Reverse Engineering a Chef's Choice Electric Knife Sharpener

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MCEN 5045: Design for Manufacturability
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Reverse Engineering a Chef'sChoice® Professional Sharpening Station® Model 130

Executive Summary

In this report we start with an existing product, the Chef's Choice electric knife sharpener, thoroughly analyze its design, and create modifications to improve it.

Reverse Engineering has many applications. It can be used to better understand competitor products, replace missing or unavailable documentation for designs, or in our case, improve a product. We analyzed part count, part design, assembly, material selection, and individual part cost with the goal of creating a better, cheaper product.

We started by looking at the overall function of the product: how it is interacted with and what it does. Next, we analyzed the subsystems that make this functionality possible. Finally, we went part by part, creating or sourcing 3D models and engineering drawings. We then scrutinized function, material, interaction with neighboring parts, and other factors. From this analysis we decided what parts could be removed, standardized, or modified in order to lower cost and improve function of the overall product.

In this process we identified 6 subsystems that each perform a function. 1) The electronics subsystem includes all the electrified elements of the design: I/O switch, power cord, motor, etc. Within the scope of this project this system will be left alone. 2) The motor shaft subsystem includes all the rotating parts that are attached to the motor. This system provides the stage 1 and stage 3 sharpening. 3) The honing subsystem contains the stage 2 components used for honing the blade. 4) The redressing subsystem contains components used for cleaning the stage 3 grinding wheels. 5) The blade guide subsystem contains the components used to guide the knife blade into position for stages 1-3. 6) The main chassis subsystem contains the parts used to support and hold everything together.

Following the analysis of these subsystems and their components, we made 5 design changes. There were several approaches we could have taken to improve the product. It could be redesigned to be more ergonomic, work more intuitively, be more durable, etc. Within the scope of this project, our goal was to maintain product functionality while driving down the cost of manufacturing and assembly. Our changes included part combination, elimination, standardization, and redesign.

Our final design has 13 fewer parts on the bill of materials than the original and a 15% decrease in overall complexity. It also features improvements for product assembly including better error proofing, easier handling, easier part insertion, and reduced secondary operations.

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Introduction

Reverse engineering a product involves an in depth analysis and investigation into a product to learn how it works and why design decisions were made. For this project, the team decided to reverse engineer a *Chef's Choice* Professional Sharpening Station 130. The knife sharpener was sourced from a local goodwill, and despite the challenges the team knew it would face with the complexity of the product, the team decided to proceed with the knife sharpener.

There were two main objectives to the project. First, to gain an intimate understanding of the knife sharpener and how it works. Secondly, to utilize the methods discussed in class to make improvements to the knife sharpener's design, backed by quantitative data. To achieve these two goals, the project underwent three phases: (1) disassembly, (2) virtual modeling and analysis, and (3) redesign and improvements. Disassembly involved the team working together to slowly take apart the knife sharpener, gaining an understanding of each subsystem and part bit by bit. Virtual modeling and analysis was the brunt of this project, there were over 30 components, many of which had a lot of curved, asymmetrical geometry. The analysis involved performing DFA, DFM, and cost analyses on the product. The results of these analyses and the understandings gained from disassembly and virtual modeling were used to come up with five potential improvements for the product. Each of these five improvements were analyzed for material, involved processes, cost, and DFA.

Original Design

Before making any modifications, we want to understand the original design as thoroughly as possible. In this section we review the functionality of the product both broadly and in detail. We also break down the design by subsystems and individual components. Each component was modeled in order to understand its features and interactions with other components. These part drawings can be seen in Appendix D: Engineering Drawings, pages D-1 through D-65.

Product Overview

Figure 1: The Chef'sChoice® Professional Sharpening Station® Model 130

The Chef'sChoice® Professional Sharpening Station® Model 130 is a 3 stage electric knife sharpener. Stage 1 uses coarse diamond abrasives to create the major bevel. Stage 3 strops and polishes the blade with ultra fine abrasives. Stage 2 creates a steeled edge similar to what is produced by a honing rod. It can be adjusted up and down to expose fresh steel as stage 2 is worn down. The sharpening station also includes angle guides to protect the user from the rotating assembly and to ensure a consistent 20° total blade angle. It can sharpen both straight and serrated knives.

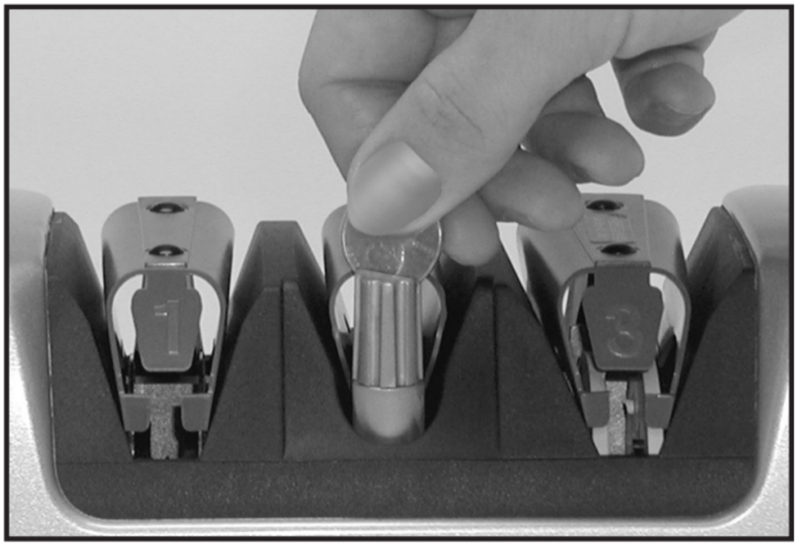

Figure 2: Exposing fresh steel on stage 2

The sharpening station also includes a redressing, or cleaning feature for the stage 3 ultra fine abrasive wheel. Over time this wheel can get clogged up with metal. On the bottom back right of the chassis is a small black toggle. Sliding this toggle left-to-right and right-to-left removes a small amount of material from each ultra fine abrasive wheel.

Figure 3: The redressing feature

The sharpening station also includes a removable magnet that catches shavings produced by sharpening. This magnet snaps into the bottom of the chassis and can be removed when the station is flipped upside down.

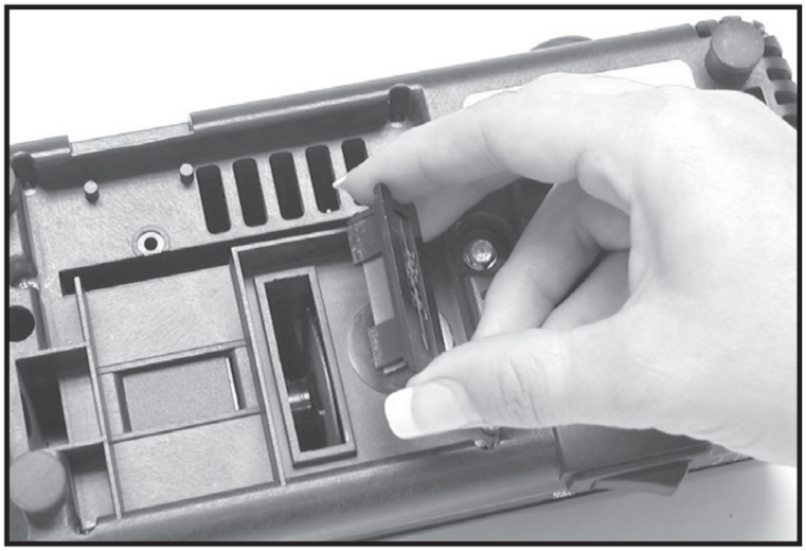

Figure 4: The removable magnet

Black Box and Glass Box

The following diagrams break down the functionality of the knife sharpening station.

The purpose of the black box diagram is to define all inputs (things that go into or are done to the product) and all outputs (things that come out of the product or that product does because of those inputs). The primary purpose of the product is to sharpen a knife, so a dull knife is an obvious input, and a sharp knife is an obvious output. However, other inputs, like electricity, pressing the power switch, and occasionally redressing the abrasive wheels are necessary for the product to function. Additionally, waste outputs like heat, sound/vibrations, and steel shavings are produced in the process.

Figure 5: Black box diagram for Knife Sharpener

The glass box diagram details more of the product's inner workings while still remaining fairly conceptual. In this diagram we can see how components interact with each other and also how they are affected by inputs. For example, a combination of power and a user press to the I/O switch sends power to the motor, which in turn provides shaft rotation to stages 1 and 3.

We can also see the effect of inputs that may not result in obvious outputs. The toggle, when pressed, removes material from stage 3. This cleans the polishing wheels, which helps them function, but it doesn't have a direct, tangible output.

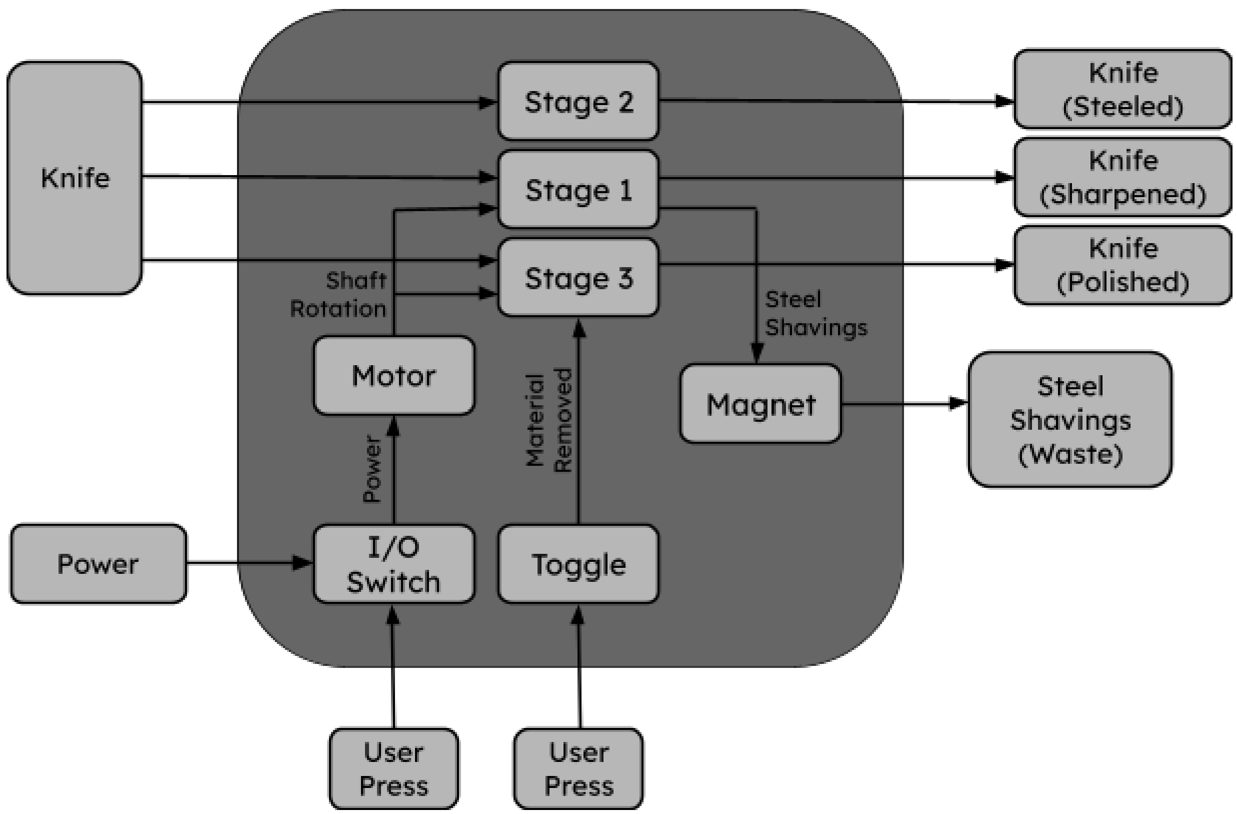

Figure 6: Glass Box Diagram

Fishbone Diagram

The following "fishbone" diagram breaks the product down into six subsystems or assemblies, each with a distinct function. Each component in the product fits into one of these assemblies. The purpose of the diagram is to visually convey the complexity of each subsystem. Subsystems with a greater number of parts could potentially be simplified if they contain parts extraneous to their function.

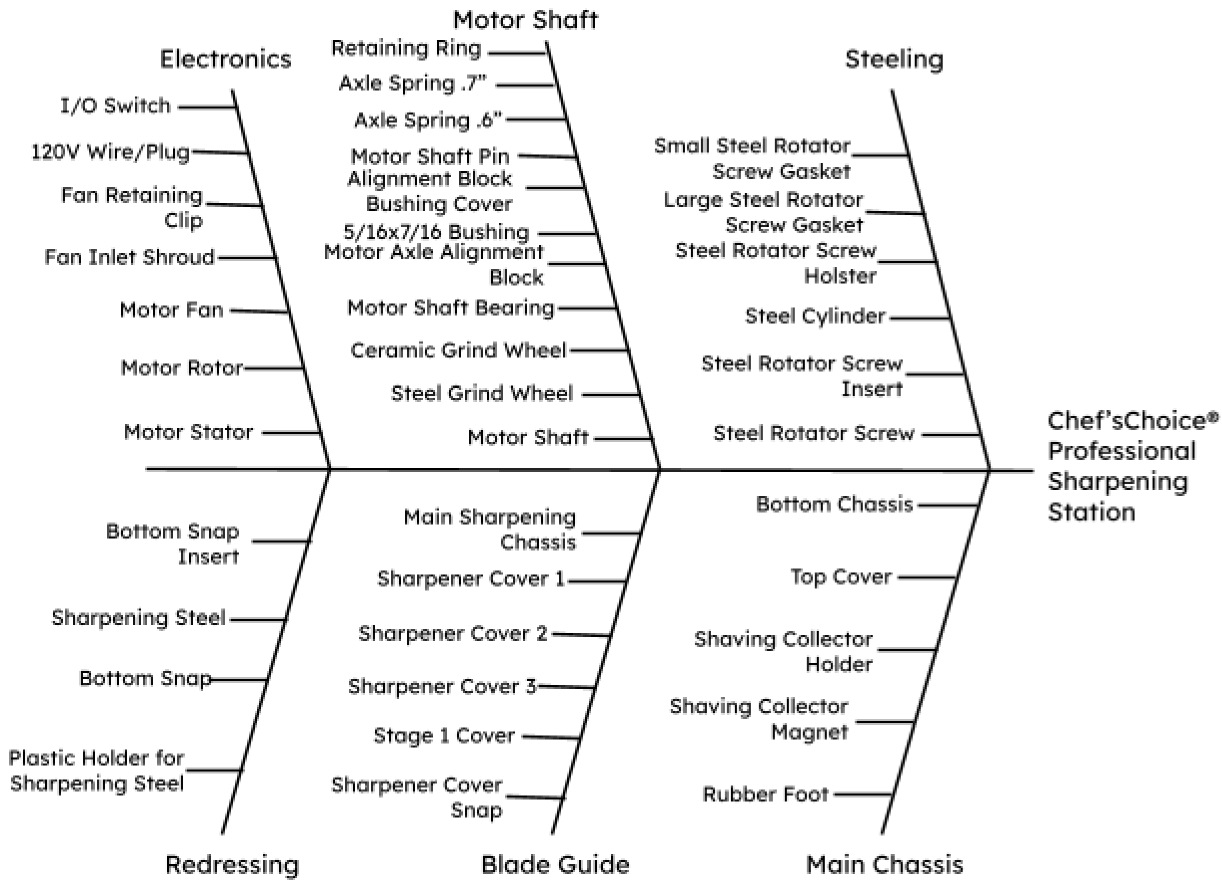

Figure 7: Fishbone Diagram

Patent Search

To better understand the electric knife sharpening tool, a patent search was performed in order to find relevant design information that may assist in understanding the original design intentions, or help spark ideas for future design changes to the product. The first patent that resembled our product is called, "Electric Knife Grinder" (Patent ID: CN2882897Y). This patent has similarities in its use of three different sharpening stages, although its second stage consists of a wheel grinder, as opposed to the model in this report that uses a semi-stationary steel pole instead of a grinder for its second stage. An exploded view of this product's assembly can be seen in Figure 8. This alternative design for the second stage could possibly help inspire a

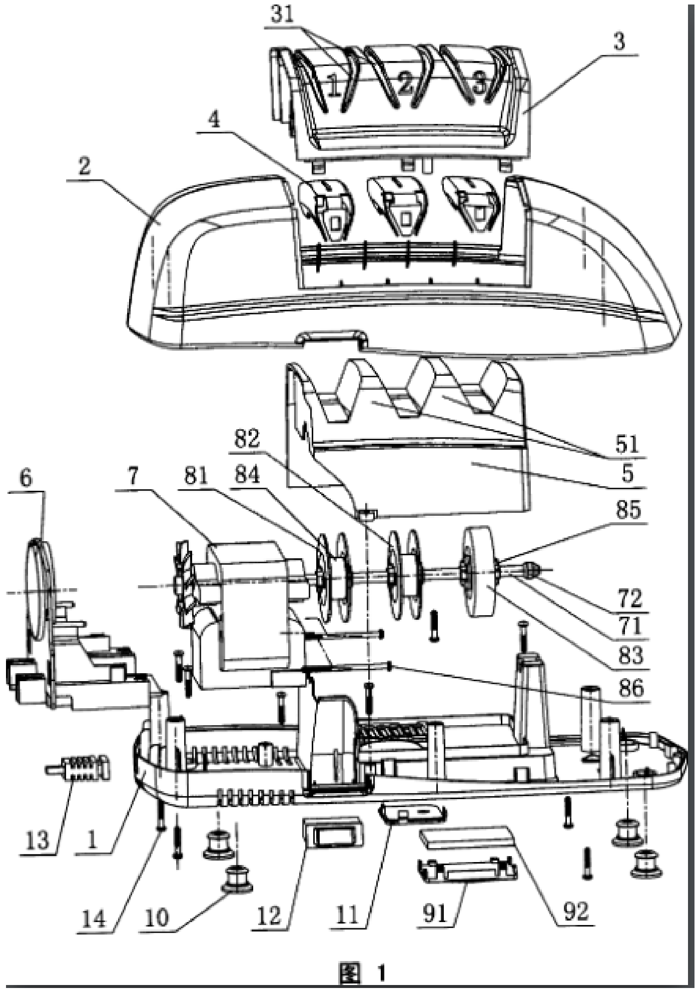

Figure 8: Exploded Assembly View of Chinese Patent CN2882897

complete redesign of our product's second stage, going from a semi-stationary piece, to a rotating sub-assembly just like the other two stages. Another patent that closely resembles our knife sharpener is called, "Precision Means for Sharpening and Creation or Microblades Along Cutting Edges" (Patent ID: CN2882897Y). This design appears to be identical to our Chefs Choice Knife Sharpening Station 130, however, it does not possess the third stage at all. A sketch of this product from the patent can be seen in Figure 9.

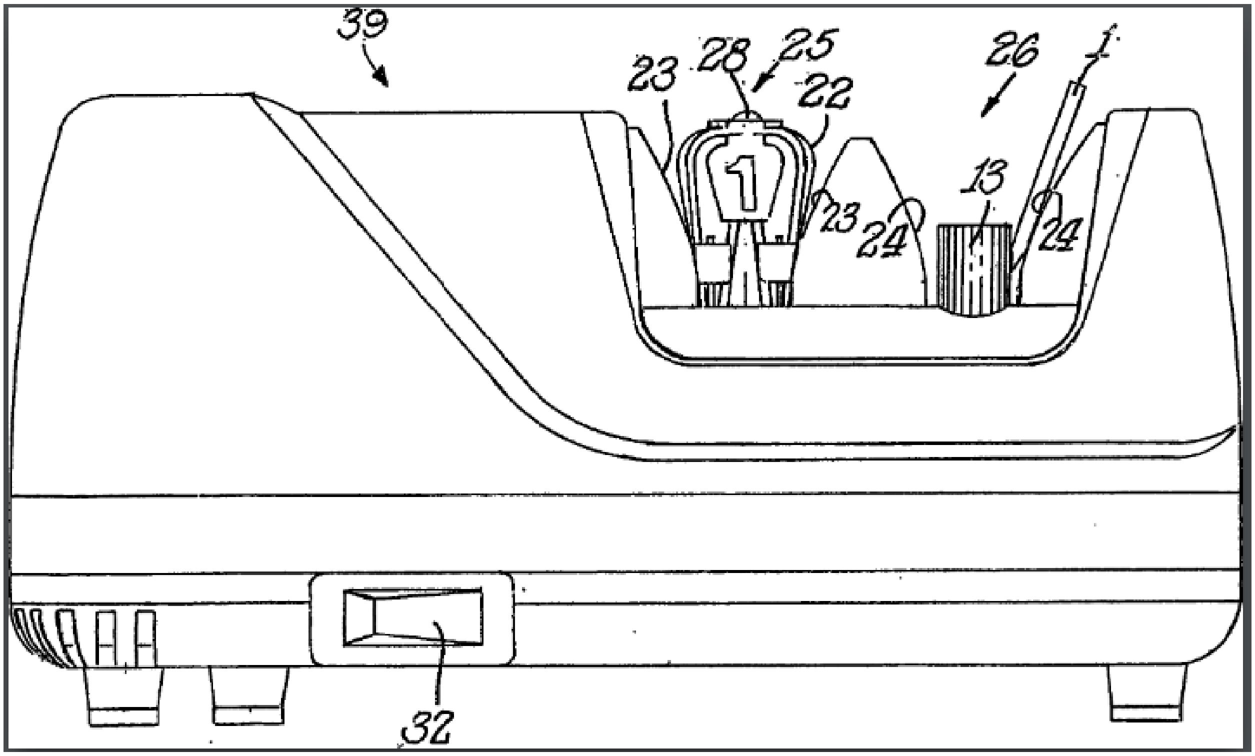

Figure 9: View of Similar Two-Stage Product Chinese Patent CN1771109A

This concept prompts a unique thought process to a possible redesign- what stage of the sharpening process is the most important? What stages are the easiest for an average consumer to use, for example, are consumers comfortable using the second stage that differs from the first and third stage sharpening processes? Which two stages are the most effective, as in do two of the three stages get the knife 90% sharp while the other third stage only gets it to 95% sharp? This two-stage design is interesting in posing the idea of eliminating a whole portion of our existing three-stage design knife sharpening product. This patent is from 2004, so there's a good possibility there remains some areas of improvement that could be had if the design hasn't really changed in two decades- either functionally, or aesthetically.

Modified Design

Objectives

In this section we review design modifications we made to improve (lower cost of, improve functionality of) the knife sharpening station. Our primary goal was lowering cost, as the original design had many unnecessary components or components that could be combined, standardized, etc. In the process, we also want to make sure that functionality is not compromised. The modified design bill of materials can be found in Appendix A.

Design Modifications

1. Redressing Assembly

Though the redressing assembly only has 3 components it was an easy candidate for revision. The bottom snap component features a bushing insert which helps it pivot more smoothly during redressing. However, the redressing function is only meant to be used approximately once per year and a separate insert is unnecessary.

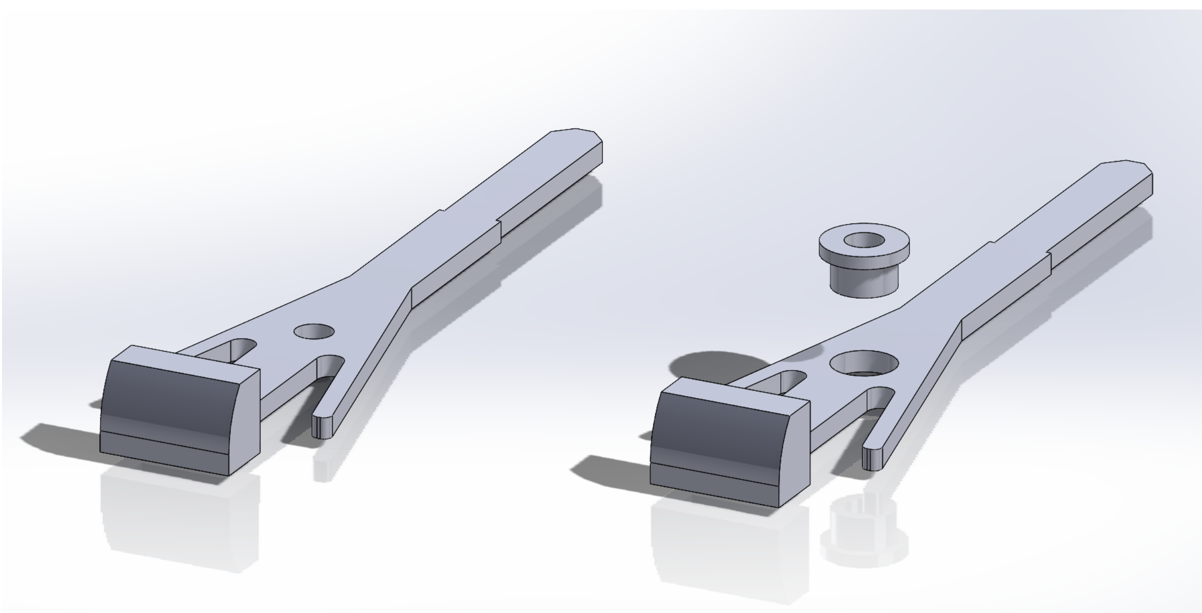

Figure 10: The new, simplified design (Left) and old design (Right)

Simplifying these components to one piece saves material, streamlines manufacturing, and decreases assembly time.

2. Stage 2 Steeling Sub-Assembly Part Reduction

The original second-stage-steeling sub-assembly consists of six different parts (part #'s: 8, 12, 16, 19, 20, 24- seen in *Figure 11*) that allow for the sharpening steel cylinder to be held in place during sharpening, and for being rotated which allows for a new circumferential position of the steel cylinder to be exposed to the sharpening process (prolonging the life of the second stage by wearing out different areas of the steel cylinder's circumference). The original rotating design allows for approximately 28 new steeling areas over the useful lifetime of the rod before the rod becomes worn out enough to make the process less efficient and under-performing in quality. It was estimated that a single steeling surface on the steel cylinder can be used several thousand times before the wear affects the rate of precision knife edges that are being formed. This means that the steel cylinder will most likely not need to be replaced under normal household conditions, but Chefs Choice does offer replacement rods if stage two is used often enough to warrant a replacement.

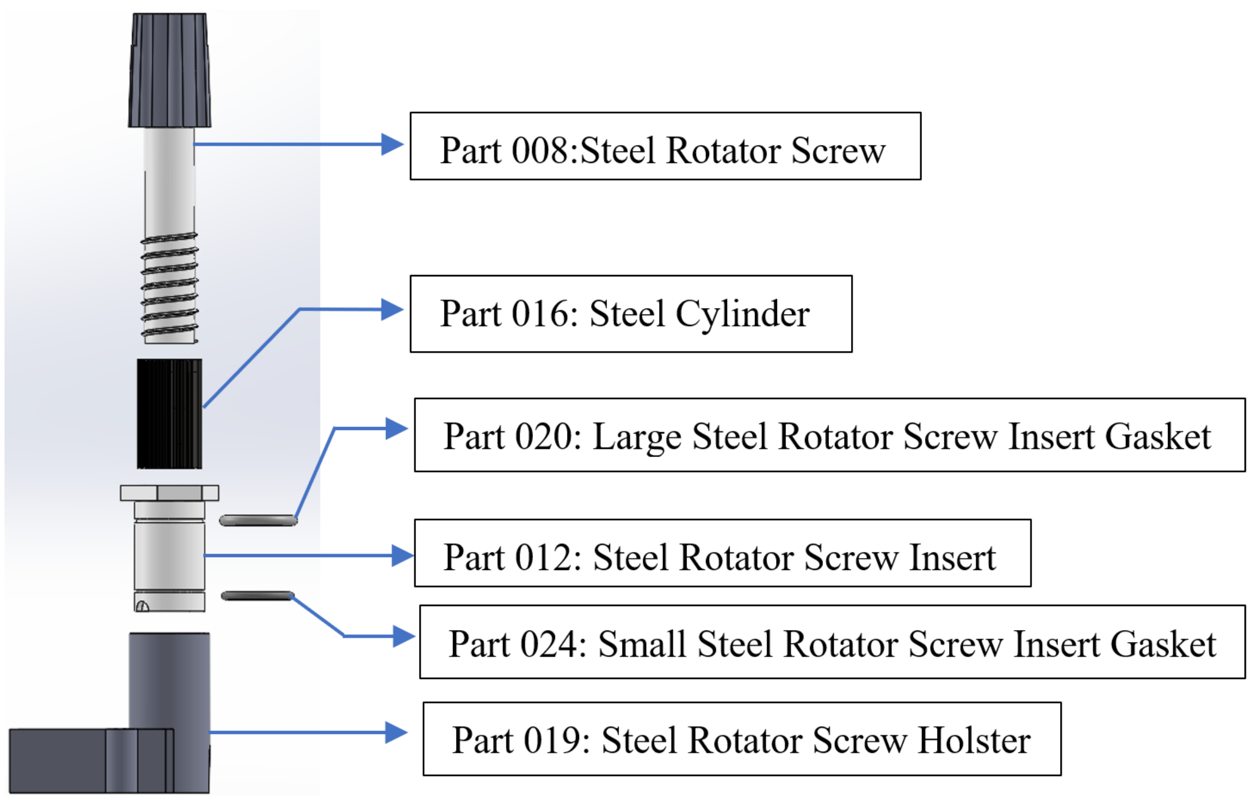

Figure 11. Original Stage 2 Steeling Sub-Assembly Diagram

The purpose of re-designing this sub-assembly, was to reduce the number of parts involved from the original six, to two, in order to decrease costs associated with: manufacturing tooling, material/part sourcing, and assembly time (and difficulty) of the "extraneous" parts. The most difficult area of assembly for this sub-system revolved around the Steel Rotator Screw Insert.

The two different-sized gaskets are installed close in respect to one another on Part 012's shaft, which could cause the potential for incorrect installation of one of the gaskets at the wrong location. Each gasket is also fairly difficult to install onto Part 012 by hand without assistance from some sort of tool to push them into place (especially the for the first larger gasket since it has to be moved over the second smaller gasket's groove to reach its dedicated gasket groove).

The approach of the redesign is centered around retaining most of the same functionality of stage two by keeping essentially the same Steel Cylinder and Steel Rotator Screw Holster with slight modifications, and removing everything else. As seen in *Figure 12*, one end of the Modified Steel Cylinder now has 14 teeth grooves, and the cylindrical end of Modified Part 019 also has 14 teeth grooves that mesh with the Modified Steel Cylinder's teeth grooves. The Modified Steel Cylinder is now held in place during operation due to gravity instead of the friction between the Steel Rotator Screw's external threads and the Steel Rotator Screw Holster's internal threads. The Modified Steel Cylinder can be rotated to allow for new steeling area exposure, just as it was able to in its original design. The amount of rotation that can be achieved by the Modified Steel Cylinder teeth meshing with the Modified Steel Rotator Screw Holster by the mesh teeth interacting with the next adjacent interface is approximately 25 degrees. This means that the Modified Steel Cylinder can be rotated seven times for a new steeling area each rotation. After seven rotations, the available steeling areas will have been used previously. By using the same steeling material as the original design, this modified stage two can still be used several thousand times before the wear affects the rate of precision knife edges that are being formed.

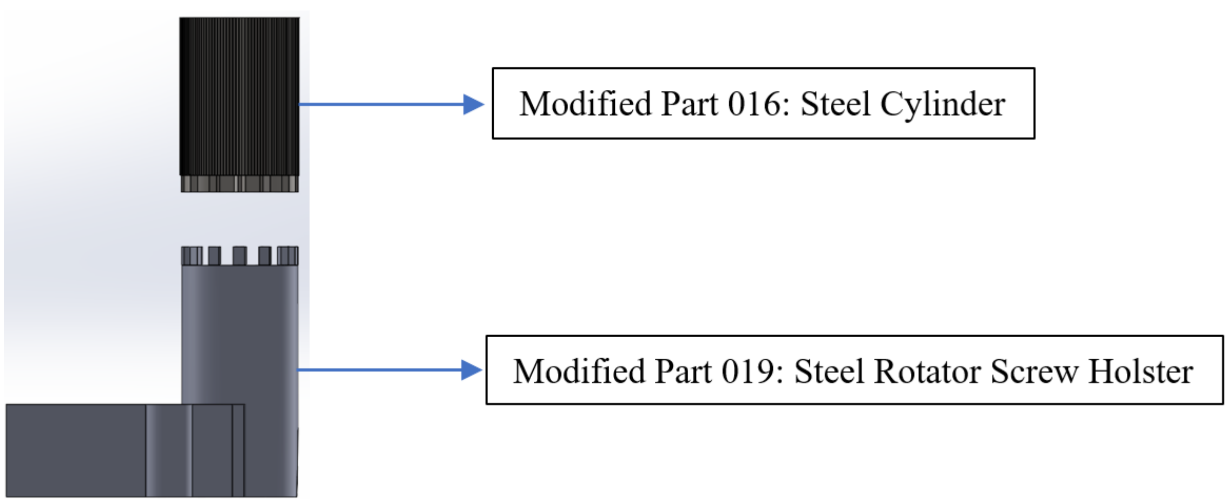

Figure 12. Modified Stage 2 Steeling Sub-Assembly Diagram

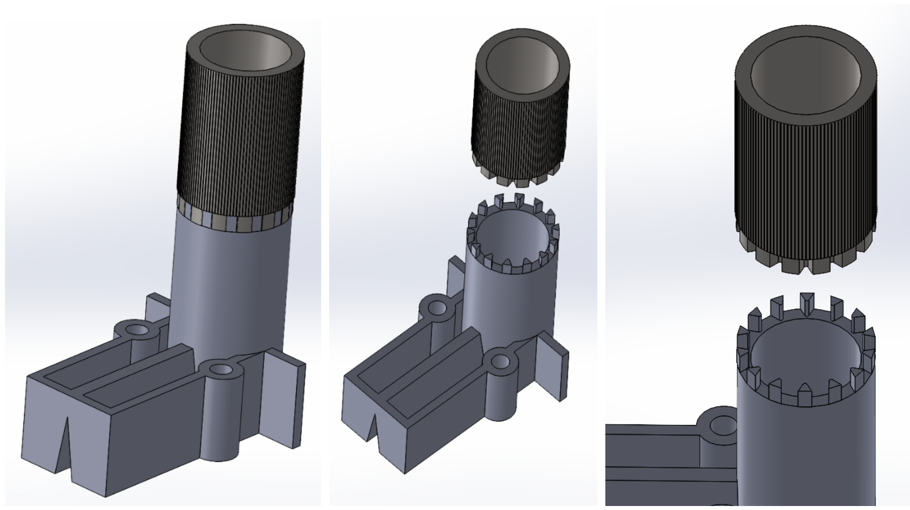

Figure 13. Modified Stage 2 Steeling Sub-Assembly Alternate Views

These sub-assembly design modifications do possess a few drawbacks, concerns, and room for further improvements. The design of the original stage two sub-assembly does claim that the Steel Cylinder is allowed to flex within its assembly (most likely due to both of the gaskets having the ability of being compressed between the Steel Rotator Screw Holster and the Steel Rotator Screw Insert parts) which allows for the prevention of excessive force being applied to a knife by the user. With the removal of the formerly mentioned parts, this prevention of excessive force being applied to a blade is no longer existent. A remedy for this is to include more precise directions in the user manual on operating stage two of the sharpener- increasing user difficulty, or to redesign the Sharpener Cover 2 part (part # 017) to provide tactile feedback when a knife is creating excessive force from being slid against it at the incorrect sharpening angle- this may be in the form of two pieces clicking when the part has an excess of pressure alongside it. The clicking could be initiated when the static friction of two pieces is overcome at an intentional force thus causing an audible "click" to alert the user of using too much force due to an incorrect sharpening angle being applied to the knife. Another drawback to this modification is the reduced number of uses of the Modified Steel Cylinder part. The original part can be rotated about 28 times, providing new steeling area for each rotation, while the modified design can only be rotated seven times with new steeling area for each rotation. Four times less cycles of sharpening is significant, but with the Chef's Choice's claimed, "several thousand times of use per steeling area before needing to rotate the Steel Cylinder", the new modified part will still last for thousands of uses despite the overall usability decrease. Another negative aspect associated with the design modification, is that the Modified Steel Cylinder is no long secured to the main assembly in any way, meaning that if the unit is knocked over/bumped hard enough, the new part could un-mesh from the Modified Steel Rotator Screw Holster and become separated and possibly lost. Under a presumed environmental use-case scenario of the sharpening unit being stored and used on a countertop, this shouldn't be of too much concern. If the unit is placed in a high-traffic area with increased potential to be disturbed (e.g. a busy restaurant kitchen), then this design becomes less favorable for use. A prospective remedy to these two inconveniences of less useful life and attachment to the main assembly of the Modified Steel Cylinder, would be another redesign, and increasing the number of parts sold with the unit as spares. The redesign would remove the steel from any area that isn't a steeling area that makes contact with a knife. This would reduce the overall material used to create the part, and no circumferential part of the cylinder would be unused and "wasted." To consider this option as viable or not, a cost analysis comparing the cost savings of using less steel overall in the part, versus the cost of new tooling and manufacturing of the more complex part, would have to be performed. The other option that could be in addition to, or stand alone, in respect to the additional redesign of the Steel Cylinder, would be for Chefs Choice to include additional Modified Steel Cylinder parts for the consumer. If the part becomes lost, or worn out/damaged, then the user can simply replace the part with a provided spare in seconds. This could increase the overall cost, or the spares could be provided upon request for additional money like the original design. These modified part drawings can be seen in Appendix D: Engineering Drawings, pages D-66 and D-67.

3. Reduce Material on Bottom Chassis

Two of the key components of the bottom chassis are: (1) the posts that attach to the top cover, keeping the entire assembly together, and (2) the attachments for the rubber feet for the knife sharpener to sit stable on a surface. As seen in *Figure 14* below for two of the top cover attachments, they use the same positioning as the rubber feet, therefore saving material.

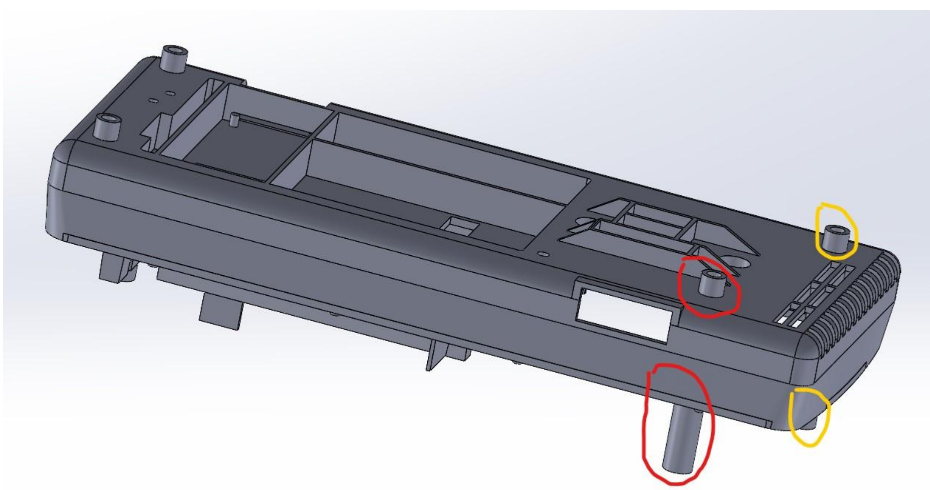

Figure 14. Matching positions for top cover and rubber feet attachment points

However, this is not the case on the left hand side of the sharpener. The features in the red and yellow circles below in *Figure 15* can be combined and save material overall. Moving the top cover attachment post (yellow circle, *Figure 15*) to overlay with the rubber foot (red circle,

Figure 15) reduces overall material and reduces the number of unique features in the bottom chassis.

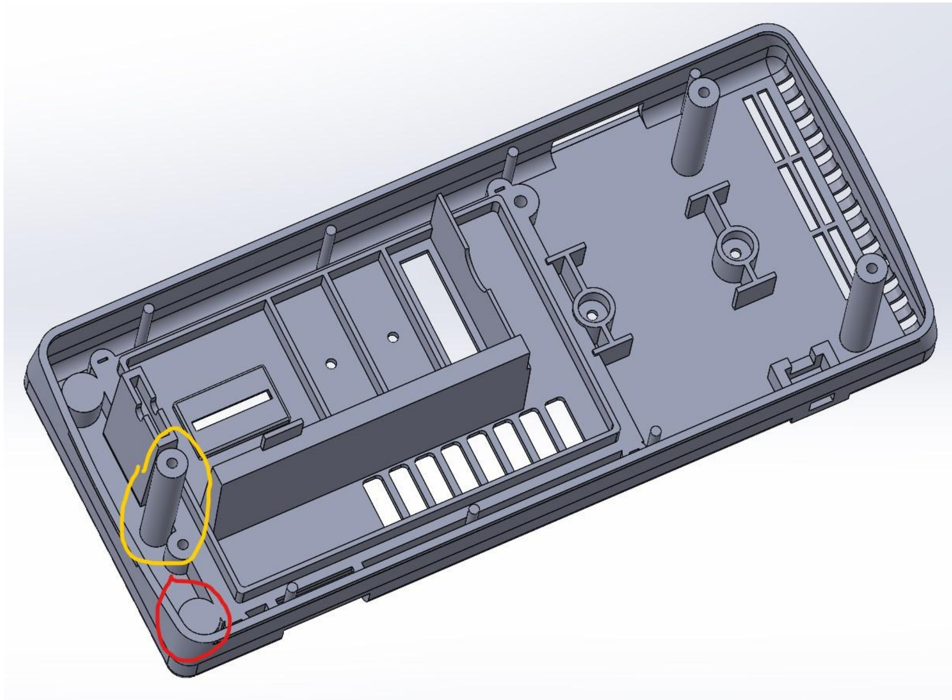

Figure 15. Non-matching positions on original knife sharpener design.

Figure 16 below depicts the new, updated version of the bottom chassis.

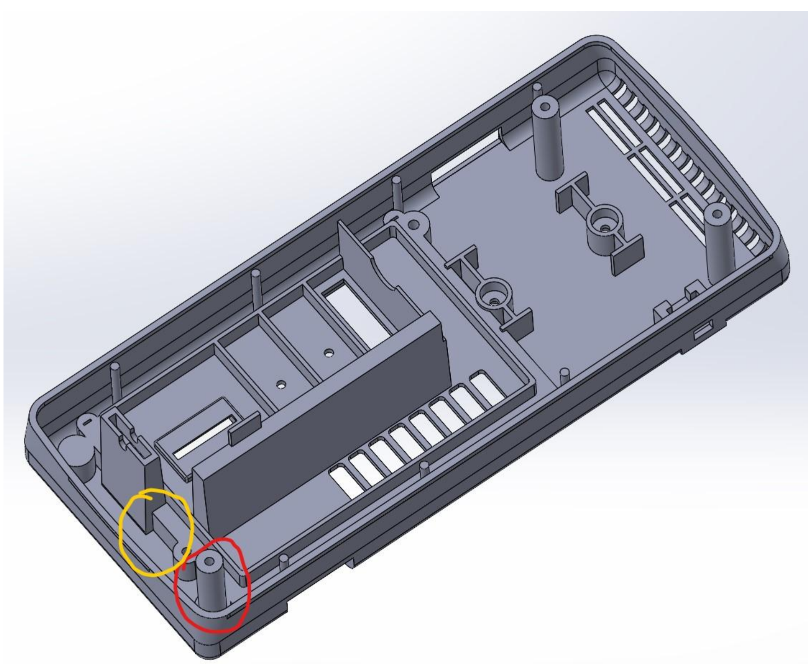

Figure 16. Proposed new position for top cover attachment post.

4. Reduce Number of Unnecessarily Different Parts

Given the small variation between some of the fasteners and springs, it makes sense to get rid of this variation and only use one kind of fastener and spring. More specifically, in the original design, there are five #5-40 UNC ¼”x1” fasteners and two #5-40 UNC ¼”x3/4” fasteners. These two fasteners are very similar to each other and could easily be selected wrong during an assembly process with no easy way to tell them apart unless they are lined up next to each other. They are placed in different parts of the assembly, so it would make the assembly person’s job easier if there were only one of these fasteners. Implementing this makes almost no change to the part itself if the five 1” fasteners are replaced with five ¾” fasteners instead. Similarly, there are two different kinds of springs in the Motor Shaft assembly with slightly different lengths and spring constants. These can be seen in *Figure 17*. One spring is 0.7” long, the other is 0.6” long, and the spring constants of the two are almost identical by feel. The outer and inner diameters of the springs are very similar too. Given that the spring constants, lengths, and diameters are not highly critical to the functionality of the shaft and are used mostly to springload some components, it makes sense to use only one kind of spring. The 0.6” spring will be replaced with another 0.7” spring.

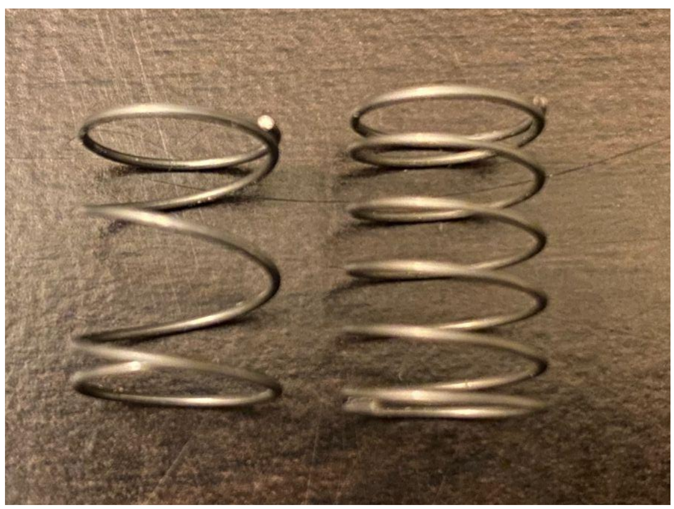

Figure 17: Two different kinds of springs from the motor shaft assembly

5. Integrate Blade Guides and Snaps

Each blade guide (sharpener cover) is held in place with two snap fitting pegs. Consolidating them removes 6 small parts from the assembly, which should decrease assembly time. Instead of holding the blade guide in position and pushing the snap fitting peg into place, the combined part can simply be inserted into the main sharpening chassis. In the figures below, the modified sharpener cover 1 with integrated snaps is shown on the left. The original sharpener cover 1 with snap fitting pins installed is shown on the right.

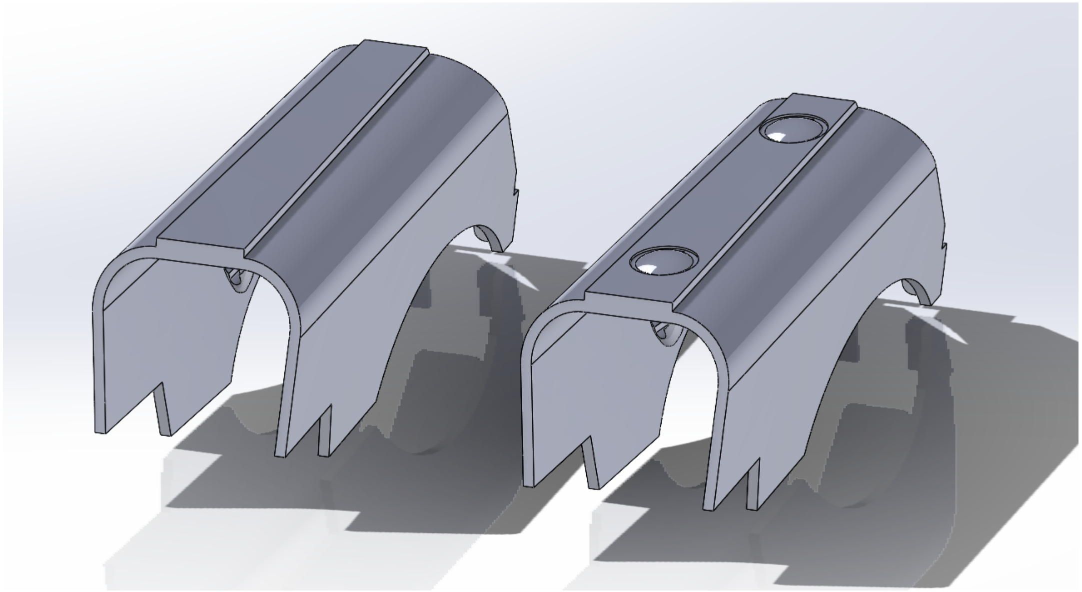

Figure 18: Sharpener Cover 1 with and without integrated snap (Top view)

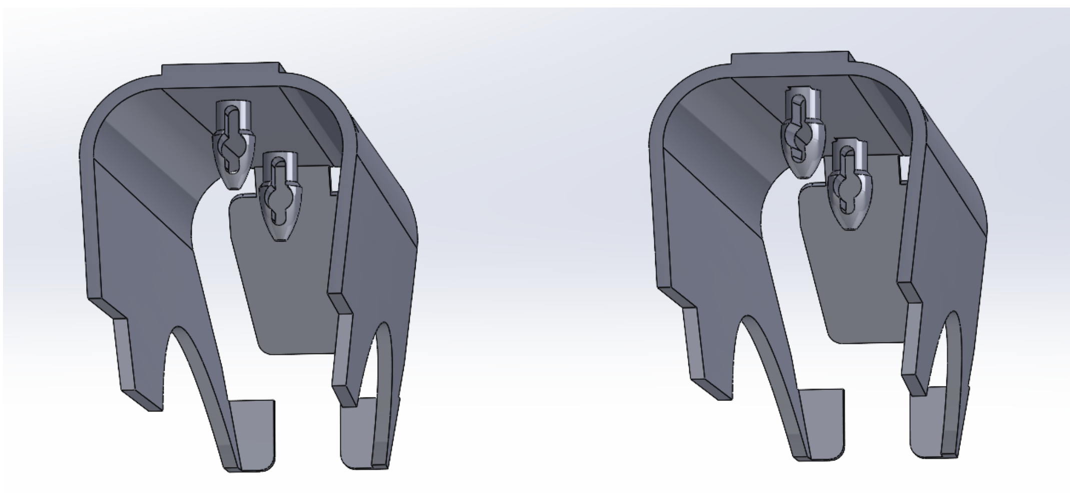

Figure 19: Sharpener Cover 1 with and without integrated snap (Bottom view)

Manufacturing Impact of Proposed Changes

In addition to improving our assembly efficiency, our proposed design modification also improved the manufacturability of several parts within the knife sharpener. Proposed design modifications 2 and 5 raise the difficulty of manufacturing, and design modifications 1, 3, and 4 lower it.

Design modification 2 involves adding 14 small grooves into a plastic and a metal part. The plastic features (Part 19: Steel Rotator Screw Holster) would be easily taken care of via injection molding. However, for the features on the metal part (Part 16: Steel Cylinder) these would take more time on the manufacturing line to machine, especially due to the numerous small nature of the groove features. Design modification 5 would also add to the manufacturing difficulty of the parts involved. Adding snap fits to the sharpener covers increases the complexity of the injection mold. This would be an upfront increase in cost but should have a smaller impact than the added machining features for design modification 2. Despite the increase in manufacturing difficulty the team still believes that these design modifications are a net good. Reducing the number of parts for the sharpener covers and the steeling assembly is worth the extra effort needed during manufacturing.

Design modifications 1, 3, and 4 lower the difficulty to manufacture their parts. Design modification 1 removes an unnecessary part from the redressing assembly. This is one less part that has to be inserted and manufactured for the knife sharpener. Design modification 3 is entirely based around easing the manufacturing process, and reduces the material and features required on the bottom chassis (Part 7). Design modification 4 standardizes a lot of the fasteners within the knife sharpener. This means that less different types of tooling processes will be needed during manufacturing.

<u>Component and Assembly Analysis</u>

Disassembly Procedure

Product Decomposition

Design Organization: MCEN 5045	**Date: 3/9/2023**

Product Decomposed: Chef's Choice Professional Sharpening Station 130

Description: The product is an electric knife sharpener. There are three sharpening stations within the sharpener that allow for a variety of sharpening methods on different types of knives.

How it works: The three sharpening stages are used for different purposes.

Disassembly:

Step #	Procedure	Part #s removed	Image
1	Remove top cover, sharpener covers, rubber feet, and surface level fasteners.	3, 4, 9, 13, 14, 17, 21, 40	

2	Remove motor shaft, electronics, redressing, blade guide, and steeling subassemblies.	43, 42, 11, 15, 33, 24, 20, 19, 16, 12, 8, 22, 26, 10	
3	Use vice, hammer, and chisel to remove retaining rings from motor shaft subassembly. Use hand tools and bare fingers to disassemble other subassemblies.	45, 30, 34, 37, 43, 38, 42, 41, 49, 48, 32, 38, 28, 47, 46, 1, 22, 26, 6, 2, 18, 29, 25	
4	Inventory, catalog, and divide up all parts.		

Links and drawing files:

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Team member: Jose Martinez	Approved by: Anna, Nolan, Jose, Iain
Team member: Iain Morgan	

Design for Assembly (DFA)

The original design for this knife sharpener assembly scored a 104.71 for its DFA Complexity due to its 85 total number of parts, and 129 interfaces between these parts. In order of highest (worst) score for other DFA metrics to lowest (best) were: “secondary operations- 5.0”, “insertion- 4.85”, “handling- 2.77”, and “error proofing- 1.92”. The theoretical efficiency was 15.30%, and the practical efficiency was 37.60%. The entire original assembly DFA metrics can be seen in Table 14, in Appendix C. The whole assembly was separated into its sub-assemblies for further analysis, which included Stage 1, Stage 2, Stage 3, Rotating, and the General Sub-Assemblies. Table 1 shows the DFA metrics for each original sub-assembly (and modified sub-assemblies). The General Sub-Assembly had the highest DFA Complexity, and Stage 3 had the lowest. The reason for the General Sub-Assembly having the highest DFA Complexity value is due to the amount of miscellaneous parts that were grouped there since they didn’t necessarily fit into a different sub-assembly category, so there’s just a greater number of parts belonging in this category. The next highest DFA Complexity sub-assembly was the Rotating Sub-assembly, which makes sense because it contains a lot of different mechanisms that essentially make Stage 1 and Stage 2 work.

Based on these results from the original design, the focus of modified design concepts were to reduce parts counts, and interactions between parts in order to decrease the metrics across the board, excluding the efficiencies of which were to hopefully be increased. A goal that this team set was to achieve approximately 5% increase in the majority of metrics.

	Sub-Assembly Name	DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
		Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/	Assemble Part Wrong Way	Tangle, Nest, or Stick	Flexible, Fragile, Sharp or	Pliers, Tweezers, or	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/	Re-orient Workpiece	Screw, Drill, Twist, Rivet,	Weld, Solder, or Glue	Paint, Lube, Heat, Apply	Test, Measure or Adjust
Original Design	Stage 1	21.21		16.7%	←Theor. Effy. Pract. Effy.→		33.3%	2.33		3.67			3.67				2.33				
	Stage 2	10.58		28.6%	←Theor. Effy. Pract. Effy.→		42.9%	2		3			5.5				4.5				
	Stage 3	5.66		25.0%	←Theor. Effy. Pract. Effy.→		50.0%	3		5			4				3				
	Rotating Assembly	32.5		13.60%	←Theor. Effy. Pract. Effy.→		40.90%	2.33		3			7				7				
	General Assembly	32.98		11.80%	←Theor. Effy. Pract. Effy.→		35.30%	1		1.25			4				6.25				
Modified Design	Stage 1	15.1		25.00%	←Theor. Effy. Pract. Effy.→		50.00%	1.67		3.67			3.33				2.33				
	Stage 2	4.58		33.30%	←Theor. Effy. Pract. Effy.→		66.70%	2		2			4				2				
	Stage 3	3.87		33.30%	←Theor. Effy. Pract. Effy.→		66.70%	2		3			4				2				
	Rotating Assembly	32.5		13.60%	←Theor. Effy. Pract. Effy.→		40.90%	2.33		3			7				7				
	General Assembly	30.98		37.50%	←Theor. Effy. Pract. Effy.→		37.50%	0.25		0.42			1.08				2				

Table 1: DFA Metric Comparison Between Original and Modified Designs

Table 1 shows that there were significant improvements across the board of the sub-assemblies, except for the Rotating Sub-Assembly; its components are optimized and cannot really be decreased, or changed unless there is a large design change implemented. For note, every metric that is shown in this table is either an improvement, or no change. There was not one metric that decreased in comparison to the original design. The largest improvement was seen in the Stage 2 Sub-Assembly with a 57% decrease in DFA complexity, although it was the only other sub-assembly to have no decrease in error proofing along with the rotating sub-assembly. This was because there wasn't much error possible with the components involved in the original sub-assembly, and even though the modified sub-assembly was only two parts, there just wasn't much improvement possible.

The modified design for this knife sharpener assembly scored an 88.99 for its DFA Complexity due to its 72 total number of parts, and 110 interfaces between these parts. In order of highest

	DFA Complexity	Functional Analysis / Redesign Opportunity			Error Proofing	Handling	Insertion	Secondary Operations
Stage 1	29%	33%	←Theor. Effy. Pract.	33%	28%	0%	9%	0%
Stage 2	57%	14%	←Theor. Effy. Pract.	36%	0%	33%	27%	56%
Stage 3	32%	25%	←Theor. Effy. Pract.	25%	33%	40%	0%	33%
Rotating Assembly	0%	0%	←Theor. Effy. Pract.	0%	0%	0%	0%	0%
General Assembly	6%	69%	←Theor. Effy. Pract.	6%	75%	66%	73%	68%

Table 2: DFA Metric Percent Change Comparison Between Original and Modified Designs Sub-Assemblies

(worst) score for other DFA metrics to lowest (best) were: "secondary operations- 4.83", "insertion- 4.33", "handling- 2.5", and "error proofing- 1.58". The theoretical efficiency was 16.67%, and the practical efficiency was 43.06%. The entire modified assembly DFA metrics can be seen in *Table 15*, in Appendix C. The only DFA metric that didn't see at least a 5% improvement from the original to the modified design, was the Secondary Operations, which only saw a 3% increase in metrics. Overall, our team reached our goal of achieving approximately 5% increase in the majority of metrics.

Design for Assembly Metrics	DFA Complexity	Functional Analysis / Redesign Opportunity			Error Proofing	Handling	Insertion	Secondary Operations
Old	104.71	15.30%	←Theor. Effy. Pract. Effy.→	37.60%	1.92	2.77	4.85	5
New	88.99	16.67%	←Theor. Effy. Pract. Effy.→	43.06%	1.58	2.50	4.33	4.83
Percent Change	15%	9%		15%	18%	10%	11%	3%

Table 3: DFA Metric Percent Change Comparison Between Original and Modified Designs

Material Analysis

In the following section, we will analyze each part by its function and determine what material is most suitable for the application. Where applicable, we will use Ashby charts to aid in the decision. Certain parts, like low stress, low wear injection molded parts, will be categorized together. Off-the-shelf hardware and electrical components will be left out of this section.

Main Chassis

1. Casing Components: Parts 023, 035, 036

The casing refers to the large, external pieces that hold the product together, protect users from touching the inner workings, and define the overall aesthetic of the product. They need to be strong enough to withstand vibration, occasional impact, and occasional knife scratches. They must also be easy to clean as the knife sharpener may be left out in a kitchen. The case of "plate in bending" will be used, leading to a required E^(⅓)/P slope, which is the red line pictured below. The line will also intersect with PTFE, since this is a close approximation of what the plastic used in the bottom chassis actually is. There are plenty of materials that meet the requirements in terms of density and Young's modulus, however when factoring in the need for less brittleness and prioritizing cost and lighter weight, plastics are still the only real option for the casing.

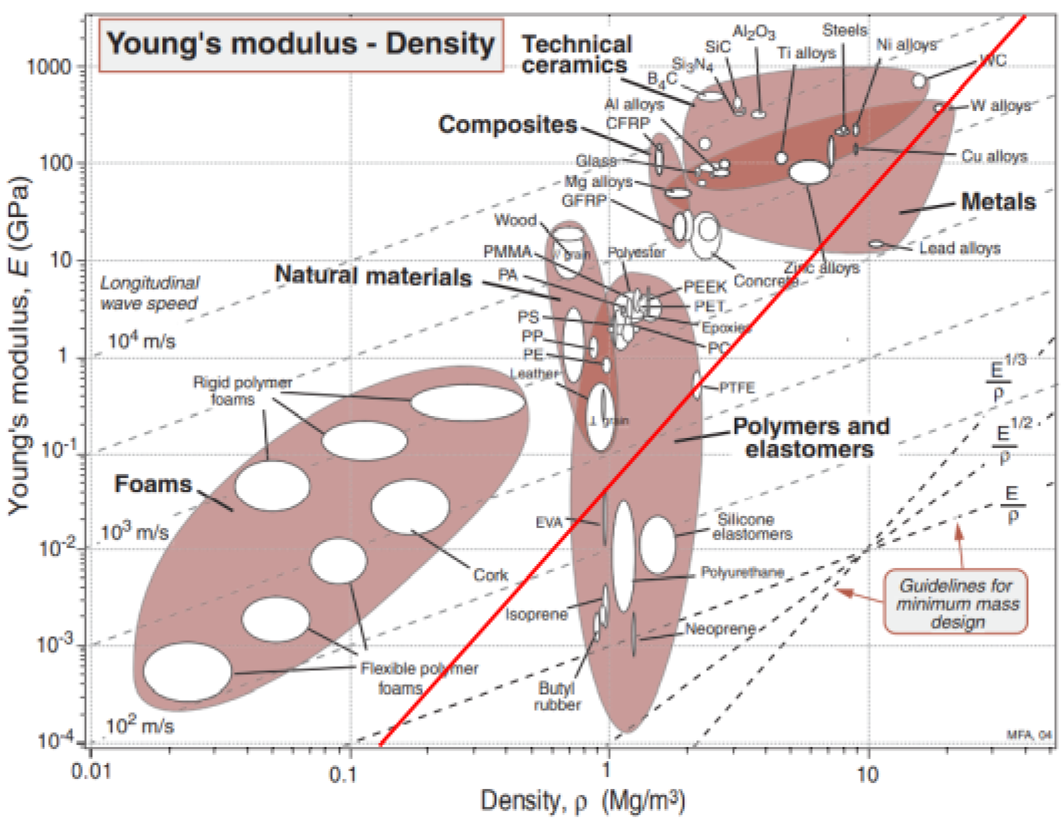

Figure 20: Ashby chart for casing components

2. **Rubber Foot: Part 004**

The Rubber foot has the unique material requirement of having high friction when in contact with common kitchen surfaces. This prevents it from moving around the table when in operation. It should also have a very low Young's modulus so that it is flexible enough to absorb vibrations. It's hard to say exactly what kind of rubber the feet are, but neoprene is probably a good guess. In that case, flexible polymer foams are the only other suitable options. In terms of vibration control, foams may work as well or better than rubber, but for grip, rubber is still the best option.

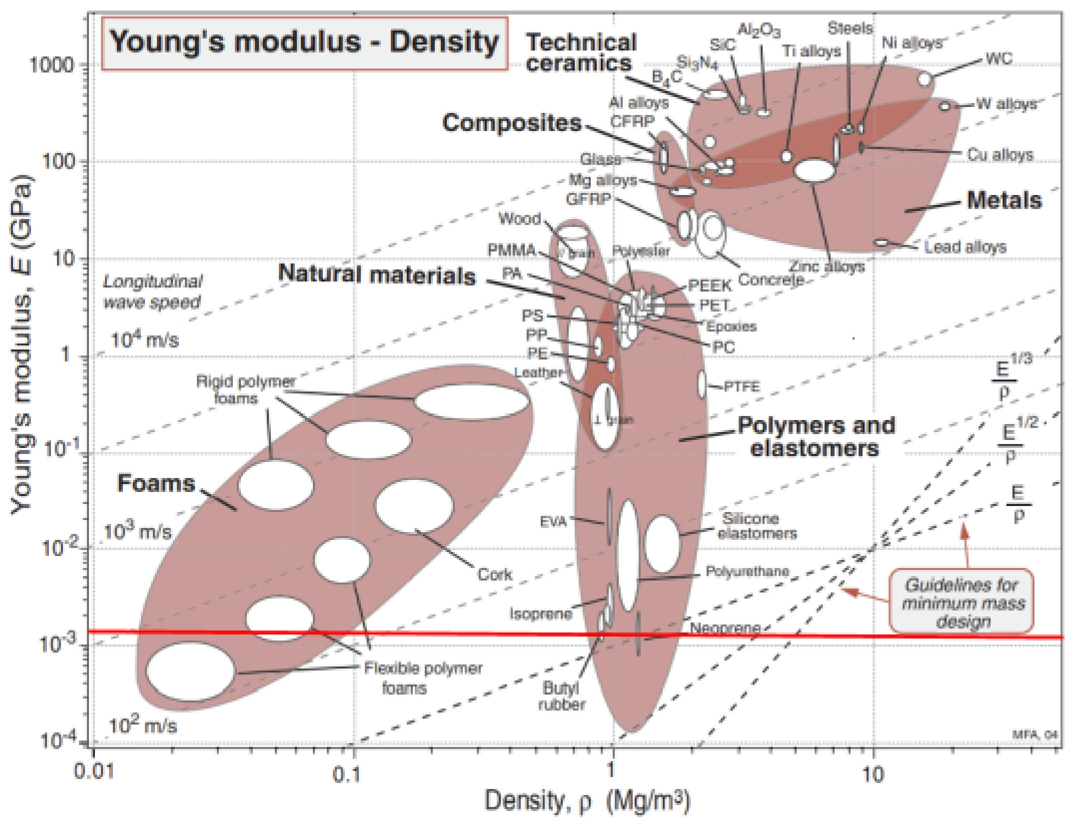

Figure 21: Ashby chart for Rubber Foot

3. **Shaving Collector Magnet: Part 025**

The shaving collector magnet is another special case. In order to do its job, it must be a magnet. It's hard to say exactly what material the magnet is, but since it's flexible, it's most likely an elastomer-ferrite powder mixture. The magnet must be easy to clean, so it actually shouldn't be so magnetic that this becomes difficult. As elastomer-ferrite powder magnets are some of the most inexpensive on the market, it is likely the best material for this application.

Motor Shaft

1. Motor Shaft: Part 033

The motor shaft transmits rotation from the motor to the grind wheels for stages 1 and 3. The shaft needs to remain rigid so that the product does not produce excessive vibration and needs to withstand the bending forces created by the knife pushing against the grind wheels. Because of this rigidity requirement, the shaft must have at least the Young's modulus of steel. The only viable materials (other than steels) are technical ceramics, and while they may function, they experience catastrophic failure that makes them undesirable. Steel will be used for the motor shaft.

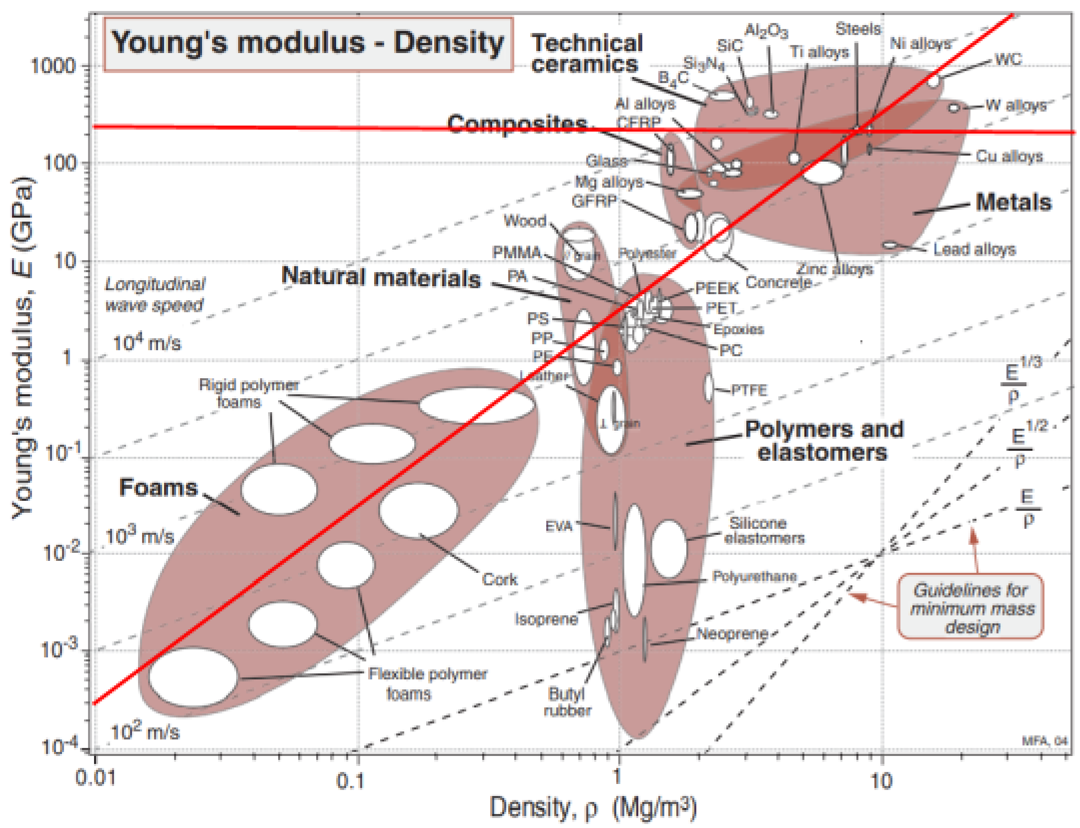

Figure 22: Ashby chart for Motor Shaft

2. Motor-Axle Alignment Block: Part 042

The motor-axle alignment block is a pair of parts that help orient and align the motor shaft. It needs to remain stiff so as to keep the motor shaft aligned under load. Using "E^(⅓)/p" (plate in bending) for the minimal weight to maximize stiffness, we see that in order to maintain this performance index and at least the current Young's modulus, our options are aluminum alloys, most composites, and some technical ceramics. Given that composites would be too expensive for this application and ceramics can't hold a bearing (another key component of this part), continuing with an aluminum alloy seems to be the right decision.

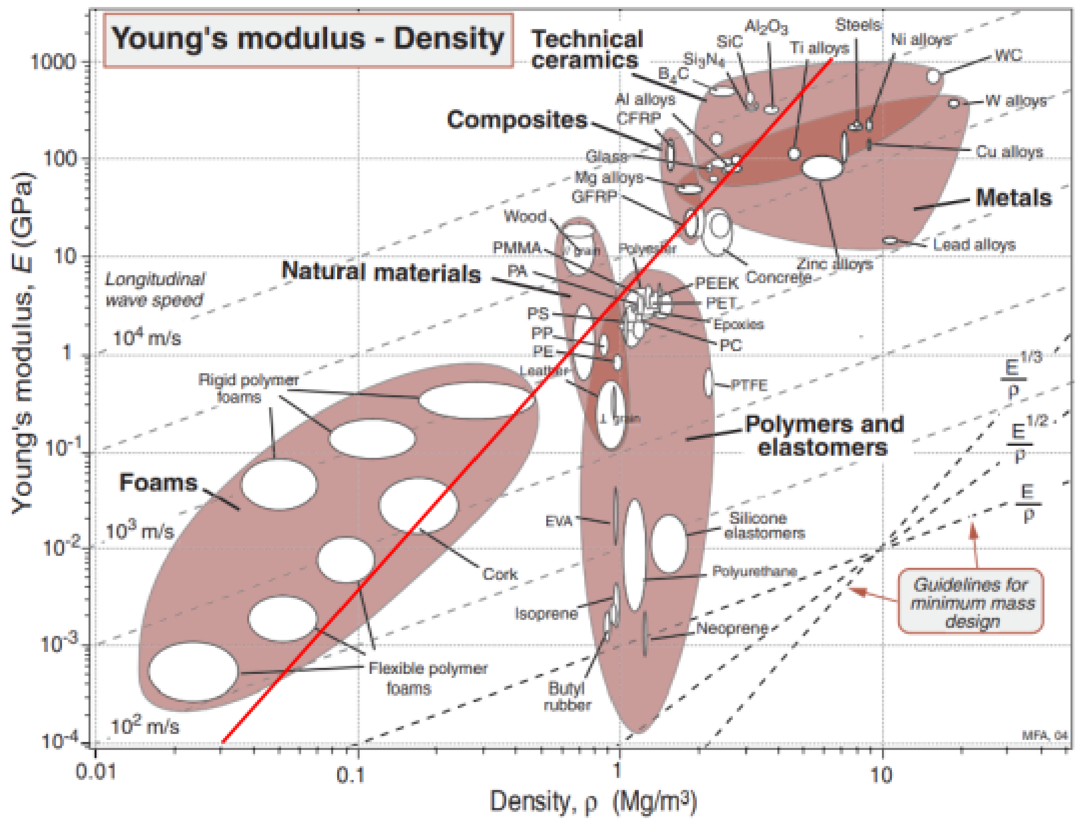

Figure 23: Ashby chart for Motor-Axle Alignment Block

3. Ceramic Grind Wheel: Part 011

The purpose of the ceramic grind wheel is to polish the edge of the blade. This must be done with a very fine abrasive to ensure a razor sharp edge. There are many abrasives available, ranging from compounds or pastes like red rouge that are applied to a polishing wheel to compounds that are applied onto surfaces like emery boards or diamond stones. Others, like whetstones, require a liquid solution for sharpening. Ceramics, while not the highest performing abrasive material, have a variety of attributes that make them ideal for this application. They are inexpensive, relatively durable, and come in solid form. They do not need a solution or compound applied to them to work. Additionally, they can be redressed (cleaned) with a rougher abrasive (in this case sandpaper) to clean off metal dust and restore the surface of the grind wheel.

4. Steel Grind Wheel: Part 015

It's difficult to say exactly what the steel grind wheels are made of. The wheels themselves are steel and have had some sort of abrasive, perhaps diamond or carbide applied to the grinding surface. While the ceramic grind wheel benefits from redressing, the coarser abrasion of the steel grind wheel lends itself to an applied grinding compound, which is cheaper and adequately durable to not require replacement or redressing.

5. **Alignment Block Bushing Cover: Part 043**

The alignment block bushing cover must come into contact with the motor shaft at high RPMs without marring the shaft. The original part is copper, which is a good choice because of its low friction against steel. However, brass has similar properties and is cheaper, so we will use brass for the final design.

6. **5/16" x 7/16" Bushing: Part 038**

The 5/16" x 7/16" bushing, like the alignment block bushing cover, must come into contact with the motor shaft at high RPMs. It must have similar material properties, and is already made of brass, which we will use in the final design.

Redressing

1. **Sharpening Steel: Part 026**

The sharpening steel is a small steel plate coated in abrasives that is used to shave off a layer of (redress) the ceramic grind wheels when they get clogged with metal. It is a similar material to the steel grind wheels and suitable for similar reasons. It needs to be durable enough to withstand removing material from the ceramic grind wheels at high RPMs but unlike the ceramic grind wheels, will not itself be redressed.

Steeling

2. **Steel Cylinder: Part 016**

The steel cylinder is the second stage sharpening device in the three stages of the knife sharpener. It’s needed to create a microscopically serrated (steeled) edge. Using the Ashby chart from “Materials Selection in Mechanical Design”, Figure 17.4, the soft to hard property axis was used, and since the original part is steel, the selection line goes on steel. Since the part is used to sharpen metal knives, the part must have hardness equal to or greater than steel, meaning anything to the right of the selection line is good to use. Glass ceramic will be used instead of steel due to glass ceramic being lower cost than steel, with about the same hardness (steel knife sharpening capability).

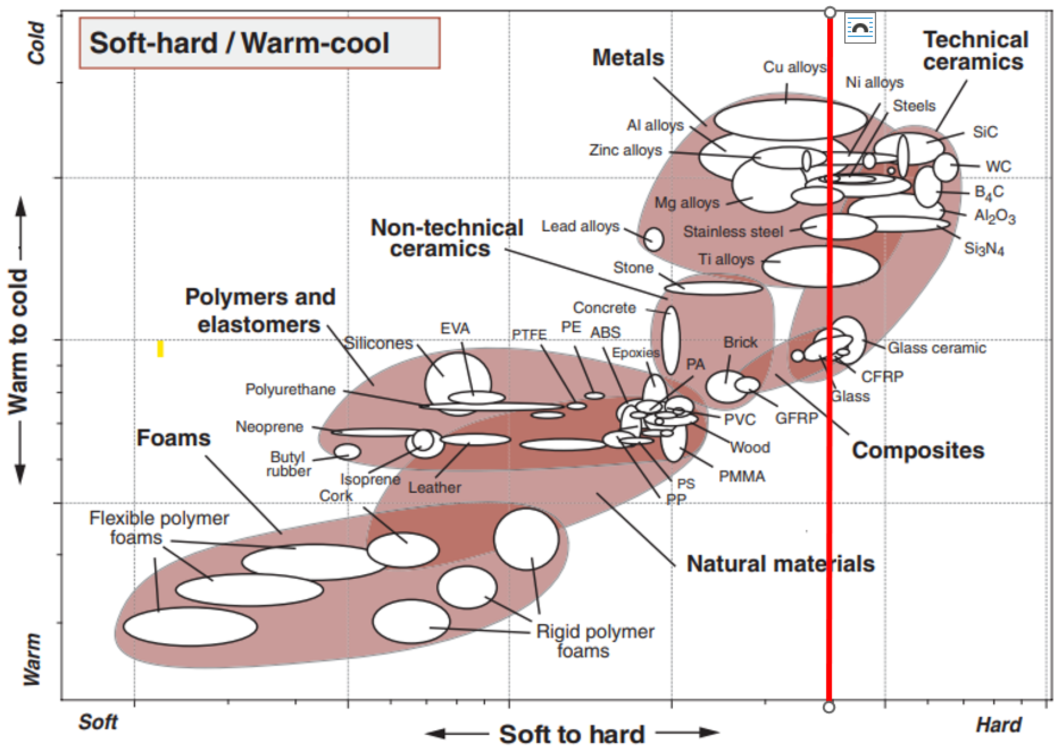

Figure 24: Ashby chart for Steel Cylinder

Injection Molded Plastic Components

Parts 001, 003, 005, 008, 009, 012, 013, 017, 019, 021, 022, 029

We've put all of the following parts into one category since they all experience similar loads and in the original design are all made from the same injection molded plastic. It's difficult to say exactly what kind, but we know that in this product they require a moderate level of stiffness to ensure parts have rigidity and spring. We guess that they are made from polyethylene and use "(E^0.5)/P" as the guideline for minimum mass design for maximum stiffness. The figure below shows the acceptable materials to use for material selection. Based on the Ashby chart, polyethylene and polypropylene are two inexpensive choices. Polypropylene is cheaper than polyethylene by about 80 cents per kilogram, therefore we choose polypropylene.

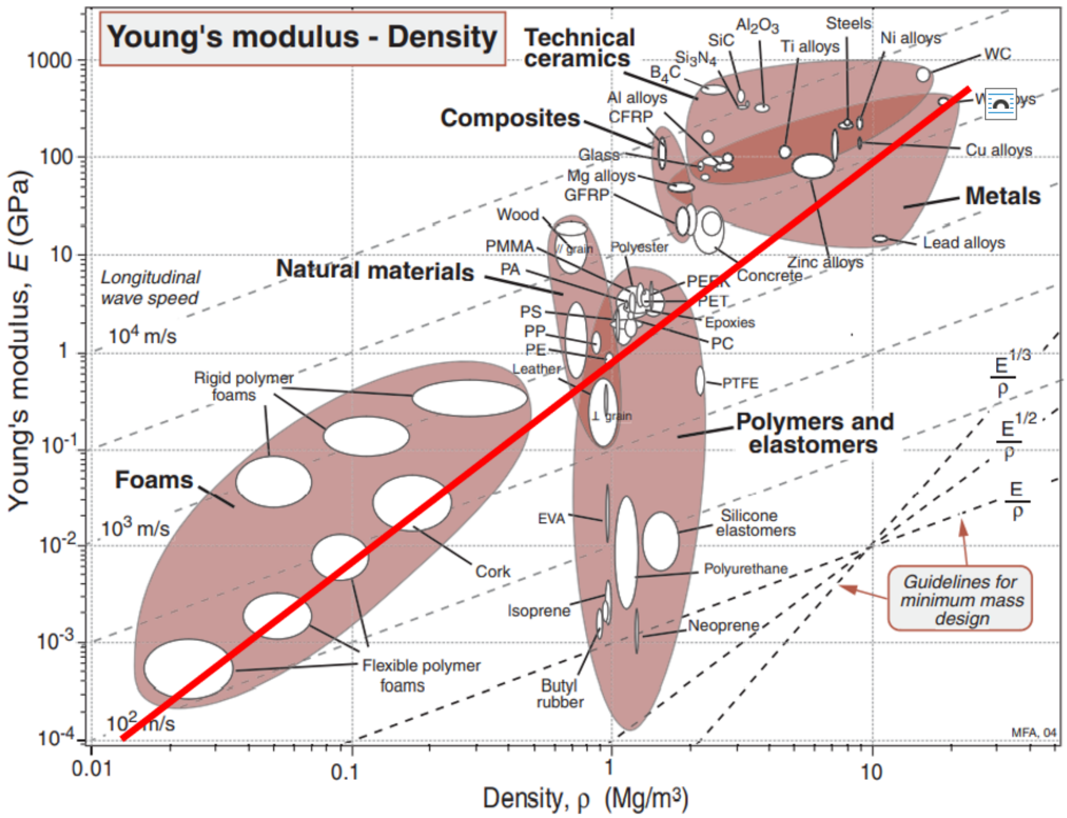

Figure 25: Ashby chart for injection molded plastic components

Process Selection

Many of the parts in this design are made from materials that lend themselves to an obvious manufacturing process. For example, the small plastic parts will largely be injection molded as at scale, this is the most economical and practical method. The steel motor shaft, on the other hand, must be ground in order to achieve tolerances necessary for its function. We will analyze the top cover (Part 040), as it could lend itself to multiple processes. Though we decided in the materials selection section that plastic is the optimal material to use for it, the cover could also be made of metals, composites, ceramics, or even some natural materials.

Theoretically, the part could be made with die casting, investment casting, permanent molding, sand casting, polymer casting, injection molding, or milling. We estimate that our batch size will be at least 500,000, which immediately eliminates investment casting, sand casting, polymer casting, and milling.

Between the three remaining options, die casting, permanent molding, and injection molding, we can compare cycle time, flexibility, material utilization, quality, and equipment tooling costs. The table below shows rankings for each. 1 is the poorest, 5 is the best.

Process	Cycle Time	Flexibility	Material Utilization	Quality	Equipment Tooling Costs	Average Score
Die Casting	5	1	4	2	1	2.6
Permanent Molding	4	2	2	3	2	2.6
Injection Molding	4	1	4	3	1	2.6

Table 4: Ratings of Manufacturing Processes

All three processes have the same average score. Therefore we can assume they are fairly comparable in terms of viability. This logically makes sense as the three are somewhat similar processes.

However, die casting and permanent molding are used for metals, whereas injection molding is used for plastic. Assuming the same part volume, plastic will have the least cost by far. It is also possible to achieve a wide range of colors and surface finishes with injection molding, therefore, it is the optimal process for making the top cover.

Cost Analysis

The main cost analysis in this report uses order of magnitude estimates (OMEs) to compare costs before and after the proposed changes to the product. These estimates were also used to conduct break even calculations to determine the selling price needed to break even over a 500,000 unit production run. Since several of the parts in this product are standard off-the-shelf components, cost estimates based on McMaster-Carr prices were used for those components, not OMEs. Full calculation tables for OMEs for the original design and the new design as well as costing for off-the-shelf components can be found in Appendix B.

Analyzing the cost to produce a product is critical during the design phase so that any changes made can have an associated cost change as well. The team thought it pertinent then to cover these changes in this product. Overall, OMEs yield a cost to produce the original design of $65.77 and a cost to produce the redesigned product of $64.08, which is a savings of $1.69 per unit. Over a 500,000 unit production run, this equates to $845,000 saved. The selling price required to break even for 500,000 units is $66.30 for the original design and $64.61for the new design. If the true selling price remains the same for both designs, this means the redesign will yield a larger profit. A table summarizing these results as well as the break even calculations can be found below.

Original OME for In-House Parts ($/unit)	34.39
Original Cost of Off-The-Shelf Parts ($/unit)	31.38
OME Total Cost of Original Design ($/unit)	65.77
Redesign OME for In-House Parts ($/unit)	32.71
Redesign Cost of Off-The-Shelf Parts ($/unit)	31.37
OME Total Cost of Redesign ($/unit)	64.08
Decrease in Cost Between Designs ($/unit)	1.69
Original Break-Even Point ($/unit)	66.3
Redesign Break-Even Point ($/unit)	64.61
Total Savings from Redesign Across Production Run ($)	845000

Table 5: Summary of OMEs for original and redesigned product

	Original	Modified
G&A ($/month)	3000	3000
Depreciation ($/month)	1500	1500
Factory Expenses ($/month)	10000	10000
Sales/OH ($/month)	30000	30000
Months of MFG (months)	6	6
Total Fixed Costs	267000	267000
Total Variable Cost	65.77	64.08
Production Run	500000	500000
Break Even Price	**66.304**	**64.614**

Table 6: Break even calculations

The team also thinks it would be pertinent to include a comparison between three different methods of estimating the costs of the various components. Only eight of the components were studied in this fashion as this section is intended to merely provide a comparison between the different methods. These three methods are using a full unit cost calculation, OMEs, and estimates from CustomPartNet.com. The full unit cost calculation sums material cost, labor cost, tooling cost, equipment cost, and overhead cost. OMEs provide a more crude estimate based on material cost per pound, part weight, and the estimated scrap fraction. CustomPartNet.com provides an estimate on the cost per unit based on fields such as the volume and mass of the part, complexity, and desired manufacturing method. Since all three methods calculate the part cost differently, they all yield different estimates. The true cost to produce the part is likely between the three estimates. Overall, CustomPartNet.com yielded the lowest estimates for part cost, with full unit cost calculations yielding a slightly higher estimate, and OMEs yielding the highest estimate. A table showing both the full unit calculations and comparison between the different estimation methods is provided below.

	Steel Rotator Screw Insert	Steel Rotator Screw	Shaving Collecter Holder	Top Cover	Stage 1 Cover	Steel Rotator Screw Holster	Motor-Axle Alignment Block	Plastic Holder for Sharpening Steel
Material Weight (lb)	0.0037	0.051	0.005	0.273	0.125	0.206	0.2	0.1
Cost of Material ($/lb)	0.6	0.6	2	2	0.6	0.6	0.6	1.2
Scrap Fraction	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.05
Material Cost	0.00233684	0.03221053	0.01052632	0.57473684	0.07894737	0.13010526	0.13333333	0.12631579
Wage ($/hr)	15	15	15	15	15	15	15	15
Production Rate (units/hr)	1000	1000	1000	350	1000	1000	250	1000
Labor Cost	0.015	0.015	0.015	0.04285714	0.015	0.015	0.06	0.015
Tool Cost ($)	15000	15000	15000	15000	15000	15000	15000	15000
Production Run (# parts)	500000	500000	500000	500000	500000	500000	1000000	500000
Tool Life (# parts)	200000	200000	200000	200000	200000	200000	200000	200000
Tool Wear Factor	3	3	3	3	3	3	5	3
Tooling Cost ($)	0.09	0.09	0.09	0.09	0.09	0.09	0.075	0.09
Equipment Cost	250000	250000	250000	250000	250000	250000	250000	250000
Load Factor	1	1	1	1	1	1	1	1
Write-Off Time	500	500	500	500	500	500	1000	500
Equipment Sharing	0.12	0.12	0.12	0.12	0.12	0.12	1	0.12
Equipment Cost	0.06	0.06	0.06	0.17142857	0.06	0.06	1	0.06
OH Rate ($/hr)	100	100	100	100	100	100	100	100
OH Cost	0.1	0.1	0.1	0.28571429	0.1	0.1	0.4	0.1
Part Cost	0.26733684	0.29721053	0.27552632	1.16473684	0.34394737	0.39510526	1.66833333	0.39131579
CustomPartNet.com	0.145	0.164	0.145	1.069	0.1	0.165	0.46	0.07
OME	0.00378	0.2835	0.070875	3.82725	1.771875	2.835	1.188	1.89

Table 7: Full unit cost calculations and comparisons between the three estimation methods

Gantt Chart

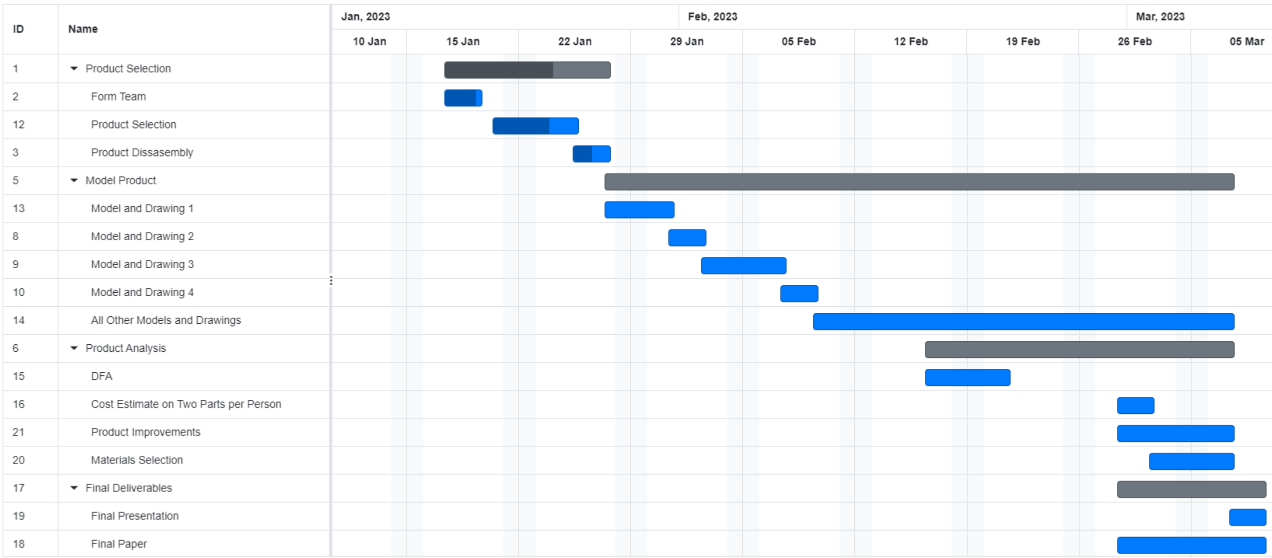

Figure 26: Gantt Chart depicting the schedule of this reverse engineering project.

Ethical Considerations

The primary objective of this project is to decrease the cost of producing a product. However, in the process, we need to be sure our design decisions do not cause harm to people working in manufacturing, people working in assembly, users of the final product, people working to dispose of the product, people working to fix the product, etc.

Since our product does not contain hazardous waste or other substances harmful to the people who interact with it, our primary concerns are sharp edges and rotating parts. The blade guides, for example, are relatively complex parts. They could be simplified a great deal by removing the section that wraps over the top of the grind wheels, but this would create a dangerous pinch point for users and assemblers testing the product.

Another ethical concern is the ability for users or repair people to take apart and fix the product. Permanent snap fittings, for example, may prevent or seriously impede this. Because the knife sharpener is an expensive and robust product, we want to make sure that access to its inner workings are not impeded. The product was possible to disassemble/reassemble when we started, and we made sure to keep it that way.

Certain assemblies also aid in the durability and longevity of the product. The redressing assembly, for example, allows stage 3 to be cleaned when it becomes clogged with metal. Removing this assembly would decrease the cost of producing the product, but would make it very difficult for the user to keep stage 3 clean and would ultimately cut short the life of the product.

Conclusion

The goals of this project were to gain an intimate understanding of the *Chef's Choice* Professional Sharpening Station 130 and to utilize the methods discussed in class to improve the product and to have those improvements backed by data. Both of these goals were achieved, and the team is happy with our results and what we learned throughout this project.

Accomplishing goal 1 began with the disassembly of the knife sharpener. Initially it was just unscrewing and removing parts, but there were hiccups with the motor shaft and snap-on retaining rings being difficult to come out. The obstacles were overcome by our use of a hammer, vice, and chisel. Through the disassembly process we were able to learn how the knife sharpener worked and what parts went into each subsystem. We grew our understanding of the knife sharpener by analyzing its assembly, material, cost, and other design decisions. This in-depth analysis was what allowed us to find ways to improve the design of the knife sharpener, which was our second main goal for this project.

Our team was able to come up with five distinct improvements to the knife sharpener: (1) Combining two parts in the redressing assembly, (2) reducing parts in the steeling assembly, (3) Reducing material and features on the bottom chassis, (4) Standardizing fasteners across the whole product, and (5) removing fasteners and adding snap fits to the sharpener covers. Each of these changes was evaluated in our DFA analysis. Implementing all five design modifications resulted in efficiency improvements in every subassembly except for the Rotating assembly, and that is only because that subassembly is already extremely optimized without much room for improvement.

This project was an in-depth practice of the methods taught in MCEN 5045. All of the team members learned via direct practice of the methods shown in class. An in-depth understanding of the knife sharpener was obtained, along with several modifications that would improve the product overall. Everyone feels that they have grown throughout the project, are grateful for the experience, and are excited to reinvent using a butter stick in the kitchen over the remainder of the semester using the lessons learned from the knife sharpener and from in class.

Acknowledgements

We would like to acknowledge Professor Dan Riffell for guidance in making our engineering drawings and all things DFMA. We would also like to acknowledge whoever donated their Chef'sChoice® Professional Sharpening Station® Model 130 to Goodwill, allowing us to purchase it at an 85% discount.

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https://custompartnet.com/

Appendices

Appendix A: Original, and Modified Design Bills of Materials

Original Design: Bill of Materials

Product : Chef's Choice Professional Sharpening Station 130	Date: 3/9/2023

Line Item #	Part #	Qty	Name	Material
Electronics				
1	049	1	I/O Switch	Off the Shelf
2	048	1	120v wire/plug	Off the Shelf
3	032	1	Fan Retaining Clip	Thermoplastic
4	038	1	Fan Inlet Shroud	Thermoplastic
5	028	1	Motor Fan	Thermoplastic
6	047	1	Motor Rotor	Off the Shelf
7	046	1	Motor Stator	Off the Shelf
Redressing				
8	001	1	Bottom Snap Insert	Thermoplastic
9	005		Bottom Snap	Thermoplastic
10	022	1	Plastic Holder for Sharpening Steel	Thermoplastic
11	026	2	Sharpening Steel	Steel, Abrasives
Motor Shaft				
12	045	2	Retaining Ring	Off the Shelf
13	030	1	Axle Spring .7"	Carbon steel
14	034	1	Axle Spring .6"	Carbon steel
15	037	2	Motor Shaft Pin	Off the Shelf
16	043	2	Alignment Block Bushing Cover	Copper
17	038	2	5/16" x 7/16" Bushing	Brass
18	042	2	Motor Axle Alignment Block	Aluminum A380
19	041	2	Motor Shaft Bearing	Off the Shelf
20	011	2	Ceramic Grind Wheel	Ceramic

21	015	2	Steel Grind Wheel	Steel, Abrasives
22	033	1	Motor Shaft	Steel
Blade Guide				
23	023	1	Main Sharpening Chassis	Thermoplastic
24	013	1	Sharpener Cover 1	Thermoplastic
25	017	1	Sharpener Cover 2	Thermoplastic
26	021	1	Sharpener Cover 3	Thermoplastic
27	003	1	Stage 1 Cover	Thermoplastic
28	009	9	Sharpener Cover Snap	Thermoplastic
Second Stage Steeling				
29	024	1	Small Steel Rotator Screw Insert Gasket	Off the Shelf
30	020	1	Large Steel Rotator Screw Gasket	Off the Shelf
31	019	1	Steel Rotator Screw Holster	Thermoplastic
32	016	1	Steel Cylinder	Steel
33	012	1	Steel Rotator Screw Insert	Thermoplastic
34	008	1	Steel Rotator Screw	Thermoplastic
Main Chassis				
35	007	1	Bottom Chassis	Thermoplastic
36	040	1	Top Cover	Thermoplastic
37	029	1	Shaving Collector Holder	Thermoplastic
38	025	1	Shaving Collector Magnet	Elastomer and Ferrite
39	004	4	Rubber Foot	Rubber
Fasteners				
40	002	2	#5-20 UNC ¼ " x ¾ " Fastener	18-8 Stainless Steel
41	006	2	#5-40 UNC ¼ " x ½ " Fastener	18-8 Stainless Steel
42	010	2	#5-40 UNC ¼" x 2.5" Fastener	18-8 Stainless Steel
43	014	5	#5-40 UNC ¼ " x 1" Fastener	18-8 Stainless Steel
44	018	2	5/16" x ⅛ " Nut	18-8 Stainless Steel

Team member: Anna Lugthart	Prepared by: Anna, Nolan, Jose, Iain
Team member: Nolan Major	Checked by: Anna, Nolan, Jose, Iain
Team member: Jose Martinez	Approved by: Anna, Nolan, Jose, Iain
Team member: Iain Morgan	

Table 8: Original Design Bill of Materials.

Modified Design: Bill of Materials

Product : Chef’s Choice Professional Sharpening Station 130	Date: 3/9/2023

Line Item #	Part #	Qty	Name	Material
Electronics				
1	049	1	I/O Switch	Off the Shelf
2	048	1	120v wire/plug	Off the Shelf
3	033	1	Fan Retaining Clip	Steel
4	036	1	Fan Inlet Shroud	Thermoplastic
5	028	1	Motor Fan	Thermoplastic
6	047	1	Motor Rotor	Thermoplastic
7	046	1	Motor Stator	Off the Shelf
Redressing				
9	005	1	Bottom Snap	Thermoplastic
10	022	1	Plastic Holder for Sharpening Steel	Thermoplastic
28	026	1	Sharpening Steel	Steel
Motor Shaft				
11	045	1	Retaining Ring	Off the Shelf
12	030	2	Axle Spring .7"	Carbon Steel
14	037	1	Motor Shaft Pin	Off the Shelf
15	043	1	Alignment Block Bushing Cover	Brass
16	038	1	5/16" x 7/16" Bushing	Brass
17	042	1	Motor Axle Alignment Block	Aluminum A380
18	041	1	Motor Shaft Bearing	Off the Shelf
19	011	2	Ceramic Grind Wheel	Ceramic
20	015	2	Steel Grind Wheel	Steel, Abrasives
21	033	1	Motor Shaft	Steel
Blade Guide				
22	023	1	Main Sharpening Chassis	Thermoplastic
23	013	1	Sharpener Cover 1	Thermoplastic
24	017	1	Sharpener Cover 2	Thermoplastic

25	021	1	Sharpener Cover 3	Thermoplastic
26	003	1	Stage 1 Cover	Thermoplastic
Second Stage Steeling				
31	019	1	Steel Rotator Screw Holster (Modified)	Thermoplastic
32	016	1	Steel Cylinder (Modified)	Steel
Main Chassis				
35	007	1	Bottom Chassis	Thermoplastic
36	040	1	Top Cover	Thermoplastic
37	029		Shaving Collector Holder	Thermoplastic
38	025	1	Shaving Collector Magnet	Elastomer, Ferrite
39	004	4	Rubber Foot	Rubber
Fasteners				
40	002	7	#5-20 UNC ¼ " x ¾ " Fastener	18-8 Stainless Steel
41	006	2	#5-40 UNC ¼ " x ½ " Fastener	18-8 Stainless Steel
42	010	2	#5-40 UNC ¼" x 2.5" Fastener	18-8 Stainless Steel
44	018	2	5/16" x ⅛ " Nut	18-8 Stainless Steel

Team member: Anna Lugthart	Prepared by: Anna, Nolan, Jose, Iain
Team member: Nolan Major	Checked by: Anna, Nolan, Jose, Iain
Team member: Jose Martinez	Approved by: Anna, Nolan, Jose, Iain
Team member: Iain Morgan	

Table 9: Modified Design Bill of Materials.

Appendix B: Additional Cost Estimation Tables

	Fan Inlet Shroud	Bottom Snap Insert	Bottom Snap	Plastic Holder for Sharpening Steel	Sharpening Steel	Motor-Axle Alignment Block	Ceramic Grind Wheel	Steel Grind Wheel	Motor Shaft	Main Sharpening Chassis	Sharpener Cover 1	Sharpener Cover 2	Sharpener Cover 3	Stage 1 Cover	Sharpener Cover Snap	Steel Rotator Screw Holster	Steel Cylinder	Steel Rotator Screw Insert	Steel Rotator Screw	Bottom Chassis	Top Cover	Shaving Collecter Holder
Material Weight (lb)	0.1	0.05	0.1	0.1	0.01	0.2	0.2	0.2	0.4	0.2	0.125	0.125	0.125	0.125	0.05	0.2	0.07	0.004	0.02	0.3	0.27	0.005
Cost of Material ($/lb)	1.5	1.5	1.5	2	0.1	0.6	1	0.1	0.1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.1	0.1	1.5	1.5	1.5	1.5
Scrap Fraction	0.05	0.05	0.05	0.05	0.01	0.1	0.05	0.15	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
OME Material	0.1575	0.07875	0.1575	0.21	0.00101	0.132	0.21	0.023	0.044	0.315	0.196875	0.196875	0.196875	0.196875	0.07875	0.315	0.00735	0.00042	0.0315	0.4725	0.42525	0.007875
OME Mfg	0.4725	0.23625	0.4725	0.63	0.00303	0.396	0.63	0.069	0.132	0.945	0.590625	0.590625	0.590625	0.590625	0.23625	0.945	0.02205	0.00126	0.0945	1.4175	1.27575	0.023625
OME Price	1.4175	0.70875	1.4175	1.89	0.00909	1.188	1.89	0.207	0.396	2.835	1.771875	1.771875	1.771875	1.771875	0.70875	2.835	0.06615	0.00378	0.2835	4.2525	3.82725	0.070875
Quantity	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total	1.4175	0.70875	1.4175	1.89	0.01818	2.376	3.78	0.414	0.396	2.835	1.771875	1.771875	1.771875	1.771875	0.70875	2.835	0.06615	0.00378	0.2835	4.2525	3.82725	0.070875

Table 10: Original design OMEs

	I/O Switch	120V wire/Plug	Motor/Fan Assembly	Retaining Ring	Axle Spring 0.7"	Axle Spring 0.6"	Motor Shaft Pin	Alignment Block Bushing Cover	5/16" x 7/16" Bushing	Motor Shaft Bearing	Small Steel Rotator Screw Insert Gasket	Steel Rotator Screw Gasket	Shaving Collecter Magnet	Rubber Foot	#5-20 UNC 1/4"x3/4" Fastener	#5-40 UNC 1/4"x1/2" Fastener	#5-40 UNC 1/4"x2.5" Fastener	#5-40 UNC 1/4"x1" Fastener	5/16"x1/8" Nut
Off the Shelf Price ($)	3	2.5	20	0.01	0.05	0.05	0.03	0.02	0.05	1	0.005	0.005	4	0.005	0.05	0.05	0.05	0.05	0.01
Quantity	1	1	1	1	1	1	1	2	2	1	1	1	1	4	2	2	2	5	2
Total	**3**	**2.5**	**20**	**0.01**	**0.05**	**0.05**	**0.03**	**0.04**	**0.1**	**1**	**0.005**	**0.005**	**4**	**0.02**	**0.1**	**0.1**	**0.1**	**0.25**	**0.02**

Table 11: Original design off-the-shelf component costs

	Fan Inlet Shroud	Bottom Snap	Plastic Holder for Sharpening Steel	Sharpening Steel	Motor-Axle Alignment Block	Ceramic Grind Wheel	Steel Grind Wheel	Motor Shaft	Main Sharpening Chassis	Sharpener Cover 1	Sharpener Cover 2	Sharpener Cover 3	Stage 1 Cover	Steel Rotator Screw Holster	Steel Cylinder	Bottom Chassis	Top Cover	Shaving Collecter Holder
Material Weight (lb)	0.1	0.1	0.1	0.01	0.2	0.2	0.2	0.4	0.2	0.125	0.125	0.125	0.125	0.2	0.1	0.3	0.27	0.005
Cost of Material ($/lb)	1.5	1.5	2	0.1	0.6	1	0.1	0.1	1.5	1.5	1.5	1.5	1.5	1.5	0.1	1.5	1.5	1.5
Scrap Fraction	0.05	0.05	0.05	0.01	0.1	0.05	0.15	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
OME Material	0.1575	0.1575	0.21	0.00101	0.132	0.21	0.023	0.044	0.315	0.196875	0.196875	0.196875	0.196875	0.315	0.0105	0.4725	0.42525	0.007875
OME Mfg	0.4725	0.4725	0.63	0.00303	0.396	0.63	0.069	0.132	0.945	0.590625	0.590625	0.590625	0.590625	0.945	0.0315	1.4175	1.27575	0.023625
OME Price	1.4175	1.4175	1.89	0.00909	1.188	1.89	0.207	0.396	2.835	1.771875	1.771875	1.771875	1.771875	2.835	0.0945	4.2525	3.82725	0.070875
Quantity	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
Total	1.4175	1.4175	1.89	0.01818	2.376	3.78	0.414	0.396	2.835	1.771875	1.771875	1.771875	1.771875	2.835	0.0945	4.2525	3.82725	0.070875

Table 12: New design OMEs

	I/O Switch	120V wire/Plug	Motor/Fan Assembly	Retaining Ring	Axle Spring 0.7"	Motor Shaft Pin	Alignment Block Bushing Cover	5/16" x 7/16" Bushing	Motor Shaft Bearing	Shaving Collecter Magnet	Rubber Foot	#5-20 UNC 1/4"x3/4" Fastener	#5-40 UNC 1/4"x1/2" Fastener	#5-40 UNC 1/4"x2.5" Fastener	5/16"x1/8" Nut
Off the Shelf	3	2.5	20	0.01	0.05	0.03	0.02	0.05	1	4	0.005	0.05	0.05	0.05	0.01
Quantity	1	1	1	1	2	1	2	2	1	1	4	7	2	2	2
Total	**3**	**2.5**	**20**	**0.01**	**0.1**	**0.03**	**0.04**	**0.1**	**1**	**4**	**0.02**	**0.35**	**0.1**	**0.1**	**0.02**

Table 13: New design off-the -shelf component costs

Appendix C: DFA Metric Data Tables

Original DFA Analysis Worksheet

Assembly Name: Chef's Choice Knife Sharpener 130 **Team:** Anna L., Nolan M., Iain M., Jose M. **Date:** 2/20/2023

If the answer is Yes to any of the metrics or questions enter a 1. If the answer is No then enter 0. Each cell must have a number.

Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name	Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/ Omit Part	Assemble Part Wrong Way Around	Tangle, Nest, or Stick Together	Flexible, Fragile, Sharp or Slippery	Pliers, Tweezers, or Magnifying Glass Needed	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility	Re-orient Workpiece	Screw, Drill, Twist, Rivet, Bend, or Crimp	Weld, Solder, or Glue	Paint, Lube, Heat, Apply Liquid or Gas	Test, Measure or Adjust
	Stage 1 Sub-Assembly																				
5	Steel Grind Wheel	2	2	1	0	M	1	1	0	0	1	0	1	0	0	0	0	0	0	1	0
3	Stage 1 Cover	1	2	0	0	L	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0
1	Bottom Snap Insert	1	2	0	1	L	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
5	Bottom Snap	1	3	0	0	L	0	1	0	1	1	0	0	1	0	1	0	1	0	0	1
5	Shaving Collector Magnet	1	1	1	0	L	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0
9	Shaving Collector Magnet Holder	1	2	0	0	L	1	0	0	1	0	0	0	0	1	1	1	0	0	0	0
3	Sharpener Cover 1	1	3	0	1	L	1	1	0	1	1	0	1	1	0	1	0	1	0	0	0
9	Sharpener Cover Snap	6	4	0	0	L	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	PLASTIC HOLDER FOR SHARPENING STEEL	1	2	0	0	L	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
6	SHARPENING STEEL	2	1	1	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	AXLE SPRING .7"	1	3	0	0	L	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0
	Stage 2 Sub-Assembly																				
7	Sharpener Cover 2	1	4	0	1	L	1	1	1	1	1	0	1	1	0	1	0	1	0	0	0
3	steel rotator screw	1	2	1	1	L	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0
2	steel screw insert	1	2	0	0	L	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
6	steel cylinder	1	1	1	1	M	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0
0	large gasket	1	2	0	1	L	0	1	0	1	1	0	0	1	1	0	0	1	0	0	0
4	small gasket	1	2	0	1	L	0	1	0	1	1	0	0	1	1	0	0	1	0	0	0
9	Steel Rotator Screw Holster	1	3	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Stage 3 Sub-Assembly																				
1	Ceramic Grind Wheel	2	2	1	0	M	1	1	0	0	1	0	1	0	0	0	0	0	0	1	0
1	Sharpener Cover 3	1	3	0	1	L	1	1	0	1	1	0	1	1	0	1	0	1	0	0	0
4	AXLE SPRING .6"	1	3	0	0	L	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0
	Rotating Sub-Assembly																				
3	Motor Shaft	1	12	1	0	M	1	0	1	0	0	0	1	0	1	1	1	1	0	0	1
7	Motor Shaft Pin	4	5	1	0	L	0	1	1	0	0	0	1	0	1	1	0	0	0	0	0
1	Motor Shaft Bearing	1	4	0	0	L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	1
5	Retaining Ring	2	2	0	0	L	0	1	0	1	1	1	1	0	1	1	0	0	0	0	0
8	motor fan	1	5	1	1	L	1	0	1	1	1	0	0	1	0	1	1	1	0	0	0
2	fan retaining clip	1	1	0	1	L	1	0	0	0	1	1	1	1	1	1	0	1	0	0	0
6	fann inlet shroud	1	3	0	0	L	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
2	MOTOR-AXLE ALIGNMENT BLOCK	2	6	0	0	M	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
6	motor stator	4	4	0	1	H	4	0	1	0	0	0	0	1	0	0	1	1	0	0	1
7	motor rotor	1	1	0	1	H	1	0	0	0	0	0	0	1	1	0	1	1	0	0	1
8	5/16" x 7/16" Bushing	2	3	0	1	L	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3	Alignment Block Bushing Cover	2	2	0	1	L	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0
	General Sub-Assembly																				
0	top cover	1	3	1	0	M	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0
7	Bottom Cover	1	4	1	1	M	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0
2	#5-20 UNC 1/4" x 3/4" FASTENER	4	2	0	0	L	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0
5	#5-40 UNC 1/4" x 1/2" FASTENER	2	2	0	0	L	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
0	#5-40 UNC 1/4" x 2.5" FASTENER	2	2	0	0	L	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
4	#5-40 UNC 1/4" x 1" FASTENER	5	2	0	0	L	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0
8	5/16" x 1/8" NUT	2	1	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
8	5/16" x 7/16" BUSHING	2	2	0	0	L	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
3	Main Sharpening Chassis	1	7	1	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1	rubber foot	1	1	0	1	L	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0
8	120 v wire/plug	9	1	1	1	L	9	0	1	1	1	0	0	0	1	0	1	1	1	1	0
9	I/O switch	3	2	0	1	L	0	0	0	0	1	0	0	1	1	1	1	1	0	0	0
6	fann inlet shroud	1	3	0	0	L	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
	Totals	85	129	13	18	0	32	18	7	16	18	2	13	21	15	14	19	29	5	7	5
	Design for Assembly Metrics	104.71		15.30%	←Theor. Effy. Pract. Effy.→		37.60%	1.92		2.77			4.85				5				
	Targets	-5%		60%				-5%		-5%			-5%				-5%				

Table 14: DFA Metric Data for Original Design

Modified DFA Analysis Worksheet

Assembly Name: Chef's Choice Knife Sharpener 130 | **Team:** Anna L., Nolan M., Iain M., Jose M. | **Date:** 3/6/2023

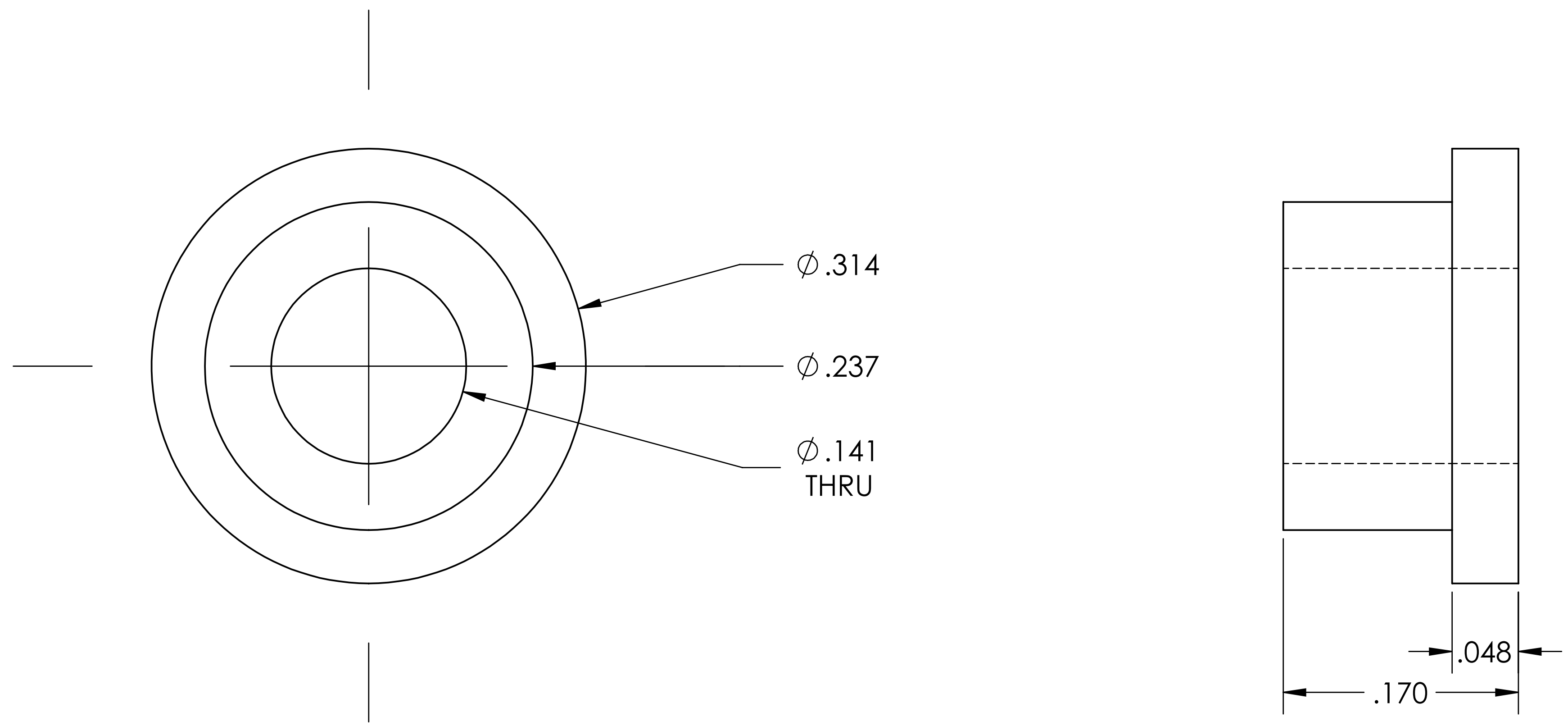
If the answer is Yes to any of the metrics or questions enter a 1. If the answer is No then enter 0. Each cell must have a number.

Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name	Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/ Omit Part	Assemble Part Wrong Way Around	Tangle, Nest, or Stick Together	Flexible, Fragile, Sharp or Slippery	Pliers, Tweezers, or Magnifying Glass Needed	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility	Re-orient Workpiece	Screw, Drill, Twist, Rivet, Bend, or Crimp	Weld, Solder, or Glue	Paint, Lube, Heat, Apply Liquid or Gas	Test, Measure or Adjust
								Stage 1 Sub-Assembly													
15	Steel Grind Wheel	2	2	1	0	M	1	1	0	0	1	0	1	0	0	0	0	0	0	1	0
3	Stage 1 Cover	1	2	0	0	L	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0
1	Bottom Snap Insert																				
5	Bottom Snap	1	3	0	0	L	0	1	0	1	1	0	0	1	0	1	0	1	0	0	1
25	Shaving Collector Magnet	1	1	1	0	L	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0
29	Shaving Collector Magnet Holder	1	2	0	0	L	1	0	0	1	0	0	0	0	1	1	1	0	0	0	0
13	Sharpener Cover 1	1	3	0	1	L	1	1	0	1	1	0	1	1	0	1	0	1	0	0	0
9	Sharpener Cover Snap																				
22	PLASTIC HOLDER FOR SHARPENING STEEL	1	2	0	0	L	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
26	SHARPENING STEEL	2	1	1	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	AXLE SPRING .7"	2	3	0	0	L	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0
								Stage 2 Sub-Assembly													
17	Sharpener Cover 2	1	4	0	1	L	1	1	1	1	1	0	1	1	0	1	0	1	0	0	0
8	steel rotator screw																				
12	steel screw insert																				
16	steel cylinder	1	1	1	1	M	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0
20	large gasket																				
24	small gasket																				
19	Steel Rotator Screw Holster	1	3	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
								Stage 3 Sub-Assembly													
11	Ceramic Grind Wheel	2	2	1	0	M	1	1	0	0	1	0	1	0	0	0	0	0	0	1	0
21	Sharpener Cover 3	1	3	0	1	L	1	1	0	1	1	0	1	1	0	1	0	1	0	0	0
34	AXLE SPRING .6"																				
								Rotating Sub-Assembly													
33	Motor Shaft	1	12	1	0	M	1	0	1	0	0	0	1	0	1	1	1	1	0	0	1
37	Motor Shaft Pin	4	5	1	0	L	0	1	1	0	0	0	1	0	1	1	0	0	0	0	0
41	Motor Shaft Bearing	1	4	0	0	L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	1
45	Retaining Ring	2	2	0	0	L	0	1	0	1	1	1	1	0	1	1	0	0	0	0	0
28	motor fan	1	5	1	1	L	1	0	1	1	1	0	0	1	0	1	1	1	0	0	0
32	fan retaining clip	1	1	0	1	L	1	0	0	0	1	1	1	1	1	1	0	1	0	0	0
36	fann inlet shroud	1	3	0	0	L	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
42	MOTOR-AXLE ALIGNMENT BLOCK	2	6	0	0	M	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
46	motor stator	4	4	0	1	H	4	0	1	0	0	0	0	1	0	0	1	1	0	0	1
47	motor rotor	1	1	0	1	H	1	0	0	0	0	0	0	1	1	0	1	1	0	0	1
38	5/16" x 7/16" Bushing	2	3	0	1	L	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
43	Alignment Block Bushing Cover	2	2	0	1	L	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0
								General Sub-Assembly													
40	top cover	1	3	1	0	M	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0
7	Bottom Cover	1	4	1	1	M	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0
2	#5-20 UNC 1/4" x 3/4" FASTENER	7	2	0	0	L	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0
6	#5-40 UNC 1/4" x 1/2" FASTENER	2	2	0	0	L	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
10	#5-40 UNC 1/4" x 2.5" FASTENER	2	2	0	0	L	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
14	#5-40 UNC 1/4" x 1" FASTENER																				
18	5/16" x 1/8" NUT	2	1	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
38	5/16" x 7/16" BUSHING	2	2	0	0	L	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
23	Main Sharpening Chassis	1	7	1	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
4	rubber foot	1	1	0	1	L	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0
48	120 v wire/plug	9	1	1	1	L	9	0	1	1	1	0	0	0	1	0	1	1	1	1	0
49	I/O switch	3	2	0	1	L	0	0	0	0	1	0	0	1	1	1	1	1	0	0	0
36	fann inlet shroud	1	3	0	0	L	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
	Totals	72	110	12	14	0	31	13	6	13	15	2	12	16	11	13	16	25	5	7	5
	Design for Assembly Metrics	88.99		16.67%	← Theor. Effy. Pract. Effy. →		43.06%	1.58		2.50			4.33				4.83				
	Targets			60%																	

Table 15: DFA Metric Data for Modified Design

Appendix D: Engineering Drawings

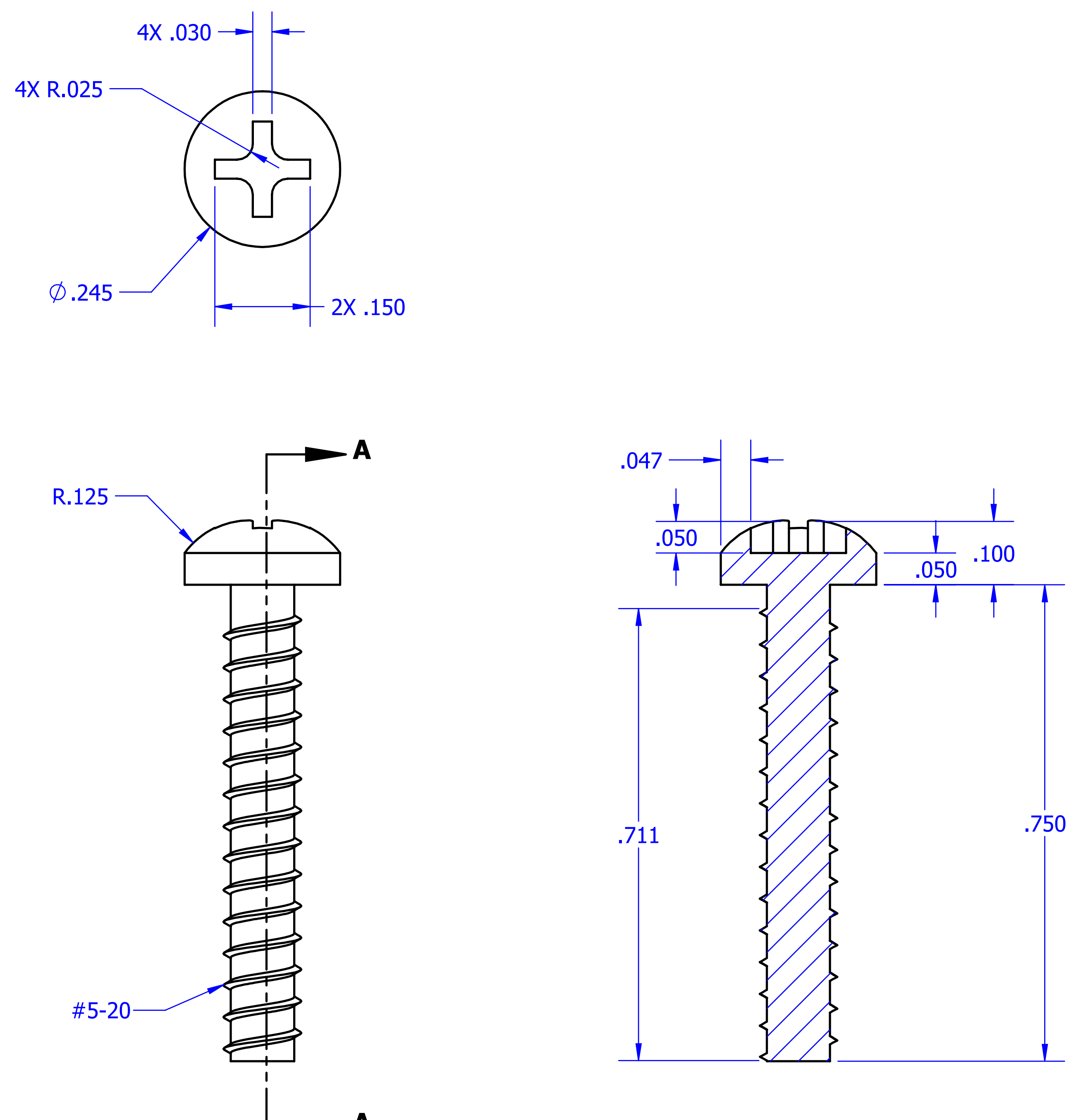
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	1/30/2023
B	CORRECTED UNITS	2/1/2023



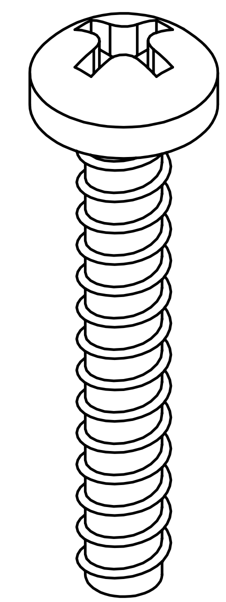
TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM SNAP INSERT
FINISH N/A		PN 001 · REV A · SHEET 1 of 1

D-1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	1/30/2023

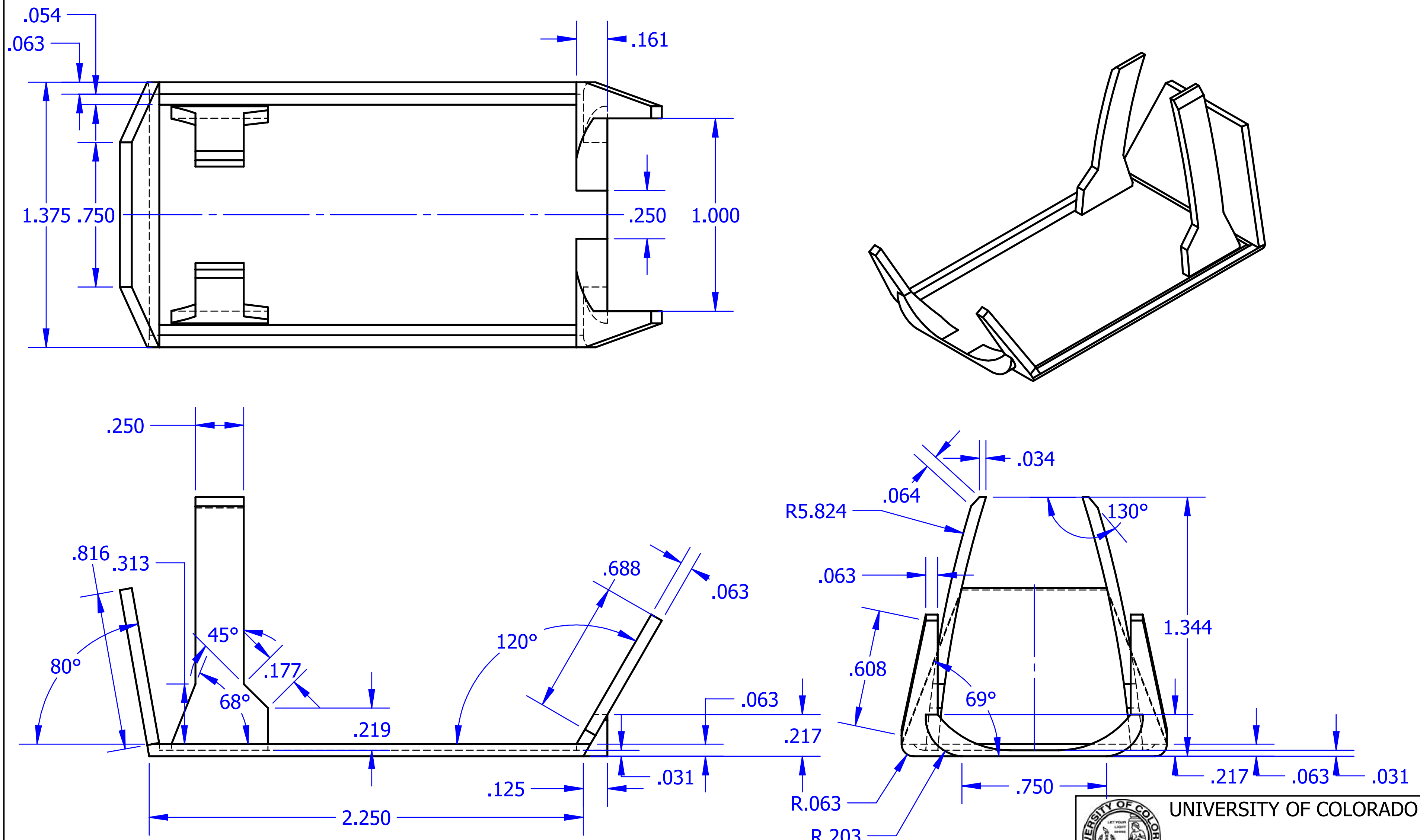


SECTION A-A



TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.005, X.X° 0.1°	UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL 18-8 Stainless Steel		DESCRIPTION #5-20tpi x 3/4"		
FINISH Passivated		PN 002_DFM	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE



UNIVERSITY OF COLORADO

1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION
STAGE 1 COVER

PN	REV		SHEET
003	1		1 of 1

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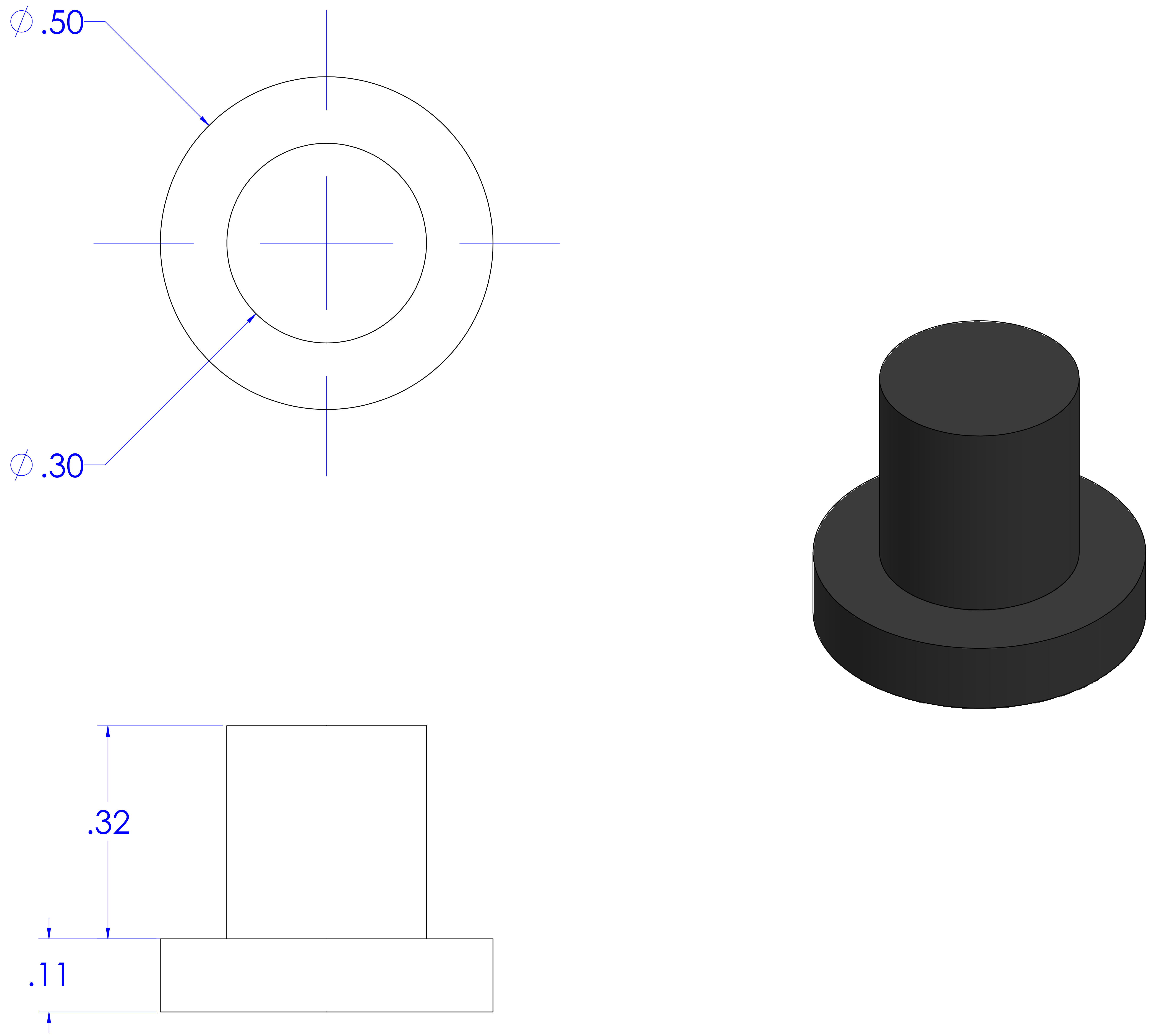
TOLERANCES UNLESS NOTED:		
	X.X	± 0.1
	X.XX	± 0.01
	X.XXX	± 0.005
UNITS: INCHES	X.X°	0.1°

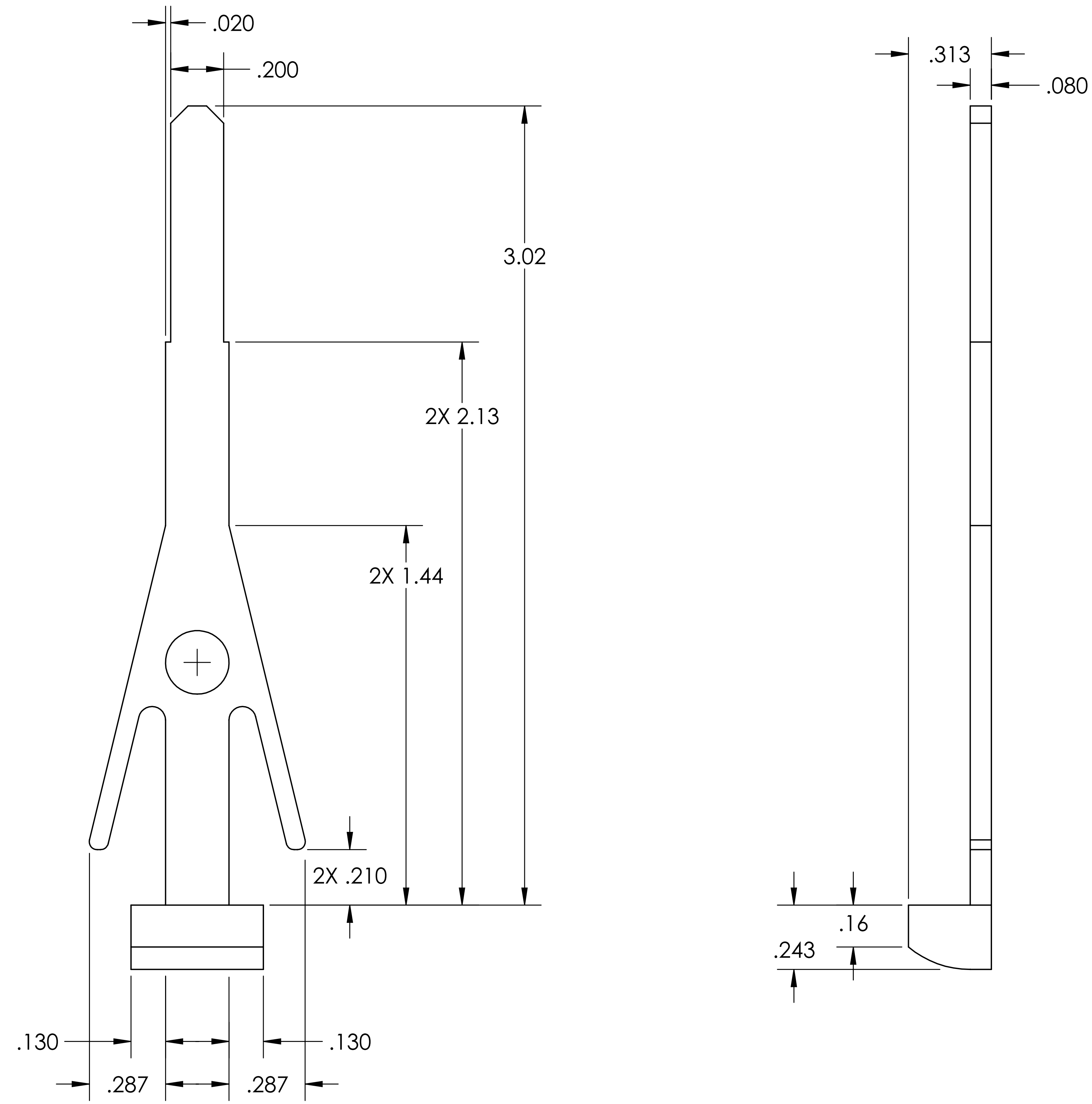


REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	1/28/2023	NOLAN MAJOR

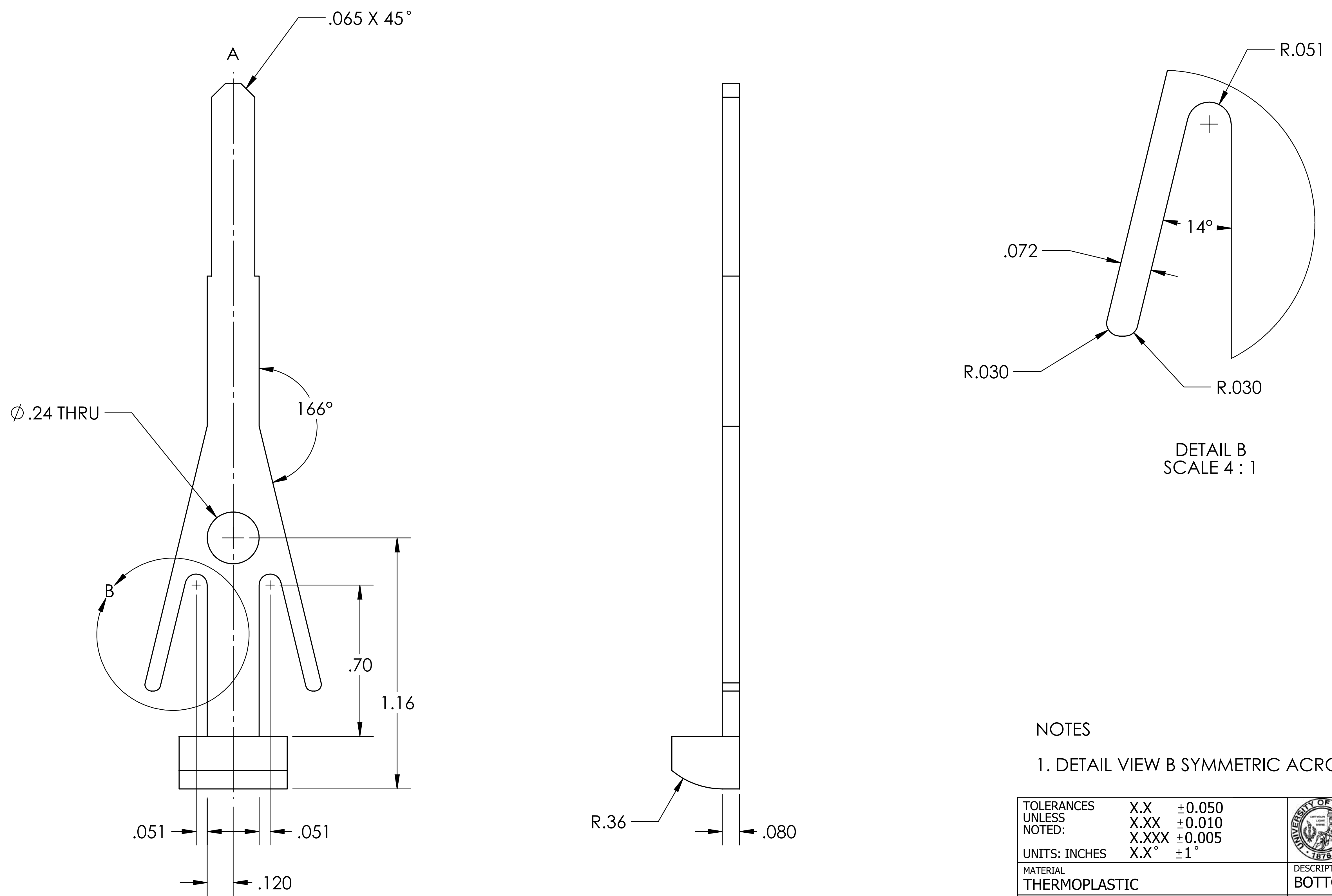
TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±0.5; UNITS: INCHES	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427
MATERIAL: SILICONE RUBBER	DESCRIPTION: NON-SLIP FEET INSERTS
FINISH: SMOOTH	PN 0004, REV A, SHEET 1 of 1

D-4

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	1/30/2023
B	CLARIFIED DIMENSIONS, SYMMETRIC FEATURES	2/28/2023



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM SNAP	
FINISH N/A		PN 005	REV A · SHEET 1 of 2

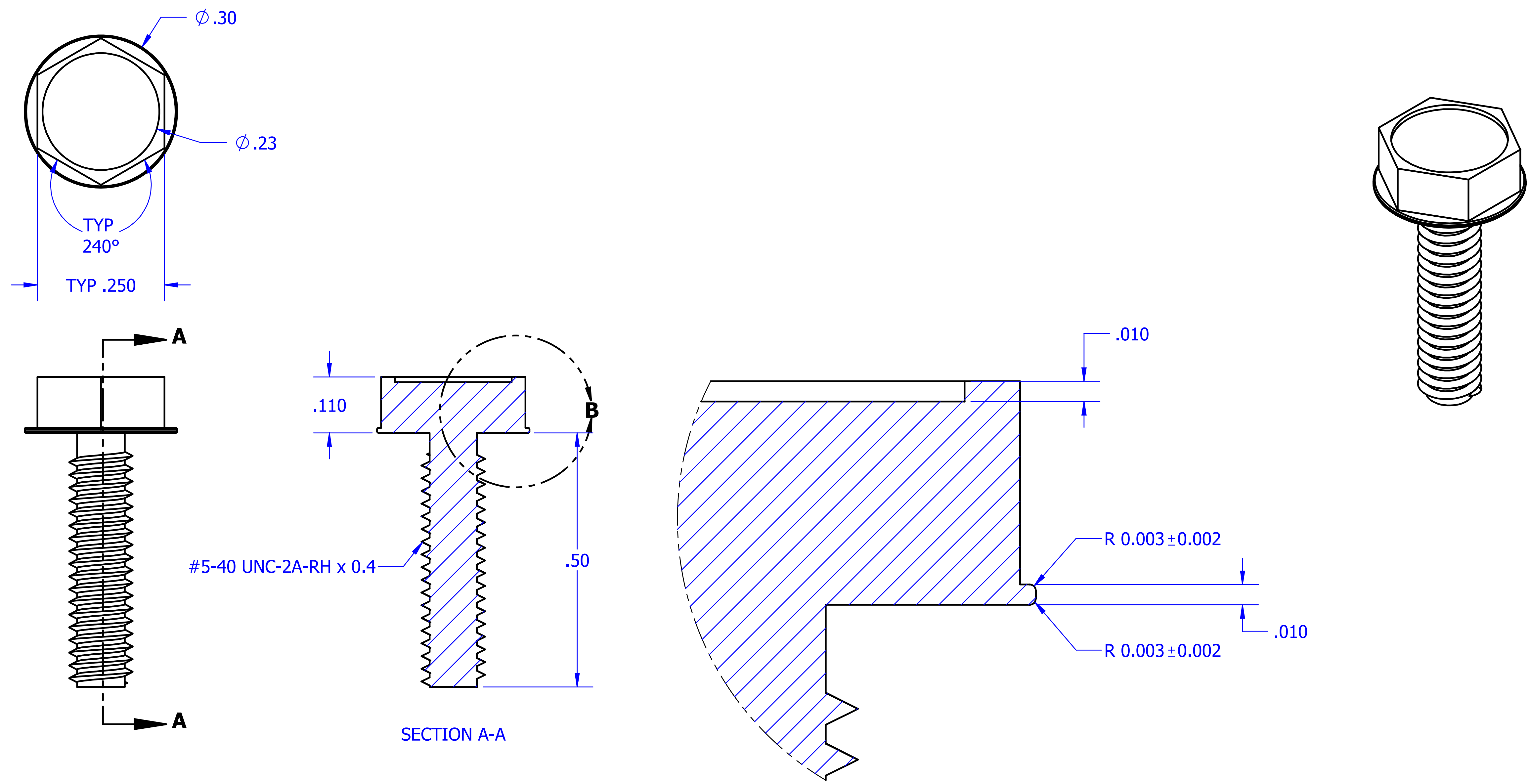


NOTES

1. DETAIL VIEW B SYMMETRIC ACROSS CENTERLINE A

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427			
MATERIAL THERMOPLASTIC	DESCRIPTION BOTTOM SNAP			
FINISH N/A	PN 005	REV A		SHEET 2 of 2

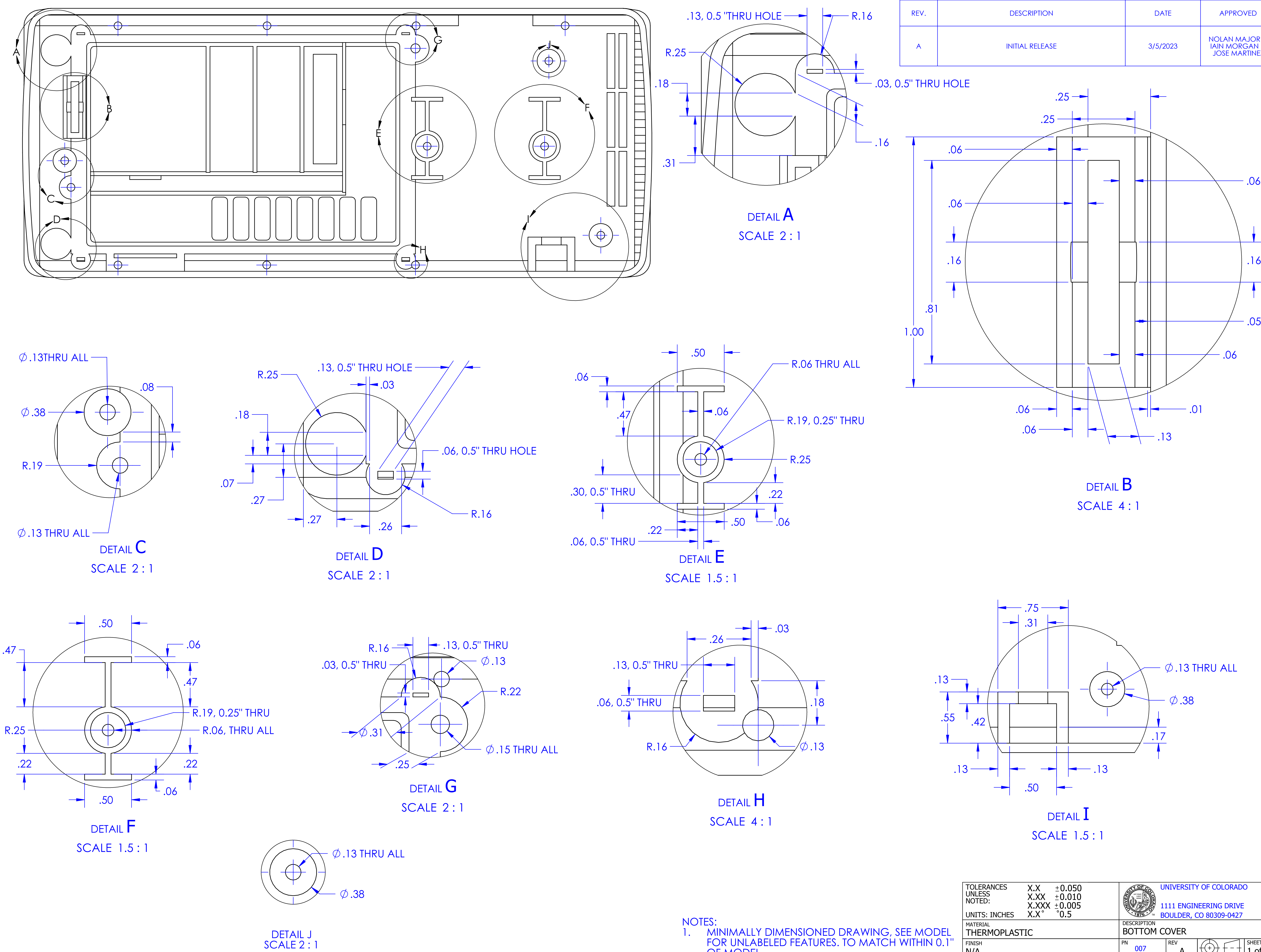
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/1/2023



DETAIL B
SCALE 16 : 1

TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 0.1°		
MATERIAL 18-8 STAINLESS STEEL		DESCRIPTION #5-40 UNC 1/4" x 1/2" FASTENER	
FINISH PASSIVATED		PN 006_DFM	REV A	SHEET 1 of 1

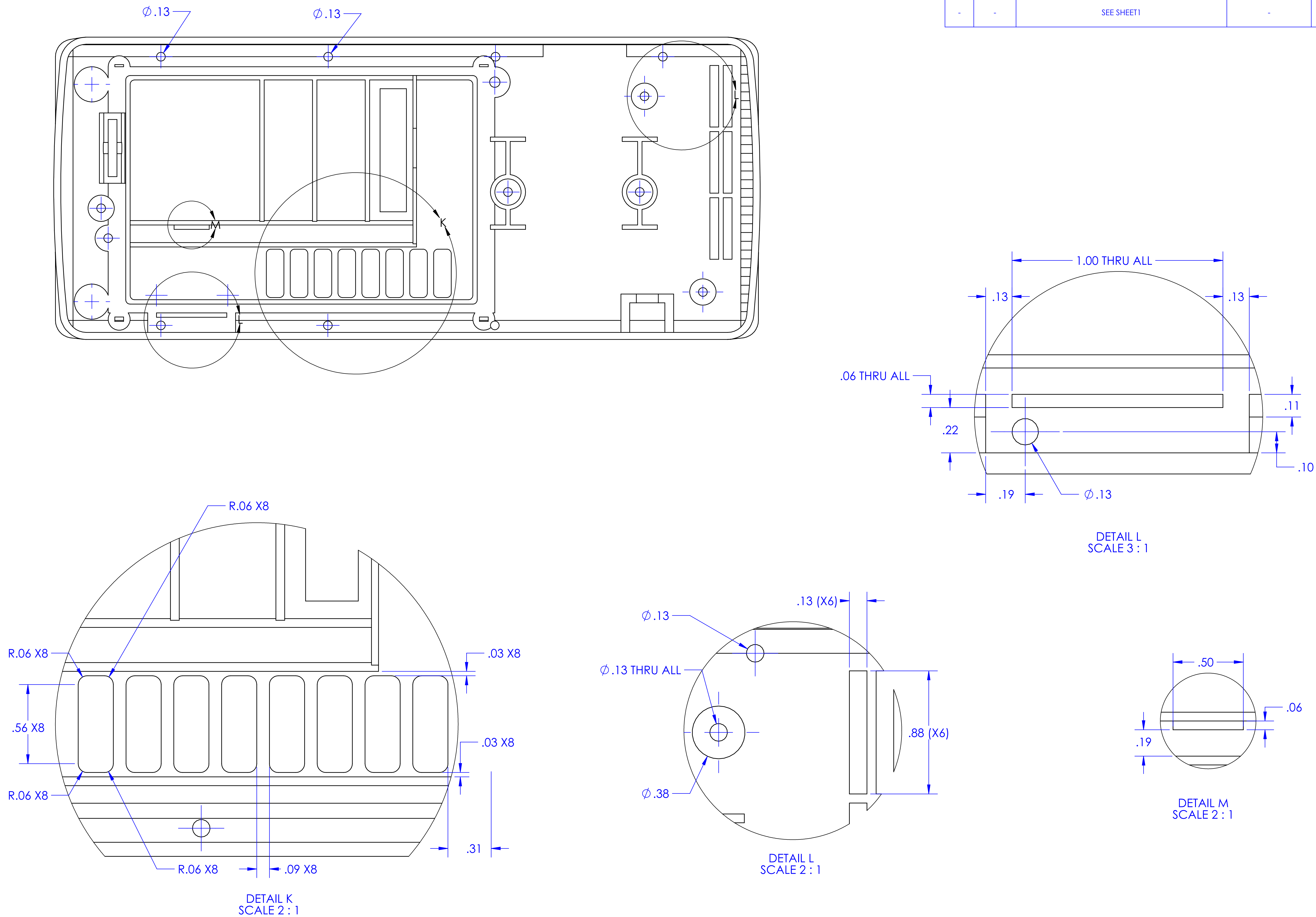
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	3/5/2023	NOLAN MAJOR & IAIN MORGAN & JOSE MARTINEZ



NOTES:
1. MINIMALLY DIMENSIONED DRAWING, SEE MODEL FOR UNLABELED FEATURES. TO MATCH WITHIN 0.1" OF MODEL.

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427	
MATERIAL: THERMOPLASTIC	DESCRIPTION: BOTTOM COVER	
FINISH: N/A	PN: 007 / REV: A	SHEET: 1 of 5

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	SEE SHEET1	-	-



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° °0.5		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM COVER	
FINISH N/A		PN 007	REV A · SHEET 2 of 5

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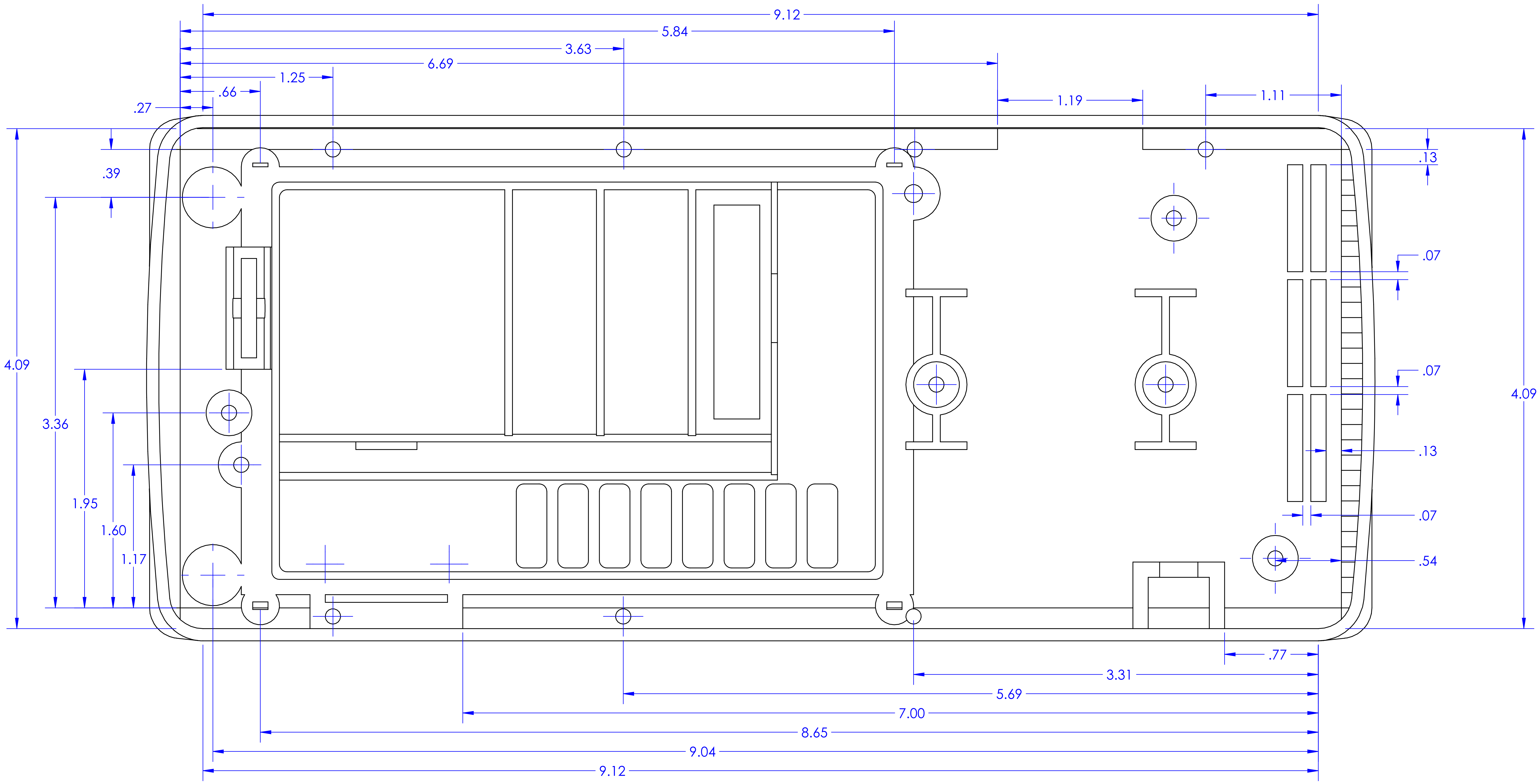
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	SEE SHEET1	-	-



TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL: THERMOPLASTIC		DESCRIPTION: BOTTOM COVER
FINISH: N/A	PN: 007	REV: A — SHEET: 3 of 5

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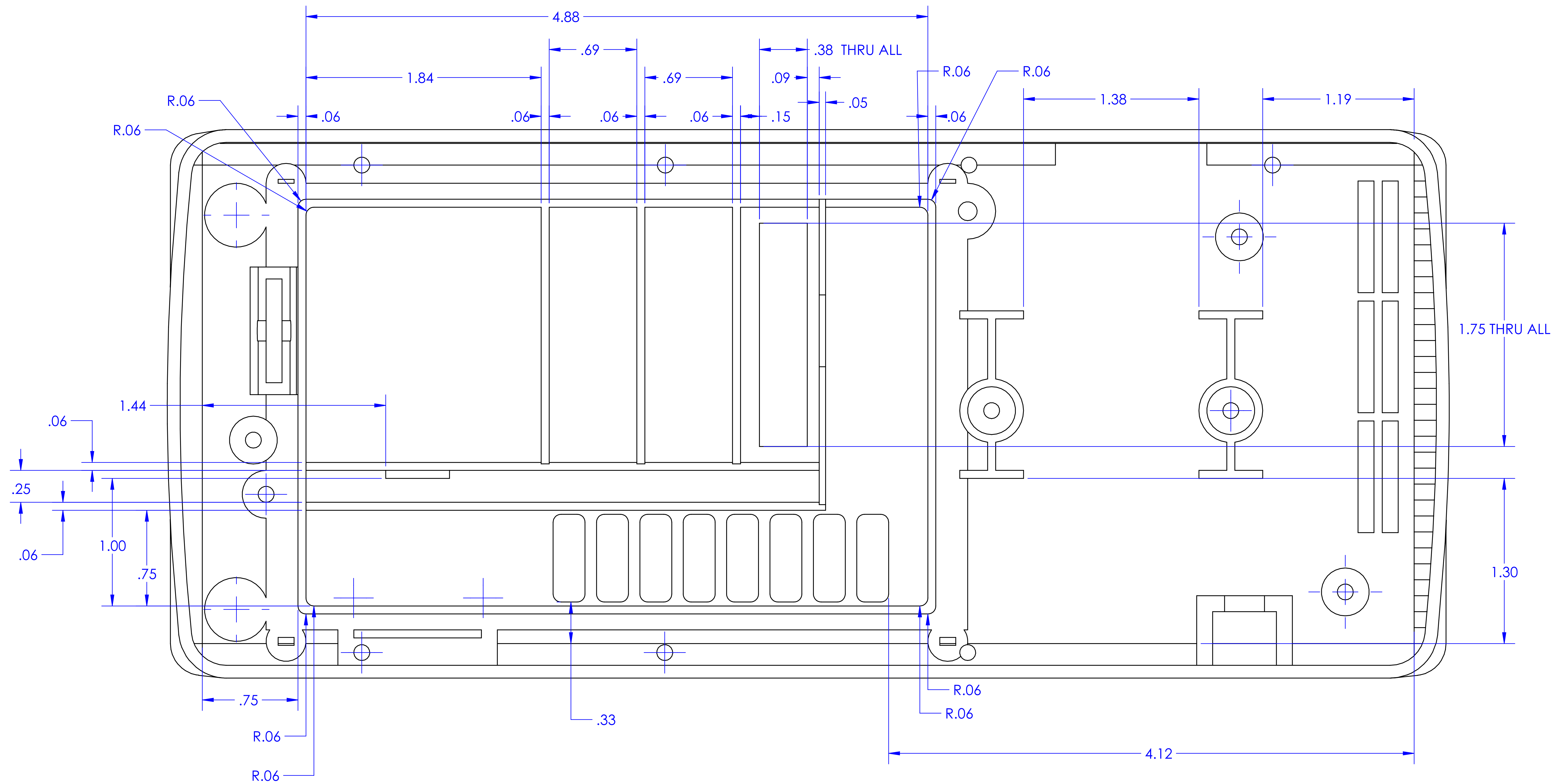
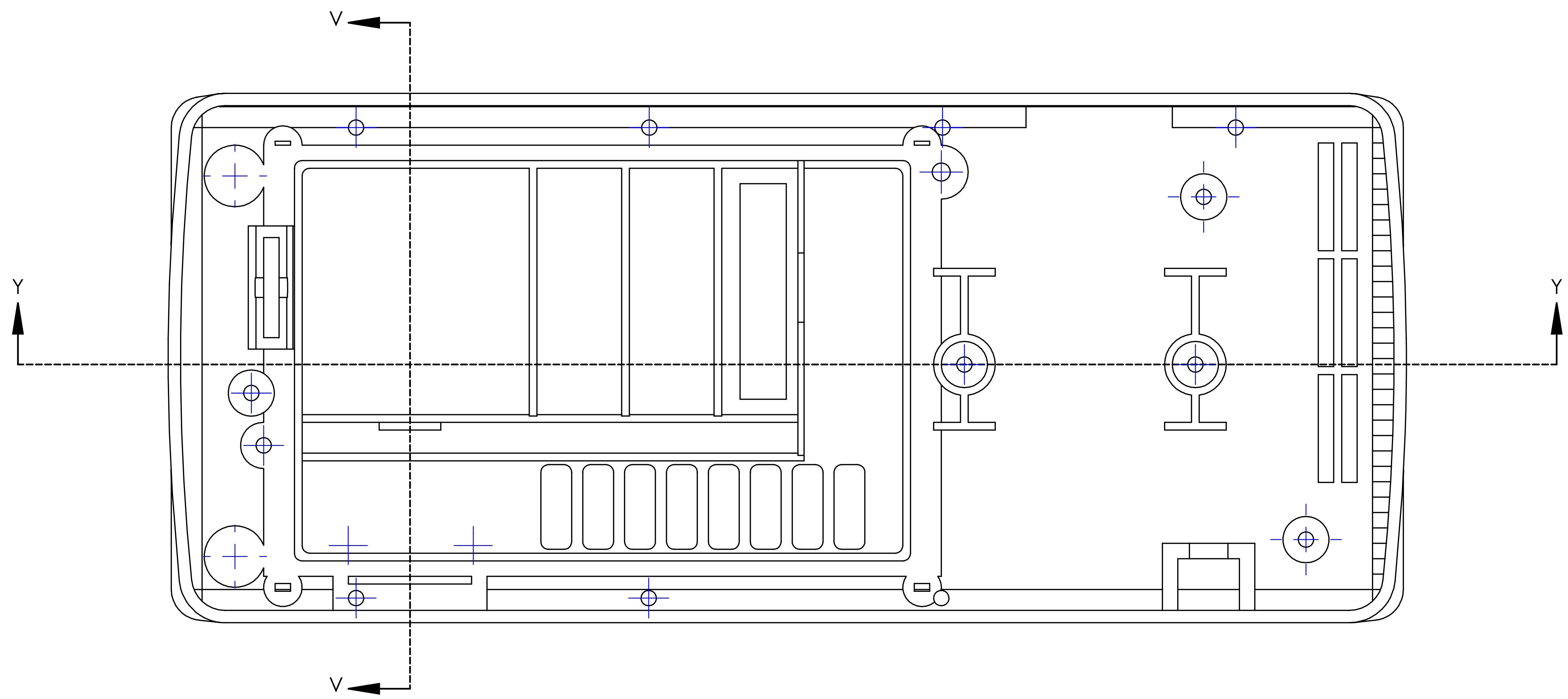
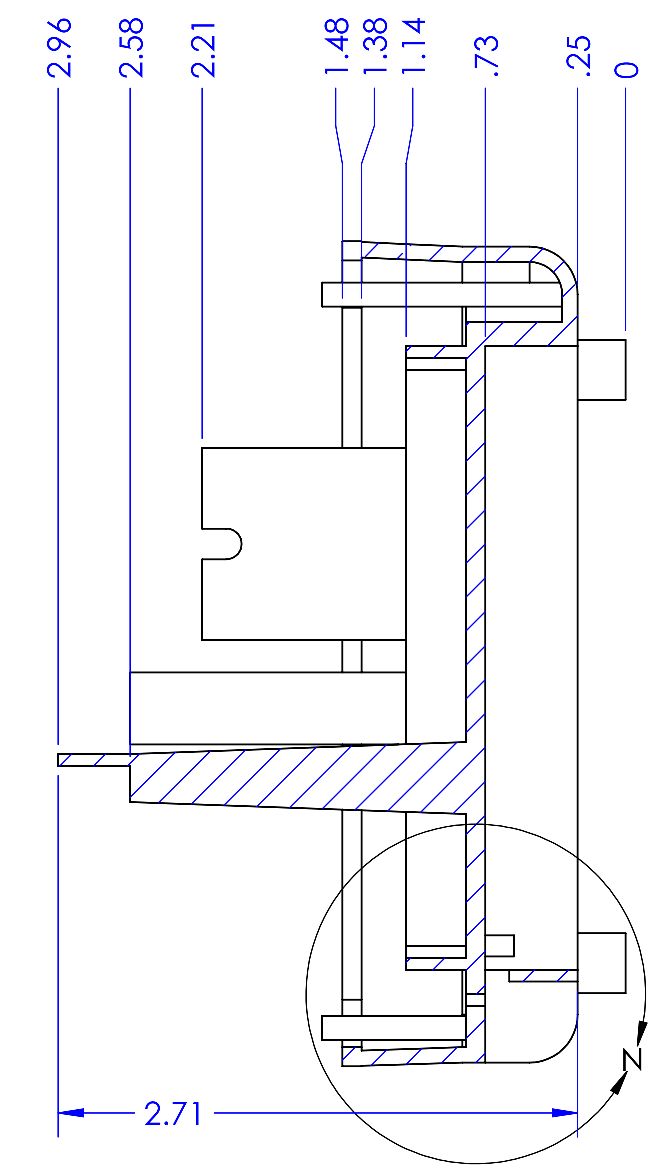
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	SEE SHEET1	-	-



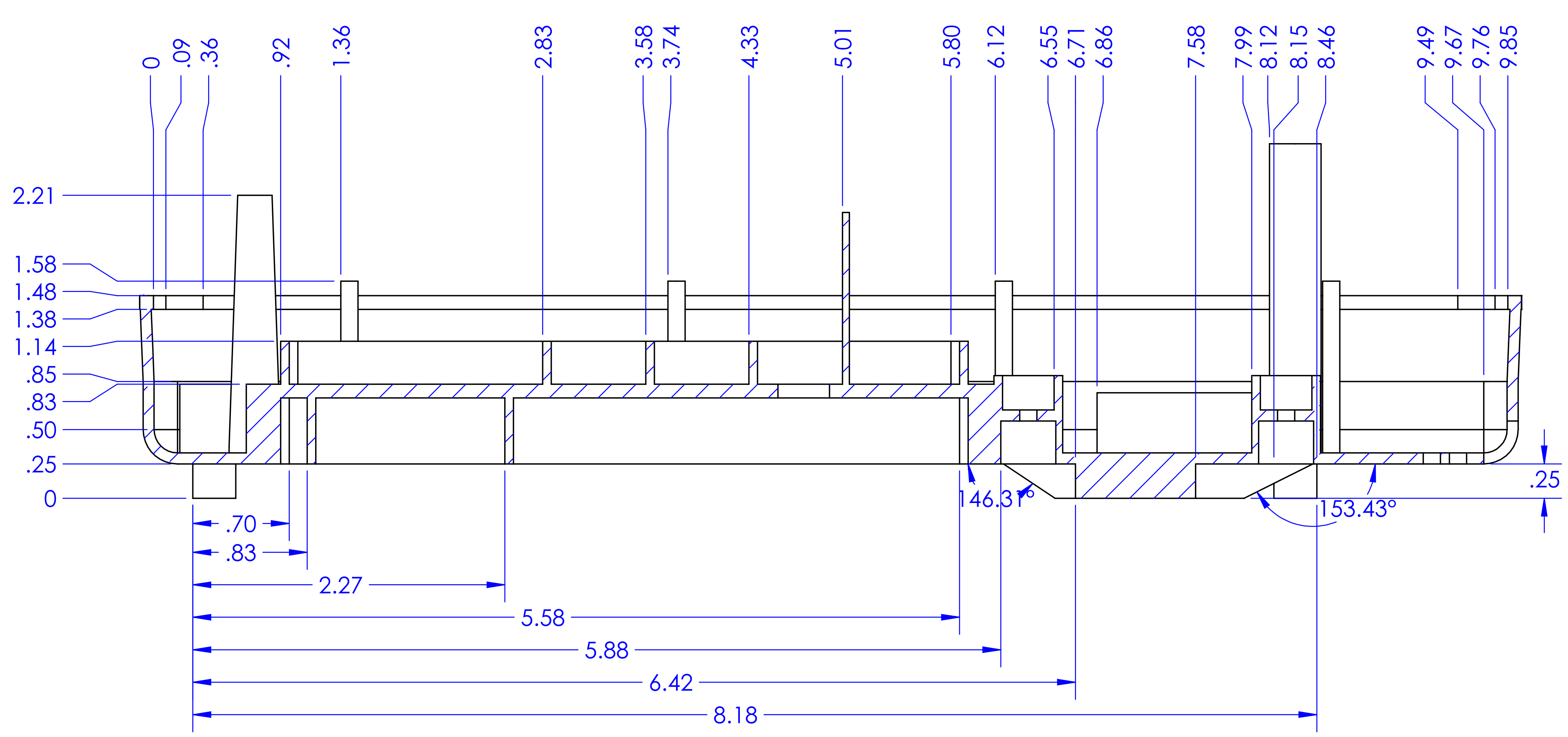
TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM COVER	
FINISH N/A	PN 007	REV A	SHEET 4 of 5

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	SEE SHEET1	-	-

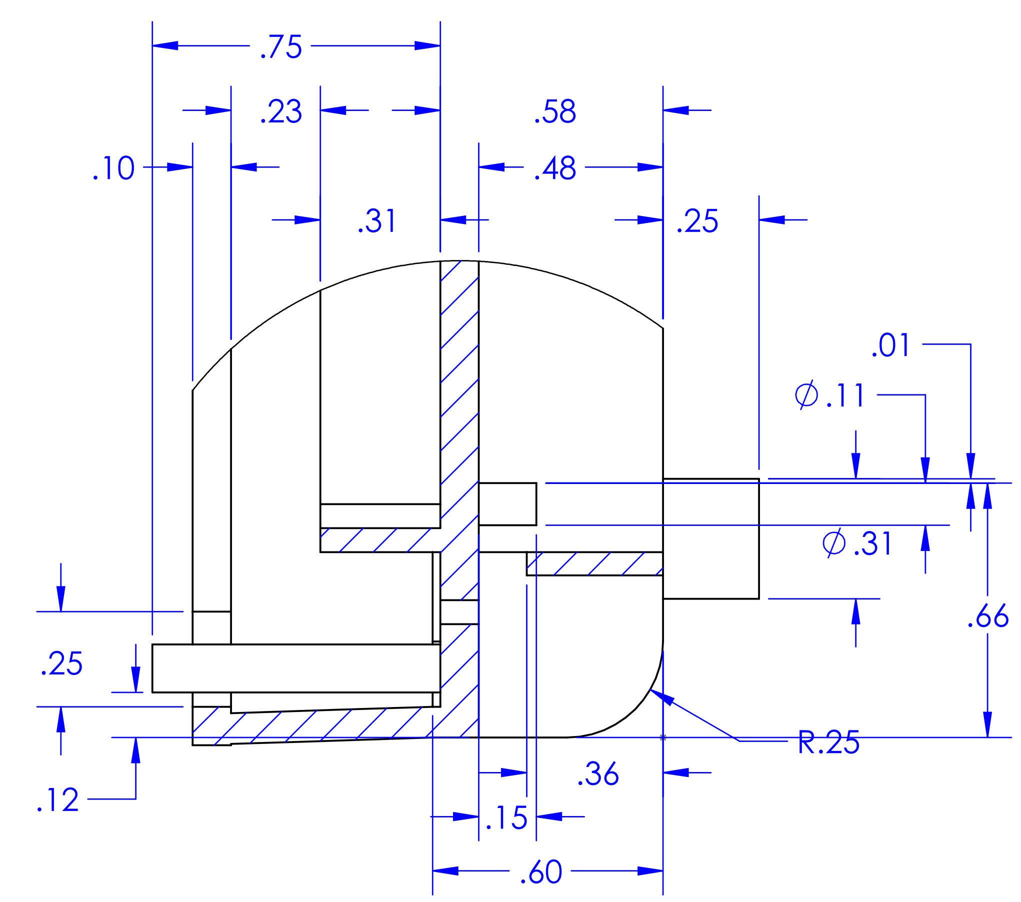




SECTION V-V
SCALE 1 : 1



SECTION Y-Y
SCALE 1 : 1

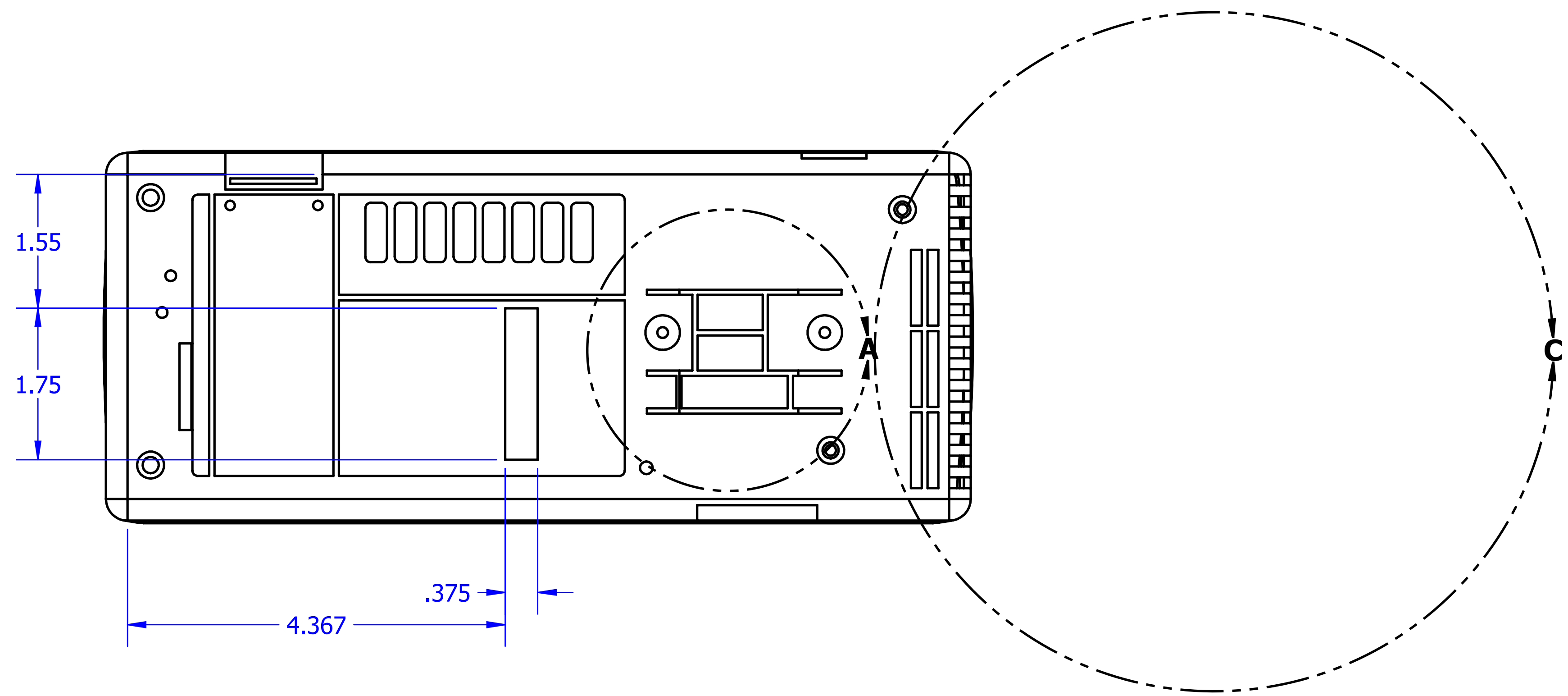


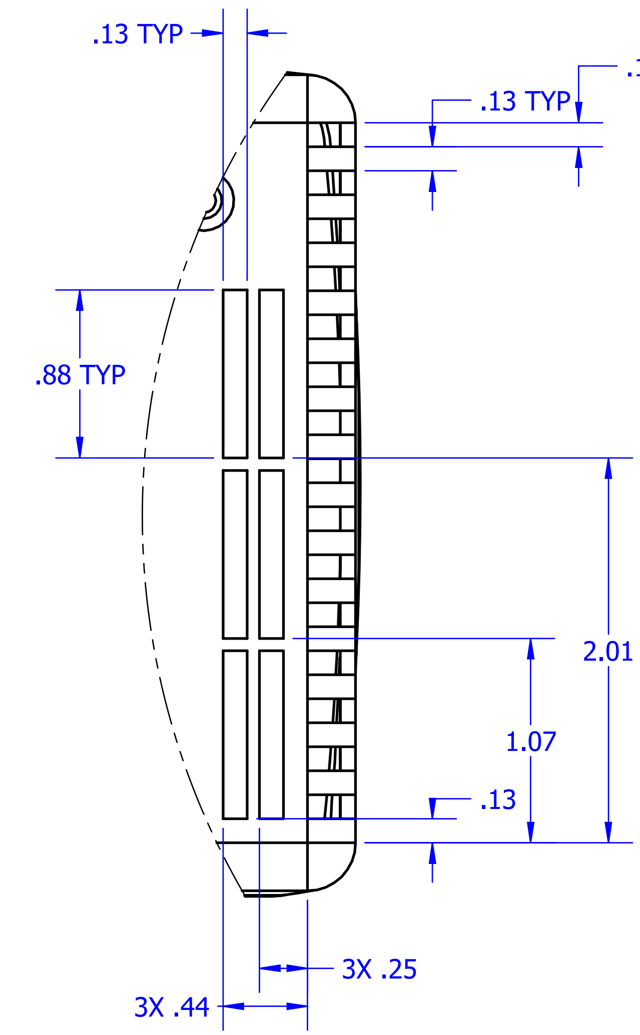
DETAIL N
SCALE 2 : 1

TOLERANCES UNLESS NOTED:	X.X ±0.050	UNIVERSITY OF COLORADO
	X.XX ±0.010	1111 ENGINEERING DRIVE
	X.XXX ±0.005	BOULDER, CO 80309-0427
UNITS: INCHES	X.X° °0.5	
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM COVER
FINISH N/A		PN 007 · REV A · SHEET 5 of 5

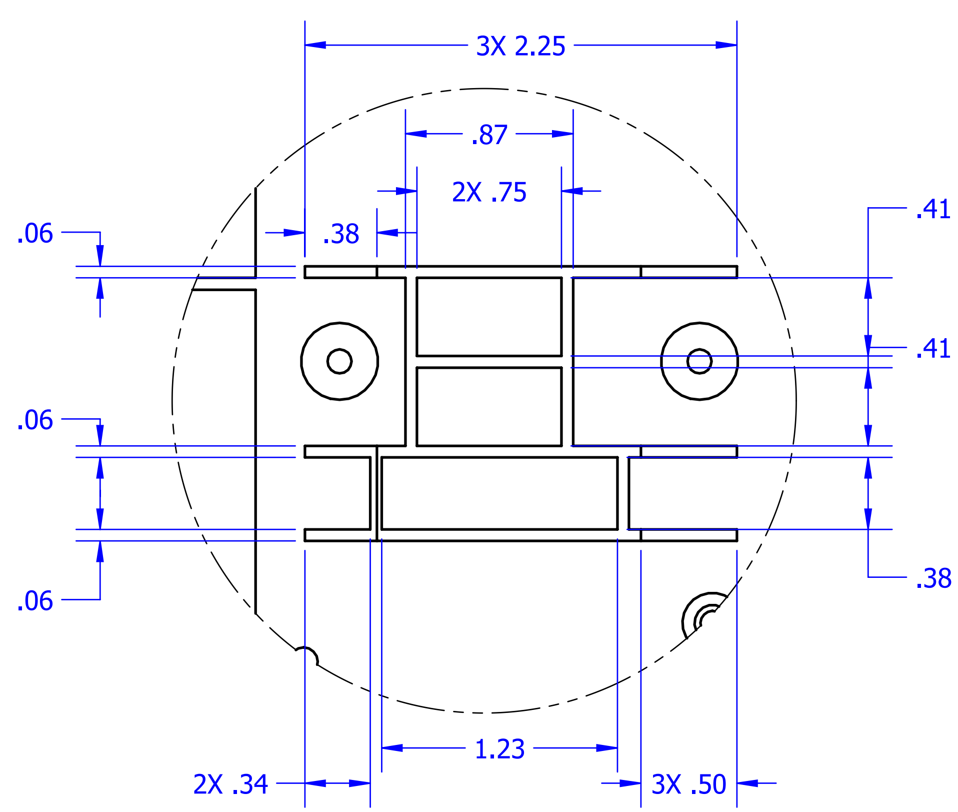
D-12

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/7/2023





DETAIL C
SCALE 1 : 1



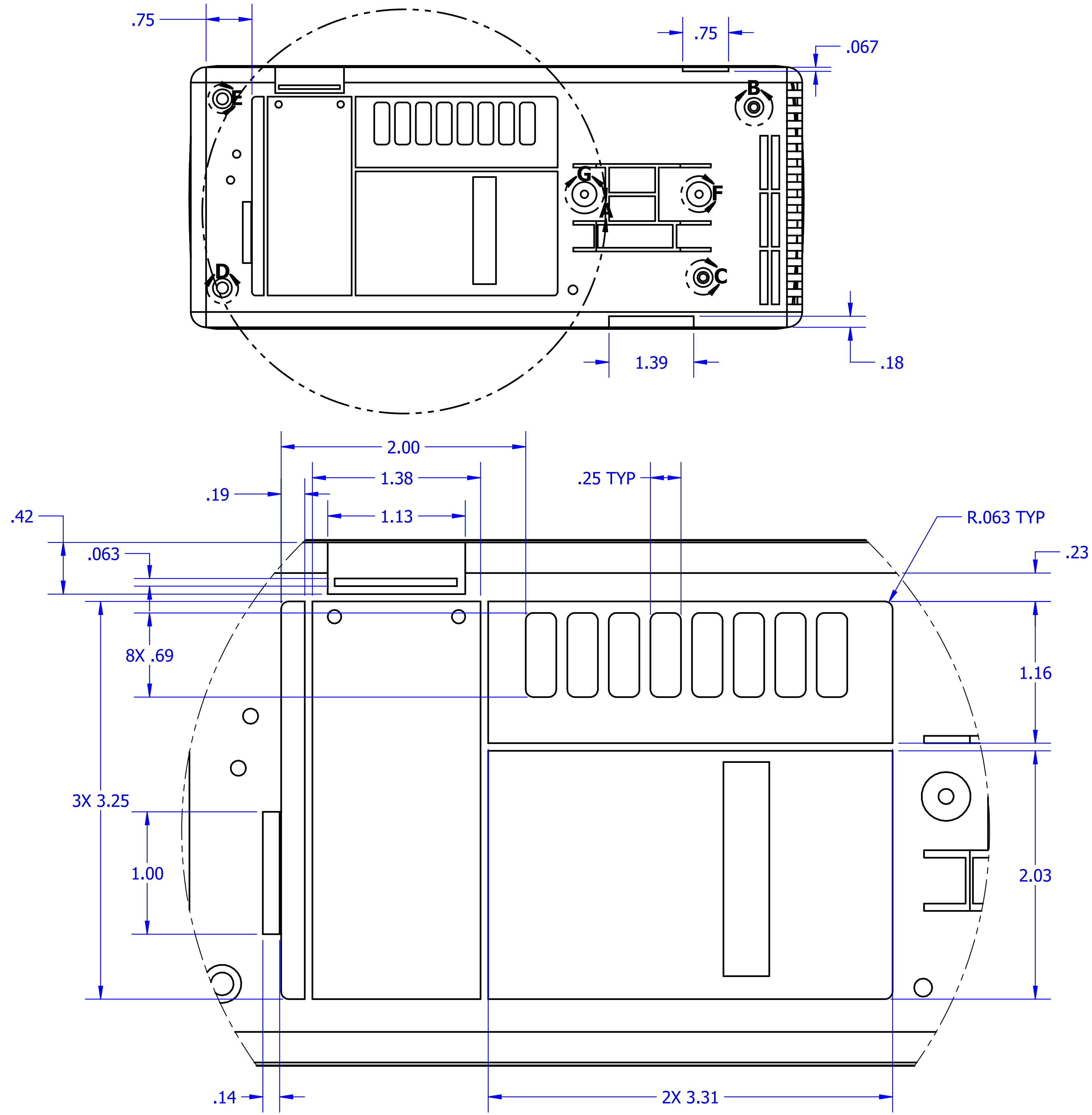
DETAIL A
SCALE 1 : 1

TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ±0.01 X.XXX ± 0.005 X.X° 0.1°
UNITS: INCHES	
MATERIAL	THERMOPLASTIC
FINISH	N/A

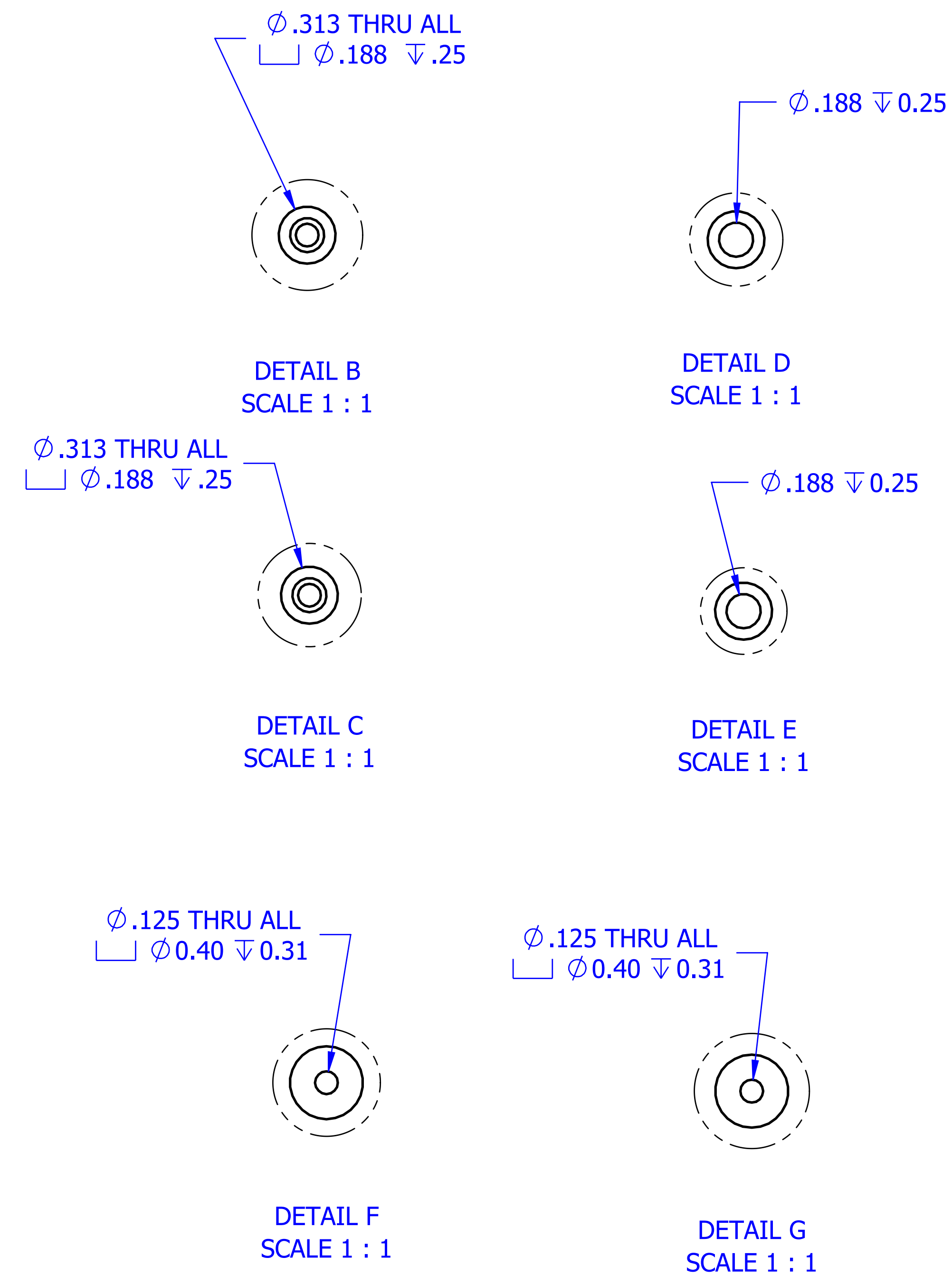
UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION	PN	REV	SHEET
BOTTOM COVER	007	A	1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/7/2023

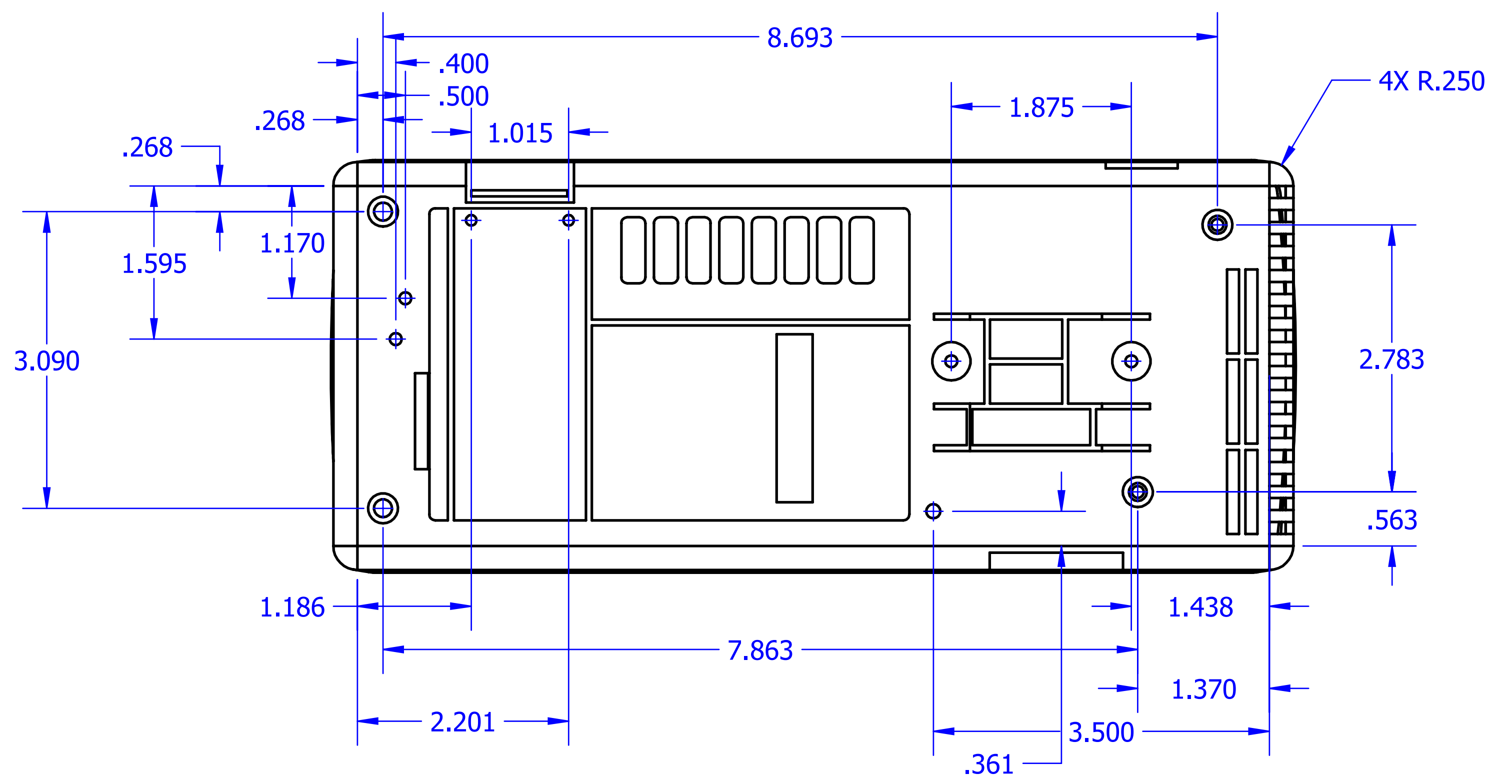


DETAIL A



TOLERANCES UNLESS NOTED:	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° 0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM COVER	
FINISH N/A		PN 007	REV A / SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/7/2023



TOLERANCES UNLESS NOTED:	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° 0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL THERMOPLASTIC		DESCRIPTION BOTTOM COVER
FINISH N/A		PN 007 / REV A / SHEET 1 of 1

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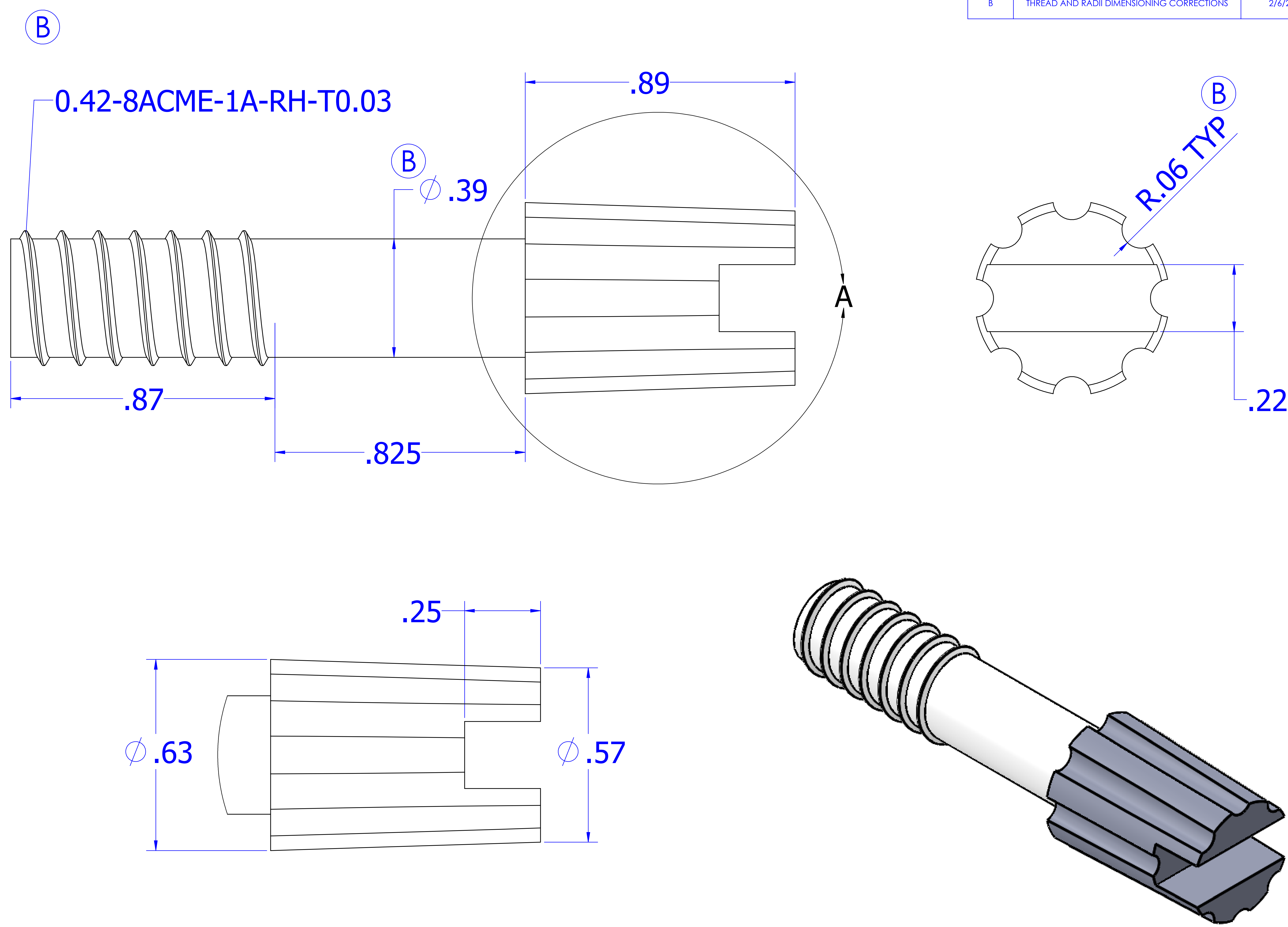
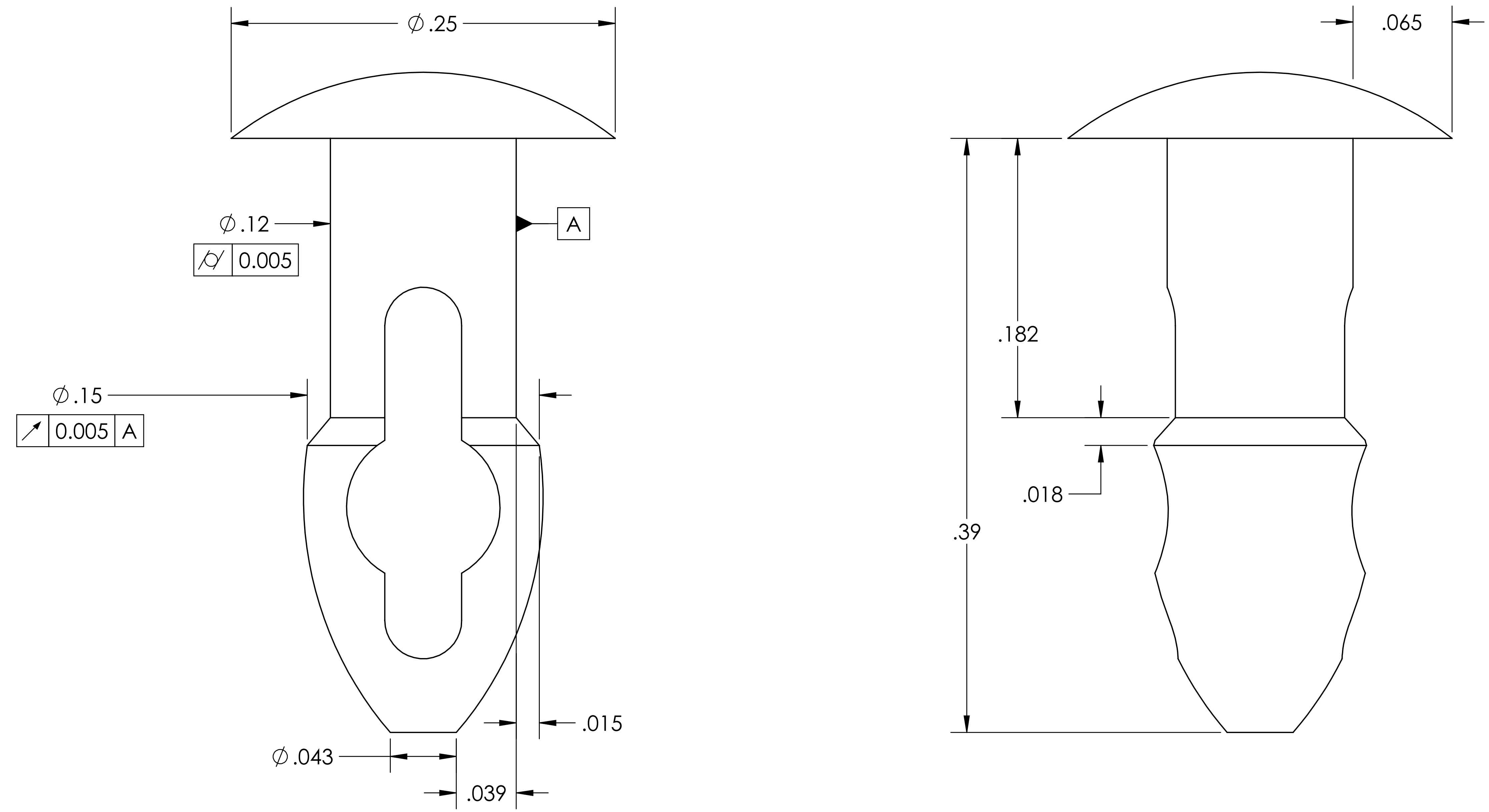
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	2/1/2023	NOLAN MAJOR
B	THREAD AND RADII DIMENSIONING CORRECTIONS	2/6/2023	NOLAN MAJOR



DETAIL A
SCALE 4 : 1

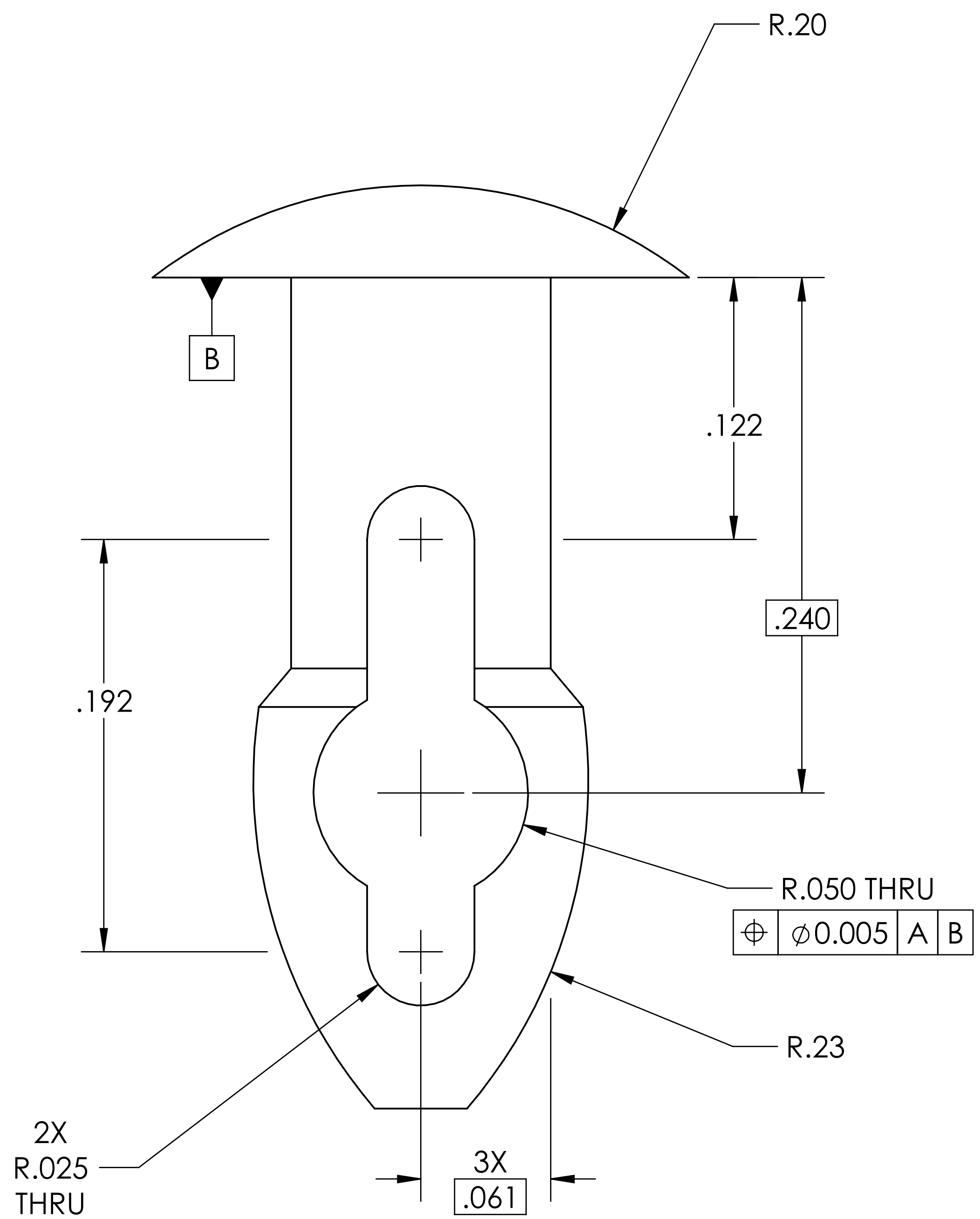
TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL: THERMOPLASTIC		DESCRIPTION: STEEL ROTATOR SCREW
FINISH: SMOOTH	PN: 0008	REV: B; SHEET: 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/6/2023
B	CLARIFIED DIMENSION LINES, ADDED GD&T	2/9/2023



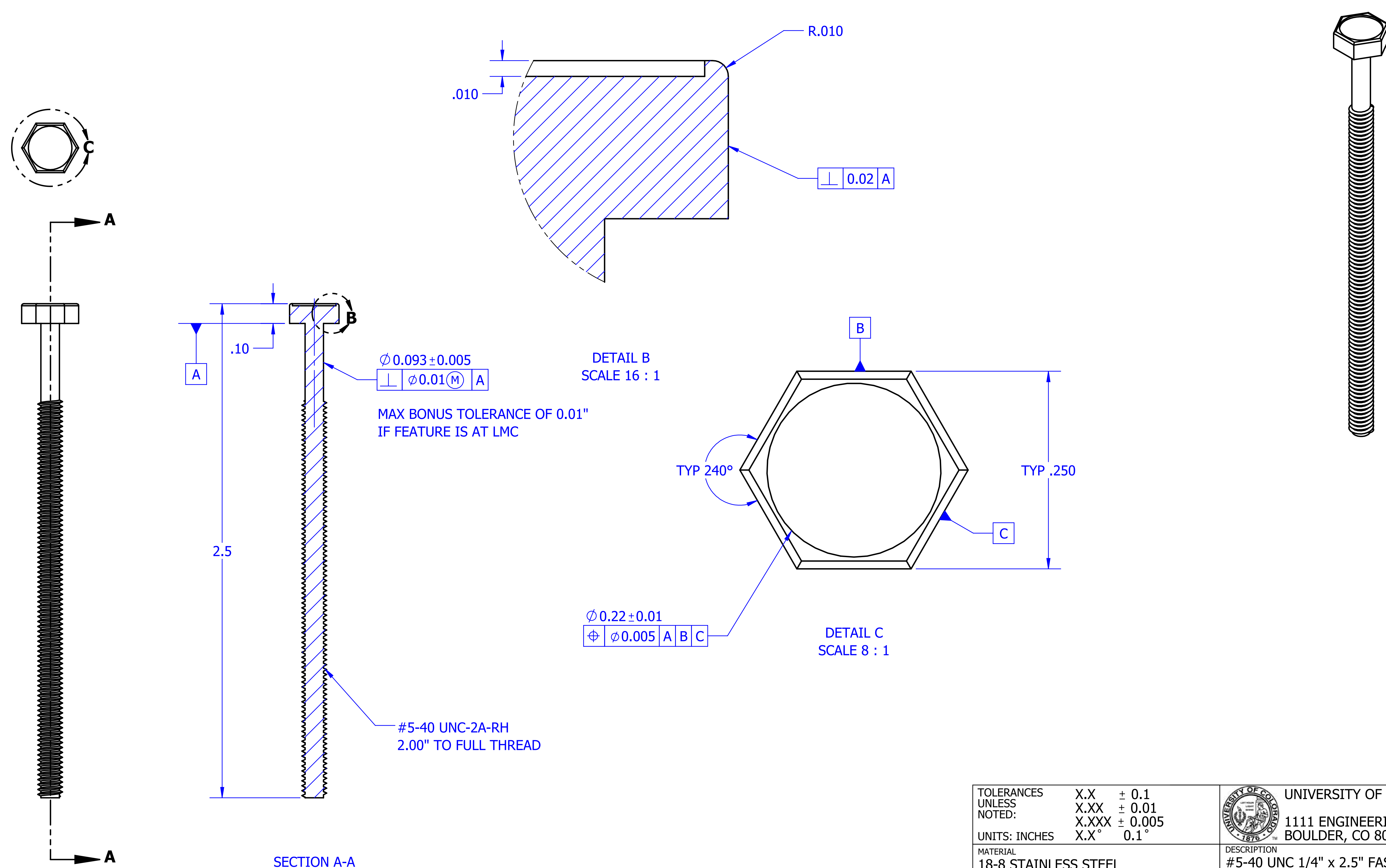
TOLERANCES UNLESS NOTED: X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER SNAP
FINISH N/A		PN 009 · REV B · SHEET 1 of 2

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.



TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL THERMOPLASTIC	DESCRIPTION SHARPENER COVER SNAP	
FINISH N/A	PN 009	REV B — SHEET 2 of 2

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/6/2023
B	ADDITION OF GD&T	2/9/2023



TOLERANCES UNLESS NOTED:		
	X.X	± 0.1
	X.XX	± 0.01
	X.XXX	± 0.005
UNITS: INCHES	X.X°	0.1°

UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

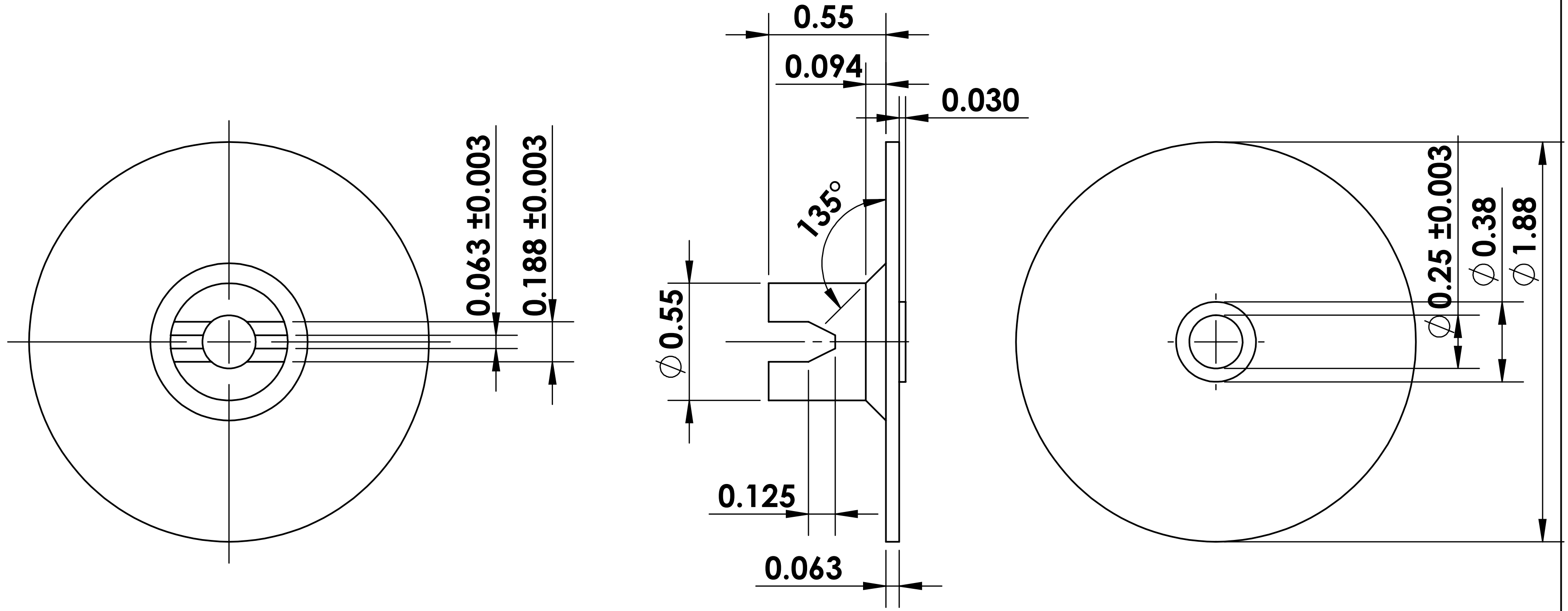
MATERIAL: 18-8 STAINLESS STEEL

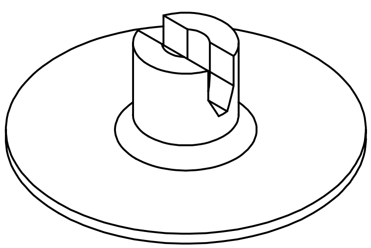
DESCRIPTION: #5-40 UNC 1/4" x 2.5" FASTENER

FINISH: PASSIVATED

PN: 010_DFM | REV: B | SHEET: 1 of 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
B1	IR	INITIAL RELEASE	2/7/2023	IR

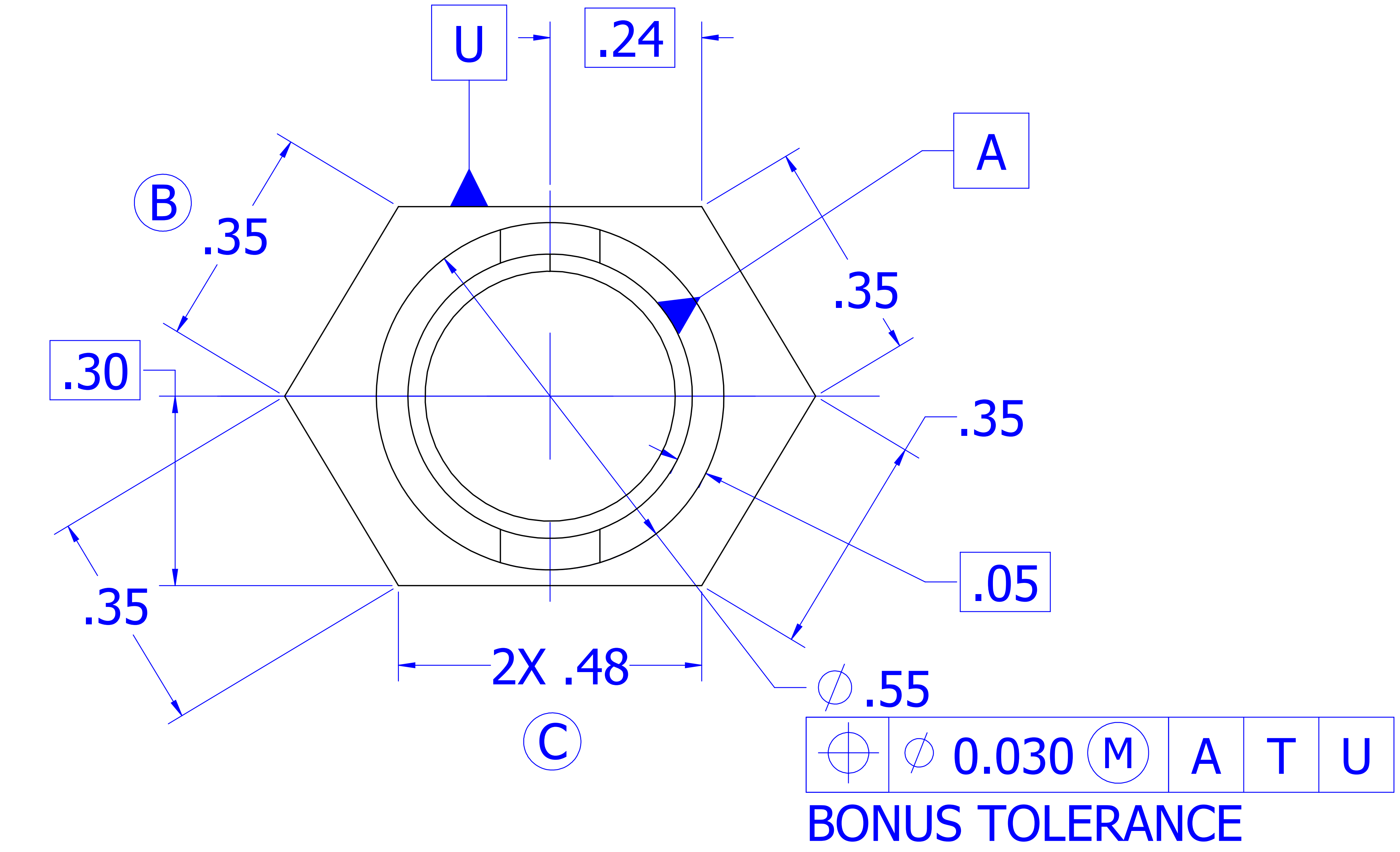




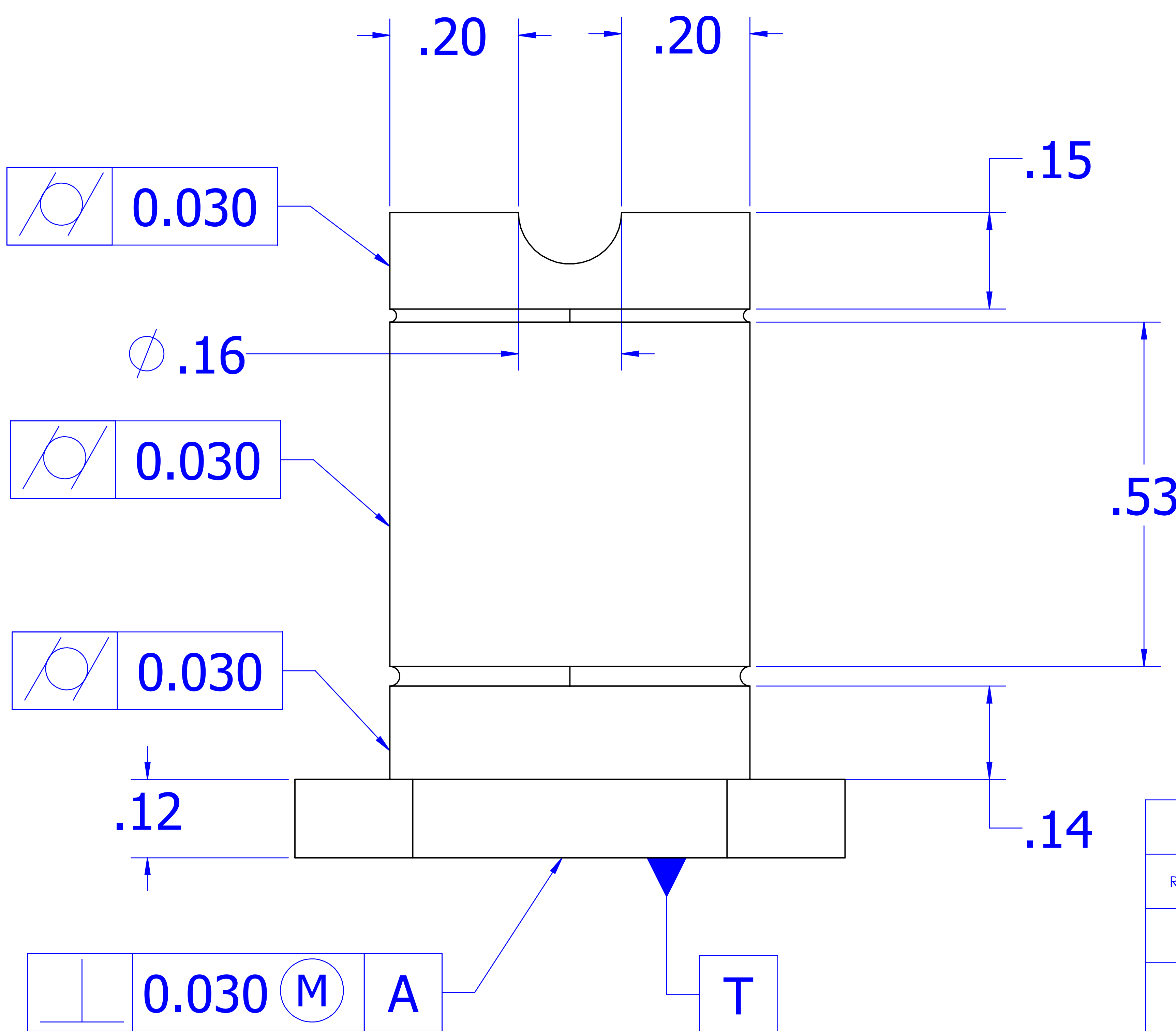
NOTES

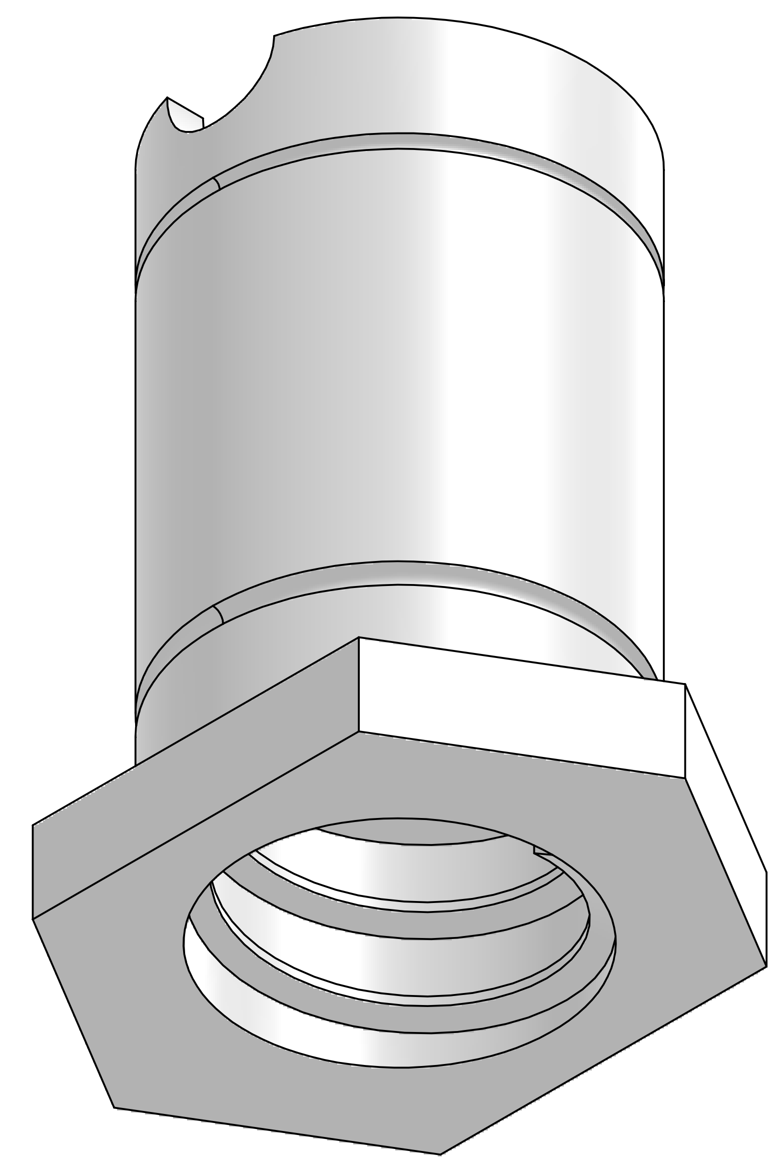
1. CENTRAL HOLE TOLERANCES INCREASED TO PREVENT WHEEL WOBBLE

TOLERANCES UNLESS NOTED: X.X ± 0.01; X.XX ± 0.01; X.XXX ± 0.0005; X.X° ± 0.5° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL CERAMIC		DESCRIPTION CERAMIC GRIND WHEEL	
FINISH FINE		PN 011	REV IR; SHEET 1 of 1
PROPRIETARY AND CONFIDENTIAL	THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.		



NOTES
1. SEE SHT 2 FOR PART LOCATION REFERENCES.
2. THE CENTER AXIS IS THE DATUM AXIS OF THE GREATEST DIAMETER CIRCULAR FEATURE.
3. THE "TOP SURFACE" AT MAXIMUM MATERIAL CONDITION MUST HAVE AXIS PERPENDICULARITY TOLERANCE OF 0.030 IN REPSECT TO THE DATUM AXIS. FOR INSPECTION USE A HEIGHT GUAGE LOCKED TO A 90 DEGREE DATUM IN RESPECT TO THE "TOP SURFACE" AND MEASURE ENTIRE SURFACE. THE HEIGHT GAUGE MUST HAVE TOTAL VARIATION LESS THAN THE TOLERANCE AMOUNT TO PASS INSPECTION.
4. THE CYLINDRICAL FEATURE ".05" MUST HAVE CYLINDRICITY TOLERANCE OF 0.030. FOR INSPECTION CONSTRAIN PART ON DATUM AXIS AND ROTATE PART WHILE A HEIGHT GAUGE RECORDS THE VARIATION OF THE SURFACE IN SEVERAL LOCATIONS ALONG THE LENGTH. THE HEIGHT GAUGE MUST HAVE TOTAL VARIATION LESS THAN THE TOLERANCE AMOUNT TO PASS INSPECTION.
5. THE PERPENDICULARITY AND CYLINDRICITY REQUIREMENT MAKES SURE THE THAT THE TWO CYLINDRICAL FEATURES WILL NOT BE TOO THIN BETWEEN EACH OTHER AND THAT THE SCREW PART WILL BE ABLE TO INTERFACE WITH THIS PART'S THREADS SINCE THE THROUGH HOLE WILL BE STRAIGHT ENOUGH TO BE FULLY COMPATIBLE AND THE THREADS WERE A LOOSE FIT DESIGN (1A).
6. THE POSITION OF DATUM AXIS A COULD VARY BETWEEN 0.520 AND 0.580 WHEN MEASURED AFTER LOCKING DATUMS A, T, THEN U. ASSOCIATED BASIC DIMENSIONS CAN VARY NO MORE THAN 0.030 IN RESPECT TO THIS FEATURE AS WELL.
7. THE THREE CYLINDRICITY FEATURES CAN VARY NO MOR THAN 0.030.
8. DATUM T CANNOT VARY MORE THAN 0.030 AT MAXIMUM MATERIAL CONDITION IN RESPECT TO DATUM A.
9. THERE IS A BONUS TOLERANCE OF .02 WITH THE ⌀.55 FEATURE MEANING DEPARTING FROM MMC TOWARDS LMC WILL BE OKAY FOR ASSEMBLY FITTING TOGETHER.





REVISIONS

REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	2/6/2023	NOLAN MAJOR
B	DIMENSIONING CORRECTIONS AND GD&T NOTES CONVERTED TO FULL GD&T NOTATION	2/8/2023	NOLAN MAJOR
C	DIMENSIONING, AND GD&T NOTE CORRECTIONS	2/19/2023	NOLAN MAJOR

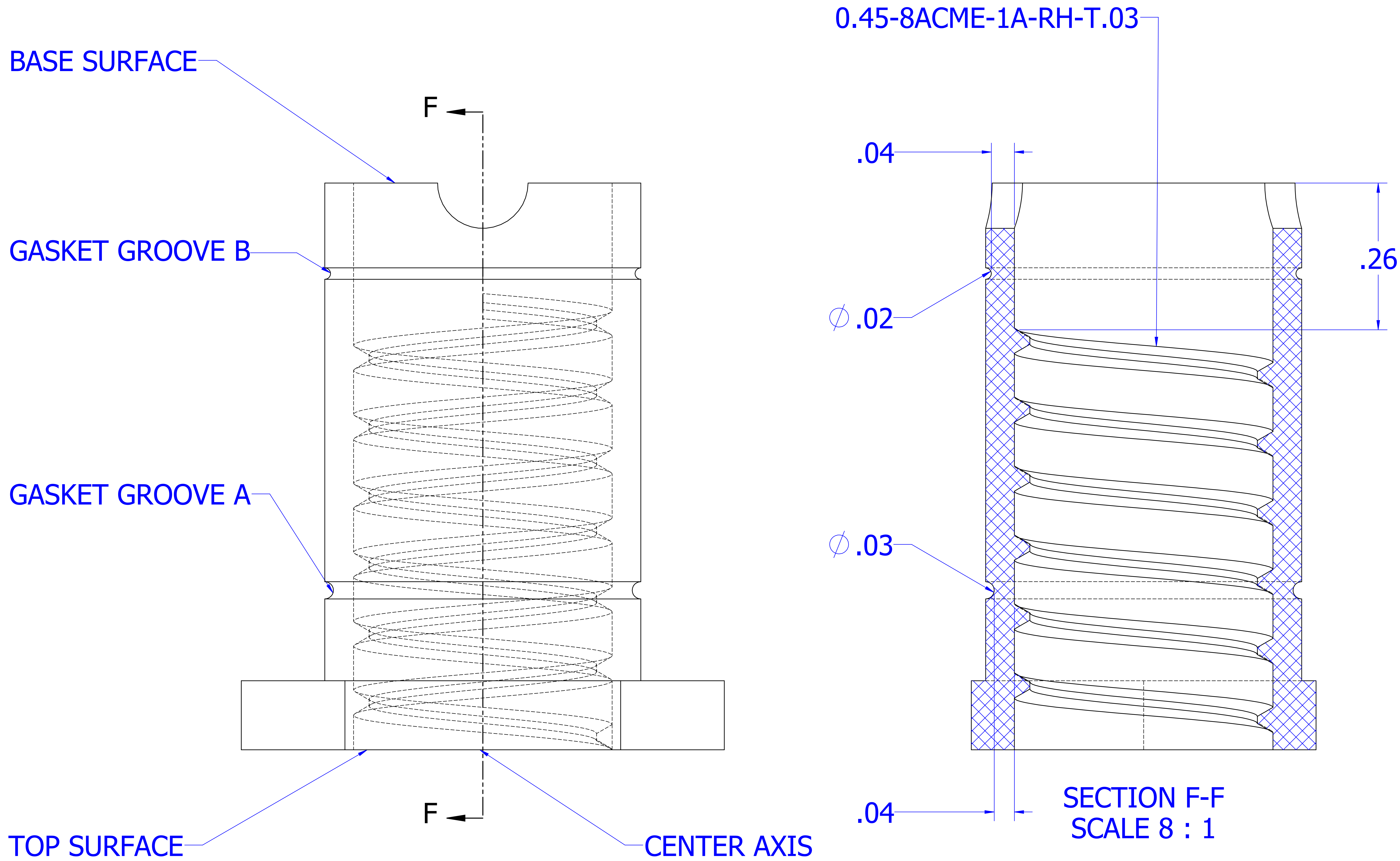
TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±0.5°
UNITS: INCEHS

MATERIAL: THERMOPLASTIC
FINISH: SMOOTH

UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION: STEEL SCREW INSERT
PN 012 | REV C | SHEET 1 of 2

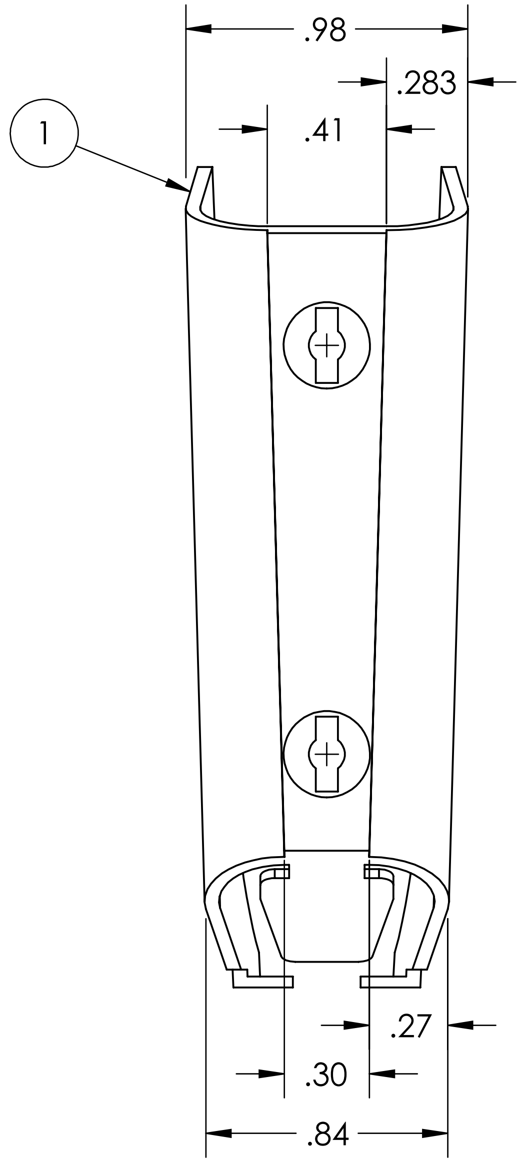
D-21



TOLERANCES UNLESS NOTED:	X.X ±0.050		UNIVERSITY OF COLORADO
	X.XX ±0.010		1111 ENGINEERING DRIVE
	X.XXX ±0.005		BOULDER, CO 80309-0427
UNITS: INCHES	X.X° °0.5		
MATERIAL THERMOPLASTIC		DESCRIPTION STEEL SCREW INSERT	
FINISH SMOOTH	PN 012	REV C	SHEET 2 of 2

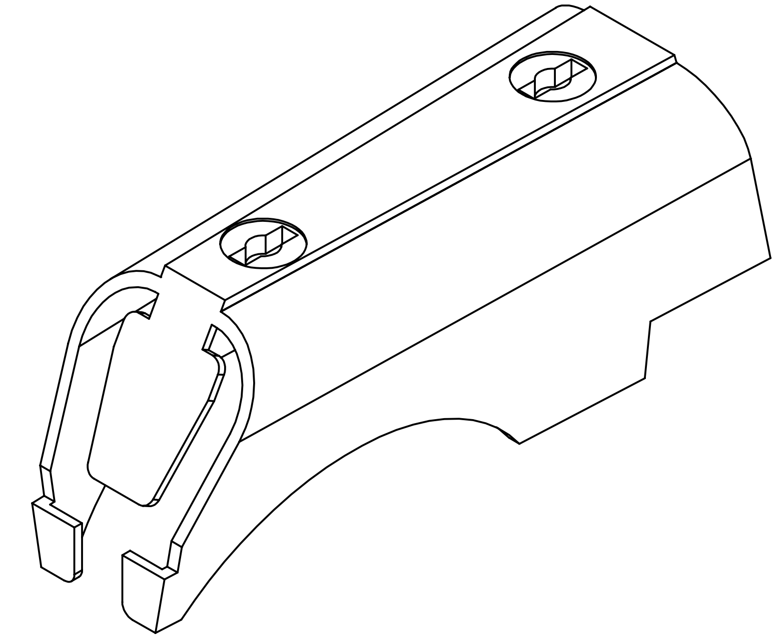
D-22

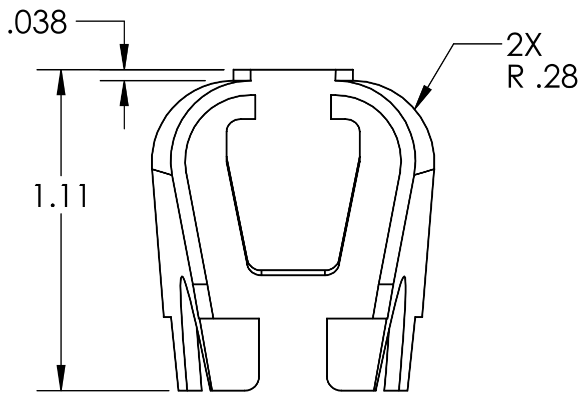
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/26/2023

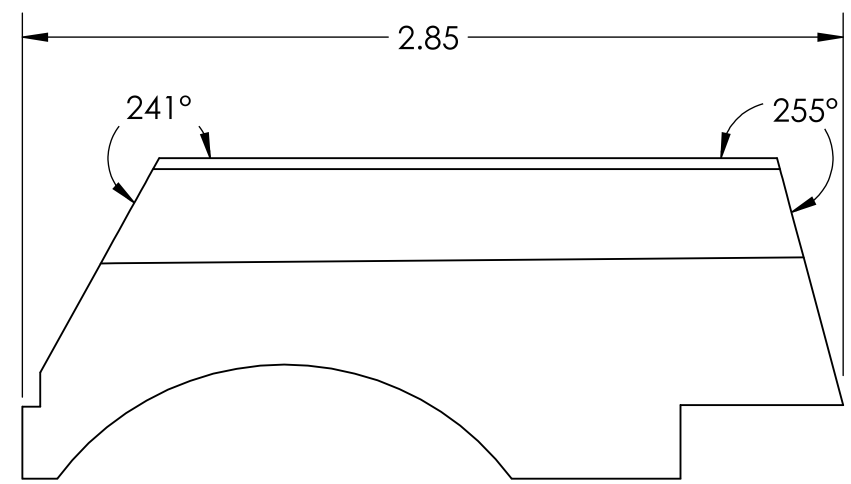


NOTES

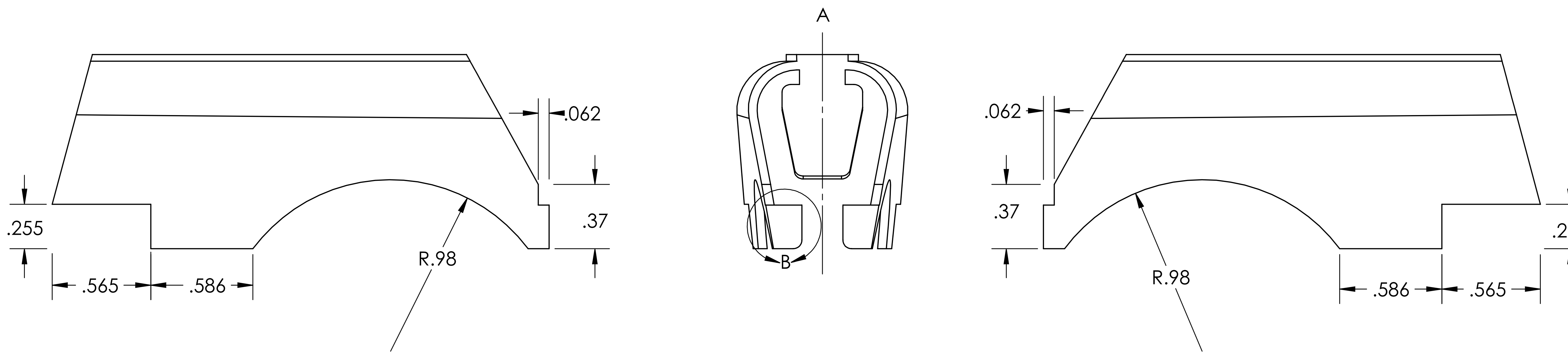
1. UNIFORM SHELL THICKNESS OF .050" UNLESS OTHERWISE SPECIFIED

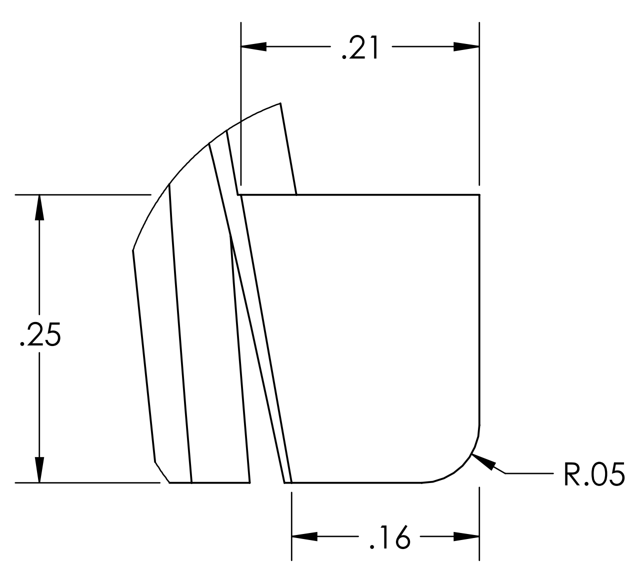






TOLERANCES UNLESS NOTED: X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL THERMOPLASTIC	DESCRIPTION SHARPENER COVER 1	
FINISH N/A	PN 013	REV A · SHEET 1 of 4
PROPRIETARY AND CONFIDENTIAL	THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.	





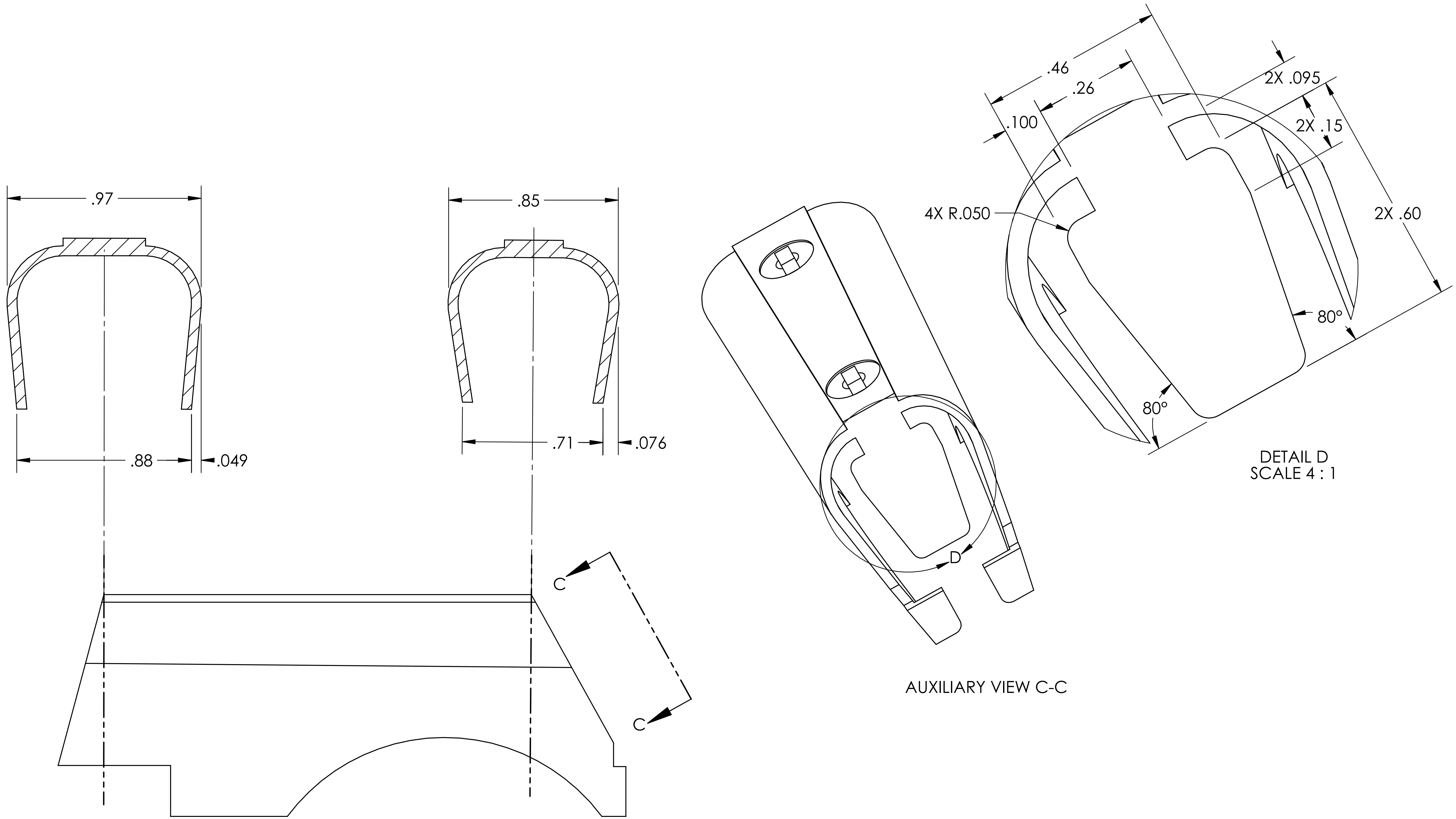
DETAIL B
SCALE 6 : 1

NOTES

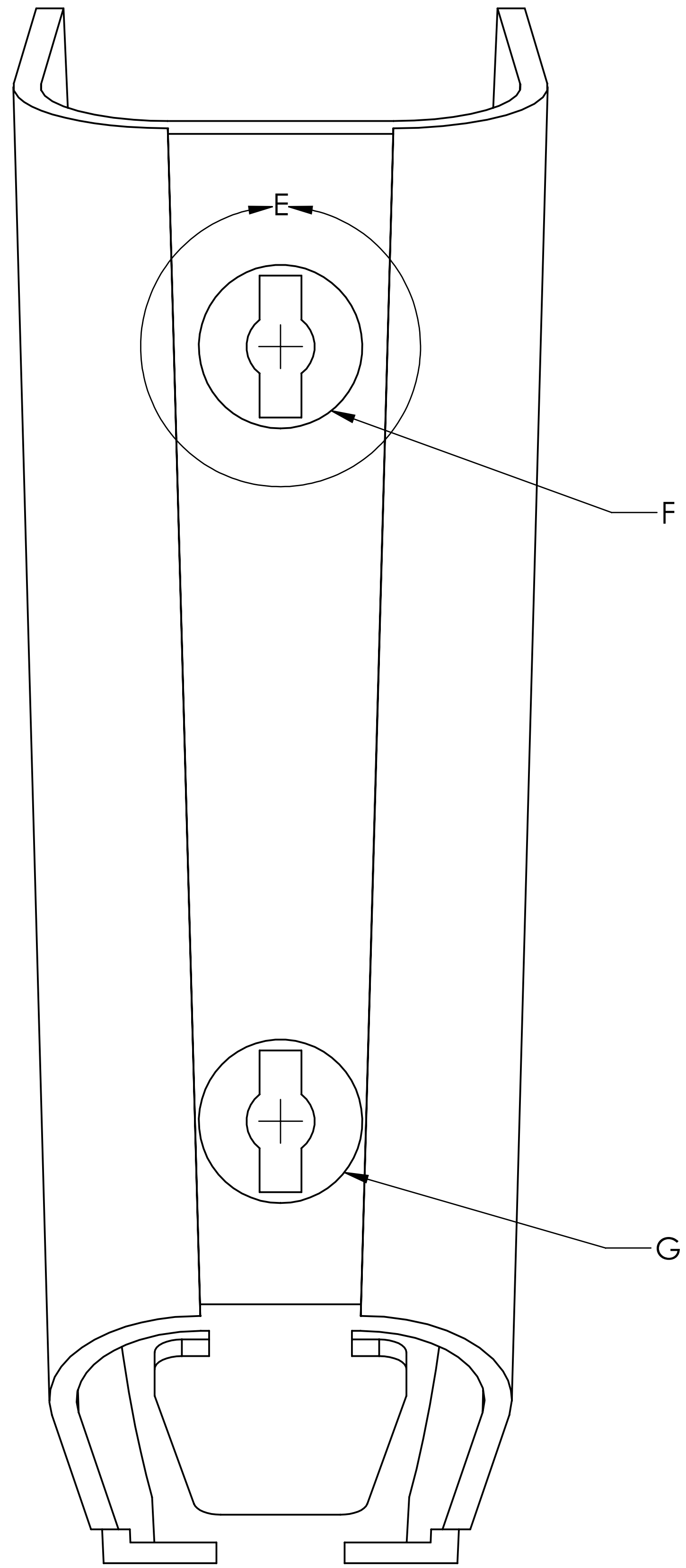
2. DETAIL VIEW B SYMMETRIC ACROSS CENTERLINE A

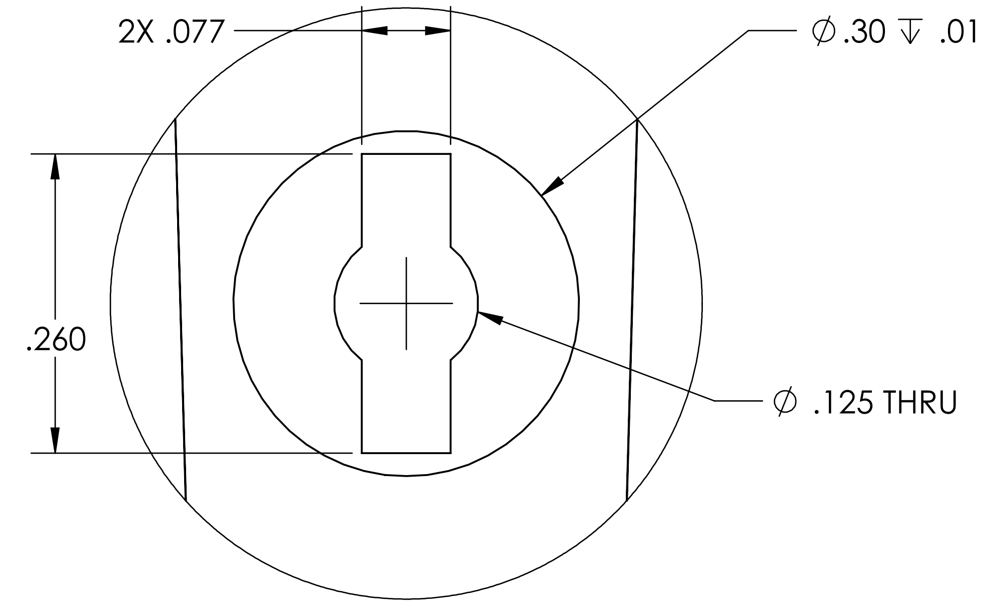
TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
UNITS: INCHES			
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 1	
FINISH N/A		PN 013	REV A · SHEET 2 of 4

D-24



TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 1	
FINISH N/A		PN 013	REV A / SHEET 3 of 4



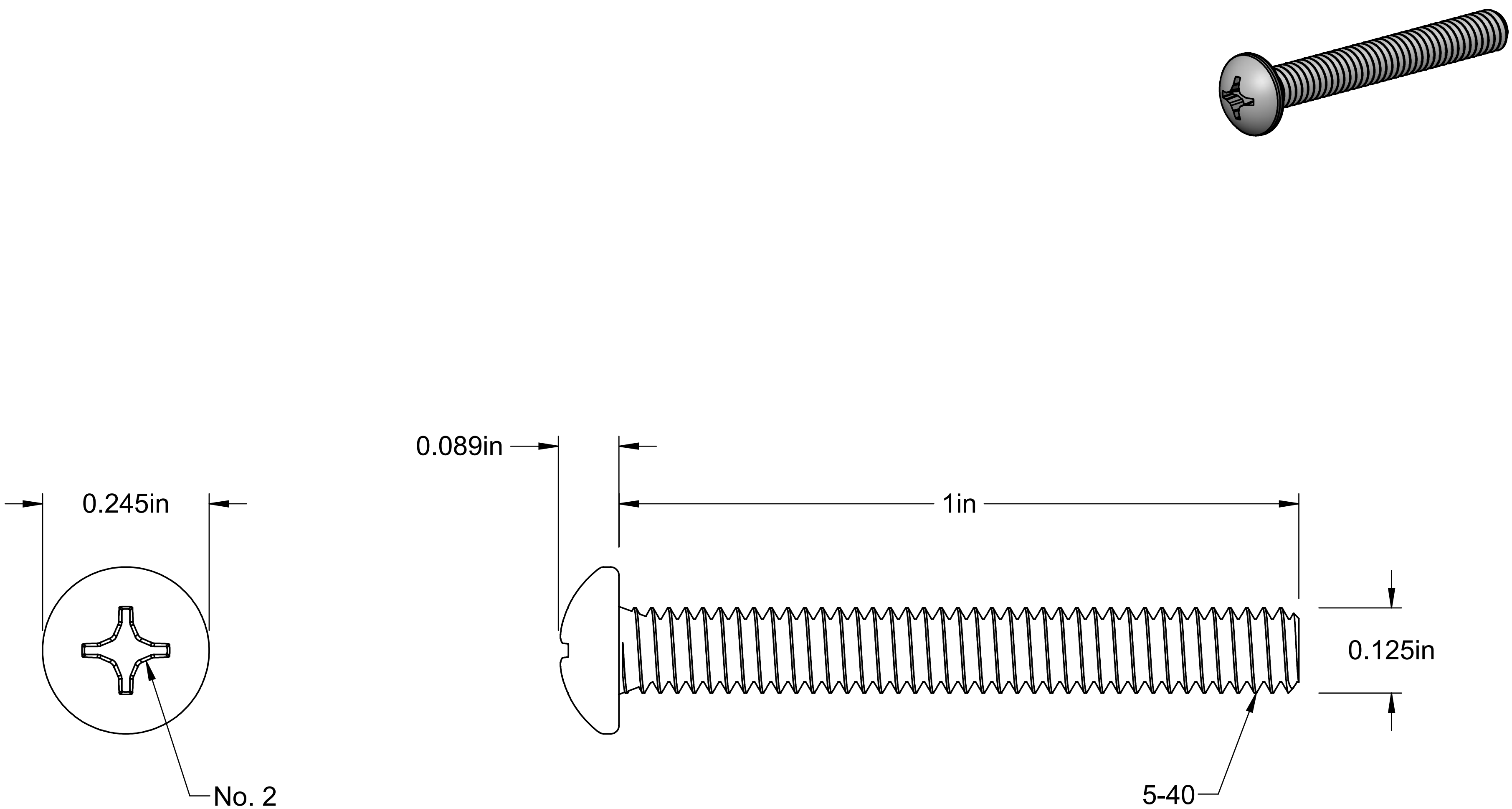


DETAIL E
SCALE 6 : 1

NOTES

3. DETAIL VIEW E SAME FOR FEATURES F AND G

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1°; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL: THERMOPLASTIC	DESCRIPTION: SHARPENER COVER 1	
FINISH: N/A	PN: 013; REV: A	SHEET: 4 of 4



TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427				
UNITS: INCHES						
MATERIAL STEEL		DESCRIPTION #5-40 UNC 1/4" X 1" FASTENER				
FINISH N/A		PN 014	REV A			SHEET 1 of 1

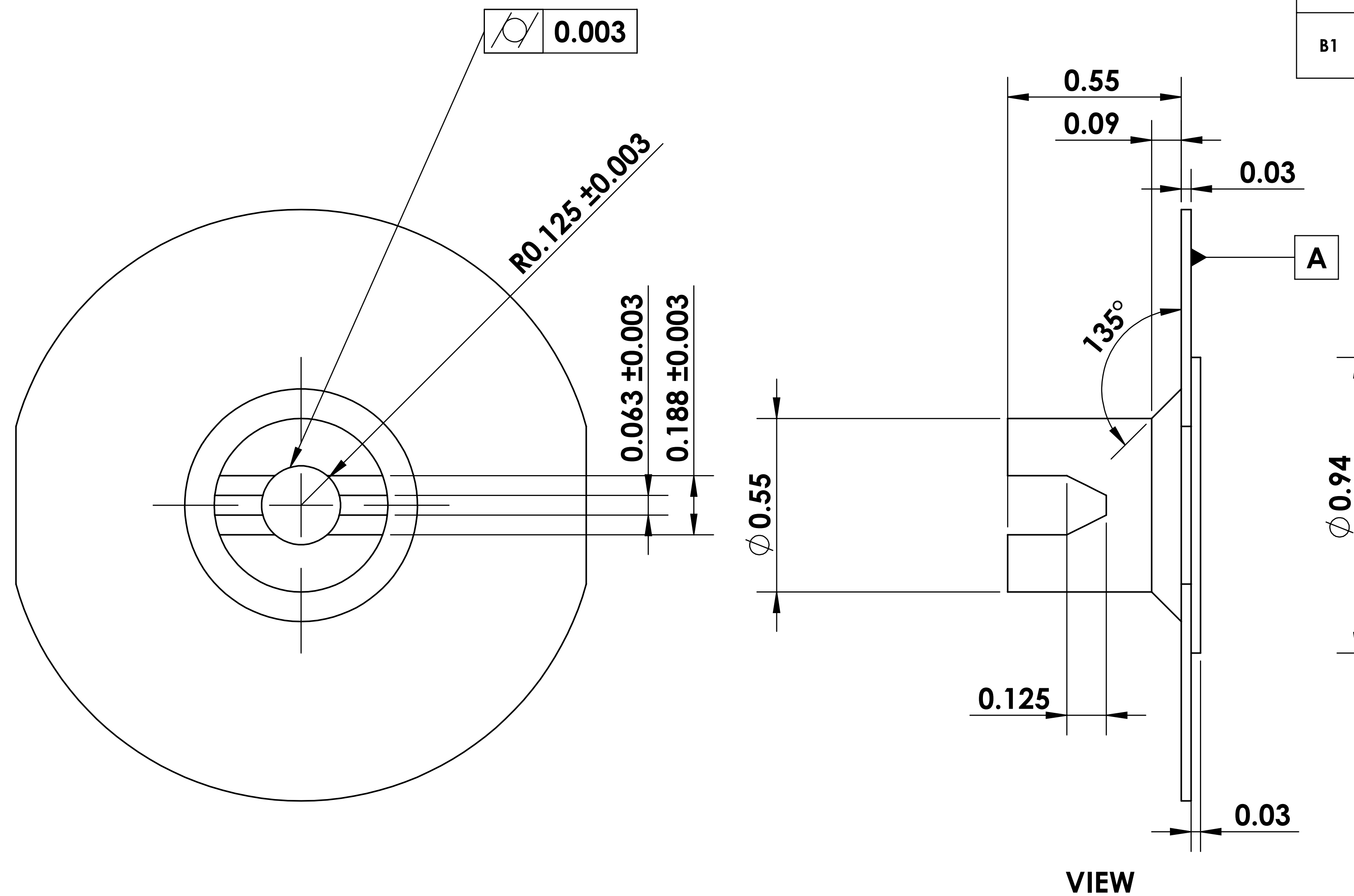
McMASTER-CARR® CAD

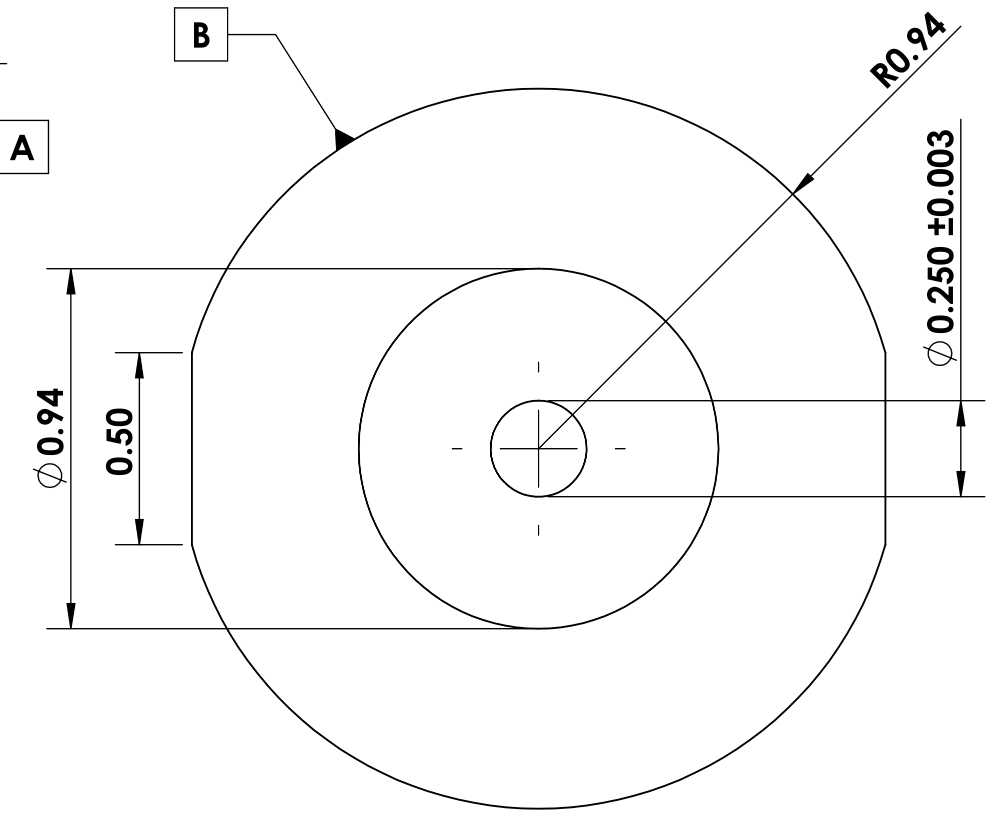
PART NUMBER **91772A133**

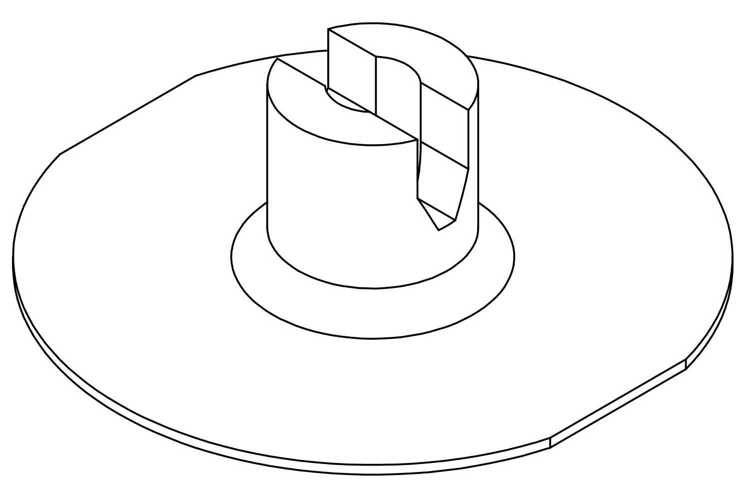
http://www.mcmaster.com

Passivated 18-8 Stainless Steel
Pan Head Phillips Screw

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
B1	IR	INITIAL RELEASE	2/9/2023	IR







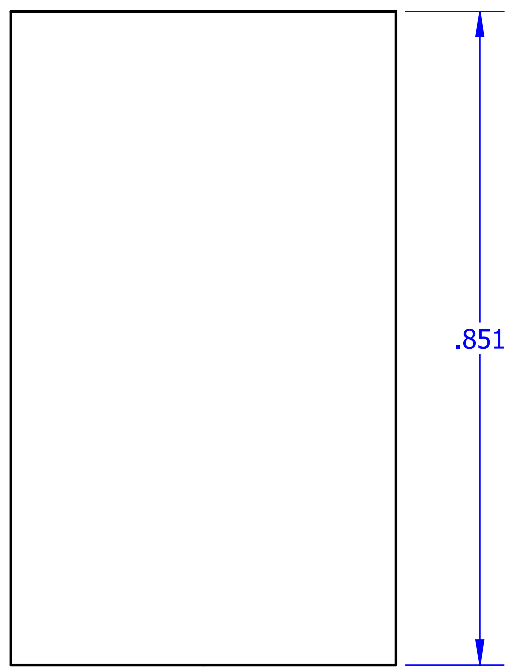
NOTES:

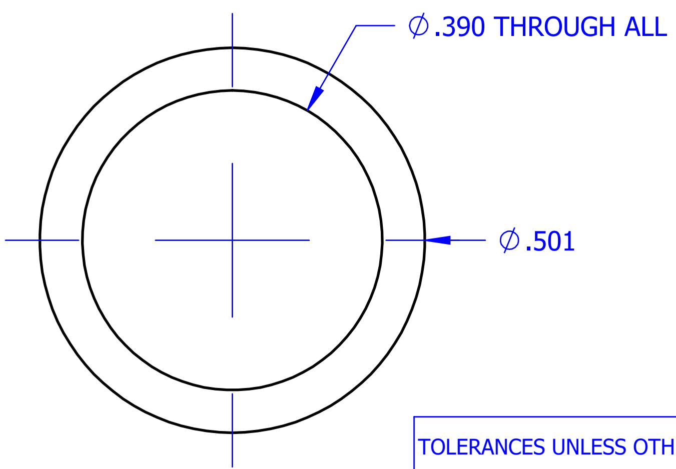
1. INCREASED TOLERANCES ABOUT MAIN SHAFT HOLE ARE TO PREVENT WHEEL WOBBLE.
2. MAIN SHAFT HOLE IS THE 0.25" DIAMETER HOLE IN CENTER OF PART.
3. THE MAIN SHAFT HOLE AND THE NOTCH IN PROTRUDING TUBE ARE THE ONLY THRU FEATURES.

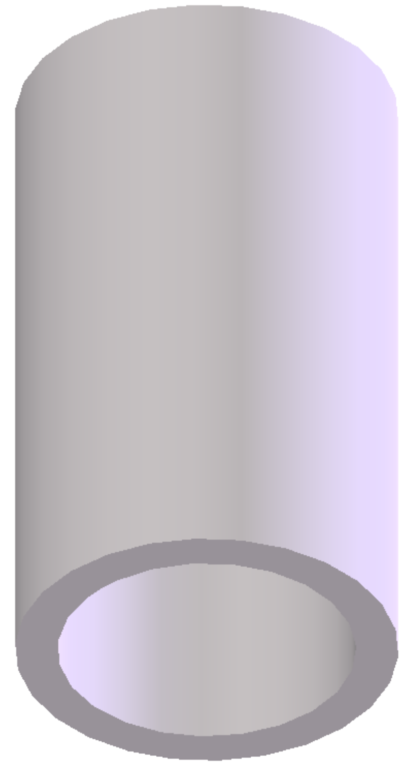
TOLERANCES UNLESS NOTED: X.X ± 0.01; X.XX ± 0.01; X.XXX ± 0.005; X.X° ± 0.5 — UNITS: **IPS**	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL: STEEL	DESCRIPTION: STEEL GRIND WHEEL	
FINISH: FINE	PN: 015 — REV: IR	SHEET: 1 of 1

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

REV.	DESCRIPTION	DATE	APPOVER
A	INITIAL RELEASE	2/25/2023	NOLAN MAJOR







UNITS: INCHES

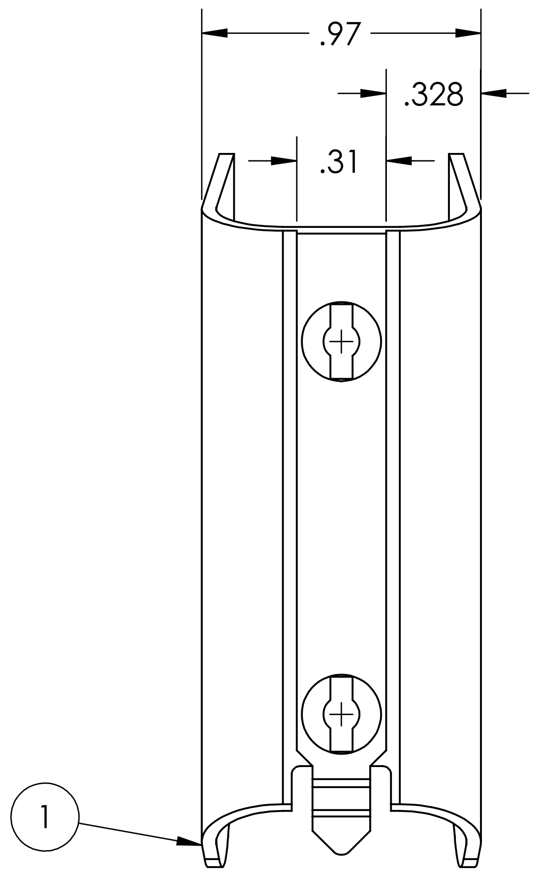
TOLERANCES UNLESS OTHERWISE NOTED:	X.X	+/- 0.050
	X.XX	+/- 0.010
MATERIAL: STEEL	X.XXX	+/- 0.005
FINISH: N/A	X.X DEGREES	+/- 0.5

UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION
STELL CYLINDER

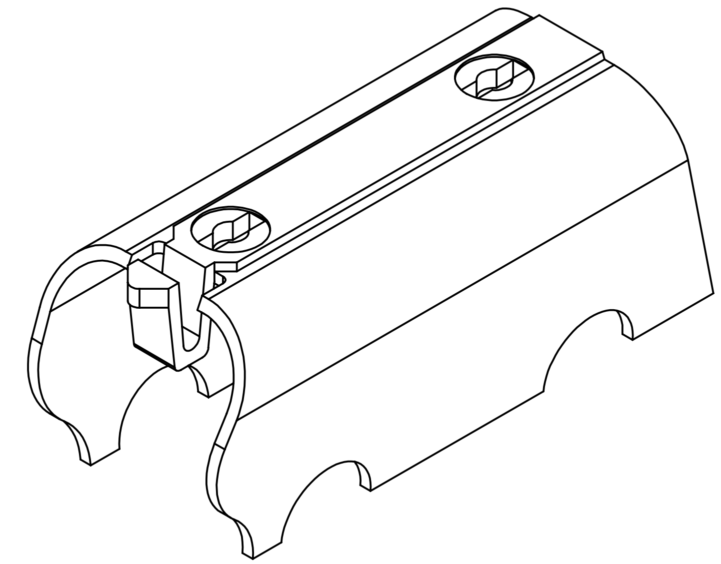
PN	REV	SHEET
016	A	1 of 1

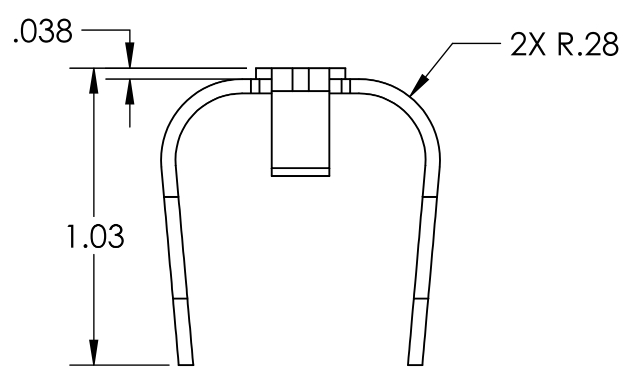
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/3/2023

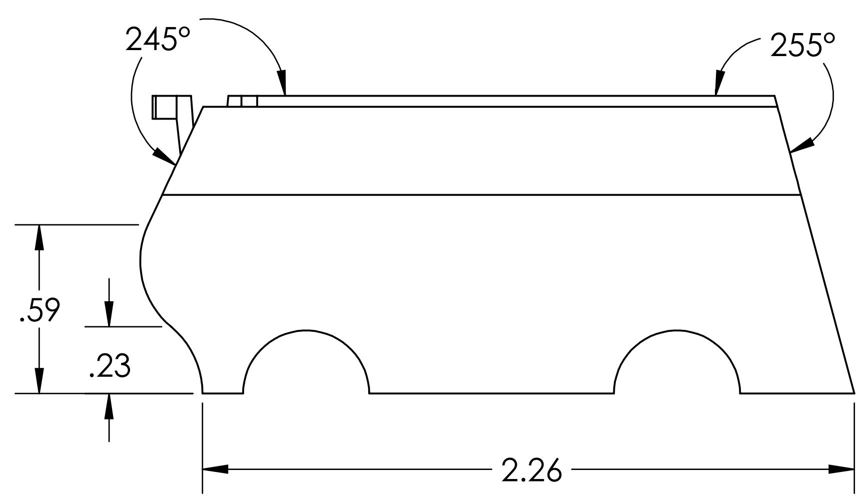


NOTES

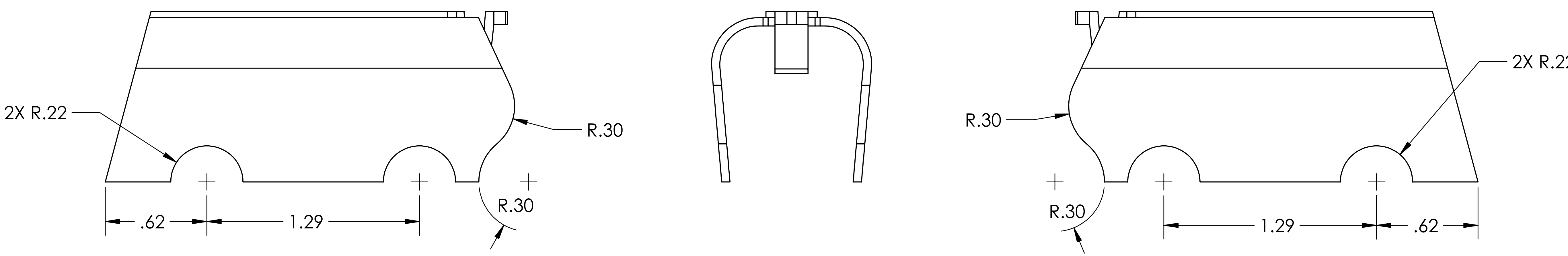
1. UNIFORM SHELL THICKNESS OF .050" UNLESS OTHERWISE SPECIFIED.



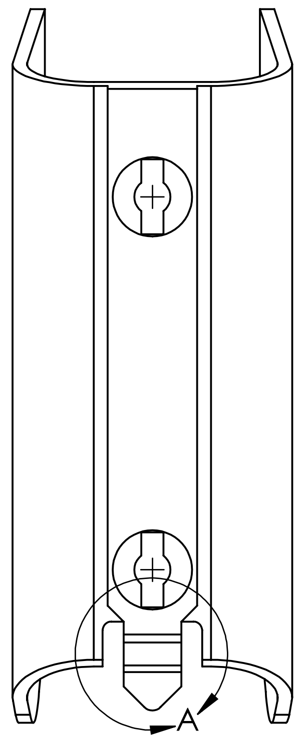


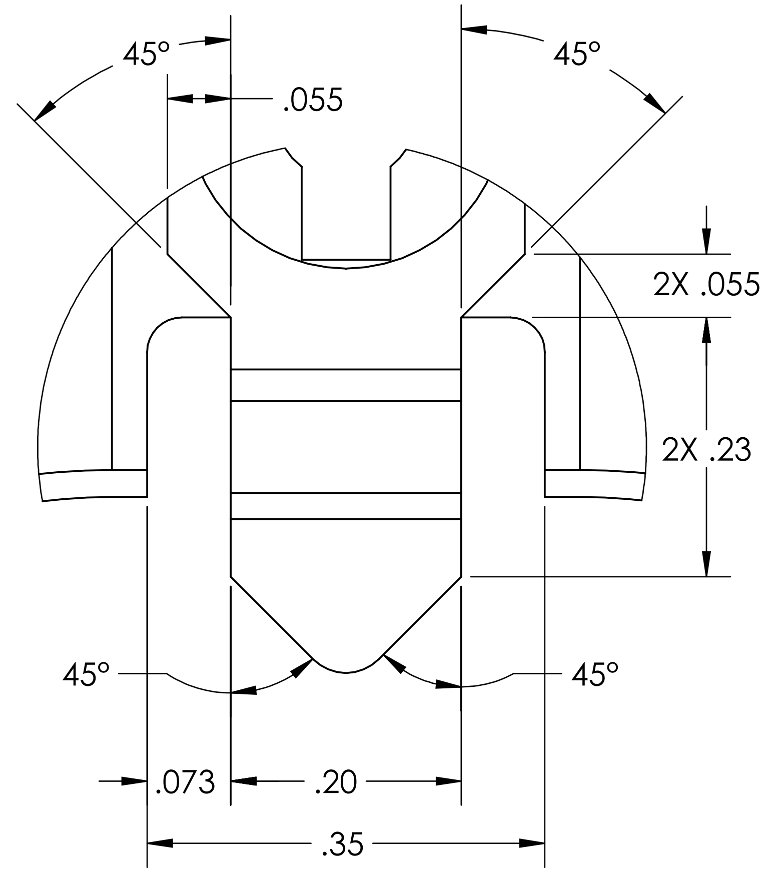


TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 2
FINISH N/A		PN 017 · REV A · SHEET 1 of 4

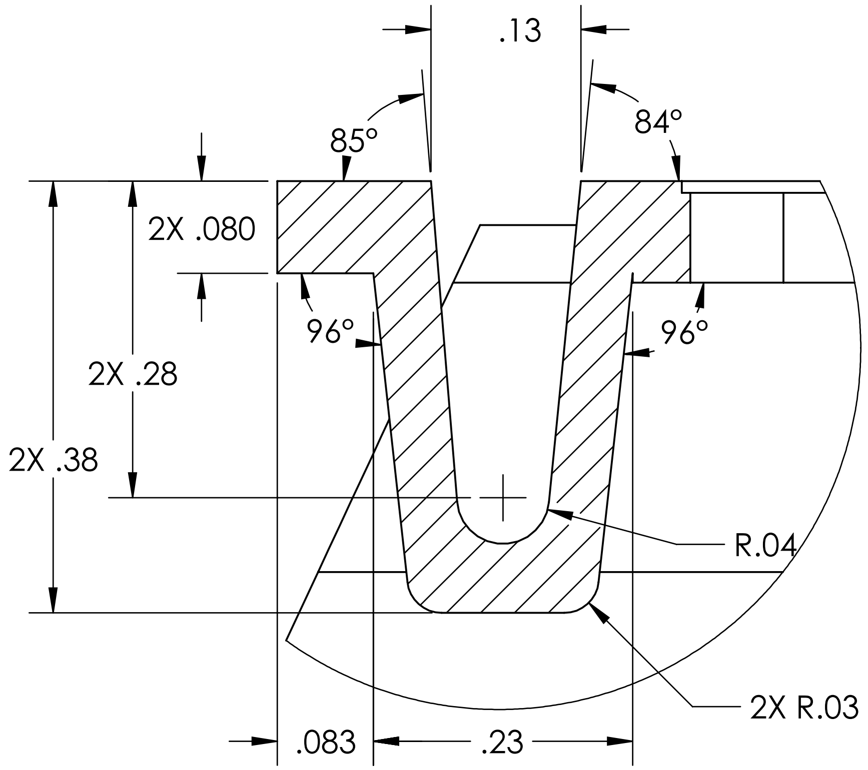


TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 2	
FINISH N/A		PN 017	REV A	SHEET 2 of 4

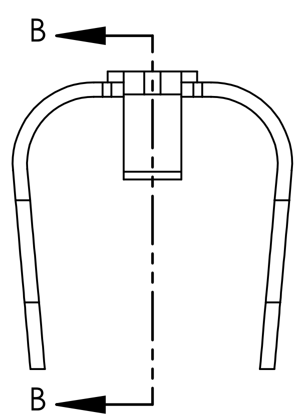


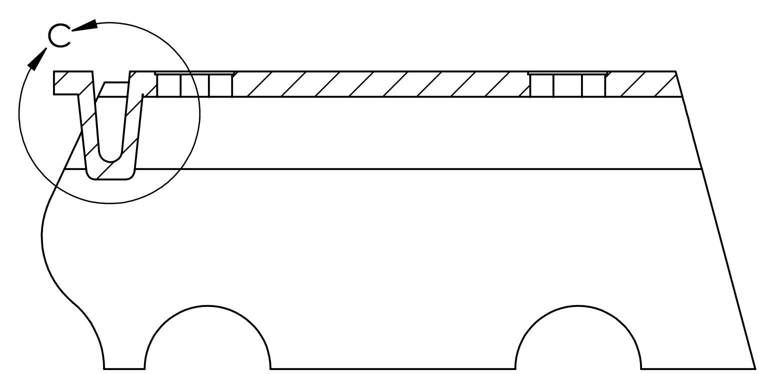


DETAIL A
SCALE 6 : 1



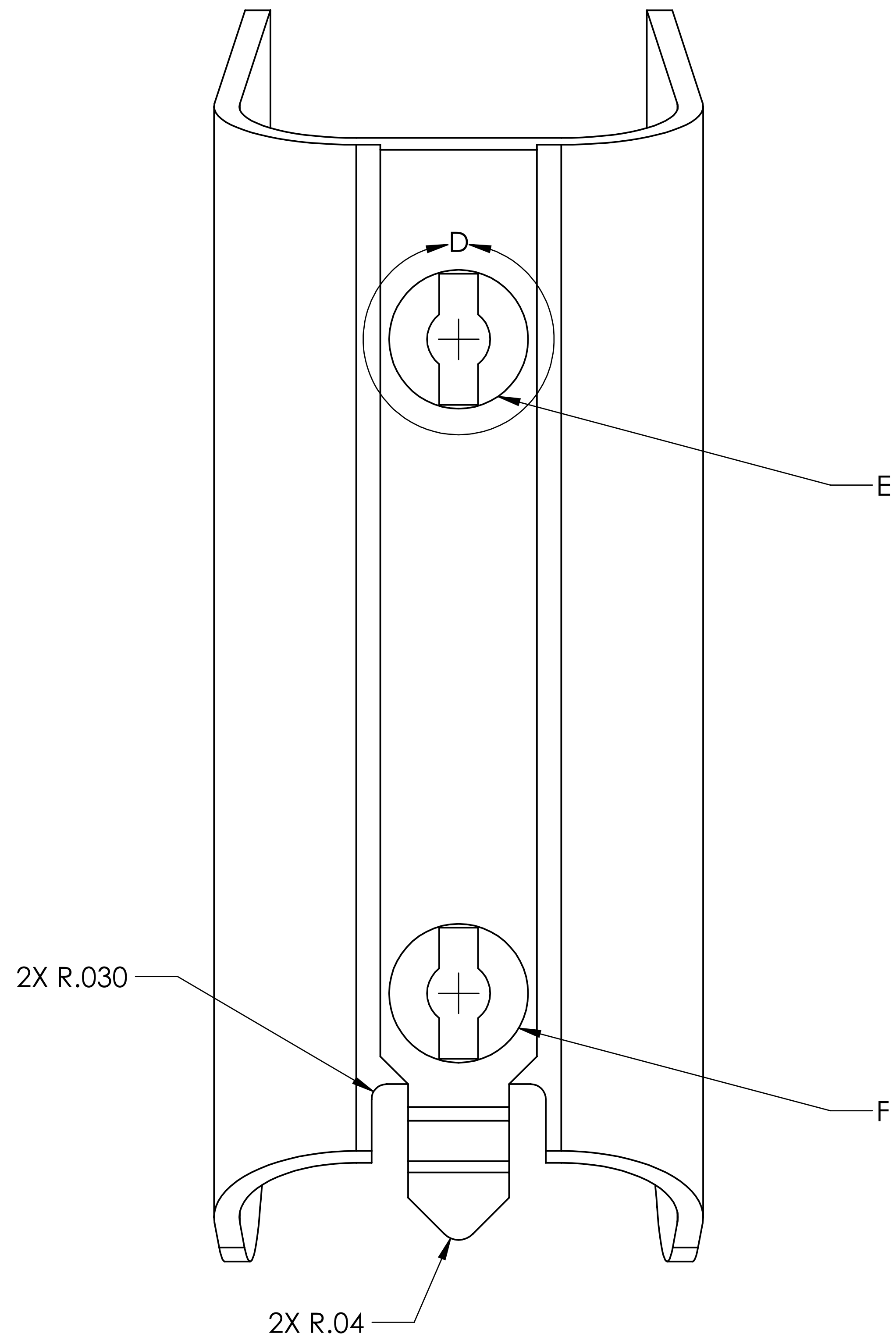
DETAIL C
SCALE 6 : 1

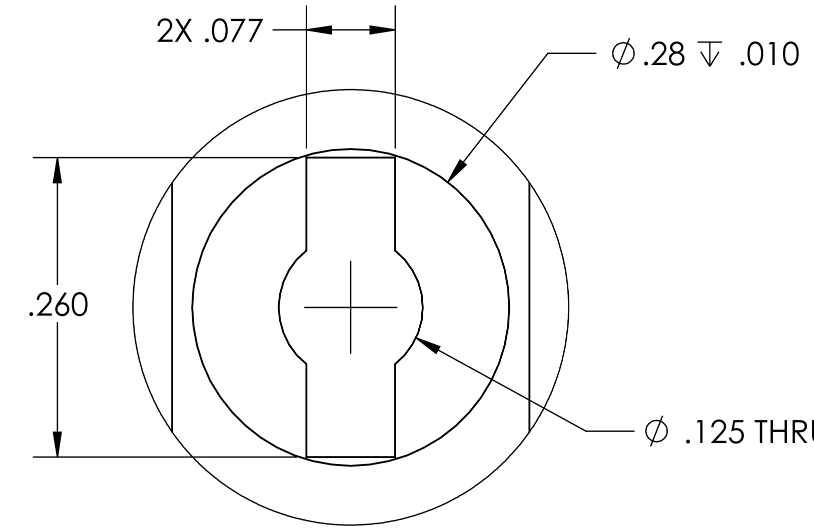




SECTION B-B
SCALE 1.5 : 1

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1°; UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 2
FINISH N/A	PN 017	REV A	SHEET 3 of 4





DETAIL D
SCALE 6 : 1

NOTES

2. DETAIL VIEW D SAME FOR FEATURES E AND F

TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±1°; UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL: THERMOPLASTIC		DESCRIPTION: SHARPENER COVER 2
FINISH: N/A	PN: 017	REV: A; SHEET: 4 of 4

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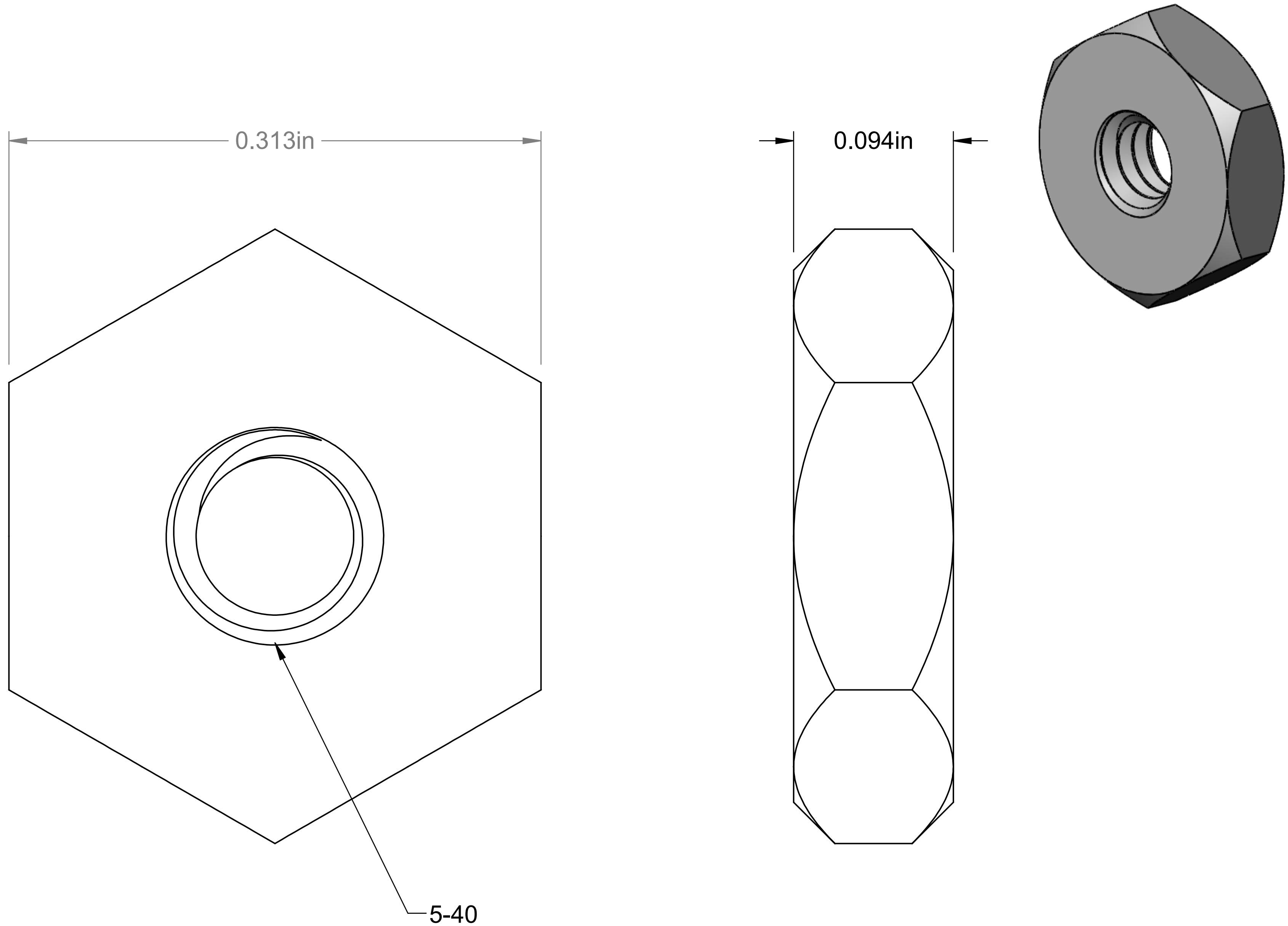


TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427			
MATERIAL STEEL		DESCRIPTION 5/16" X 1/8" NUT			
FINISH N/A		PN 018	REV A		SHEET 1 of 1

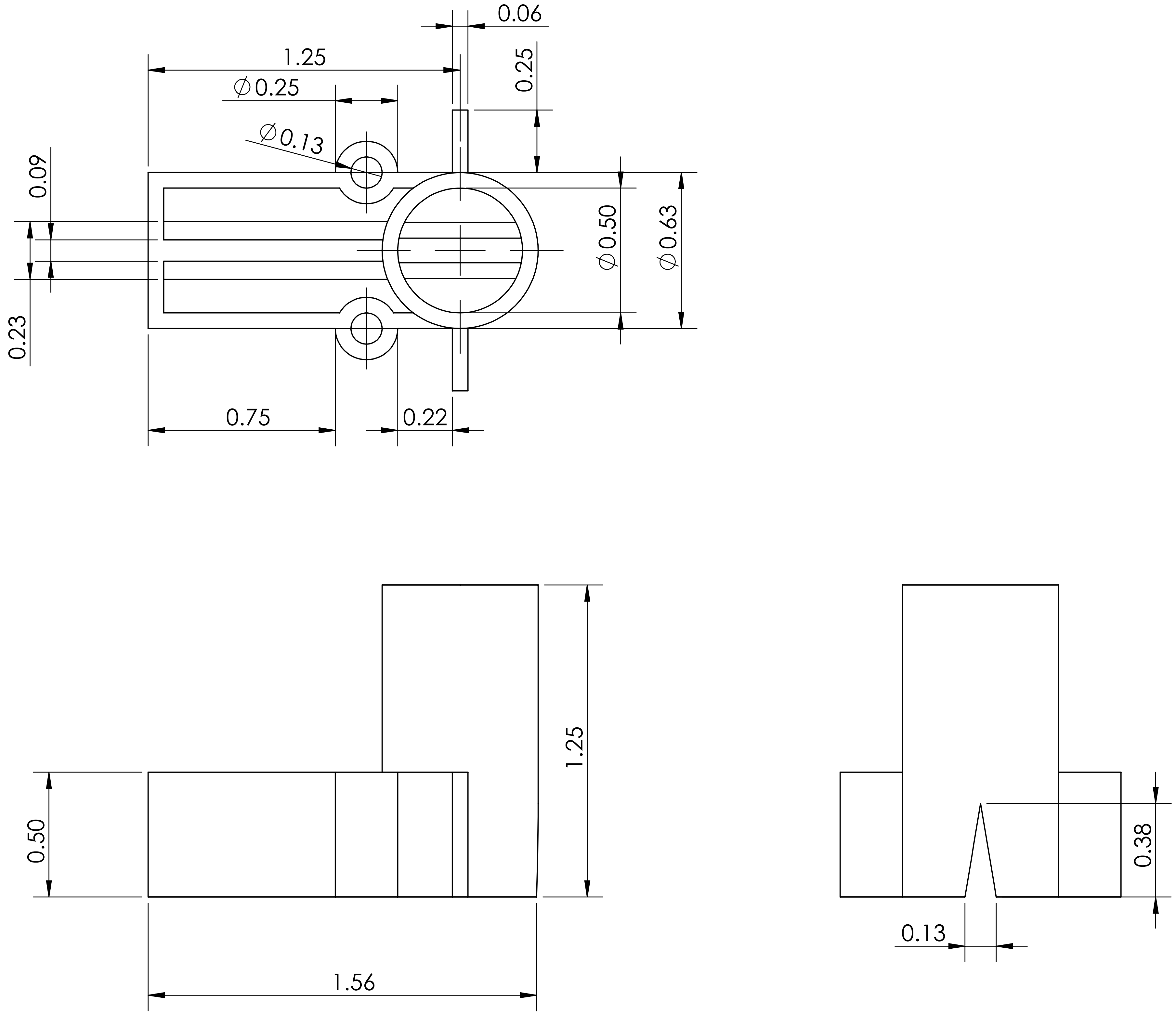
McMASTER-CARR® CAD

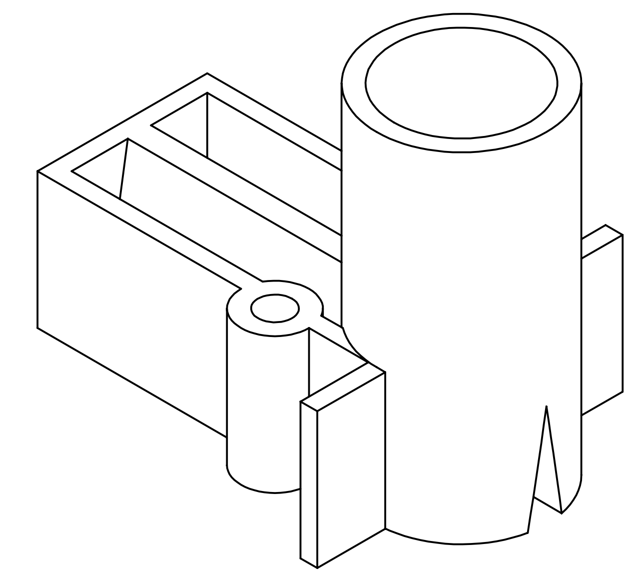
PART NUMBER 94450A513

http://www.mcmaster.com

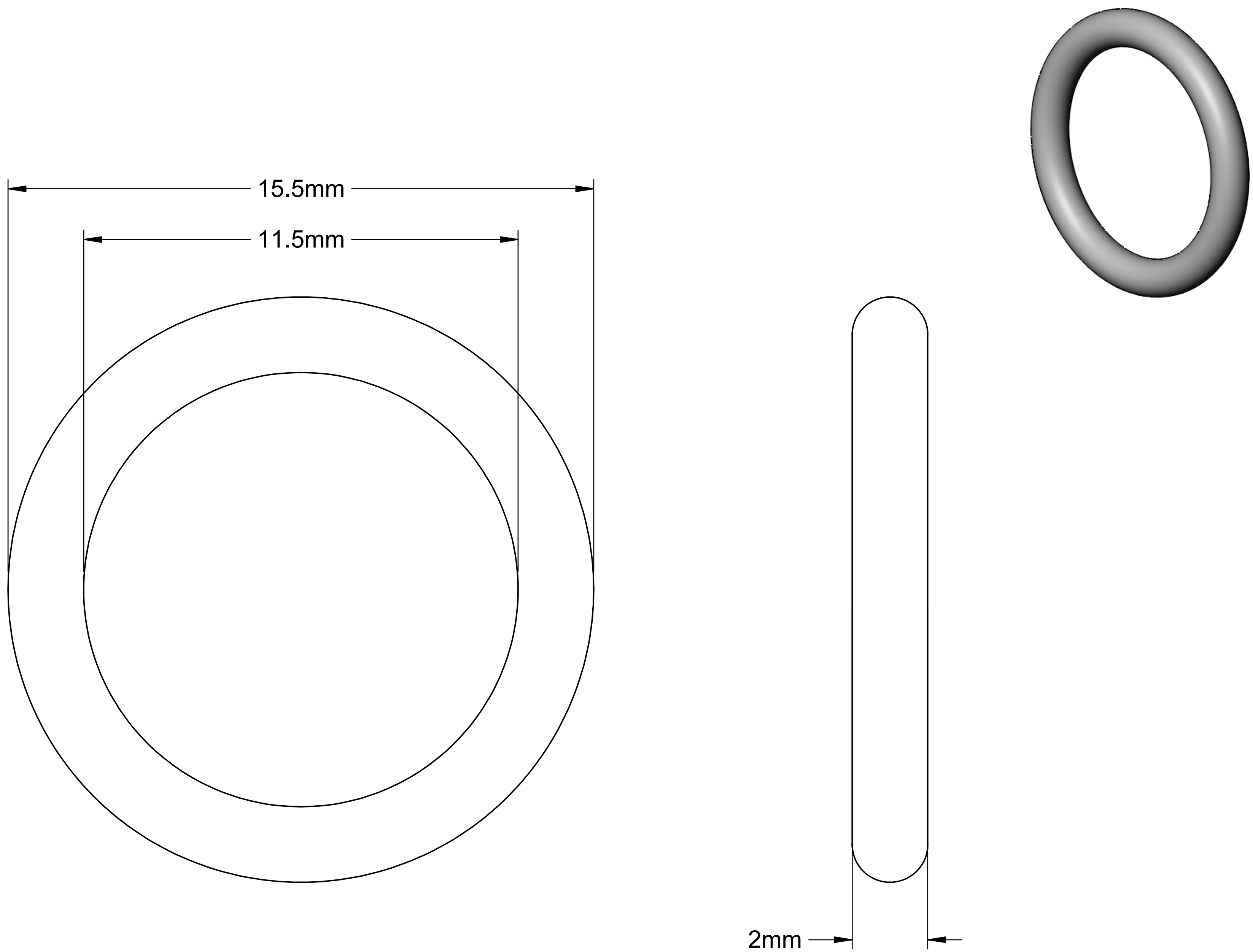
Left-Hand Threaded 18-8 Stainless Steel Thin Hex Nut

REVISIONS				
ZONE	IR	STEEL ROTATOR SCREW HOLSTER	3/9/2023	APPROVED



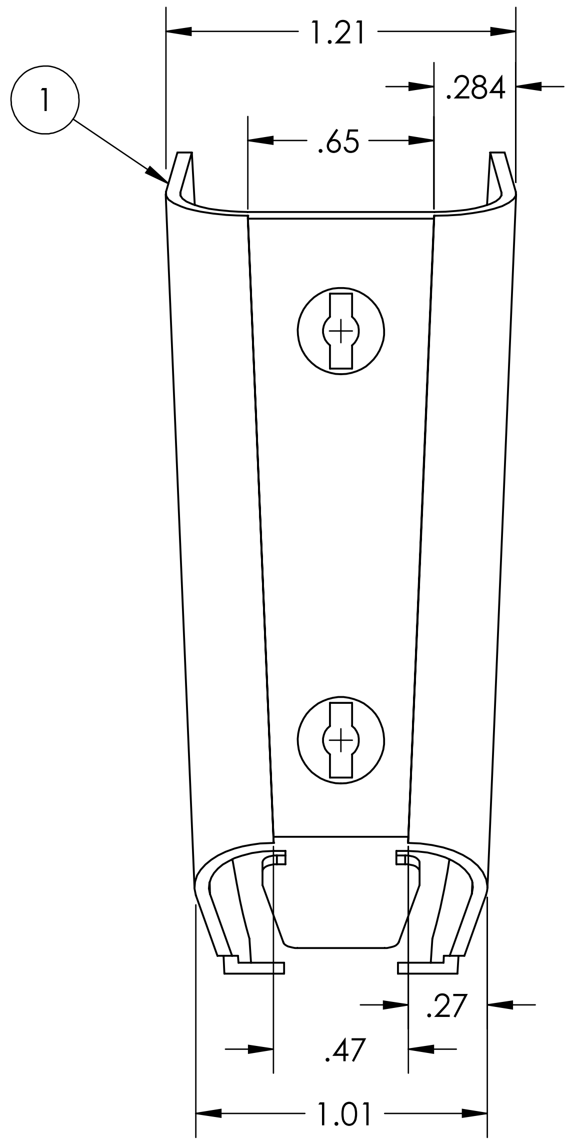


TOLERANCES UNLESS NOTED: X.X ±0.05 X.XX ±0.005 X.XXX ±0.0005 X.X° °0.05 UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL PLASTIC		DESCRIPTION STEEL ROTATOR SCREW HOLSTER
FINISH N/A		PN 019 / REV IR / SHEET 1 of 1



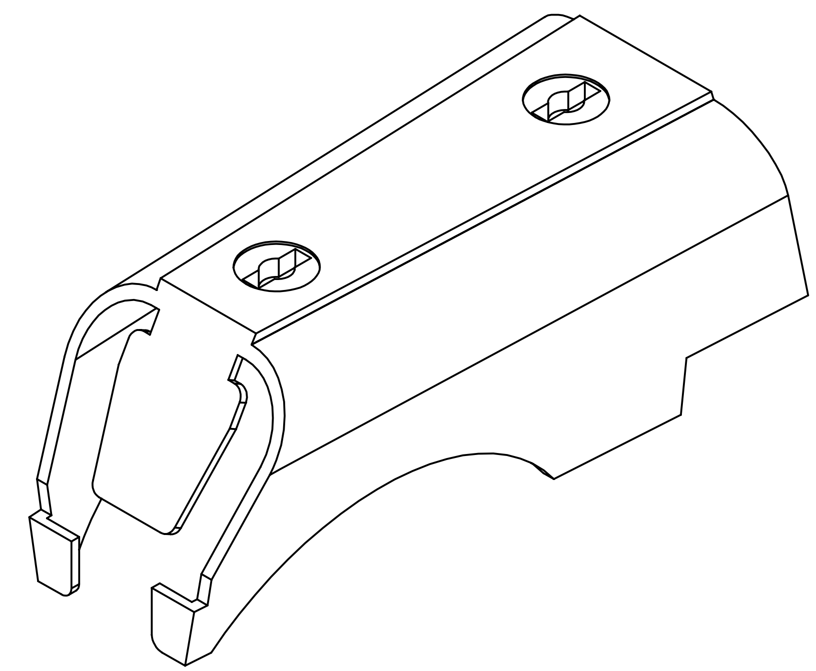
TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1°; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL RUBBER	DESCRIPTION LARGE ROTATOR SCREW INSERT GASKET	McMASTER-CARR® CAD — PART NUMBER 9262K851
FINISH N/A	PN 020 — REV A — SHEET 1 of 1	http://www.mcmaster.com © 2022 McMaster-Carr Supply Company Information in this drawing is provided for reference only. — Oil-Resistant Buna-N O-Ring

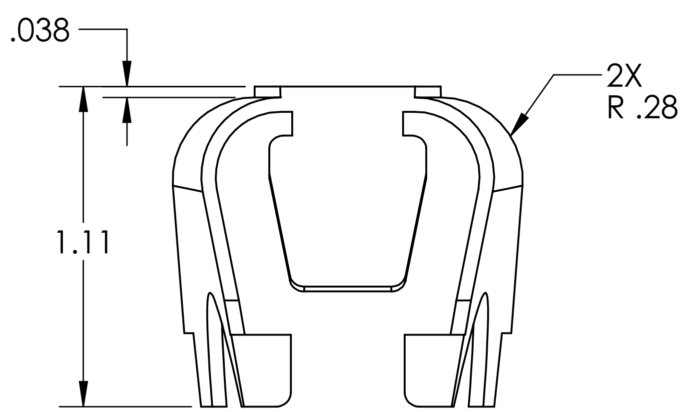
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/28/2023

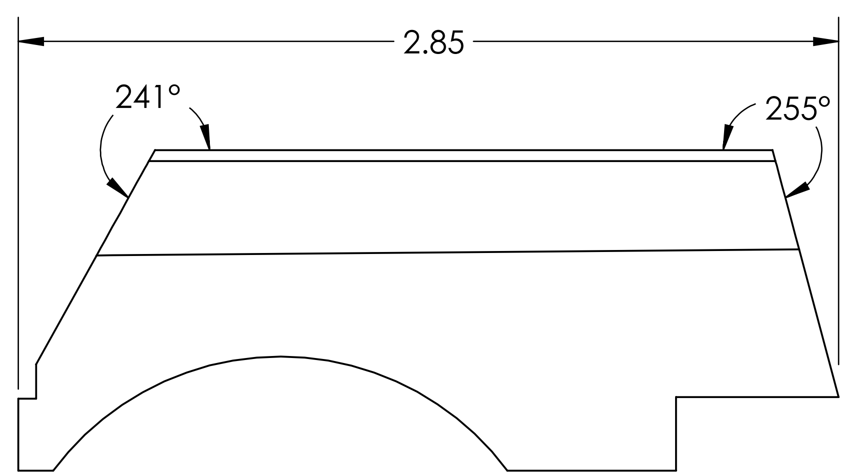


NOTES

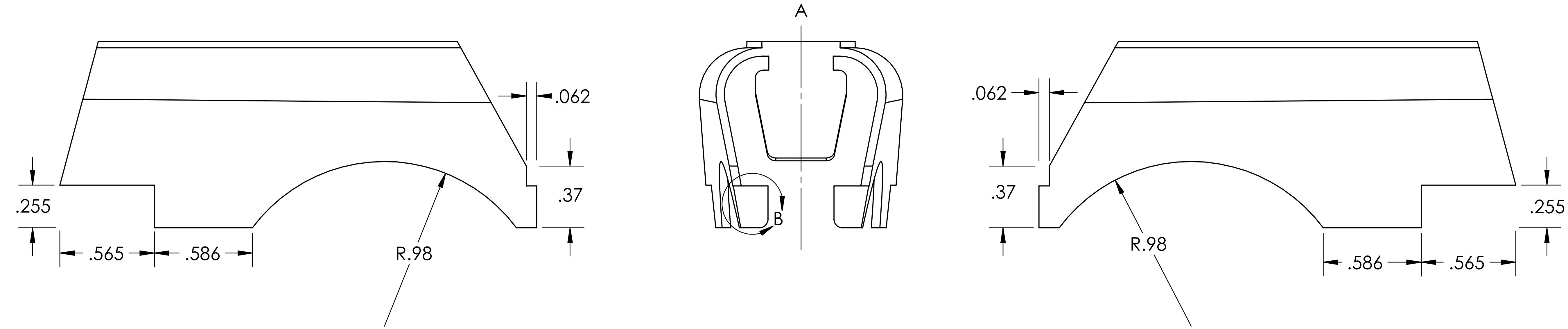
1. UNIFORM SHELL THICKNESS OF .050" UNLESS OTHERWISE SPECIFIED

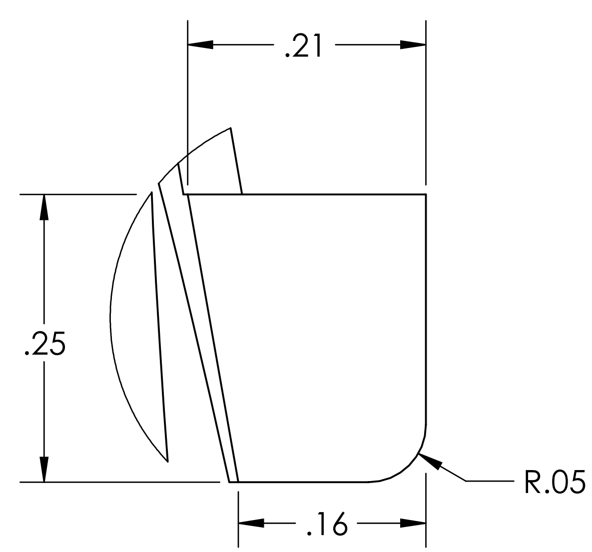






TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±1° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 3
FINISH N/A		PN 021 / REV A / SHEET 1 of 4





DETAIL B
SCALE 6 : 1

NOTES

2. DETAIL VIEW B SYMMETRIC ACROSS CENTERLINE A

TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±1°; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427		
MATERIAL THERMOPLASTIC	DESCRIPTION SHARPENER COVER 3		
FINISH N/A	PN 021	REV A	SHEET 2 of 4

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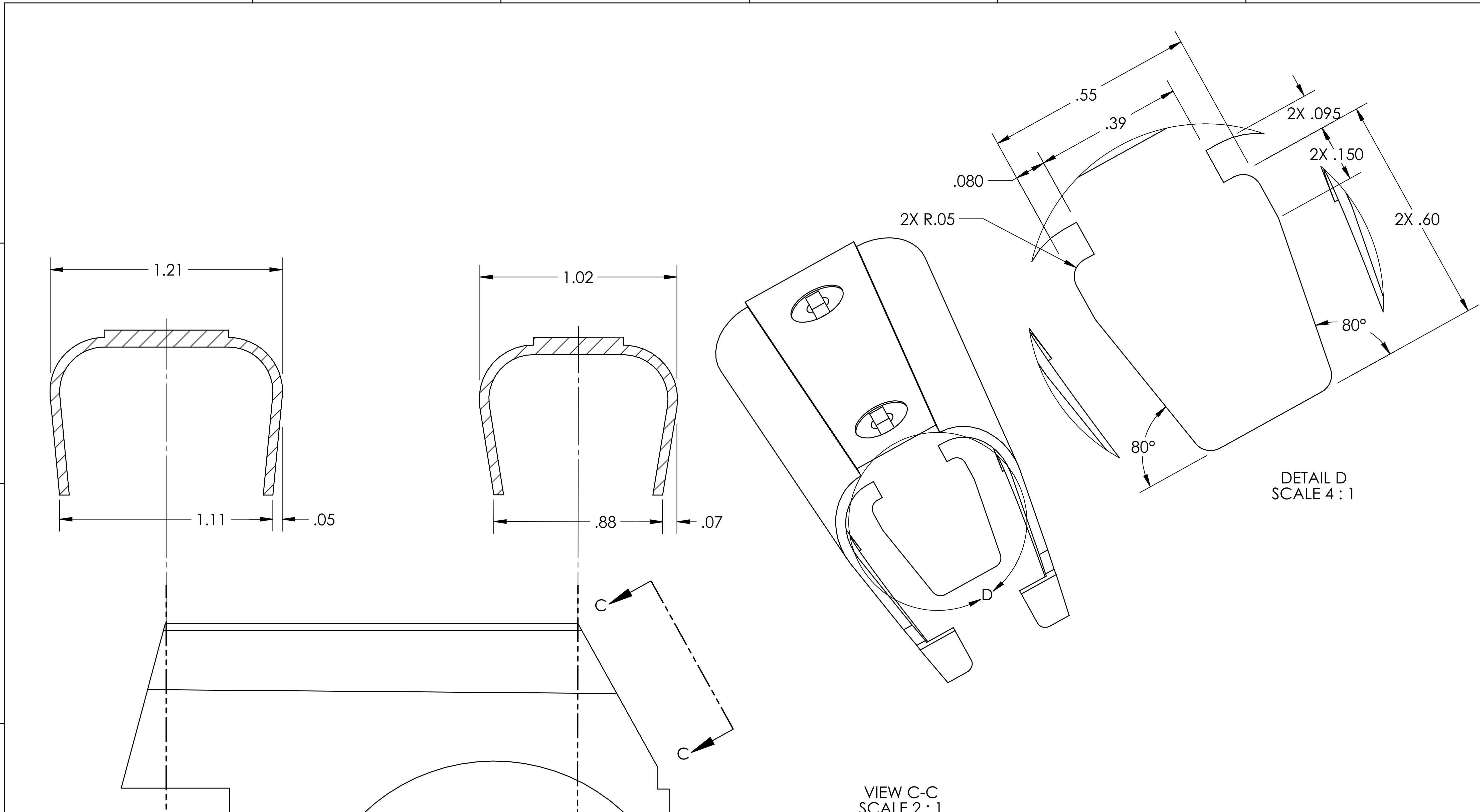
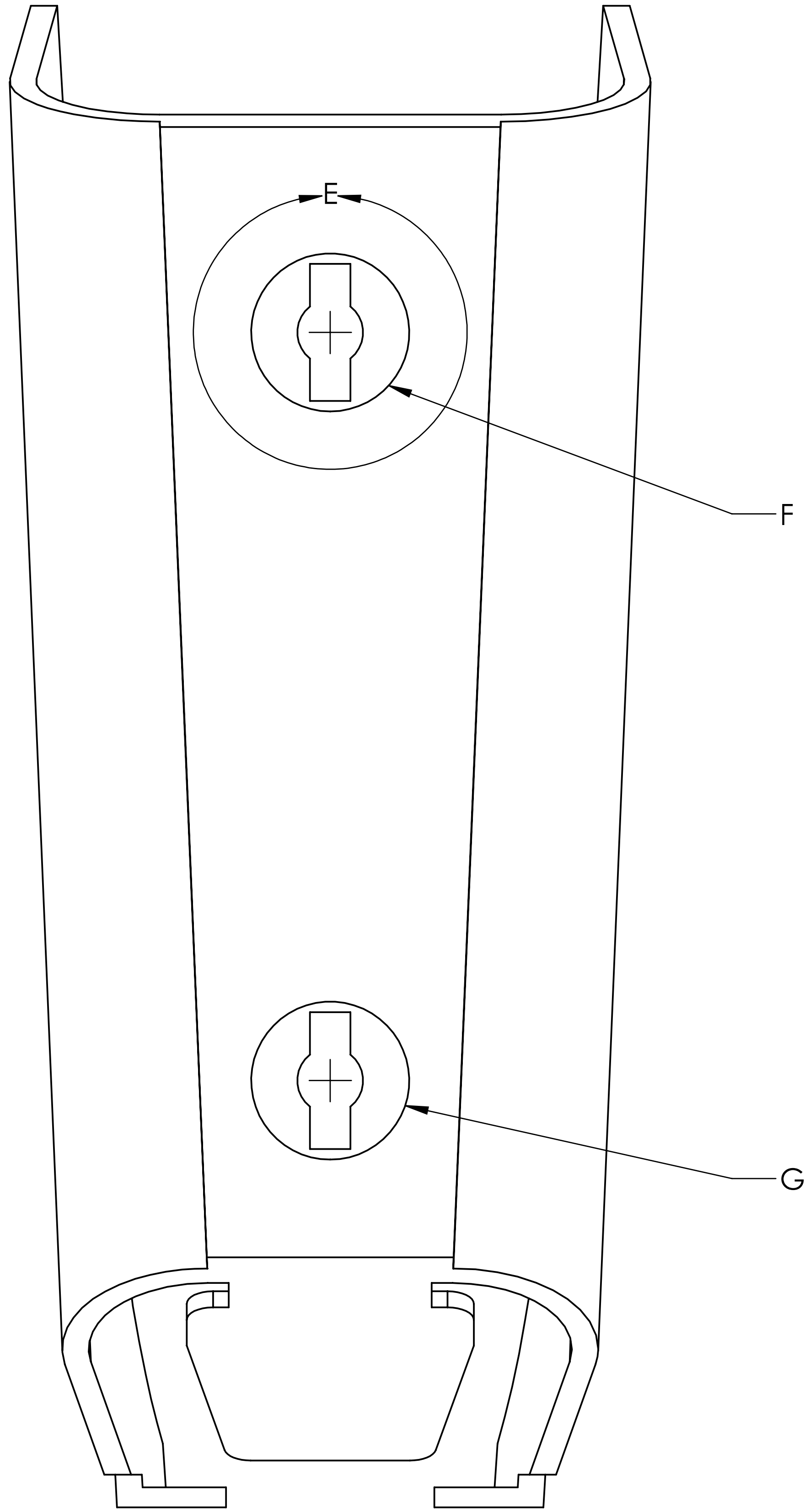
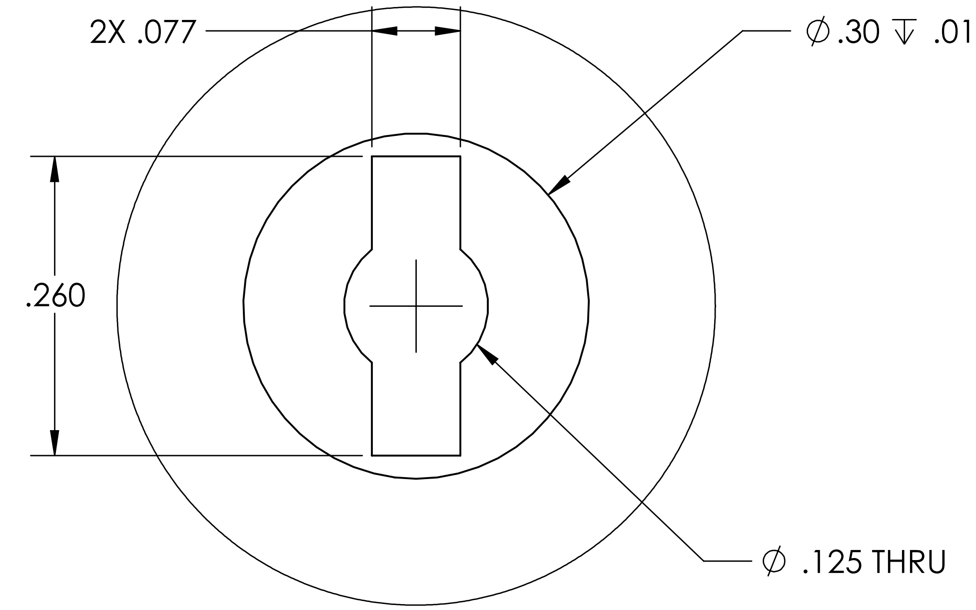


TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 3	
FINISH N/A	PN 021	REV A	SHEET 3 of 4

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.





DETAIL E
SCALE 6 : 1

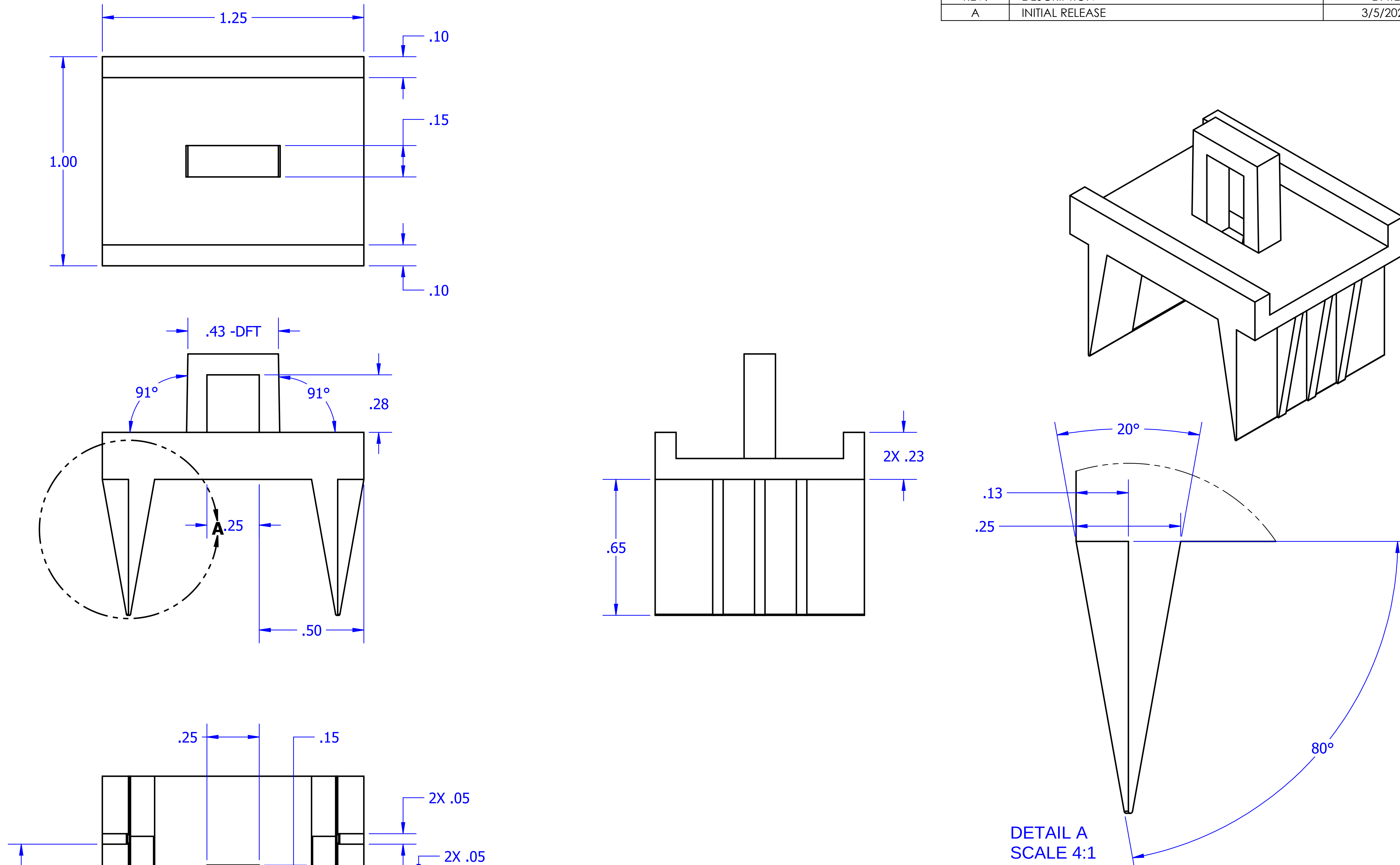
NOTES

3. DETAIL VIEW E SAME FOR FEATURES F AND G

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° ±1° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHARPENER COVER 3
FINISH N/A	PN 021	REV A	SHEET 4 of 4

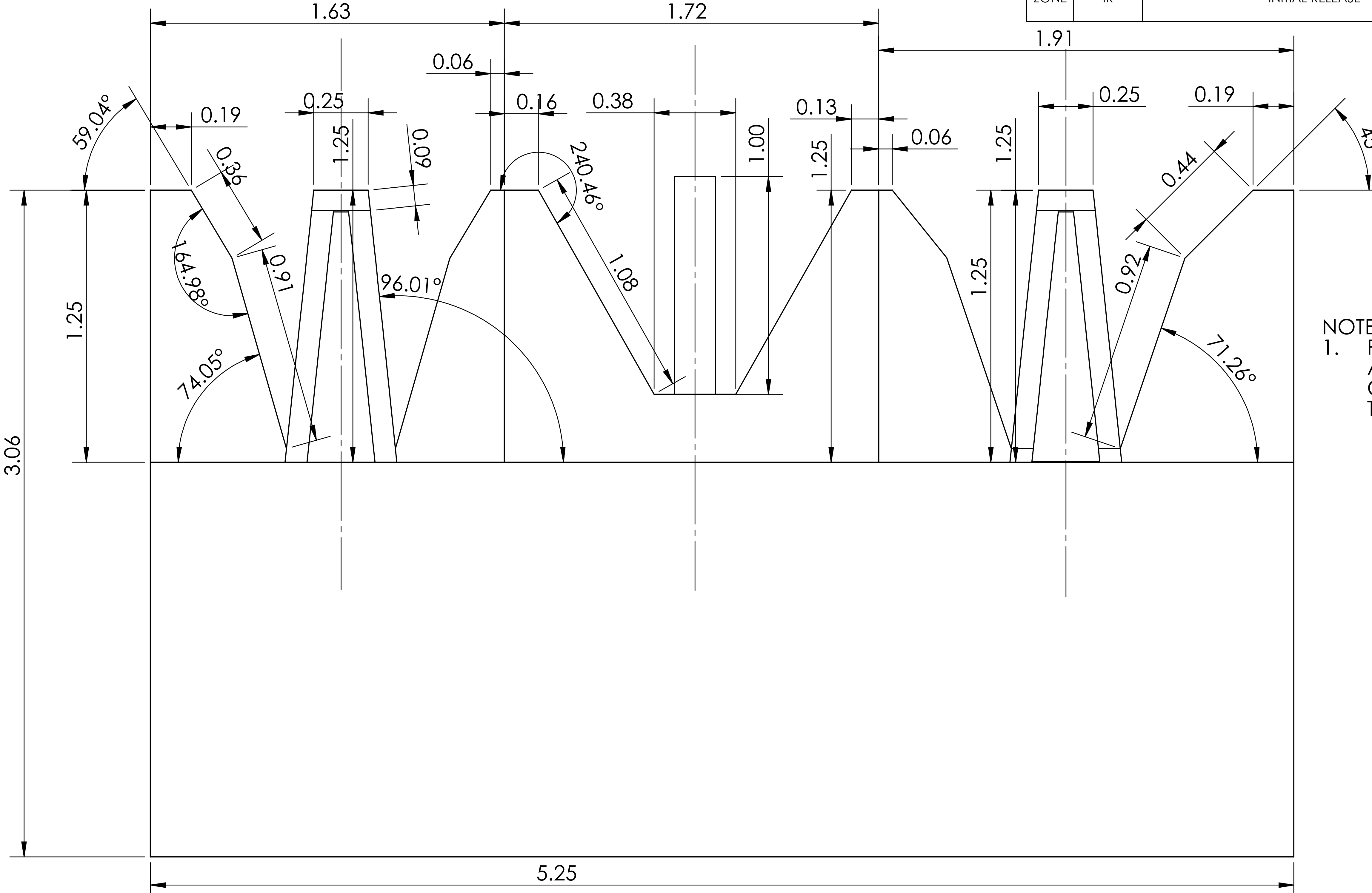
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/5/2023



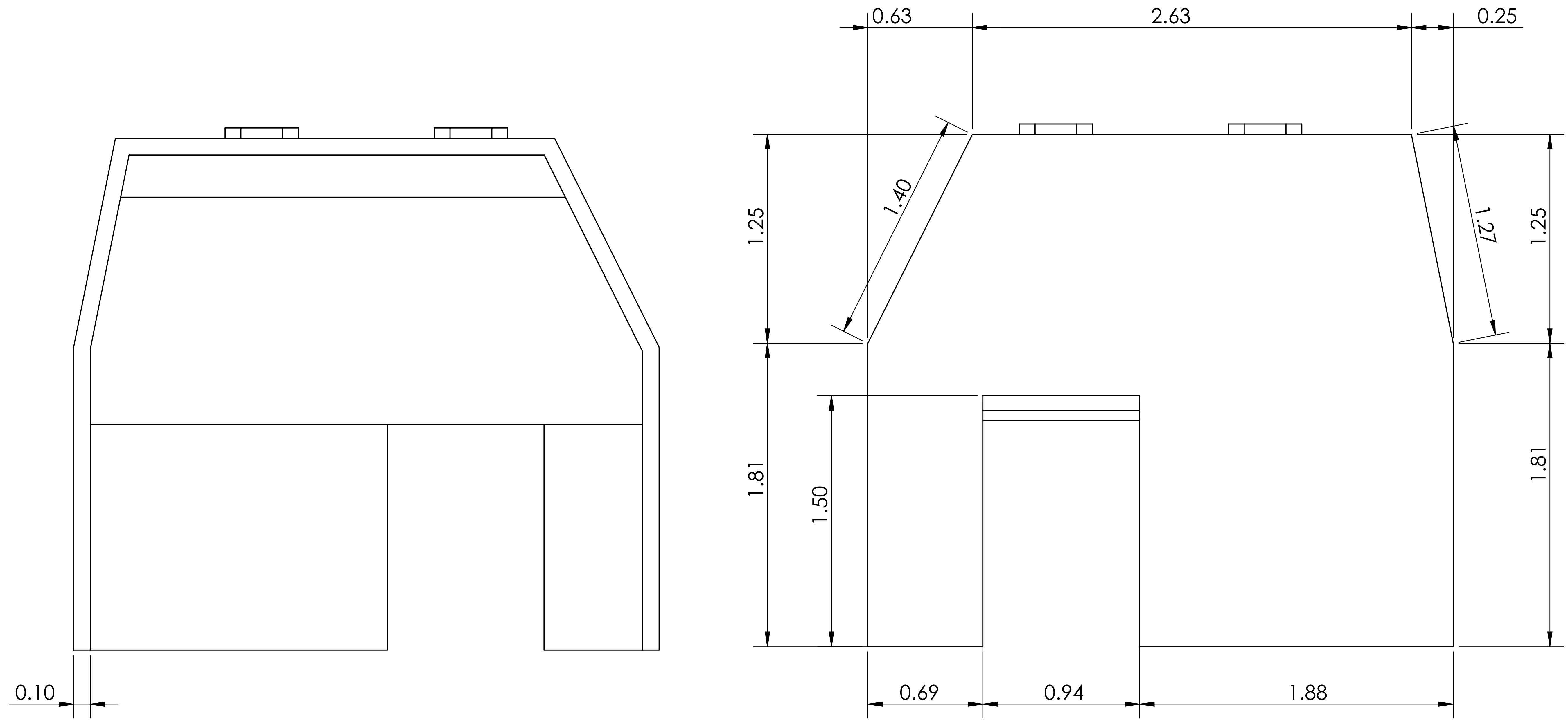
TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL NYLON 6		DESCRIPTION PLASTIC HOLDER FOR SHARPENING STEEL	
FINISH NONE		PN 022_DFM	REV A / SHEET 1 of 1

REVISIONS				
ZONE	IR	INITIAL RELEASE	3/9/2023	APPROVED



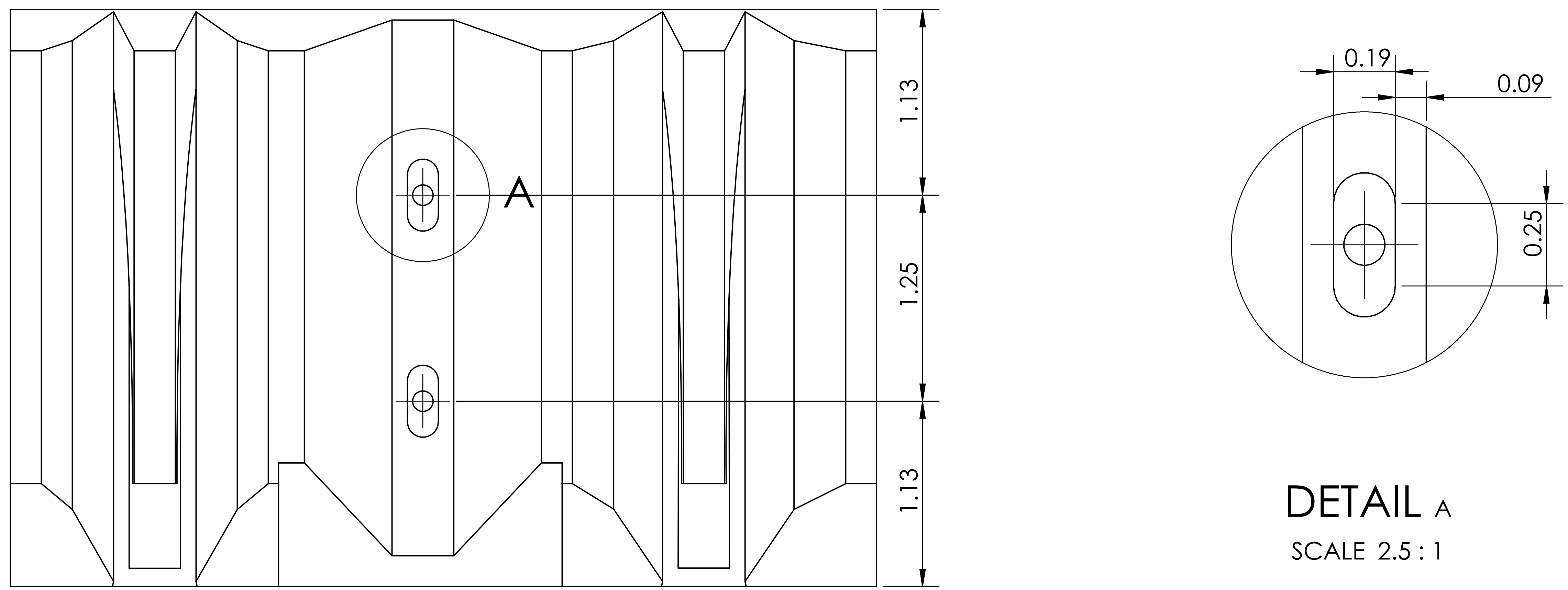
NOTES
1. PART HAS SYMETRICAL FEATURES ABOUT EACH OF THE THREE CENTERLINES FOR EACH OF THE THREE SHARPENING SLOTS.

TOLERANCES UNLESS NOTED: X.X ± 0.05, X.XX ± 0.005, X.XXX ± 0.0005, X.X° ± 0.05°; UNITS: IPS	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL: PLASTIC	DESCRIPTION: MAIN SHARPENING CHASSIS
FINISH: N/A	PN: 023 · REV: IR · SHEET: 1 of 3



NOTES
1. WALL THICKNESS IS 0.10 INCHES FOR ALL OF PART

TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.005 X.XXX ± 0.0005 X.X° ° 0.05	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL PLASTIC		DESCRIPTION MAIN SHARPENING CHASSIS	
FINISH N/A		PN 023	REV IR · SHEET 2 of 3

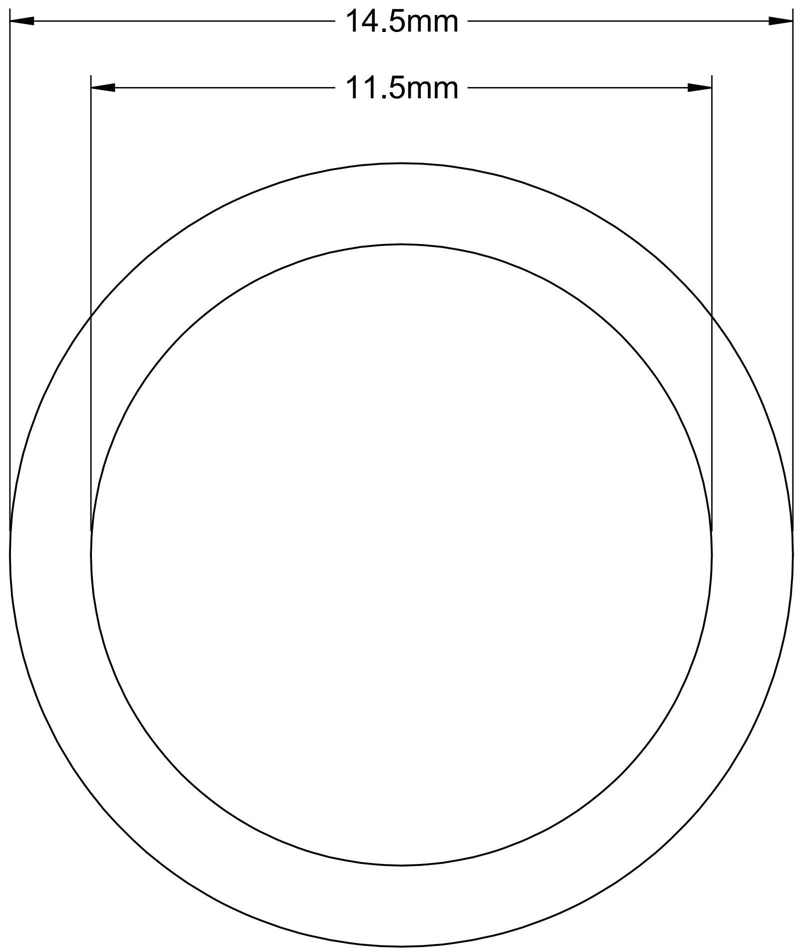


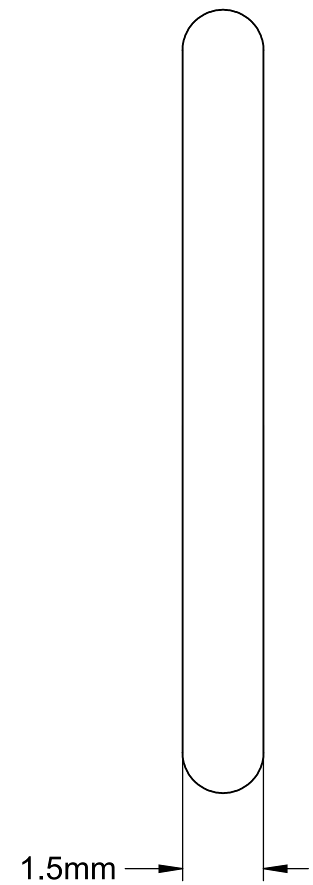
DETAIL A

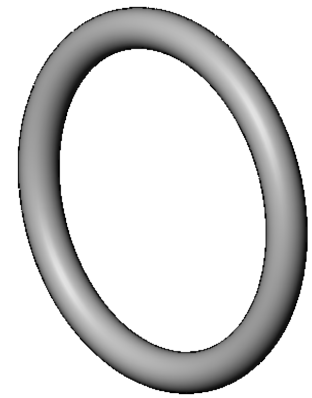
SCALE 2.5 : 1

NOTES
1. POST BELOW DETAIL VIEW A POST IS IDENTICAL

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.05 X.XX ± 0.005 X.XXX ± 0.0005 X.X° ° 0.05	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL PLASTIC		DESCRIPTION MAIN SHARPENING CHASSIS	
FINISH N/A		PN 023 · REV IR	SHEET 3 of 3







TOLERANCES UNLESS NOTED:	X.X	±0.050
	X.XX	±0.010
	X.XXX	±0.005
UNITS: INCHES	X.X°	±1°

UNIVERSITY OF COLORADO
1111 ENGINEERING DR
BOULDER, CO 80309-0427

MATERIAL
RUBBER

DESCRIPTION
SMALL STEEL ROTATOR SCREW INSERT GASKET

FINISH
N/A

PN
024

REV
A

SHEET
1 of 1

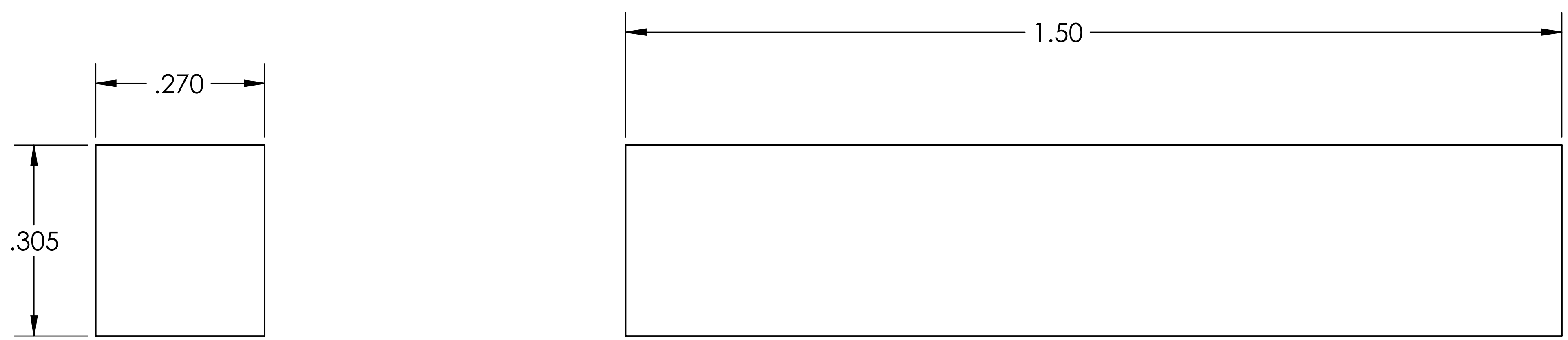
McMASTER-CARR® CAD

PART NUMBER **9262K523**

http://www.mcmaster.com

Oil-Resistant
Buna-N O-Ring

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/21/2023



TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL MAGNET		DESCRIPTION SHAVING COLLECTOR MAGNET	
FINISH N/A		PN 025	REV A · SHEET 1 of 1

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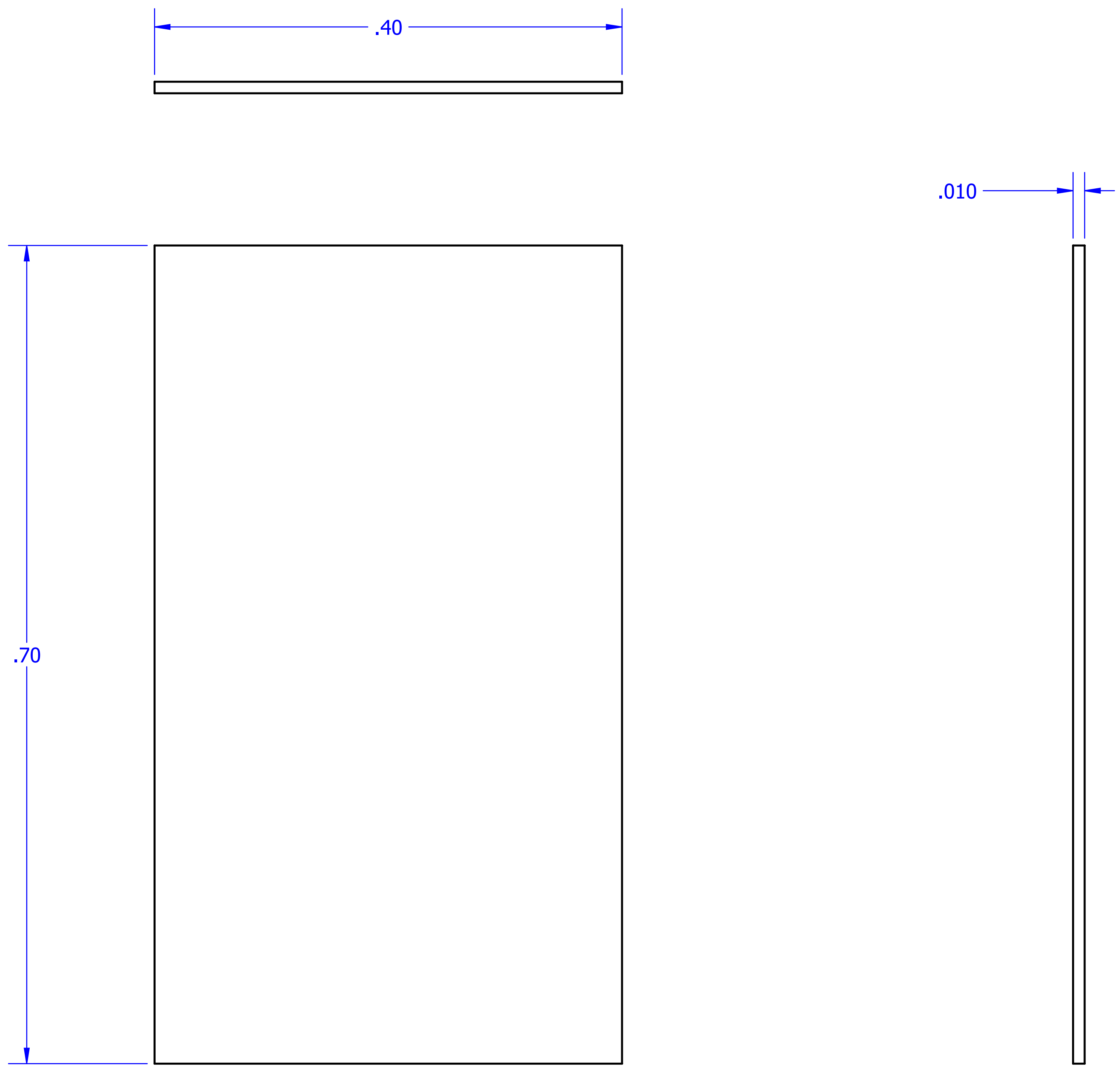
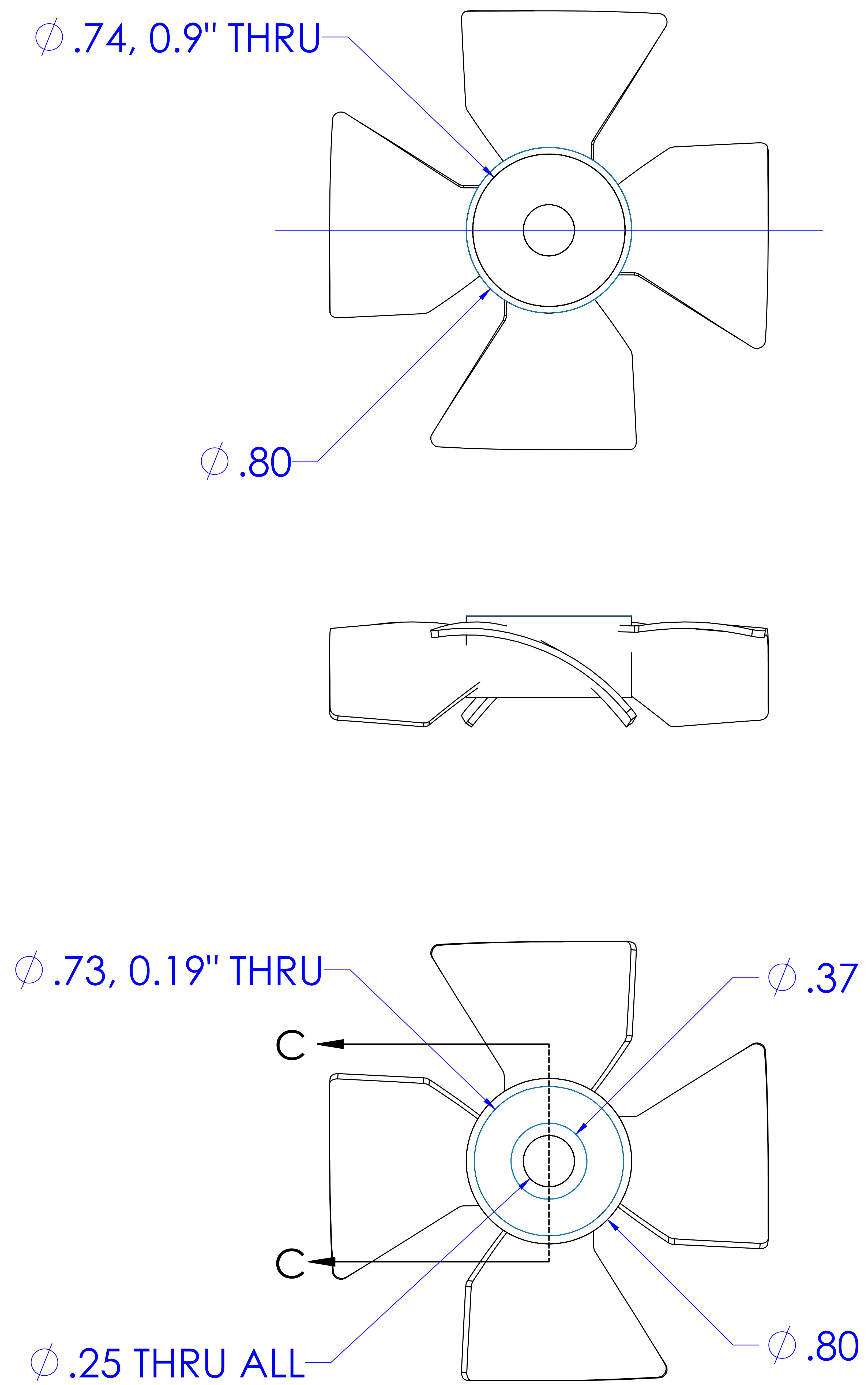
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/11/2023

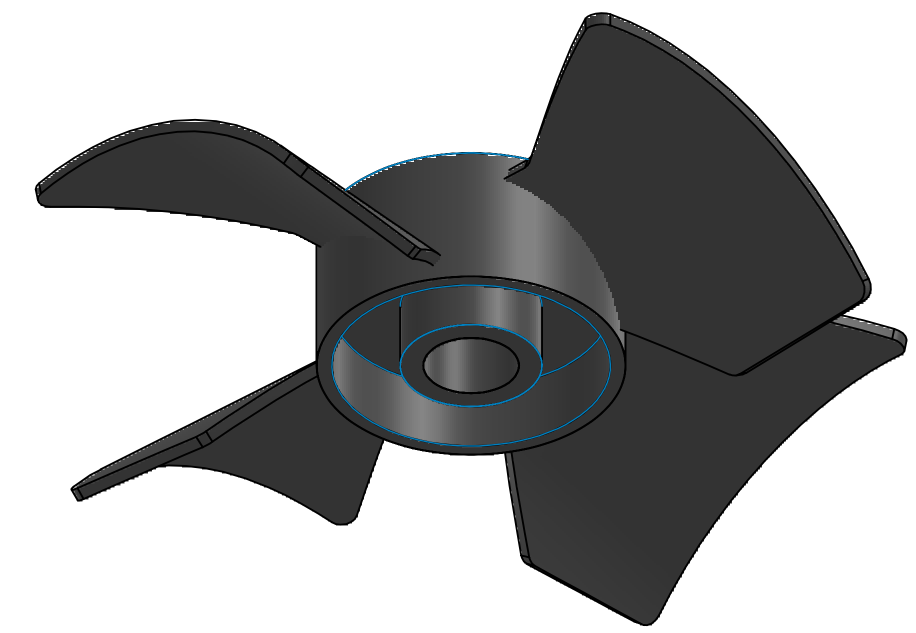


TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL STEEL		DESCRIPTION SHARPENING STEEL	
FINISH ROUGH		PN 026_DFM	REV A — SHEET 1 of 1

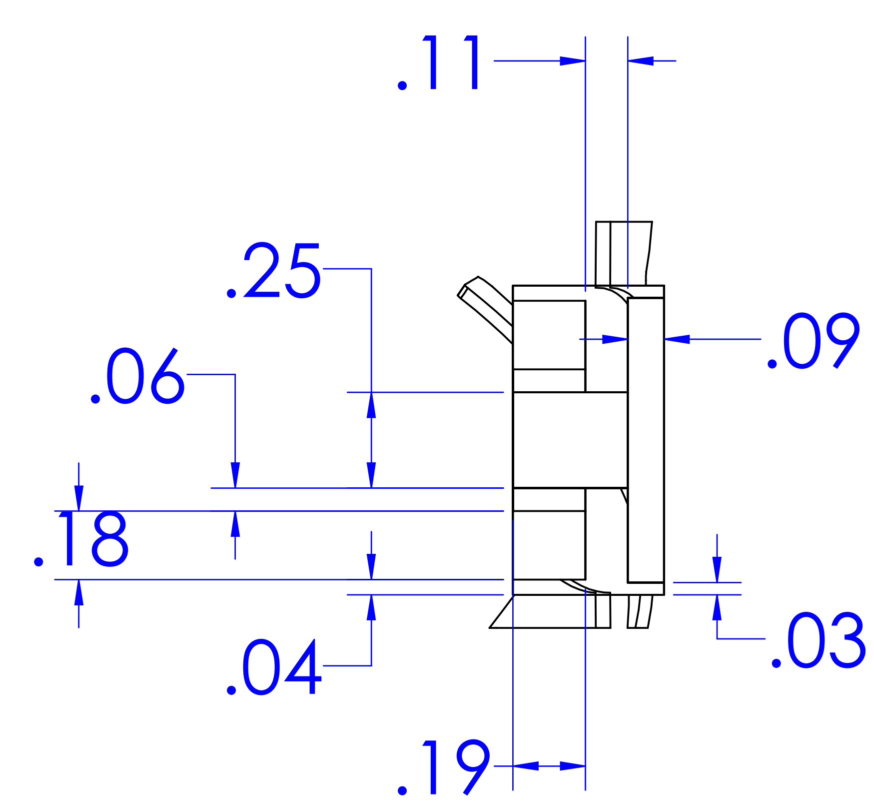
NOTE:

1. MINIMALLY DIMENSIONED. REFERENCE MODEL FOR ALL OTHER DIMENSIONS.





SECTION C-C



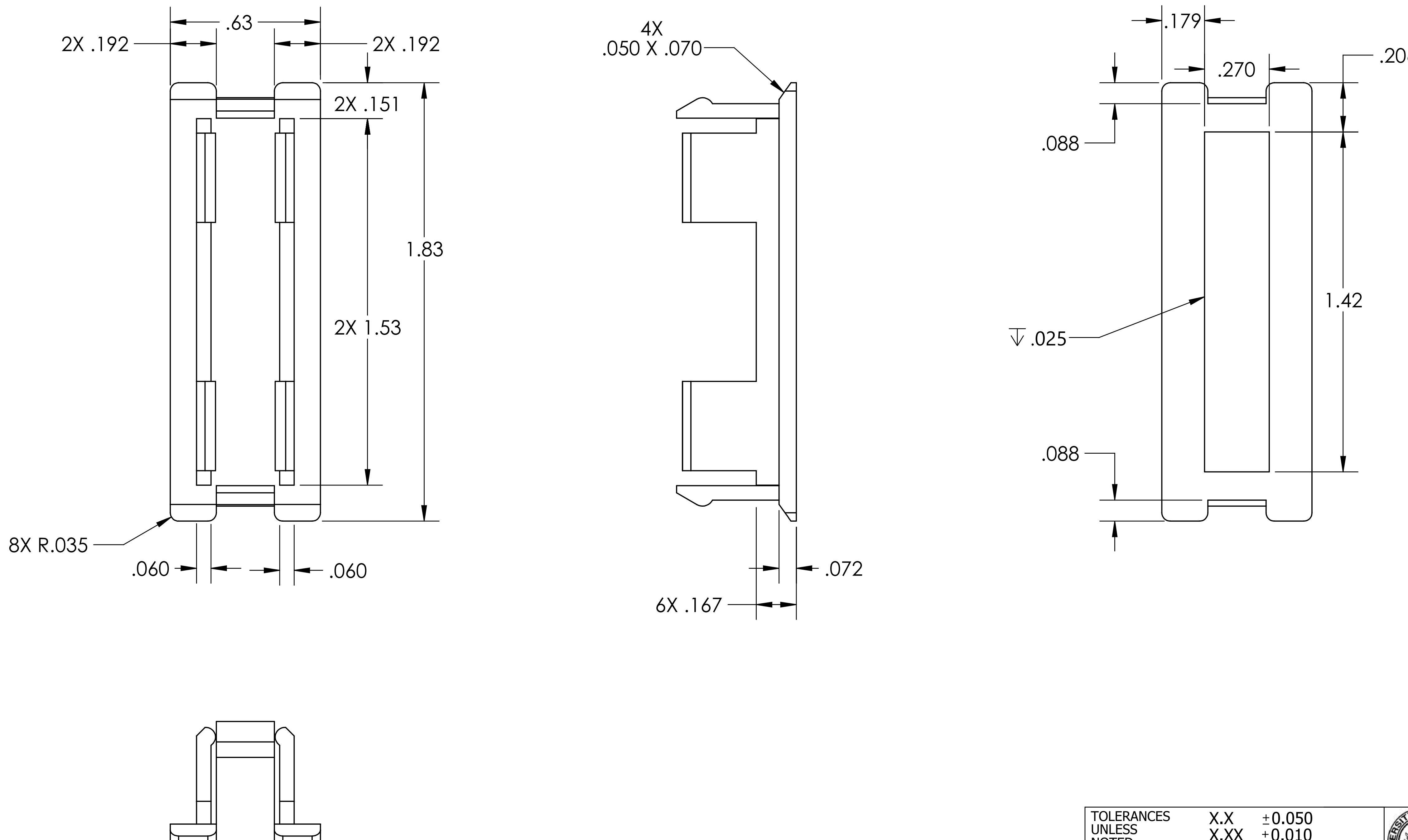
REVISIONS

REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	3/6/2023	NOLAN MAJOR

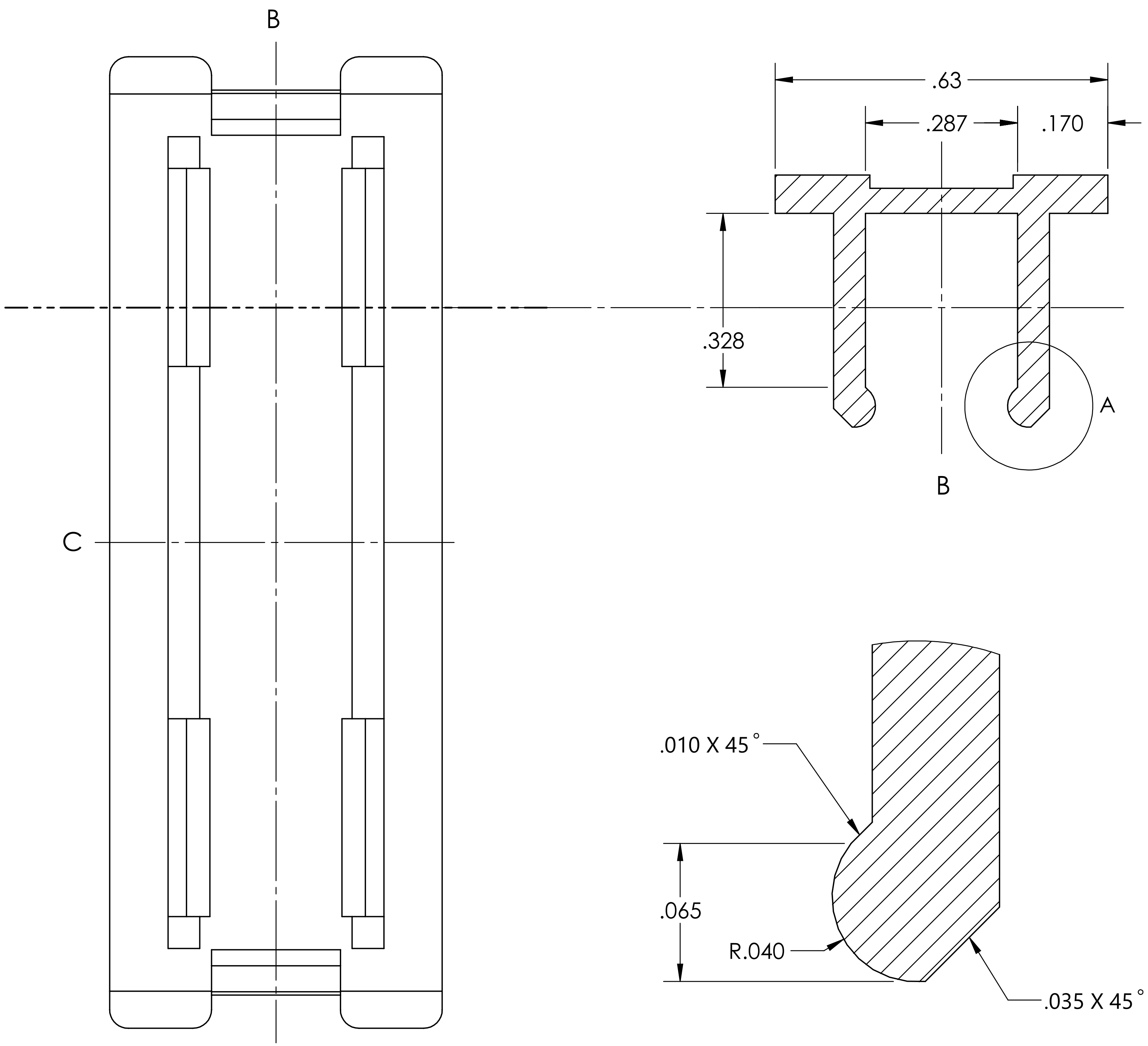
TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427	
MATERIAL: THERMOPLASTIC	DESCRIPTION: MOTOR FAN	
FINISH: SMOOTH	PN: 028	REV: A / SHEET: 1 of 1

D-48

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/19/2023



TOLERANCES UNLESS NOTED: X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC	DESCRIPTION SHAVING COLLECTOR HOLDER
FINISH N/A	PN 029 REV A SHEET 1 of 3

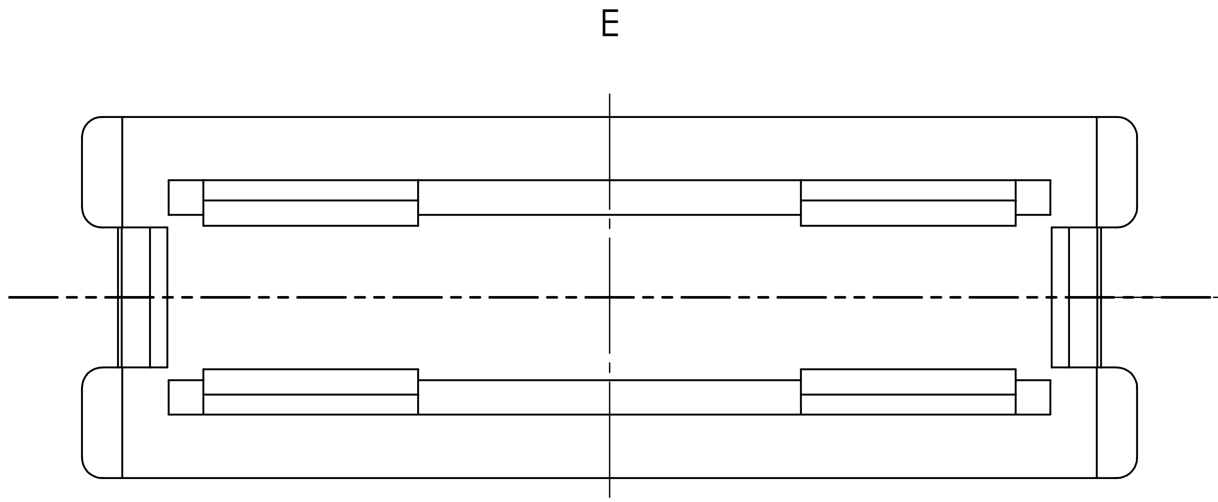


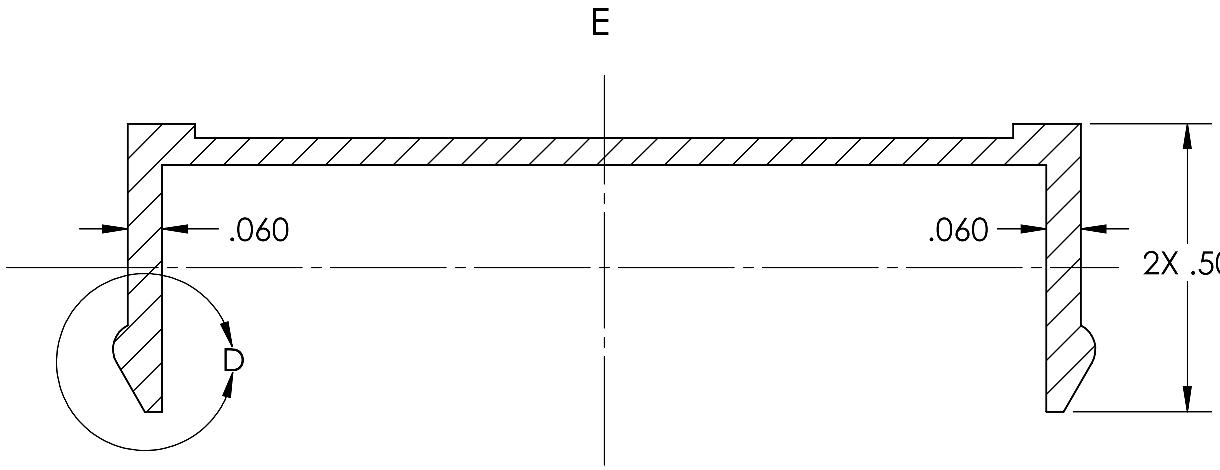
DETAIL A
SCALE 12:1

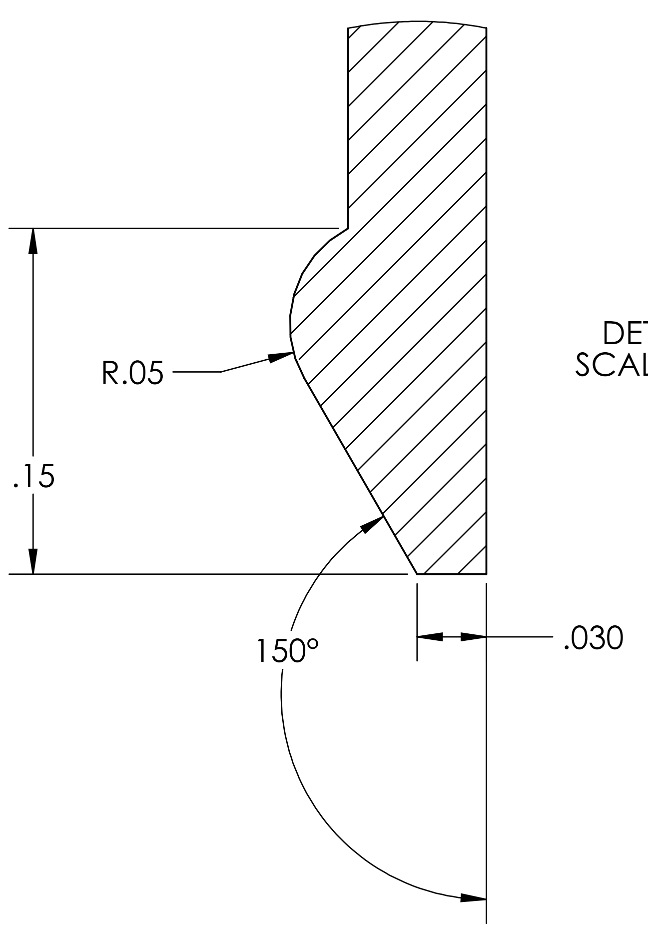
NOTES:

DETAIL VIEW SYMMETRIC ACROSS CENTERLINES B, C

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHAVING COLLECTOR HOLDER
FINISH N/A		PN 029 · REV A · SHEET 2 of 3





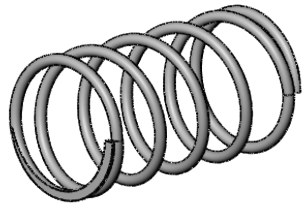


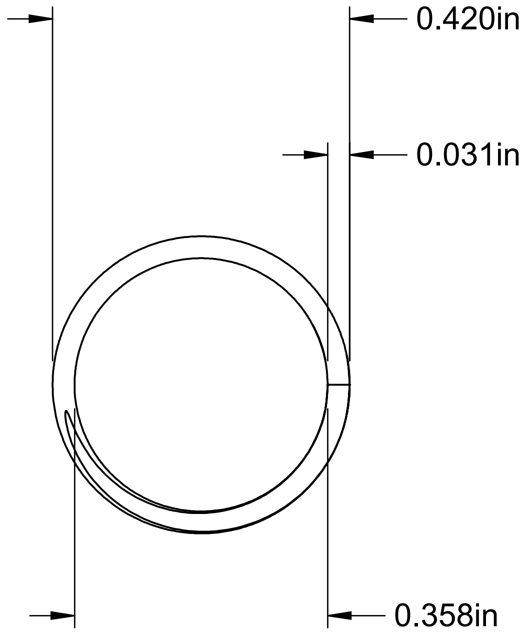
DETAIL D
SCALE 12 : 1

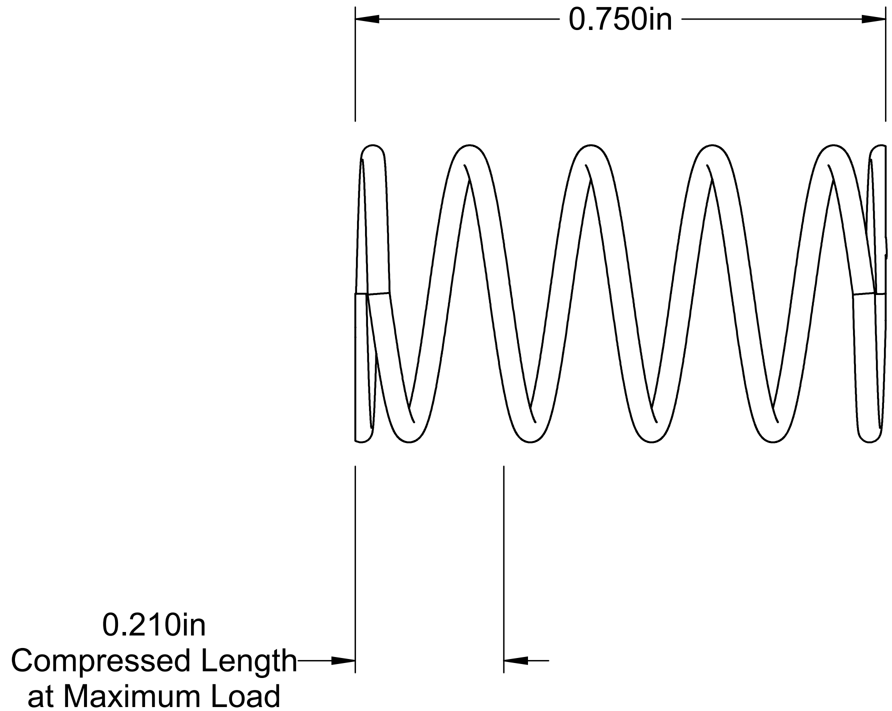
NOTES:

DETAIL VIEW SYMMETRIC ACROSS CENTERLINE E

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC		DESCRIPTION SHAVING COLLECTOR HOLDER
FINISH N/A		PN 029 · REV A · SHEET 3 of 3







TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL STEEL		DESCRIPTION AXEL SPRING 0.7"	
FINISH N/A		PN 030	REV A · SHEET 1 of 1

McMASTER-CARR® CAD

PART NUMBER **9657K675**

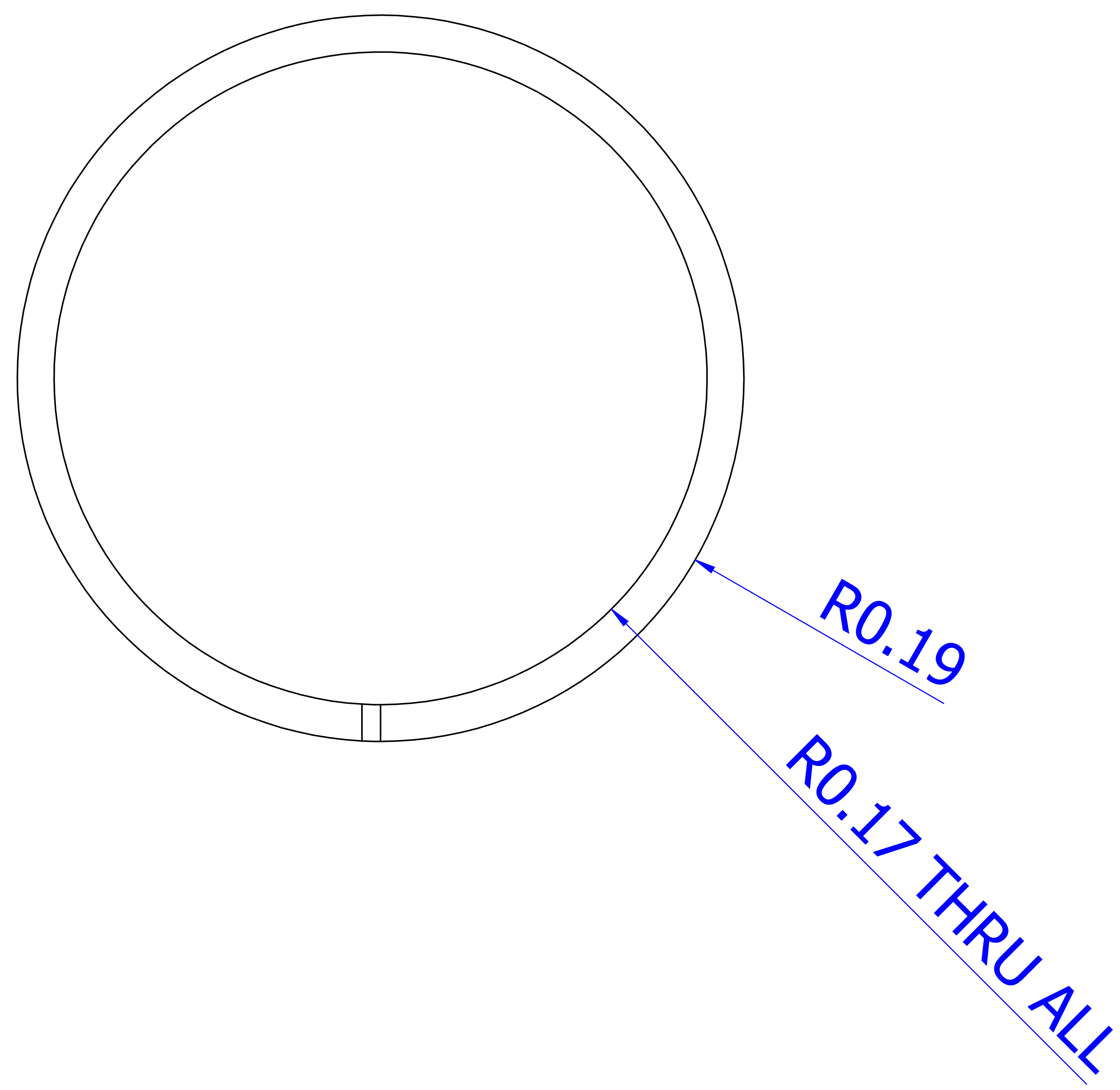
http://www.mcmaster.com

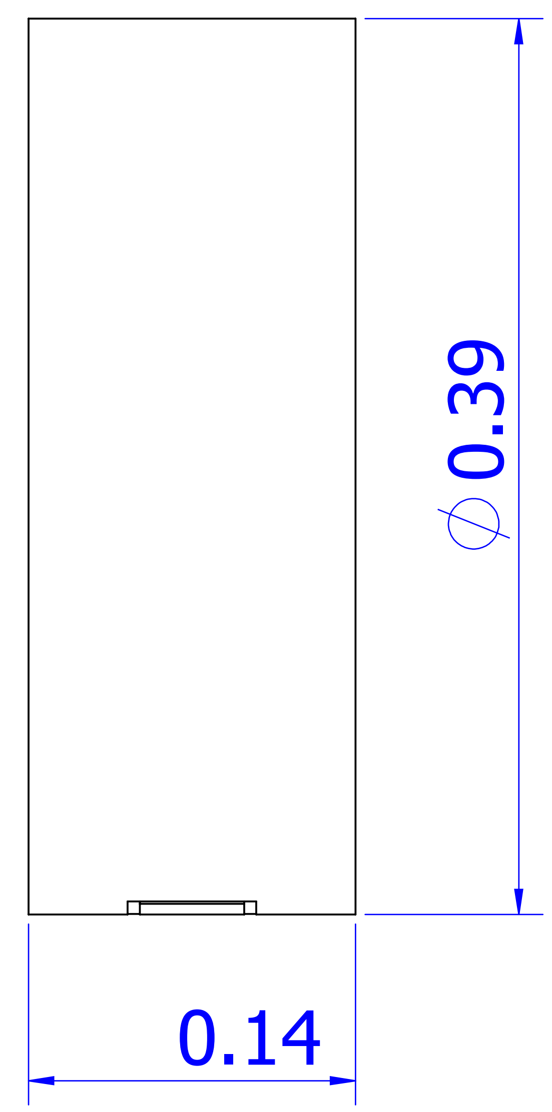
Compression
Spring

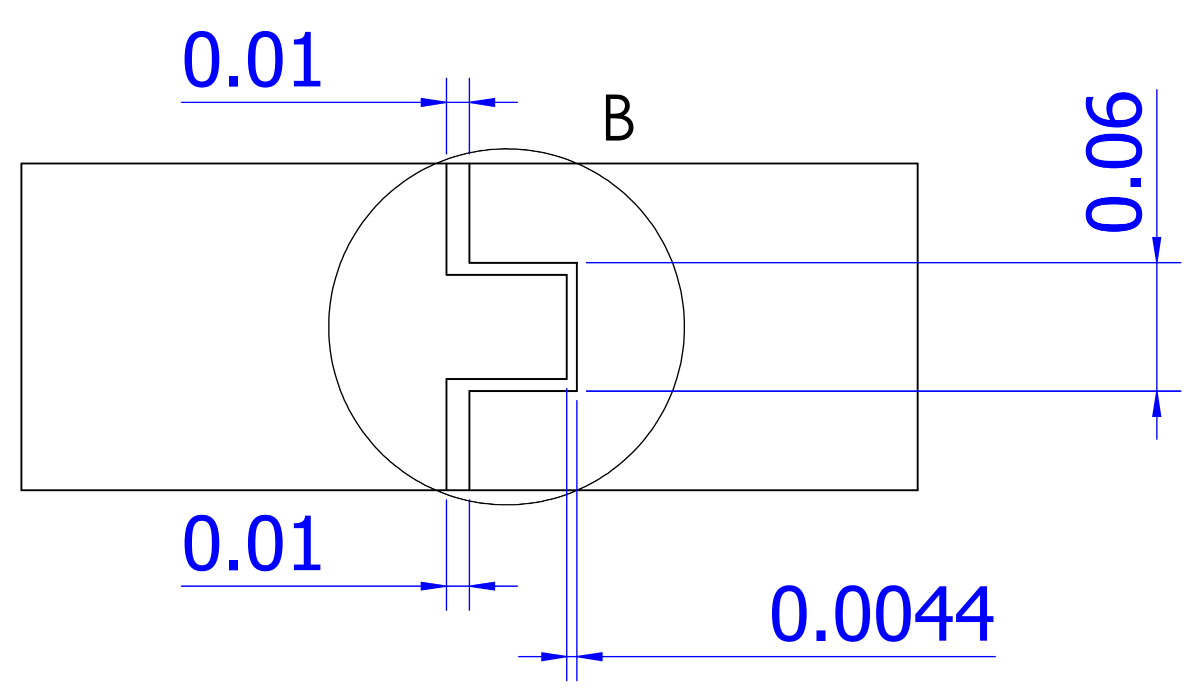
Maximum Load: 3.00 lbs.
Spring Rate: 5.600 lbs./in.

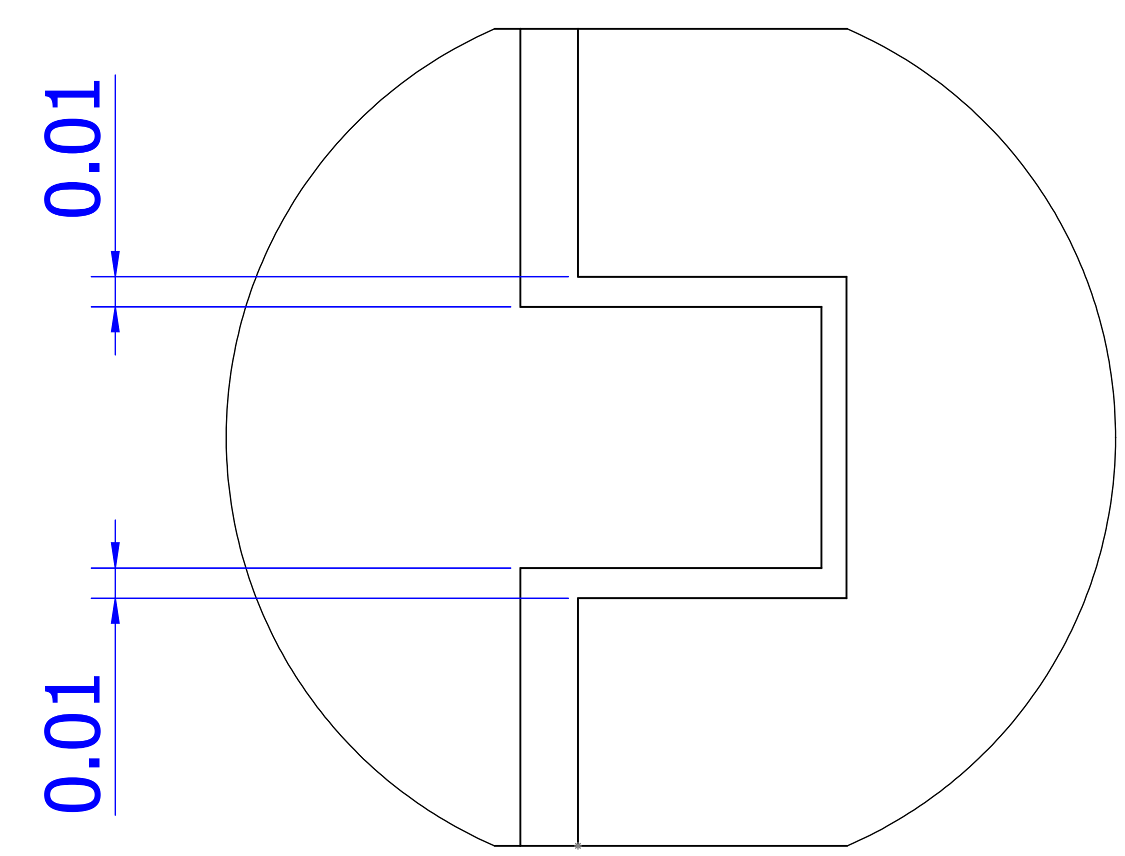
NOTES:

1. THE FEATURE SHOWN IN "DETAIL B" REPRESENTS A FREE GAP THROUGH "0.02 INCHES" OF MATERIAL.





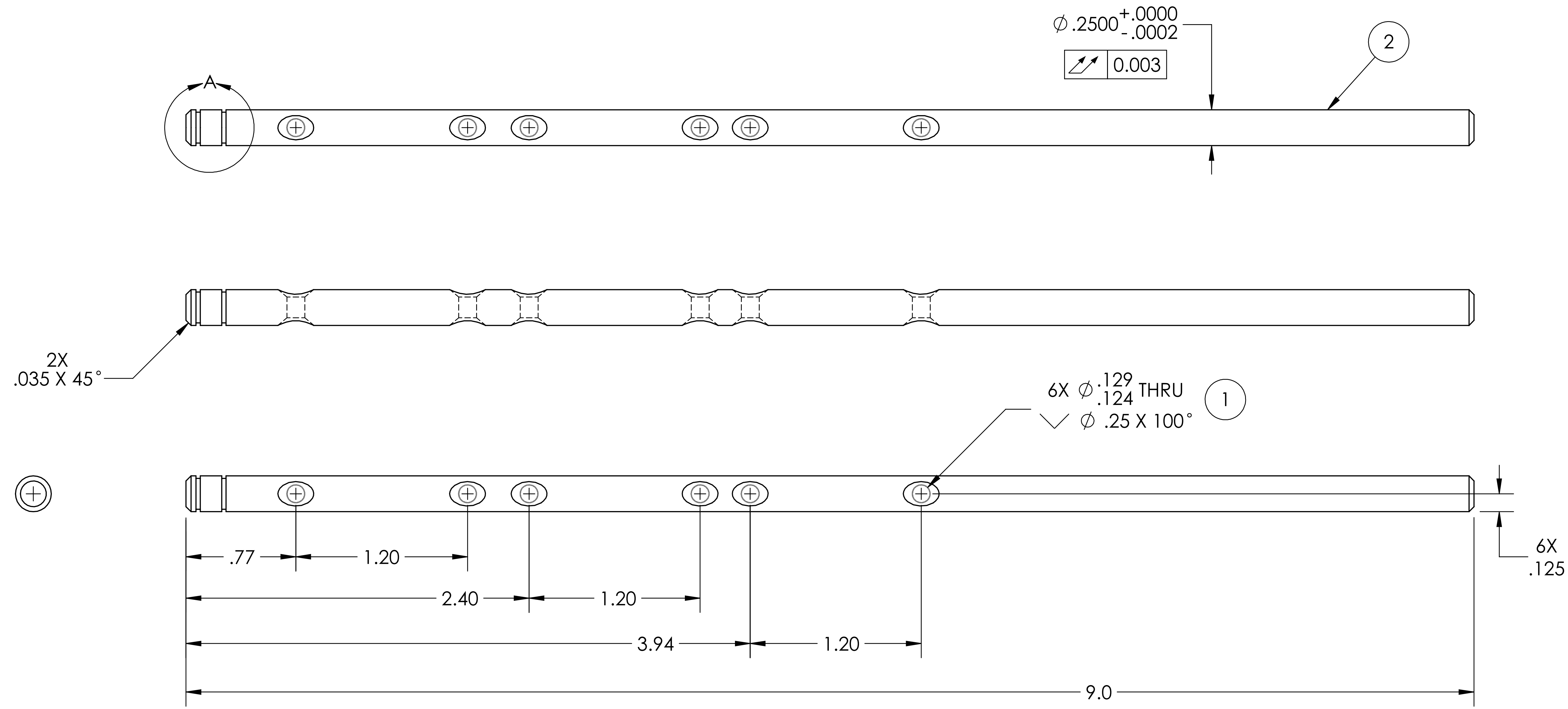




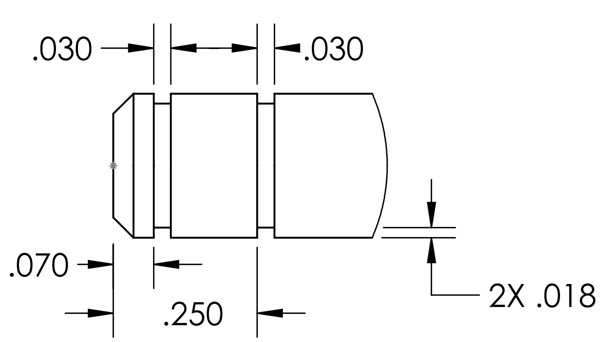
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	3/5/2023	NOLAN MAJOR

TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
MATERIAL STEEL	DESCRIPTION FAN RETAINING CLIP			
FINISH SMOOTH	PN 032	REV A		SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/21/2023



DETAIL A
SCALE 3 : 1

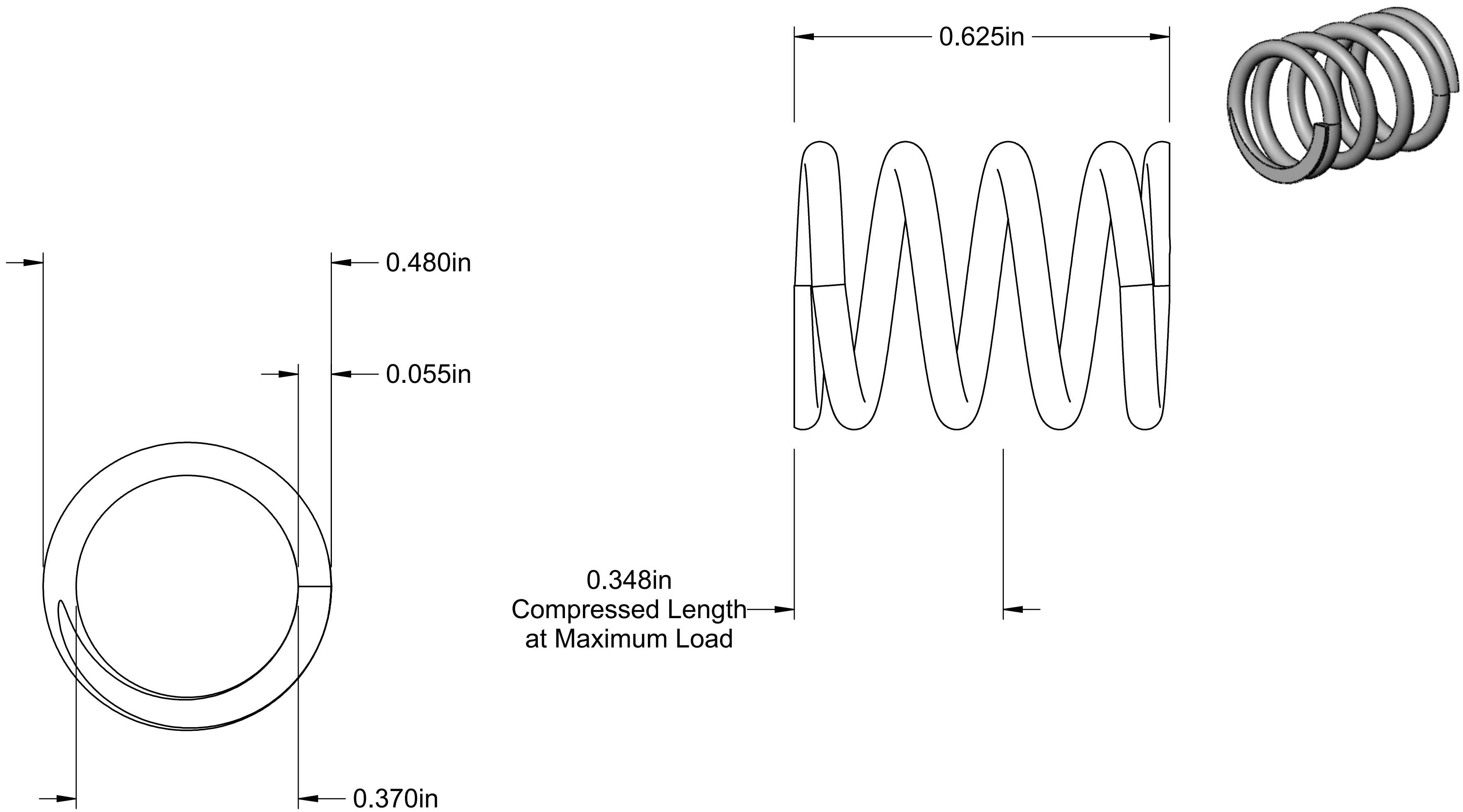


NOTES

1. COUNTERSINK HOLES BOTH SIDES

2. GROUND FINISH

TOLERANCES UNLESS NOTED: X.X ±0.050; X.XX ±0.010; X.XXX ±0.005; X.X° ±1° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL STEEL	DESCRIPTION MOTOR SHAFT	
FINISH N/A	PN 033	REV A / SHEET 1 of 1

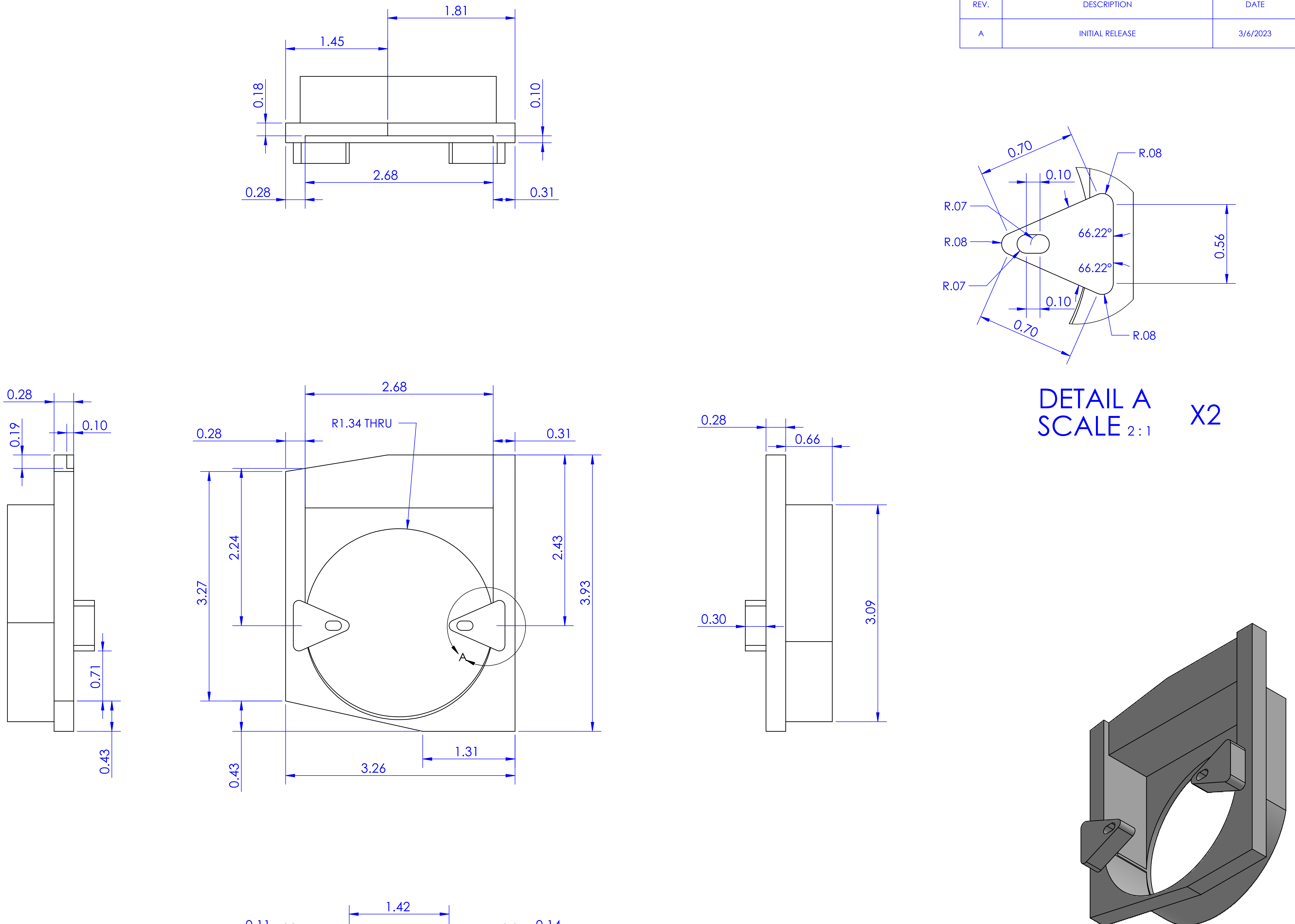


TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
MATERIAL STEEL		DESCRIPTION AXEL SPRING 0.6"	
FINISH N/A		PN 034	REV A / SHEET 1 of 1
McMASTER-CARR® CAD		PART NUMBER	9657K664
http://www.mcmaster.com © 2022 McMaster-Carr Supply Company Information in this drawing is provided for reference only.		Compression Spring	

Maximum Load: 15.50 lbs.

Spring Rate: 56.000 lbs./in.

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	3/6/2023	NOLAN MAJOR



TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL THERMOPLASTIC		DESCRIPTION FAN INLET COVER
FINISH SMOOTH		PN 036 · REV A · SHEET 1 of 1

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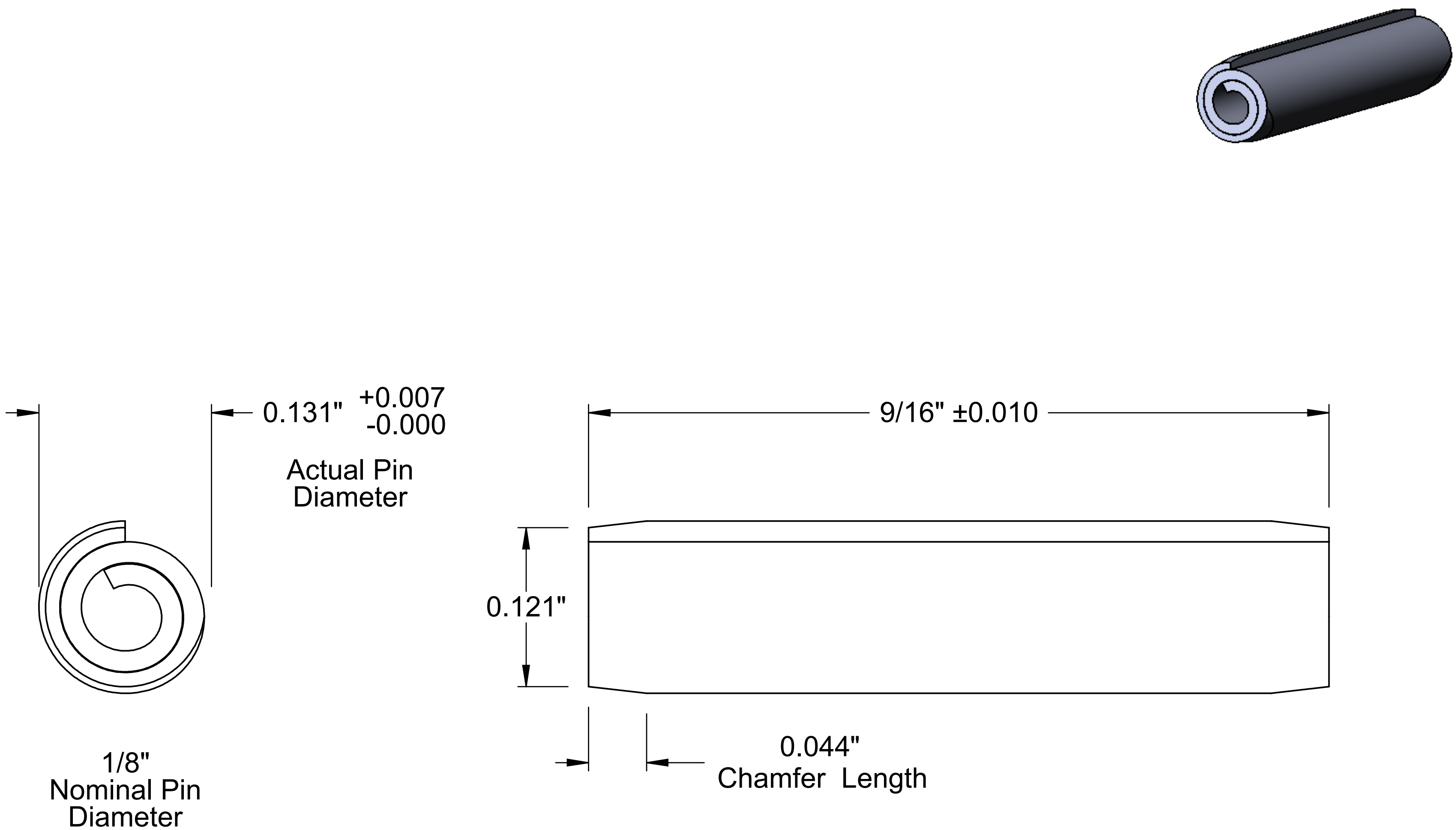


Recommended 0.124" to 0.129" Diameter Hole Size

TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL STEEL		DESCRIPTION MOTOR SHAFT PIN
FINISH N/A		PN 037 · REV A · SHEET 1 of 1

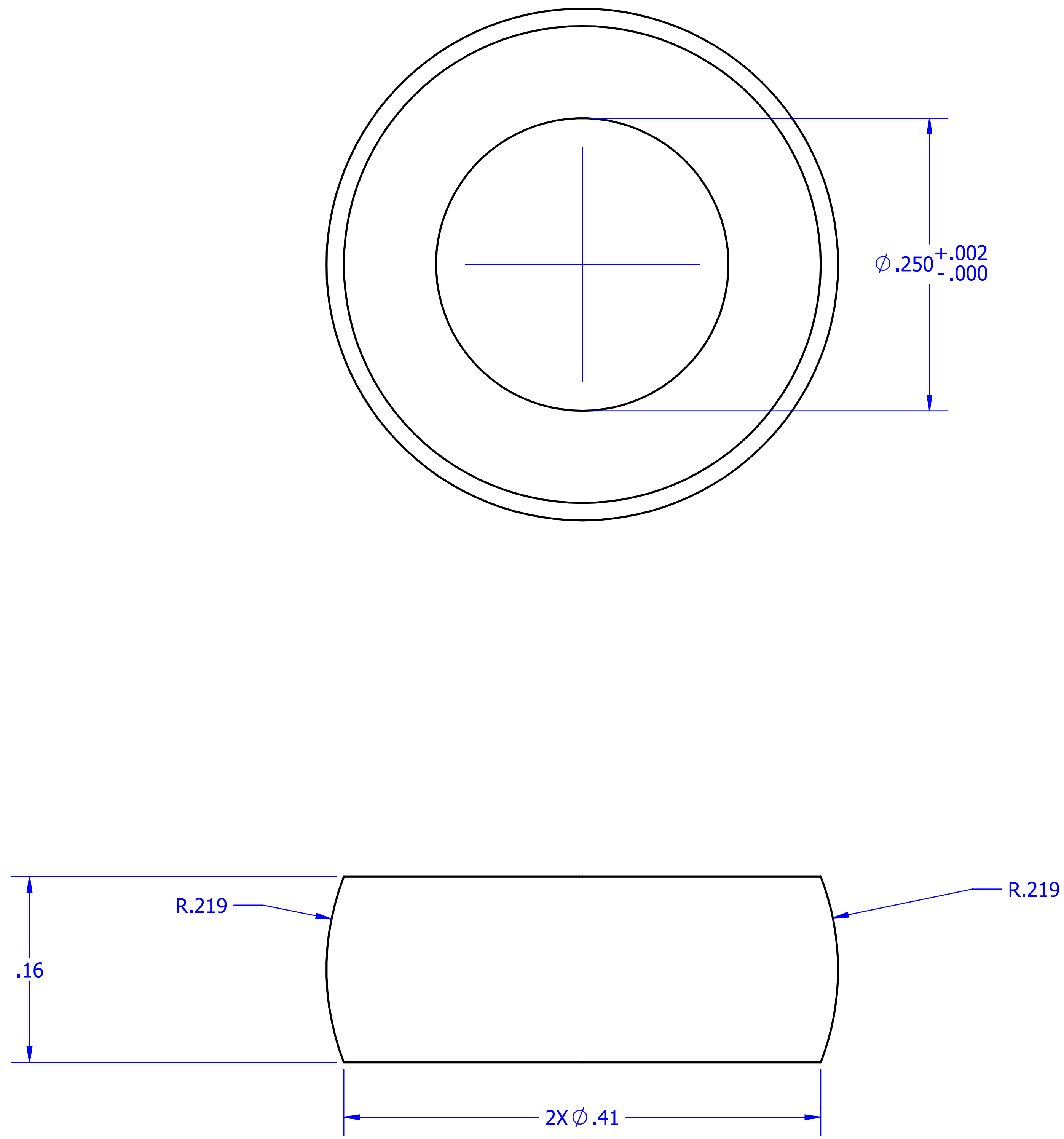
McMASTER-CARR® CAD

PART NUMBER **98195A515**

http://www.mcmaster.com

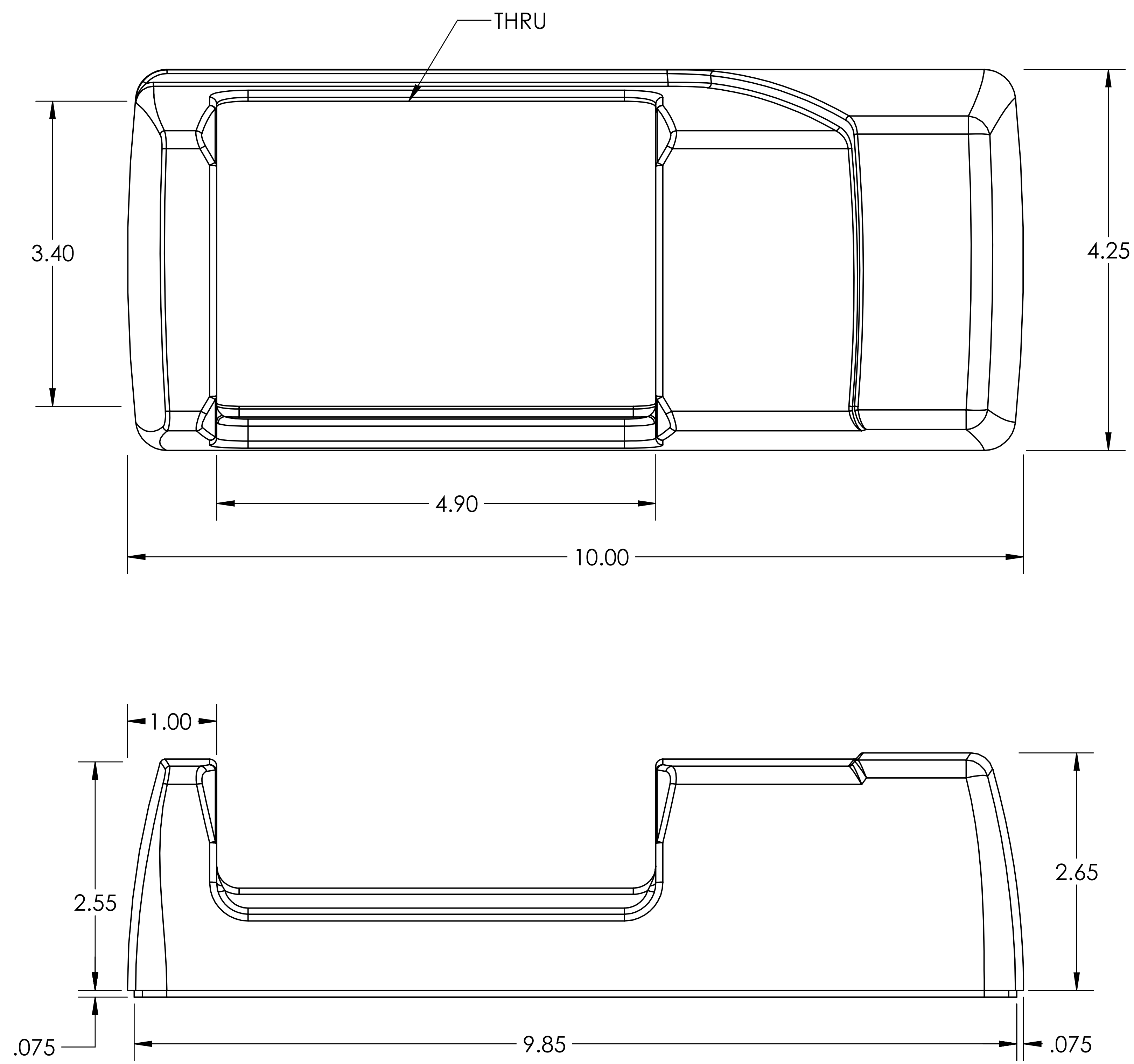
18-8 Stainless Steel
Coiled Spring Pins

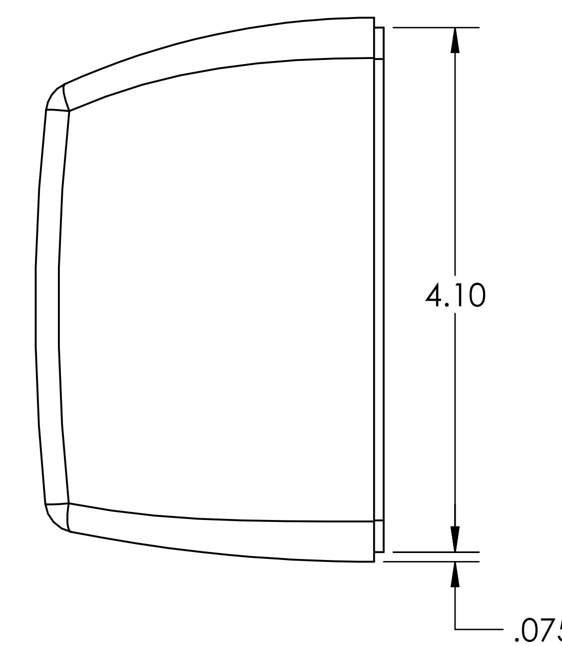
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/5/2023



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.1 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL BRASS		DESCRIPTION 5/16 X 7/16 BUSHING		
FINISH NONE		PN 038_DFM	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/3/2023

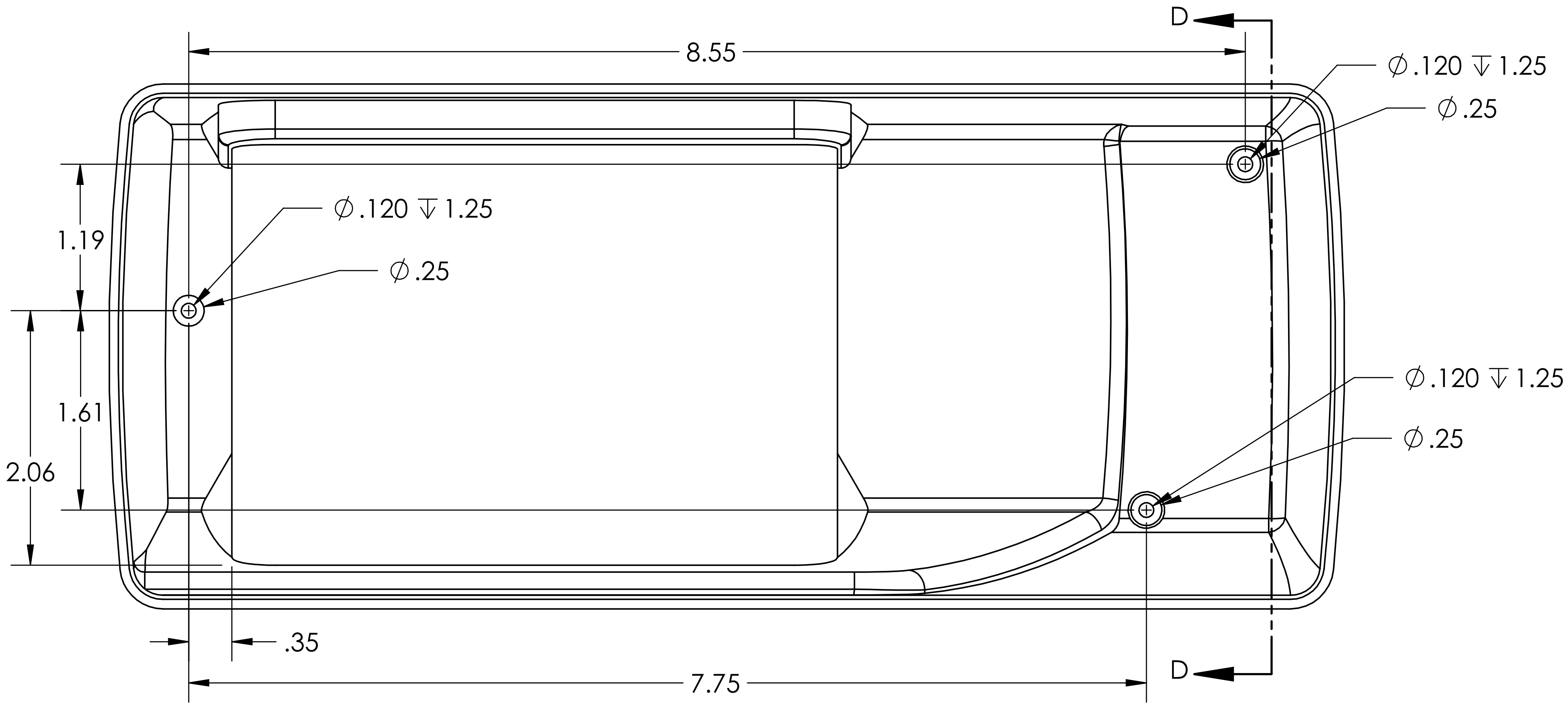


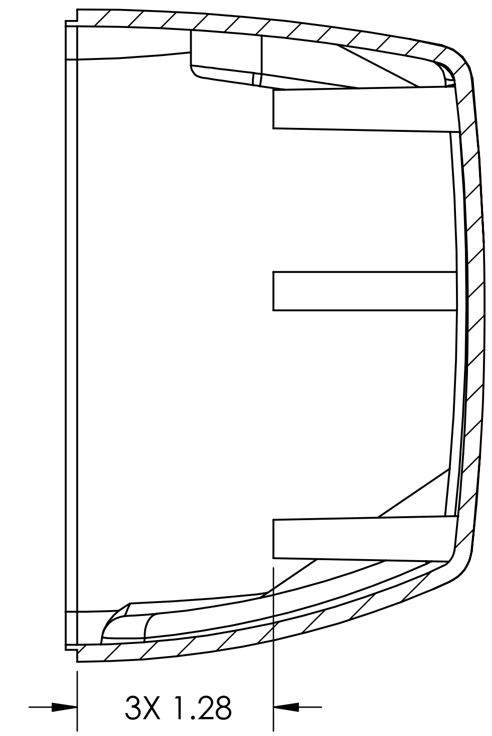


NOTES

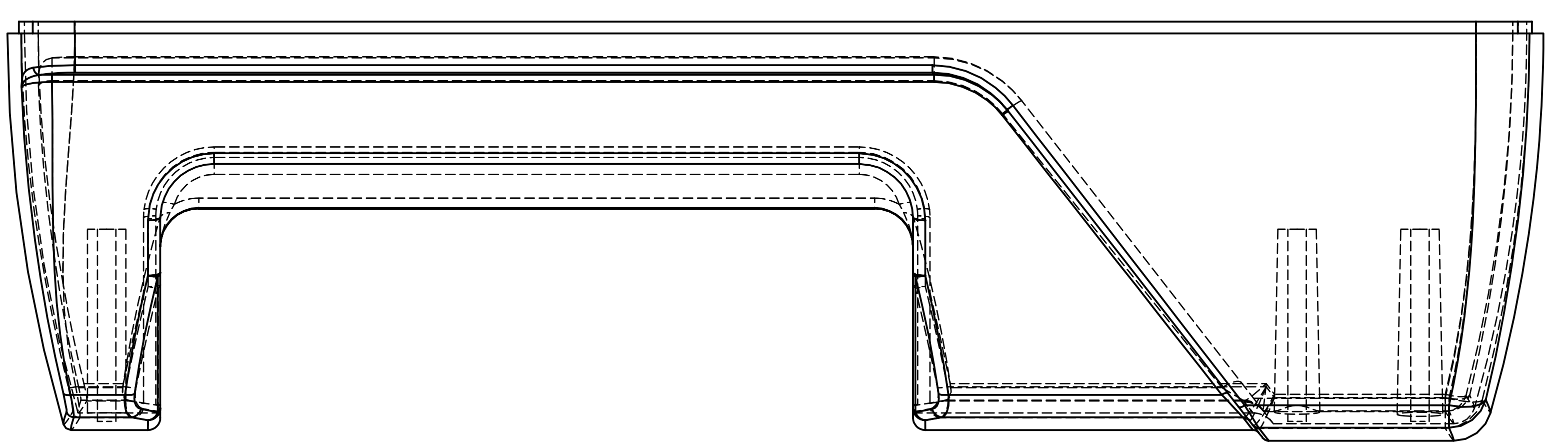
1. SURFACE PROFILES TO MATCH MODEL WITHIN .01" UNLESS OTHERWISE SPECIFIED

TOLERANCES UNLESS NOTED: X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
MATERIAL THERMOPLASTIC	DESCRIPTION TOP COVER
FINISH N/A	PN 040 REV A SHEET 1 of 2





SECTION D-D



TOLERANCES UNLESS NOTED:
X.X ±0.050
X.XX ±0.010
X.XXX ±0.005
X.X° ±1°

UNITS: INCHES

UNIVERSITY OF COLORADO
1111 ENGINEERING DR
BOULDER, CO 80309-0427

MATERIAL
THERMOPLASTIC

DESCRIPTION
TOP COVER

FINISH
N/A

PN
040

REV
A

SHEET
2 of 2

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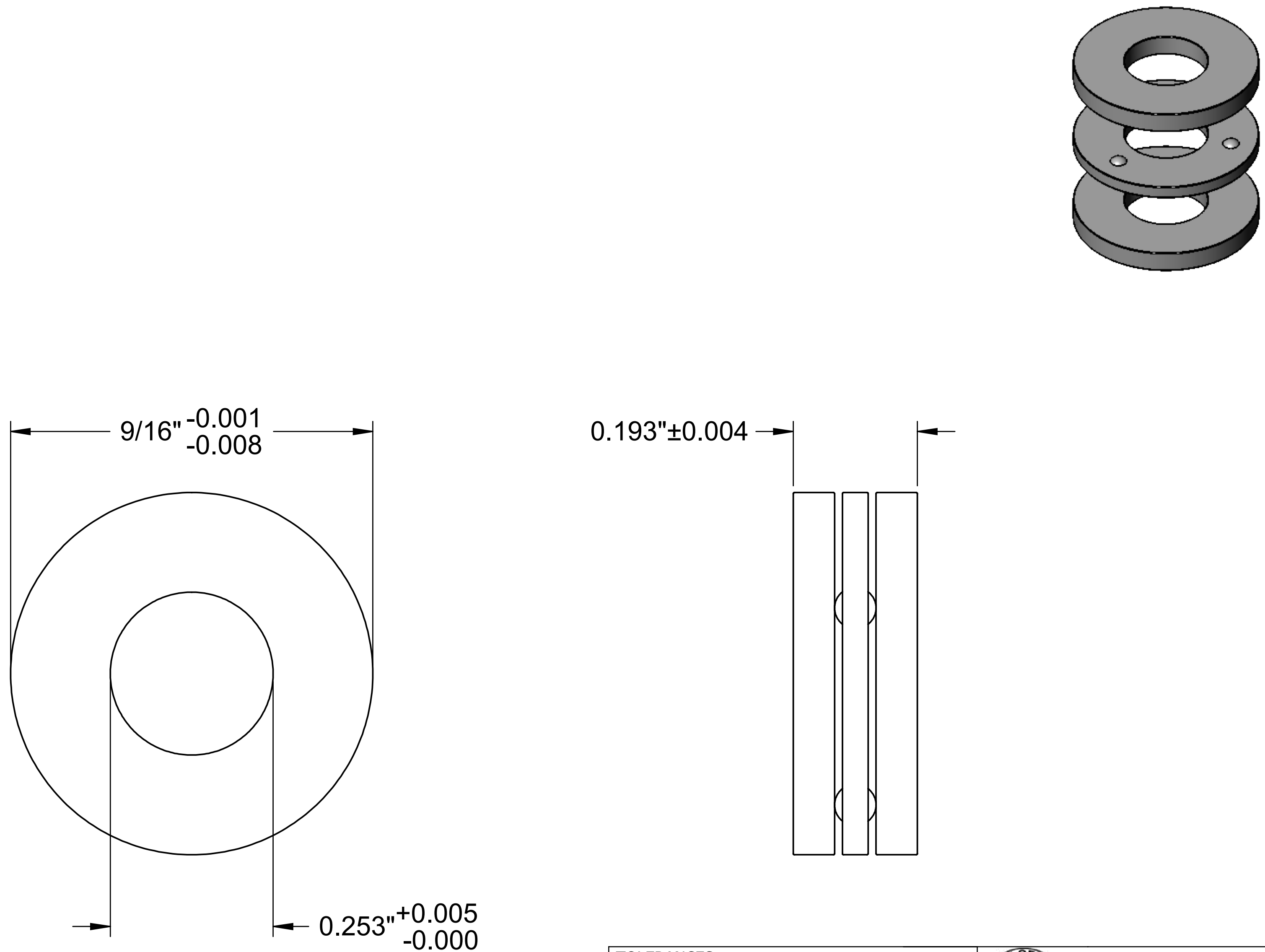


TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427	
UNITS: INCHES			
MATERIAL STEEL		DESCRIPTION MOTOR SHAFT BEARING	
FINISH N/A		PN 041 · REV A	SHEET 1 of 1

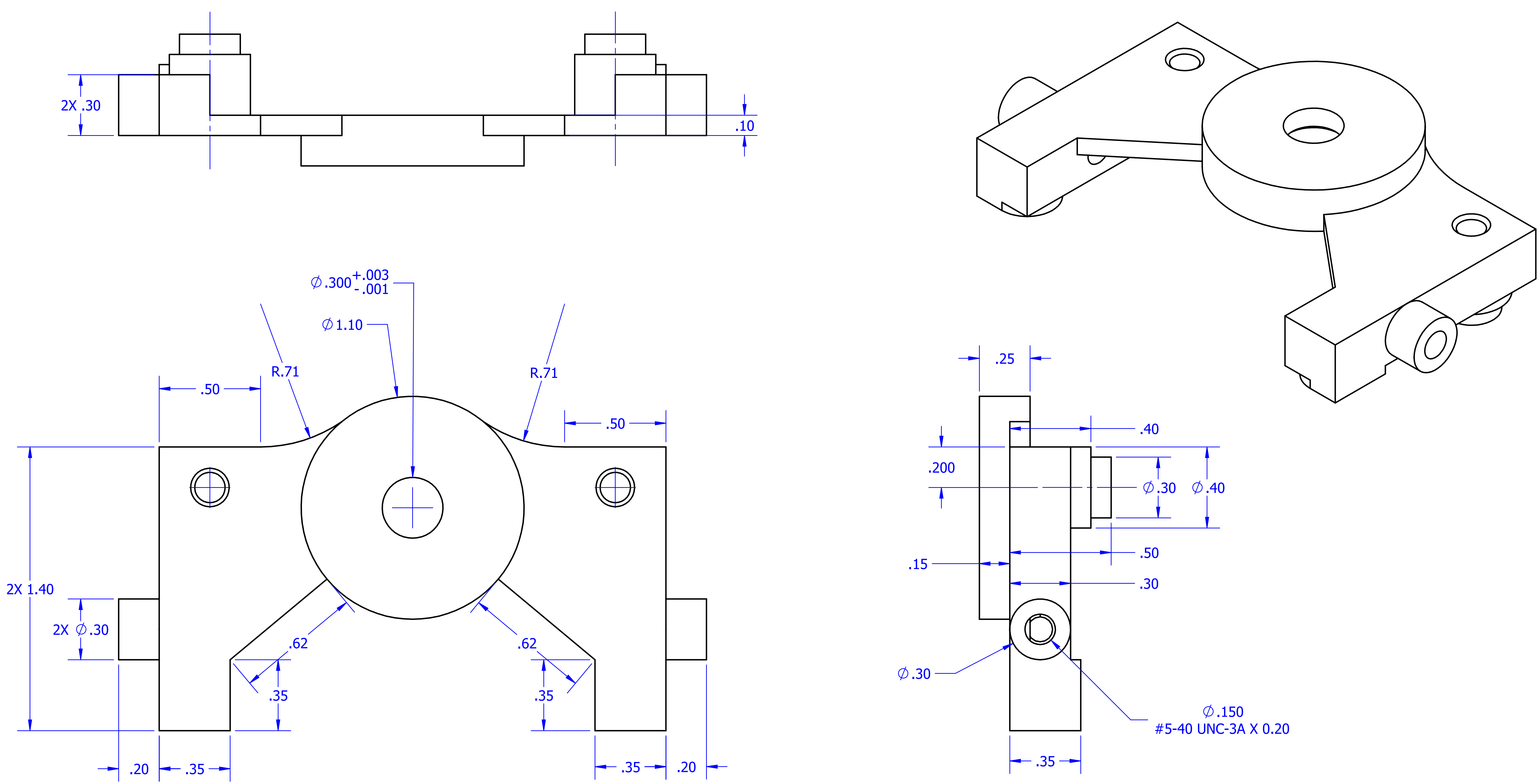
McMASTER-CARR® CAD

PART NUMBER **6655K13**

http://www.mcmaster.com

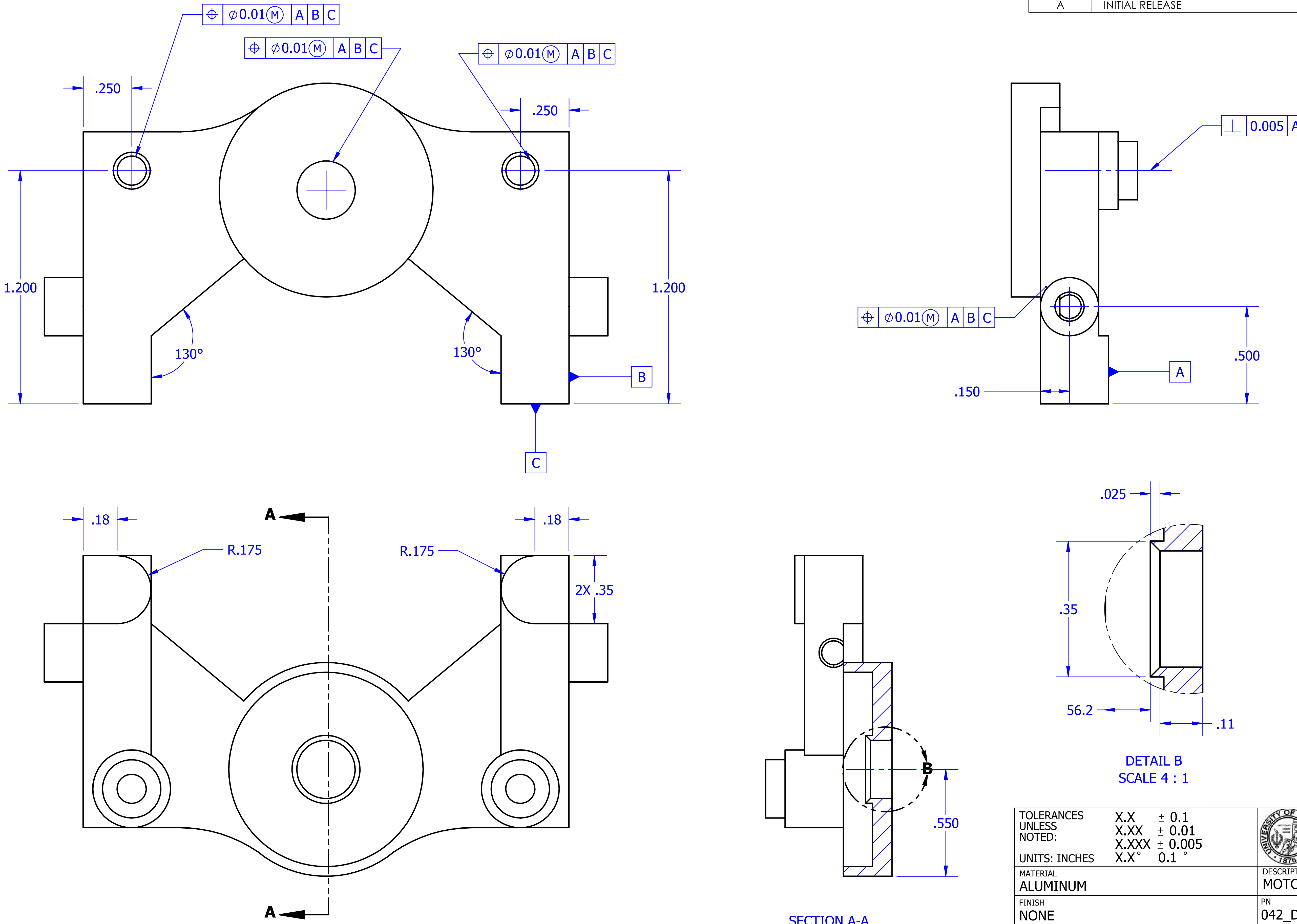
Thrust Ball Bearing

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/2/2023



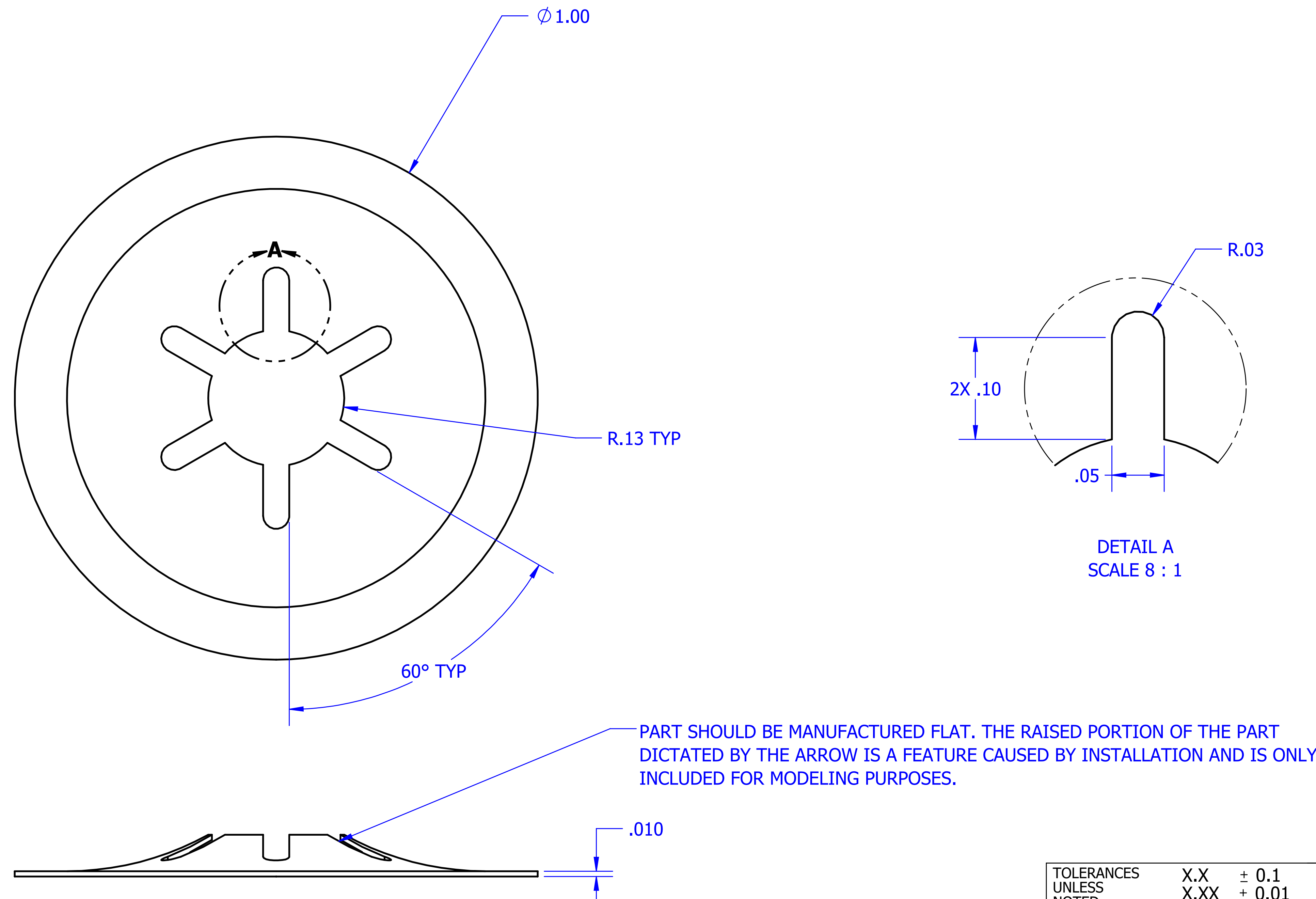
TOLERANCES UNLESS NOTED: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ALUMINUM	DESCRIPTION MOTOR-AXLE ALIGNMENT BLOCK	
FINISH NONE	PN 042_DFM	REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/5/2023



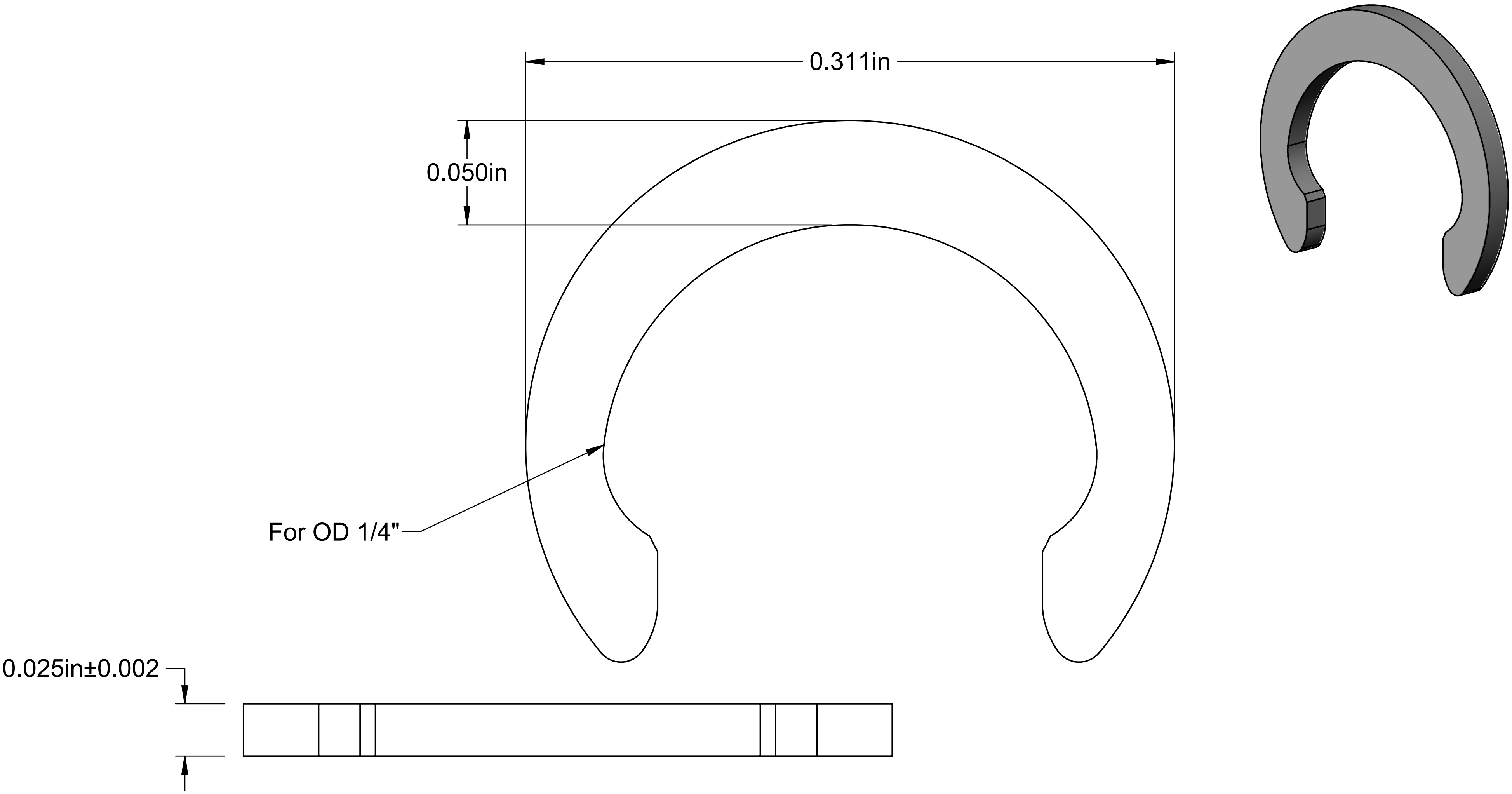
TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.1 °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL ALUMINUM		DESCRIPTION MOTOR-AXLE ALIGNMENT BLOCK
FINISH NONE		PN 042_DFM · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	3/5/2023



TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.01 X.XXX ±0.005 X.X° 0.1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL COPPER		DESCRIPTION ALIGNMENT BLOCK BUSHING COVER
FINISH POLISHED		PN 043_DFM · REV A · SHEET 1 of 1

PROPRIETARY AND CONFIDENTIAL



For Groove Width 0.029in+0.003in/0.000in
For Groove Diameter 0.220in+0.002in/-0.002in

TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DR BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL STEEL		DESCRIPTION RETAINING RING
FINISH N/A		PN 045 · REV A · SHEET 1 of 1

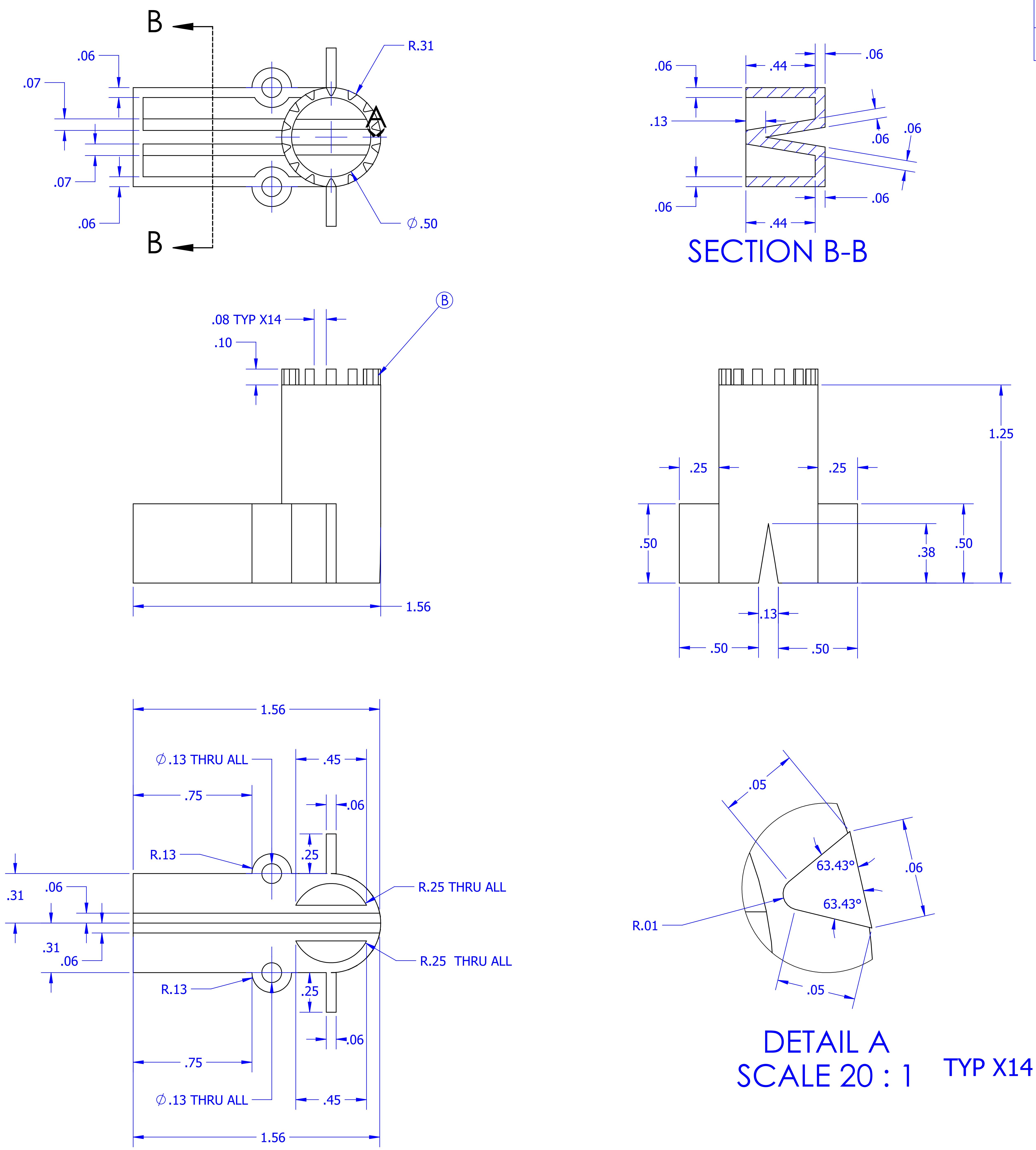
McMASTER-CARR® CAD

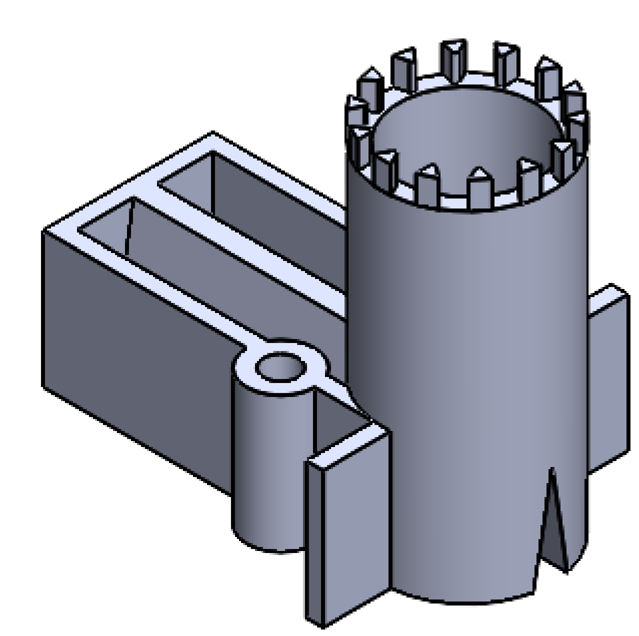
PART NUMBER 97414A630

http://www.mcmaster.com

Low-Clearance External Retaining Ring

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
B	INITIAL RELEASE	3/6/2023	NOLAN MAJOR
B	MODIFIED TOP OF CYLINDRICAL SHAFT	3/12/2023	NOLAN MAJOR





TOLERANCES UNLESS NOTED: X.X ±0.050, X.XX ±0.010, X.XXX ±0.005, X.X° °0.5; UNITS: INCHES		UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427	
MATERIAL: THERMOPLASTIC		DESCRIPTION: MOD STEEL ROTATOR SCREW HOLSTER	
FINISH: N/A	PN: 019	REV: B	SHEET: 1 of 1

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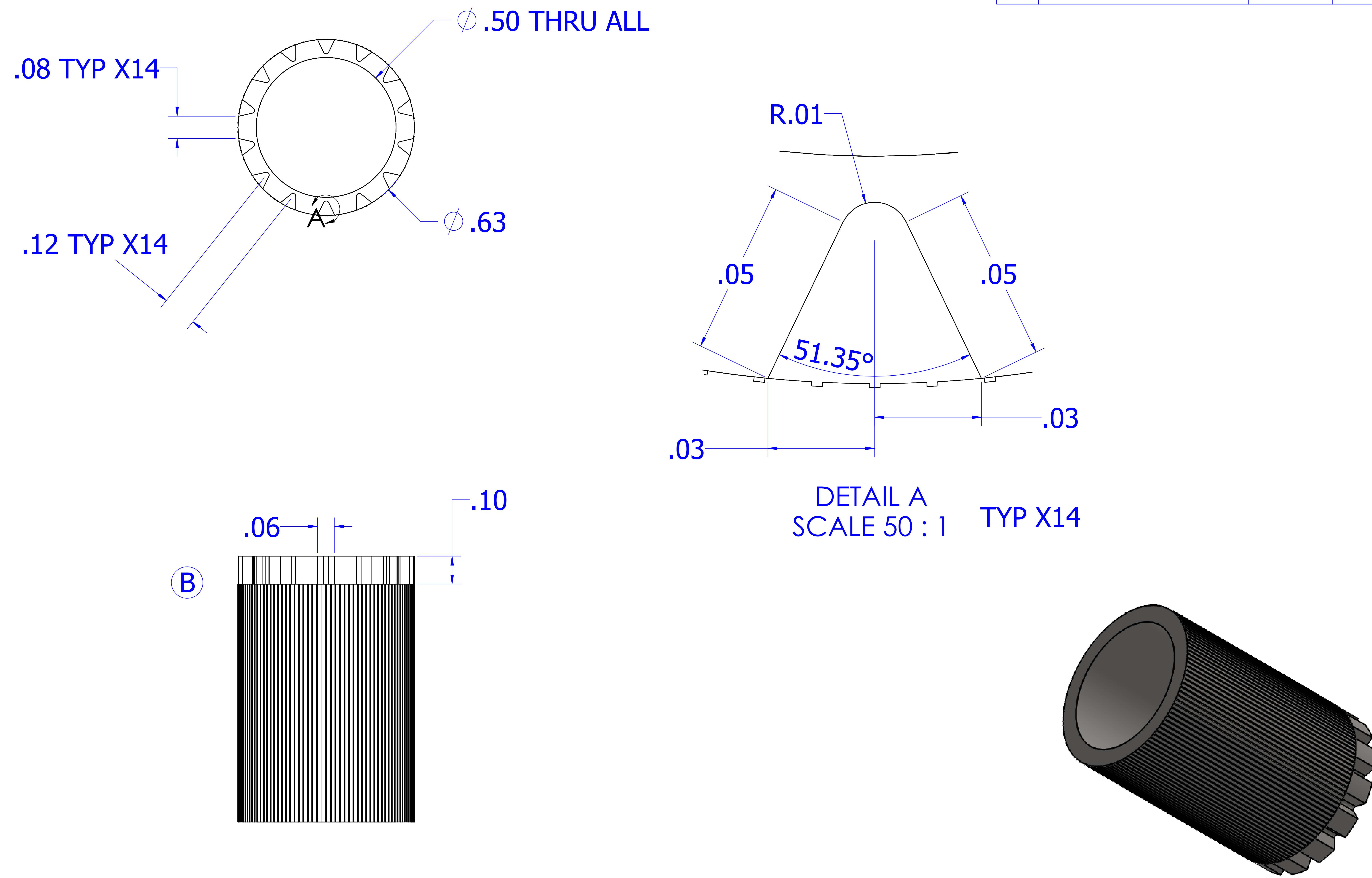
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	3/6/2023	NOLAN MAJOR
B	MODIFIED END OF CYLINDER AND ADDED BUSHED FINISH	3/7/2023	NOLAN MAJOR



TOLERANCES UNLESS NOTED:
X.X ±0.050
X.XX ±0.010
X.XXX ±0.005
X.X° ±0.5
UNITS: INCHES

UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

MATERIAL: STEEL

DESCRIPTION: MODIFIED STEEL CYLINDER

FINISH: BRUSHED

PN 016 | REV B | SHEET 1 of 1