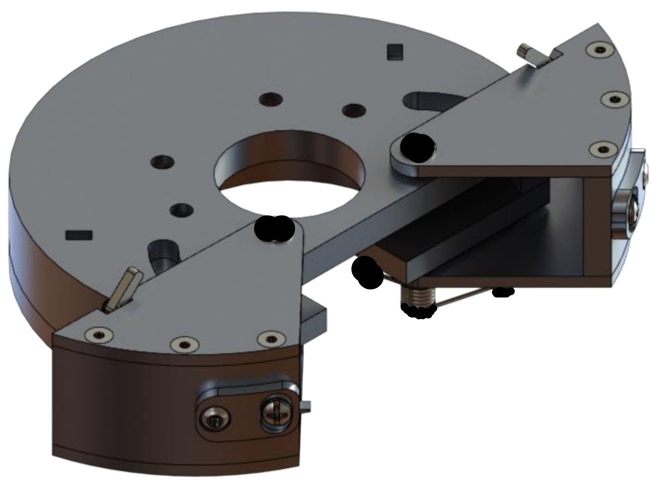
MECH 4860 - Final Project Report

FRP GRINDER GUARD DESIGN PROJECT

Sponsoring Company: Carfair Composites



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Executive Summary

Carfair Composite is a division of New Flyer Industries Group Inc. and manufacturer of Fiber-Reinforced Plastics (FRP) and composites. Operators at Carfair are using an AP10-4 Diatrim 4-inch fiberglass grinder from Applifast suppliers to trim the manufactured parts to the correct final dimensions which are marked by scribe lines on the fiberglass parts. The hand grinders are supplied with a guard to protect the operator from the fast-moving diamond cutting blade. The guards provided are bulky and opaque which greatly reduces the operators' visibility when making cuts and inhibits them from trimming the parts to the allowable tolerance of 0.03 inches. To circumvent this issue, the operators have removed the grinder guards throughout Carfair's facilities, resulting in high cut accuracy but introducing safety hazards. The project objective was to design a custom guard for the 4-inch pneumatic hand grinders to protect the operator from the cutting blade while allowing them to maintain a high cut accuracy to the specified tolerance.

Six preliminary concept guard designs were generated and presented to the client. The client opted to move forward with the Retractable Guard design, which reflected the team's concept selection analysis. The Retractable Guard design assembly consists of 11 custom parts and 15 different types or hardware supplied by McMaster-Carr. The design of the guard consists of a two-piece main guard body and two three-piece pivot guard assemblies. The design allows the guard to open and close, exposing approximately 40% of the cutting edge of the blade when open, which reduces to 25% in the closed resting position. The motion of the pivot guards is restricted by arc slots on the main body of the guard. Furthermore, torsional springs apply a torque to the pivot guards, ensuring that the guard remains closed when a cut is not being made. The pivot guards house scribe line guides which protrude in front of the blade when the guard is in its resting position. The guides have a fine tip, 0.03 inches thick, which fits into the scribe lines which are approximately 0.06 inches wide. When the grinder is pushed against the work piece, the two pivot guards opens to reveal the blade, cutting into the part precisely below the scribe line. The grinder can then slide along the piece with the leading guide sliding in the scribe line while the trailing guide slides below the cut, ensuring precision cuts of the piece to the allowable tolerance. The guide tips are adjustable by 4.29 degrees, ensuring that the precision of the guards can be calibrated with the top of the blade, mitigating any error produced in manufacturing. A locking mechanism allows the operator to lock the guard in the open position, allowing the grinder to be used without the pivot guards engaged, increasing the versatility of the grinder. The locks have an approximate safety factor of 7.08 with respect to the load applied by the springs, ensuring that they can easily withstand holding the guard in the open position. The locks are made from AISI 304 Stainless Steel and are held in the unlocked position by a magnet. The material of the other custom parts is 6061 aluminum alloy and the estimated final weight is 1.3 pounds, which includes the estimated weight of all the hardware. The final design was evaluated using the metrics established by the team to ensure that all the client's needs were met. The preliminary cost of the design was estimated to be $6400.

The report includes an operator's handbook, consisting of a Job Hazard Analysis (JHA), a Safe Work Procedure (SWP) and guard assembly instructions, as well as the preliminary engineering drawings, Failure Mode, Effects and Criticality Analysis (FMECA), the bill of materials and the final CAD models of the design as requested by the client.

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1.0 Introduction

Carfair Composites, a division of New Flyer Industries (NFI) Group Inc., creates fiber-reinforced plastics (FRP) and composites for the Original Equipment Manufacturer (OEM), agriculture, automotive, transportation and medical industries [1]. Carfair Composites is committed to providing a safe workplace for its employees and is working to improve their manufacturing process for their FRP parts.

The fiberglass parts at Carfair's facilities are trimmed to the correct dimensions to a tolerance of 0.03 inches by skilled operators who primarily use a 4-inch pneumatic hand grinder with diamond cutting blades to complete the task. The operators follow scribe lines which are either molded into the parts or scribed by the operators themselves using a template. The scribed lines are only 0.03 inches deep and 0.06 inches wide, making the trimming process time consuming and difficult. The detailed process of fiberglass components made in the roofline station can be found in Appendix A.

The pneumatic hand grinders used at Carfair feature large guards to ensure some protection to the operator from the cutting blade. Unfortunately, most of these guards have been removed from the grinders as they greatly reduce the visibility of the blade and scribe line, inhibiting the operators from making precise cuts and increasing the overall process time. This is a major concern for Carfair as the safety of their employees is paramount.

The roof components for the busses and coaches are the largest parts manufactured by Carfair, and therefore require the most cutting and trimming. The roofline is the most time-consuming trimming process which can take approximately 30 to 60 minutes depending on the operator. The client has stated that the roofline is the focus of the project due to the high process time and the increased chance of operator injury as shown in figure 1.

Figure 1: Operator cutting a roof component, while being exposed to the cutting blade (taken with permission)

The team's objective for this project is to develop a guard design for the 4-inch pneumatic hand grinders used at Carfair's facilities that provides safeguard from the cutting blade while allowing the operators to maintain a high cut accuracy to a tolerance of 0.03 inches.

1.1 Grinder Specifications

The grinder used throughout the manufacturing floor is an AP10-4 Diatrim 4" Fibreglass Saw supplied by Applifast for which the specifications are shown in table I. The technical information of the grinder was used by the design team throughout the design phase to ensure compatibility of the design with the grinder for which it will be attached.

TABLE I: GRINDER AND BLADE SPECIFICATIONS– ADAPTED FROM AP10-4 DIATRIM 4" FIBERGLASS SAW APPLIFAST TECHNICAL SPECIFICATIONS DOCUMENT

Technical Information						
Item	Blade			Air Consumption	Speed RPM	Weight
	Arbor	Diameter	Thickness			
AP10-4	¾ in	4 in	1/16 – 3/32 in	23 cfm @80psi	12700	4.5 lbs

1.2 Project Deliverables

The final deliverables for this project include a report outlining a final design concept with technical specifications and engineering fabrication drawings with Bill of Materials (BoM), a budgetary pricing estimate, Failure Mode, Effects and Criticality, Analysis (FMECA) , as well as Safe Work Procedure (SWP) with Job Hazard Analysis (JHA).

1.3 Target Specifications

To determine the target specification that the team must achieve for the final design, a list of client needs was developed, as well as the metrics to quantify the developed needs. The customer needs were compiled based on primary specifications gathered from the client.

1.3.1. Customer Needs

The customer needs are listed in hierarchal order in table II with the main needs in bold. The main needs are divided further into their respective sub needs which have an importance rating ranging from one (1) to five (5), five being the most important. The project needs with the highest importance were determined based on primary project specifications, which are the health and safety of the operator and maintaining cut accuracy. Secondary project specifications include tool versatility, ease of use, ergonomics, and process productivity.

TABLE II: PROJECT NEEDS AND IMPORTANCE

#	NEEDS	Importance (1-5)
	Provide safeguard to the operator	
1	The design protects operator from moving parts	5
2	The design protects the operator from shrapnel/dust	5
3	The design avoids interaction with the grinder blade	5
	Provide high cut accuracy and/or visibility of the scribe line	
4	The cut accuracy is not affected in the presence of dust	5
5	The design allows high cut accuracy	5
	The design is user friendly	
6	The design is lightweight	5
7	The design is comfortable to use	4
8	The design is easy to set up and use	4
9	The design is easy to use in right and left hands	4
10	The design allows easy replacement of worn parts	3
11	The design requires minimal additional training	3
	Compatible with the existing 4in pneumatic hand grinders	
12	The design does not affect the grinder's performance	4
13	The design allows for easy removal of the cutting disk	4
	The design allows versatile use of the grinder	
14	The design can be maneuvered in tight areas	4
15	The design works in poor conditions	3
16	The design prevents damage to the work piece	3
17	The design is easy to store	2
	The design is of professional quality	
18	The design withstands everyday use	3

Health and safety of the operator was the primary requirement for the project; thus, all sub needs which reflect the safety of the operator were assigned an importance of five (5). Cut accuracy was the secondary requirement, therefore any needs that help the operator cut accurately was given an importance of four (4) or higher. Furthermore, the needs which would affect the existing process negatively if not met, either by performance, efficiency, or throughput time, were given an importance of three (3).

Lastly, easy storage of the design was given an importance of two (2) as it does not reflect the performance of the design and tool storage space was not a major restriction of the project. The metrics were used to quantify the needs to ensure the design met customer's expectations. The following section 1.4 outlines the metrics established based on the needs to allow quantitative testing of the design.

1.4 Metrics and Technical Specifications

A list of quantifiable engineering parameters for the primary guard design was established to satisfy the project needs as shown in table III. Each metric was given the importance rating of one (1) to five (5) based on the importance of the corresponding needs, five being the most important, and was assigned an appropriate unit. The table showcases the marginal and ideal value ranges for each metric which the final design must meet to ensure that the project needs have been satisfied.

TABLE III: PRIMARY DESIGN METRIC SPECIFICATION

Metrics #	Needs	Metrics	Importance (1-5)	Units	Marginal Value	Ideal Value
1	**1,2,14,17**	Size of design	**5**	in	T: 2 in, L and W: 6 in	T: 1 in, L and W: 5 in
2	**2,3,18**	Material strength	**4**	MPa	68 MPa	305 MPa
3	**3,4,8-11, 13**	Design consideration	**5**	Subjective	Client Approved	Client Approved
4	**6,7**	Weight	**5**	Kg or lbs	Grinder Weight + 40%	Grinder Weight + 30%
5	**12**	Grinder speed	**4**	rpm	Grinder Speed	Grinder Speed
6	**15**	Temp range not affecting material properties	**3**	^oC	-20 ^oC to 140 ^oC	-20 ^oC to 140 ^oC
7	**16**	Material Hardness	**4**	Mohs scale	5 to 6	5 to 6
8	**4,5,15**	Visibility / Cut accuracy	**5**	Subjective	Client Approved	Client Approved

To clarify the metrics established above, table IV explains what is being measured for each metric and how the team will determine if the design has met the metrics.

TABLE IV: METRIC DESCRIPTION AND EVALUATION METHOD

Metric	Metric Description	Metric Evaluation
Size of design	The design must fit within a box of Volume WxWxT specified by marginal and ideal values	The team will evaluate the final dimensions of the design
Material strength	Material strength in MPa	The team will evaluate the material properties
Design consideration	The design must meet the related needs	The team will evaluate the design and receive client approval on if their needs are met
Weight	The design must be below a set weight compared to the original weight of the grinder	The team will determine the approximate weight of the design based on the design geometry and material density
Grinder speed	The design must not affect the rotational speed of the grinder	The team will determine if the design has any significant affect on the grinder's rotational speed
Temp range not affecting material properties	The material properties must not significantly change within the set temperature range	The team will evaluate the material properties within the set temperature range
Material hardness	The material hardness, should not exceed the set limits	The team will evaluate the material properties
Visibility / Cut accuracy	The design must not negatively affect the achievable cut accuracy	The team will evaluate the design to determine if the cut accuracy required is still achievable

The marginal values were necessary as they provided the team with tolerable design values. The ideal values are the desired optimal target values of the design. The team researched material properties of commonly used safety guards to determine marginal and ideal values of the size of the design, the material strength, the material temperature range, and hardness [2]. For detailed explanation of each matric refer to Appendix A.

1.5 Constraints and Limitations

Constraints and limitations were identified to evaluate their implications on the design concepts. Two constraints were identified: compatibility with the main compressed air supply of 80-110 psi and maintaining the cut accuracy to a tolerance of 0.03-inch. The compressed air supply to the tool must remain between 80-110 psi to ensure that the grinders can operate normally at the intended speed of approximately 12,700 revolutions per minute. The implication of this constraint for the design was that it must not significantly affect air pressure from the main compressed air supply. Cut accuracy of the design is constrained to a tolerance of 0.03-inch to ensure that the dimensions of the final roof parts are in accordance with the assembly process of the coaches. The implications of this constraint are that the design must allow operator visibility of the scribe line and the grinder blade and it must allow the operator to make precision cuts while removing human error from low visibility.

Time was the only limitation to the project. The project deliverables were due on December 4th, 2019, for both the advisor and the client, which implied that proper time management was needed to be implemented to ensure that the project deliverables were completed and delivered on schedule.

1.6 Design Methodology and Concept Generation

To initiate the design phase, the team met with the client to discuss potential solutions that could be implemented, and which solutions have been attempted in the past. The two design categories discussed with the client were a jig design and a guard design, both to be implemented with the 4-inch pneumatic hand grinder. The team pursued the design of a guard over a jig as it met the needs specified by the client. A detailed review of this decision process can be found in Appendix B.

Prior to starting concept generation, the team researched standards that were applicable to guard designs. The team used the "ANSI Standard B7.1, The Use, Care and Protection of Abrasive Wheels" standard. The only standard which was applicable to this design and for which the team had control was the following:

- "The maximum angular exposure of the grinding wheel periphery and sides for safety guards used on cylindrical grinding machines shall not exceed 180 degrees" **[3]**.

All other abrasive wheel standards for guards are determined by the manufacturer specification.

After determining the relevant standard, the team had multiple brainstorming sessions to develop primary concept designs to evaluate based on the customer needs outlined in section 1.3.1. The primary concepts were reduced to seven concepts considered by the team, which were then subjected to a concept screening proceeded by a concept scoring. A detailed description of the seven generated concepts as well as the screening and scoring process can be found in Appendix B. Through the concept scoring process, the seven concept designs were narrowed down to the two final concepts, retractable guard and a swivel mesh guard which are described below.

1.6.1. Retractable Guard Design

The retractable guard design ranked 1st with a score of 3.96 out of 5 on the scoring matrix. The design is shown in figure 2.

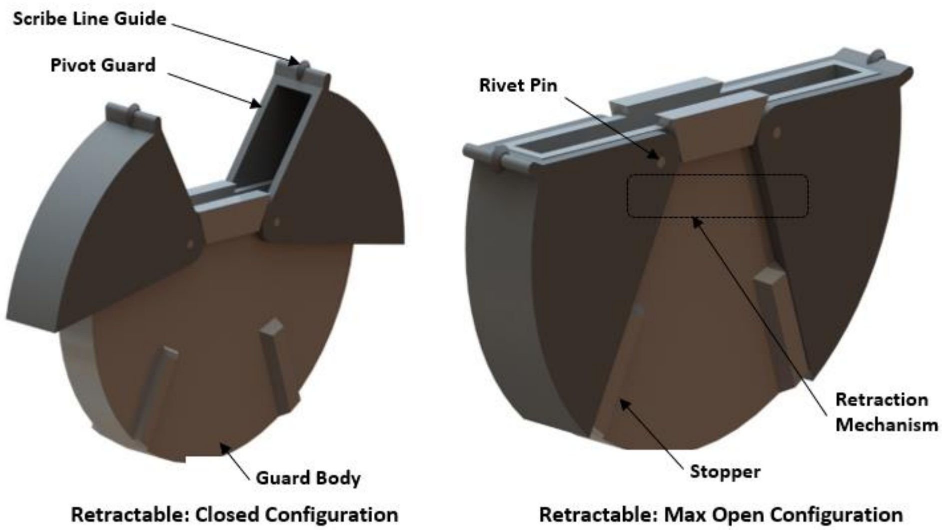

Figure 2: Retraction Guard Design Concept

The design consists of three assembly parts: the main guard body, and two pivot guard pieces that have scribe line guide features built into them. The two retractable guard pieces are attached to the guard body with the rivet pins. The guard body has a built-in stop to prevent the two pivoting guards from travelling past the parallel edge of the main guard body. The two pivot guards rely on a retraction mechanism (not shown in the model) that will retract back when the operator pushes the grinder against the surface of the fiberglass to expose the full blade and allow the cut to occur. Once the cut has been made and the grinder is lifted from the surface, the pivoting guards will go back to their original closed position and enclose a certain portion of the blade (estimation is approximately 87% of the area of the blade).

1.6.2. Mesh Swivel Design

The mesh swivel design ranked 2nd with a score of 3.53 out of 5 on the scoring matrix as shown in figure 3.

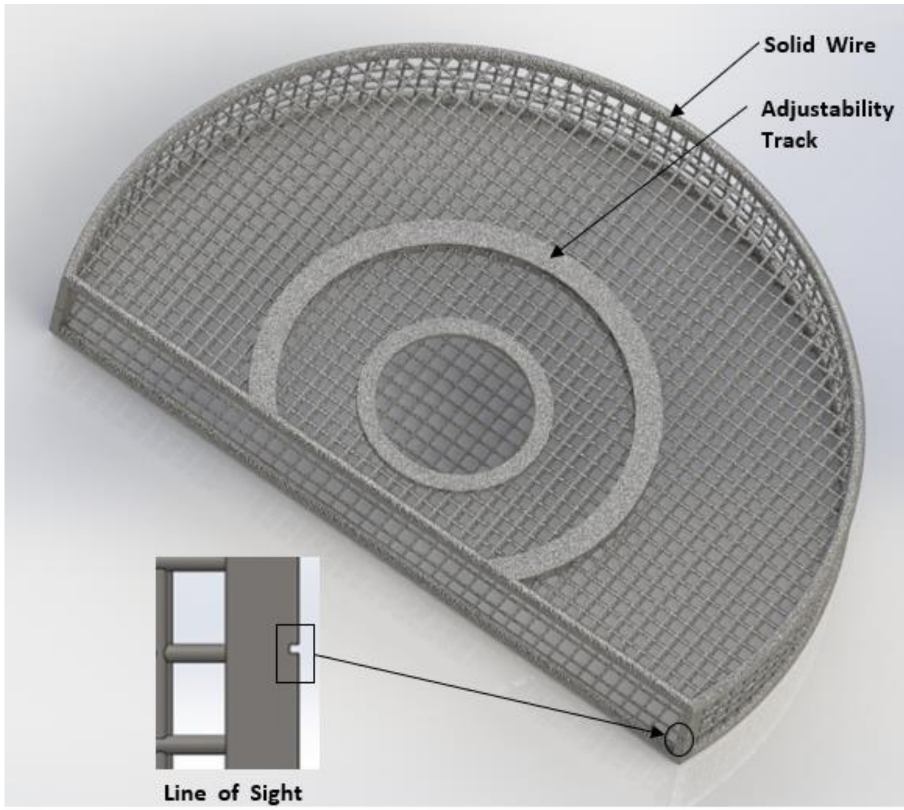

Figure 3: Swivel Mesh Concept Design

The mesh swivel guard design consists of a solid wire frame with adjustability track to provide structural stability and guard orientation adjustment. The entire structure is bounded by a mesh to provide the operator with increased visibility to see the scribe line. The adjustability track allows the operator to adjust the guard to a specified angle and allow the use of the grinder at acute or obtuse angles. The adjustability track would either be a specific number of steps or holes to provide adjustability to the operators via the use of a pin mechanism. The design would also have a safety mechanism built into it to fool-proof the guard, constraining the guard's degree of freedom (i.e. the guard will not be able to rotate 360 degrees). Furthermore, there is a line of sight slot built into the frame of the design to allow the operators to see where the blade will be cutting the material.

The team reviewed and discussed the seven generated concepts with the client including the final two designs selected. The design features pertaining to both designs, along with the design selection process used was also reviewed and discussed with the client, which is located in Appendix B. Carfair opted to proceed with the retractable guard design due to it covering approximately 87% of the grinder blade in the closed position as opposed to 50% coverage for the Mesh swivel design. Due to these numbers, the client deemed the Retractable guard design safer. Furthermore, the client also showed preference in the scribe line guide feature of the Retractable guard in comparison to the line of site slot on the Mesh swivel design due to it providing higher cut accuracy.

The main concern the client had for the Mesh swivel design was that the operator would be exposed to the dust particles as the mesh would allow the dust to go through when in the line of sight of the operator. Furthermore, the adjustability track of the swivel mesh guard is a feature that the operators would have to manually adjust to a correct setting before operating the grinder. The client preferred the automatic self-retraction feature of the Retractable guard over the manual adjustment feature of the mesh swivel design. Taking client feedback into consideration, the team proceeded to develop the retractable design further.

2.0 Final Design

The final retraction design is made up of 11 custom and 15 different types of standard purchased hardware from McMaster-Carr. Figure 4 shows the render of the final guard design.

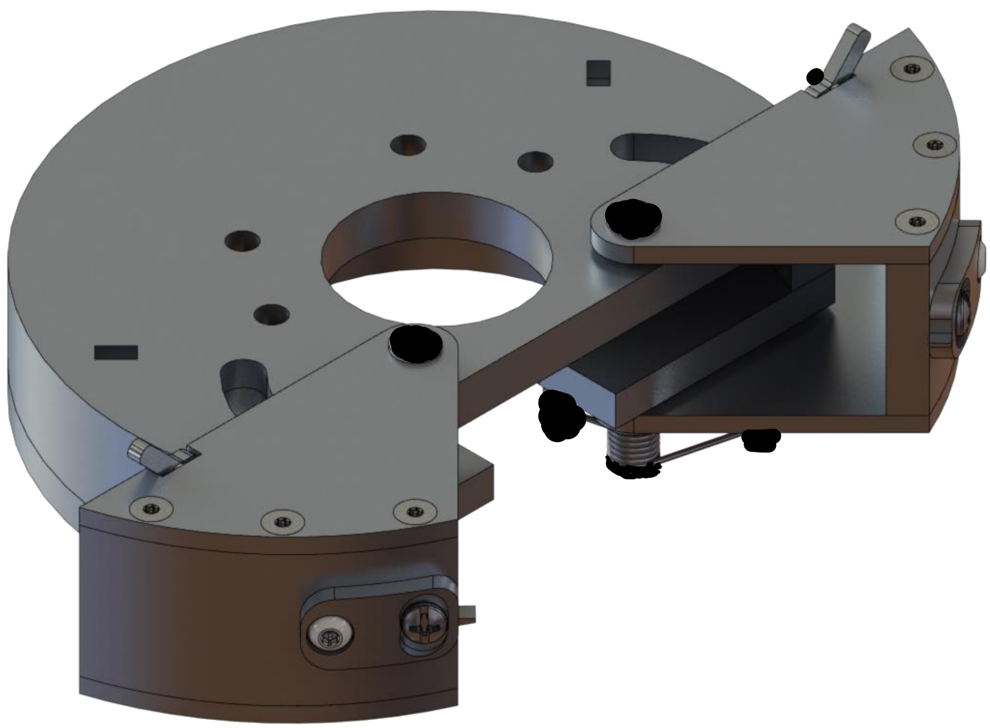

Figure 4: Final guard design

This section starts with the overview of the final design that highlights the key features and functionality of the design. Afterwards, the section proceeds into the functionality of the key features as well as the design methodology. The importance of each key feature, how they meet the customer needs and how it is incorporated into the overall final design is discussed. Lastly, the team explored possible materials and selected the final material based on client inputs and discusses the overall final cost of the design.

2.1 Overview of the Final Design

The assembly was designed to be compatible with Carfair's 4-inch pneumatic grinder. The team first had to accurately model the features of the grinder, especially the guard attachment point which was achieved by using a 3D scanner and a caliper to ensure the dimensions of the grinder to guard attachment points were accurately modeled (for grinder modelling details refer to Appendix D). The final design and all key features of the design are shown in figure 5 and figure 6.

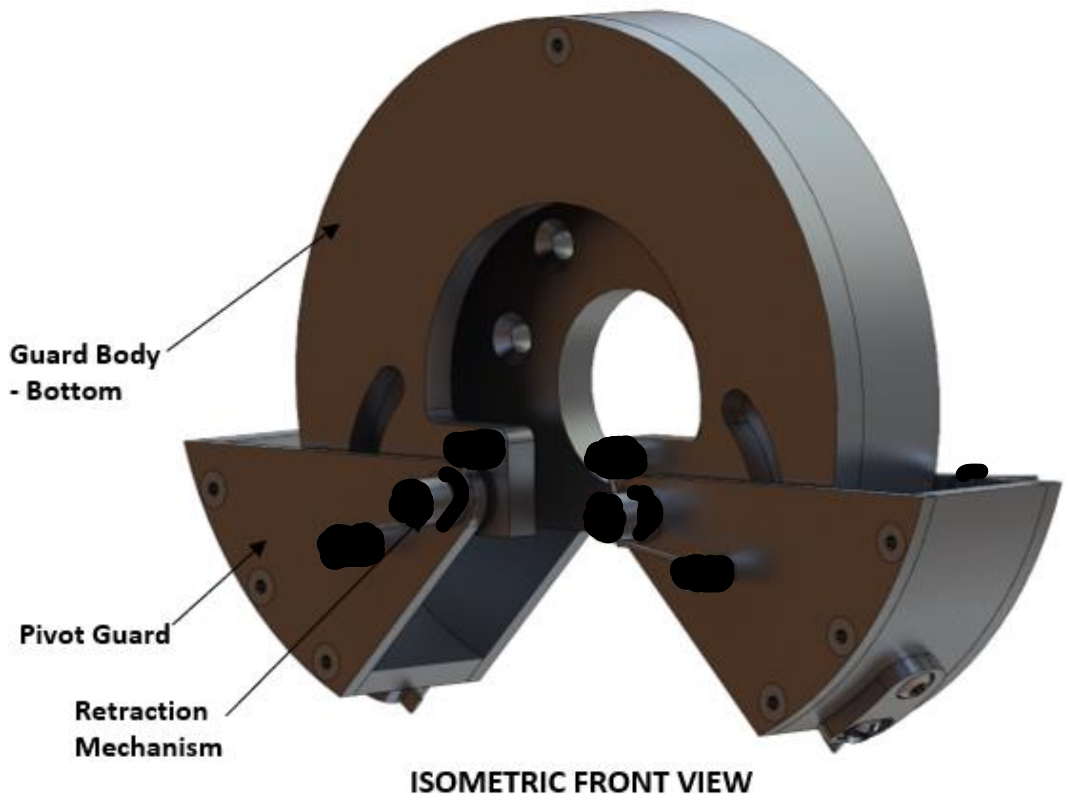

Figure 5: Final guard design isometric front view

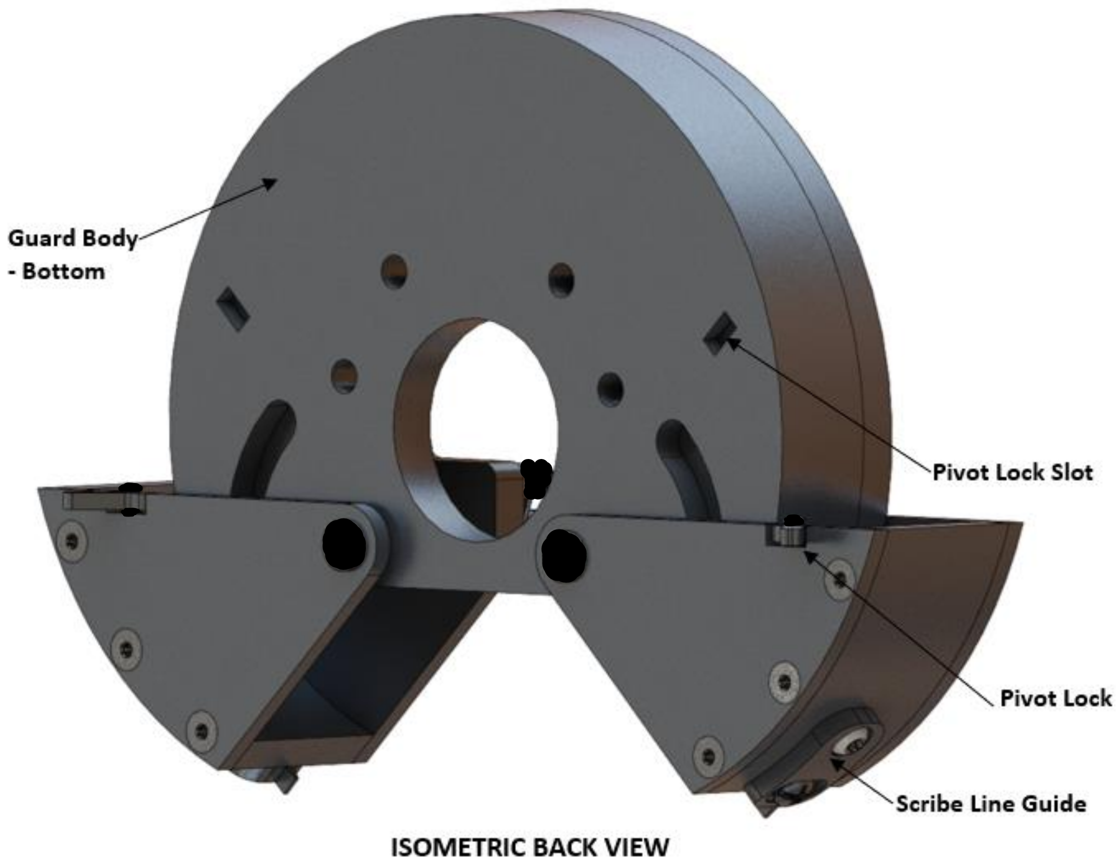

Figure 6: Final guard design isometric back view

As shown in figure 5 and figure 6, the key features of the design are the guard body (Front and Back), pivot guard, retraction mechanism, scribe line guides and pivot lock. The details and design methodology for each of the features will be discussed in section 2.2

The design works by having the pivot guards cover the grinder blade when grinder is not in use. However, when the it is being pushed down against the surface by the operator's applied force, the pivot guard retracts back. The team used torsional springs for the retraction mechanism. The design also has a scribe line guide mechanism attached to the two pivot guards. The operators are able to align the guides to scribe lines on the work piece to achieve the 0.03-inch cut accuracy as specified by client needs. Lastly, to allow the operators to cut in tight corners, the design has a pivot lock which allows the operators to fully push the pivot guards back and lock it in place.

2.2 Function and Design Methodology of Discrete Features

The design methodology, and feature for each part and how it meets the overall customer needs are discussed here. Firstly, the team discussed the guard body of the final design, then moved on to the pivot guards, retraction mechanism (torsional spring), scribe line guides and pivot locking mechanism.

2.2.1. Guard Body (Top and Bottom)

The main guard body, consisting of a top and bottom plate, encompasses the majority of the cutting blade, providing the primary level of protection to the operator.

The top guard body is a modified version of the existing top guard body supplied by the grinder manufacturer. The modification to the guard body was done to accommodate other features of the design. The bottom plate is a custom part that attaches to the top guard, covering the bottom of the blade while allowing access to the blade attachment screw for easy blade replacement. The main guard body is shown in figure 7 and figure 8.

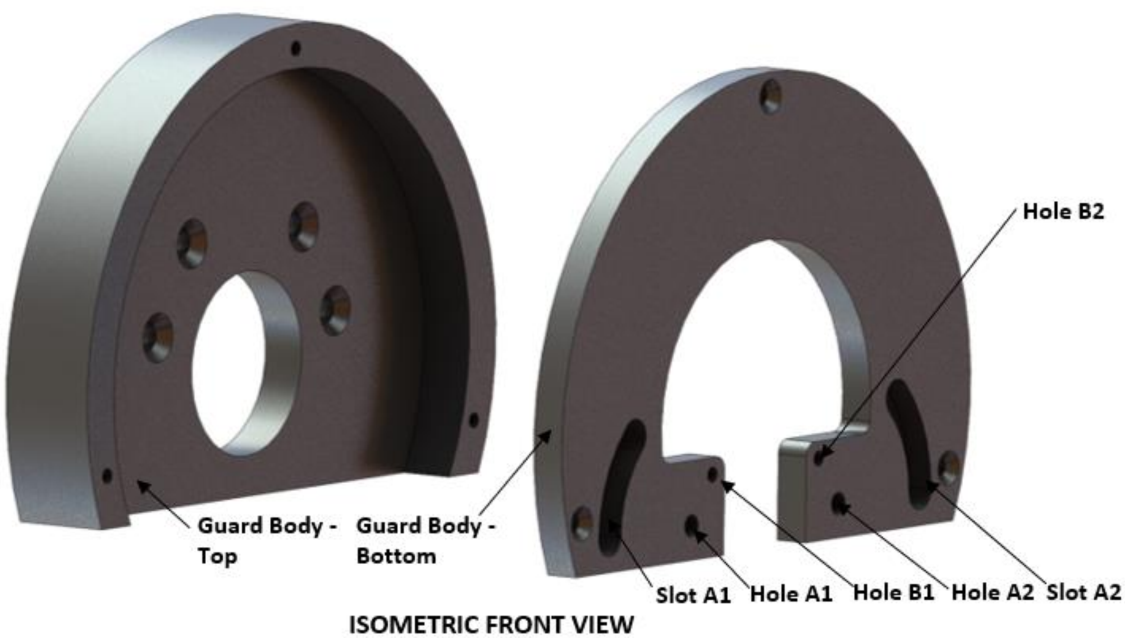

Figure 7: Isometric back view of guard body

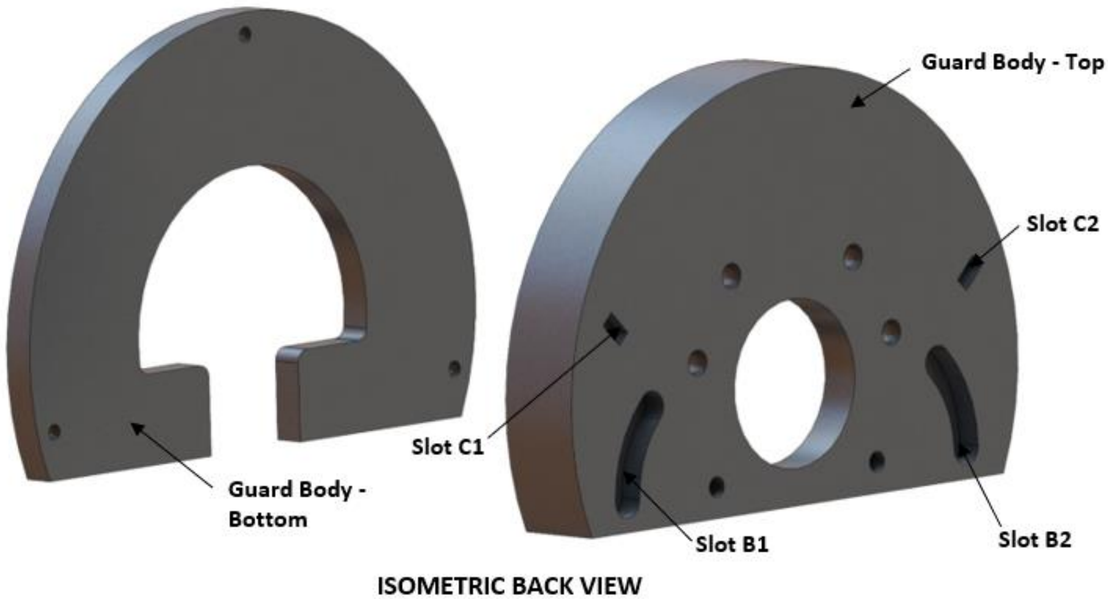

Figure 8: Isometric front view of guard body

As shown in figure 7 and figure 8, the modifications and main features include the addition of 4 arc slots labelled as slot A1, A2, B1, and B2. The arc slots' function is to accommodate and guide the pivot guards. Furthermore, hole A1, and A2 are the pivot points of the pivot guard covered in section 2.2.2. Hole B1 and B2 are to anchor one side of the retraction spring. Slot C1 and C2 are designed to allow the pivot guard to lock in for the pivot lock mechanism covered in section 2.2.5. The slots B1 and B2 are designed to provide a maximum of 45 degrees range of motion to the pivot guard from its resting closed position to open position.

2.2.2. Pivot Guard

The pivot guard design is a three-piece assembly as seen in figure 9. It is a modification from the one-piece shell design proposed in phase 2. The function of pivot guard is to cover the cutting blade when the grinder is not in use and retract back when operator pushes the grinder into the surface of the fiberglass part. The design sits within arc slot of the guard body and is able to follow the path of the arc slot as the force from the retraction mechanism (discussed in section 2.2.3) pushes against it.

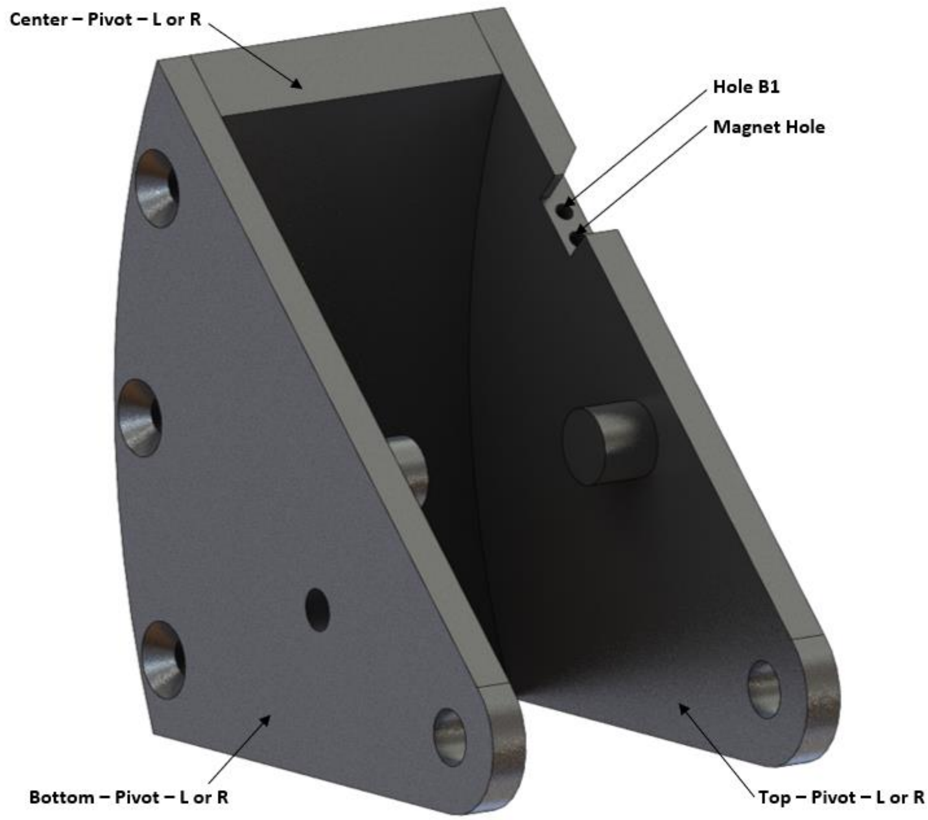

Figure 9: Pivot guard - isometric view

The design was made a three-piece design to ensure that the part was easy to fabricate and assemble onto the guard body. The three sides of the design are called "Top – Pivot – L or R", "Bottom – Pivot – L or R" and "Center – Pivot – L or R". L represents left side and R represents the right side. The design is held together by a total of 6 Tamper-Resistant Torx Flat Head Screws, 3 per side. The thickness of the top and bottom pieces was chosen to be 1/8 inch to withstand everyday use while not being too heavy. The center pieces were designed to be a little thicker at ¼ inch to provide more protection to the main body when closed, and enough material for the screws to fasten into other components. The top guard also has a cut-out for the pivot locking mechanism; hole B1 is made to hold the pivot lock in place, while magnet hole houses a neodymium magnet which holds the pivot lock in open position.

Moreover, as shown in figure 10, the inside surface of the top and bottom pivot guard houses a ¼ inch long welded rod. This rod is designed to sit within the arc slot of the guard body (top and bottom). The outside surface of the front pivot guard has a hole F1 for a screw to fasten the other end of the torsional spring.

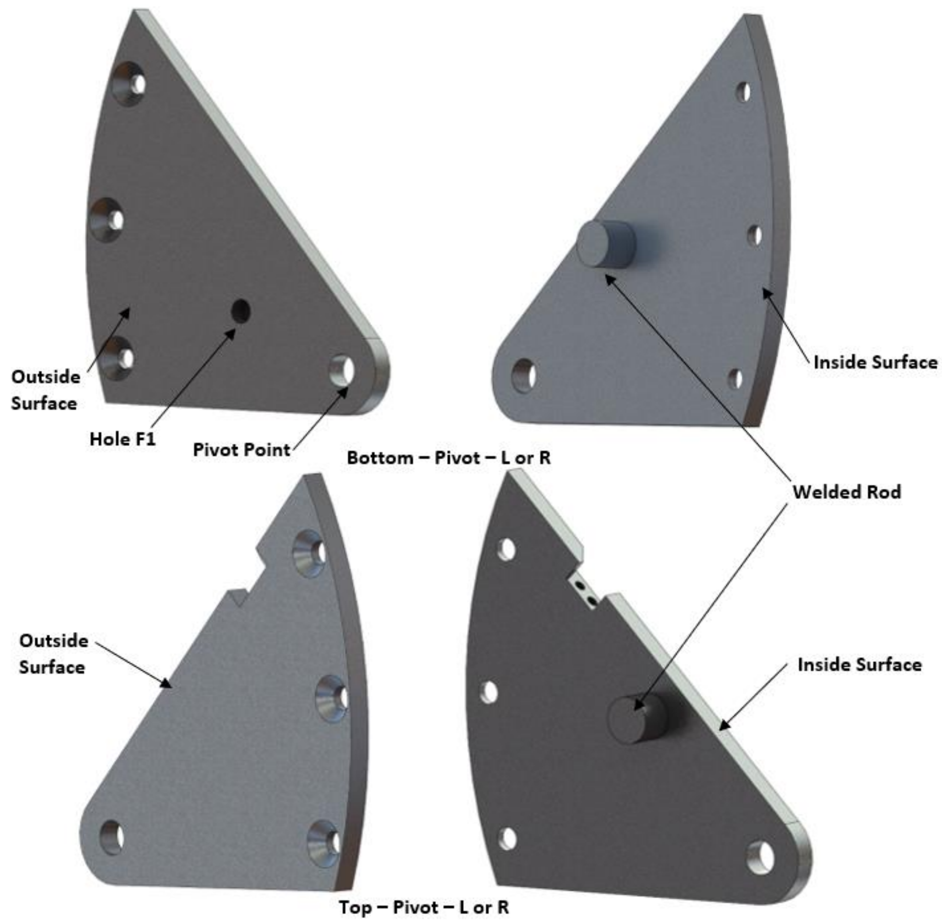

Figure 10: Top and bottom pivot guard pieces - isometric views

Lastly, the “Center – Pivot – L or R” has two holes to account for the attachment of the scribe line guide as shown in figure 11. The hole locations for the left and right side are slightly different to ensure that the scribe line guides sit flush with the grinder blade. More details on scribe line guide will be discussed in section 2.2.4.

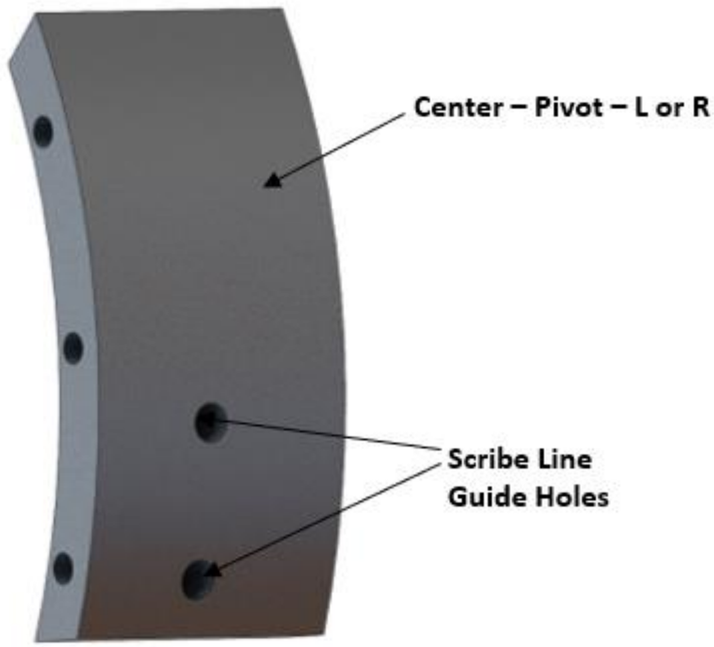

Figure 11: Center pivot guard piece- isometric view

2.2.3. Torsional Spring Retraction Mechanism

The team investigated various retraction mechanisms and presented two retraction design concepts to the client; linear spring and torsional spring mechanisms. The client decided to move forward with the torsional spring mechanism as it was simpler to maintain and easier to keep clean from dust accumulation. The team’s investigation of the retraction mechanism and a linear compression spring mechanism design concept is shown in Appendix D.

The torsional spring retraction design consists of two torsional springs providing the necessary force to keep the guard in its closed position when grinder is not in use or when cuts are not being made. As the grinder is pushed against a work piece, the angle between two ends of torsional spring reduces from equilibrium angle and a torque is applied proportional to the change in angle. The design with torsional spring retraction mechanism is shown in figure 12.

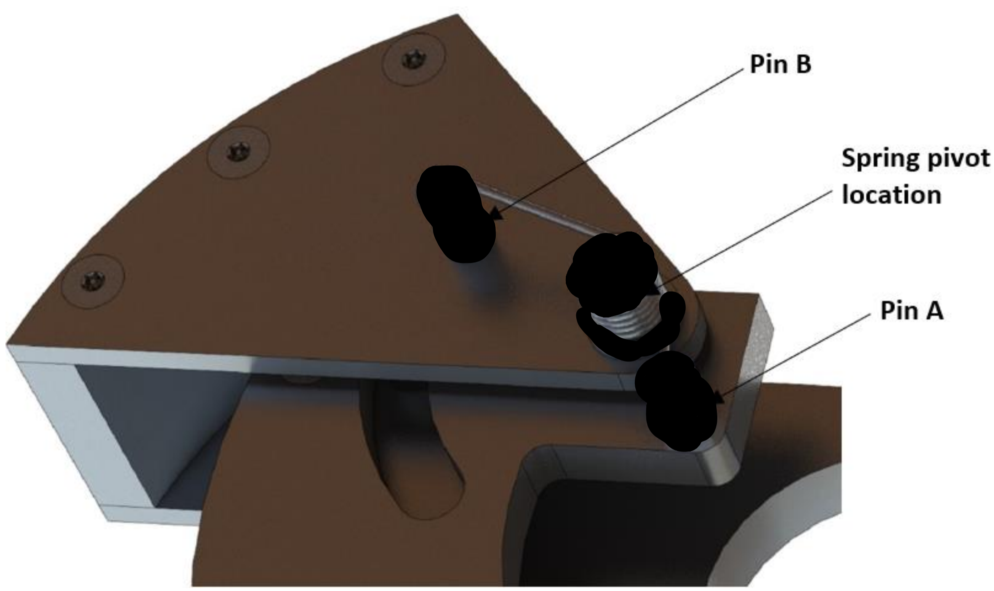

Figure 12: Torsional spring retraction final design

The springs are attached to the bottom side of the pivot guard with the spring coiled around the guards’ pivot points. One end of the spring was attached on main guard body at pin A, while the other end was attached to pin B on the pivot guard’s bottom face.

A 120° spring was chosen to allow for better pin locations based on the guard's shape and to provide higher maximum torque.

All the previous torsional spring mechanisms considered by the team are discussed below followed

Version 1:

The original torsional spring design consisted of attaching the spring at retractor pivot point, in the clearance between pivot guard and main guard body. But upon further inspection, the team found that the clearance was too small for a spring to fit in, and the design modification required to adjust for that would include changing the main guard body significantly. Therefore, this design was scrapped due to feasibility issues and design constraints.

Version 2:

For this version of the model, the problems faced in version 1 were improved upon. The spring location was changed to be on the main guard body, with one end at the same level and the other at a height on the retractor as shown in figure 13.

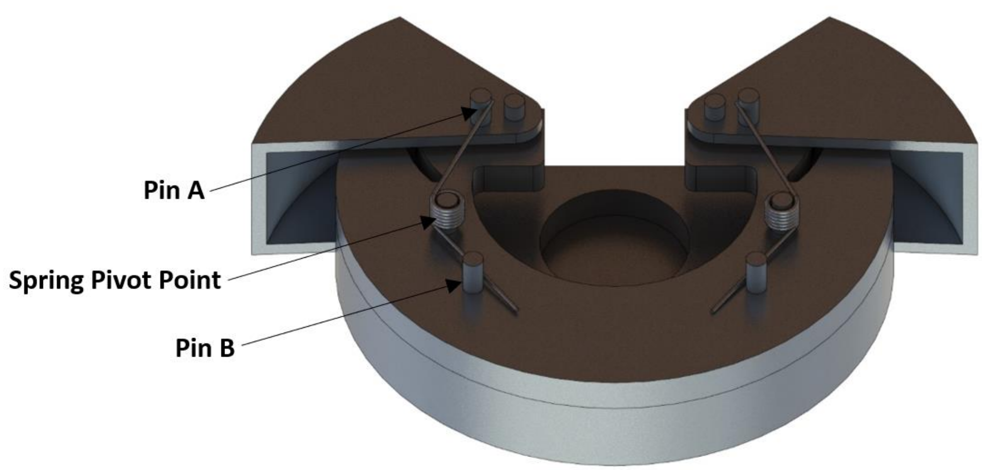

Figure 13: Torsional spring design version 2

A 120° torsional spring was chosen for this design which satisfied all the criteria including the maximum possible deflection of 45° for the retractor. However, the team realized that the distance between spring pivot and pin A could not be kept constant. As a result, when the guard is pushed down, one arm of the spring would be sticking out causing a safety concern.

Version 3:

Since the team could not fix the spring to both pins, the design was modified again with the spring resting on top of retractor at the pivot point. Considering this point stationary during the push-back motion of the retractor, distances between the spring and both pins were always constant. In this design, one of the pins were fixed on the retractor and the other on main guard body at a reasonable distance such that at equilibrium the spring was at 90°. This design is shown in figure 14 and figure 15.

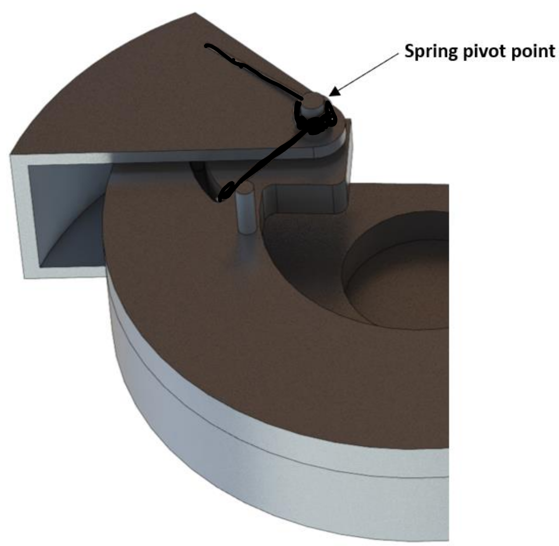

Figure 14: Torsional spring design version 3 spring location

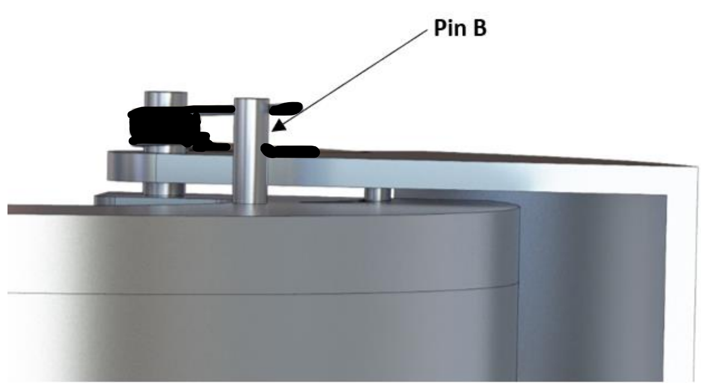

Figure 15: Torsional spring design version 3 pin location

After modelling the design on SolidWorks, the team realized the spring arm would be in contact with the retractor edge whenever the guard is pushed open, significantly increasing wear and tear of the components involved. Additionally, the pins (especially pin B, on main guard body) would need to be significant long to be in contact with the spring arm, as shown in figure 15. These long pins made the guard visually unappealing and were also at a risk of being under cyclic moment of high amplitude due to the height difference from point of contact with spring edge and their base.

Therefore, the team decided to fix this issue before proceeding further. Pin A location was changed to be close to the pivot point which resulted in a much shorter arm length and the pin design was changed from standard material welded to the surface to an Ultra-low-profile precision shoulder screws. The updated and final spring location, pivot point and arm positions are shown in figure 16.

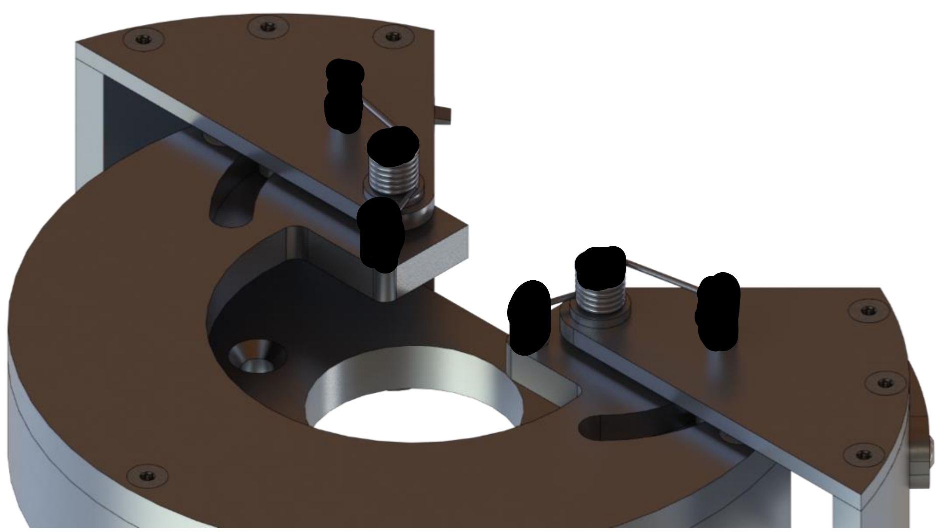

Figure 16: Updated and final torsional spring design

2.2.4. Scribe Line Guide

The scribe line guides are an integral feature of the final design as they allow for precision cuts to be made without the need for a clear line of sight to the scribe line. The design is shown in figure 17.

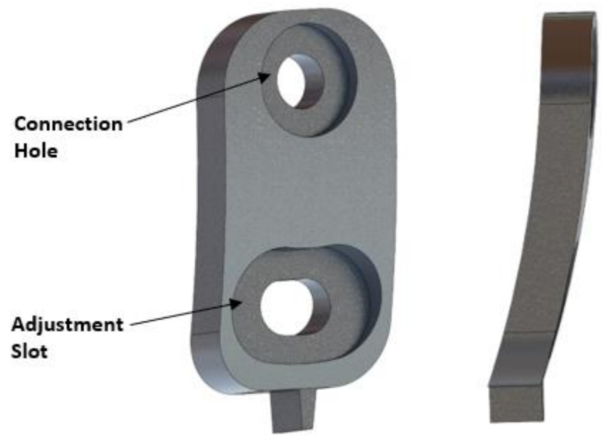

Figure 17: Scribe line guide - isometric view

The tips of the guides fit inside the scribe lines on the fiberglass parts and ensure proper alignment of the cutting blade and the scribe line. When the grinder is pushed towards the work piece the guides remain in the scribe lines, and the location of the guides on the grinder ensure that the blade cuts directly under the scribe line. Once the grinder cuts into the work piece the operator can run the grinder along the scribe line to cut the excess material. The leading guide rides in the scribe line while the trailing guide follows the cut being made and help maintain the correct grinder orientation, ensuring precision cuts along the scribe line.

The final design is an improvement to the original design. In version 1 of the design, the design was part of the pivot guard which had limitations in terms of adjustability and fabrication. The final design is modular and consists of adjustment slot and the connection hole. The design attaches to the “Center – Pivot – L or R” via a Connection Hole and Adjustment Slot. The connection hole is held to the pivot guard by a temper resistant screw, while the adjustment slot uses a Philips screw to enable operators to calibrate the guides if and when needed.

The adjustment slot provides adjustment of less then 2.14 degrees from the center line and is intended adjust to ensure the guide meets the accuracy of 0.03 inch. The width of the scribe line is 0.06 inch.

2.2.5. Pivot Guard Locking Mechanism

The pivot guard locking mechanism is another feature in the final design. This mechanism was put in place to give operators the option to lock the pivot guard in open position to help them make cuts in hard to reach areas. For this mechanism, a magnetic lock was used. The complete mechanism is shown in figure 18.

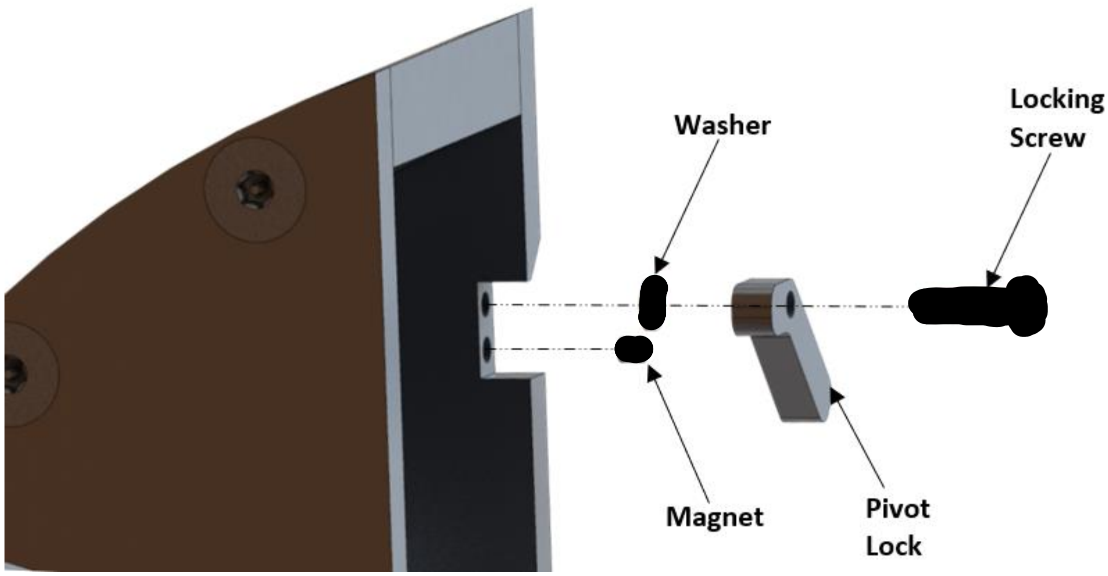

Figure 18: Pivot locking mechanism – exploded view

The mechanism consists of a pivot lock installed on the side of pivot guard body, held in an upright position by the magnet when not in use as shown in figure 19.

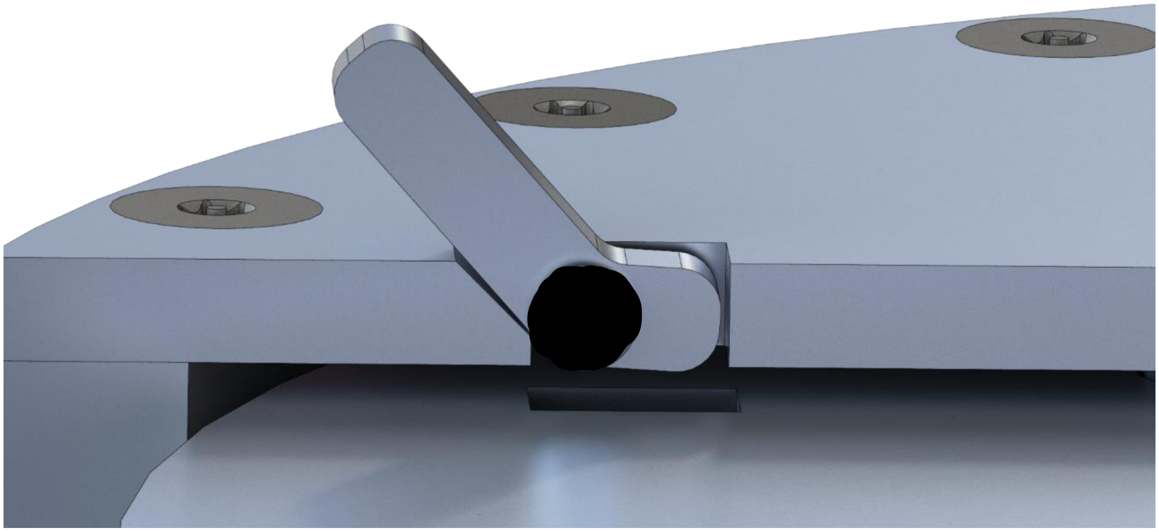

Figure 19: Locking mechanism – open position

Maintaining this open position is critical otherwise pivot lock could scratch top surface of main guard body during every retraction cycle, thus damaging the guard. In order to lock pivot guard in place, it can be pulled back and pivot lock turned such that it enters slots C1 and C2 shown in figure 8 in section 2.2.1. This closed position is shown in figure 20.

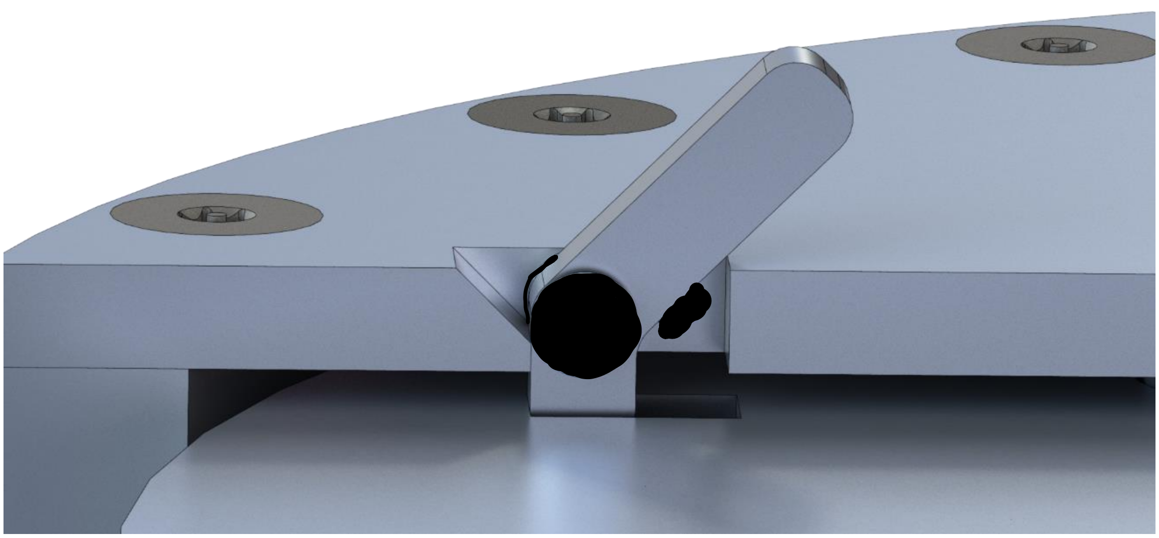

Figure 20: Locking mechanism – closed position

2.3 Design Materials

After developing the design, the material had to be chosen for rest of the custom parts excluding main guard body as the team, with client's approval assumed the material for the main guard body to be Aluminum 6061. The initial research gave the team two classes of materials to analyze – polycarbonate and aluminum alloys.

The properties for all materials considered for retractor are listed and compared in table V.

TABLE V: MATERIAL SELECTION FOR RETRACTOR

Properties	Polycarbonate [4]	Aluminum 6061 [5]	Aluminum 2011 [6]	Aluminum 5052 [7]
Hardness	70 Rockwell M	120 Knoop	120 Knoop	96 Knoop
Chemical Reactivity	Yes	No	No	No
Density [g/cm^3]	1.15-1.2	2.70	2.83	2.68
Ultimate Tensile strength [MPa]	55	310	379	276
Transparency	Yes	No	No	No

One of the main criteria for selection was based on the possible reactivity between the material and the two main chemicals found on Carfair Composites' work floor: isocyanates (found in gel coats) and styrene (found in fiberglass resin). It was found that polycarbonates have a severe affect when in contact with styrene [8], and therefore the team chose an Aluminum alloy for the custom parts.

Three Aluminum alloys were selected for further comparison due to some unique properties exhibited as shown in table VI [9].

TABLE VI: ALUMINUM ALLOYS CONSIDERED AND THEIR PROPERTIES

Material	Relevant Properties
Aluminum 6061	• Great versatility • High manufacturability • High mechanical strength • Low density • Corrosion Resistant • Can be welded by all methods
Aluminum 2011	• Also known as Free Machining Alloy (FMA) due to excellent machining capabilities • High strength • Great for manufacturing complex and detailed parts
Aluminum 5052	• Very high fatigue strength • Excellent workability • Can be easily formed into intricate shapes

All these alloys do not have any severe interaction with isocyanates or styrene. The hardness of material was considered to ensure that the part does not scratch the surface or cosmetically damage the fiberglass part. To prevent the cosmetic damage, the material hardness needs to be less than that of fiberglass part. Fibreglass hardness was noted to be 6.5 on Moh's scale, which is converted to Knoop scale using figure 21 as reference.

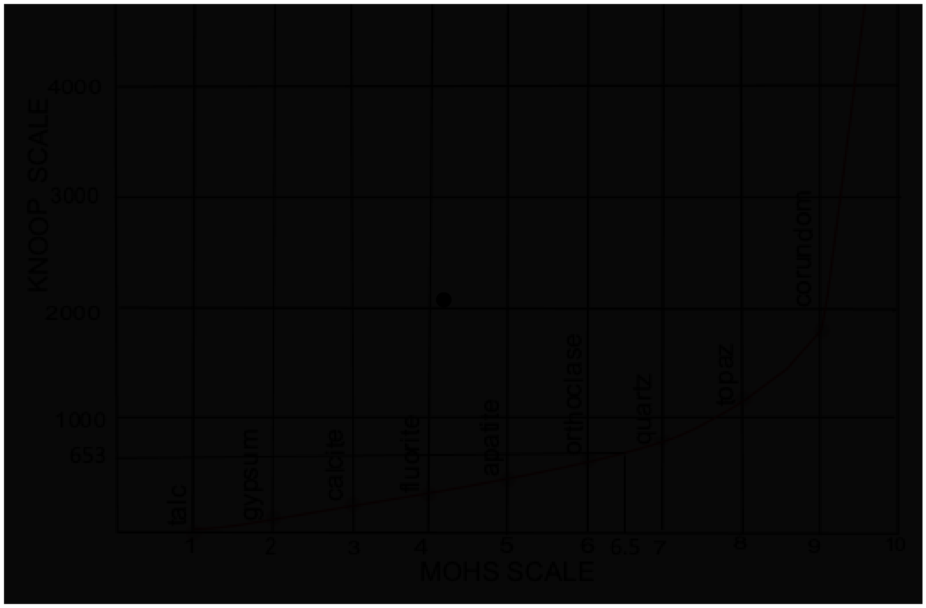

Figure 21: Mohs vs Knoop scale conversion (adapted from reference [10])

Using conversion plot, it was determined that, to maintain product surface finish, the hardness for guard (and retractor) material should be less than 653 Knoop which is true for all 3 Aluminum allows being considered.

Aluminum 2011 was rejected due to comparatively high density, and 6061 was chosen due to its lower density but higher material strength. It is the same material used for the main guard body, which adds the uniformity in the design.

Using the density of the selected material and the volume of the final design obtained from the CAD model, the team calculated the total weight to be 1.30lbs including the weight of all screws, washers and springs.

2.4 Failure Mode, Effects and Criticality Analysis (FMECA)

A Failure Mode Cause Effects Analysis (FMECA) was performed for the final design in order to identify and analyze all possible failure modes, and to identify how to mitigate their causes to reduce the risk of failure as shown in table VII.

TABLE VII: FMECA ANALYSIS

[redacted]

The severity (SEV) was rated on a scale of 1-10 and factors considered were how severe the effect would be for each failure effect to the client. Operator safety was a major client need. Therefore, the possibility of operator being exposed to moving blade without a guard in-between was given the highest severity of 10. The potential failure mode for this was the pivot guard not being able to move at all defeating the purpose of the design and leaving the operator without any protection from the grinder blade. If the spring mechanism does not function properly, or pivot guard does not close completely (changed resting position), the severity of possible failure was given a rating of 9 as the blade was still partially covered.

The frequency (OCC) of potential failures happening was also ranked on a scale of 1-10. The chances of the scribe lines being misaligned were one of the highest among other potential causes, but it was still given a rating of 5 on the occurrence scale. This was done to account for the low frequency of this misalignment happening. The probability of dust/swarf fill-up in the arc slot on main guard body was also given the same occurrence rating of 5.

For detection (DET) as well, a scale of 1-10 was and the detection rate for potential causes or failure modes was considered for the ranking. The team determined that dull scribe line guides would be the hardest to detect because of gradual decrease in grinder cutting accuracy and were therefore given a detection rating of 6. To tackle that, regular check-ups of scribe line guides were suggested. And if the scribe line guides were too sharp, the scratches observed on the final product surface would be too easy to see and therefore that was given a detection rating of 1.

Combining all these ratings, a risk priority number (RPN) was assigned to each potential failure mode. After further analysis, it was found that the misalignment of scribe line guides and dust/swarf fill up in arc slot had highest RPN for their failure modes. The team identified critical failure components which are listed in table VIII.

TABLE VIII: CRITICAL FAILURE PARTS

Critical Failure Part	Part #	Recommended Quantity
Torsional Spring (Left and Right)	9271K637, 9271K701	2 of each
Scribe Line guides (Left and Right)	Custom part 010, 011	1 of each

2.5 Design Cost and Bill of Materials

The final design cost includes the cost of off the shelf components from McMaster-Carr and the components that require fabrication. The team received the approximate cost based on the preliminary engineering drawings for the 11 components that required fabrication from the Winnipeg company "Standard Machine Works" The cost breakdown for the project is shown in table IX.

TABLE IX: FINAL DESIGN COST

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	Vendor	Minimum Qty.	Price
1	001	GUARD BODY - TOP - CUSTOM PART	1	NA	NA	
2	002	GUARD BODY - BOTTOM - CUSTOM PART	1	NA	1 ea.	
3	003	BOTTOM - PIVOT - LEFT - CUSTOM PART	1	NA	1 ea.	
4	004	BOTTOM - PIVOT - RIGHT - CUSTOM PART	1	NA	1 ea.	
5	005	CENTER - PIVOT - LEFT - CUSTOM PART	1	NA	1 ea.	
6	006	CENTER - PIVOT - RIGHT - CUSTOM PART	1	NA	1 ea.	~$6300 total
7	007	TOP - PIVOT - LEFT - CUSTOM PART	1	NA	1 ea.	
8	008	TOP - PIVOT - RIGHT - CUSTOM PART	1	NA	1 ea.	
9	009	PIVOT LOCK - CUSTOM PART	2	NA	1 ea.	
10	010	SCRIBE LINE GUIDE LEFT - CUSTOM PART	1	NA	1 ea.	
11	011	SCRIBE LINE GUIDE RIGHT - CUSTOM PART	1	NA	1 ea.	
12	[redacted]					$ 8.30
13	90604A144	Pan Head Combination Phillips/Slotted Screws - 6-32 Thread, 1/4" Long	2	McMaster- Carr	pk of 100	$ 4.09
14	91900A144	Stainless Steel Tamper-Resistant Button Head Torx Screws - 6-32 Thread Size, 1/4" Long	2	McMaster- Carr	pk of 25	$ 8.84
15	91900A105	Stainless Steel Tamper-Resistant Button Head Torx Screws - 4-40 Thread, 3/16" Long	2	McMaster- Carr	pk of 50	$ 10.85
16	91870A130	Tamper-Resistant Torx Flat Head Screws - 4-40 Thread, 3/8" Long	15	McMaster- Carr	pk of 50	$ 11.40
17	[redacted]					$ 4.84
18						$ 0.18
19						$ 12.57
20						$ 6.15
21						$ 4.81
22						$ 0.96
23						$ 0.33
24	9271K637	Torsion Spring - 120 Degree Left-Hand Wound, 0.309" OD	1	McMaster- Carr	1 ea.	$ 4.63
25	9271K701	Torsion Spring - 120 Degree Right-Hand Wound, 0.309" OD	1	McMaster- Carr	1 ea.	$ 4.63
26	[redacted]					$ 8.30
					Final Design Cost in US Dollars	$ 6390.88

3.0 Final Design Calculations

To ensure the validity of the design, hand calculations were performed for the torsional spring, the pivot lock mechanism. These calculations ensure that the springs provide enough torque to the pivot guards to keep them closed in their rest position as well as confirming that the pivot locks can easily withstand the torque applied. Moreover, the calculations were also performed for the scribe line guide mechanism.

3.1 Torsion Spring Calculations

Calculation of spring constant for the main torsional springs was done using the following equation: [11]

$$k = \frac{PM}{\theta_{max}}$$

Where P is the force exerted on spring in pounds, M is the length of moment arm in inches, θ_{max} is the deflection in degrees and k is the spring constant with units of inch-pounds per degree.

θ_{max} was determined to be 45 degrees, which is the maximum angle that the torsional spring is compressed when the pivot guards are completely open while the grinder is in use. M is the arm length for the spring arm in motion which is equal to 0.8 inches.

The weight of the pivot guards was determined to be 0.124 pounds each using the SolidWorks model. This weight was multiplied by a factor of 4.5 to ensure that pivot guards have enough torque to feasibly protect the operator from the blade. After unit conversion, P was determined to be 0.56218 pounds.

Substituting the variable values into the above equation, the value of k is determined as follows:

$$k = \frac{0.56218 \times 0.8}{45} = 0.01 \; [in \cdot \frac{lbs}{deg}]$$

Since the spring used is known to have a 120-degree deflection angle, the maximum torque, T_{max}, is determined by the following equation:

$$\mathrm{T} = k \times \theta$$

$$\mathrm{T}_{max} = 0.01 \times 120 = 1.20\ [in \cdot lbs]$$

Besides a requirement to have a minimum T_{max} of 1.2 inch-pounds, another requirement for the spring was to fit on a shoulder screw of 3/16 of an inch in diameter, which is the locks point of pivot. The spring must therefore have an internal diameter greater than 3/16 of an inch. Combining these two requirements, a left-hand wound torsional spring, with McMaster-Carr part # 9271K637 [12], and a right-hand wound torsional spring, with McMaster-Carr part # 9271K701 [13], were selected for the pivot guards. These springs have a T_{max} of 1.43 inch-pounds.

3.2 Pivot Lock Shear Force

As the pivot locks keep the pivot guards in the open position, resisting the torsional springs, there was a risk of the pivot locks shearing. To ensure that the pivot locks are sufficiently strong to hold the pivot guard in place, the shear stress applied was calculated and compared to the maximum shear strength for Aluminum 6061. The calculations of the applied shear stress are shown below.

The pivot lock needs to overcome the torsional force from the spring. To calculate the spring torque, the same equation shown in section 3.1 is used:

$$\mathrm{T} = k \cdot \theta_{max}$$

Where k is the known spring constant, and θ is the maximum angle that the spring is compressed in the design. From torque spring calculation section, the k is 0.01 and θ_{max} is taken to be 45 degrees as shown in the previous section which yields the following:

$$\mathrm{T} = 0.01 \times 45 = 0.45\ \frac{in \cdot Ib}{Deg}$$

The assumption is made that the spring torque is equal on both top and bottom faces of the pivot guard to simplify calculations.

The angle between the spring arm and the line of action between the spring pivot point and the pivot lock was determined to be γ = 108.9337 degrees, as shown in appendix G. The torque was calculated using the following general torque equation:

$$\text{Torque} = r \cdot F \cdot \sin(\gamma)$$

Where r is the distance between the spring pivot point and the slot when the pivot lock would close, and F is shear force. Using the above equation, F was calculated to be 0.2276 pounds.

The following equation was used to calculate the average shear stress in the pivot lock:

$$\text{Shear Stress} = \frac{Shear\ Force\ (F)}{Cross\ Sectional\ Area\ (A)}$$

Where A = Width * Thickness = 0.125 inch * 0.1 inch = 0.0125 $inch^2$.

The shear stress was calculated to be 18.21 psi. The material used for pivot lock, AISI Type 304 Stainless Steel, has a tensile yield strength of 215 MPa [14]. Multiplying the yield strength by 0.6 gives an estimate for the shear yield strength of 129 MPa. Using this strength, a factor of safety of 7.08 was calculated which shows the pivot lock mechanism is safe to use.

3.3 Scribe Line Guide Maximum Calibration Angle

The maximum adjustment is restricted to only 2.14 degrees to ensure that the scribe line guide stays within the scribe line width to maintain the accuracy. Calculations for the adjustment angle are shown below:

Total length of the slot is taken to be 0.21 inch from the model, and the diameter for the Philips screw to be used to provide the adjustment is 0.138 inch and leave 0.072 inches adjustment space. From the model the length is taken to be 0.96 inch.

Using the tan formula, the maximum angle is:

$$\theta = tan^{-1}\left(\frac{0.072}{0.96}\right) = 4.29\ degrees$$

From centerline, the maximum adjustment that can be made per side will then be 4.29/2 = 2.14 degrees.

4.0 Final Design Standing

The Final design was evaluated based on the metrics established in section 1.4 in order to determine if the design met all the customer needs. The final design has features that addresses all the primary needs, however, some features are more developed than others. In this section, the design features were given a rating to quantify their development stage. Table X shows the current evaluation of the design for each metrics to determine if the metrics, and in turn the project needs, have been met.

TABLE X: EVALUATION OF THE DESIGN BASED ON THE ESTABLISHED METRICS

Metrics #	Needs	Metrics	Importance (1-5)	Units	Marginal Value	Ideal Value	Actual Value	Is the Metric Met
1	**1,2,14,17**	Size of design	**5**	in	T: 2 in, L and W: 6in	T: 1 in, L and W: 5in	T=1.9 in and W=5.9 in	Yes
2	**2,3,18**	Material strength	**4**	in & MPa	68 MPa	305 MPa	310 MPa	Yes
3	**3,4,8-11, 13**	Design consideration	**5**	Subjective	Client Approval	Client Approval	Related needs are met and approved	Yes
4	**6,7**	Weight	**5**	kg	1.5 lbs (40% of grinder weight)	1.125 lbs (30% of grinder weight)	1.3 lbs	Yes
5	**12**	Grinder speed	**4**	rpm	Grinder Speed	Grinder Speed	No change	Yes
6	**15**	Temp range not affecting material properties	**3**	^{o}C	-20 ^{o}C to 140 ^{o}C	-20 ^{o}C to 140 ^{o}C	Insignificant change in set range	Yes
7	**16**	Material Hardness	**4**	Mohs scale	5 to 6	5 to 6	< 1	Yes
8	**4,5,15**	Cut Tolerance	**5**	in	0.03”	≤0.03”	Adjustable guides allow high cut accuracy	Yes

The final design features are given a rating of 1 to 3 to capture their standings. The ratings are defined in table XI.

TABLE XI: DESIGN FEATURE RATINGS

Rating	**1**	**2**	**3**
Standing description	Concept stage. The feature may be replaced to improved feature that satisfies the customer needs more effectively	Satisfactory. The concept requires finer detailed improvement to reach the fully developed stage.	Fully developed. Concept requires no improvements.

The project needs that each feature satisfies have been shown in table XII. The corresponding rating for each feature has been given with their justification as well as the areas of improvement that the current design requires.

TABLE XII: FINAL DESIGN FEATURE EVALUATION

Primary Needs	Design Features	Rating	Justification
Provides Safeguard to the operators	• Retraction mechanism and Guard body	3	• The retractable guard ensures that 75% of the cutting edge of the blade is enclosed when a cut is not being made
Provides high cut accuracy / visibility of the scribe line to the operator	• Scribe line guide	2	• The scribe line guides allow precision cuts along the scribe line • Adjustability of the guides allow accurate alignment with the blade • The scribe lines guides need additional testing to determine optimal geometry for ease of use and reliability • The guides are easily replaceable in the case of damage of design changes
The design is user friendly	• Locking mechanism • Design Weight • Design Simplicity	3	• The simple locking mechanism allows the guard to be locked into and used in the fully open position for unusual cuts. • The weight of the design does not significantly increase the weight carried by the operator • The design requires minimal additional training
The design allows versatile use of the grinder	• Retraction mechanism	3	• The design can be used to make precision cuts wherever straight scribe lines are present. • The locking mechanism allows the grinder to be used in the fully open position for unusual cuts.
The design is compatible with existing 4-inch pneumatic hand grinder	• Overall guard design	3	• The grinder is designed to be compatible with and fasten to the existing 4in pneumatic hand grinder.
The design is of professional quality	• All above features are satisfied.	2	• Satisfied only when every other design feature receives a rating of 3.

5.0 Project Deliverables

This section will discuss the final project deliverables requested by the client. Aside from the final design cost mentioned in section 2.5, the final deliverables are broken down in an operator's handbook and fabrication drawings. The final CAD model will also be given to the client attached to the report.

5.1 Operator's Handbook

In addition to the final design, the team made an operator's handbook that consists of a Job Hazard Analysis (JHA), a Safe Work Procedure (SWP) and assembly instructions. The JHA was performed to determine the hazards at each step of the job and was ultimately used in creating the SWP. The SWP was necessary as it allows the operators to safely use the grinder with the new guard attachment.

As the final design has 26 separate parts, the assembly instructions were necessary to ensure that the part gets assembled accurately and easily. The operator's handbook is attached in Appendix E.

5.2 Fabrication Drawings

There are 11 custom parts that were used in the final design and will need to be fabricated for the final design assembly. The necessary technical drawings were created for the part fabrication in accordance with geometric dimensioning and tolerancing per ASME Y14.5-2009. The technical drawings for the custom parts are in Appendix F.

6.0 Recommendations

The current design prepared by the team meets all the customer needs, but it is still a preliminary design and could be further improved. Below is a list of recommendations to further improve the preliminary design:

- The team recommends the final design to be fabricated and tested for proof of concept. This will expose the areas that require further improvement. Moreover, the team recommends the client to perform FEA as it would show the stress behaviour throughout the design, giving the client an opportunity to further optimize the design with respect to size and weight. In this report, the team did not perform FEA due to time constraints and the fact that it was outside of the scope of the project.
- The design has a retraction mechanism (torsional spring) on the bottom plate only due to space constraints. Having the retraction mechanism on both the bottom plate and the top plate would transfer the force evenly to the pivot guards and would reduce the possibility of motion jitter. More testing is required to determine if this feature is needed. Currently, the torsional springs are listed as a critical component from the FMECA, following this recommendation would reduce the probability of spring failure.
- The scribe line guide is not function tested. The team designed the scribe line guide system to the specifications given in the drawings from the client. However, the scribe lines are not consistent to their specified dimensions. If the consistency of the scribe lines could be improved, then the tools tip could be optimized to work with greater reliability. For this reason, the team opted to make the scribe line guide a modular piece so that it could be improved if required in the future.

7.0 Conclusion

At Carfair's facilities, 4-inch pneumatic hand grinders are used to trim fiberglass parts to their final dimensions. The parts are marked with scribe lines to show the operators where the cuts are to be made. The guards provided with the grinders have been removed from grinders throughout Carfair's facilities as they inhibit visibility of the scribe lines and reduce the accuracy of the cuts being made. The objective of the project was to develop a custom guard design for the 4-inch pneumatic hand grinders used at Carfair's facilities to safeguard the operators from the cutting blade while allowing them to maintain high accuracy to a tolerance of 0.03 inches.

The final design developed is a retraction guard designed for the 4-inch pneumatic hand grinders used at Carfair's facilities, designed for the specific task of cutting fiberglass parts accurately by following the scribe lines located on the parts. The guard is primarily made from 6061 aluminum alloy, excluding the store-bought hardware which are supplied by McMaster-Carr. The estimated weight of the design was 1.3 pounds and the preliminary estimated cost of the design is $6400. A render of the final CAD model, with the main features of the design labeled is shown in figure 22.

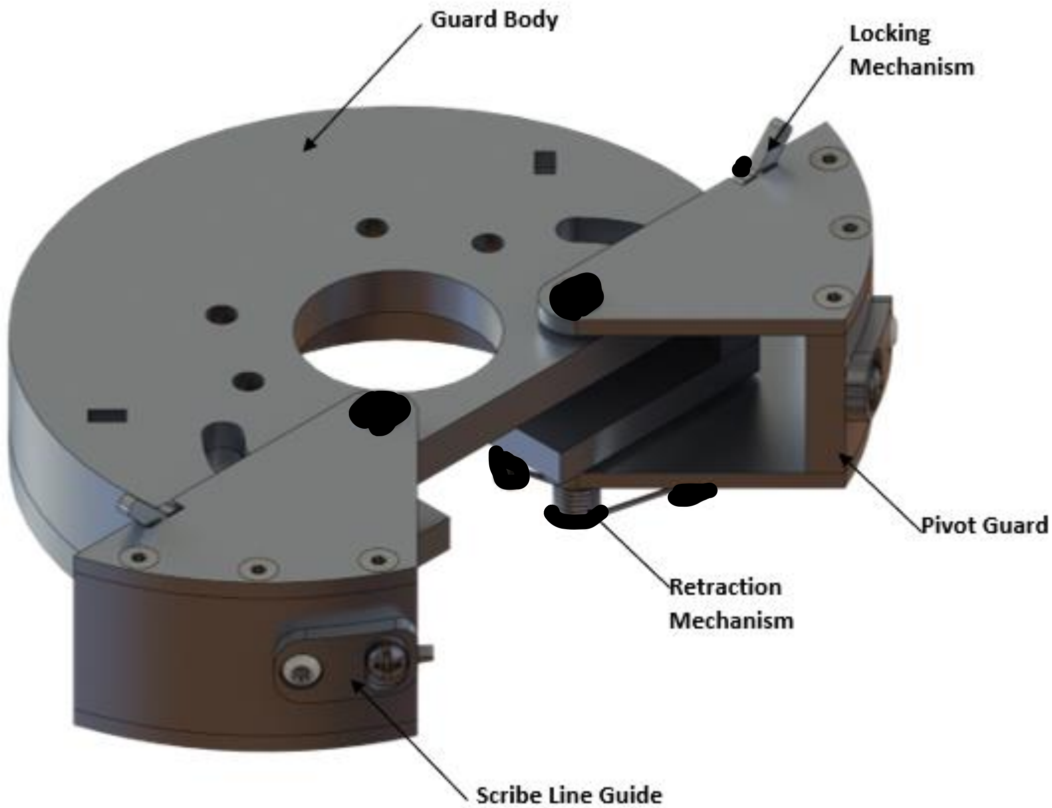

Figure 22: Final CAD model of design

The final design consists of 26 parts. The guard body consists of 11 custom parts, while the other 15 are different types of standard purchased hardware. The main features of the design are the main guard body, the pivot guards, the retraction mechanism, the locking mechanism, and the scribe line guides which are described below.

Main Features	Description
Main Guard Body	• Primary level of protection • Top plate is a modified version of the existing guard used available at Carfair • Attachment points of the grinder • Provides attachment points for other features • Integrated slots constraining the motion of the pivot guards • Allows access to the main screw fastening the blade to the grinder, allowing for easy replacement of the blade
Pivot Guards	• Secondary level of protection • 3-piece assembly • Extends around and past the blade • Rotation of 45^{o}, restricted by the slots in the main body
Retraction Mechanism	• Provides a torque to the pivot guard to keep the guards extended when no cut is being made • Allows the pivot guards to retract when the guard is pushed against a workpiece
Scribe Line Guides	• Fine point on the guides fit inside the scribe lines on the workpieces • Allows the tool to be precisely aligned with the scribe lines without the blade interacting with the workpiece • Ensures that the blade position is aligned with the scribe lines while the blade cuts into the material • Leading guide slides inside the scribe line while the trailing guide slides along the cut, ensuring the alignment of the blade with the scribe lines • Adjustment slots allow the guides to be precisely aligned with the blade, removing the possible error introduced by manufacturing
Locking Mechanism	• Gives the option of locking the guard in the open position • Allows cuts to be made without the interaction of the guides with the workpiece

This design meets the project objective by providing a custom-made guard design for the task of cutting fiberglass parts with the hand grinders used throughout Carfair's facilities. The guard provides maximum safeguard to the operator from the cutting blade by encompassing most of the blade with a strong and lightweight aluminum guard. The pivot guards provide increased protection by extending around and past the blade, covering 75% of the cutting edge, reducing the chance of the blade making an unintended cut. The cut accuracy of the tool was greatly increased by removing human error with the use of the scribe line guides. The design allows the guard, and therefore the blade, to be precisely aligned with the scribe lines before the blade cuts into the workpiece. The guides ensure that the blade remains precisely aligned with the scribe line while the blade initially cuts into the workpiece and while the cut is made along a scribe line.

To ensure that all the project requirements have been met, the team evaluated the design using the metrics established for the customer needs. The design met, at the minimum, the marginal values of each metric, confirming that each costumer need established at the beginning of the project have also been met.

The guard was designed for the AP10-4 DIATRIM 4" fiberglass saw model, which is the primary tool used at Carfair's facilities to cut the fiberglass parts. Therefore, the guard can be implemented not only for the roof manufacturing station, for which the team was assigned, but throughout the facilities and workstations. The guard design presented allows for precision cuts to be made on any fiberglass part that has scribe lines on its surface showing where the cuts are to be made.

8.0 References

[1] "Carfair Composites Inc.," [Online]. Available: https://carfaircomposites.com/about/. [Accessed 13 September 2019].

[2] "Product Design Specification," 8 Feburary 2011. [Online]. Available: http://www.me.umn.edu/courses/me4054/assignments/pds.html. [Accessed 24 September 2019].

[3] "ANSI B7.1-1970: Safety Code for the Use, Care, and Protection of Abrasive Wheels, page 29," 29 December 1970. [Online]. Available: https://law.resource.org/pub/us/cfr/ibr/002/ansi.b7.1.1970.pdf. [Accessed 24 October 2019].

[4] SpecialChem, "A Complete Guide to Polycarbonate (PC)," Omnexus, [Online]. Available: https://omnexus.specialchem.com/selection-guide/polycarbonate-pc-plastic#targetText=The%20polymer%20shows%20excellent%20mechanical,%C2%B0C)%20but%20more%20expensive. [Accessed 20 September 2019].

[5] "Aluminum 6061-T6; 6061-T651," [Online]. Available: http://www.matweb.com/search/datasheet.aspx?MatGUID=1b8c06d0ca7c456694c7777d9e10be5b&ckck=1. [Accessed 11 November 2019].

[6] "Aluminum 2011-T3," [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=8c05024423d64aaab0148295c5a57067. [Accessed 11 November 2019].

[7] "Aluminum 5052-H36," [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=1a5729196f264cc78a3233bf558aee8a. [Accessed 11 November 2019].

[8] "Polycarbonate Chemical Compatibility Chart," [Online]. Available: https://www.calpaclab.com/polycarbonate-chemical-compatibility-chart/. [Accessed 9 November 2019].

[9] "WHAT ALUMINUM GRADE SHOULD I USE? | Metal Supermarkets," [Online]. Available: https://www.metalsupermarkets.com/what-aluminum-grade-should-i-use/. [Accessed 11 November 2019].

[10] E. Zimbres, Artist, *Comparison between Mohs and Knoop hardness scales.* [Art]. 2008.

[11] Engineerd Edge, LLC, [Online]. Available: https://www.engineersedge.com/spring_torsion_calc.htm. [Accessed 23 November 2019].

[12] "Torsion Spring, 120 Degree Left-Hand Wound, 0.309" OD," McMaster-Carr, [Online]. Available: https://www.mcmaster.com/9271k637. [Accessed 23 November 2019].

[13] "Torsion Spring, 120 Degree Right-Hand Wound, 0.309" OD," McMaster-Carr, [Online]. Available: https://www.mcmaster.com/9271k701. [Accessed 23 November 2019].

[14] "304 Stainless Steel - ASM Material Data Sheet - MatWeb," [Online]. Available: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=mq304a. [Accessed 3 December 2019].

Appendices

Appendix A: Project Definition

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A.1 Company Background

Carfair Composites supplies fiberglass components to major industry customers such as New Flyer Industries (NFI) and Motor Coach Industries (MCI). Due to the scope of this project, this section will discuss the manufacturing process of the roofline only. The scope of the project is discussed in section 2 of the report. The roofline component manufacturing processes are divided into two sub processes. First, the fiberglass composites part is manufactured. Second, the part is trimmed and grinded to desired customer specifications. The following process flow chart shown in figure A-1 summarizes the process of components made in the roofline.

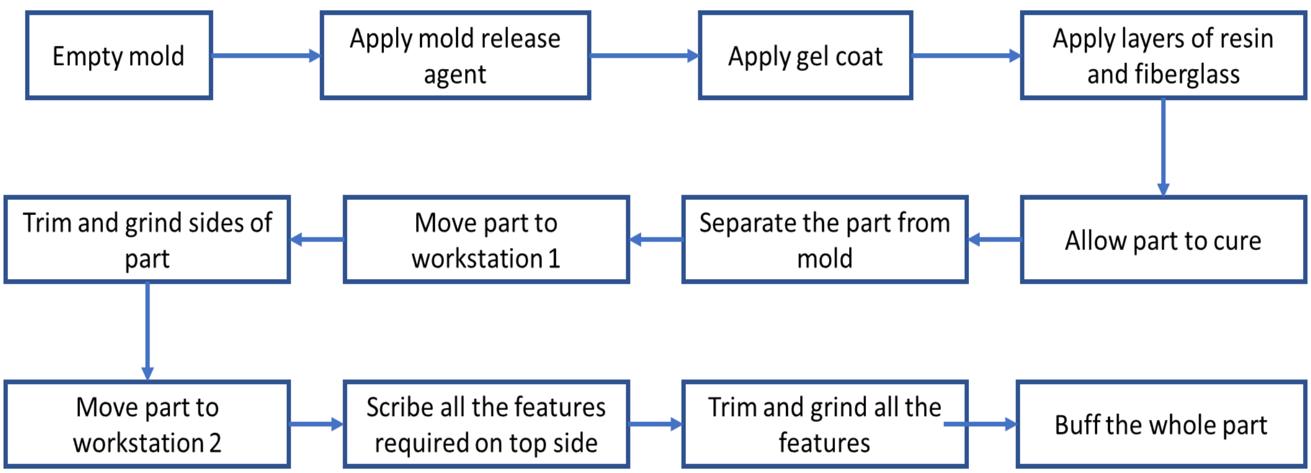

Figure A-1: The process flow diagram of fiberglass components made in roofline

The following sub sections will elaborate on two sub processes to provide a detailed summary of the manufacturing of the roofline components.

A.2 Making of Fiberglass Composite Parts

The general manufacturing process of fiberglass composite parts begins by applying the release agent and gel coating to the mold. This gel coating is applied to give the part color, whereas the release agent is applied to prevent the part from adhering to the mold surface. Afterwards, the fiberglass and resin are applied in layers to the gel coated mold and the layers are compressed by rollers to distribute the resin evenly and remove air pockets. Multiple layers of fiberglass are applied until the desired customer specified thickness is achieved. Lastly, the part is set aside to be cured before the next process as shown in figure A-2.

Figure A-2: Part curing before the grinding process (taken with permission)

A.3 Trimming and Grinding of Part

An overhead crane is used to move the separated cured fiberglass part from the mold to workstation 1 where the part is trimmed and sanded to specifications. This workstation provides a pivot point to rotate the part right side up and raises it approximately five feet from the ground. This allows easy work conditions for removal of excess material from the long sides of the part as shown in figure A- 3.

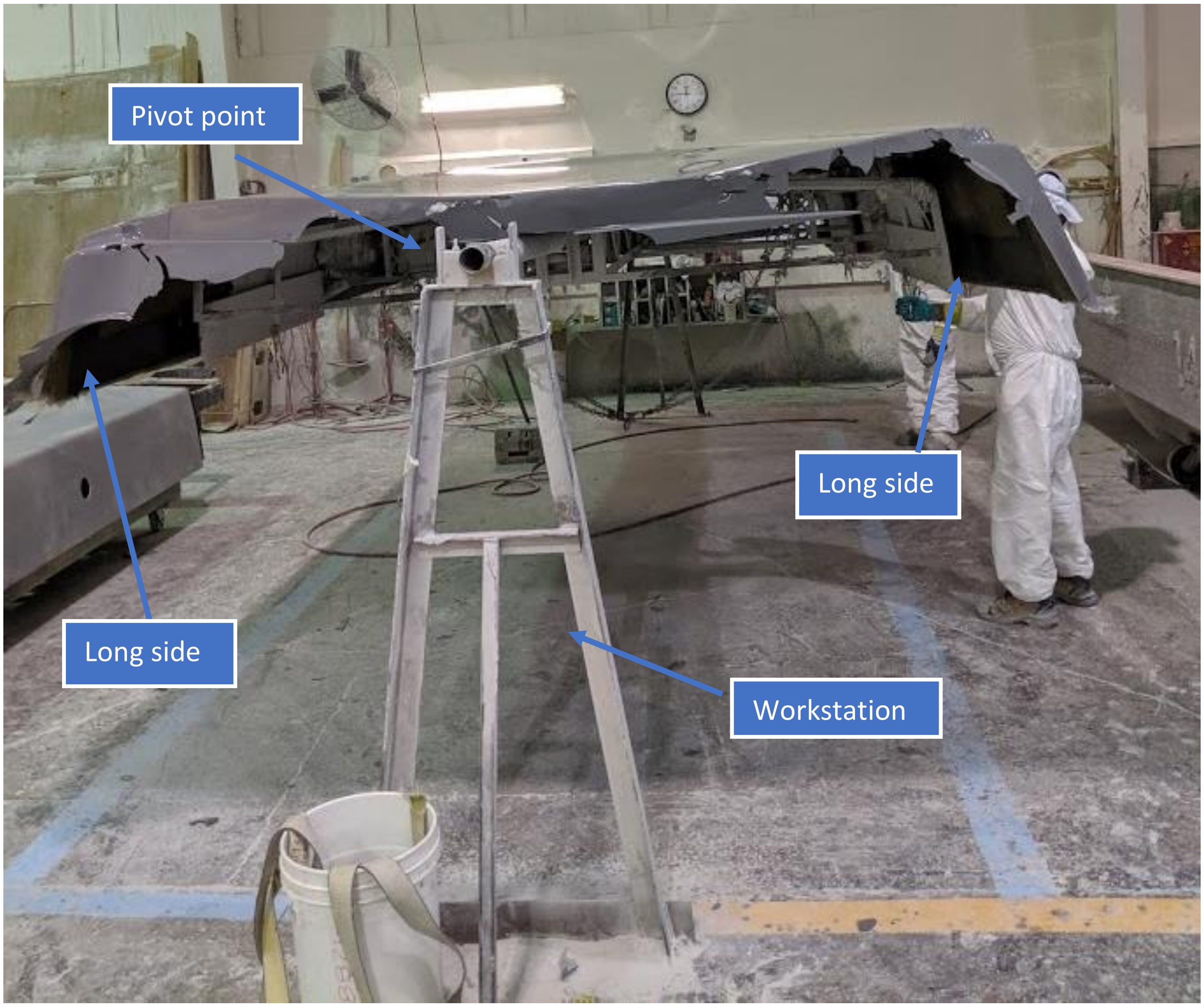

Figure A-3: Workstation 1, trimming and sanding of the sides (taken with permission)

After trimming the excess materials from both sides, pneumatic grinders are used to smooth the newly cut sharp edges. Sanders are then used to remove the gel coating to ready the part for painting operations. The part is then moved to workstation 2 using a vacuum lift for further work. This workstation is raised approximately two feet from the ground to easily perform operations on the top side of the part. The raised workstation and vacuum lift are shown in figure A-4 on the following page.

Figure A-4: Part is being moved to workstation 2 using vacuum lift (taken with permission)

First, the operators scribe the lines for all the features using multiple templates to meet the desired final specifications. The features include the front pattern, back pattern, emergency exit cut-outs, and any other features requested by the customer. Similarly, they trim all the excess material and features, grind down the sharp edges, then sand the part to remove the gel coating. Finally, they look for any defects such as low spots and scratches which get fixed with putty and are then sanded to an even surface.

A.4 Metrics Description

Metric 1 and 2:

The marginal values for metric two were determined to be 68 MPa for the polycarbonate material due to its visibility and high energy absorption capacity. For metric 1, the material thickness that corresponds to the material strength was taken to be [redacted] The material and its value are tolerable for the customer since polycarbonates are commonly used for guards on machine tools. Ideally, the team would like to increase the material strength to [redacted] and decrease the material thickness to [redacted]. Additionally, polycarbonate materials are positively rated for resistance classes A1, A2 and B1 which means the material will not contribute to any stage [redacted]. The resistance class results are shown in table A-I.

[redacted]

The length and width of the design is based on the existing guard supplied by the hand grinder supplier. Ideally the final design will be smaller than the supplied guard which is bulky and awkward to use. If the team develops a jig design over a guard this metric will be obsolete, and the allowable design size will be determined by further discussion with the client.

Metric 4:

The marginal weight of the design is set to 40% of the current weight of the grinder. Through operator surveys and discussions, it was determined that the increase in weight would unlikely impact the process productivity and operator comfort. The team will aim to reduce the design weight to 30% of the grinder weight. Currently, the weight of the grinder used by Carfair is approximately 4. 5lbs.

Metric 5:

The speed of the current 4-inch pneumatic grinder is not to be impacted; hence, the marginal and ideal grinder speed values will stay same.

Metric 6:

The marginal values of the temperature range are [redacted] These values correspond to the polycarbonate material which maintains its toughness in this temperature range. Since the design will be used indoors, the team deemed it sufficient to keep the ideal values for this metric the same as the marginal [redacted]

Metric 7:

The hardness value of the potential design must be equal to or less than the material hardness for fiberglass grade B, which is [redacted], which will prevent scratching and damage to the work piece. The team will use a marginal and ideal hardness range of 5-6 on Mohs scale which corresponded closely to the hardness value of fiberglass.

Metric 3 and 8:

The marginal and ideal values for metric 3 are subjective as they are design dependent. For metric 8, the visibility parameters depend on concept design, hence, this parameter is labelled as TBD.

Reference

[redacted]

Appendix B: Concept Development

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B.1 Jig Vs Guard

To initiate the design phase, the team met with the client to discuss potential solutions that could be implemented, and which solutions have been attempted in the past. Through the discussion, a jig design and guard designs were determined to be the best potential solutions to satisfy the client needs. The customer expressed that a jig design specific to the roofline station could help them decrease the process time, whereas the guard design would provide them with more flexibility and tool versatility throughout the facilities. The customer desired both designs to be considered but due to the time constraints of the project, it was decided that only one design option was to be developed. The team had to choose between jig or guard as a primary design, for which the advantages and disadvantages of each design were discussed.

The team started by conducting a series of brainstorming sessions where the advantages and disadvantages for each system were established and the possible needs that the designs would be able to meet were determined. In order to effectively determine which design to proceed with, the team reviewed and highlighted key concerns that had to be satisfied, highlighting the following issues:

- **Visibility and accuracy issues:** The opaque default guards installed on the grinders interfered with the line of sight of the operators and prevented them from precisely following the scribe lines to achieve the required 0.03” accuracy. In order to address the line of sight issue, Carfair tried using a transparent guard. However, that design was not successful due to dust accumulating in the guard, rendering it opaque after a short operating time.
- **Versatility issues:** The grinder with an original guard did not work as the grinder made it difficult to reach tight corners where the grinder was used at awkward angles.

A redesigned guard could combat the versatility issues by exploring more flexible guard structure options that can self-adjust to allow the grinder to be used in tight corners without sacrificing safety. The team will explore other material types and add-on mechanisms that can improve the cut accuracy and visibility of the design. In contrast, the team determined that a jig design could address the visibility and accuracy issues as well as reduce the overall process time by possibly removing any human error. However, after reviewing and discussing the jig design, several issues were discovered:

- The mold design of the roofline structure is subject to change. This is problematic as jig designs are very specific and will have to be based on current mold dimensions.
- The jig design may not work for tight corners of the mold. Versatility of the design will be an issue.
- A jig design may not be user friendly as it will require the operators to mount and adjust the jig to align it with the scribe lines before making the cut. This has the possibility of increasing the process time. The jig may also have to be adjusted every couple of feet due to the large size of the roofline. This issue may be solved by simplifying the purpose of the jig to be simple, lightweight, easy to use and aimed at only cutting short and straight sections.

The comparison of a guard and jig design based on their advantages and disadvantages is shown in TABLE B-I.

TABLE B-I: GUARD VS. JIGS COMPARISON WITH PRIMARY NEEDS

Primary Customer Needs	Guard	Jig
Provide safeguard to the operator	Yes – with added mechanism	Yes
Provide visibility of the scribe line to the operator	Yes- with added mechanism	Yes
The design is user friendly	Yes	Maybe
Compatible with the existing 4in pneumatic hand grinders	Yes	Yes
The design allows versatile use of the grinder	Yes- with added mechanism	No – Mold design varies
The design is of professional quality	Yes	Yes

The team discussed the jig and guard design advantages and disadvantages with Carfair and received the following input:

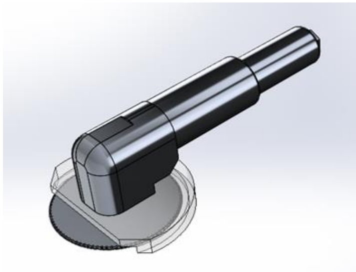
- Carfair was interested in a guard design as it provides the operators with a flexibility to perform various cuts at different workstations. The design would be compatible with any mold design.
- Carfair was concerned that multiple jigs would have to be designed for the current mold designs to capture all the cuts that would have to be made. This solution is not feasible and practical, however, Carfair agreed that the jig design for straight cuts could be useful if it is easy to use and reduces the process time.

Based on the client input, the team decided to proceed forward with guard design as the primary design and a jig design as the secondary. The team proceeded to generate preliminary guard concept designs through brainstorming.

B.2 Concept Generation

The following section outlines the seven concept designs considered by the team, starting with the clear guard, which will be used as a reference baseline design to which the other concepts were compared.

Clear Guard (baseline)



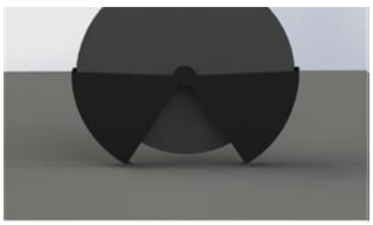
Key Advantages

- Initially, extremely high visibility to scribe lines.
- Provide safety to operator from grinder blade.
- Easy to replace considering this is an off-the-shelf product with readily available spare parts.

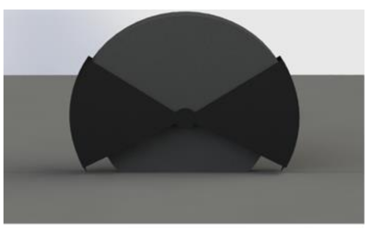
Key Disadvantages

- Dust accumulation inside the grinder inhibiting visibility after each cut.
- Constant cleaning required to maintain visibility, which requires removal of the guard.
- Hard to cut in tight areas or corners.

Retractable Guard



Closed guard



Open guard

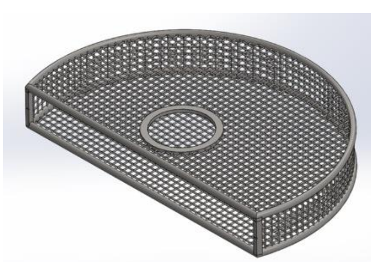
Key Advantages

- Precision cuts if guides remain precise.
- Visibility is no longer a factor.
- Provides safeguard to the operator as most of the blade is covered until a cut is being made. 60 degrees of the blade, around 17% of the blade remains uncovered when the guard is closed.

Key Disadvantages

- The scribe line guides may not reliably stay in the scribe line.
- Moving parts affect durability and in turn precision.
- Does not allow precision cuts of curved lines.
- Cuts must be made with the grinder perpendicular to the work piece.
- Custom parts not available off the shelf.
- The dust and swarf accumulation

Mesh Guard

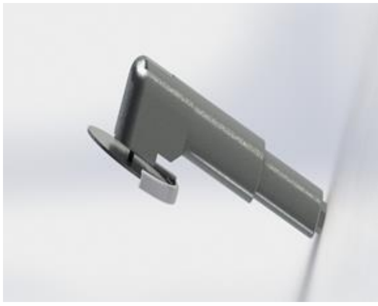


Key Advantages

- Provides more visibility to cutting blade and scribe lines than opaque guard.
- Dust accumulation will be reduced.
- A minimum of 180 degrees (50%) of the blade is covered.

Key Disadvantages

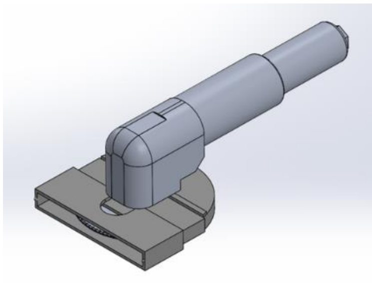
- Little to no protection from fiberglass dust as they can pass through wire mesh material. The full mesh design also posses a risk to the operators if the grinder disk explodes during its operation.

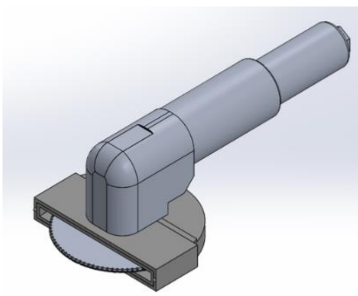
Swivel Guard	Key Advantages	Key Disadvantages
	• 180 degrees (50 %) of blade is covered. • Clear visibility of scribe lines. • Guards available off the shelf. • High tool versatility for tight areas and multiple cut orientations.	• Difficult to change the parts. • Other part of body still would be exposed to the blade. • Does not protect operator fully from shrapnel/dust.

Cone Guard	Key Advantages	Key Disadvantages
	• Clear visibility of the scribe lines. • Easy to maneuver in tight space. • Easy to attach and detach.	• The blade will not be covered. • other parts of the body exposed to the blade.

Inverted Cone Guard	Key Advantages	Key Disadvantages
	• The shield would protect the operator from dust and debris. • Protects the operator from the blade. • Easy to attach and detach using a clamping mechanism.	• The shield inhibits visibility of the blade and scribe line. • Swarf would accumulate in the shield. • Decreases grinder versatility in tight areas.

Linear Retraction Guard





Key Advantages

- Provides full blade coverage when grinder is not in use.

Key Disadvantages

- Limited visibility to the scribe lines.
- Hard to replace parts or repair the guard.
- Dust accumulation is possible.
- Not available off the shelf.

B.3 Concept Analysis and Selection

After the team developed preliminary design concepts, a two-stage concept selection method, concept screening and concept scoring, was used to evaluate the concepts generated by the team. The concept screening was used to eliminate the designs that were not worth pursuing using the main needs as the criteria. The concepts scoring was used to evaluate the remaining design ideas using the sub needs defined as weighted criteria.

B.3.1 First Stage: Concept Screening

The concepts screening stage was used to evaluate the high-level generated concept ideas to ensure they are feasible and desirable. In order to evaluate the concept ideas, the team decided to use the six main needs defined for concept screening criterion shown below.

- **Provide safeguard to the operator:** The design shall have a guard to protect the operator from the blade.
- **Provide high cut accuracy and/or visibility of the scribe line to the operator:** The design shall allow the operator to make accurate cuts.
- **The design is user friendly:** The design shall be easy to use for everyday operations.
- **Compatible with the existing 4in pneumatic hand grinders:** The design shall be compatible with the existing 4-inch pneumatic hand grinders used throughout the Carfair facility.
- **The design allows versatile use of the grinder:** The design shall be adapted throughout the Carfair facility.
- **The design is of professional quality:** The design shall be acceptable by the operators.

After the concept screening criterion were defined, the team used a concept screening matrix to filter through the generated concepts. The concept screening matrix was created to compare the generated concepts to the reference design with each defined criterion to satisfy the project needs. Each generated concept was compared to reference concept based on the established customer needs criterion. Scores of "+", "-", or "0" were given to each generated idea if the generated concept met that criteria better, worse or same than the reference concept respectively. A net value was derived by the summation of "+" assigned as +1, "-" assigned -1 and 0 being a neutral value. Each concept was ranked based on the net value in descending order. If a concept design received a score less than a zero it was eliminated, and no further investigation was performed on it.

Table B-II shows the concept screening matrix with clear guard being the reference concept design.

Selection Criteria	Mesh Guard	Swivel Guard	Cone Guard	Inverted Cone Guard	Retractable Guard	Linear Retractable Guard	Clear Guard (Ref)
Provide safeguard to the operator	0	+	-	0	+	+	0
Provide visibility of the scribe line to the operator	+	0	+	-	+	-	0
The design is user friendly	0	0	0	-	-	-	0
Compatible with the existing 4in pneumatic hand grinders	0	0	0	0	0	0	0
The design allows versatile use of the grinder	0	+	+	0	+	-	0
The design is of professional quality	0	0	0	0	0	0	0
Pluses	1	2	2	0	3	1	
Same	5	4	3	4	2	2	
Minuses	0	0	1	2	1	3	
Net	1	2	1	-2	2	-2	
Rank	3	1	3	5	1	5	
Continue?	Yes	Yes	Yes	No	Yes	No	

(Concepts)

table B-II: CONCEPT SCREENING MATRIX

The results from screening matrix show that the inverted cone guard, and the linear retractable guard concept designs had a net value less than zero and were therefore eliminated and no further investigation was performed. The team moved forward with the mesh guard design, the swivel guard design, the cone guard design and retractable guard design were analyzed further in a scoring matrix.

B.3.2 Criteria Weighting

After the selection criterion were established, a criteria weighting matrix was used to assign a weight to each criterion. Criteria weights is an important criterion as it determines the importance of each needs that will be used in the concept scoring stage.

In the criteria weighting matrix, each of the criterion were one to one compared with other criteria that need with higher importance was given the selected. The number of hits of each criterion or appearance of each criterion within matrix were added up and divided by the total number of comparisons in the matrix to obtain the percentage weight of each criterion. The table B-III shows the criteria weighting matrix used to assign a weight to each criterion.

TABLE B-III: CRITERIA WEIGHTING MATRIX

	Criteria: Primary Needs	Provide safeguard to the operator A	Provide visibility of the scribe line to the operator B	The design is user friendly C	Compatible with the existing 4in pneumatic hand grinders D	The design allows versatile use of the grinder E	The design is of professional quality F
A	Provide safeguard to the operator		A	A	A	A	A
B	Provide visibility of the scribe line to the operator			C	D	B	B
C	The design is user friendly				D	E	C
D	Compatible with the existing 4in pneumatic hand grinders					D	D
E	The design allows versatile use of the grinder						F
F	The design is of professional quality						
	Total Hits	5	2	2	4	1	1
	Weightings	33%	13%	13%	27%	7%	7%

The results from the criteria weighting matrix indicated that providing safeguard to operator, and compatibility with the existing 4-inch grinder criteria were the most heavily weighted with a weight of 33%, and 27% respectively.

B.4 Second Stage: Concept Scoring

In the concept scoring stage, competitive concepts were evaluated based on the weighted score. It was important to use the criteria that was more defined than the general criteria that were used in the concept screening stage. The team used the 18 needs for the concept scoring criterion. The criterion allowed the team to thoroughly evaluate each concept and select the appropriate designs that satisfied the most customer needs to develop further.

To evaluate all remaining concept designs, the first step was to divide the total weight of each primary need amongst its secondary needs established in section 4.2. The secondary needs' weights were then achieved by multiplying the total weight of the primary need with the ratio of importance given to each secondary need. The ratio of importance was determined by dividing the importance of the secondary need by the total importance of all secondary needs under the primary need. Each of the concepts were assigned a rating from 1 to 5 with the scale shown in table B-IV. Each team member rated the concepts individually based on the features of that design, and the ratings were then averaged and rounded to the nearest larger integer value.

TABLE B-IV: RATING CRITERIA

Rating Criteria	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

The weighed score was achieved by multiplying the assigned rating with the weight of each criteria. The total score for each concept was obtained by adding together the weighted score of each criterion the design met. Each concept was ranked based on their total score in descending order. The designs with the highest total score were selected for further concept development. The concept scoring matrix in table B-V shows the results obtained from the scoring stage.

TABLE B-V: CONCEPT SCORING MATRIX

#	Selection Criteria	Weight	Clear Guard (Ref) Rating	Clear Guard (Ref) Weighted score	Simple Mesh Guard Rating	Simple Mesh Guard Weighed Score	Swivel Rating	Swivel Weighted score	Retractable Rating	Retractable Weighted score	Cone Guard Rating	Cone Guard Weighted score
	Provide safeguard to the operator	33.33%										
1	The design protects operator from moving parts	11.11%	3	0.33	3	0.33	4	0.44	5	0.56	1	0.11
2	The design protects the operator from shrapnel/dust	11.11%	3	0.33	3	0.33	3	0.33	5	0.56	1	0.11
3	The design avoids interaction with the grinder blade	11.11%	3	0.33	3	0.33	3	0.33	3	0.33	3	0.33
	Provide visibility of the scribe line to the operator	13%										
4	The design provides visibility in presence of swarf	6.5%	3	0.20	4	0.26	5	0.33	5	0.33	4	0.26
5	The design allows high cut accuracy	6.5%	3	0.20	4	0.26	5	0.33	5	0.33	3	0.20
	The design is user friendly	13.33%										
6	The design is lightweight	2.90%	3	0.09	4	0.12	3	0.09	3	0.09	3	0.09
7	The design is comfortable to use	2.32%	3	0.07	4	0.09	3	0.07	4	0.09	4	0.09
8	The design is easy to set up and use	2.32%	3	0.07	3	0.07	3	0.07	3	0.07	3	0.07
9	The design is easy to use in right and left hands	2.32%	3	0.07	4	0.09	3	0.07	3	0.07	3	0.07
10	The design allows easy replacement of worn parts	1.74%	3	0.05	2	0.03	2	0.03	2	0.03	3	0.05
11	The design requires minimal additional training	1.74%	3	0.05	3	0.05	3	0.05	3	0.05	3	0.05
	Compatible with the existing 4in pneumatic hand grinders	26.67%										
12	The design does not affect the grinder's performance	8.89%	3	0.27	3	0.27	3	0.27	3	0.27	3	0.27
13	The design allows for easy removal of the cutting disk	8.89%	3	0.27	3	0.27	3	0.27	3	0.27	3	0.27
14	The design can be maneuvered in tight areas	8.89%	3	0.27	3	0.27	4	0.36	5	0.44	3	0.27
	The design allows versatile use of the grinder	6.67%										
15	The design works in poor conditions	2.50%	3	0.08	3	0.08	3	0.08	3	0.08	3	0.08
16	The design is easy to store	1.67%	3	0.05	3	0.05	4	0.07	3	0.05	2	0.03
17	The design prevents damage to the work piece	2.50%	3	0.08	3	0.08	3	0.08	3	0.08	3	0.08
	The design is of professional quality	7%										
18	The design withstands everyday use	7%	3	0.21	3	0.21	4	0.28	4	0.28	3	0.21
	Total Score			**3**		**3.19**		**3.53**		**3.96**		**2.63**
	Rank		**4**		**3**		**2**		**1**		**5**	

The results from the concept scoring matrix indicates that the Retractable guard and the Swivel guard were the top two concepts receiving the highest total score of 3.96 and 3.19 respectively. A sensitivity analysis was performed to validate the results of the concept scoring matrix.

B.4.1 Sensitivity Analysis

The sensitivity analysis was performed by changing the ratings of a concept's particular criteria by +1 and -1. The rank of that concept was then observed to see if it deviated from the original rank obtained. For example, the swivel design's selection criteria #1, the rating was changed by +1 and -1 and the adjusted scores were obtained as shown in table B-VI.

TABLE B-VI: RESULT EXAMPLE OF SENSITIVITY ANALYSIS

Adjusted Selection Criteria #1

Adjusted Rating Score	**Swivel**	
0 (Original Score)	**Total Score**	3.53
	Rank	2
+1	**Total Score**	3.64
	Rank	2
-1	**Total Score**	3.42
	Rank	2

The total score for the swivel design varied to 3.64 and 3.42 when rating score was adjusted to +1 and -1 respectively, but the rank remained the same for all three cases. 180 iterations were performed for every criterion and for all the concepts.

The results from the analysis indicated that the rank remained the same for all the design concepts throughout the 180 iterations. Therefore, the team concluded that the results from the concept scoring stage were accurate and the Retractable guard and Swivel guard designs will be developed further. The detailed information on the sensitivity analysis are shown in table B-VII.

The sensitivity analysis was carried out by varying the rating score of a concept's particular selection criteria by +1 or -1 and observed the ranking of the concepts. For example, the selection criteria #1 for swivel design was varied by +1 and -1 as shown in table C-III highlighted in yellow. The total score and ranked are shown at the bottom of the table highlighted in yellow.

TABLE B-VII: SENSITIVITY ANALYSIS EXAMPLE FOR SWIVEL DESIGN

#	Selection Criteria	Weight	Swivel Guard					
			Original Score		Adjusted +1 Score		Adjusted - 1 Score	
			Rating	Weighted score	Rating	Weighed Score	Rating	Adjusted Score
	Provide safeguard to the operator	33.33%						
1	The design protects operator from moving parts	11.11%	4	0.44	5	0.56	3	0.33
2	The design protects the operator from shrapnel/dust	11.11%	3	0.33	3	0.33	3	0.33
3	The design avoids interaction with the grinder blade	11.11%	3	0.33	3	0.33	3	0.33
	Provide visibility of the scribe line to the operator	13%						
4	The design provides visibility in presence of swarf	6.5%	5	0.33	5	0.33	5	0.33
5	The design allows high cut accuracy	6.5%	5	0.33	5	0.33	5	0.33
	The design is user friendly	13.33%						
6	The design is lightweight	2.90%	3	0.09	3	0.09	3	0.09
7	The design is comfortable to use	2.32%	3	0.07	3	0.07	3	0.07
8	The design is easy to set up and use	2.32%	3	0.07	3	0.07	3	0.07
9	The design is easy to use in right and left hands	2.32%	3	0.07	3	0.07	3	0.07
10	The design allows easy replacement of worn parts	1.74%	2	0.03	2	0.03	2	0.03
11	The design requires minimal additional training	1.74%	3	0.05	3	0.05	3	0.05
	Compatible with the existing 4in pneumatic hand grinders	26.67%						
12	The design does not affect the grinder's performance	8.89%	3	0.27	3	0.27	3	0.27
13	The design allows for easy removal of the cutting disk	8.89%	3	0.27	3	0.27	3	0.27
14	The design can be maneuvered in tight areas	8.89%	4	0.36	4	0.36	4	0.36
	The design allows versatile use of the grinder	6.67%						
15	The design works in poor conditions	2.50%	3	0.08	3	0.08	3	0.08
16	The design is easy to store	1.67%	4	0.07	4	0.07	4	0.07
17	The design prevents damage to the work piece	2.50%	3	0.08	3	0.08	3	0.08
	The design is of professional quality	7%						
18	The design withstands everyday use	7%	4	0.28	4	0.28	4	0.28
		Total Score	3.53		3.64		3.43	
		Rank	2		2		2	

The results from table B-VII shows that the total scored were changed to 3.64 and 3.43 after varying the rating score by +1 and -1 but the rank remained the same for all three cases.

The following table B-VIII shows the results of all the iterations performed for each selection criteria and for all the concept designs.

TABLE B-VIII: SENSITIVITY ANALYSIS ITERATION

Adjusted Selection Criteria #1							
Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.11	3.30	3.64	3.96	2.74
	Rank	4	3	2	1	5
-1	Total Score	2.89	3.08	3.42	3.85	2.52
	Rank	4	3	2	1	5
Adjusted Selection Criteria #2						
Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.11	3.30	3.64	3.96	2.74
	Rank	4	3	2	1	5
-1	Total Score	2.89	3.08	3.42	3.85	2.52
	Rank	4	3	2	1	5.00
Adjusted Selection Criteria #3						
Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.11	3.30	3.64	4.07	2.74
	Rank	4	3	2	1	5
-1	Total Score	2.89	3.08	3.42	3.85	2.52
	Rank	4	3	2	1	5
Adjusted Selection Criteria #4						

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.07	3.25	3.53	3.96	2.69
	Rank	4	3	2	1	5
-1	Total Score	2.94	3.12	3.46	3.89	2.56
	Rank	4	3	2	1	5
Adjusted Selection Criteria #5						

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.07	3.25	3.53	3.96	2.69
	Rank	4	3	2	1	5
-1	Total Score	2.94	3.12	3.46	3.89	2.56
	Rank	4	3	2	1	5
Adjusted Selection Criteria #6						

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.03	3.22	3.56	3.99	2.66
	Rank	4	3	2	1	5
-1	Total Score	2.97	3.16	3.50	3.93	2.60
	Rank	4	3	2	1	5
Adjusted Selection Criteria #7						

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.16	3.51	3.93	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #8

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.17	3.51	3.93	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #9

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.16	3.51	3.93	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #10

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.17	3.51	3.94	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #11

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.17	3.51	3.93	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #12

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.09	3.28	3.62	4.05	2.72
	Rank	4	3	2	1	5
-1	Total Score	2.91	3.10	3.44	3.87	2.54
	Rank	4	3	2	1	5

Adjusted Selection Criteria #13

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.09	3.28	3.62	4.05	2.72
	Rank	4	3	2	1	5
-1	Total Score	2.91	3.10	3.44	3.87	2.54
	Rank	4	3	2	1	5

Adjusted Selection Criteria #14

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.09	3.28	3.62	3.96	2.72
	Rank	4	3	2	1	5
-1	Total Score	2.91	3.10	3.44	3.87	2.54
	Rank	4	3	2	1	5

Adjusted Selection Criteria #15

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.03	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.16	3.50	3.93	2.60
	Rank	4	3	2	1	5

Adjusted Selection Criteria #16

Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.02	3.20	3.55	3.97	2.64
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.17	3.51	3.94	2.61
	Rank	4	3	2	1	5
Adjusted Selection Criteria #17						
Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.03	3.21	3.55	3.98	2.65
	Rank	4	3	2	1	5
-1	Total Score	2.98	3.16	3.50	3.93	2.60
	Rank	4	3	2	1	5
Adjusted Selection Criteria #18						
Adjusted Rating Score		Clear Guard (Ref)	Simple Mesh Guard	Swivel	Retractable Guard	Cone Guard
0	Total Score	3.00	3.19	3.53	3.96	2.63
	Rank	4	3	2	1	5
+1	Total Score	3.07	3.26	3.60	4.03	2.70
	Rank	4	3	2	1	5
-1	Total Score	2.93	3.12	3.46	3.89	2.56
	Rank	4	3	2	1	5

The results of sensitivity analysis show that the rank of all the concept designs remained same through all the iteration performed, therefor team has concluded that the results from the concept scoring matrix are accurate.

B.5 Final Designs

The Retractable guard design and the Mesh Swivel guard design were both modelled on Solidworks to fully showcase the preliminary design details and features. This section discusses the key specifications and features of the two designs in detail. Following are the design assumptions applicable to both the Retractable guard and the Mesh Swivel guard designs.

1. These preliminary designs are not 100% dimensionally accurate as it is based on the approximate grinder dimensions. The purpose of these designs is to communicate detailed design functionality, features and missing design details. The dimensionally accurate detailed designs will be presented in phase 3 of the project.
2. Both designs are assumed to be center mounted on the guard. Center mounted guard design was chosen to provide the center pivot point for the designs. The team will validate this assumption in phase 3 or change the mounting mechanism to make it compatible with the existing grinder.

B.5.1 Design 1: Retractable Guard

The preliminary retractable design is made up of three assembly parts: the main guard body, and two pivot guard pieces that have scribe line guide features built into them. The two retractable guard pieces are attached at the top and bottom of the guard body using rivet pins. The guard body has a built-in stop to prevent the two pivoting guards from travelling past the parallel edge of the main guard body. The two pivot guards rely on a retraction mechanism (not shown in the model) that will push back when the operator pushes the grinder against the surface of the fiberglass to expose the full blade and allow the cut to occur. Once the cut has been made and the grinder is lifted from the surface, the pivoting guards will go back to their original closed position and enclose a certain portion of the blade (estimation is approximately 87% of the area of the blade). The labelled rendering of this design is shown in Figure B-1

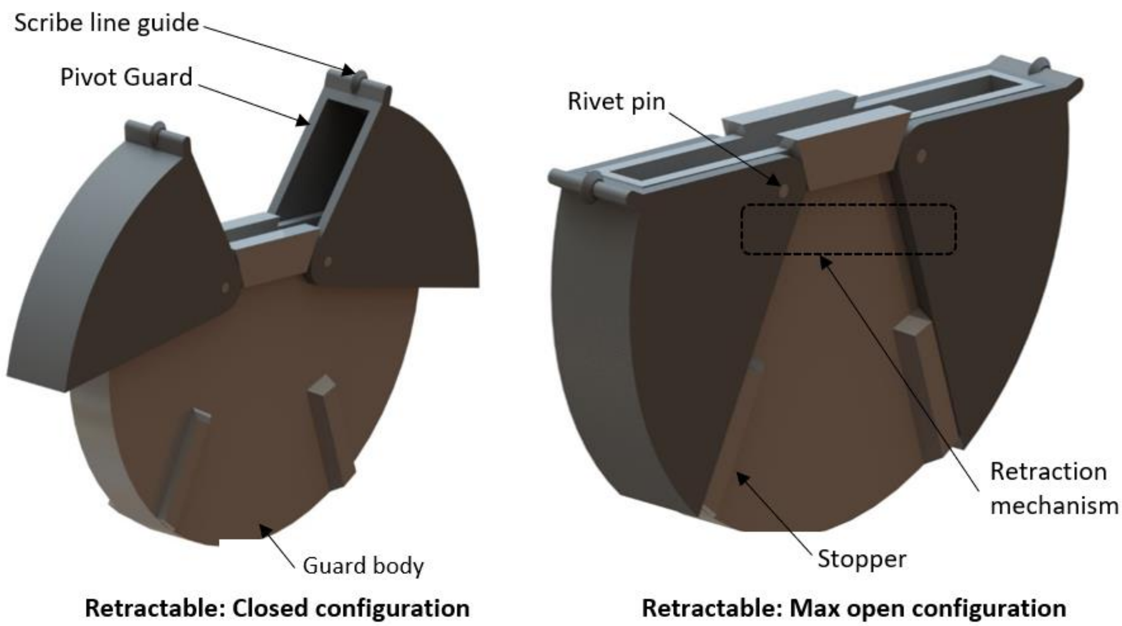


Figure B-1: Retractable design configurations

B.5.1.1 Design Assumptions

Following are the design assumptions that are specific to this design.

1. The specific materials to be used are not specified yet. For the purpose of a preliminary design, the structure is assumed to be polycarbonate. The team will perform research and will be looking into the materials that are lightweight and strong.
2. The exact percentage of the area of the blade the guard covers has not been defined. Approximated measurements from the Solidworks model estimates 87% coverage. The team desires to reach close to 100% coverage without compromising the guard functionality.

B.5.1.2 Design features and missing detail

This design has two primary features that are intended to address cut accuracy and safety of the operators which are discussed below:

1. **Accuracy:** The scribe line guide has been given a diamond shape to allow it to easily sit and slide in the scribe line groove. The scribe line guide accounts for the dimensions of the scribe line, which were determined to be 0.06-inch wide and 0.03-inch deep obtained from the technical drawings for the fiberglass roof templates. The client has specified that the cut must be made directly below the scribe line, therefore the guides are positioned to ensure the cut is made in the correct location. This ensures that the final cut part has proper dimensions to the allowable tolerance of 0.03 inches.

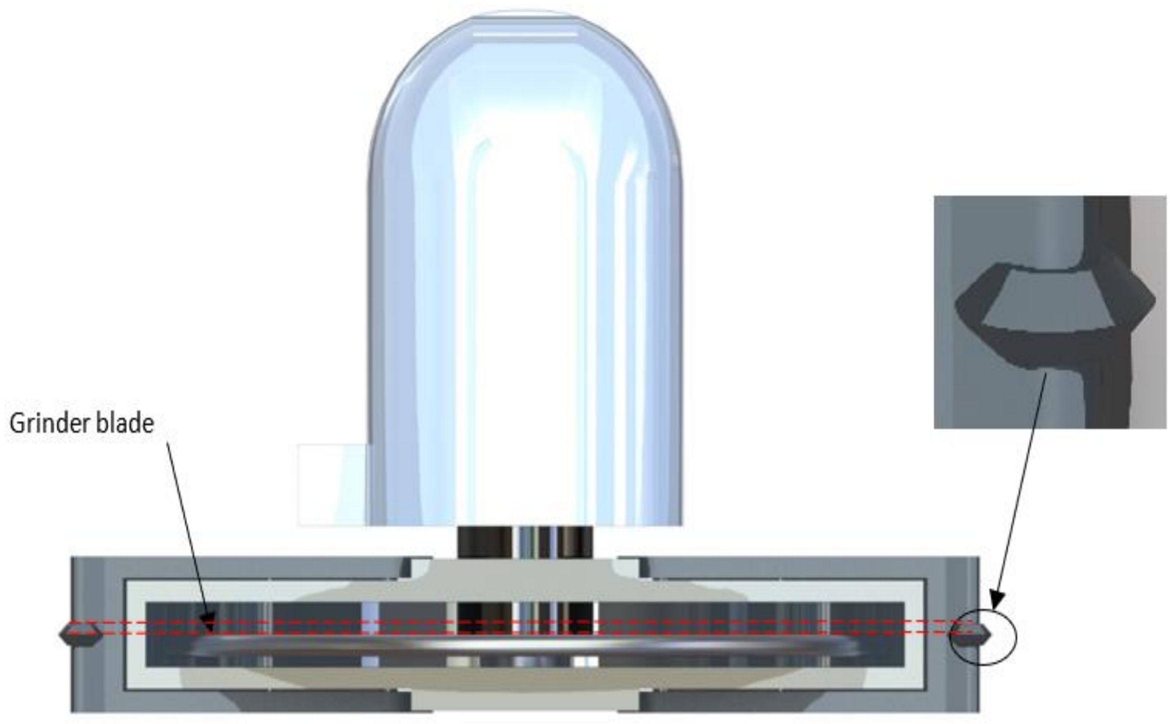


Figure B-2: Front View: Retractable guard with grinder

2. **Safety:** Another key feature of this design is the ability of the guard to enclose the majority of the blade when not in use, as specified earlier, and keeps the blade covered when the cut is being made.

The current design details that are not known by the team but will be addressed in phase 3 are the following:

1. The solid design is susceptible to dust accumulation. The team will be looking to using mesh materials and other solutions to address the problem.
2. The scribe line guides could skip out of the scribe line path. The reliability of the scribe line guide has not been tested yet. The team will test the scribe line mechanism in phase 3 to validate the feature. Furthermore, the optimum wheel diameter size will have to be determined such that the contact area of the wheel to the cutting material surface is maximized without slowing the grinder down or affecting its performance.
3. The turning radius of the grinder with the guard needs to be tested. Using the grinder at acute or obtuse angle may affect the performance of the two retractable guard pieces and the scribe guide.

The team is prepared to tackle the listed unknown design details by accurately designing the guards to appropriate dimensions and potentially 3D printing prototype models of the guard and testing them to validate the design.

B.5.2 Design 2: Mesh swivel

The preliminary mesh swivel design consists of a solid wire frame with adjustability track to provide structural stability and guard orientation adjustment. The entire structure is bounded by a mesh structure to provide the operator with increased visibility to see the scribe line. The adjustability track allows the operator to adjust the guard to a specified angle and allow the use of the grinder at acute or obtuse angles. The adjustability track will either be a specific number of steps or holes to provide adjustability to the operators via the use of a pin mechanism. The design will also have a safety mechanism built into it to fool proof the guard, constraining the guard's degree of freedom (i.e. the guard will not be able to rotate 360 degrees). Furthermore, there is a line of sight slot built into the frame of the design to allow the operators to see where the blade will be cutting the material. The design features are shown in Figure B-3

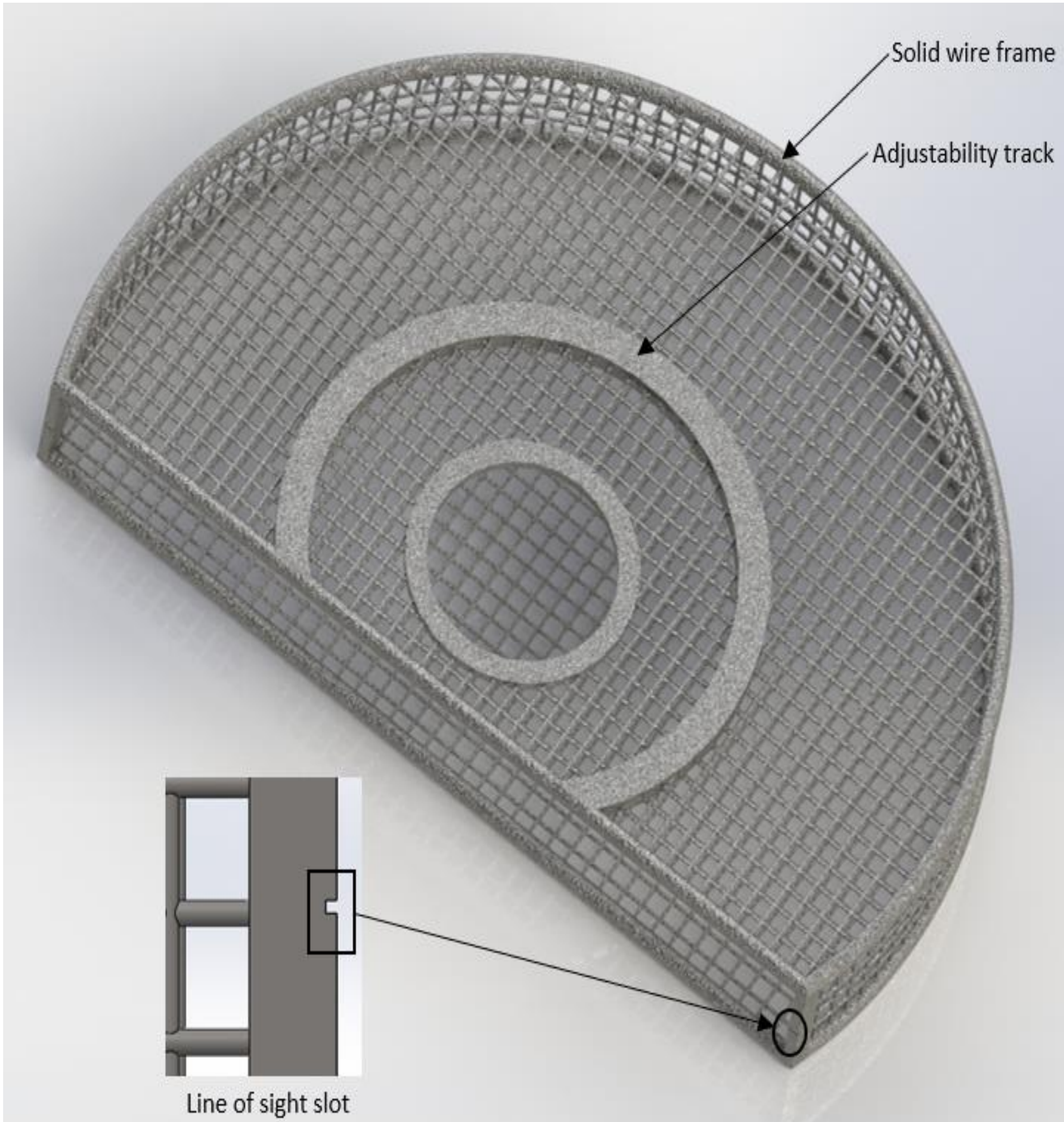


Figure B-3: Mesh swivel design

B.5.2.1 Design Assumptions

Following are the design assumptions that are specific to this design.

1. In the fabrication of this design, the mesh is assumed to be available off shelf.
2. The specific material to be used in the wire guard design has not been specific yet. For the purpose of a preliminary design, the structure is assumed to be metal.

B.5.2.2 Design features and missing detail

This design has two primary features that are intended to address the visibility, and versatility issues experienced by the operators. The design features are discussed below:

1. **Visibility and Accuracy:** The visibility issue is addressed by the mesh, which aims to increase the operator's visibility of the scribe line which in turn increases the accuracy of the cut that the operator is able to make. Furthermore, the line of sight slot would also contribute in increasing the accuracy of the slot.
2. **Versatility:** Due to the guards built in adjustability track, the design is very versatility as it allows the operators to manually adjust the position of the guard and use the grinder in multiple positions (perpendicular to the material, or at a range of specified angle).

The current design details that are not known by the team but will be addressed in phase 3 are the following:

1. **Mesh size, type, material:** Optimum mesh size is currently not known. The team will have to find the optimum mesh size that is big enough to prevents dust accumulation on the corners of the mesh, but small enough to ensure operator safety is not compromised to the potential blade explosion. The strength and material type of the mesh would also have to be considered to ensure that design lasts everyday use.
2. **Adjustability track slots and safety mechanism:** The exact number of steps or holes that are required to provide the operator with optimum adjustability needs to be determined. The team will also need to introduce the safety mechanism in the design

to restrict the adjustability and to prevent the guard from rotating a full 360 degrees. The exact position of the safety mechanism is not currently known.

3. **Safety:** The guard being fully a mesh design, the operator safety is at risk if the grinder blade failure occurs (i.e. blade exploding).

B.5.3 Customer Feedback on Final Designs

The team reviewed and discussed the final two selected designs with the client as well as the overall 7 concepts, the design features pertaining to each design, along with the design selection process used. The following were the feedback given back to the team on the retractable guard:

- The pivot guard pieces, and the guard body needs to be joined together with temper proof screws to ensure that the operators do not temper with the guard structure.
- The client asked the team to consider Rosta tensioning technology as a potential solution for the retraction mechanism.
- Dust accumulation is a concern with the design, and to address that the client would like the team to integrate breathing room window/slot into the design. However, the window/slot must be strategically placed to prevent the dust from going into the line of sight of the operator and to mitigate the disk explosion causing harm to the operator. If possible, flow study will be performed to determine the exact locations for the window/slot.
- The client would like the team to add a lock mechanism to the design that would allow the operators to manually push the pivot guard pieces back and lock it in place to the full range. This is to a controlled risk and would give the operators the flexibility to reach tight corners and have some control over the guard's mechanisms.
- Operator feedback and opinions on the design will aid the team to make design decisions.

The main concern the client had for the Mesh swivel design was that the operator would be exposed to the dust particles as the mesh would allow the dust to go through when in the line of sight of the operator posing a potential hazard. Furthermore, the adjustability track of the swivel guard is a feature that the operators would have to manually adjust to a correct setting before operating the grinder. The client preferred automated self-retraction feature of the Retractable guard over the manual adjustment feature of the mesh swivel design.

Appendix C: FMEA Failure Modes Effects Analysis

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C.1 Rating Scales

Various rating tables were used for assigning values and obtaining RPN (Risk Priority Number). The severity rating is shown inTABLE C-I, frequency rating in TABLE C-II, and detection rating in TABLE C-III

TABLE C-I: SEVERITY RATING SCALE

Severity Effect		Ranking
Minor	Failure mode causes no significant or permanent damage to final product, product dimensions well within allowed tolerance or no performance degradation for the grinder.	1
Low	Failure mode causes very minor inaccuracies, or excessive force required by operator to use the guard.	2, 3, 4
Moderate	Significant customer dissatisfaction due to unplanned and unpleasant surface defects caused by the safety guard during grinder process, minor inaccuracies in final product dimensions but still close to company allowed tolerances, or significant additional difficulty for operator while using the grinder.	5, 6
High	High inaccuracy in final product dimensions leading to extreme customer dissatisfaction, loss in scribe line guide accuracy or some loss of pivot guard functionality (mainly via change in restoration time of the pivot guard).	7, 8
Very High	Failure mode causes serious operator safety concerns, complete failure of pivot guard functionality or total loss of control over scribe line accuracy or visibility to the scribe lines	9, 10

TABLE C-II: FREQUENCY RATING SCALE (REMADE FROM MECH 4860 FMEA LECTURE – OCTOBER 2016)

Possibility of Failure	Ranking	Possible Failure Rates
Remote. Failure may happen after new part(s) installation	1	< 1 in 20,000
Very Low. Only isolated instances of failure, most likely on new part(s) only	2	1 in 20,000
Low. Failure unlikely to happen.	3, 4	1 in 5,000 1 in 1,000
Moderate. Significant chances of failure.	5, 6	1 in 100 1 in 80
High chances of failure	7, 8	1 in 50 1 in 25
Very high. Failure is inevitable	9, 10	1 in 10 1 in 2

TABLE C-III: DETECTION RATING SCALE (ADAPTED FROM MECH 4860 FMEA LECTURE – OCTOBER 2016)

Likelihood of Detection		Ranking
Very High	Current controls will almost certainly prevent the failure	1
High	Current controls have a good chance of detecting the failure	2, 3, 4
Moderate	Current controls may detect the failure	5, 6
Low	Current controls have a poor chance of detecting the failure.	7, 8
Very low	Current controls probably will not detect the failure	9
Absolute certainty of non-detection	Current controls will not or cannot detect the failure	10

Appendix D: Grinder Model and Retraction Mechanism

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D.1 Grinder model and Retraction Mechanism

D.1.1 Grinder Model

To improve upon the preliminary design concept developed in phase 2 report, the team first had to develop an accurate model of the grinder itself to ensure design accuracy and compatibility with the existing 4 in pneumatic grinder. To do this, the team was given a grinder by the client. The team used CREAFORM 3D scanner in combination with a digital caliper to determine the dimensions of the top surface of the grinder, particularly the region around the wheel holder nut, flange nut and the diamond grinding wheel as shown in Figure D-1.

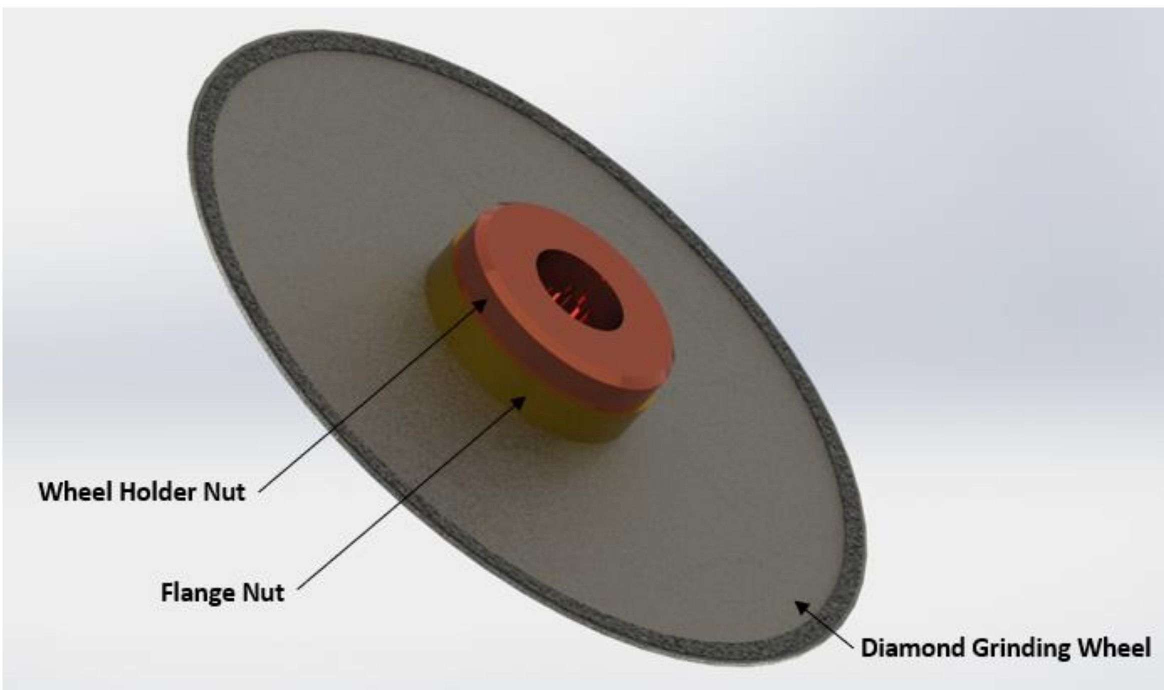

Figure D-1: Top surface of the grinder

D.2 Retraction Mechanism

The team investigated elastic, springs and [redacted] for the retraction mechanism. [redacted] and elastic were rejected from consideration for the reasons discussed below:

- The [redacted] is developed for use in belt and chain drives for maintenance free tensioning. The smallest tensioning devic[redacted] which has a [redacted] Based on preliminary guard dimensions[redacted]he team determined that the tensioner is very large to be compatible with the guard body.
- The elastic solution was not considered as the client did not approve of using it due to reliability concerns.

For the spring mechanism, the team opted to proceed with linear and torsional spring. It was decided that a design for each mechanism would be created and presented to the client for final selection. Both spring and torsional retraction are discussed below.

D.3 Compressed Spring Retraction Design

The compressed spring is made up of two compression springs that sit in an arc slot. When the guard is pushed down, the springs experiences a force pressing on its axis causing the spring coils to shorten and store energy. [redacted] This is described by the Hooke's law assuming that spring used in the design will not stretch or compress beyond its elastic limit. The equation is:

$$F = -kx$$

Where F is resulting force vector, both magnitude and direction the spring exerts, x is the distance and the direction the spring deforms from its equilibrium position, and k is the spring constant that is depended on the springs material and construction. [redacted]

[redacted]

The spring design consists of two compressed springs, that sit in the slots on the back-guard body as seen in Figure D-2. The springs are only inserted in the back side of the grinder to reduce the probability of the dust getting into the slot and affecting the functionality of the retraction mechanism. Note that the design below does not show all of the features of the retraction mechanism design is shown such as the cover plate for the spring slot.

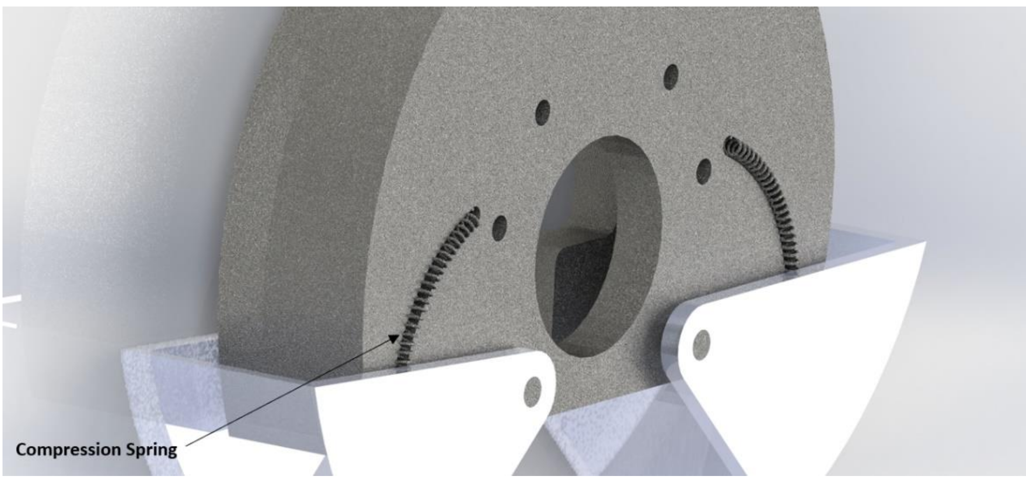

Figure D-2: The Compressed Spring Design

Throughout the design process for the retraction mechanism design, the team faced many design limitations and constraints. During the design, the team took the following features in mind.

1. The spring must not compress more than half of its resting length.
2. There is a concern that spring will dislodge itself from the slot. To address this, the design must cover a certain portion of the spring so that it cannot pop out or fall out of the slot.
3. The spring must be off the shelf-item and must be easily replaceable. The design must make the spring easily removable and replaceable.

In the first design iteration, the team addressed the potential of the spring popping out of the slot by designing a plate that would sit into a countersink slot around the current slot. The plate would be fastened in place with two machine screws. The plate would cover the certain portion of the spring to prevent the spring from popping out. Next, the team decided to address the issue of spring being easily replaceable. To do that, the current slot had to be made wider than the current length to allow for easy removal and insertion of the spring. For ease of spring removability and the team determined that the spring would be easily removable when the guard is in the closed position. For the spring only being able to compress half the distance when the guard is in open position, the team has selected the appropriate spring with optimum stiffness.

D.3.1 Client Input and Selection of Retraction Mechanism and Material

At this stage of the design, the team had a meeting with the client to seek approval and selection for the retraction mechanism designs to proceed forward (compressed or torsional spring), and the material choice for the design. Firstly, the client was presented with both retraction mechanism options and was explained the advantages and disadvantages of each design. The client chose the torsional spring design for the retraction mechanism due to the following reasons:

- The compressed spring is subject to dust accumulation that will impact the functionality and the reliability of the design. The design is attractive and pleasing to look but is complex in terms of use and functionality.
- In contrast, the torsional spring is external, making it easy to clean and maintain should the dust be accumulated. The spring is also easy to replace and maintain. The torsional spring is not as pleasing looking as the compression spring design but is more functional and robust for everyday use.

References

[1] ROSTA, "Tensioner Devices," ROSTA, [Online]. Available: https://www.rosta.ch/en/products/docs/Tensioning-Technology/ROSTA_Produktkatalog_EN-low%205.pdf. [Accessed 23 November 2019].

[2] "Master SPring & Wire Form Co.," [Online]. Available: https://www.masterspring.com/spring-wire-form-technical-resources/what-is-a-compression-spring/. [Accessed 12 November 2019].

[3] "Spring (device)," 25 September 2019. [Online]. Available: https://en.wikipedia.org/wiki/Spring_(device)#Theory. [Accessed 12 November 2019].

Appendix E: Operator Handbook- JHA, SWP, Assembly Instructions

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List of Figures

List of Tables

E.1 User Instructions and Safe Work Procedure (SWP)

In this section, the assembly instructions and installation instructions will be provided. The team will also develop a Safe Work Procedure (SWP) for the grinder with the new final guard installed. The SWP will allow the users to operate the grinder with the new guard in a safe manner.

E.1.1 Job Hazard Analysis (JHA) and SWP

In industry, a need for a SWP comes from a Critical Job Inventory (CJI) which identifies the list of jobs or tasks that require a SWP. However, in this case, the client determined the need for a SWP through experience. Firstly, the team did a Job Hazard Analysis (JHA) from which the job was broken down into smaller tasks to determine the hazard and mitigation control at each task. Afterwards, a SWP was created to capture all of the information to execute the job in safe [redacted]

E.1.1.1. Job Hazard Analysis (JHA)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

E.1.2 Assembly & Installation Instructions

This section is broken down into relevant tools and drawings required for the assembly and the assembly instructions.

E.1.2.1 Relevant Tools and Drawings

To begin the guard assembly and its installation to the grinder, collect and keep aside all the tools listed in TABLE E-I.

TABLE E-I:REQUIRED TOOLS

Tool #	Tool Required
A	No. 2 Phillips
B	No. 0 Phillips
C	T10
D	T8
E	3/32" Hex key
F	3/16" Wrench
G	Pallet

The TABLE E-II lists all the parts required for the assembly. Prior to starting the assembly, ensure that all parts listed in table are nearby. The item number 1 to 11 in the assembly are custom parts. Ensure that these parts are fabricated ahead of time.

The exploded view drawing of the assembly is shown in Figure E-1, when following the assembly, refer to the exploded view drawing for guidance. Moreover, Figure E-2, Figure E-3 shows important details that will be referred to during the assembly instructions.

TABLE E-II: BILL OF MATERIALS

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	GUARD BODY - TOP - CUSTOM PART	1
2	2	GUARD BODY - BOTTOM - CUSTOM PART	1
3	3	BOTTOM - PIVOT - LEFT - CUSTOM PART	1
4	4	BOTTOM - PIVOT - RIGHT - CUSTOM PART	1
5	5	CENTER - PIVOT - LEFT - CUSTOM PART	1
6	6	CENTER - PIVOT - RIGHT - CUSTOM PART	1
7	7	TOP - PIVOT - LEFT - CUSTOM PART	1
8	8	TOP - PIVOT - RIGHT - CUSTOM PART	1
9	9	PIVOT LOCK - CUSTOM PART	2
10	10	SCRIBE LINE GUIDE LEFT - CUSTOM PART	1
11	[redacted]	SCRIBE LINE GUIDE RIGHT - CUSTOM PART	1
12	[redacted]	Aluminum Unthreaded Spacer - 3/8" OD, 1/16" Long, for Number 10 Screw Size	2
13	[redacted]	Pan Head Combination Phillips/Slotted Screws - 6-32 Thread, 1/4" Long	2
14	[redacted]	Stainless Steel Tamper-Resistant Button Head Torx Screws - 6-32 Thread Size, 1/4" Long	2
15	[redacted]	Stainless Steel Tamper-Resistant Button Head Torx Screws - 4-40 Thread, 3/16" Long	2
16	[redacted]	Tamper-Resistant Torx Flat Head Screws - 4-40 Thread, 3/8" Long	15
17	[redacted]	Ultra-Low-Profile Precision Shoulder Screw - 3/16" Shoulder Diameter, 1/2" Shoulder Length, 8-32 Thread	2
18	[redacted]	Neodymium Magnet - Magnetized Through Thickness, 1/16" Thick, 1/16" OD	2
19	[redacted]	Sealing Pan Head Screws - with Buna-N Rubber O-Ring, 0-80 Thread Size, 1/4" Long	2
20	[redacted]	18-8 Stainless Steel Washer - for Number 0 Screw Size, 0.062" ID, 0.125" OD	2
21	[redacted]	Ultra-Low-Profile Precision Shoulder Screw - 3/16" Shoulder Diameter, 1/8" Shoulder Length, 8-32 Thread	2
22	[redacted]	Male-Female Threaded Hex Standoff - Aluminum, 3/16" Hex Size, 3/16" Long, 4-40 Thread Size	2
23	[redacted]	Aluminum Unthreaded Spacer - 3/16" OD, 1/4" Long, for Number 4 Screw Size	2
24	[redacted]	Torsion Spring - 120 Degree Left-Hand Wound, 0.309" OD	1
25	[redacted]	Torsion Spring - 120 Degree Right-Hand Wound, 0.309" OD	1
26	[redacted]	Stainless Steel Tamper-Resistant Button Head Torx Screws - 4-40 Thread Size, 3/8" Long	2

[redacted]

Figure E-1: Exploded view of assembly

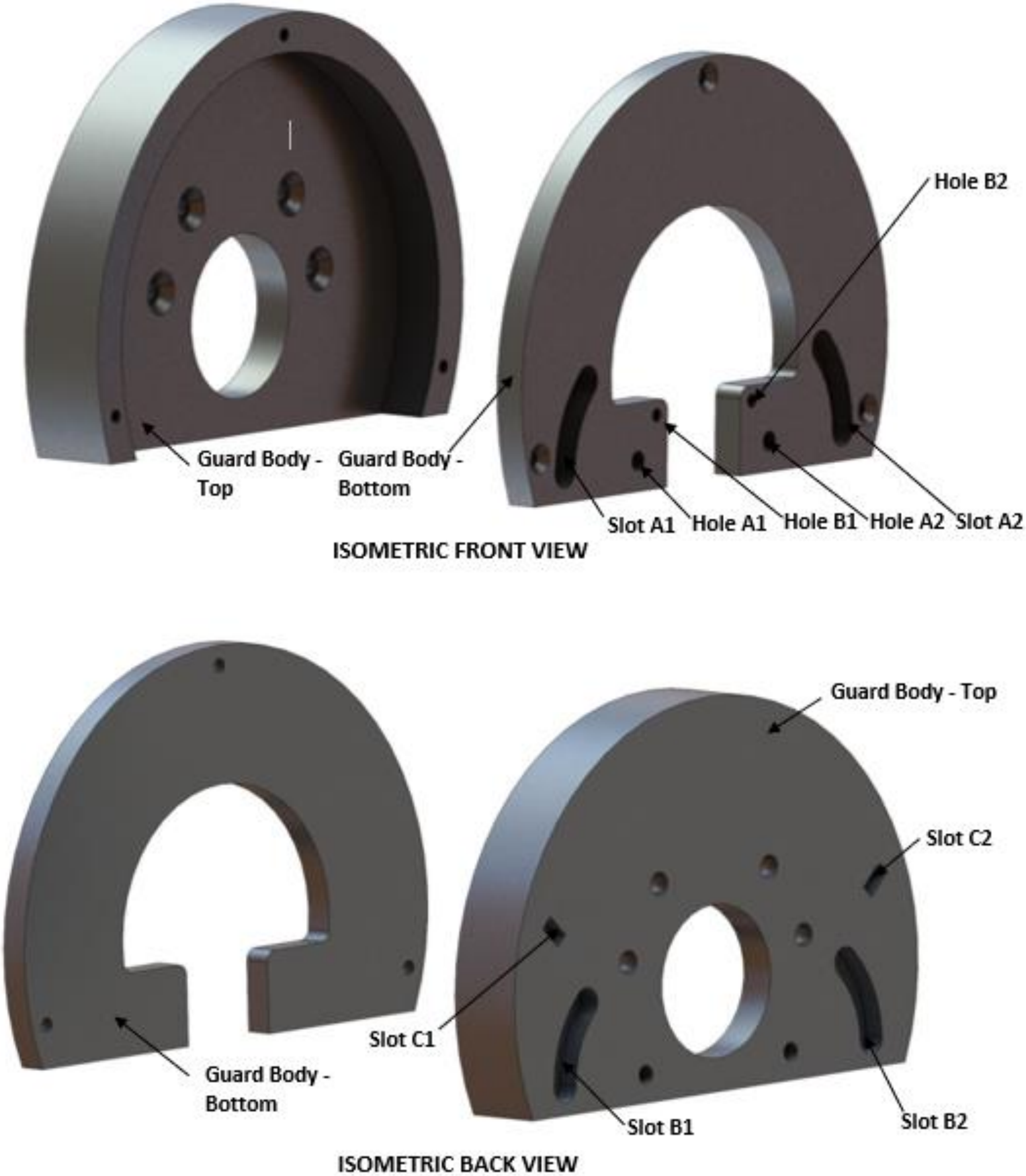

Figure E-2: Isometric view top and bottom

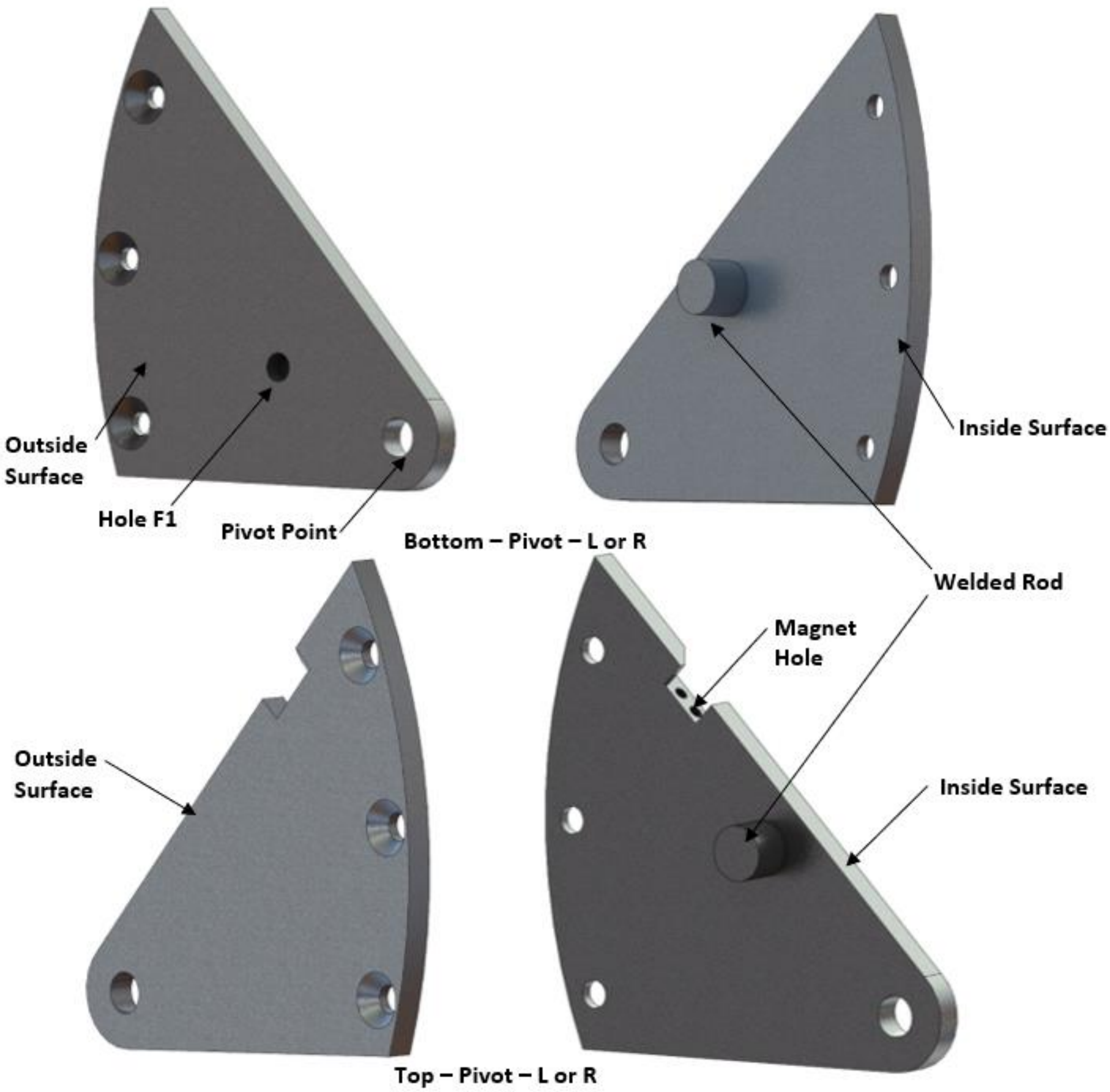

Figure E-3: Top and bottom pivot guard

E.1.2.2 Instructions

The assembly instructions are shown below.

Steps	Instructions
1	If Applicable, removing the existing guard assembly from the grinder including the grinder blade and other subcomponents.
2	Attach Item no. 1 to the grinder body using the existing grinder screws. Afterwards, put back the other corresponding grinder parts.
3	Align and attach item 2 to item 1. Use item 16 to fasten the two plates together. Requires tool T8.
4	Attach item 22 to item 2 Hole A1 and A2. Refer to Figure E-2 to see the location of Hole A1 and A2.
5	Attach item 8 to item 5 and item 7 to item 6 using item 16. Requires tool D.
6	Attach item 10 to item 5 and item 11 to item 6 using item 13 and 14. Requires tool A and C.
7	Place item 18 in the magnet hole of item 8 and 7. See Figure E-3. Use tool G.
8	Place item 9 to the hole beside the magnet hole. Have item 20 in between the two. Fastener then part with item 19. Requires tool B.
9	Align step 5 to item and place step 5 in the slot B1 and B2 as shown in Figure E-2. Use item 21 to fasten step 5 in place. Requires tool E.
10	Align the holes of item 3 and 4 with item 9. Ensure that the attached rod of the item 3 sits into slot A1 and A2. Use item 16 to fasten the screw in place. See Figure E-2 for reference. Requires tool D.
11	Attach item 23 with item 3 and item 4 in hole B1 and B2 (See Figure E-2). Fasten it in place using item 26. Requires tool D.
12	For spring, to attach item 24 and 25 to the rest of the assembly align the large end of the spring to the hole B1 and B2. Afterwards, align the center of the torsional spring to hole A1 and A2. Ensure the holes are concentric. Place item 12 between the holes and the spring. Afterwards, use item 17 to fasten spring in place. This will also fasten the pivot guards in place. Requires tool D.
13	Loosely wind the spring around the pin ½ turn attached to hole B1 and B2.
14	Test the scribe line guides to ensure that they are in line with the grinder blade. Otherwise adjust the guides. The slot provides a maximum adjustment of 2.14 degrees to either side from the centerline.

[redacted]

Appendix F: Fabrication Drawings

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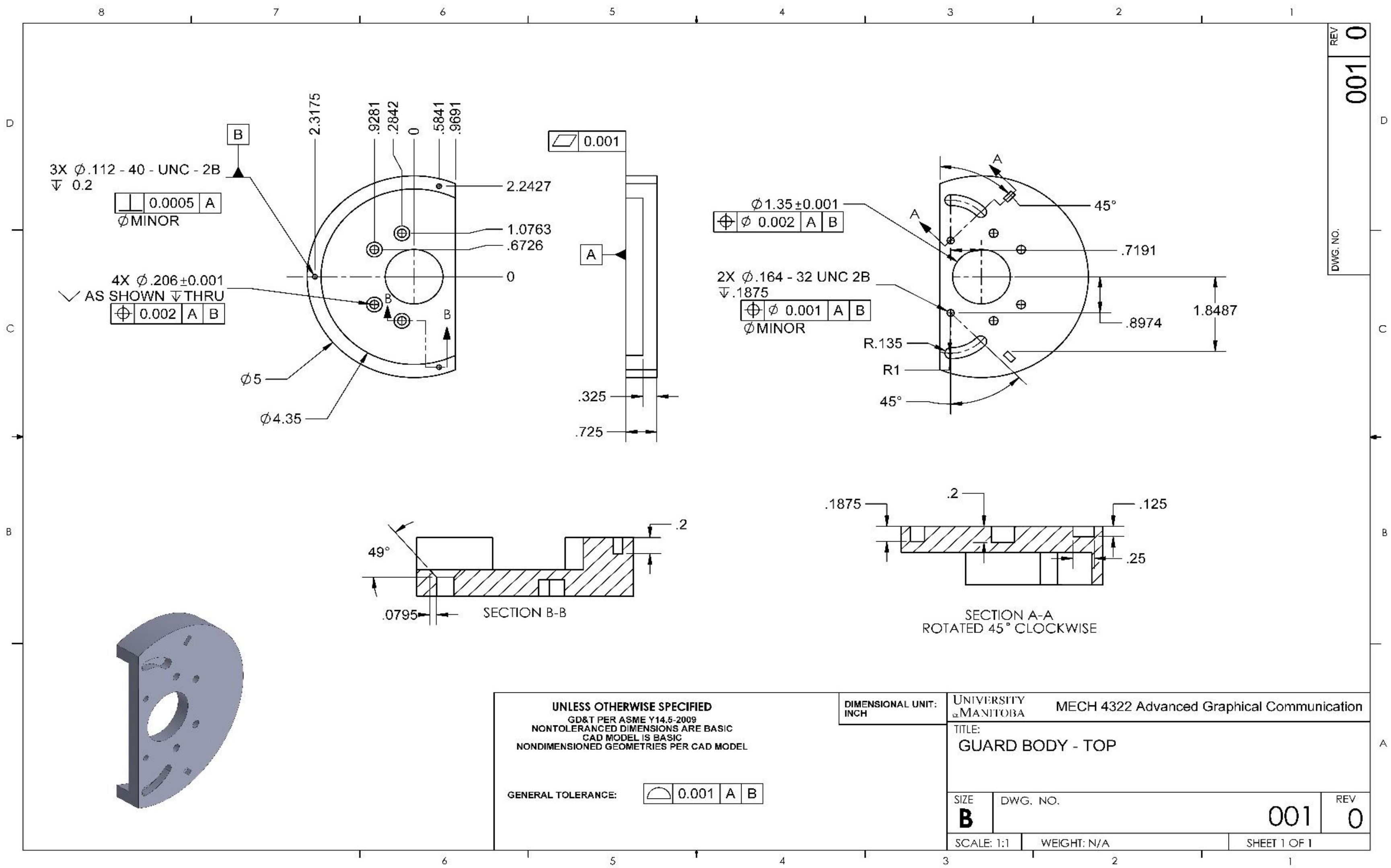
F.1 Technical Drawings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4X ⌀.206±0.001
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⌀5
⌀4.35
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.5841
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R1
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45°
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.8974
1.8487
49°
.0795
SECTION B-B
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.125
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UNIVERSITY OF MANITOBA
MECH 4322 Advanced Graphical Communication
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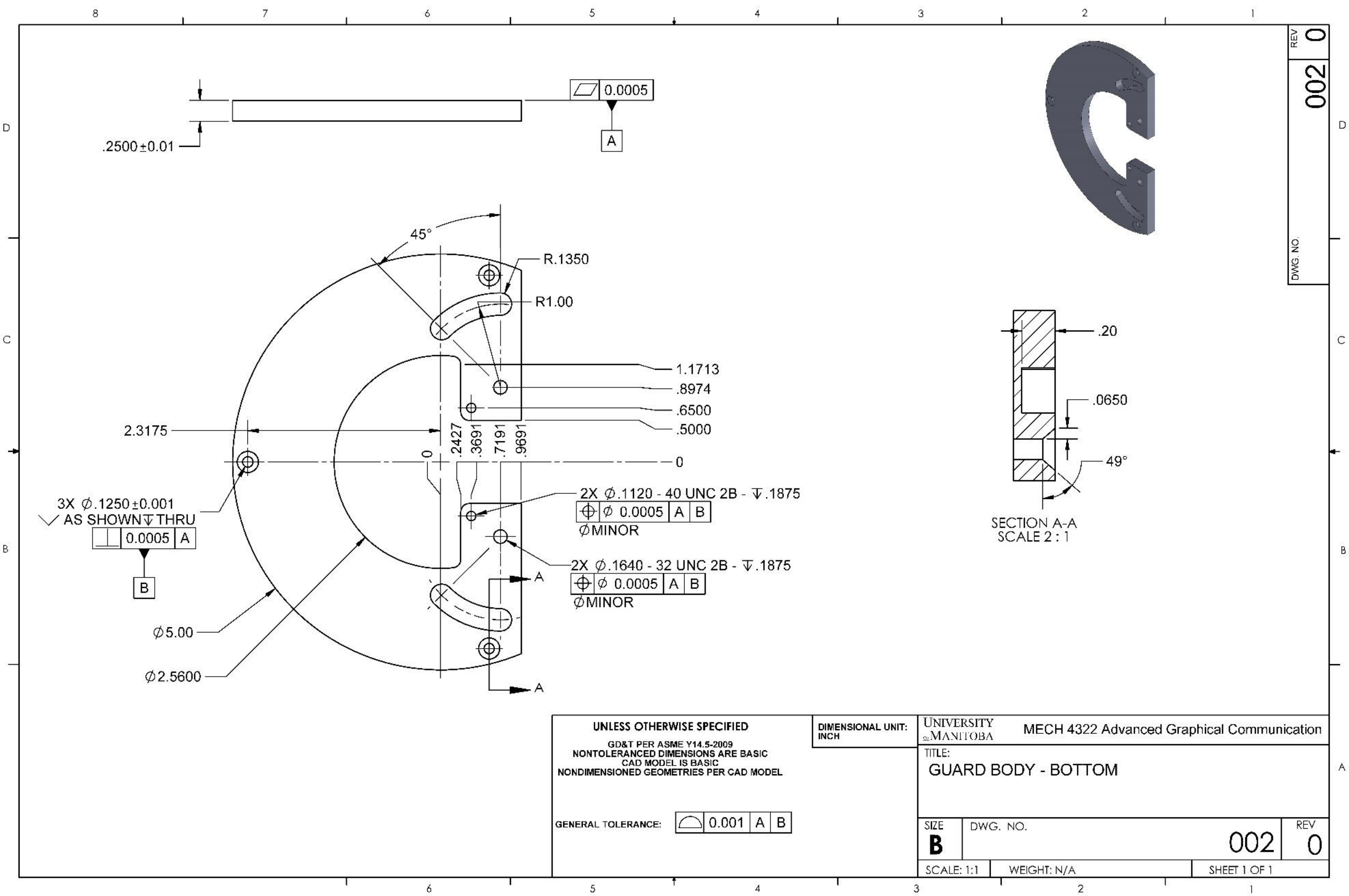
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R1.00
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.7191
.9691
0
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B
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∅MINOR
2X ∅.1640 - 32 UNC 2B - ↧.1875
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∅MINOR
A
A
∅5.00
∅2.5600
.20
.0650
49°
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UNIVERSITY of MANITOBA
MECH 4322 Advanced Graphical Communication
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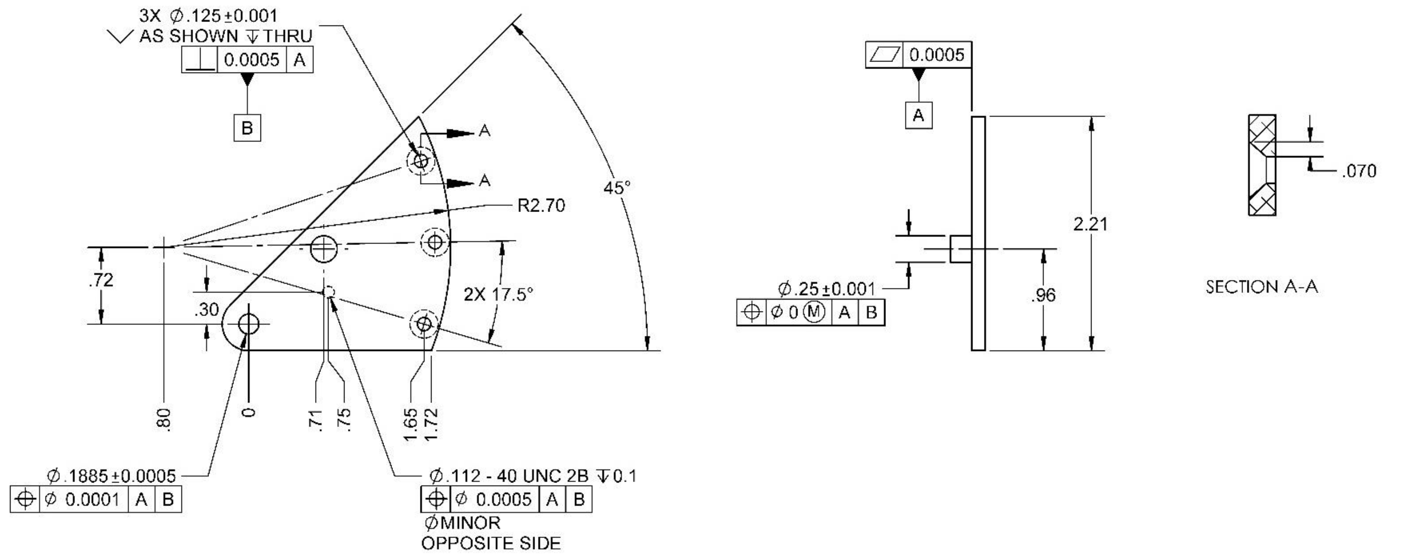

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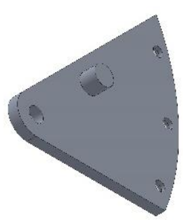

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NONDIMENSIONED GEOMETRIES PER CAD MODEL

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UNIVERSITY of MANITOBA — MECH 4322 Advanced Graphical Communication

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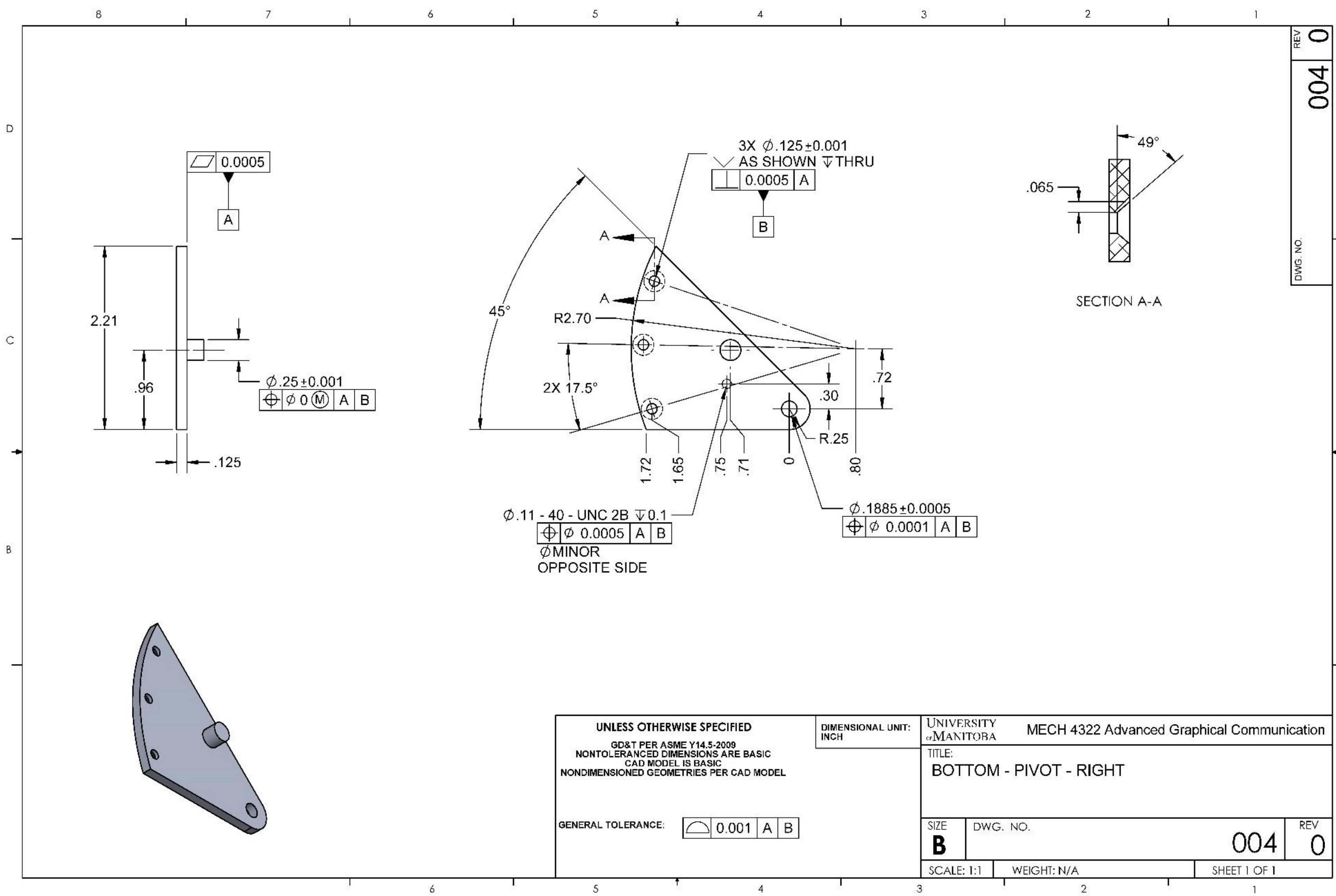
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∅ 0 Ⓜ A B
3X ∅.125±0.001
AS SHOWN ⊽THRU
0.0005 A
B
A
A
45°
R2.70
2X 17.5°
.72
.30
R.25
1.72
1.65
.75
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0
.80
∅.11 - 40 - UNC 2B ⊽0.1
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∅MINOR
OPPOSITE SIDE
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∅ 0.0001 A B
49°
.065
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MECH 4322 Advanced Graphical Communication
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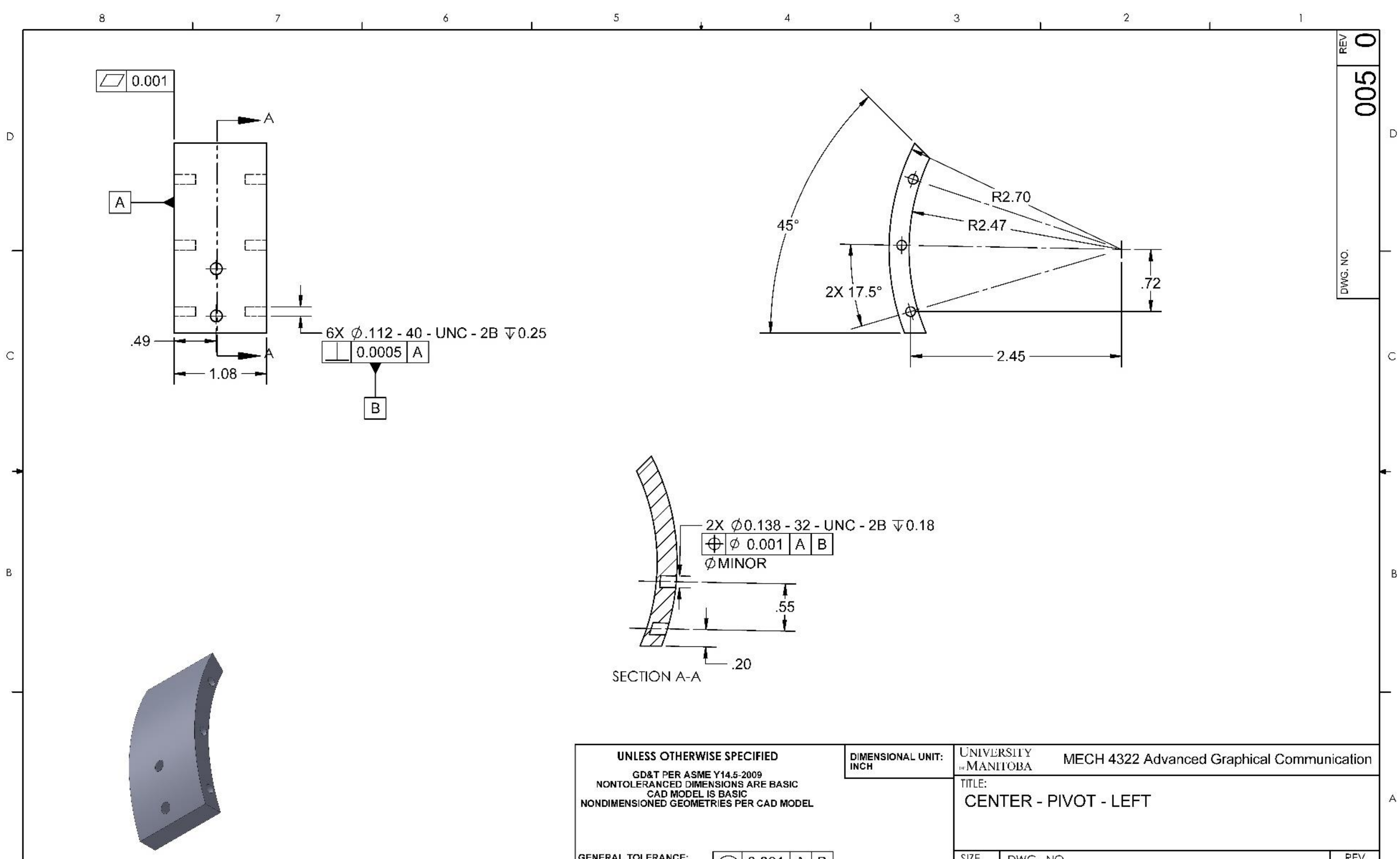

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UNIVERSITY OF MANITOBA — MECH 4322 Advanced Graphical Communication

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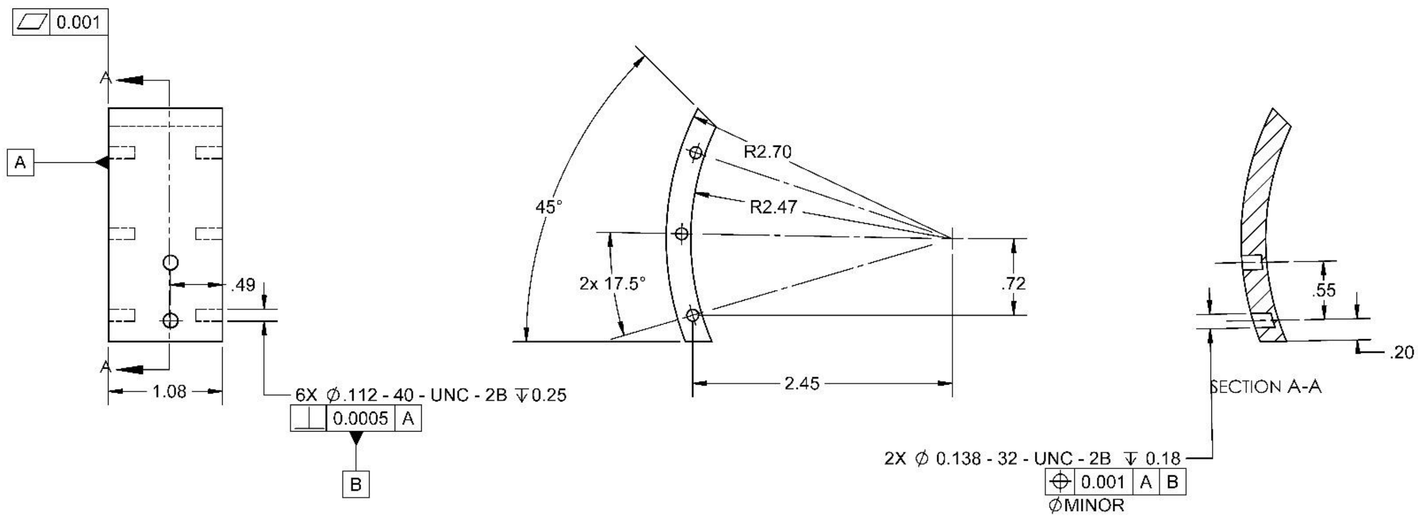

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NONDIMENSIONED GEOMETRIES PER CAD MODEL

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DIMENSIONAL UNIT: INCH

UNIVERSITY OF MANITOBA — MECH 4322 Advanced Graphical Communication

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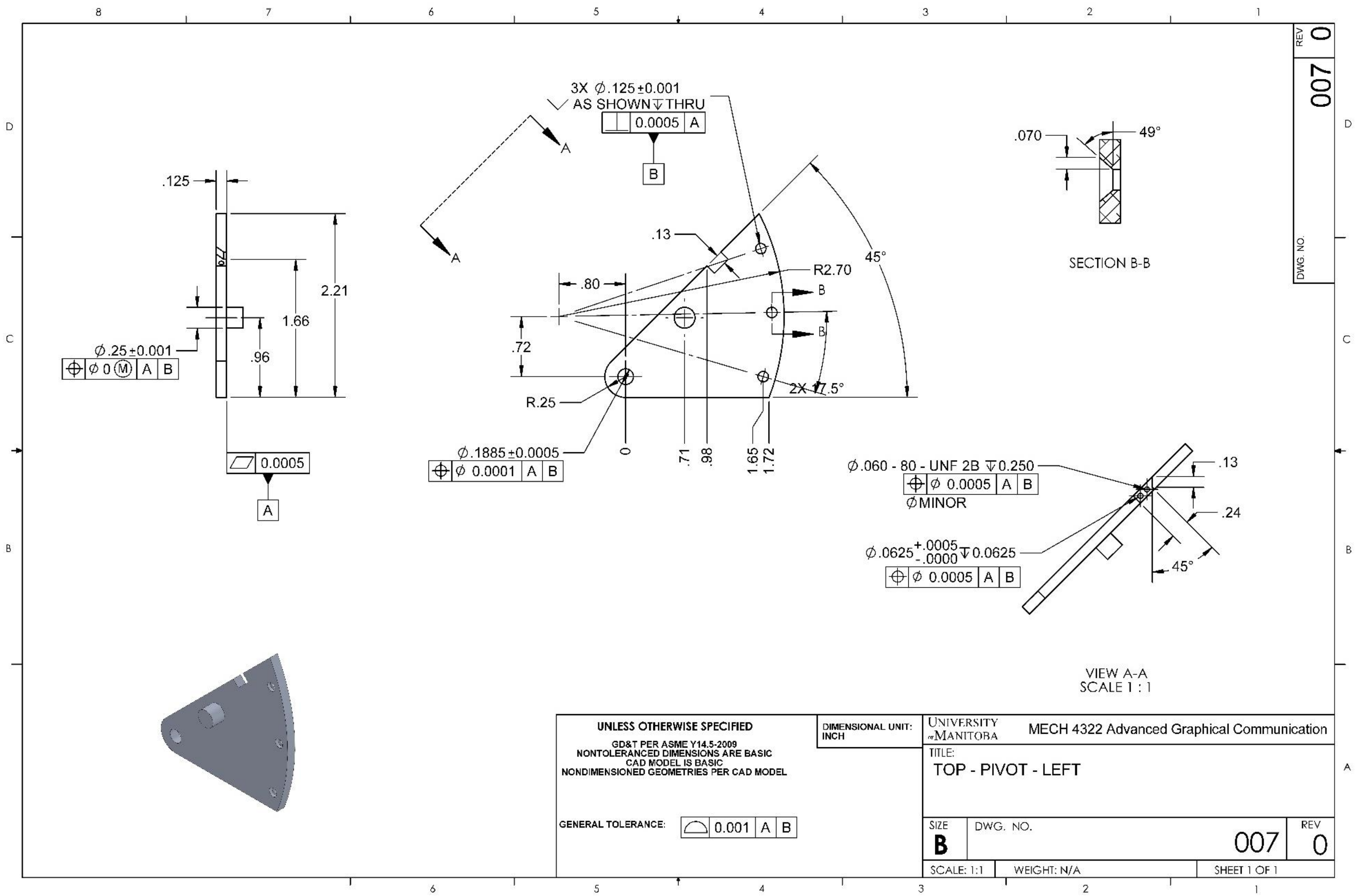
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A
.13
R2.70
45°
.80
B
B
.72
R.25
2X 17.5°
Ø.1885±0.0005
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1.65
1.72
.070
49°
SECTION B-B
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MECH 4322 Advanced Graphical Communication
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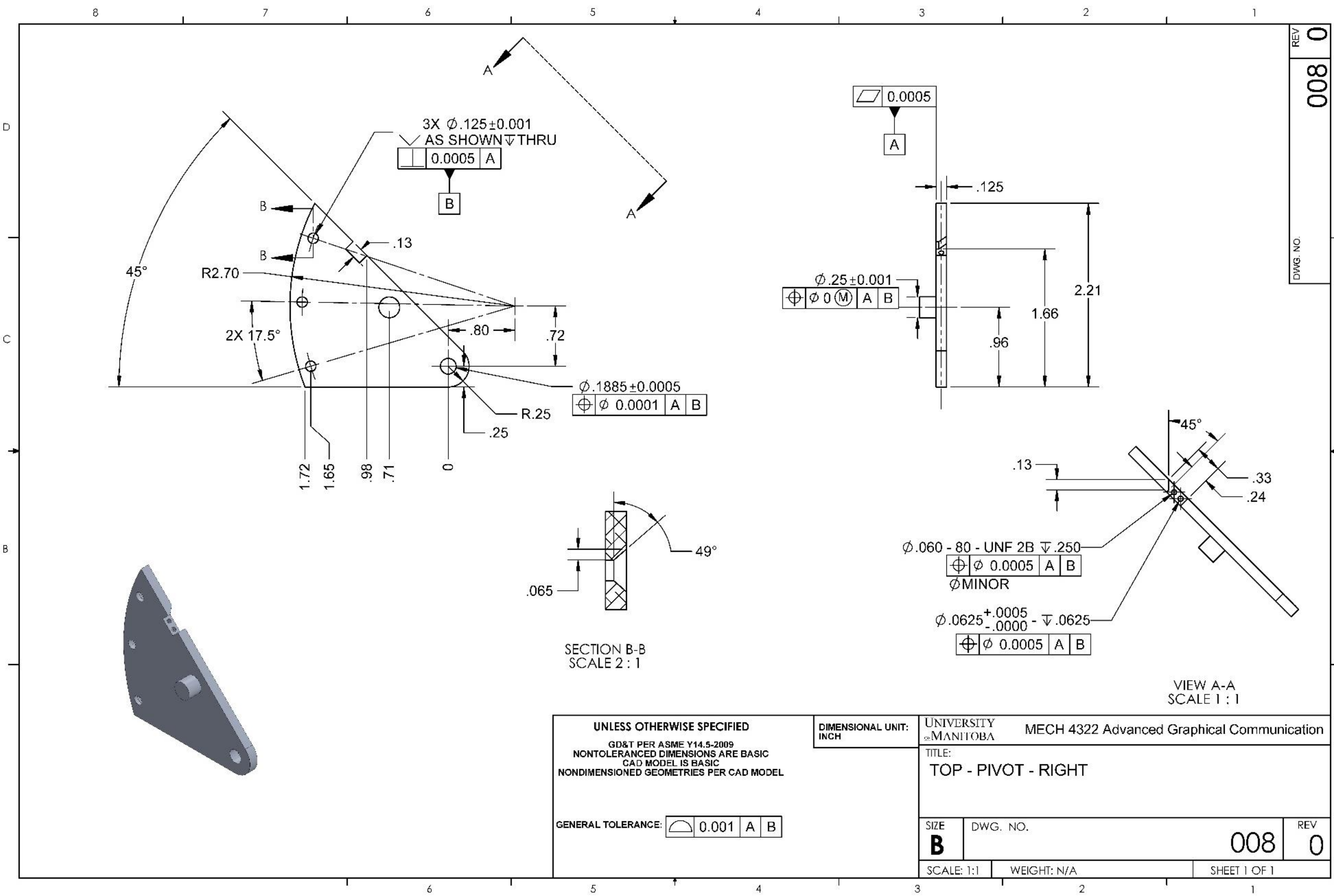
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⊕ ∅ 0.0001 A B
R.25
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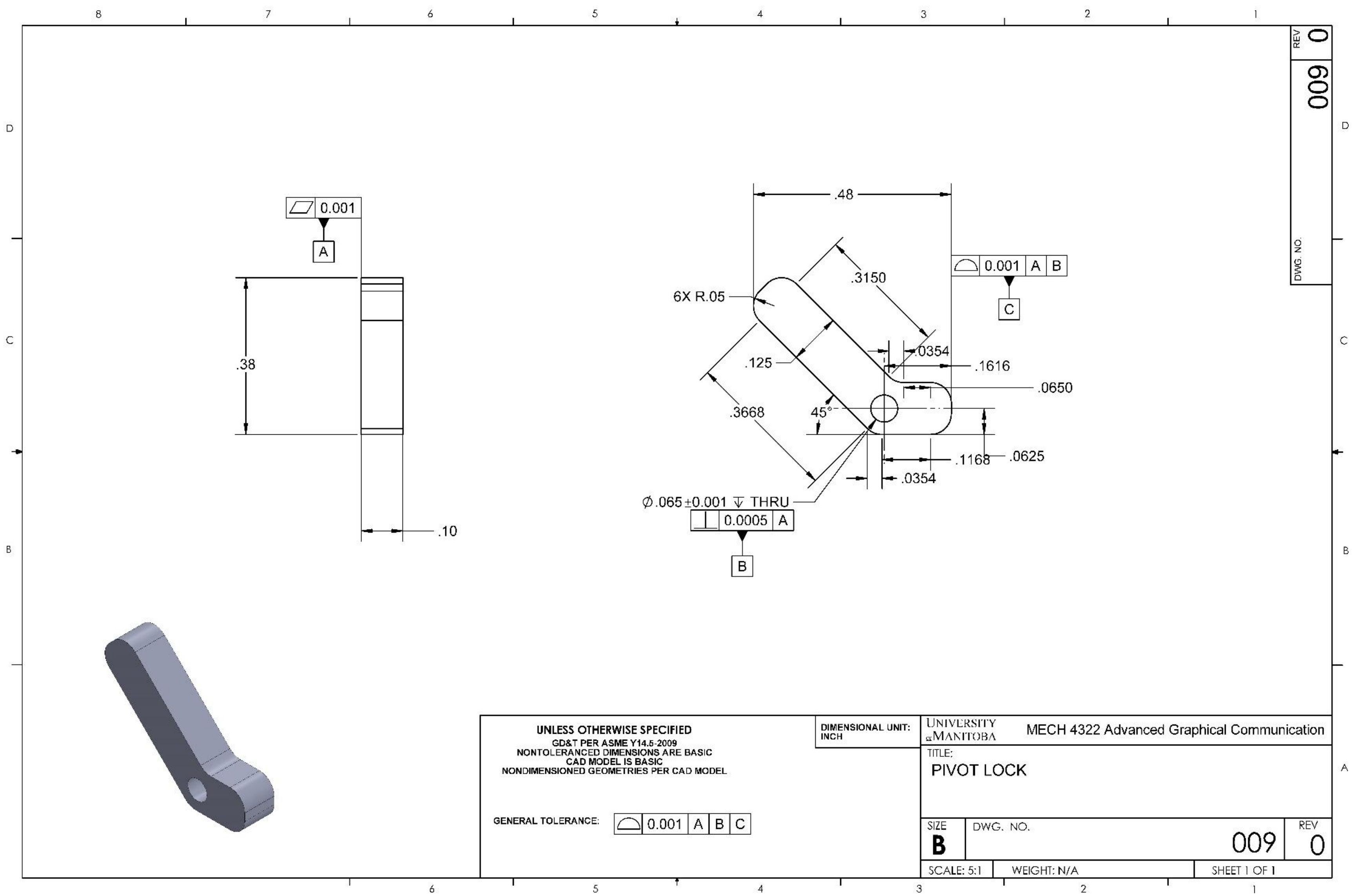
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.0354
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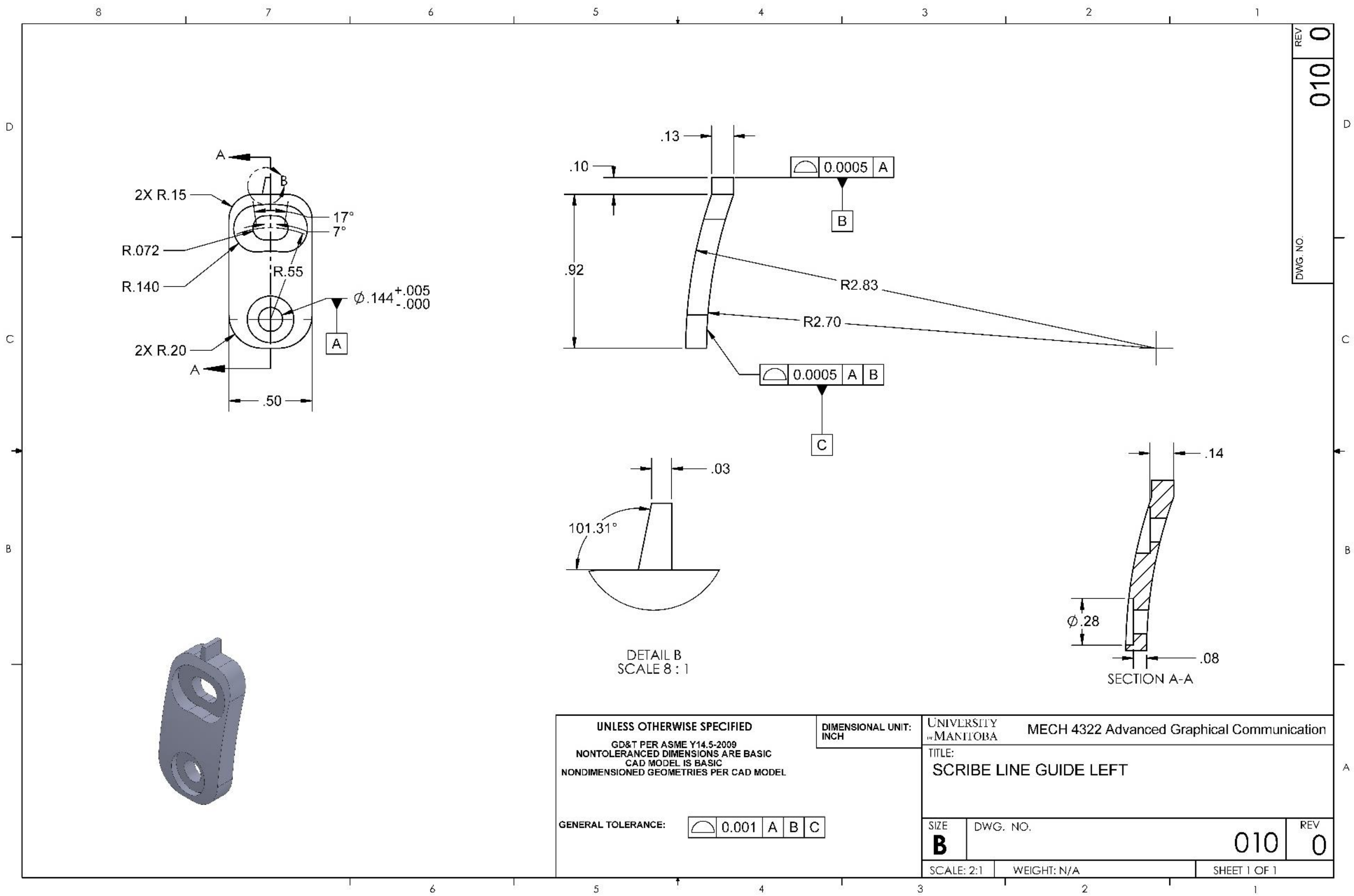
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R.072
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B
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R2.83
R2.70
0.0005 A B
C
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DETAIL B
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UNIVERSITY OF MANITOBA
MECH 4322 Advanced Graphical Communication
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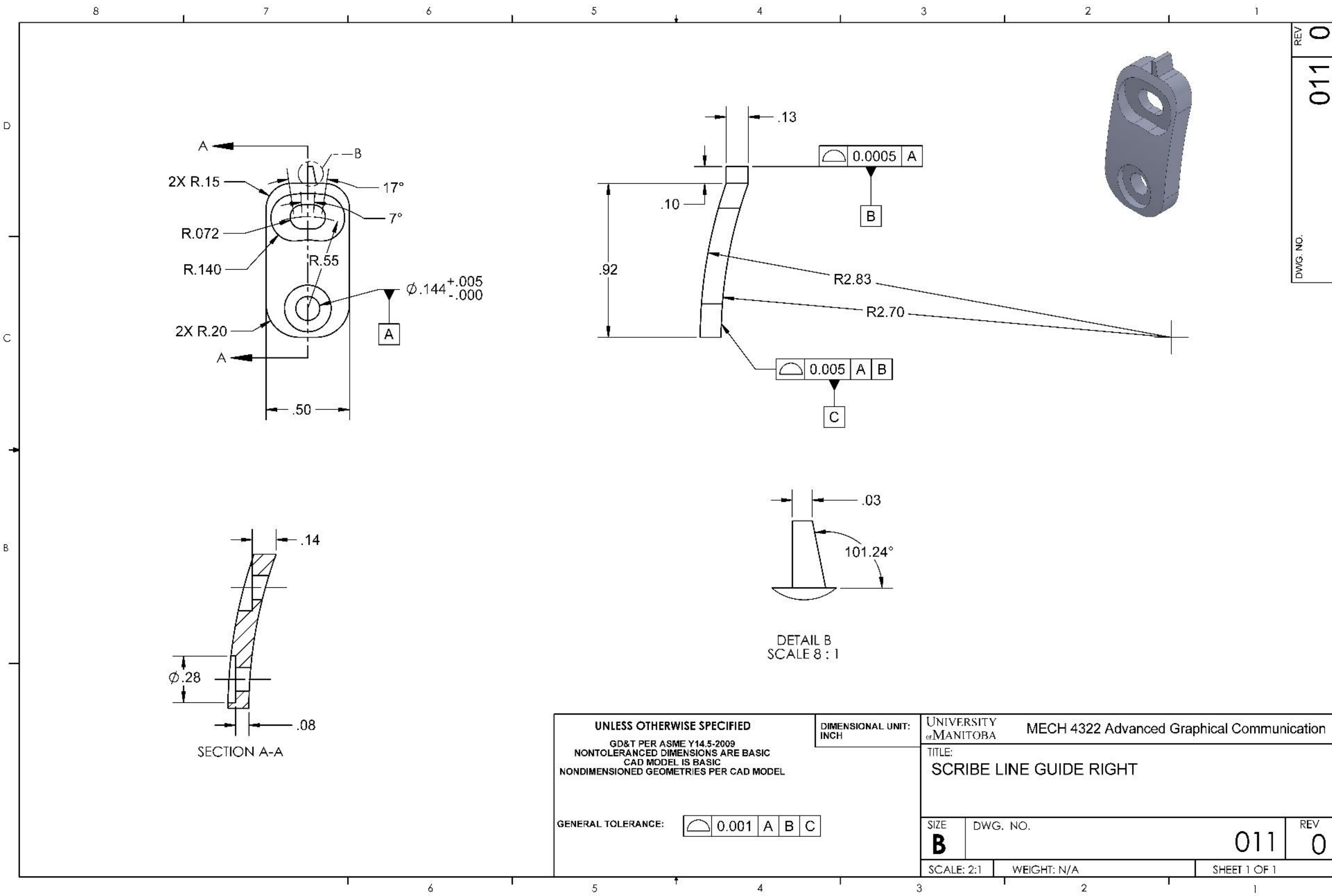

A
B
2X R.15
17°
7°
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R.140
R.55
⌀.144 +.005 -.000
A
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A
.50
.13
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B
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.92
R2.83
R2.70
0.005 A B
C
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⌀.28
.08
SECTION A-A
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101.24°
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UNIVERSITY of MANITOBA
MECH 4322 Advanced Graphical Communication
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SHEET 1 OF 1

Appendix G: Pivot Lock Calculations

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G.1 Pivot lock angle calculation

To calculate the angle required for getting spring force, the angle between line of action of spring torque and the distance vector from spring pivot point to pivot lock slot was needed. This was done in two steps, and both angles were calculated with respect to z-axis

G.1.1 Angle of spring torque with Z-axis

The angle of spring arm was calculated from the SolidWorks model and is found to be 59.02° as shown in Figure G-1.

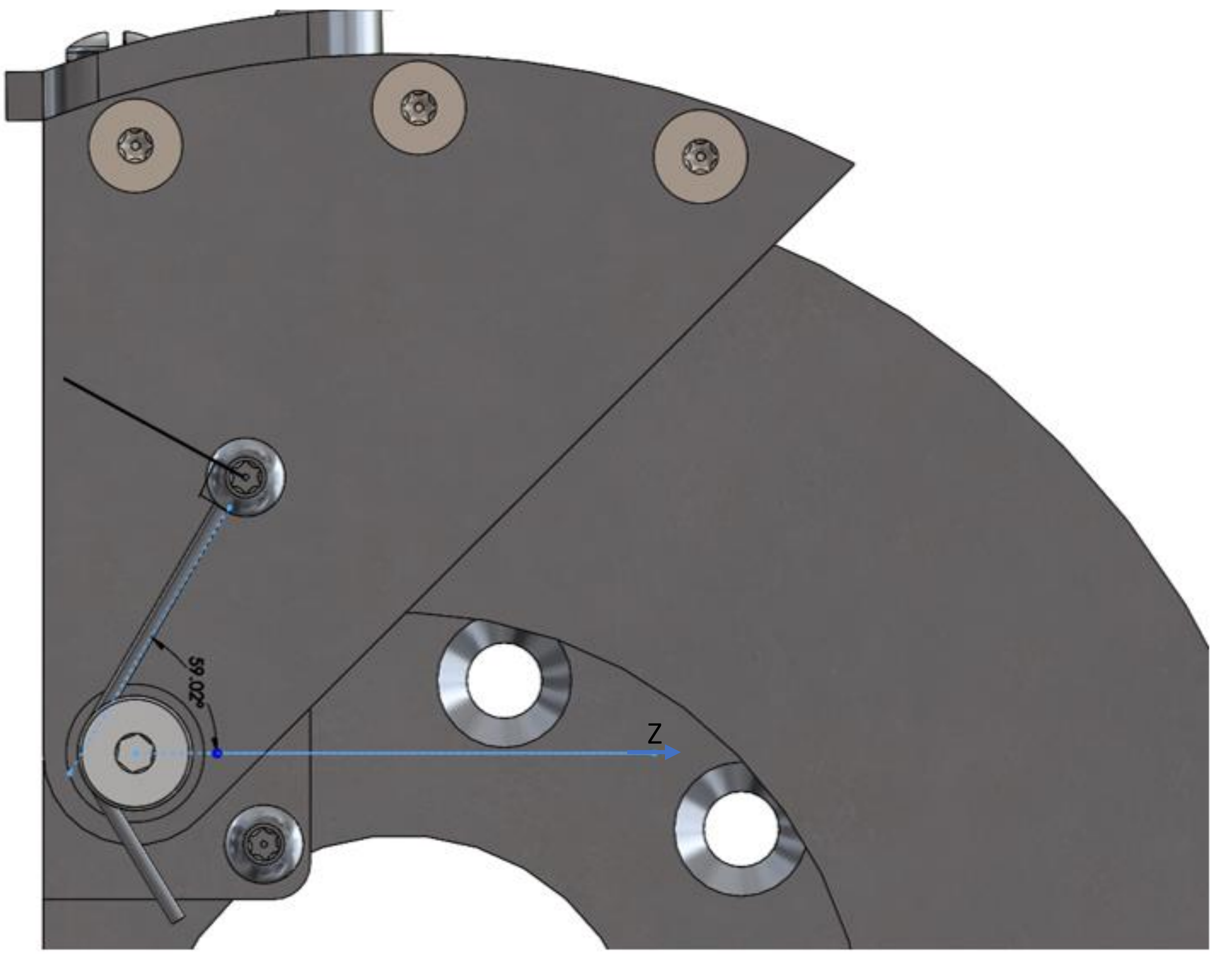

Figure G-1: Angle between Z-axis and spring arm

The line of action of Spring Torque is perpendicular to spring arm, therefore it makes an angle of 149.02°

G.1.2 Angle between spring pivot point and pivot lock slot

For this angle calculation, an assumption is made that spring and pivot lock are on the same face. The angle that the distance vector makes with Z-axis is calculated as follows, and shown in Figure G-2:

$$\tan(\alpha) = \frac{dx}{dz} = \frac{1.01}{1.2} = 0.841667$$

$$\alpha = Tan^{-1}(0.841667) = 40.086°$$

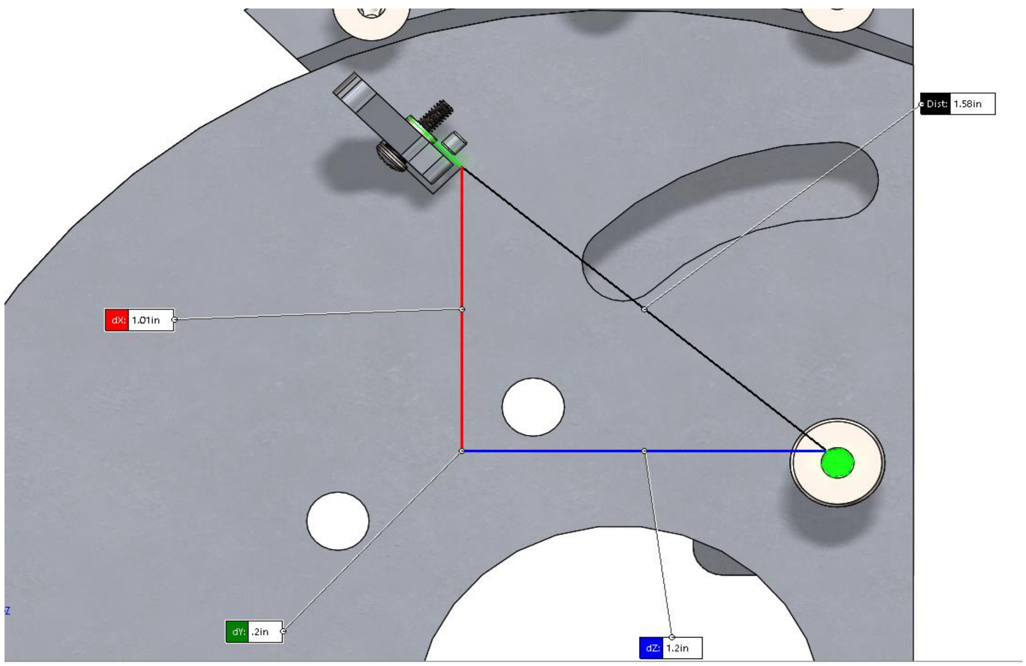

Figure G-2: Distance vector between spring pivot and pivot lock slot

G.1.3 Net angle between distance vector and spring Torque

This angle is calculated simply by subtracting the two angles, and the net angle is found as follows:

$$\gamma = 149.02° - 40.086° = 108.9338°$$