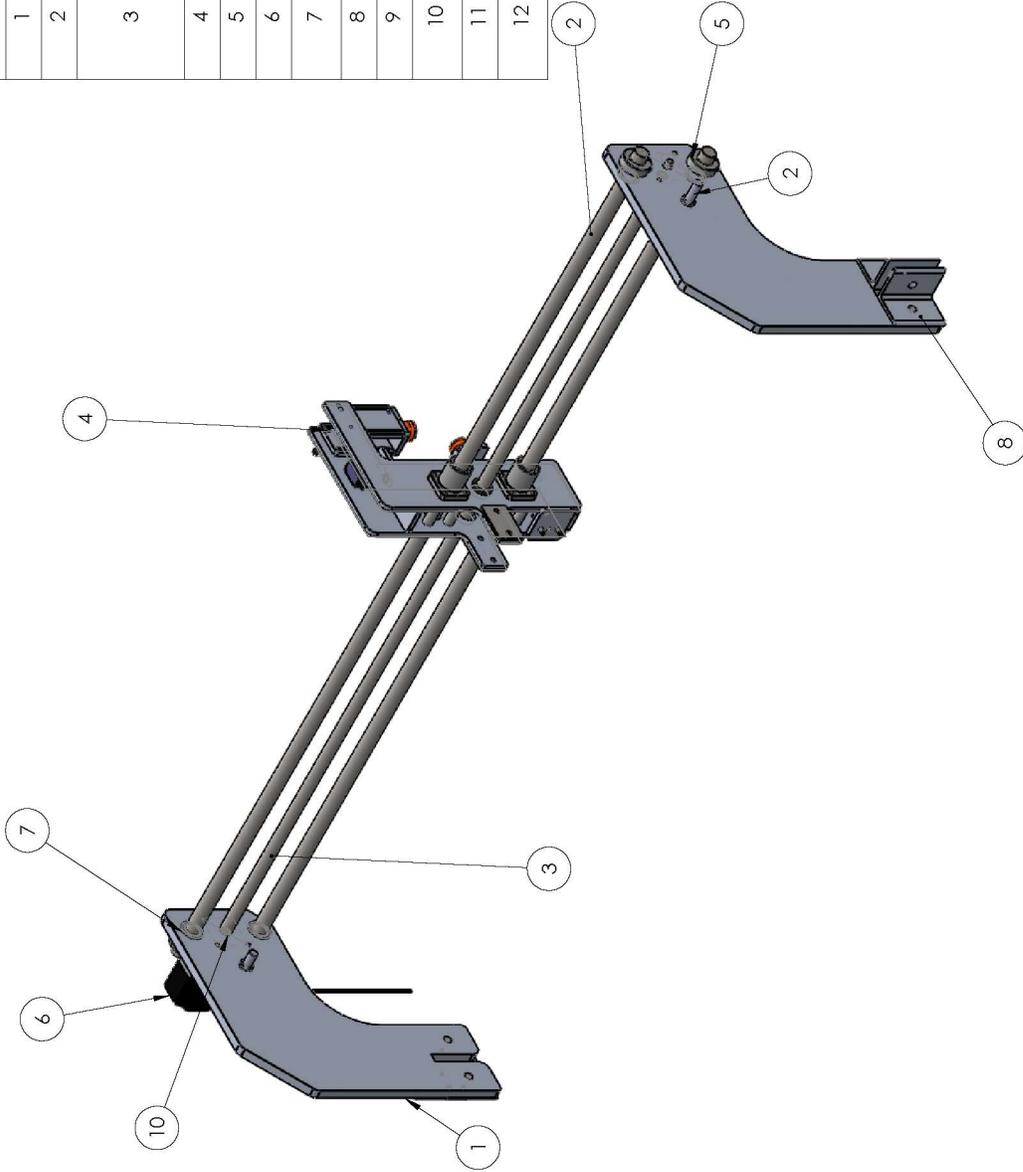
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	JHAN	NAME	JHAN	DATE	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CHECKED	CWATSON				2016/1/20/5
DIMENSIONS ARE IN INCHES		MATERIAL					
TOLERANCES		FINISH					
ANGULAR: MACH: 0°30'							
TWO PLACE DECIMAL ±.01							
THREE PLACE DECIMAL ±.002							

SIZE	DWG. NO.	REV
<b>B</b>	M4860-A04	<b>0</b>
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

A

4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-007	Front Rail Mounting Bracket	2
2	M4860-017	Front Carriage Guide Rail	2
3	99030A600_1018 CARBON STEEL PRECISION ACME THREADED ROD front side	Fast-Travel Precision Acme Threaded Rod	1
4	M4860-A06	Front Carriage Assembly	1
5	6435K16	One-Piece Clamp-On Shaft Collar	4
6	STP-1MTR-23055	Stepper Motor	1
7	2938T53	High-Load Oil-Embedded Flanged Sleeve Bearing	4
8	M4860-000	Angle Bracket 1	4
9	U-CPDW19-L0_25-R8	Couplings - Disc for Servo Motors	1
10	5448T2	Multipurpose Flanged Sleeve Bearing	2
11	92510A251	Unthreaded Spacer	4
12	PMW-0P-2H Proc Sensor	Inductive Proximity Sensor	2



B

D-9

A



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Automated Fixture for Leak Detection Scanning  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES:  
 ANGULAR: MACH: 0°30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

DO NOT SCALE DRAWING

MATERIAL FINISH

DATE: 2016/12/03  
 NAME: JHAN  
 DRAWN: 2016/12/05  
 CHECKED: COWATSON

TITLE: FRONT CARRIAGE RAIL ASSEMBLY  
 SIZE: B  
 DWG. NO.: M4860-A05  
 REV: 0  
 SCALE: 1:6 WEIGHT: SHEET 1 OF 1

4

3

2

1

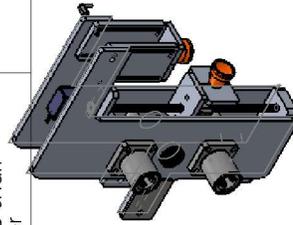
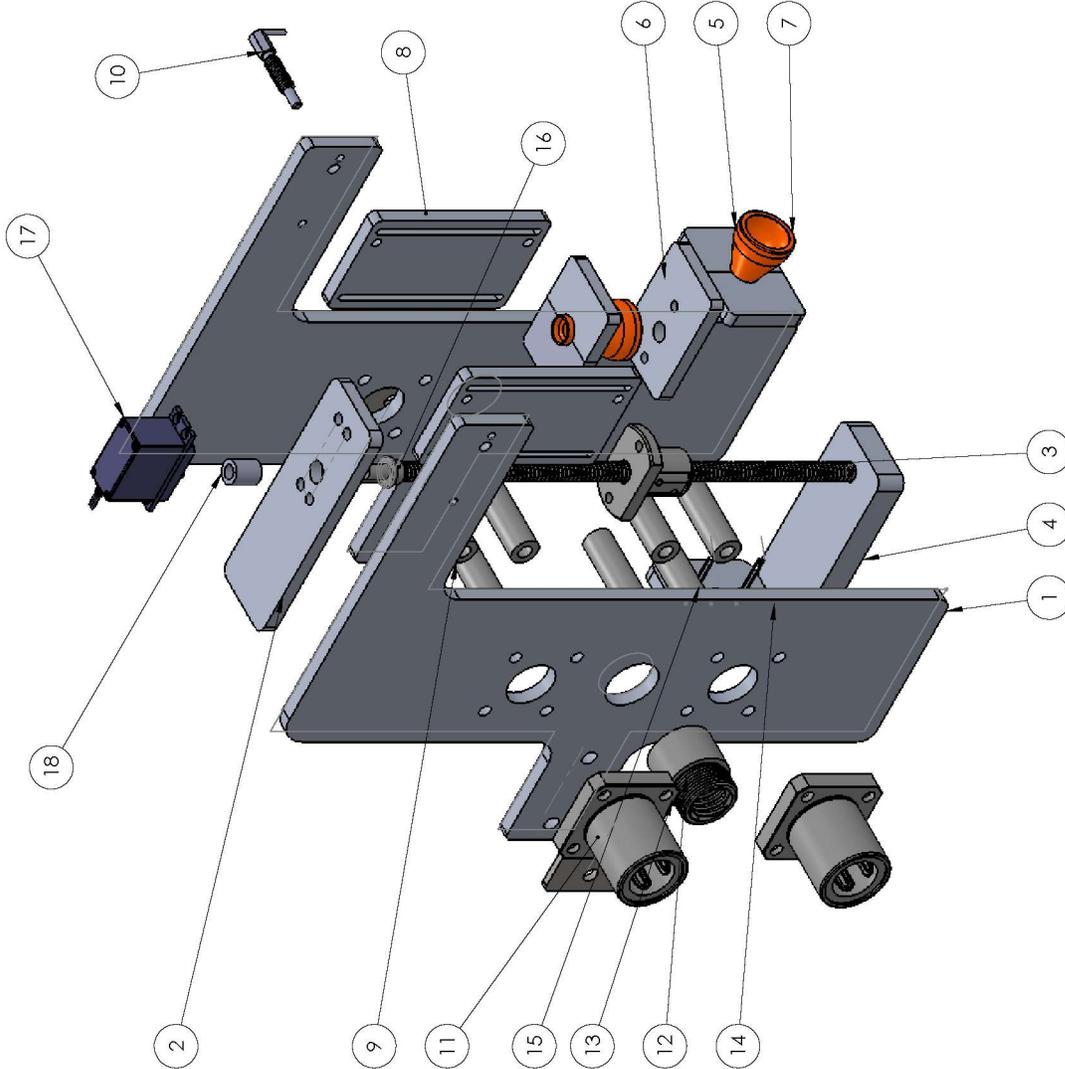
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3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-034	Front Carriage Plate	2
2	M4860-011	Servo Mounting Plate	1
3	6638K300 MINIATURE METRIC BALL SCREW WITH BALL NUT	Miniature Metric Ball Screw with Ball Nut	1
4	M4860-035	Ball Screw Plate	1
5	M4860-008	Nozzle Retainer	4
6	M4860-006	Nozzle to Ball Nut Plate	1
7	User Library-loc-line 59869	Loc Line Nozzle	2
8	M4860-010	Upper Nozzle Adjuster	2
9	92510A771	Unthreaded Spacer	8
10	8498A76	Retractable Spring Plunger without Locking Nose	1
11	6483K65	Flange-Mount Linear Ball Bearing	2
12	95072A540	Fast-Travel Precision Acme Round Nut	1
13	M4860-012	Proximity Sensor Detection Plates	2
14	M4860-009	LED Mounting Bracket	1
15	LED 5mm	Red LED	2
16	2938T1	High-Load Oil-Embedded Flanged Sleeve Bearing	1
17	HS5245MG	Servo Motor	1
18	5245MG Shaft Coupler	Shaft Coupler	1



B

D-10

A



**UNIVERSITY OF SASKATCHEWAN**  
**ANITIBA**

**MECH 4860**  
**ENGINEERING**  
**DESIGN**



4

3

2

1

TITLE:

FRONT CARRIAGE ASSEMBLY

INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	CHECKED	NAME	DATE
		JHAN	CWATSON		2016/2/03

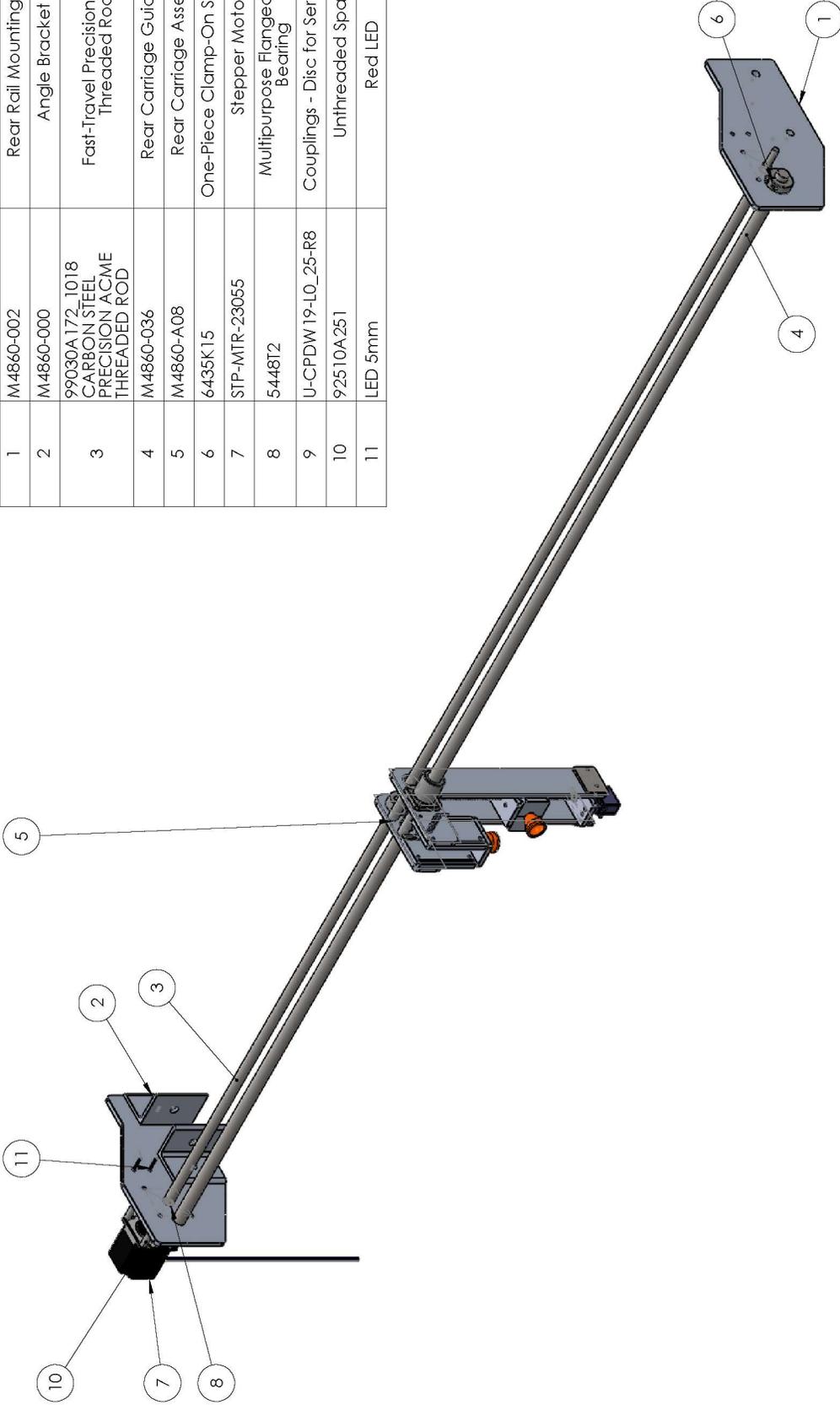
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 TWO PLACE DECIMAL ± .01  
 THREE PLACE DECIMAL ± .002

MATERIAL FINISH  
 DO NOT SCALE DRAWING

SIZE DWG. NO. M4860-A06  
 REV 0  
 SCALE: 1:5 WEIGHT: SHEET 1 OF 1

4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M-4860-002	Rear Rail Mounting Plate	2
2	M-4860-000	Angle Bracket 1	4
3	99030A172_1018 CARBON STEEL PRECISION ACME THREADED ROD	Fast-Travel Precision Acme Threaded Rod	1
4	M-4860-036	Rear Carriage Guide Rail	1
5	M-4860-A08	Rear Carriage Assembly	1
6	6435K15	One-Piece Clamp-On Shaft Collar	2
7	STP-MTR-23055	Stepper Motor	1
8	5448T2	Multipurpose Flanged Sleeve Bearing	2
9	U-CPDW19-L0_25-R8	Couplings - Disc for servo Motors	1
10	92510A251	Unthreaded Spacer	4
11	LED 5mm	Red LED	2



B

D-11

A



UNIVERSITY OF MANITOBA  
MECH 4860  
ENGINEERING  
DESIGN

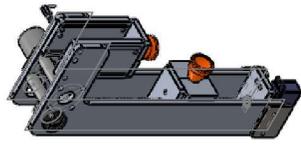
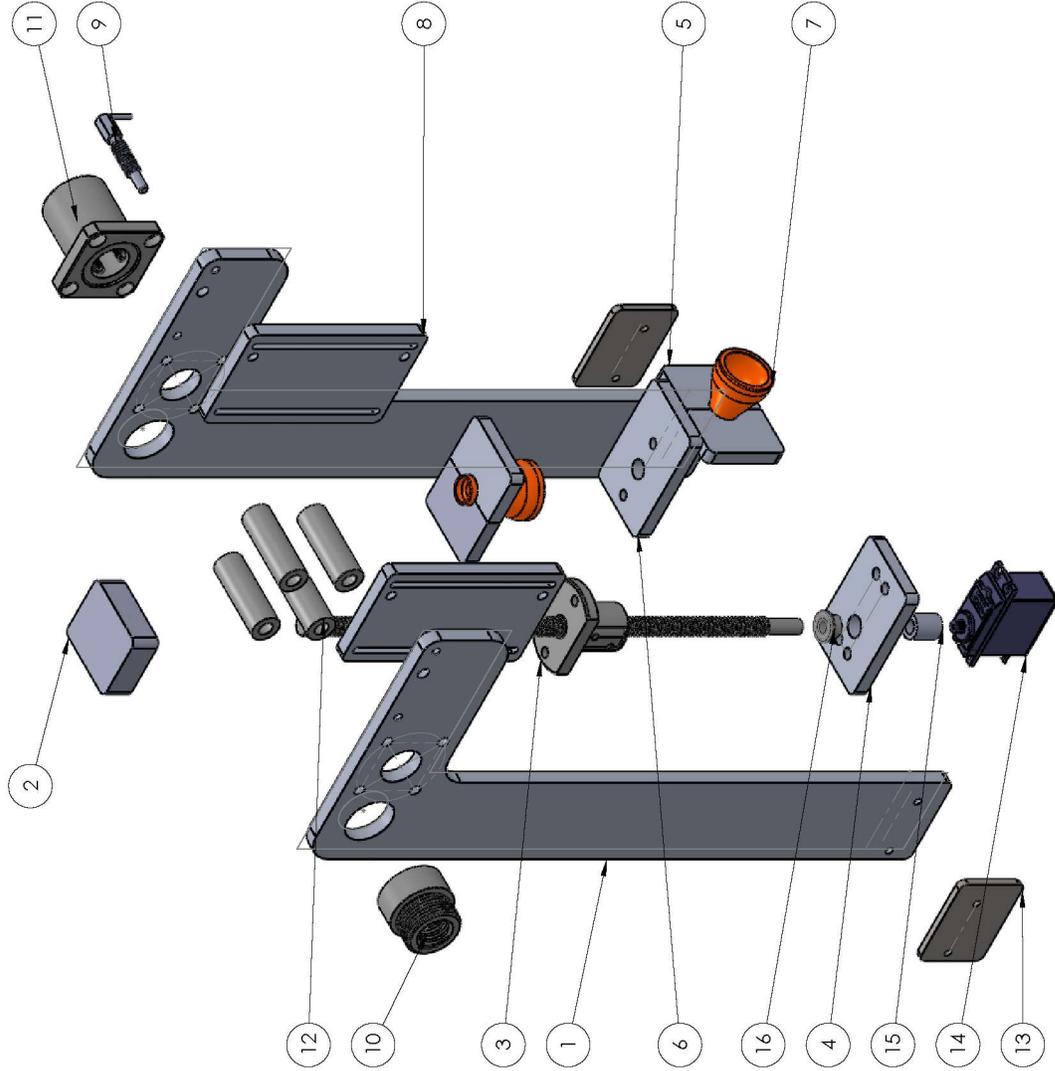
PROJECTION

<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002		DRAWN: JHAN CHECKED: COWATSON DATE: 2016/12/03 DATE: 2016/12/05
TITLE: BACK CARRIAGE RAIL ASSEMBLY		SIZE: B DWG. NO.: M4860-A07 REV: 0
DO NOT SCALE DRAWING		SCALE: 1:5 WEIGHT: SHEET 1 OF 1

4 3 2 1

4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-003	Rear Carriage Plate	2
2	M4860-037	Ball Screw Plate	1
3	6638K300 MINIATURE METRIC BALL SCREW WITH BALL NUT back side	Miniature Metric Ball Screw with Ball Nut	1
4	M4860-001	Servo Mounting Bracket	1
5	M4860-008	Nozzle Retainer	4
6	M4860-006	Nozzle to Ball Nut Plate	1
7	User Library-loc-line	Loc Line Nozzle	2
8	M4860-010	Upper Nozzle Adjuster	2
9	8498A76	Retractable Spring Plunger without Locking Nose	1
10	95072A321	Fast-Travel Precision Acme Round Nut	1
11	6483K64	Flange-Mount Linear Ball Bearing	1
12	92510A771	Unthreaded Spacer	4
13	M4860-038	Proximity Sensor Detection Plate	2
14	HS5245MG	Servo Motor	1
15	5245MG Shaft Coupler	Shaft Coupler	1
16	2938T1	High-Load Oil-Embedded Flanged Sleeve Bearing	1



TITLE:		REAR CARRIAGE ASSEMBLY	
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	JHAN
UNLESS OTHERWISE SPECIFIED:		CHECKED	CWATSON
DIMENSIONS ARE IN INCHES		MATERIAL	
TOLERANCES:		FINISH	
ANGLES: 30°			
TWO PLACE DECIMAL	±.01		
THREE PLACE DECIMAL	±.002		
DO NOT SCALE DRAWING			

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4 3 2 1

SIZE	DWG. NO.	REV
<b>B</b>	M4860-A08	<b>0</b>
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

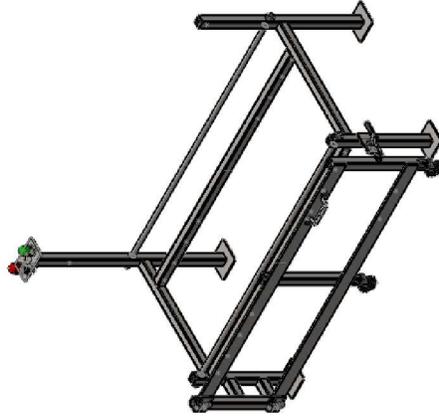
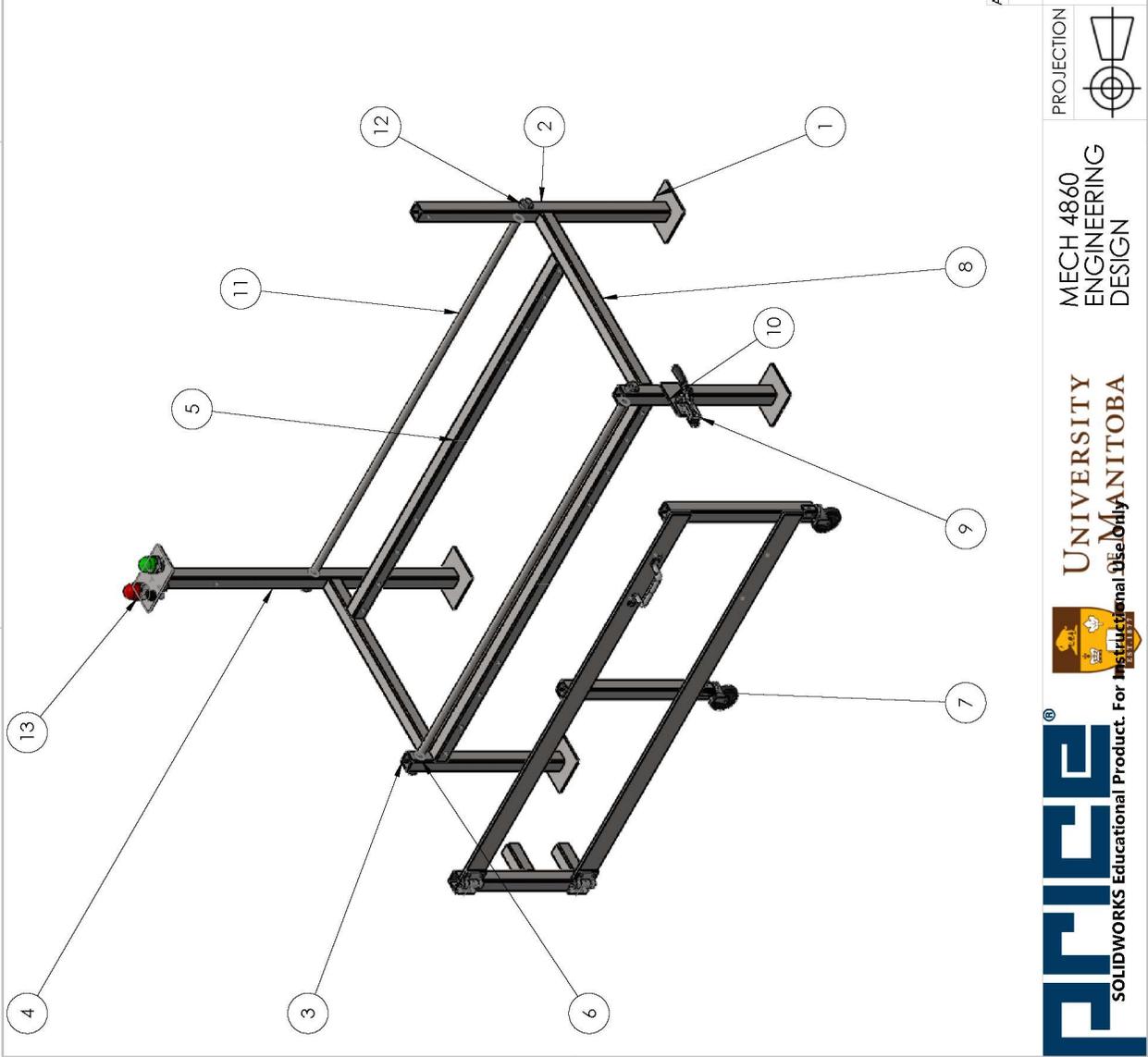
B

D-12

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4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-005	Footing	4
2	M4860-018	Back Leg 1	1
3	M4860-019	Front Leg	2
4	M4860-020	Back Leg 2	1
5	M4860-021	Cross Brace 2	2
6	2938T25	High-Load Oil-Embedded Flanged Sleeve Bearing	4
7	M4860-A10	Gate Assembly	1
8	M4860-027	Cross Brace 2	2
9	5071A530_PULL-ACTION TOGGLE CLAMP	Pull Action Toggle Clamp	1
10	M4860-016	Toggle Clamp Mounting Plate	1
11	M4860-032	Adjustability Guide Rail	2
12	6435K18	One-Piece Clamp-On Shaft Collar	4
13	M4860-A11	Beacon Light Alarm Assembly	1



<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002		DRAWN: JHAN CHECKED: COWATSON MATERIAL: FINISH:	NAME: JHAN DATE: 2016/12/03 NAME: COWATSON DATE: 2016/12/05	TITLE: GATE AND FRAME ASSEMBLY SIZE: B DWG. NO.: M4860-A09 REV: 0 SCALE: 1:1.5 WEIGHT: SHEET 1 OF 1
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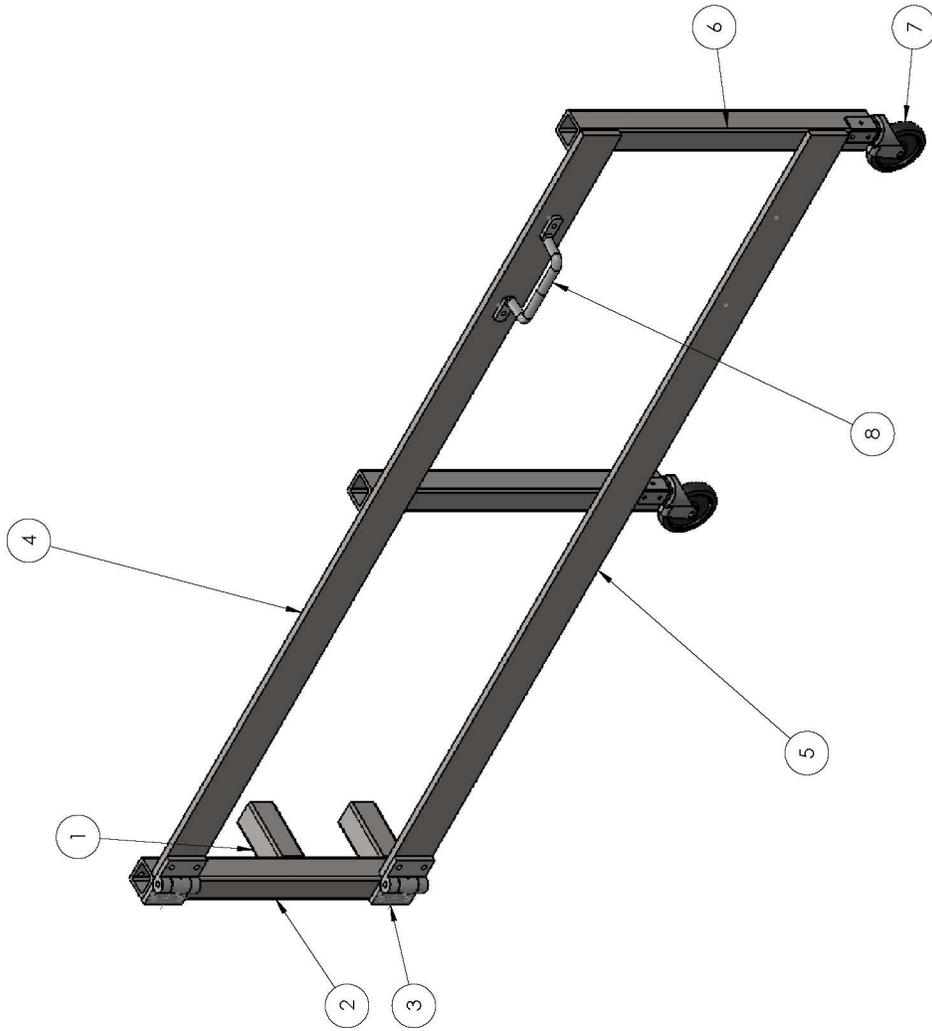
B

D-13

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4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-022	Hinge Post	2
2	M4860-023	Hinge Vertical Post	1
3	1852A59	Load-Rated Heavy Duty Surface-Mount Hinge	2
4	M4860-024	Gate Top Horizontal Plate	1
5	M4860-025	Gate Bottom Horizontal Plate	1
6	M4860-026	Vertical Gate Post	2
7	2399T3	Angle-Mount Swivel Caster	2
8	17135A41	Dull Finish Formed Steel Pull Handle	1



B

D-14

A



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Automated Fixture for Leak Detection Scanning INTERPRET GEOMETRIC TOLERANCING PER: ANS1 Y14.5M-1994		DRAWN: JHAN CHECKED: CWATSON	NAME: JHAN DATE: 2016/12/03	TITLE: GATE ASSEMBLY
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL: ±.01 THREE PLACE DECIMAL: ±.002		MATERIAL: FINISH:	DO NOT SCALE DRAWING	SIZE: B DWG. NO.: M4860-A10 REV: 0
		SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

4

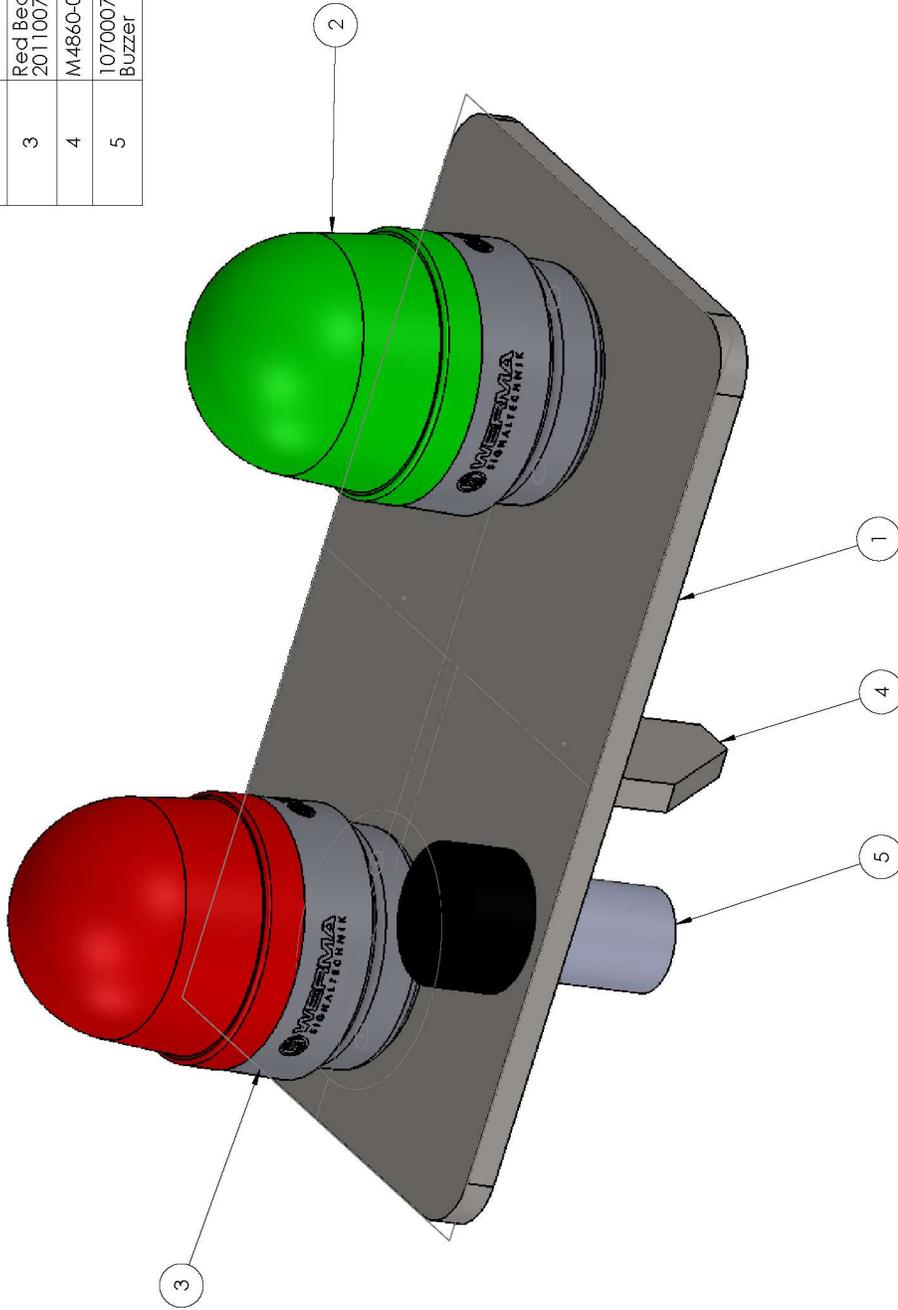
3

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4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	M4860-004	Beacon Mounting Plate	1
2	Green Beacon Light - 20120075	Green Beacon Light	1
3	Red Beacon Light - 20110075	Red Beacon Light	1
4	M4860-039	Beacon Mount Flange	2
5	10700077 Audible Buzzer	Audible Buzzer Alarm	1



B

D-15

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<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002		NAME: JHAN DATE: 2016/12/03 CHECKED: COWATSON DATE: 2016/12/05
PROJECT: MECH 4860 ENGINEERING DESIGN 		TITLE: BEACON LIGHT ALARM ASSEMBLY SIZE: B DWG. NO.: M4860-A11 REV: 0
UNIVERSITY OF SASKATCHEWAN SOLIDWORKS Educational Product. For Instructional Use Only.		SCALE: 1:1 WEIGHT: SHEET 1 OF 1

4

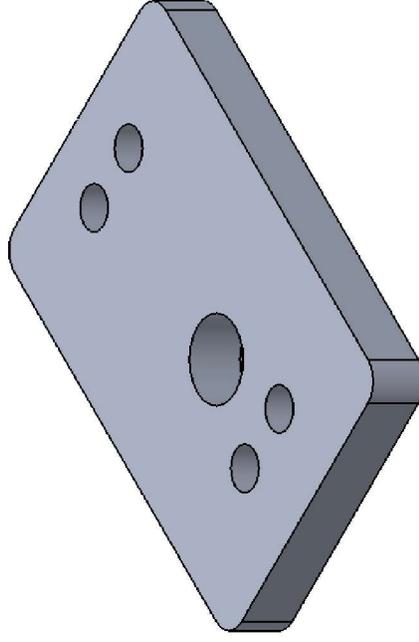
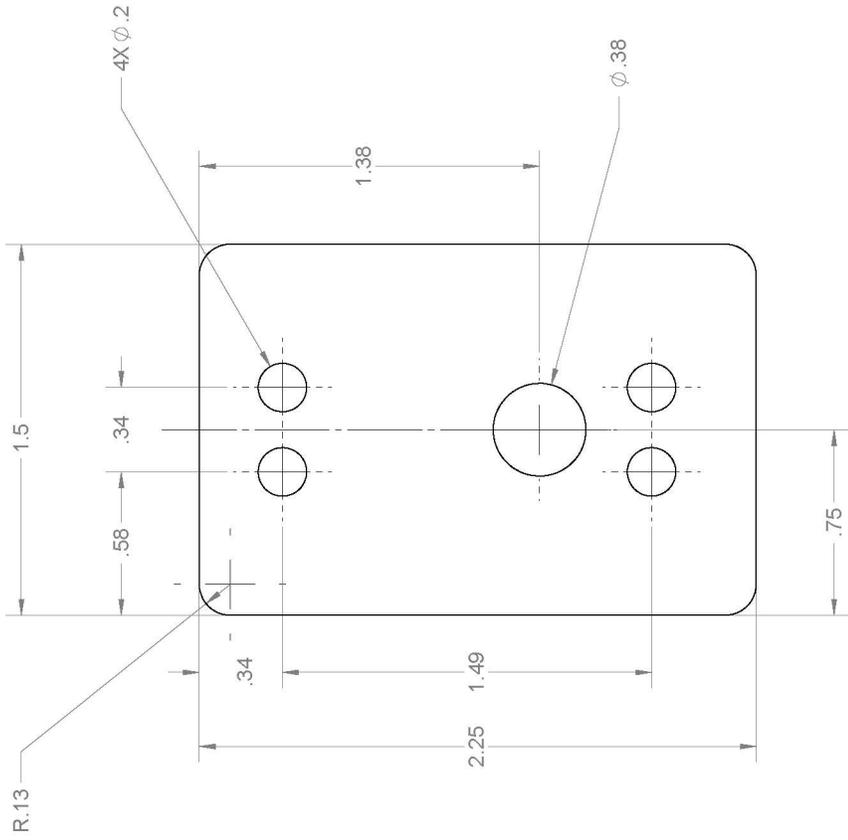
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D-17

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MECH 4860  
ENGINEERING  
DESIGN



Automated Fixture for Leak Detection Scanning

INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	NAME	DATE
		JHAN <td>2016/12/03</td> <td></td>	2016/12/03	
		CWATSON	2016/12/05	

UNLESS OTHERWISE SPECIFIED:  
DIMENSIONS ARE IN INCHES  
TOLERANCES  
ANGULAR: MACH: 0°30'  
TWO PLACE DECIMAL ±.01  
THREE PLACE DECIMAL ±.002

MATERIAL: 1/4" 6061-T6 ALUMINUM  
FINISH:

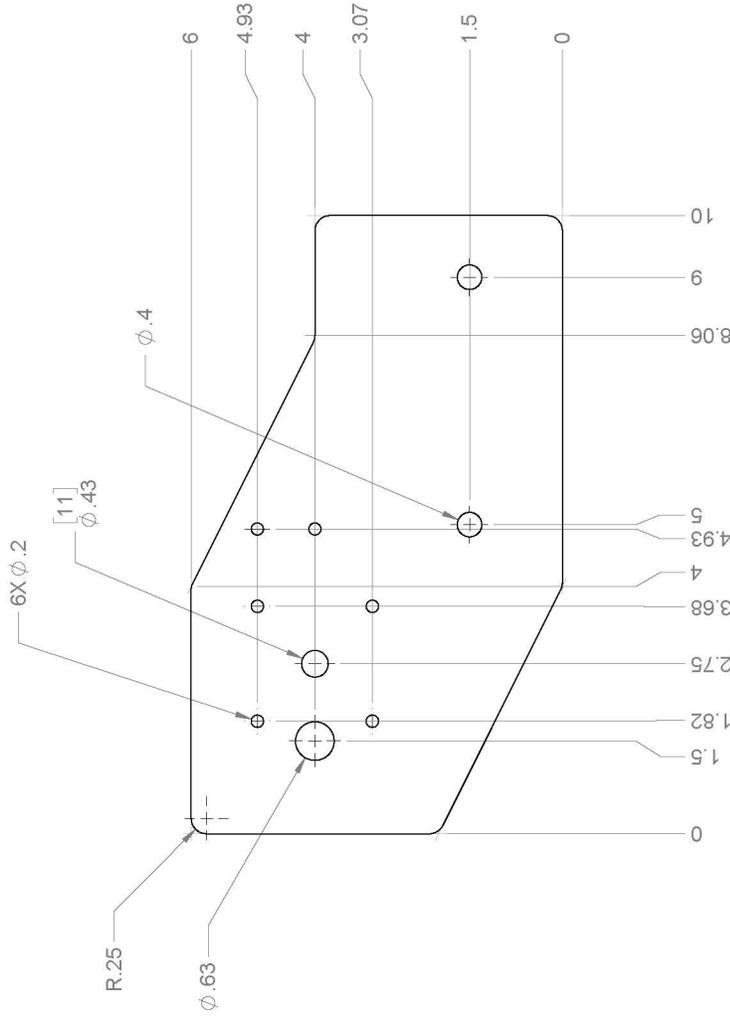
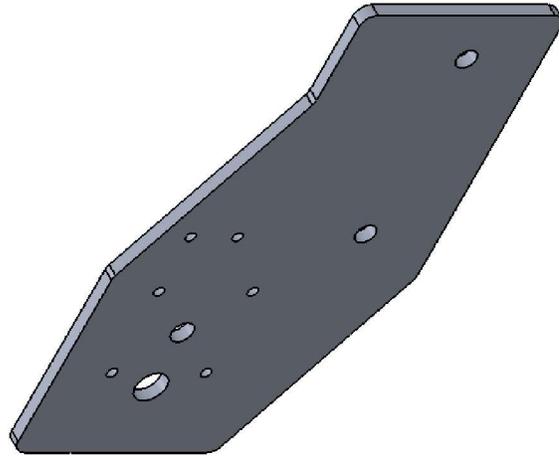
DO NOT SCALE DRAWING

TITLE:

SERVO MOUNTING BRACKET

SIZE	DWG. NO.	REV
B	MM4860-001	0
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

4 3 2 1



B

D-18

A

TITLE:

Back Side Mounting Plate

NAME	DATE
JHAN	2016/12/03
CRAWSON	2016/12/05

Automated Fixture for Leak Detection Scanning

DRAWN	CHECKED
ANSI Y1.4.5M-1994	

INTERPRET GEOMETRIC TOLERANCING PER: UNLESS OTHERWISE SPECIFIED:

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES FOR HORIZONTAL DIMENSIONS:  
 ANGULAR: MACH: 0°30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

PROJECTION



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 MANITOBA



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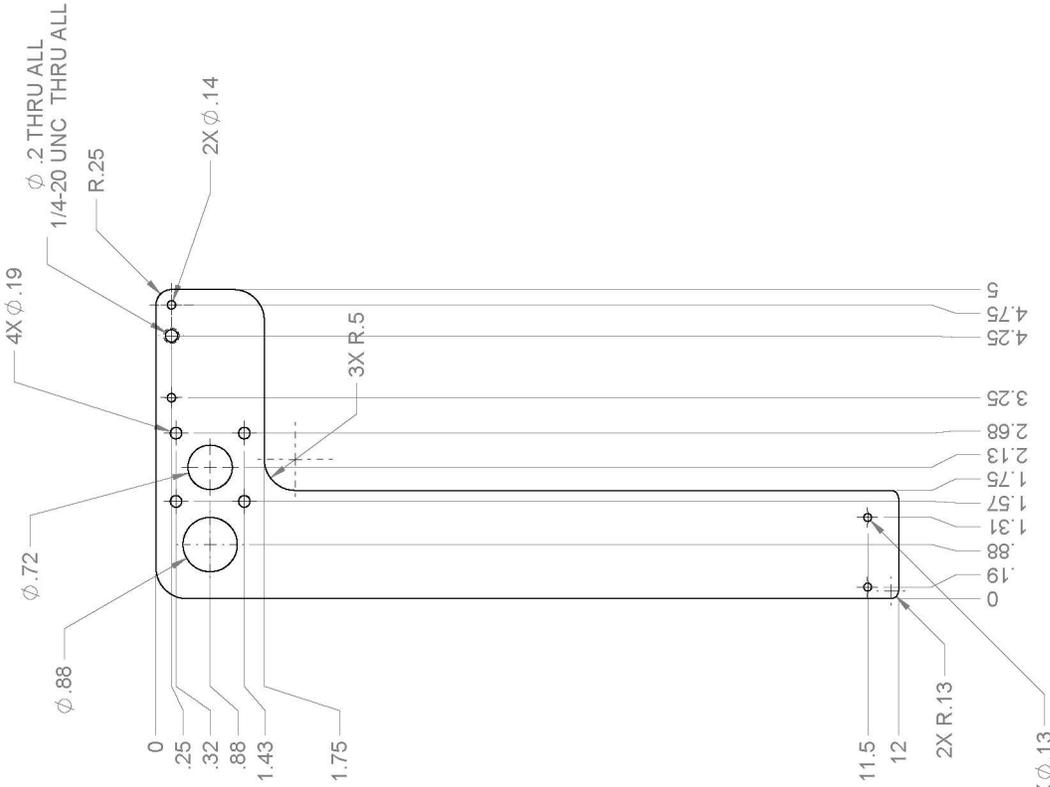
SIZE DWG. NO. REV

B M4860-002 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

4 3 2 1

4 3 2 1



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D-19

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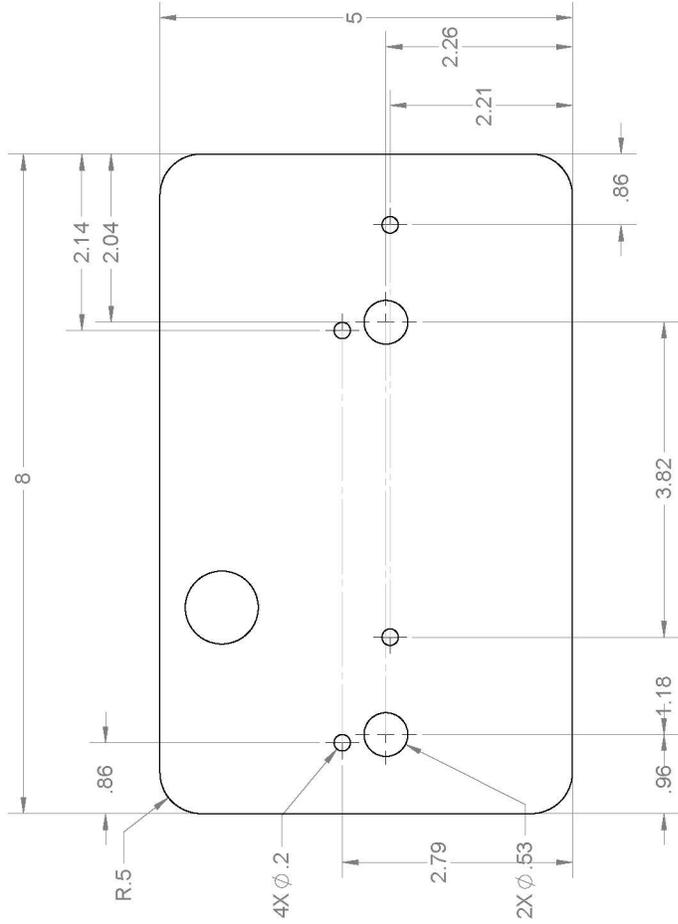
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DESIGN



<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002		DRAWN: JHAN CHECKED: CWATSON MATERIAL: 1/4" 6061-T6 ALUMINUM FINISH:	NAME: JHAN DATE: 2016/2/03 NAME: CWATSON DATE: 2016/1/20/5	TITLE: REAR CARRIAGE PLATE SIZE: B DWG. NO.: MM4860-003 REV: 0 SCALE: 1:2 WEIGHT: SHEET 1 OF 1
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DO NOT SCALE DRAWING

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D-20

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TITLE:

BEACON MOUNTING PLATE

INTERPRET	GEOMETRIC	ANSI Y14.5M-1994	DRAWN	JHAN	DATE	2016/12/03
TOLERANCING	FER:	UNLESS OTHERWISE SPECIFIED:	CHECKED	CWATSON	DATE	2016/12/05
MATERIAL		1/4" AISI 1020 STEEL				
FINISH						

DO NOT SCALE DRAWING



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Saskatoon, Saskatchewan, Canada



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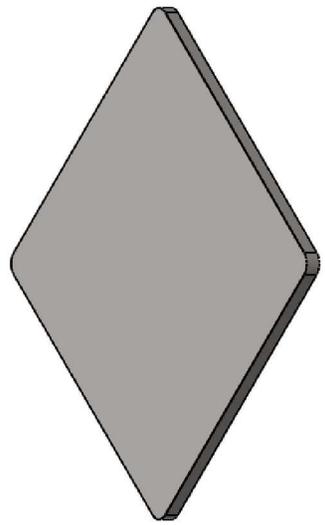
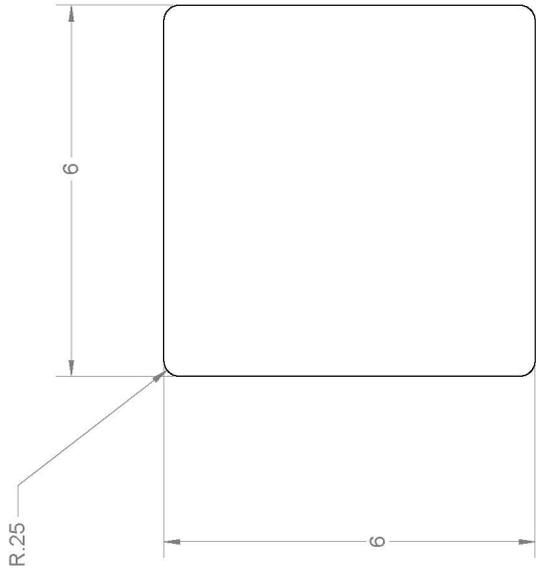
A

SIZE DWG. NO. REV

B MM4860-004 0

SCALE: 2:3 WEIGHT: SHEET 1 OF 1

4 3 2 1



B

D-21

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MECH 4860  
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Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/12/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/12/05
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED:			
ANGULAR TOLERANCES:	0°30'		
TWO PLACE DECIMAL:	±.01		
THREE PLACE DECIMAL:	±.002		
MATERIAL		1/4" AISI 1020 STEEL	
FINISH			
DO NOT SCALE DRAWING			

TITLE:		FOOTING	
SIZE	DWG. NO.	REV	
B	M4860-005	0	
SCALE:	1:2	WEIGHT:	SHEET 1 OF 1

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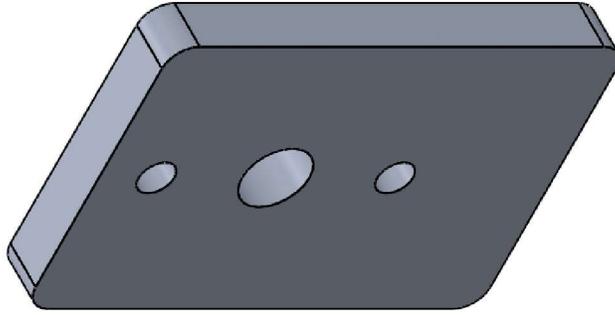
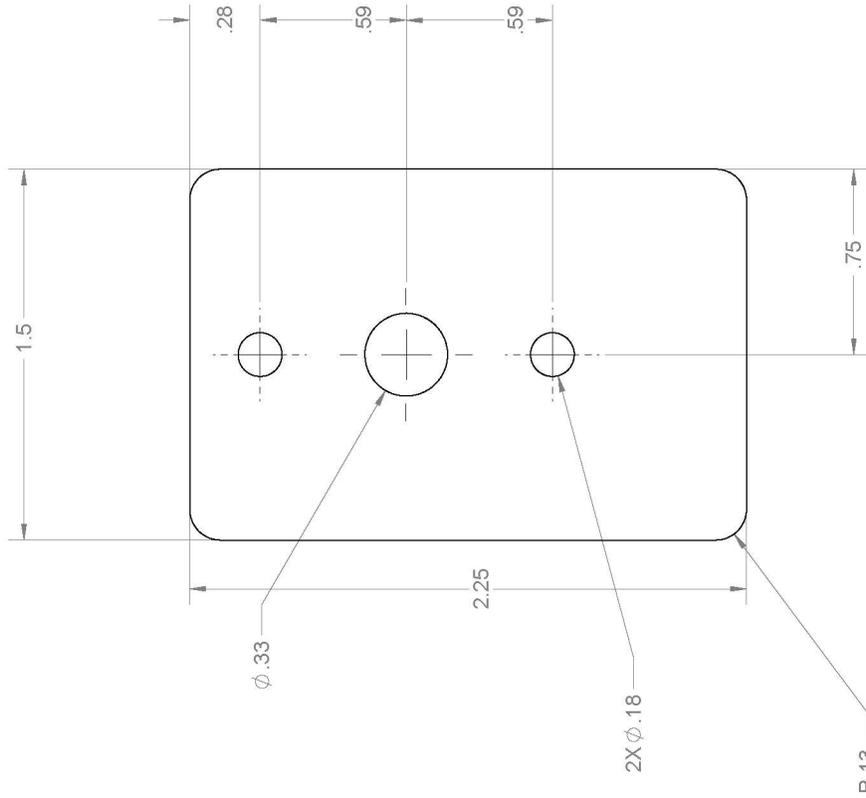
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D-22

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TITLE:

NOZZLE TO BALL NUT PLATE

INTERPRET	GEOMETRIC	ANSI	Y1	4.5M	1994	DRAWN	NAME	DATE
						JHAN	JHAN	2016/12/03
						CWATSON	CWATSON	2016/12/05

UNLESS OTHERWISE SPECIFIED:	MATERIAL	SIZE	DWG. NO.	REV
DIMENSIONS ARE IN INCHES TOLERANCES UNLESS OTHERWISE SPECIFIED: ANGULAR: MACH: 0°30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	1/4" 6061-T6 ALUMINUM	B	M4860-006	0

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



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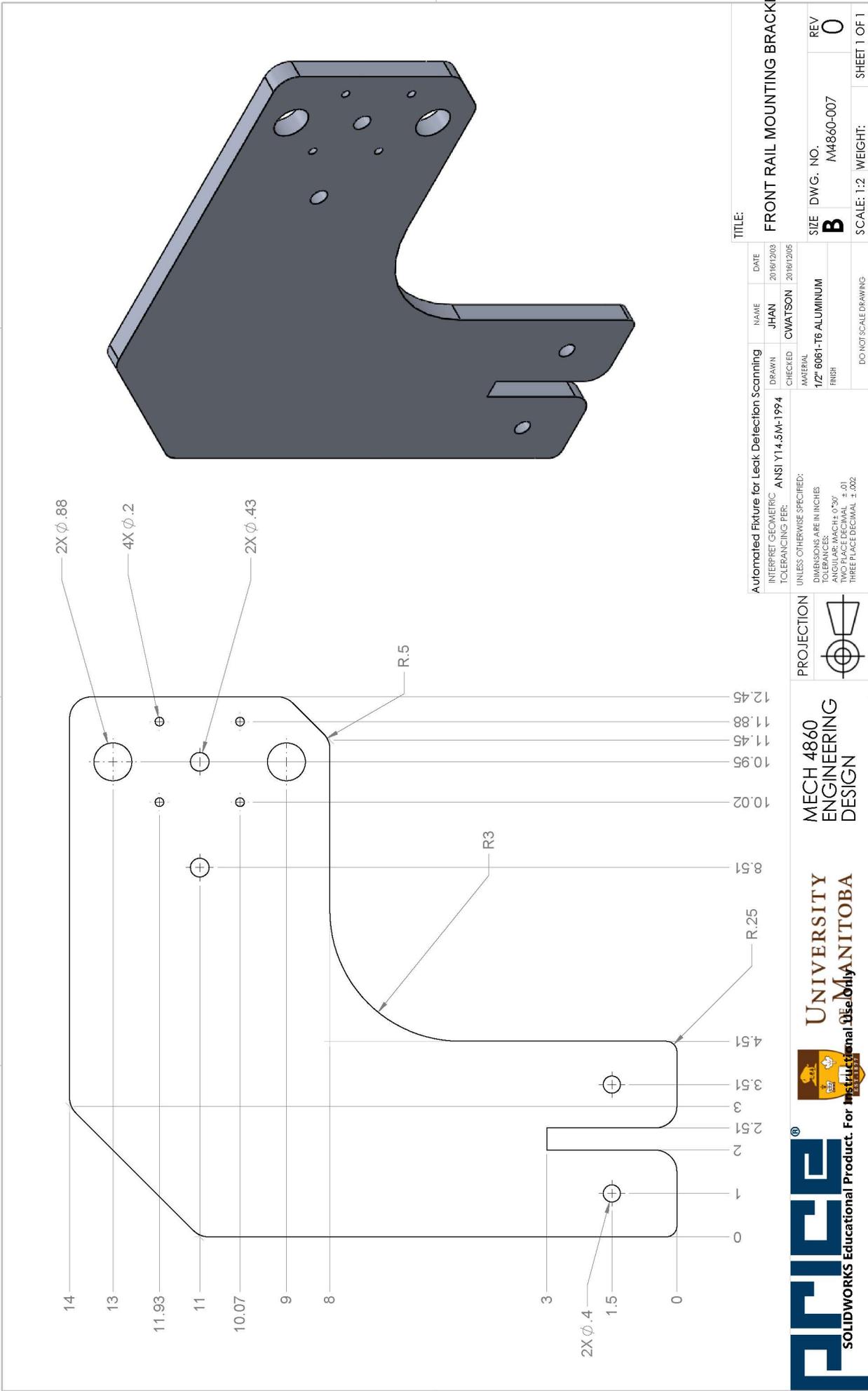
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<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994		DRAWN: JHAN CHECKED: CWATSON	NAME: JHAN DATE: 2016/12/03
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONS ANGULAR: MACH: 0°30' TWO PLACE DECIMAL: ±.01 THREE PLACE DECIMAL: ±.002		MATERIAL: 1/2" 6061-T6 ALUMINUM FINISH:	TITLE: FRONT RAIL MOUNTING BRACKET SIZE: B DWG. NO.: M4860-007 REV: 0 SCALE: 1:2 WEIGHT: SHEET 1 OF 1



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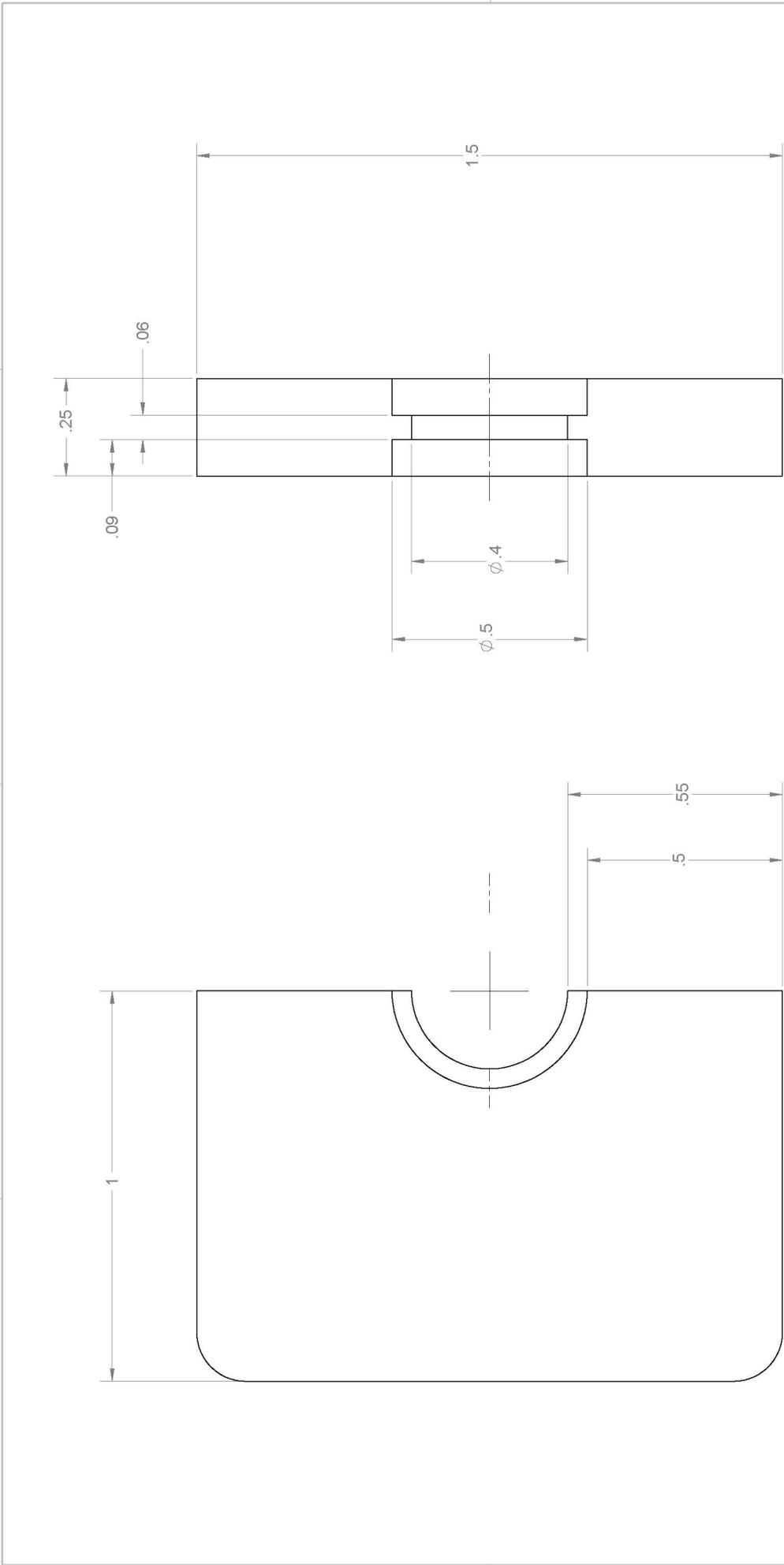
UNIVERSITY OF  
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Saskatoon, Saskatchewan, Canada



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D-24

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TITLE:

NOZZLE RETAINER

Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/205

MATERIAL		SIZE	DWG. NO.	REV
1/4" 6061-T6 ALUMINUM		B	MM4860-008	0
FINISH		SCALE: 4:1		WEIGHT:
DO NOT SCALE DRAWING		SHEET 1 OF 1		



MECH 4860  
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DESIGN

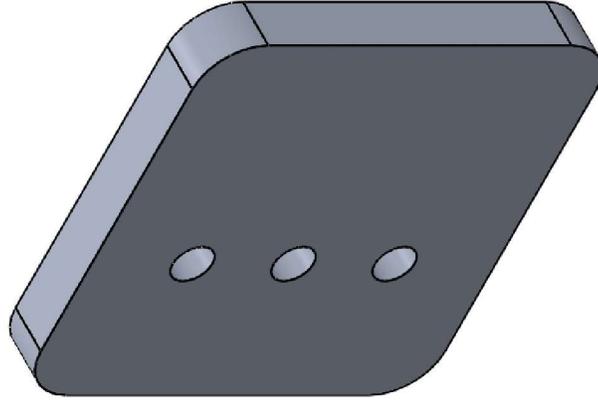
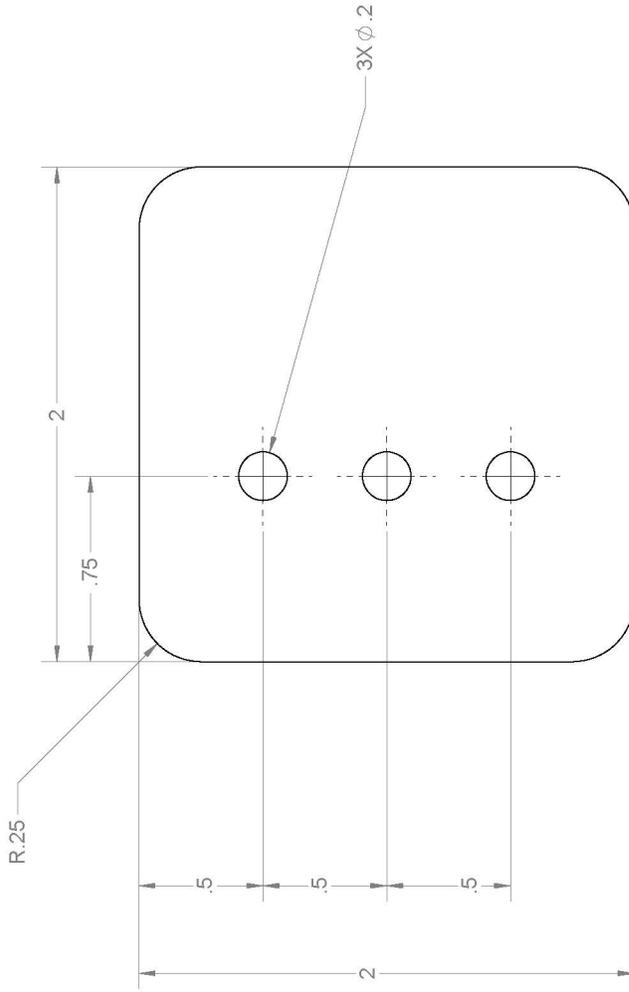
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Saskatoon, Saskatchewan, Canada



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D-25

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SCHOOL OF ENGINEERING

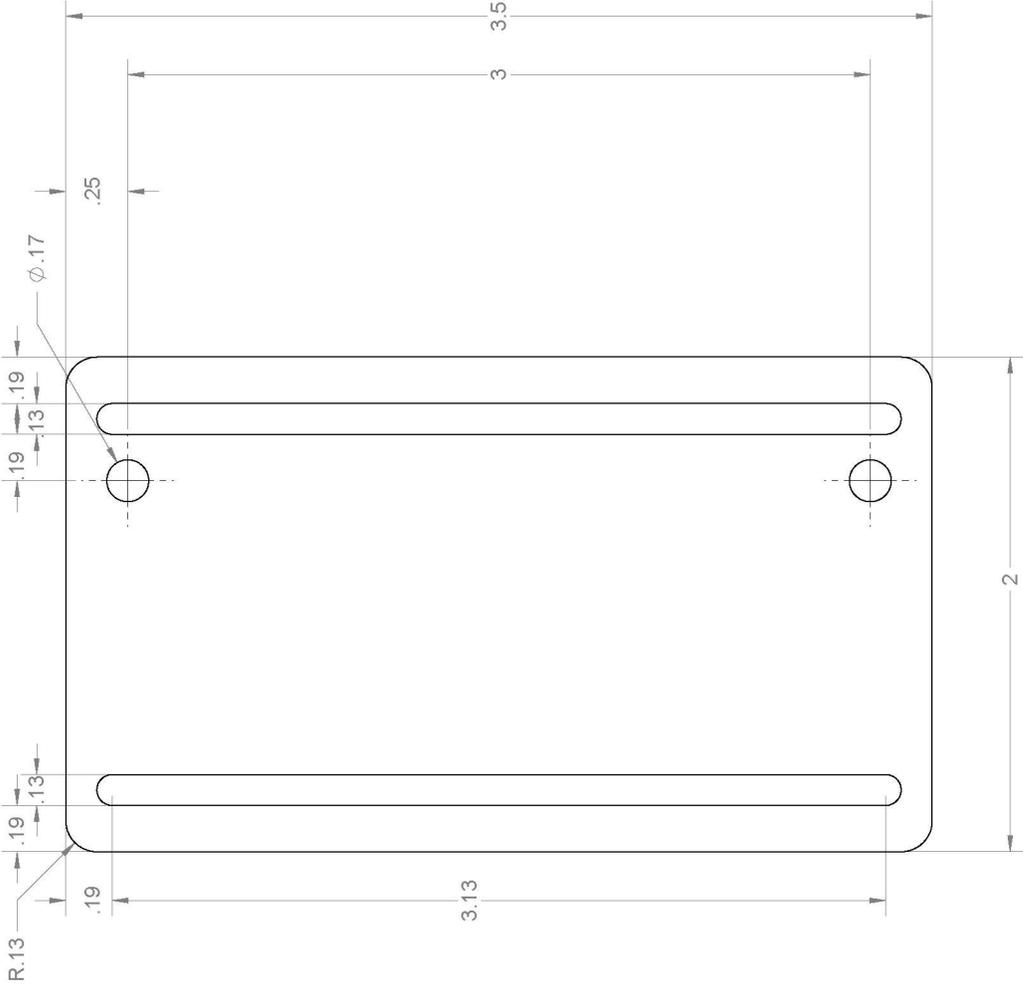
MECH 4860  
ENGINEERING DESIGN



Automated Fixture for Leak Detection Scanning INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONS: 0/100 DECIMALS: .01 ANGULAR: 30° TWO PLACE DECIMAL: .01 THREE PLACE DECIMAL: .002		DRAWN: JHAN CHECKED: CWATSON MATERIAL: 1/4" 6061-T6 ALUMINIUM FINISH:	DATE: 2016/12/03 DATE: 2016/12/05
TITLE: LED MOUNTING BRACKET		SIZE: B DWG. NO.: MM4860-009	REV: 0
SCALE: 2:1		WEIGHT: SHEET 1 OF 1	

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4 3 2 1



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D-26

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MECH 4860 ENGINEERING DESIGN



Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/12/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/12/05
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED:		MATERIAL	1/4" 6061-T6 ALUMINUM
ANGULAR TOLERANCES:	0°30'	FINISH	
TWO PLACE DECIMAL	±.01		
THREE PLACE DECIMAL	±.002		
DO NOT SCALE DRAWING			

TITLE:

UPPER NOZZLE ADJUSTER

SIZE	DWG. NO.	REV
B	MM4860-010	0
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

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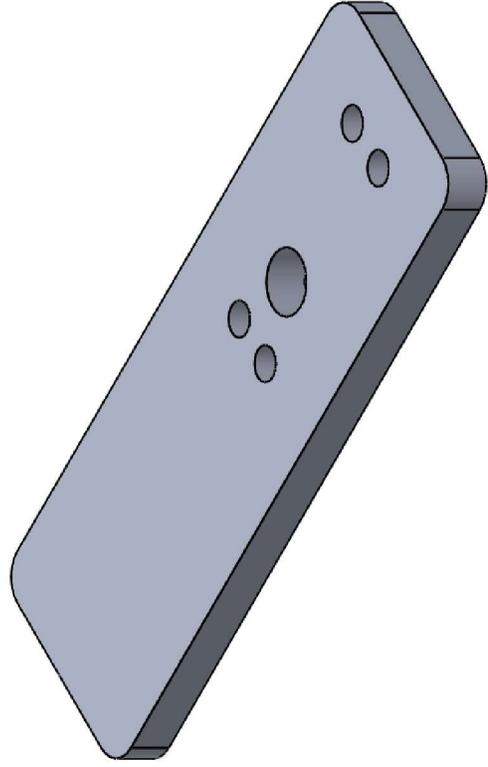
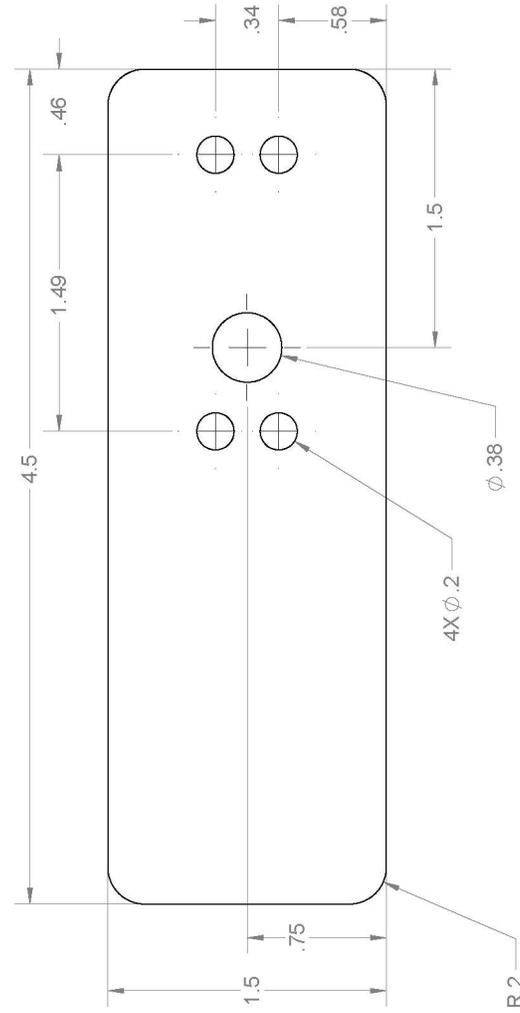
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4 3 2 1

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D-27

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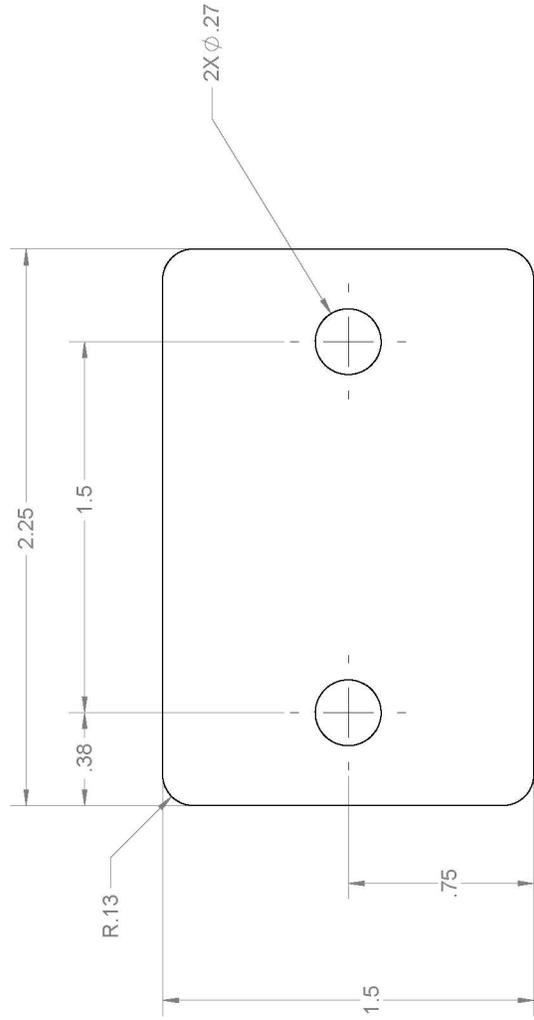
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Automated Fixture for Leak Detection Scanning INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± 0°30' TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .002 DO NOT SCALE DRAWING		DRAWN: JHAN CHECKED: CWATSON MATERIAL: 1/4" 6061-T6 ALUMINUM FINISH:	NAME: JHAN DATE: 2016/12/03 DATE: 2016/12/05
TITLE: SERVO MOUNTING PLATE		SIZE: B DWG. NO.: MM4860-011	REV: 0
SCALE: 3:2		WEIGHT: SHEET 1 OF 1	

4 3 2 1

4 3 2 1



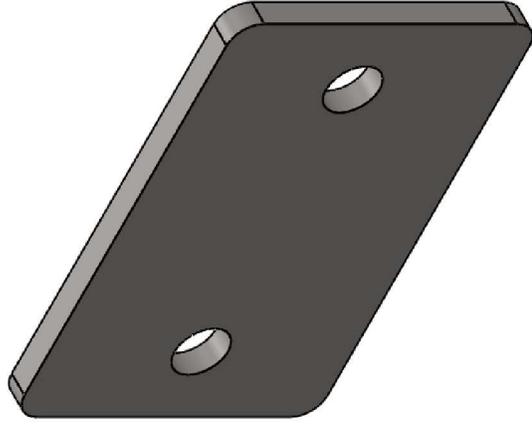
B

D-28

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B

A



TITLE:

PROXIMITY SENSOR DETECTION PLATE

INTERPRET	GEOMETRIC	ANSI Y14.5M-1994	DRAWN	NAME	DATE
			JHAN		2016/2/03
			CWATSON		2016/1/20/5
TOLERANCING PER:					
UNLESS OTHERWISE SPECIFIED:					
DIMENSIONS ARE IN INCHES					
TOLERANCES:					
HORIZONTAL: ±.005					
ANGULAR: ±.030					
TWO PLACE DECIMAL					
THREE PLACE DECIMAL					
DO NOT SCALE DRAWING					

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Saskatoon, Saskatchewan, Canada



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1/8" AISI 1020 STEEL  
FINISH

MATERIAL

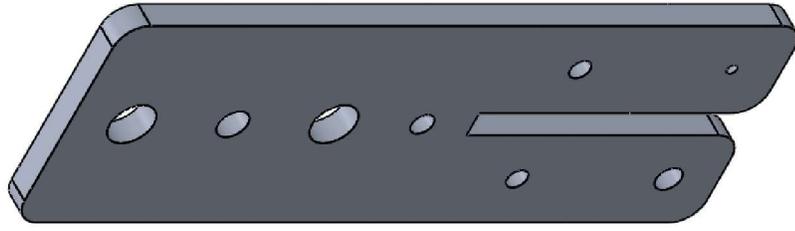
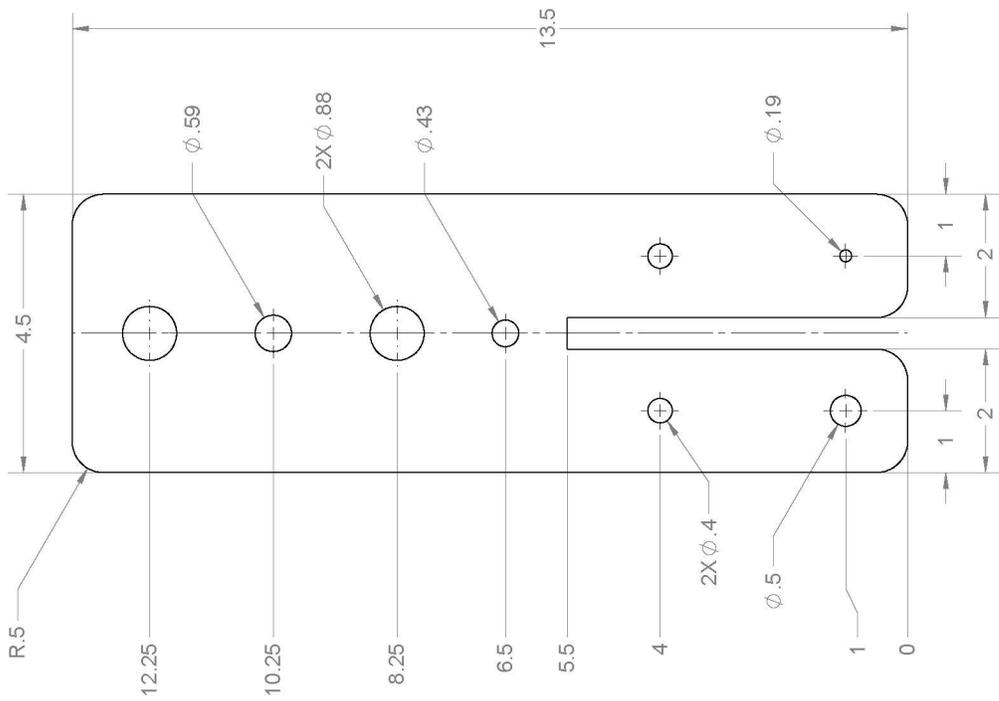
SIZE DWG. NO. REV  
B MM4860-012 0

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

4 3 2 1



4 3 2 1



B

D-30

A

TITLE:

SIDE RAIL MOUNTING BRACKET 1

INTERPRET	GEOMETRIC	ANSI	Y1	4.5M-1994	DRAWN	JHAN	2016/12/03	DATE	2016/12/03
TOLERANCING PER:		UNLESS OTHERWISE SPECIFIED:		CHECKED		CWATSON	2016/12/05	DO NOT SCALE DRAWING	
DIMENSIONS ARE IN INCHES		UNLESS OTHERWISE SPECIFIED:		MATERIAL		1/2" 6061-T6 ALUMINUM		SIZE DWG. NO. M4860-014	
TOLERANCES:		FRACTIONS		FINISH				REV 0	
ANGULAR: MACH. 0°30'		TWO PLACE DECIMAL ±.01						SCALE: 1:2 WEIGHT: SHEET 1 OF 1	
THREE PLACE DECIMAL ±.002									

PROJECTION



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SASKATCHEWAN  
Saskatoon, Saskatchewan, Canada

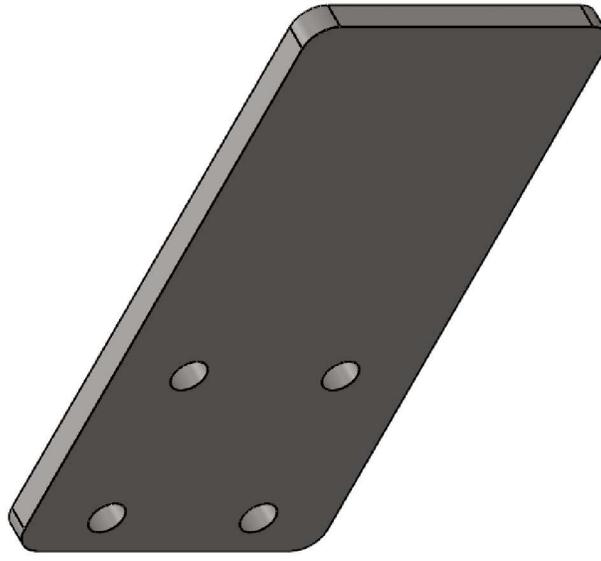
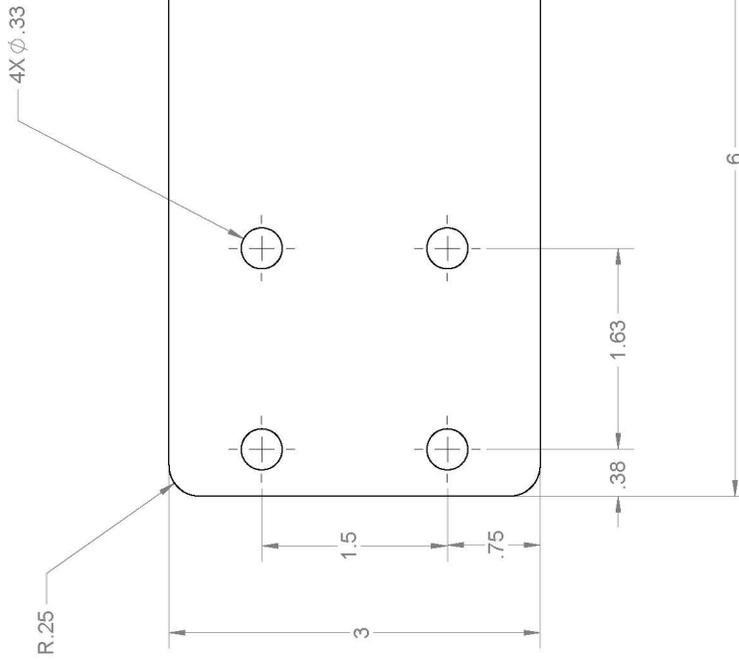


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**DESIGN**

MECH 4860



PROJECTION

Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/12/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/12/05
DIMENSIONS ARE IN INCHES		MATERIAL	
TOLERANCES		1/4" AISI 1020 STEEL	
ANGULAR: MACH ±0.30°		FINISH	
TWO PLACE DECIMAL ±.01		DO NOT SCALE DRAWING	
THREE PLACE DECIMAL ±.002			

TITLE:

TOGGLE CLAMP MOUNTING PLATE

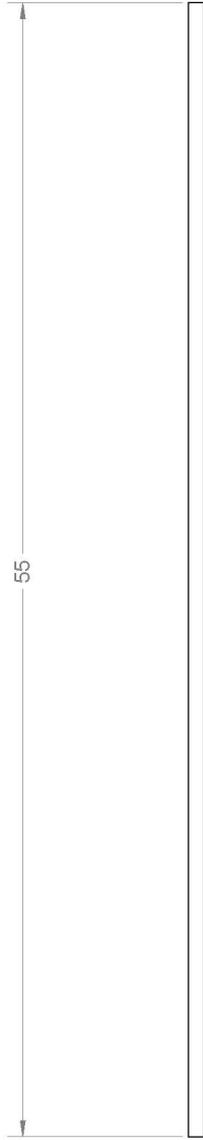
SIZE DWG. NO. REV  
**B** M4860-016 **0**

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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 DESIGN

**MECH 4860**  
 ENGINEERING  
 DESIGN



Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/05
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED:			
ANGULAR TOLERANCES:	±0.30°		
TWO PLACE DECIMAL:	±.01		
THREE PLACE DECIMAL:	±.002		

TITLE:		FRONT CARRIAGE GUIDE RAIL	
SIZE	DWG. NO.	REV	
B	MM4860-017	0	
SCALE: 1:6		WEIGHT:	
		SHEET 1 OF 1	

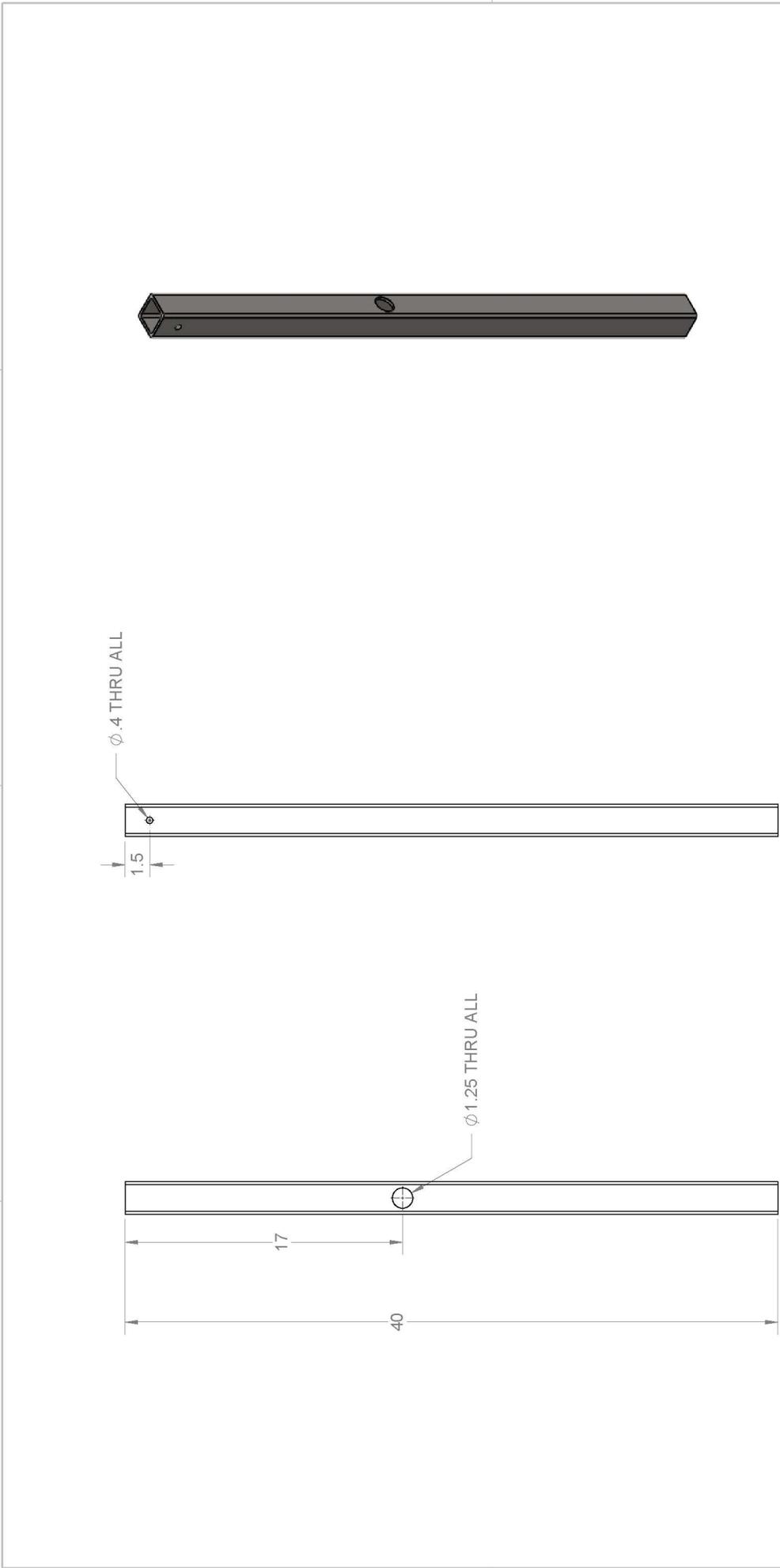
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MECH 4860  
ENGINEERING  
DESIGN



<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES DIMENSIONS IN PARENTHESES ANGULAR DIMENSIONS: TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002 DO NOT SCALE DRAWING		DRAWN: JHAN CHECKED: CWATSON MATERIAL: 2"x2"x3/16" AISI 1020 STEEL FINISH:	DATE: 2016/12/03 2016/1/2005	NAME: JHAN CWATSON	TITLE: <b>BACK LEG 1</b>
SIZE: <b>B</b>	DWG. NO.: M4860-018	REV: <b>0</b>	SCALE: 1:6 WEIGHT: SHEET 1 OF 1		

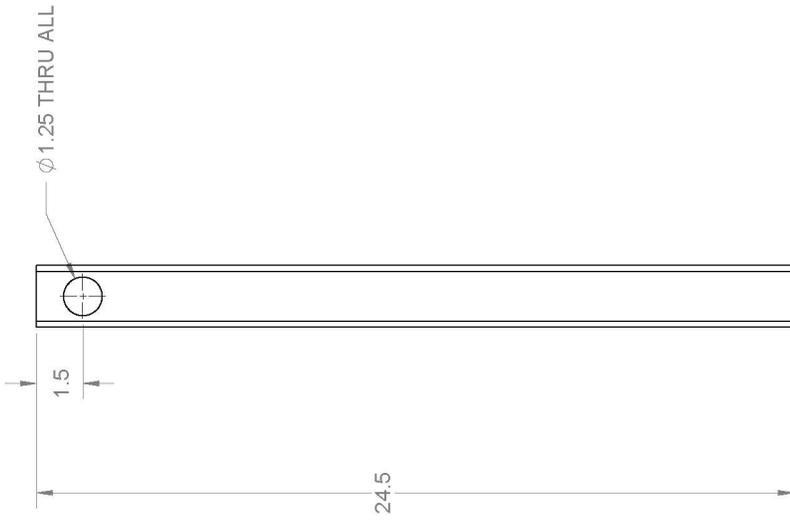
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MECH 4860 ENGINEERING DESIGN



Automated Fixture for Leak Detection Scanning  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 DECIMALS TO FIFTEENTHS  
 ANGULARS TO 30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

DO NOT SCALE DRAWING

DRAWN	CHECKED	MATERIAL	FINISH
JHAN	CWATSON	2"x2"x3/16" AISI 1020 STEEL	

TITLE: FRONT LEG  
 SIZE: B  
 DWG. NO.: MM4860-019  
 SCALE: 1:4 WEIGHT: SHEET 1 OF 1

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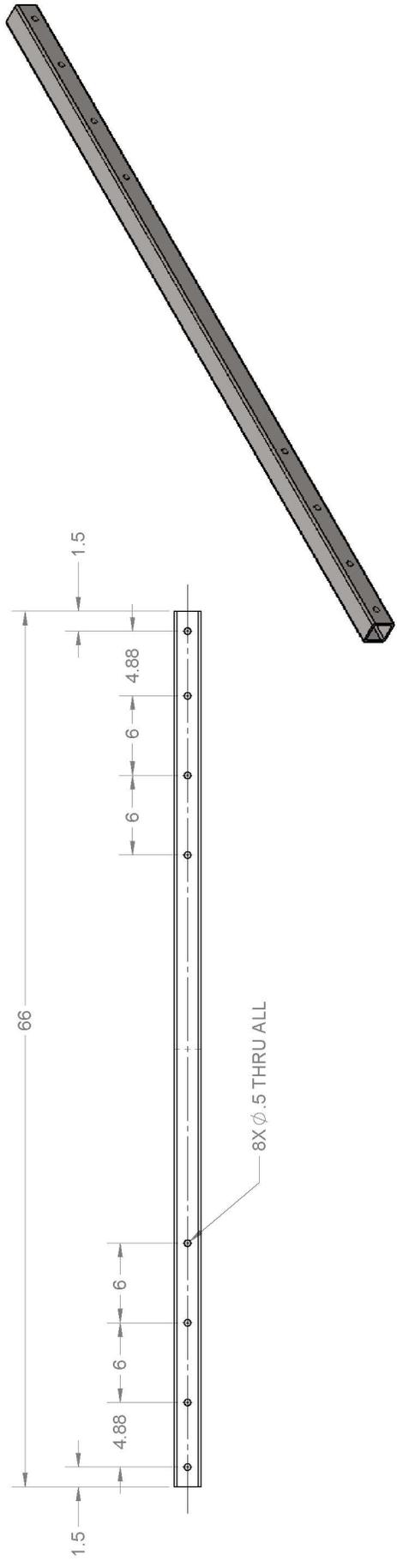


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TITLE:

CROSS BRACE 2

Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/05
DIMENSIONS ARE IN INCHES			
TOLERANCES:			
ANGLES:	MACH ± 0.30°		
FINISH:	TWO PLACE DECIMAL ±.01		
	THREE PLACE DECIMAL ±.002		



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Saskatoon



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SIZE	DWG. NO.	REV
B	MM4860-021	0
SCALE: 1:8		WEIGHT:
		SHEET 1 OF 1

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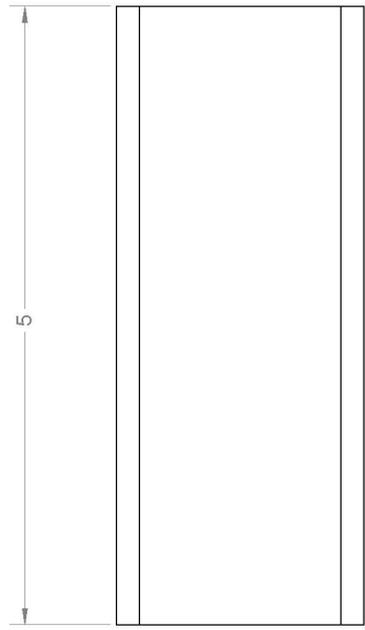
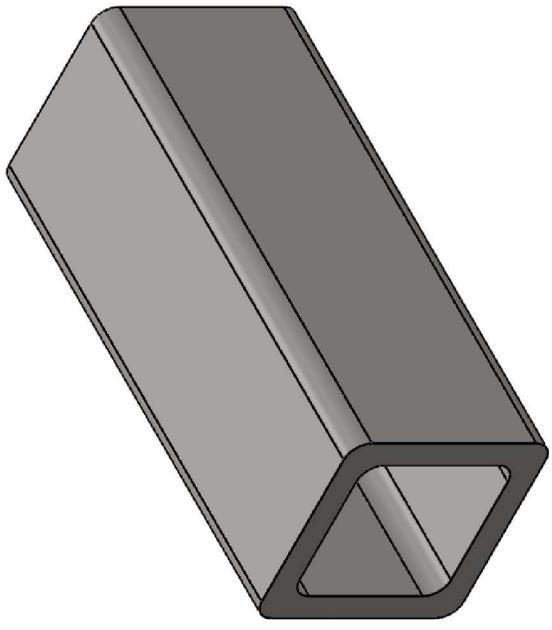
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TITLE:

HINGE POST

Automated Fixture for Leak Detection Scanning			
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	DATE
		JHAN	2016/2/03
		CWATSON	2016/1/05
UNLESS OTHERWISE SPECIFIED:		CHECKED	
DIMENSIONS ARE IN INCHES		MATERIAL	
TOLERANCES		2"X2"X1/4" AISI 1020 STEEL	
ANGULAR: MACH: 0.30°		FINISH	
TWO PLACE DECIMAL ±.01			
THREE PLACE DECIMAL ±.002			

PROJECTION



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SIZE	DWG. NO.	REV
B	MM4860-022	0
SCALE: 1:1		WEIGHT:
		SHEET 1 OF 1

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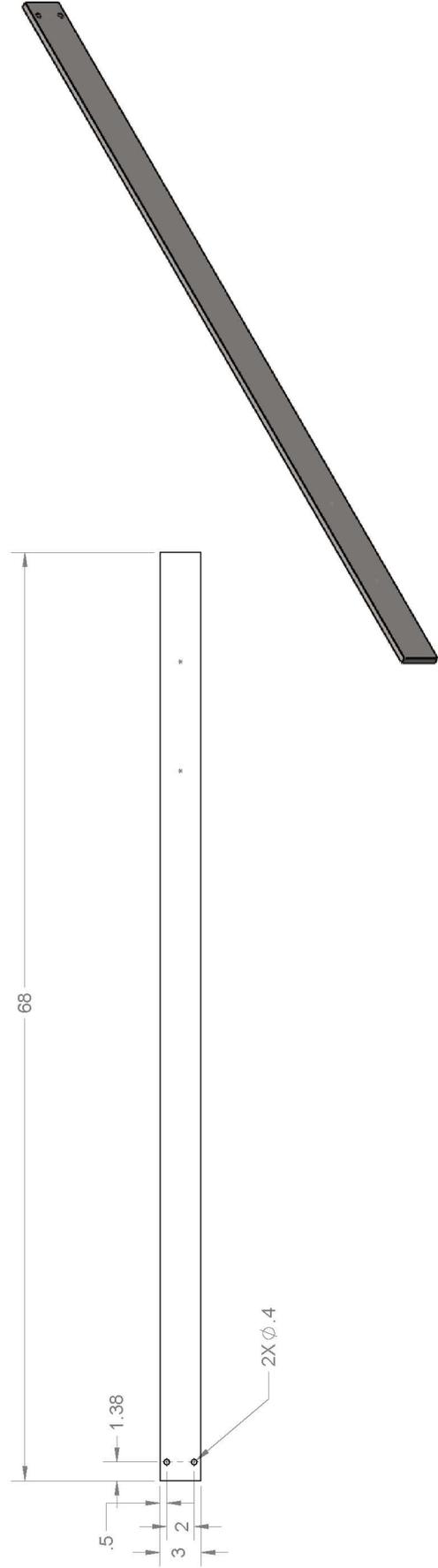




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TITLE:

GATE BOTTOM HORIZONTAL PLATE

Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/05
DIMENSIONS ARE IN INCHES		MATERIAL	1/2" AISI 1020 STEEL
TOLERANCES		FINISH	
ANGULAR: MACH: 0°30'			
TWO PLACE DECIMAL ±.01			
THREE PLACE DECIMAL ±.002			



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SIZE	DWG. NO.	REV
B	MM4860-025	0
SCALE: 1:8		WEIGHT:
		SHEET 1 OF 1

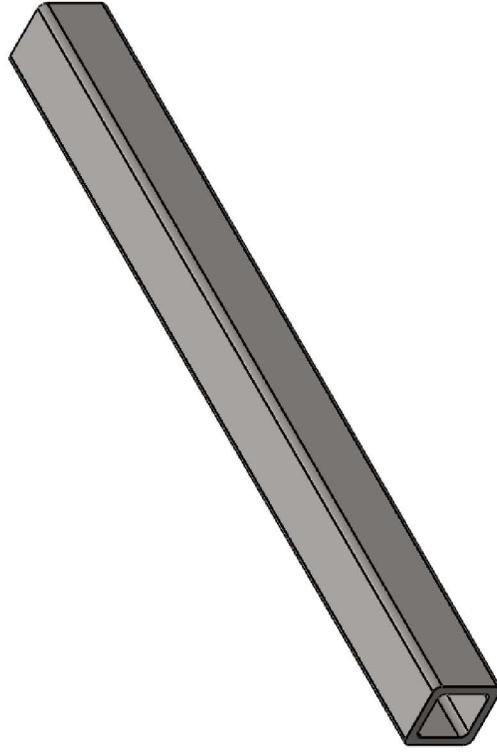
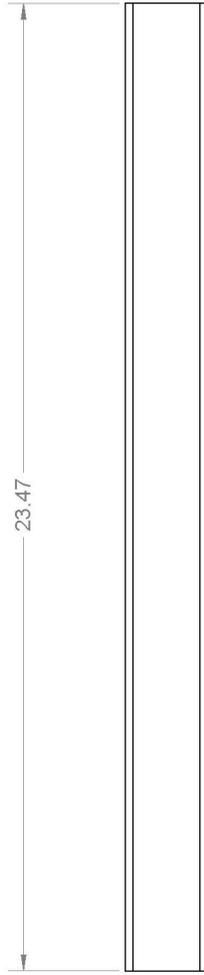
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**DESIGN**



<b>Automated Fixture for Leak Detection Scanning</b> INTERPRET GEOMETRIC TOLERANCING PER: ANS1 Y14.5M-1994 UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES ANGULAR: MACH ± 0.30° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.002 DO NOT SCALE DRAWING		DRAWN: JHAN CHECKED: CWATSON MATERIAL: 2"x2"x1/4" AISI 1020 STEEL FINISH:	NAME: JHAN DATE: 2016/12/03 NAME: CWATSON DATE: 2016/12/05	TITLE: VERTICAL GATE POST SIZE: B DWG. NO.: M4860-026 REV: 0 SCALE: 1:3 WEIGHT: SHEET 1 OF 1
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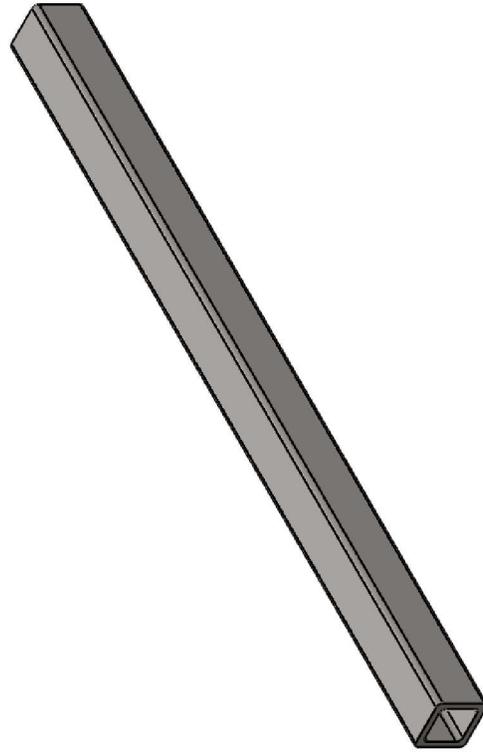
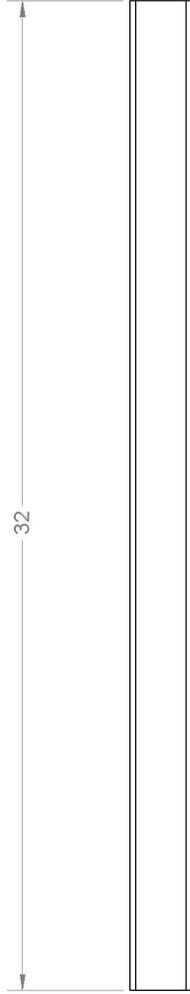
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PROJECTION

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES FOR HORIZONTAL DIMENSIONS:  
 ANGULAR DIMENSIONS: 0.30°  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

Automated Fixture for Leak Detection Scanning  
 DRAWN: JHAN  
 CHECKED: CWATSON  
 MATERIAL: 2"x2"x1/4" AISI 1020 STEEL  
 FINISH: DO NOT SCALE DRAWING

DATE: 2016/12/03  
 NAME: JHAN  
 DATE: 2016/12/05

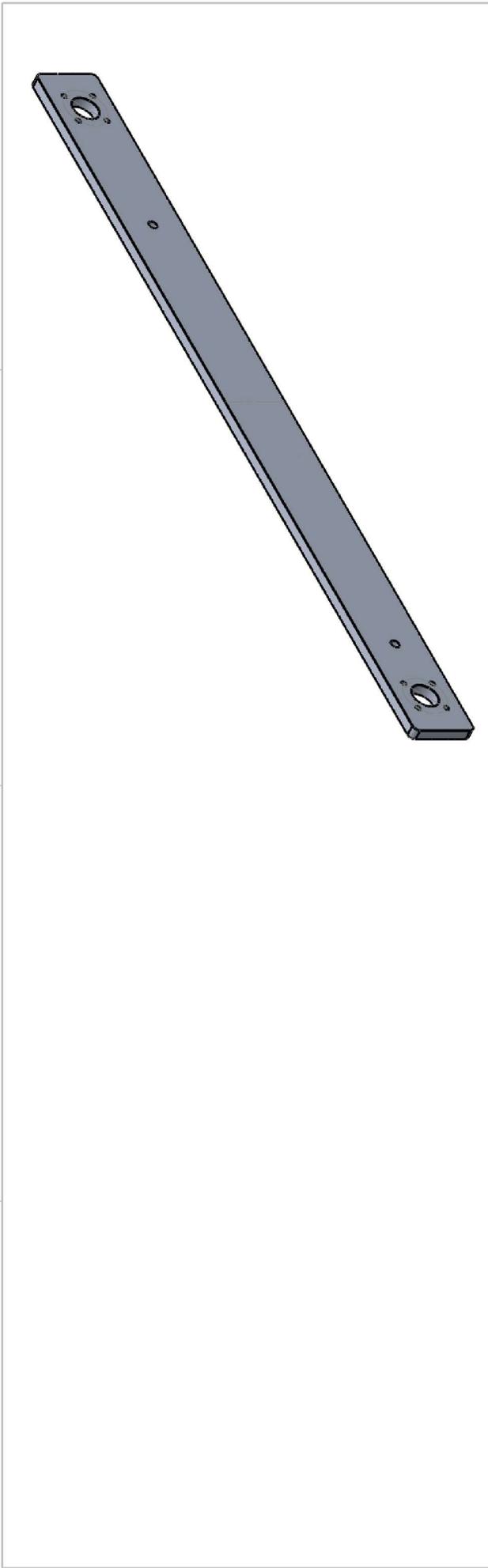
TITLE:

CROSS BRACE 2

SIZE: DWG. NO. REV  
**B** MM4860-027 **0**  
 SCALE: 1:4 WEIGHT: SHEET 1 OF 1

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TITLE:

SIDE RAIL FRONT PLATE

SIZE DWG. NO. REV  
**B** M4860-028 **0**  
 SCALE: 1:4 WEIGHT: SHEET 1 OF 1

INTERPRET	GEOMETRIC	ANSI	Y1	4.5M-1994	DRAWN	NAME	DATE
					JHAN	2016/2/03	
					CWATSON	2016/1/205	

Automated Fixture for Leak Detection Scanning  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES TO FOLLOW UNLESS OTHERWISE SPECIFIED:  
 ANGULAR: MACH: 0°30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002



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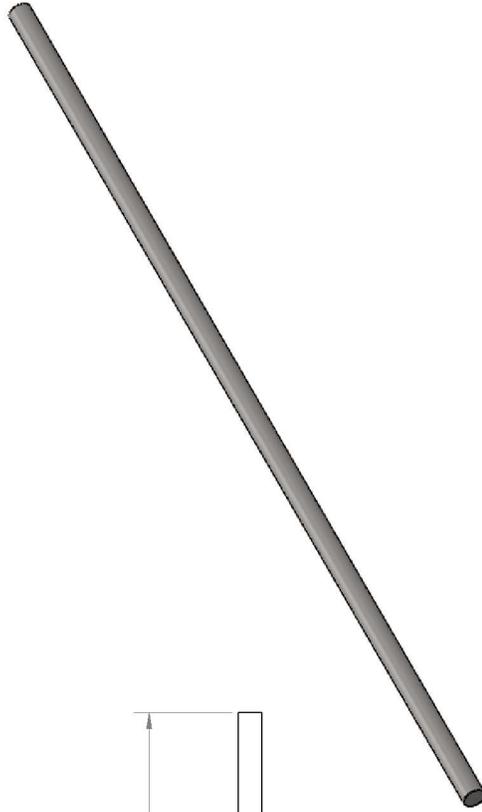
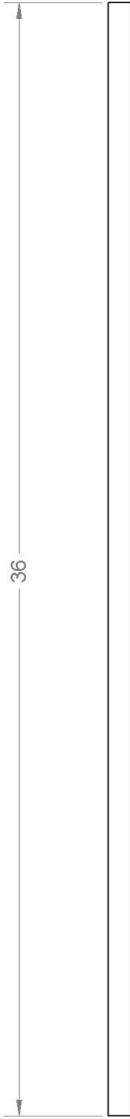
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 DESIGN DEVELOPMENT

**MECH 4860**  
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Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/05
DIMENSIONS ARE IN INCHES		MATERIAL	
TOLERANCES		3/4" ANSI 1020 ROUND STEEL	
ANGULAR: MACH ± 0.30°		FINISH	
TWO PLACE DECIMAL ± 0.01			
THREE PLACE DECIMAL ± 0.002			
DO NOT SCALE DRAWING			

TITLE:

SIDE RAIL GUIDE BAR

SIZE	DWG. NO.	REV
<b>B</b>	MM4860-029	<b>0</b>
SCALE: 1:4		WEIGHT:
		SHEET 1 OF 1

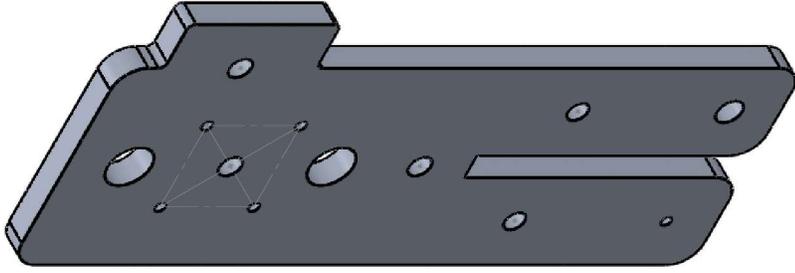
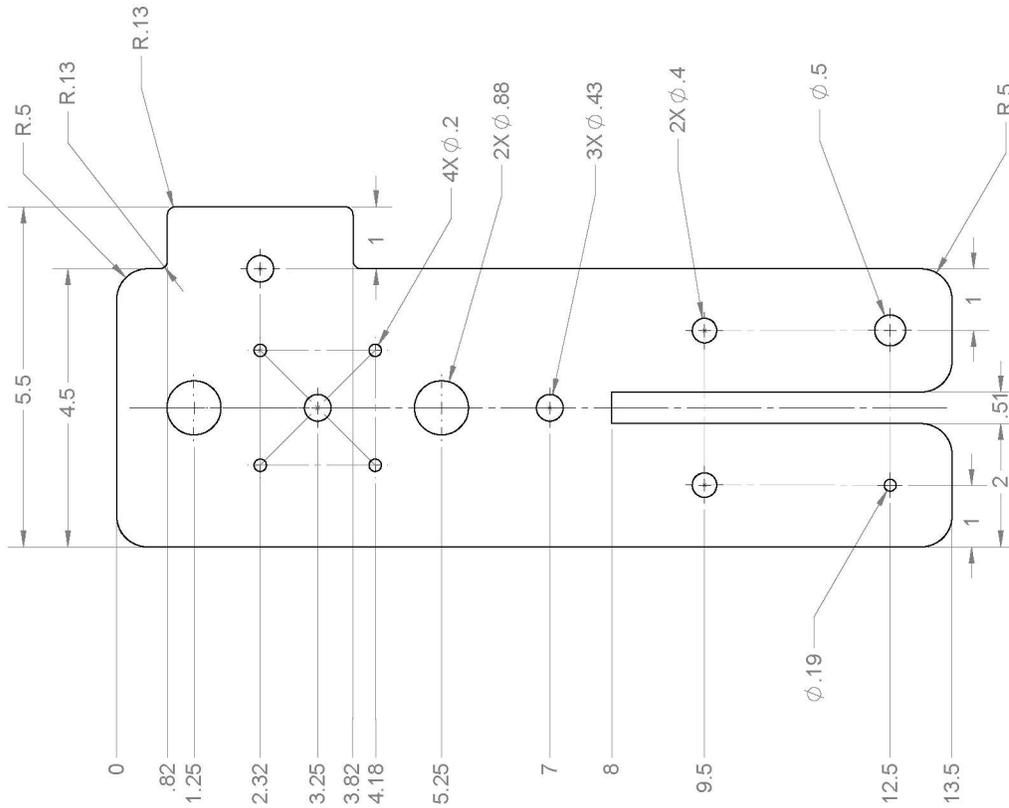
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Automated Fixture for Leak Deflection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/12/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/12/05
DIMENSIONS ARE IN INCHES		MATERIAL	1/2" 6061 T6 ALUMINUM
TOLERANCES:		FINISH	ANODIZED
ANGULAR: MACH: 0°30'		DO NOT SCALE DRAWING	
TWO PLACE DECIMAL ±.01			
THREE PLACE DECIMAL ±.002			

PROJECTION:

TITLE: SIDE RAIL MOUNTING BRACKET 2

SIZE DWG. NO. M4860-030

REV 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

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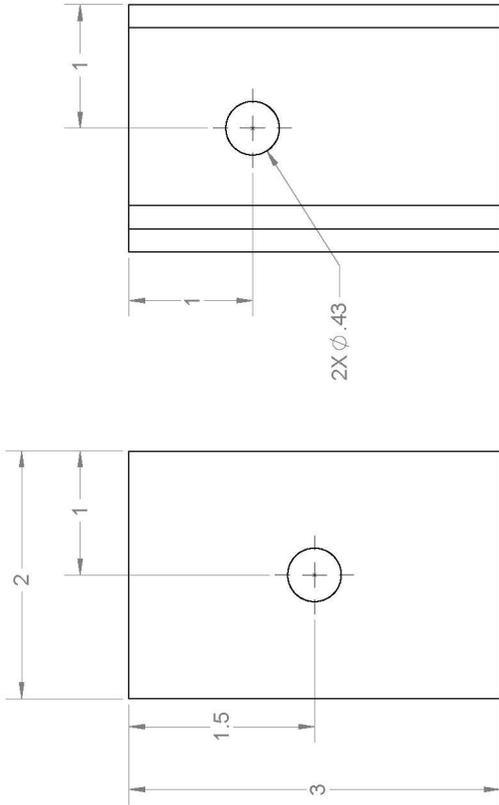
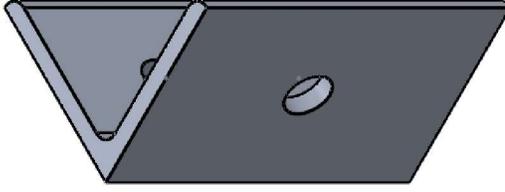
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ANITIBA

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TITLE:

PROC SENSOR BRACKET

INTERPRET	GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	DRAWN	NAME	DATE
			JHAN	CWATSON	2016/12/03

UNLESS OTHERWISE SPECIFIED:	SIZE	DWG. NO.	REV
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED ANGULAR TOLERANCES TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	<b>B</b>	MM4860-031	<b>0</b>

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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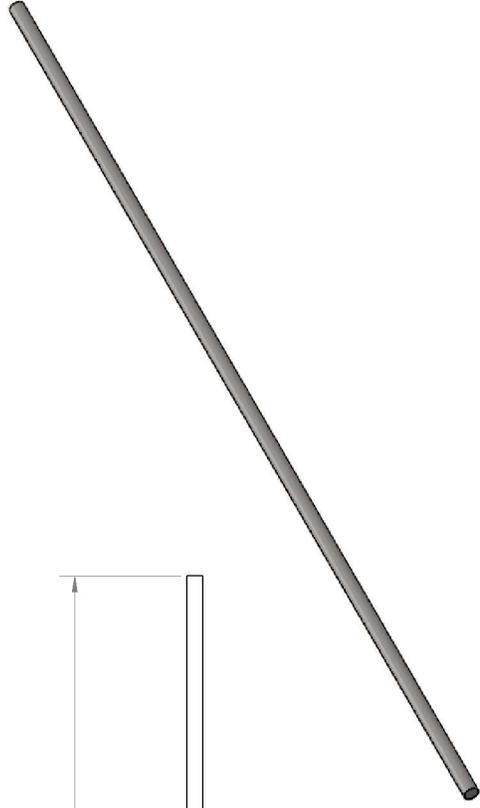
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**MANITOBA**

**MECH 4860**  
**ENGINEERING**  
**DESIGN**



**Automated Fixture for Leak Detection Scanning**  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES FOR HORIZONTAL DIMENSIONS ARE:  
 ANGULAR: MACH ± 0.30°  
 TWO PLACE DECIMAL ± 0.01  
 THREE PLACE DECIMAL ± 0.002

**DO NOT SCALE DRAWING**

TITLE:

ADJUSTABILITY GUIDE RAIL

SIZE	DWG. NO.	REV
<b>B</b>	MM4860-032	<b>0</b>
SCALE: 1:8		WEIGHT:
		SHEET 1 OF 1

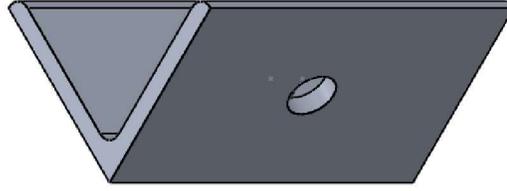
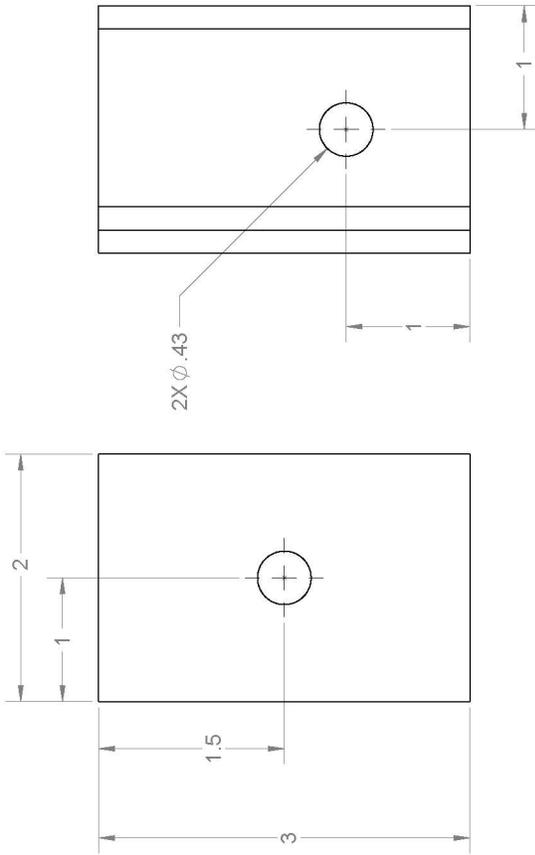
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Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/205
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED:			
ANGULAR TOLERANCES:	0°30'		
TWO PLACE DECIMAL:	±.01		
THREE PLACE DECIMAL:	±.002		
MATERIAL		7075-T6 ALUMINUM	
FINISH		ANODIZED	
DO NOT SCALE DRAWING			

TITLE:		PROC SENSOR ANGLE BRACKET	
SIZE	DWG. NO.	REV	
B	M4860-033	0	
SCALE:	1:1	WEIGHT:	SHEET 1 OF 1

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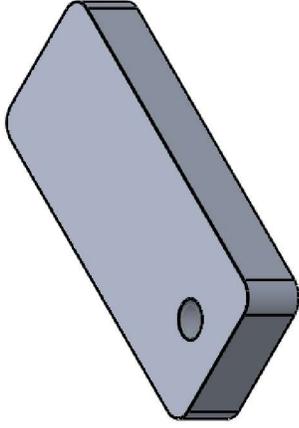
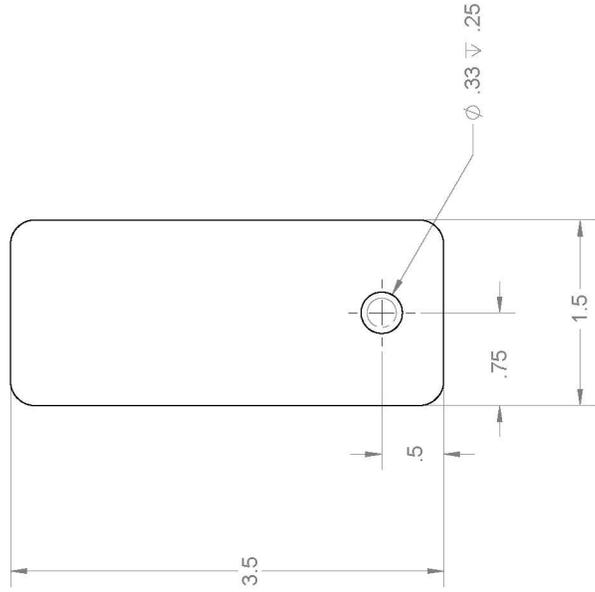


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Automated Fixture for Leak Detection Scanning		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14.5M-1994	JHAN	2016/2/03
UNLESS OTHERWISE SPECIFIED:		CWATSON	2016/1/05
DIMENSIONS ARE IN INCHES		MATERIAL	
TOLERANCES:		1/2" ØØØ1 T6 ALUMINUM	
ANGULAR: MACH ±0.30°		FINISH	
TWO PLACE DECIMAL ±.01			
THREE PLACE DECIMAL ±.002			
DO NOT SCALE DRAWING			

TITLE:

BALL SCREW PLATE

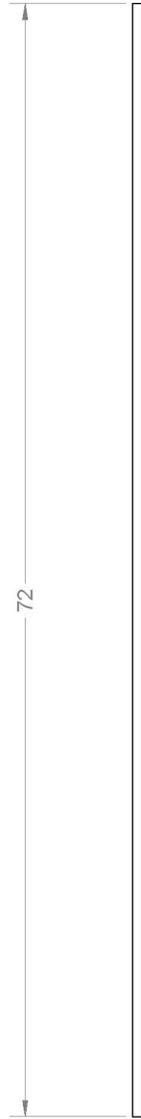
SIZE	DWG. NO.	REV
B	MM4860-035	0
SCALE: 1:1		WEIGHT:
		SHEET 1 OF 1

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Automated Fixture for Leak Detection Scanning  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES FOR HORIZONTAL ANGULAR: MACH ± 0.30°  
 TWO PLACE DECIMAL ± .01  
 THREE PLACE DECIMAL ± .002

TITLE:

REAR CARRIAGE GUIDE RAIL

SIZE: **B**  
 DWG. NO.: MM4860-036  
 REV: **0**

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

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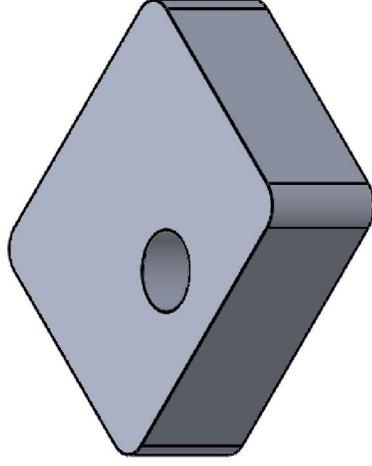
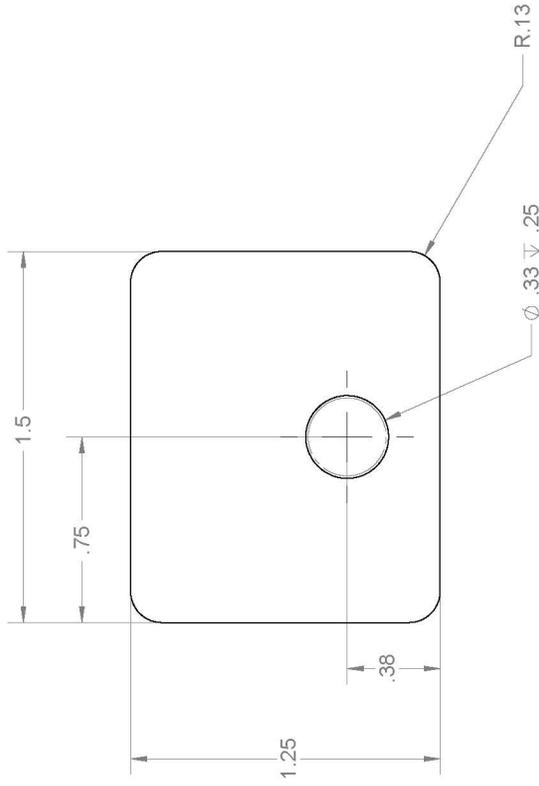
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DO NOT SCALE DRAWING

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PROJECTION

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES  
 ANGULAR: MACH: 0°30'  
 TWO PLACE DECIMAL ±.01  
 THREE PLACE DECIMAL ±.002

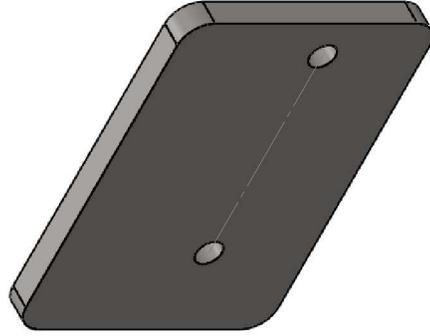
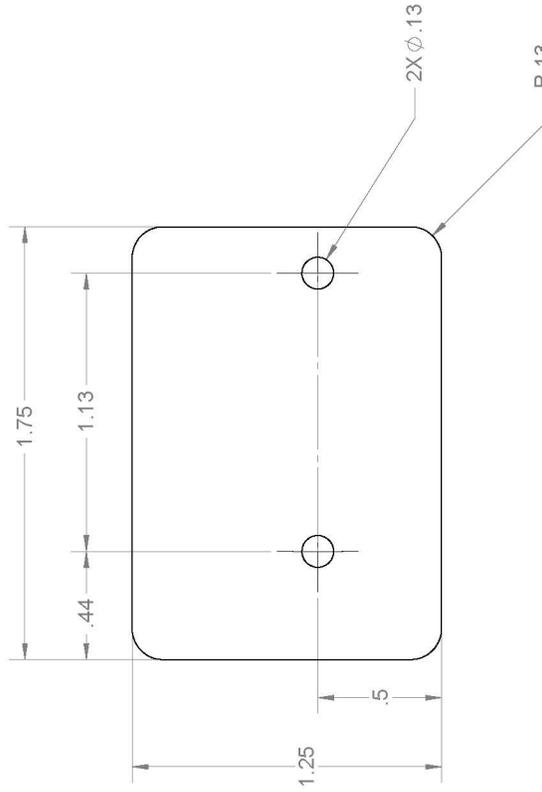
Automated Fixture for Leak Detection Scanning  
 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 DRAWN: JHAN  
 CHECKED: CWATSON  
 MATERIAL: 1/2" 6061 T6 ALUMINUM  
 FINISH: DO NOT SCALE DRAWING

TITLE:

BALL SCREW PLATE

SIZE	DWG. NO.	REV
B	MM4860-037	0
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

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TITLE:

PROXIMITY SENSOR  
DETECTION PLATE

INTERPRET	GEOMETRIC	ANSI	Y1	4.5M	1994	DRAWN	NAME	DATE
						JHAN		2016/12/03
						CWATSON		2016/12/05

UNLESS OTHERWISE SPECIFIED:	MATERIAL	SIZE	DWG. NO.	REV
DIMENSIONS ARE IN INCHES	3/16" AISI 1020 STEEL	B		
TOLERANCES				
ANGULAR: MACH: 0°30'				
TWO PLACE DECIMAL ±.01				
THREE PLACE DECIMAL ±.002				

DO NOT SCALE DRAWING

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

4

3

2

1

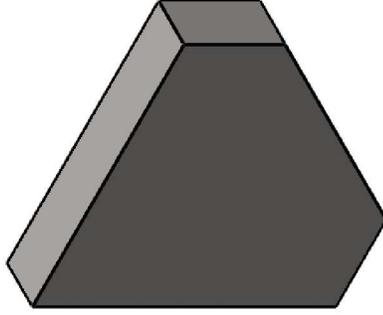
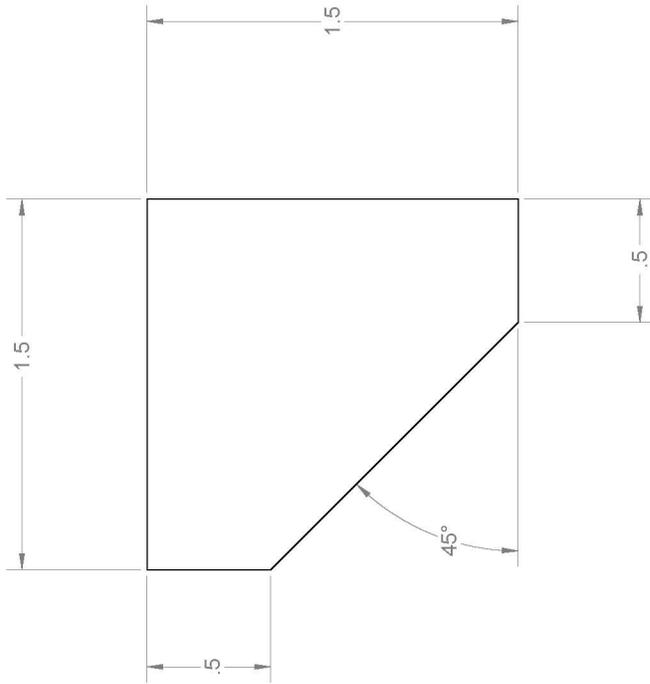
A

1

2

3

4



B

D-55

A



**UNIVERSITY OF MANITOBA**  
**Design Only**

**MECH 4860**  
**ENGINEERING**  
**DESIGN**



PROJECTION

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES FOR FINISHES:  
 ANGULAR: MACH ± 0.30°  
 TWO PLACE DECIMAL ± .01  
 THREE PLACE DECIMAL ± .002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994  
 MATERIAL: 1/2" AISI 1020 STEEL  
 FINISH: DO NOT SCALE DRAWING

Automated Fixture for Leak Detection Scanning  
 DRAWN: JHAN  
 CHECKED: CWATSON  
 NAME: JHAN  
 DATE: 2016/12/03  
 DATE: 2016/12/05

TITLE:

BEACN MOUNT FLANGE

SIZE: B  
 DWG. NO.: M4860-039  
 REV: 0  
 gusset plate  
 SCALE: 2:1  
 WEIGHT:  
 SHEET 1 OF 1

4

3

2

1

## Appendix E

### Component Specification Sheets

(Ommitted)