Reverse Engineering of an Xbox One Controller

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MCEN 5045: Design for Manufacturability

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Executive Summary:

This report explains the reverse engineering analysis on a Microsoft model 1697 Xbox One controller. The analysis includes basic design investigation with a variety of diagrams (black box, glass box, and fishbone), relevant patent research, disassembly of the controller, design for assembly analysis, material analysis of each part, and economic analysis. As part of this project, redesign of the controller was also investigated and analyzed.

The Xbox One controller was chosen for this project because everyone on the team plays video games as a hobby and uses the Xbox One controller frequently. Using this device for the reverse engineering project offered free individual accessibility and the opportunity to gain a greater understanding of what goes into a controller we have enjoyed using for over 10 years.

The Xbox One controller has 36 unique parts (including COTS). We decided that for our redesign we would combine the three separate parts that make up the back of the controller. The left and right grip shell pieces cover up the screws that are needed to disassemble the controller as well. The redesign will decrease the complexity factor of the assembly of the controller, as well as make inspection easier since the screws will be visible while the whole controller is assembled.

The initial controller as well as the redesign was modeled in SolidWorks and those drawings can be found in the appendix of this report.

Using our cost analysis, we found that the controller costs $37.42, which is mainly from the cost of the COTS used in the controller. For retail, a new Xbox controller costs about $50, so from our assumptions and estimates the percentage markup from Microsoft is about 25.16%.

Researching and analyzing the Xbox One controller provided a lot of information that the team didn't know before. We hope you find the information provided as interesting as we did.

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Design Problem & Objectives:

Microsoft's Xbox One controller has had many iterations throughout its lifetime. It currently is on its fourth main revision, released in 2020 with the Xbox Series X/S consoles, and rumors are circulating about a fifth revision releasing in Q4 2024. Microsoft sold over 58 million Xbox One consoles throughout its lifetime of 2013-2020. Each console comes standard with one controller, but since Microsoft offers individual controllers in a variety of styles, patterns, and colors there are well over 58 million controllers sold worldwide.

The Xbox One controller was chosen for the reverse engineering project because it is a common, well-known product. The team was all familiar with the specific controller and found interest in learning more about what components go into the controller, how the controller was designed, and why certain design choices were made.
The controller has 35 unique parts (56 when you consider parts that have multiples). Our goals are to reduce the number of parts to decrease the cost of manufacturing and increase ease of assembly.

Black Box Diagram:

The black box diagram breaks down a given object into the basic terms of what is inputted into the system, and what the system outputs, without any knowledge of what the inside workings of the object are. The Xbox One controller has four inputs and outputs as shown below. Once this analysis is complete, a glass box diagram is created for a more detailed breakdown of the whole system. The glass box diagram is in the next section.

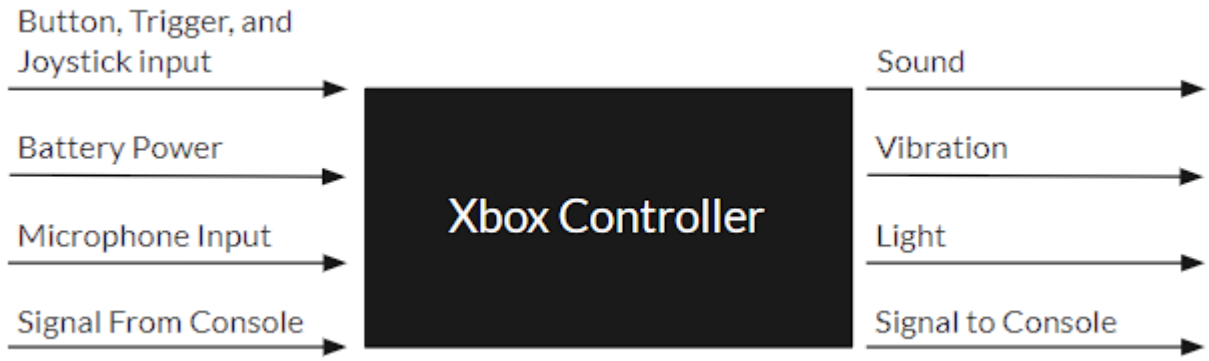


Figure 1: Black box diagram of Xbox One controller.

Glass Box Diagram:

After the black box analysis, the Xbox One controller was broken down further to understand how the inputs and outputs are connected within the controller. As shown in the figure below, the controller has many interworking parts within the glass box that is the inner system of the controller.

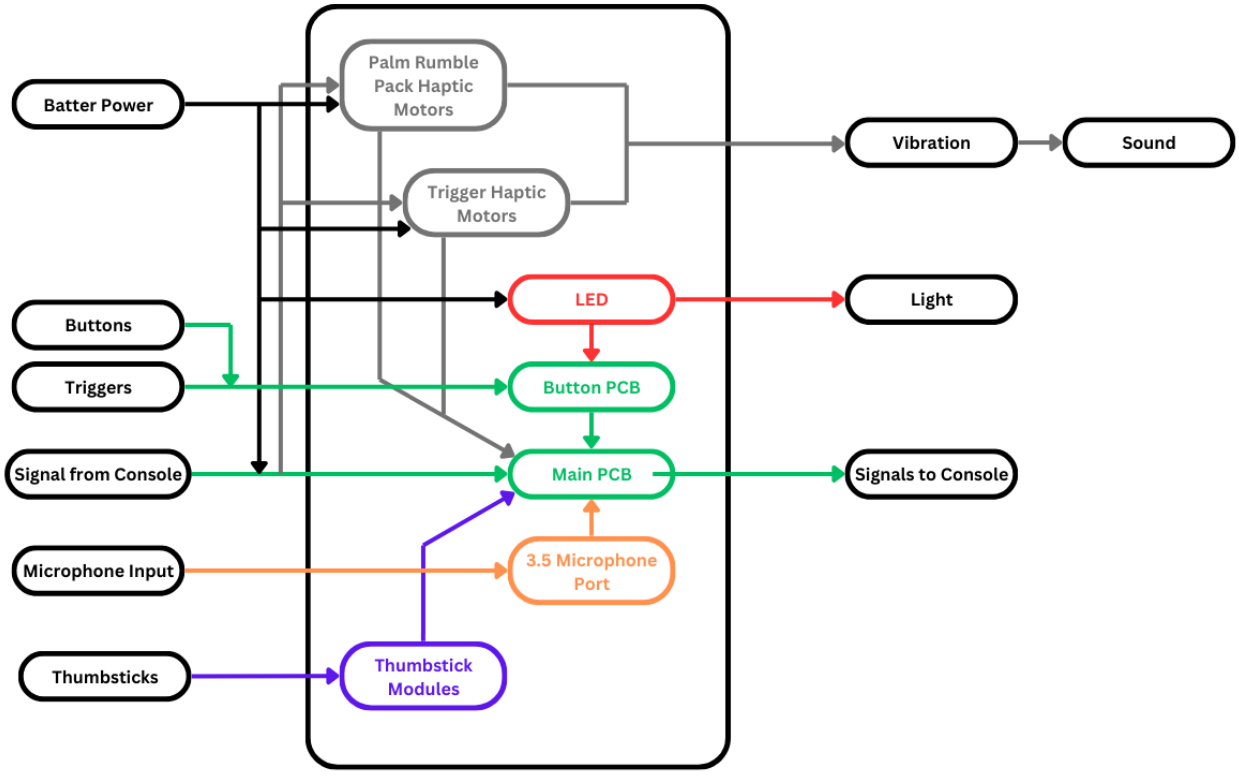


Figure 2: Glass box diagram of Xbox One controller.

Fishbone Diagram:

The fishbone diagram shows a breakdown of the subassemblies and components that make up the full Xbox One controller. In the figure below, we have 36 total individual parts that make up 4 different sub-assemblies. All sub-assemblies and parts connect to the inner frame as it makes up the full controller.

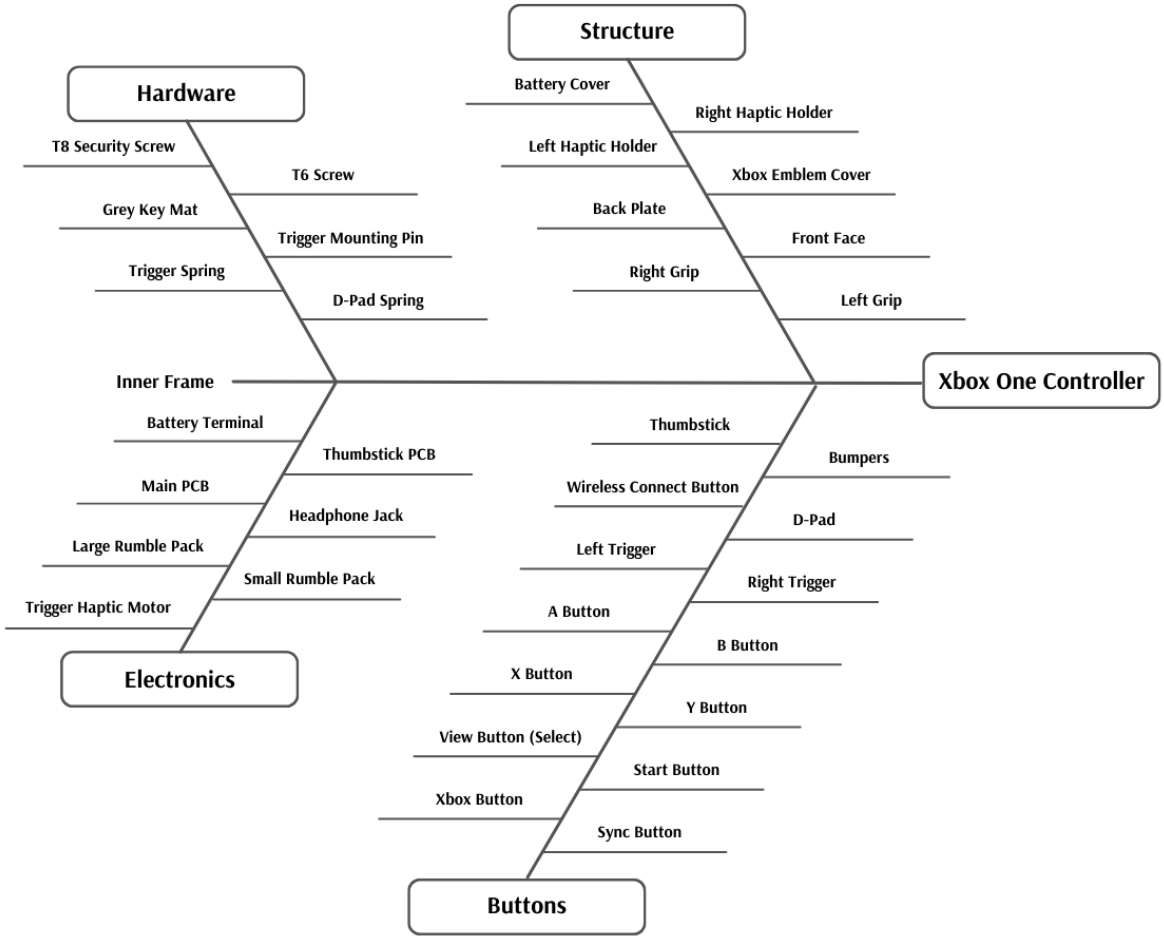


Figure 3: Fishbone diagram of Xbox One controller.

Project Schedule:

The reverse engineering project took eight weeks from start to finish. Over that time period, the below Gantt chart shows how our work was scheduled. The end of the project shows more variety of objectives than the rest of the project timeline since we focused more on our models and drawings more heavily. The orange diamonds show deadlines for certain assignments that are related to the project. As a team, we met after every class period to discuss what needed to be worked on and to make sure everything was on track to be completed.

Table 1: Gantt chart.

Project: Reverse Engineering Xbox One Controller	Team Members:				Date:															
	Evan	Jacob	Luke	Rick	26-Aug	28-Aug	2-Sep	4-Sep	9-Sep	11-Sep	16-Sep	18-Sep	23-Sep	25-Sep	30-Sep	2-Oct	7-Oct	9-Oct	14-Oct	16-Oct
Project Proposal	X	X	X	X																
Diagrams: Black box, Glass box, Fishbone		X	X																	
Disassemble Controller	X																			
Part Modeling	X	X	X	X																
Part Drawings	X	X	X	X																
Full Assembly Model				X																
DFA Analysis	X	X	X	X																
Economic Analysis	X	X	X	X																
Material Selection Analysis	X	X	X	X																
Design Changes	X	X	X	X																
Redesign Analysis: DFA		X																		
Redesign Analysis: Economic			X																	
Redesign Analysis: Assembly Model				X																
Write Final Report	X	X	X	X																
Final Report Presentation	X	X	X	X																

: Assignment Due
: Team met for quick check-ins after ever class period

Patent Search:

Patent research on the Xbox One controller was performed to gain a better understanding of the controller and how Microsoft has changed its design over time. Many of their patents are ornamental design patents that pertain to the shape and design of the exterior of the controller itself. Other new patents may shed light on the direction Microsoft may go with future models of their controller.

Patent: US D 709,882 S

This ornamental patent for the design of the Xbox One controller was filed on January 28th, 2013, prior to the launch of the Xbox one on November 11th, 2013. The patent specifically mentions the outside form of the controller.

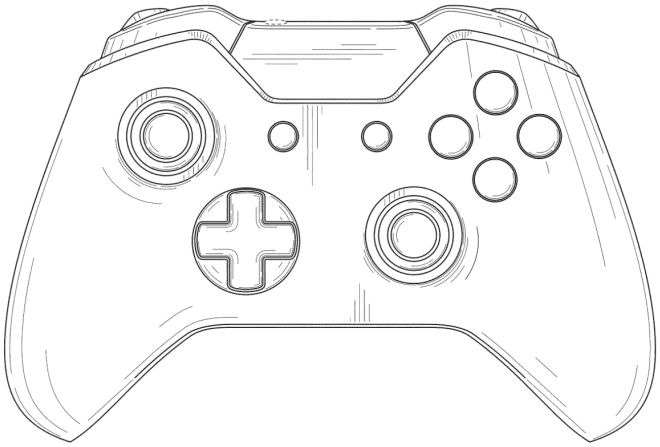


Figure 4: Patent US D709,882 S

Patent: US D872,183 S

This patent is on the claim of ornamental design for the controller as shown. This patent is specifically on the pattern of the design on the front face of the controller. One of the team members has a controller with this design, which made this ornamental patent particularly interesting.

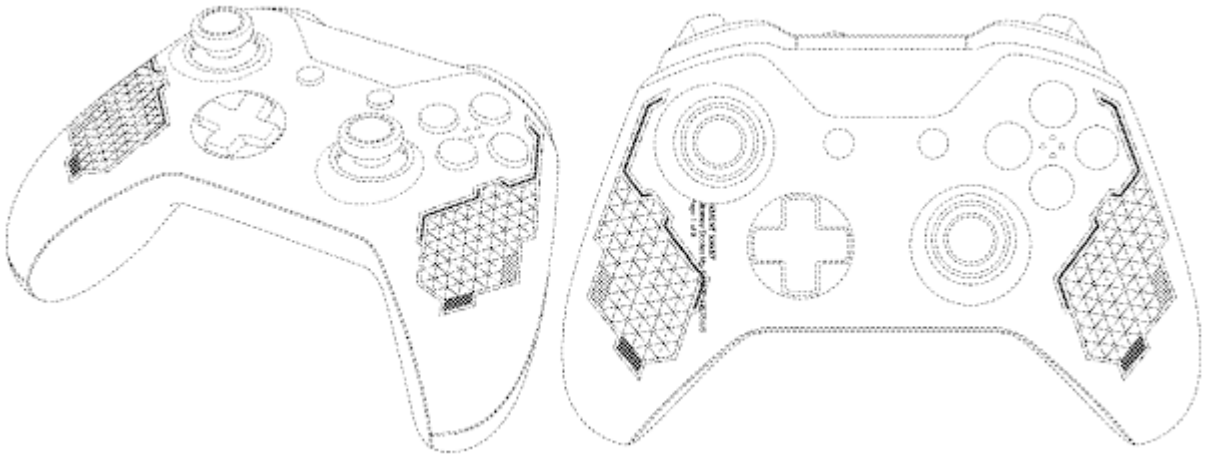


Figure 5: Patent US D872,183 S

Figure 6: Real life example of patent US D872,183 S

Patent: US D872,185 S

This patent is also an ornamental claim patent. This patent highlights the knurling on the ends of the triggers, previously smoothed. This provides a better grip on the triggers and could be considered an ergonomic improvement to the controller.

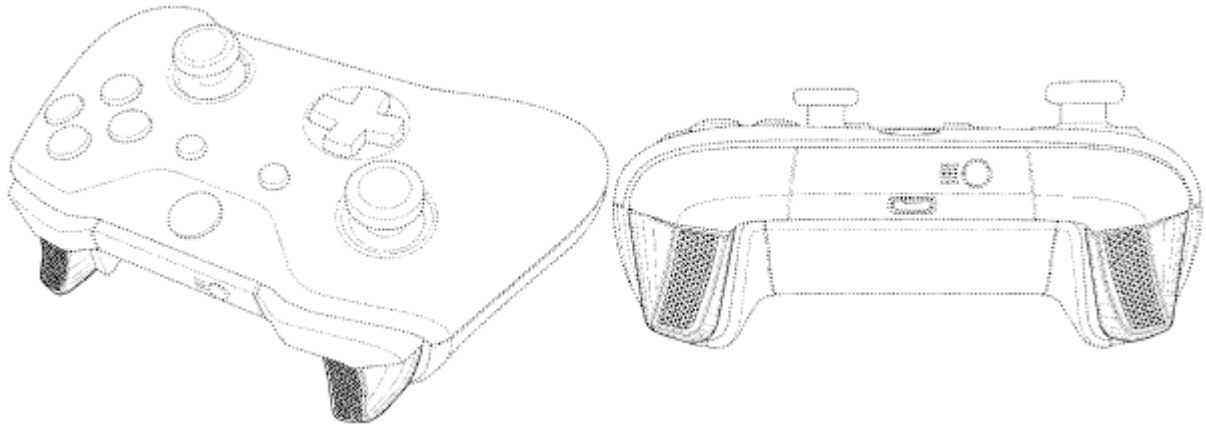


Figure 7: Patent US D872, 185 S

Patent: US D1,037,370 S

This ornamental patent was published July 30, 2024, implying new changes are being developed for a new iteration of the Xbox controller. This patent highlights the area of the left and right palm grips with what looks like small perforations. It will be interesting to see if this design is a part of the new generation of controllers.

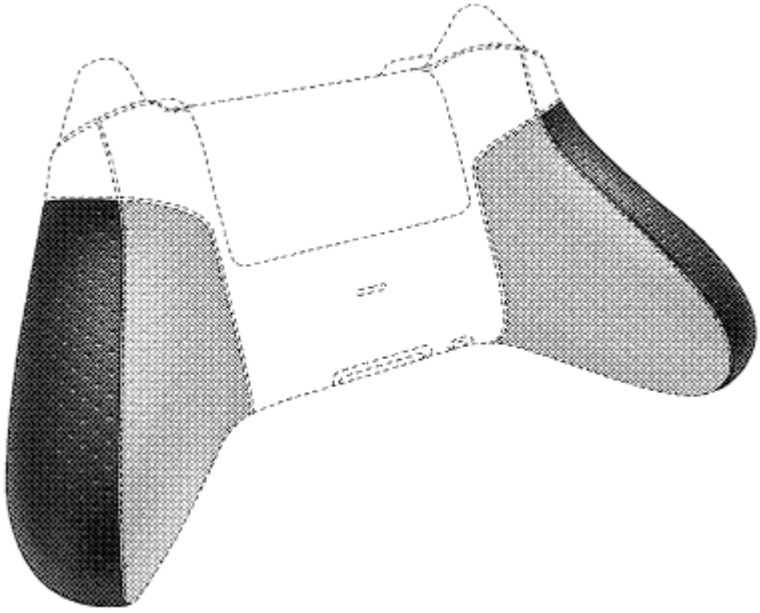


Figure 8: Patent US D1,037,370 S

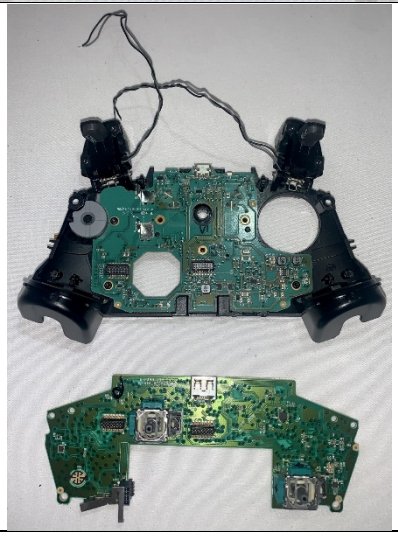
Disassembly:

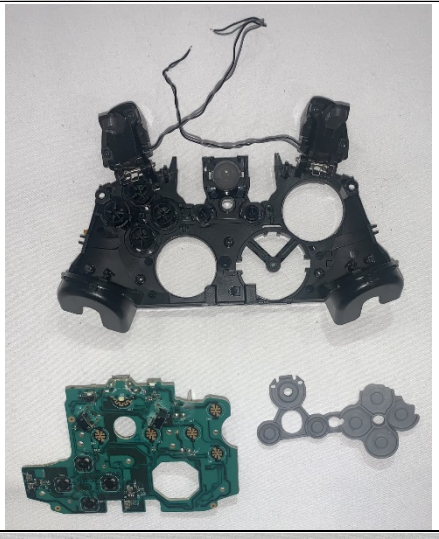
The table below outlines the complete, 13 step process for disassembling an Xbox one controller. The disassembly utilizes a T9 security driver, a T6 Torx driver, and a small flathead screwdriver for removing snap-fit components. The item numbers referenced below correspond to the bill of materials in Table 2.

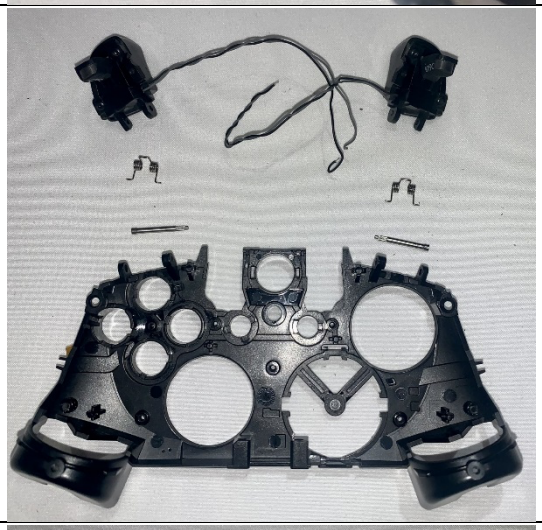
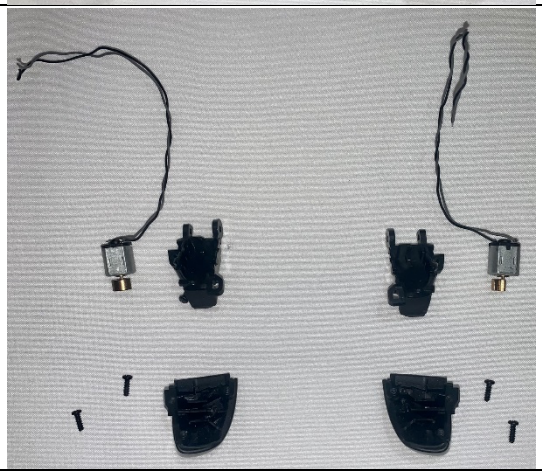
Table 2: Xbox One disassembly steps.

1	Remove the T9 security screw (401) from the battery compartment located beneath the security sticker. Additionally, detach the left (101) and right (102) grips by carefully prying open the snap fittings.	

2	Remove the four T9 security screws located in the corners of the back plate. Once completed, detach the face of the controller along with the backing plate.	
3	Using a pry tool, carefully lift the D-pad spring to remove both the spring and the D-pad. Next, pull up on the thumb sticks to detach them from the joysticks.	
4	Using a pry tool, carefully lift the Xbox emblem holder and slide it forward to detach it.	

5	After removing the Xbox emblem cover, remove the left and right bumpers.	
6	Remove the five T6 screws that are visible on the circuit board.	
7	Disconnect the rumble packs and trigger haptic motor by either desoldering or cutting the wires. Then, remove the joystick motherboard.	

8	Remove the 3 T6 screws Remove the three T6 screws securing the remaining circuit board.	
9	Remove the motherboard and carefully separate the gray key mat from the circuit board.	
10	Remove the buttons from the inner frame of the Xbox controller.	

11	Press out the trigger pin to detach the trigger assembly.	
12	Separate the trigger assembly from the trigger pins and trigger springs.	
13	Unscrew the two T6 screws located on each trigger to remove the haptic trigger motor.	

The disassembly process consists of 13 total steps, involving the removal of 56 parts. It requires three tools: two Torx drivers and a pry tool. Additionally, the controller needs to be reoriented thrice throughout the process.

DFA Analysis & Comparison:

Initial DFA:

For the Xbox One controller, design for assembly analysis was performed, as shown in the table below. With 54 total parts (including hardware and electronics) and 170 total interfaces, the controller has a complexity factor of 95.812. This factor comes from the equation:

$$DCF = \sqrt{\sum N_p * \sum N_i}$$

To minimize this factor, the part number and/or the interface number should be minimized as much as possible. As a team, we decided that the theoretical minimum number of parts for the basic function of a controller was 12 parts. This gives us a theoretical efficiency of 22.2%, which represents the absolute bare minimum theoretical part count vs the real part count as a percentage of efficiency. This metric is very low due to the aggressive approach our group took when determining what constitutes a theoretical part. Initially, we set the goal of achieving 60% theoretical efficiency, but this wouldn't be achievable without redesigning the controller's form in its entirety.

By our group's decision, the theoretical part count only really considers a PCB with some buttons sitting on top, which isn't very practical for consumer use. To provide a more realistic guideline, we decided upon a practical minimum part count of 35, giving the current controller a practical efficiency of 63.0%, which is much better than the 21% that the theoretical efficiency was.

Some other analysis we looked at were error proofing, assembly handling, insertion difficulty, and secondary operations. In general, the Xbox One controller is very well designed and has decent metrics in these regards.

The error metric is 0.17, which is caused by the two different sizes of rumble packs in the palms of the controller. To eliminate errors, and make it easier for assembly, we are considering standardizing the rumble packs to one size. This would decrease the number of unique parts as well as reducing the error metric to 0.0.

In terms of handling, the four rumble/haptic motors require small scale soldering to the PCBs. The PCBs can be considered fragile, and the grey silicone key mat is a flexible part and increases the handling metric to 0.50 for the controller.

For insertion, the metric is 0.50. The trigger springs require acute alignment, as well as compression to fit into place. Three parts have high resistance for insertion: the trigger pins and the left / right grip shells. The only part that has obstructed access is the bumper, which mildly increases the difficulty of installation.

The last metric is secondary operations, in which the Xbox One controller is scored 0.75. There are quite a few screws in the assembly (17 in total) which requires a secondary operation for assemblers to screw in the 17 different screws. There are also four motors that require a positive and negative lead to be soldered to the lower PCB.

Table 3: Initial DFA Analysis

DFA Analysis Worksheet

Assembly Name: Xbox One Controller **Team:** Evan, Jacob, Luke, Rick **Date:** 9/26/2024

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
101	Left Grip	1	1	0	0	LOW	0	0	0	0	0	0		0	0	1	0	0	0	0	0	0
102	Right Grip	1	1	0	0	LOW	0	0	0	0	0	0		0	0	1	0	0	0	0	0	0
103	Front face	1	10	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	1	0	0	0
104	Back face	1	7	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	1	0	0	0
105	Xbox emblem cover	1	4	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
106	Controller frame	1	15	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
107	Haptic holder right	1	3	0	0	LOW	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
108	Haptic holder left	1	3	0	0	LOW	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
109	Battery door	1	1	0	0	LOW	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
201	Thumbstick	2	4	1	0	LOW	2	0	0	0	0	0		0	0	0	0	0	0	0	0	0
202	Left/right bumpers	1	5	1	0	LOW	1	0	0	0	0	0		0	0	0	1	0	0	0	0	0
204	Dpad	1	3	3	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
205	Left trigger	1	3	1	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
206	Right trigger	1	3	1	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
207	A button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
208	B button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
209	X button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
210	Y button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
211	View button (select)	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
212	Start button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
213	Xbox button	1	3	0	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
214	Sync button	1	3	1	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
301	Dpad spring	1	2	1	0	LOW	1	0	0	0	0	0		0	0	0	0	0	0	0	0	0
302	Trigger springs	2	2	0	0	LOW	0	0	0	0	0	0		1	1	0	0	0	0	0	0	0
303	Trigger mounting pins	2	2	0	0	LOW	0	0	0	0	0	0		0	0	1	0	0	0	0	0	0
304	Gray Rubber Keymat	1	8	0	0	LOW	1	0	0	0	1	0		0	0	0	0	0	0	0	0	0
305	T6 Screw (x12)	12	24	0	0	LOW	8	0	0	0	0	0		0	0	0	0	0	1	0	0	0
306	T9 security screw (x5)	5	10	0	0	LOW	5	0	0	0	0	0		0	0	0	0	0	1	0	0	0
401	Battery terminals	1	2	2	0	LOW	0	0	0	0	0	0		0	0	0	0	0	1	0	0	0
402	Joystick PCB	1	18	0	0	LOW	0	0	0	0	1	0		0	0	0	0	0	0	0	0	0
403	Lower PCB	1	5	1	0	LOW	1	0	0	0	1	0		0	0	0	0	0	1	0	0	0
404	Headphone jack	1	2	0	0	LOW	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
405	Rumble pack large	1	2	0	0	LOW	0	1	0	0	0	1		0	0	0	0	0	0	1	0	0
406	Rumble pack small	1	2	0	0	LOW	0	1	0	0	0	1		0	0	0	0	0	0	1	0	0
407	Trigger haptic motor	2	4	0	1	LOW	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0
	Totals	54	170	12	1	0	34	2	0	0	3	3		1	1	3	1	0	6	3	0	0
	Design for Assembly Metrics	**95.81231654**		**22.2%**	←Theor. Effy. Pract. Effy.→		**63.0%**	**0.17**		**0.50**				**0.50**				**0.75**				
	Targets			**60.0%**			**80.0%**	**0.00**		**0.25**				**0.25**				**0.50**				

Redesign DFA:

With the redesign applied, our metrics changed in a way that was favorable. Our complexity factor decreased from 95.8 to 92.1 since we decreased parts and interfaces. We now have 52 total parts and 163 total interfaces. This also caused our theoretical and practical efficiencies to increase a few percent as well, not quite hitting our ambitious target, but it is going in the correct direction. We were able to fully eliminate the error matric. One of our original plans was to standardize the rumble packs to eliminate the error of misplacing one on the wrong side of the controller, but when we tried to do that, we found that the large rumble pack was not able to fit in the slot where the small rumble pack fits. This discovery allowed us to fully eliminate the error matric from our DFA. As shown by the tables, all other analysis matrix is decreased from our redesign.

Table 4: Redesign DFA analysis.

DFA Analysis Worksheet

Assembly Name: Xbox One Controller **Team:** Evan, Jacob, Luke, Rick **Date:** 9/26/2024

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
103	Front face	1	10	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
105	Xbox emblem cover	1	4	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106	Controller frame	1	15	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	Haptic holder right	1	3	0	0	LOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	Haptic holder left	1	3	0	0	LOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	Battery door	1	1	0	0	LOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
201	Thumbstick	2	4	1	0	LOW	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
202	Left/right bumpers	1	5	1	0	LOW	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
204	Dpad	1	3	3	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
205	Left trigger	1	3	1	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
206	Right trigger	1	3	1	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
207	A button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
208	B button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
209	X button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	Y button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
211	View button (select)	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
212	Start button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	Xbox button	1	3	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
214	Sync button	1	3	1	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
301	Dpad spring	1	2	1	0	LOW	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
302	Trigger springs	2	2	0	0	LOW	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
303	Trigger mounting pins	2	2	0	0	LOW	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
304	Gray Rubber Keymat	1	8	0	0	LOW	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
305	T6 Screw (x12)	12	24	0	0	LOW	8	0	0	0	0	0	0	0	0	0	0	1	0	0	0
306	T9 security screw (x5)	5	10	0	0	LOW	5	0	0	0	0	0	0	0	0	0	0	1	0	0	0
401	Battery terminals	1	2	2	0	LOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
402	Joystick PCB	1	18	0	0	LOW	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
403	Lower PCB	1	5	1	0	LOW	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0
404	Headphone jack	1	2	0	0	LOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	Rumble pack large	2	1	0	0	LOW	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
407	Trigger haptic motor	2	4	0	1	LOW	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
601	Redesigned Back Plate	1	5	0	0	LOW	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Totals	52	163	12	1	0	34	0	0	0	3	2	1	1	1	1	0	6	2	0	0
	Design for Assembly Metrics	**92.06519429**		**23.1%**	←Theor. Effy, Pract. Effy.→		**65.4%**	**0.00**		**0.42**			**0.33**				**0.67**				
	Targets			**60.0%**			**80.0%**	**0.00**		**0.25**			**0.25**				**0.50**				

Material & Manufacturing Analysis:

Manufacturing

Twenty-five of the thirty-six total parts utilized in the Xbox controller are produced using injection molding. Injection molding is employed due to its high repeatability and capacity to maintain tight tolerances. Tight tolerancing of parts is crucial in the Xbox controller, given the compact arrangement of components within the device. Tight tolerancing is particularly important because the buttons must operate smoothly without binding when pressed. Additionally, the capability to rapidly produce multiple parts through the use of multi-cavity molds significantly reduces the cost per part for injection-molded components. This efficiency is crucial for Microsoft, as it enables the company to leverage economies of scale and maximize profits. By standardizing the production method, all injection-molded components can utilize the same material. However, the types and complexities of the injection molds used to manufacture Xbox parts can vary significantly from one component to another.

Many parts, such as the wireless connect button and front face are produced using relatively simple single-shot injection molds. In contrast, components like the select and view buttons utilize two-shot molds, while the A, B, X, and Y buttons are manufactured using three-shot molds. In a typical two-shot mold operation, the mold features two cavities: one for the initial molding process and the other for the over molding process. After the initial part has been created, the mold separates and rotates 180 degrees, allowing the second cavity to be pressed over the initial part. In the case of the Xbox controller, two- and three-shot molds are utilized to incorporate symbols onto the buttons instead of relying on screen printing or laser engraving. This method ensures that the symbols remain legible after extended use, in contrast to printed finishes that may fade or wear away over time.

The only components not produced through injection molding are the commercial off-the-shelf parts, D-pad spring, and printed circuit boards (PCBs). The commercial off-the-shelf parts are manufactured through a variety of different traditional manufacturing methods. The D-pad spring is made from steel sheet metal and is stamped using a combination die. This means that the part is blanked and bent in a single operation, allowing the manufacturing process to be extremely efficient and capable of keeping pace with injection molding production. The printed circuit boards are produced using surface mount technology and involve several different processes. The electrical pathways are created through machining and chemical etching. Subsequently, a machine applies solder to all surface mounting locations, followed by another machine that places surface-mounted components onto the board. Finally, the board is placed in an oven to melt the solder, securing all components to the board.

Material

Most of the parts in this assembly are made from acrylonitrile butadiene styrene (ABS), as it is well-suited for injection molding and offers good mechanical properties. It provides good electrical insulation and can withstand temperatures up to 257°F [4]. ABS can be easily post-processed chemically or machined to achieve an attractive surface finish. Furthermore, ABS is widely available, making it cost-effective, and additives can be readily incorporated to enhance specific properties, such as flow rate for improved injection molding or to modify flammability. These characteristics make ABS a highly advantageous material choice for consumer electronics.

The only parts not made from ABS were those that were not injection molded, with the exception of the key mat, which is made of silicone. The requirement for elasticity and the capability to be die-stamped guided the material selection for the D-pad spring towards sheet metals. Steel is the most common metal used in springs and is the optimal choice for this part. Another component, the key mat, consists of silicone over molded onto electrically conductive pads. Silicone is the industry standard for key mats due to its injection moldability, electrical insulation properties, and ability to enable noiseless operation of the buttons on the PCB. Lastly, the commercial off-the-shelf fasteners are primarily made from steel, owing to their ease of manufacture and favorable mechanical properties for screws and springs.

Manufacturing and Material Selection Case Studies

The inner frame of the Xbox controller, illustrated in figure 9, is one of the most critical components, serving as the skeleton of the controller and ensuring that all parts remain in the correct position. The controller requires moderate strength to maintain stiffness and rigidity;

however, this component cannot be metallic due to its contact with the PCBs. The material selection for the inner frame is representative of the process used for all ABS injection-molded parts on the Xbox controller.

Figure 9: Part 106, Inner Frame

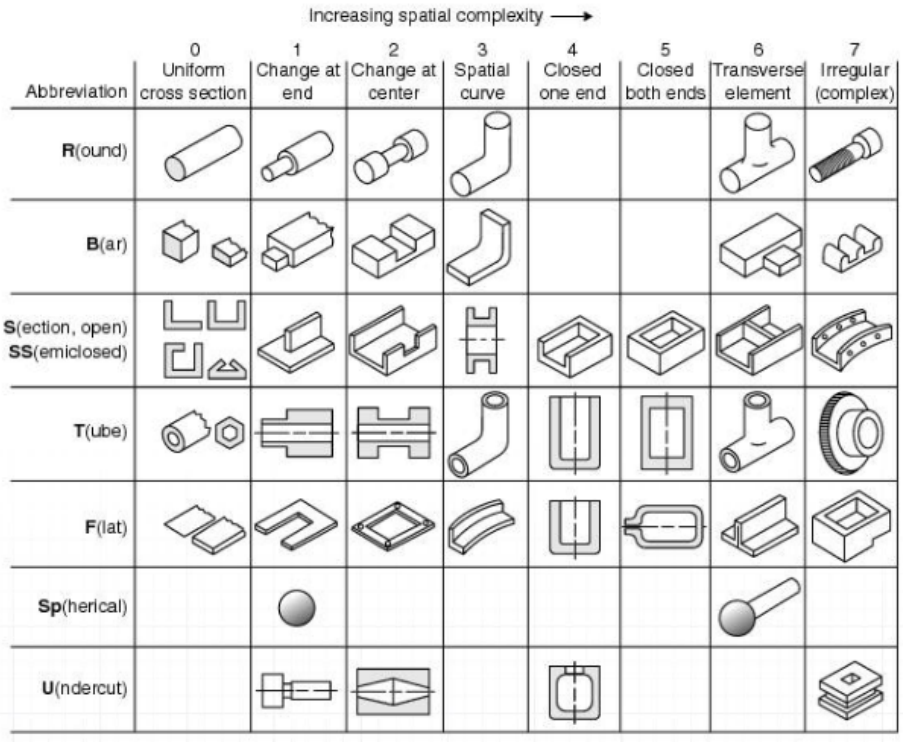


Figure 10: Part Complexity

Based on Figure 10 above, the inner frame is classified as a U7 part. There are very few processes capable of producing this level of part complexity. This indicates that, based on Figure 11 below, only casting processes are viable options. The various casting methods must now be assessed for their production quantities and the materials they can accommodate. These Xbox controllers are produced in quantities exceeding 100,000 from thermoplastics. Therefore, based on Figure 12, the only applicable processes are injection molding, blow molding, and contact molding. Blow molding and contact molding can be eliminated, as they are not capable of producing the complex shape of the inner frame. This means that the only process capable of producing the inner frame from thermoplastics at the required scale is injection molding.

Ability of Manufacturing Processes to Produce Shapes

Process	Capability for Producing Shapes
Casting processes	
Sand casting	Can make all shapes
Plaster casting	Can make all shapes
Investment casting	Can make all shapes
Permanent mold	Can make all shapes except T3, T5; F5; U2, U4, U7
Die casting	Same as permanent mold casting
Deformation processes	
Open-die forging	Best for R0 to R3; all B shapes; T1; F0; Sp6
Hot impression die forging	Best for all R, B, and S shapes; T1, T2; Sp
Hot extrusion	All 0 shapes
Cold forging/cold extrusion	Same as hot die forging or extrusion
Shape drawing	All 0 shapes
Shape rolling	All 0 shapes
Sheet-metal working processes	
Blanking	F0 to F2; T7
Bending	R3; B3; S0, S3, S7; T3; F3, F6,
Stretching	T4; S7
Deep drawing	T4; F4, F7
Spinning	T1, T2, T4, T6; F4, F5
Polymer processes	
Extrusion	All 0 shapes
Injection molding	Can make all shapes with proper coring
Compression molding	All shapes except T3, T5, T6, F5, U4
Sheet thermoforming	T4, F4, F7, S5
Powder metallurgy processes	
Cold press and sinter	All shapes except S3, T2, T3, T5, T6, F3, F5, all U shapes
Hot isostatic pressing	All shapes except T5 and F5
Powder injection molding	All shapes except T5, F5, U1, U4
PM forging	Same shape restrictions as cold press and sinter
Machining processes	
Lathe turning	R0, R1, R2, R7; T0, T1, T2; Sp1, Sp6; U1, U2
Drilling	T0, T6
Milling	All B, S, SS shapes; F0 to F4; F6, F7, U7
Grinding	Same as turning and milling
Honing, lapping	R0 to R2; B0 to B2; B7; T0 to T2, T4 to T7; F0 to F2; Sp

Figure 11: The ability of manufacturing processes to produce shapes.

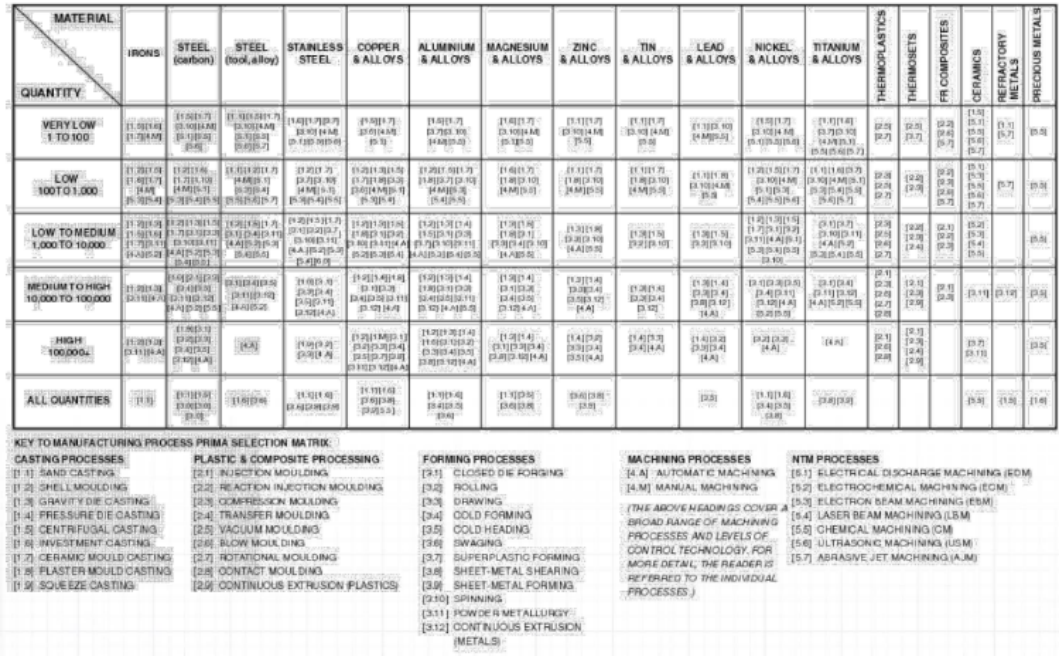


Figure 12: The ability of manufacturing processes to produce different quantities of parts based on the material being used.

Since injection molding is the chosen process for the inner frame, a suitable thermoplastic must be selected. Based on its application, the inner frame needs to be lightweight, moderately strong, and cost-effective for high production quantities. The performance index governing these criteria is presented in the equation below:

$$C = \sigma_f^{\frac{1}{2}} / C_R \rho$$

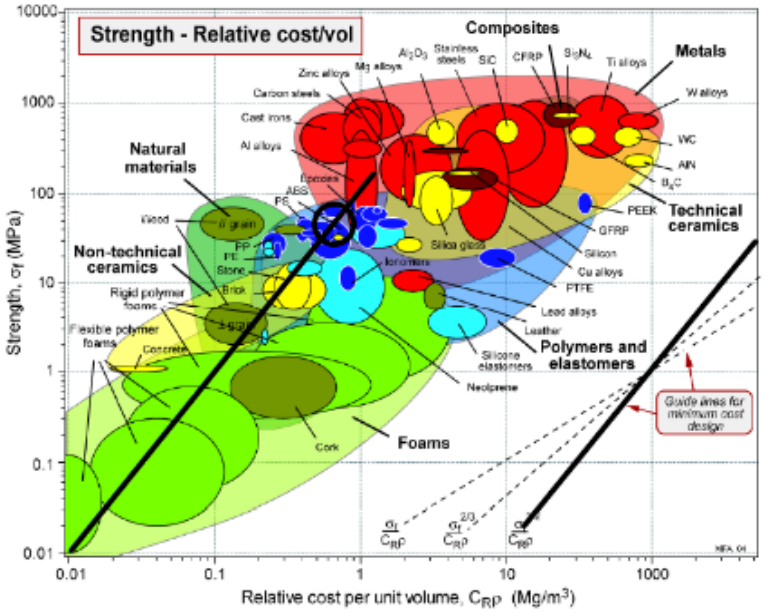


Figure 13: Ashby chart showing the strength of materials as a function of cost per unit volume.

Based on the results plotted on the Ashby chart in Figure 13 above, ABS is identified as the material of choice, as it is the most cost-effective thermoplastic in terms of strength.

Figure 14: Part 304, Key mat

The key mat (part number 304) is used to actuate buttons 207-213 and has the requirement of being flexible and relatively durable whilst being non-conductive. Because of the shape and function of this component, material selection is extremely important for this component. The performance index governing the criteria defined above can be described with the equation:

$$\sigma_f^{\frac{3}{2}} / E = C$$

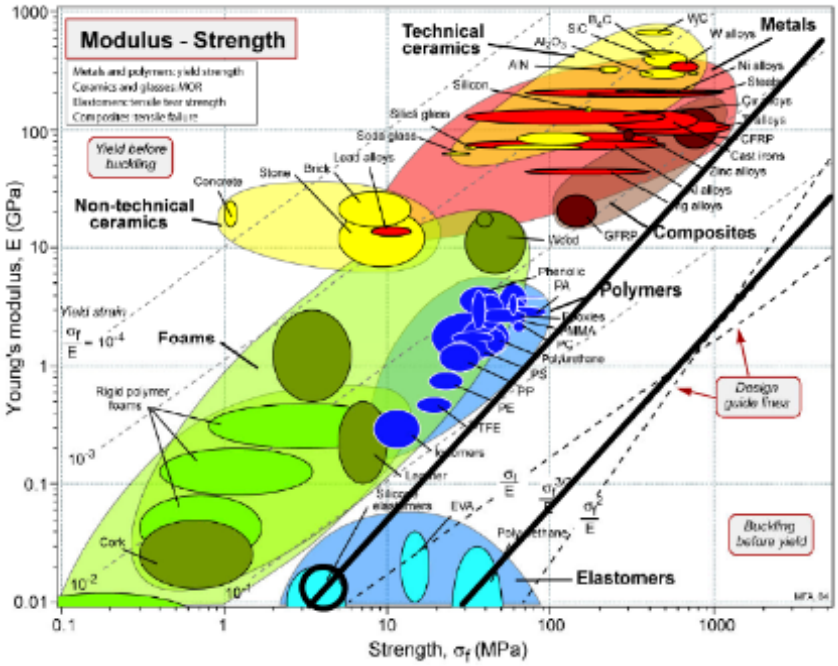


Figure 15: Ashby chart showing the Young's modulus of materials as a function of strength

Based on the results plotted on the Ashby chart in Figure 14 above, silicone is identified as the material of choice, as it provides a low Young's modulus and passable strength for this application while still being relatively cheap and offering a large range of scalable manufacturing options.

The high quantity (100,000+) row and thermoset column are then referenced in figure 12, which indicates that injection molding, compression molding, transfer molding, and continuous extrusion are suitable processes to produce thermosets at high volume. The shape of the key mat can be seen in figure 14 and described as an F7 shape using the part complexity matrix found in figure 10. Figure 11 indicates that this part cannot be manufactured using a continuous extrusion process.

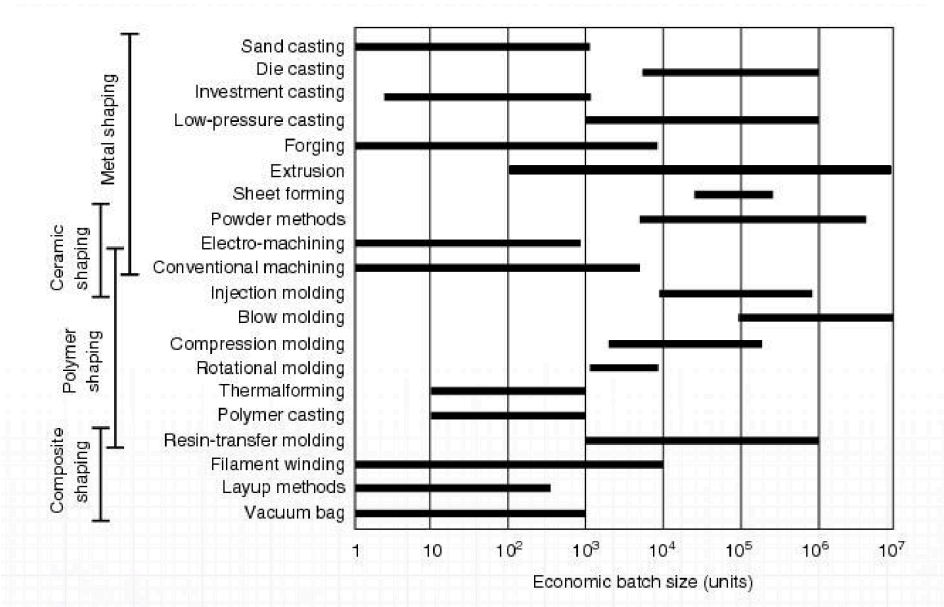


Figure 16: Economic batch sizes for multiple manufacturing processes

Out of the options for injection molding, compression molding, and transfer molding, injection molding was ultimately chosen for the manufacture of part 304, as figure 16 illustrates it has the largest economic batch size.

The D-pad spring, shown in figure 17 below, in an Xbox One controller is a small but essential component that ensures the D-pad returns to its neutral position after being pressed. When you press the D-pad, the spring compresses, allowing for smooth movement and directional input. Once released, the spring expands back to its original shape, providing a satisfying click and feel, which enhances gameplay precision and responsiveness.

Figure 17: D-pad spring for an Xbox One Controller

The design is aimed at balancing durability and a comfortable user experience during extended gaming sessions. Due to the volume and design of the spring it is manufactured using a combination die to form the spring in one action. The material must be able to provide a spring force yet needs to be able to resist breaking under cyclical loading. The performance equation and Ashby chart for these criteria are shown below:

$$\sigma_f^2 \,/\, E \;=\; C$$

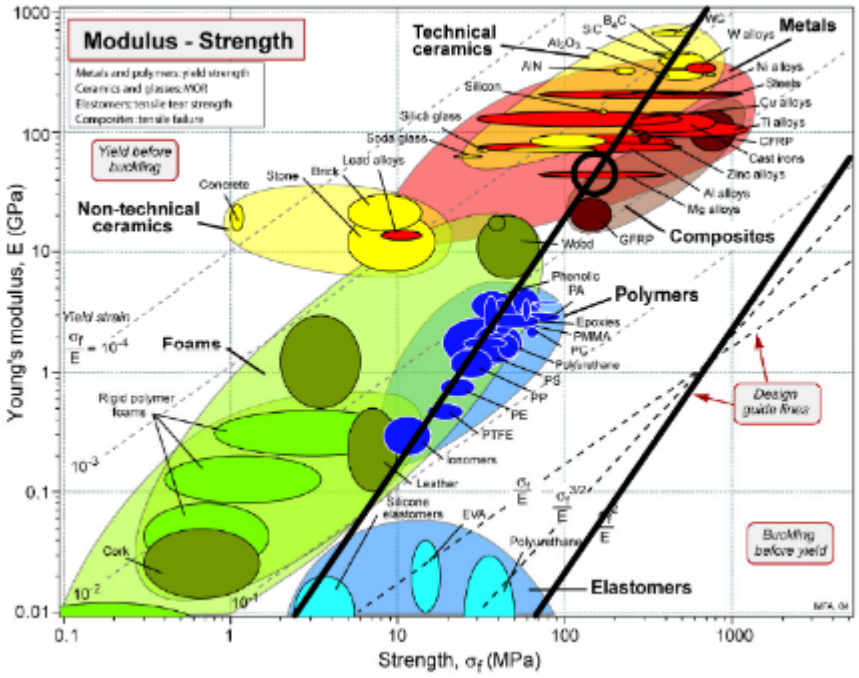


Figure 18: Ashby chart showing the performance index for the Xbox one d-pad spring

From figure 18 above, metals are shown as the ideal candidates for the material selection of the d-pad spring. Steel is the best material choice for this application because it is the industry standard for making springs, as well as its desirable ratio of strength and elasticity.

Economic Analysis:

For the Xbox One controller, economic analysis was performed to find the unit cost of each part in the assembly. Considering COTS parts, there were 28 parts that analysis was performed on. Since we did not design, manufacture, or assemble the Xbox One controller a few assumptions needed to be made.

The total unit cost is made up from five different equations that aim to estimate the full price of the controller.

For the analysis, magnitude estimates were also performed as a comparison. Magnitude estimates only consider the material cost and the weight of the part; this makes the estimate very crude but usually can get into the ballpark of a good estimate. Without considering the cost of the COTS used, our magnitude estimate for total cost of the 28 parts was $1.78, which is very close to the real estimate we came up with using the full analysis at $1.45.

For our initial analysis, the controller total cost of assembly is $37.42, which seems very reasonable given a controller for retail cost around $60 currently. A large percentage of the price was from the cost of the COTS parts. The COTS cost around $36, which shows just how inexpensive it is to mass produce by the millions of small injection molded parts.

Material Cost:

$$C_M = \frac{mc_m}{1-f}$$

$m = weight\ of\ material\ (lb)$

$c_m = cost\ of\ material\ (\frac{\$}{lb})$

$f = fraction\ of\ material\ that\ ends\ up\ as\ scrap$

Labor Cost:

$$C_L = \frac{c_w}{n'}$$

$c_w = hourly\ cost\ of\ wages\ and\ benefits\ (\frac{\$}{hr})$

$n' = production\ rate\ (\frac{units}{hr})$

Tooling Cost:

$$C_T = \frac{c_t k}{n}$$

$c_t = cost\ of\ making\ tooling\ (\$)$

$n = entire\ production\ run\ (\#\ of\ parts)$

$k = tooling\ wear\ factor\ (k = \frac{n}{lifespan\ of\ tooling})$

Equipment Cost:

$$C_E = \left(\frac{1}{n'}\right)\left(\frac{c_e}{Lt_{wo}}\right)q$$

$c_e = cost\ of\ capital\ equipment\ (\$)$

$n' = production\ rate\ (\frac{units}{hour})$

$L = load\ factor, fractional\ time\ equipment\ is\ productive$

$t_{wo} = capital\ write\ off\ time\ (yr)$

$q = fraction\ of\ equipment\ sharing\ between\ products$

Overhead Cost:

$$C_{OH} = \frac{c_{OH}}{n'}$$

$c_{OH} = overhead\ hourly\ rate\ (\frac{\$}{hr})$

$n' = production\ rate$

Economic Analysis Assumptions:

1. There have been about 7.5 million Xbox consoles sold per year, each one comes with at least one controller. [1]
2. Assuming each console owner has at least three controllers:
    a. 22.5 million controllers per year.
3. Microsoft spent over $100 million on R&D for the Xbox One controller. [2]
    a. Divide that by the number of parts (36 total) to get $1,750,000 for capital costs.
4. Controller generations usually last about one console generation lifespan which is about 10 years.
5. 225 million controllers total for this generation over 10 years.
6. COTS cost estimates come from McMaster Carr and Amazon.
7. Labor rate comes from the average rate of a machinist in the United States. [3]
8. One operator per machine.
9. Each part has one machine that works 2 shifts for 50 weeks a year.
    a. 4000 work hours per year.
10. The production rate is 5625 controllers per hour.
    a. 22.5 million controllers per year divided by 4000 hours per year.
    b. Some parts are used multiple times, the rate for those is multiplied by how many times they are used per one controller.
11. ABS and silicone processes are done via injection molding.
12. Steel processes are done via sheet metal stamping for the purpose of this analysis.

Initial Economic Analysis:

Table 5: Initial economic analysis.

Part Number	101	102	103	104	105	106	107	108
Part Name	Left Grip	Right Grip	Front Face	Battery Cover	Xbox Emblem Cover	Inner Frame	Right Haptic Holder	Left Haptic Holder
Cost Element	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**
Material Cost, c_m ($/lb)	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72
Fraction of Process that is Scrap, *f*	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Part, *m* (lb)	0.023	0.023	0.05	0.011	0.003	0.044	0.0035	0.0035
C_m Unit Cost of Material	**$ 0.0174**	**$ 0.0174**	**$ 0.0379**	**$ 0.0083**	**$ 0.0023**	**$ 0.0333**	**$ 0.0027**	**$ 0.0027**
Labor Cost, c_w ($/hr)	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00
Production Rate, *n* ' (units/hr)	5625	5625	5625	5625	5625	5625	5625	5625
C_L Unit Cost of Labor	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**
Tooling Cost, c_t ($/set)	$ 15,000.00	$ 15,000.00	$ 20,000.00	$ 12,000.00	$ 12,000.00	$ 15,000.00	$ 12,000.00	$ 12,000.00
Total Production Run, *n* (units)	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000
Tooling Life, n_t (units)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Sets of Tooling Required, *k*	225	225	225	225	225	225	225	225
C_T Unit Cost of Tooling	**$ 0.0150**	**$ 0.0150**	**$ 0.0200**	**$ 0.0120**	**$ 0.0120**	**$ 0.0150**	**$ 0.0120**	**$ 0.0120**
Capital Cost, c_e ($)	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00
Captial Write-Off Time, t_{wo} (yrs)	5	5	5	5	5	5	5	5
Load Fraction, *L* (fraction)	1	1	1	1	1	1	1	1
Load Sharing Fraction, *q*	1	1	1	1	1	1	1	1
C_E Unit Cost of Capital Equipment	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**
Factory Overhead, c_{OH} ($/hr)	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00
Production Rate, *n* ' (units/hr)	5625	5625	5625	5625	5625	5625	5625	5625
C_{OH} Unit Cost of Factory Overhead	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**
Total Unit Cost = $C_M + C_L + C_T + C_E + C_{OH}$	**$ 0.0633**	**$ 0.0633**	**$ 0.0887**	**$ 0.0512**	**$ 0.0451**	**$ 0.0792**	**$ 0.0455**	**$ 0.0455**
Cost of Various Part via CustomPartNet				$ 0.5900				
Total Product Cost = Sum of Total Unit Costs	**$ 37.3830**							
	$ 1.4242							
Order of Magnitude Calculation:	$ 1.7739							
Material Cost:	$ 0.0166	$ 0.0166	$ 0.0360	$ 0.0079	$ 0.0022	$ 0.0317	$ 0.0025	$ 0.0025
MFG Cost:	$ 0.0497	$ 0.0497	$ 0.1080	$ 0.0238	$ 0.0065	$ 0.0950	$ 0.0076	$ 0.0076
Price:	$ 0.1490	$ 0.1490	$ 0.3240	$ 0.0713	$ 0.0194	$ 0.2851	$ 0.0227	$ 0.0227

Part Number	109	201	202	204	205	206	207	208	209
Part Name	Back Face	Thumbstick	Bumpers	D-Pad	Left Trigger	Right Trigger	A Button	B Button	X Button
Cost Element	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**
Material Cost, c_m ($/lb)	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72
Fraction of Process that is Scrap, *f*	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Part, *m* (lb)	0.056	0.003	0.01	0.0032	0.0052	0.0052	0.001	0.001	0.001
C_m Unit Cost of Material	**$ 0.0424**	**$ 0.0023**	**$ 0.0076**	**$ 0.0024**	**$ 0.0039**	**$ 0.0039**	**$ 0.0008**	**$ 0.0008**	**$ 0.0008**
Labor Cost, c_w ($/hr)	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00
Production Rate, *n* ' (units/hr)	5625	11250	5625	5625	5625	5625	5625	5625	5625
C_L Unit Cost of Labor	**$ 0.0046**	**$ 0.0023**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**
Tooling Cost, c_t ($/set)	$ 20,000.00	$ 12,000.00	$ 12,000.00	$ 10,000.00	$ 12,000.00	$ 12,000.00	$ 12,000.00	$ 12,000.00	$ 12,000.00
Total Production Run, *n* (units)	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000
Tooling Life, n_t (units)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Sets of Tooling Required, *k*	225	225	225	225	225	225	225	225	225
C_T Unit Cost of Tooling	**$ 0.0200**	**$ 0.0120**	**$ 0.0120**	**$ 0.0100**	**$ 0.0120**	**$ 0.0120**	**$ 0.0120**	**$ 0.0120**	**$ 0.0120**
Capital Cost, c_e ($)	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00
Captial Write-Off Time, t_{wo} (yrs)	5	5	5	5	5	5	5	5	5
Load Fraction, *L* (fraction)	1	1	1	1	1	1	1	1	1
Load Sharing Fraction, *q*	1	0.5	1	1	0.5	0.5	0.25	0.25	0.25
C_E Unit Cost of Capital Equipment	**$ 0.0156**	**$ 0.0039**	**$ 0.0156**	**$ 0.0156**	**$ 0.0078**	**$ 0.0078**	**$ 0.0039**	**$ 0.0039**	**$ 0.0039**
Factory Overhead, c_{OH} ($/hr)	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00
Production Rate, *n* ' (units/hr)	5625	11250	5625	5625	5625	5625	5625	5625	5625
C_{OH} Unit Cost of Factory Overhead	**$ 0.0107**	**$ 0.0053**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**
Total Unit Cost = $C_M + C_L + C_T + C_E + C_{OH}$	**$ 0.0933**	**$ 0.0258**	**$ 0.0504**	**$ 0.0433**	**$ 0.0390**	**$ 0.0390**	**$ 0.0319**	**$ 0.0319**	**$ 0.0319**
Cost of Various Part via CustomPartNet		$ 0.5070		$ 3.4000					
Total Product Cost = Sum of Total Unit Costs									
Order of Magnitude Calculation:									
Material Cost:	$ 0.0403	$ 0.0022	$ 0.0072	$ 0.0023	$ 0.0037	$ 0.0037	$ 0.0007	$ 0.0007	$ 0.0007
MFG Cost:	$ 0.1210	$ 0.0065	$ 0.0216	$ 0.0069	$ 0.0112	$ 0.0112	$ 0.0022	$ 0.0022	$ 0.0022
Price:	$ 0.3629	$ 0.0194	$ 0.0648	$ 0.0207	$ 0.0337	$ 0.0337	$ 0.0065	$ 0.0065	$ 0.0065

Part Number	210	211	212	213	214	301	302	303	304
Part Name	Y Button	View Button (Select)	Start Button	Xbox Button	Sync Button	D-Pad Spring	Trigger Springs	Trigger Mounting Pins	Gray Key Mat
Cost Element	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**Steel**	**Steel**	**Steel**	**Silicone**
Material Cost, c_m ($/lb)	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.33	$ 0.33	$ 0.33	$ 5.24
Fraction of Process that is Scrap, *f*	0.05	0.05	0.05	0.05	0.05	0.15	0.15	0.15	0.05
Mass of Part, *m* (lb)	0.001	0.0006	0.0006	0.00083	0.0003	0.002	0.0002	0.00095	0.003
C_m Unit Cost of Material	**$ 0.0008**	**$ 0.0005**	**$ 0.0005**	**$ 0.0006**	**$ 0.0002**	**$ 0.0008**	**$ 0.0001**	**$ 0.0004**	**$ 0.0165**
Labor Cost, c_w ($/hr)	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00
Production Rate, *n* ' (units/hr)	5625	5625	5625	5625	5625	5625	11250	11250	5625
C_L Unit Cost of Labor	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0023**	**$ 0.0023**	**$ 0.0046**
Tooling Cost, c_t ($/set)	$ 12,000.00	$ 10,000.00	$ 10,000.00	$ 12,000.00	$ 10,000.00	$ 60,000.00	$ 60,000.00	$ 60,000.00	$ 10,000.00
Total Production Run, *n* (units)	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000
Tooling Life, n_t (units)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Sets of Tooling Required, *k*	225	225	225	225	225	225	225	225	225
C_T Unit Cost of Tooling	**$ 0.0120**	**$ 0.0100**	**$ 0.0100**	**$ 0.0120**	**$ 0.0100**	**$ 0.0600**	**$ 0.0600**	**$ 0.0600**	**$ 0.0100**
Capital Cost, c_e ($)	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00
Captial Write-Off Time, t_{wo} (yrs)	5	5	5	5	5	5	5	5	5
Load Fraction, *L* (fraction)	1	1	1	1	1	1	1	1	1
Load Sharing Fraction, *q*	0.25	0.5	0.5	1	1	1	1	1	1
C_E Unit Cost of Capital Equipment	**$ 0.0039**	**$ 0.0078**	**$ 0.0078**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0078**	**$ 0.0078**	**$ 0.0156**
Factory Overhead, c_{OH} ($/hr)	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00
Production Rate, *n* ' (units/hr)	5625	5625	5625	5625	5625	5625	11250	11250	5625
C_{OH} Unit Cost of Factory Overhead	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0053**	**$ 0.0053**	**$ 0.0107**
Total Unit Cost = $C_M + C_L + C_T + C_E + C_{OH}$	**$ 0.0319**	**$ 0.0335**	**$ 0.0335**	**$ 0.0435**	**$ 0.0411**	**$ 0.0916**	**$ 0.0755**	**$ 0.0758**	**$ 0.0574**
Cost of Various Part via CustomPartNet		$ 0.1300	$ 0.1300	$ 1.8400					$ 0.5350
Total Product Cost = Sum of Total Unit Costs									
Order of Magnitude Calculation:									
Material Cost:	$ 0.0007	$ 0.0004	$ 0.0004	$ 0.0006	$ 0.0002	$ 0.0007	$ 0.0001	$ 0.0003	$ 0.0157
MFG Cost:	$ 0.0022	$ 0.0013	$ 0.0013	$ 0.0018	$ 0.0006	$ 0.0020	$ 0.0002	$ 0.0009	$ 0.0472
Price:	$ 0.0065	$ 0.0039	$ 0.0039	$ 0.0054	$ 0.0019	$ 0.0059	$ 0.0006	$ 0.0028	$ 0.1415

Part Number	305	306	401	402	403	404	405	406	407
Part Name	T6 Screw	T8 Security Screw	Battery Terminal	Thumbstick PCB	Main PCB	Headphone Jack	Large Rumble Pack	Small Rumble Pack	Trigger Haptic Motor
Cost Element	**COTS**	**COTS**	**Steel**	**COTS**	**COTS**	**COTS**	**COTS**	**COTS**	**COTS**
Material Cost, c_m ($/lb)			$ 0.33						
Fraction of Process that is Scrap, *f*			0.15						
Mass of Part, *m* (lb)			0.0012						
C_m Unit Cost of Material			**$ 0.0005**						
Labor Cost, c_w ($/hr)			$ 26.00						
Production Rate, *n* ' (units/hr)			11250						
C_L Unit Cost of Labor			**$ 0.0023**						
Tooling Cost, c_t ($/set)			$ 60,000.00						
Total Production Run, *n* (units)			225,000,000						
Tooling Life, n_t (units)			1,000,000						
Sets of Tooling Required, *k*			225						
C_T Unit Cost of Tooling			**$ 0.0600**						
Capital Cost, c_e ($)			$ 1,750,000.00						
Captial Write-Off Time, t_{wo} (yrs)			5						
Load Fraction, *L* (fraction)			1						
Load Sharing Fraction, *q*			0.5						
C_E Unit Cost of Capital Equipment			**$ 0.0039**						
Factory Overhead, c_{OH} ($/hr)			$ 60.00						
Production Rate, *n* ' (units/hr)			11250						
C_{OH} Unit Cost of Factory Overhead			**$ 0.0053**						
Total Unit Cost = $C_M + C_L + C_T + C_E + C_{OH}$	**$ 0.0080**	**$ 0.2508**	**$ 0.0720**	**$ 10.0000**	**$ 10.0000**	**$ 5.3500**	**$ 3.4500**	**$ 3.4500**	**$ 3.4500**
Cost of Various Part via CustomPartNet									
Total Product Cost = Sum of Total Unit Costs									
Order of Magnitude Calculation:									
Material Cost:			$ 0.0004						
MFG Cost:			$ 0.0012						
Price:			$ 0.0036						

Redesign Economic Analysis:

The table below shows the economic analysis of our redesign of eliminating the left and right grips and combining them into the back plate. The table below shows only the first eight parts since the rest of the assembly stayed the same other than parts 101 and 102 being eliminated.

The price difference is $0.09, so in terms of only economics, this redesign does not have much of an impact on the controller. But we do see improvements in assembly, manufacturability, and inspection with this redesign.

Table 6: First part of redesign economic analysis

	Part Number	101	102	103	104	105	106	107	108	201	202
	Part Name					Xbox Emblem		Right Haptic	Left Haptic		
		Left Grip	Right Grip	Front Face	Battery Cover	Cover	Inner Frame	Holder	Holder	Thumbstick	Bumpers
Cost Element		**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**	**ABS**
Material Cost, c_m ($/lb)		-	-	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72	$ 0.72
Fraction of Process that is Scrap, *f*		-	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Part, *m* (lb)		-	-	0.05	0.011	0.003	0.044	0.0035	0.0035	0.003	0.01
C_m Unit Cost of Material		-	-	**$ 0.0379**	**$ 0.0083**	**$ 0.0023**	**$ 0.0333**	**$ 0.0027**	**$ 0.0027**	**$ 0.0023**	**$ 0.0076**
Labor Cost, c_w ($/hr)		-	-	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00	$ 26.00
Production Rate, *n* ' (units/hr)		-	-	5625	5625	5625	5625	5625	5625	11250	5625
C_L Unit Cost of Labor		-	-	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0046**	**$ 0.0023**	**$ 0.0046**
Tooling Cost, c_t ($/set)		-	-	$ 20,000.00	$ 12,000.00	$ 12,000.00	$ 15,000.00	$ 12,000.00	$ 12,000.00	$ 12,000.00	$ 12,000.00
Total Production Run, *n* (units)		-	-	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000	225,000,000
Tooling Life, n_t (units)		-	-	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Sets of Tooling Required, *k*		-	-	225	225	225	225	225	225	225	225
C_T Unit Cost of Tooling		-	-	**$ 0.0200**	**$ 0.0120**	**$ 0.0120**	**$ 0.0150**	**$ 0.0120**	**$ 0.0120**	**$ 0.0120**	**$ 0.0120**
Capital Cost, c_e ($)		-	-	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00	$ 1,750,000.00
Captial Write-Off Time, t_{wo} (yrs)		-	-	5	5	5	5	5	5	5	5
Load Fraction, *L* (fraction)		-	-	1	1	1	1	1	1	1	1
Load Sharing Fraction, *q*		-	-	1	1	1	1	1	1	0.5	1
C_E Unit Cost of Capital Equipment		-	-	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0156**	**$ 0.0039**	**$ 0.0156**
Factory Overhead, c_{OH} ($/hr)		-	-	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00
Production Rate, *n* ' (units/hr)		-	-	5625	5625	5625	5625	5625	5625	11250	5625
C_{OH} Unit Cost of Factory Overhead		-	-	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0107**	**$ 0.0053**	**$ 0.0107**
Total Unit Cost = $C_M + C_L + C_T + C_E + C_{OH}$		-	-	**$ 0.0887**	**$ 0.0512**	**$ 0.0451**	**$ 0.0792**	**$ 0.0455**	**$ 0.0455**	**$ 0.0258**	**$ 0.0504**
Cost of Various Part via CustomPartNet					$ 0.5900					$ 0.5070	
Total Product Cost = Sum of Total Unit Costs		**$ 37.2874**									
		$ 1.2044									
Order of Magnitude Calculation:		$ 1.8258									
	Material Cost:	$ -	$ -	$ 0.0360	$ 0.0079	$ 0.0022	$ 0.0317	$ 0.0025	$ 0.0025	$ 0.0022	$ 0.0072
	MFG Cost:	$ -	$ -	$ 0.1080	$ 0.0238	$ 0.0065	$ 0.0950	$ 0.0076	$ 0.0076	$ 0.0065	$ 0.0216
	Price:	$ -	$ -	$ 0.3240	$ 0.0713	$ 0.0194	$ 0.2851	$ 0.0227	$ 0.0227	$ 0.0194	$ 0.0648

Component & Assembly Drawings:

A combined PDF of all component and assembly drawings can be found in appendix A.
In the tables below you will find the initial bill of materials for the controller as is, as well as a bill of materials for the controller after our redesign was completed.

Initial Bill of Materials:

Table 7: Initial bill of materials.

Bill of Material				
Product: Xbox One Controller				Date: 10/16/2024
Item #	**Part #**	**Qty**	**Name**	**Material**
1	101	1	Left Grip	ABS
2	102	1	Right Grip	ABS
3	103	1	Front Face	ABS
4	104	1	Battery Cover	ABS
5	105	1	Xbox Emblem Cover	ABS
6	106	1	Inner Frame	ABS
7	107	1	Right Haptic Holder	ABS
8	108	1	Left Haptic Holder	ABS
9	109	1	Back Face	ABS
10	201	2	Thumb stick	ABS
11	202	1	Bumpers	ABS
12	204	1	D-Pad	ABS
13	205	1	Left Trigger	ABS
14	206	1	Right Trigger	ABS
15	207	1	A Button	ABS
16	208	1	B Button	ABS
17	209	1	X Button	ABS
18	210	1	Y Button	ABS
19	211	1	View Button (Select)	ABS
20	212	1	Start Button	ABS
21	213	1	Xbox Button	ABS
22	214	1	Sync Button	ABS
23	301	1	D-Pad Spring	Aluminum
24	302	2	Trigger Springs	Steel
25	303	2	Trigger Mounting Pins	Steel
26	304	1	Gray Key Mat	Silicone
27	305	12	T6 Screw	Steel
28	306	5	T8 Security Screw	Steel
29	401	2	Battery Terminal	Steel
30	402	1	Thumb stick PCB	COTS
31	403	1	Main PCB	COTS
32	404	1	Headphone Jack	COTS

Item #	Part #	Qty	Name	Material
33	405	1	Large Rumble Pack	COTS
34	406	1	Small Rumble Pack	COTS
35	407	2	Trigger Haptic Motor	COTS
Team Member: Evan McCleary				Prepared by: Luke Jensen
Team Member: Jacob Foley				Checked by: Jacob Foley
Team Member: Luke Jensen				Approved by: Evan McCleary
Team Member: Rick Jones				

Redesign Bill of Materials:

Table 8: Redesign bill of materials

Bill of Material - Redesign				
Product: Xbox One Controller - Redesign				Date: 10/16/2024
Item #	**Part #**	**Qty**	**Name**	**Material**
1	101	1	Front Face	ABS
2	102	1	Battery Cover	ABS
3	103	1	Xbox Emblem Cover	ABS
4	104	1	Inner Frame	ABS
5	105	1	Right Haptic Holder	ABS
6	106	1	Left Haptic Holder	ABS
7	201	2	Thumb stick	ABS
8	202	1	Bumpers	ABS
9	204	1	D-Pad	ABS
10	205	1	Left Trigger	ABS
11	206	1	Right Trigger	ABS
12	207	1	A Button	ABS
13	208	1	B Button	ABS
14	209	1	X Button	ABS
15	210	1	Y Button	ABS
16	211	1	View Button (Select)	ABS
17	212	1	Start Button	ABS
18	213	1	Xbox Button	ABS
19	214	1	Sync Button	ABS
20	301	1	D-Pad Spring	Steel
21	302	2	Trigger Springs	Steel
22	303	2	Trigger Mounting Pins	Steel

Item #	Part #	Qty	Name	Material
23	304	1	Gray Key Mat	Silicone
24	305	12	T6 Screw	Steel
25	306	5	T8 Security Screw	Steel
26	401	2	Battery Terminal	20 Ga. Steel
27	402	1	Thumb stick PCB	COTS
28	403	1	Main PCB	COTS
29	404	1	Headphone Jack	COTS
30	405	2	Large Rumble Pack	COTS
31	407	2	Trigger Haptic Motor	COTS
32	601	1	Redesigned Rear Shell	ABS
Team Member: Evan McCleary				Prepared by: Luke Jensen
Team Member: Jacob Foley				Checked by: Jacob Foley
Team Member: Luke Jensen				Approved by: Evan McCleary
Team Member: Rick Jones				

Professional, Ethical, & Safety Issue Discussion:

When designing, the goal is usually to create a great product for a great price, while keeping it as low cost as possible to manufacture and assemble. Since Microsoft spent over $100 million in R&D work for the Xbox One controller it is fair to say that they have created a professional, ethical, and safe device.

Microsoft had to make a lot of decisions based on the fact that many different humans would be using their product anywhere from a short period of time to hours on hours of use. This requires designers to heavily include human factors in their design. The design has to consider a vast variety of different hand sizes that would use the controller and what the best ergonomic shape would provide the most comfort for the users.

Microsoft provides a variety of safety documentation on how to game safely, as well as sections on health gaming practices. [5] The safety of the controller also includes the material chosen for each part, and more importantly the exterior parts. The controller materials would have to be selected so that the controller could handle all sorts of unpredictable forces that could be imposed upon it. A chipped or broken shell of a controller could be sharp and could cause injury. The controller also makes it difficult for users to take the controller apart for the safety of the integrity of the controller internals being taken apart and put back together incorrectly.

Redesign Discussion:

For the Xbox One controller redesign, after consulting the DFA analysis we decided to try decrease the part count as well as exposing the screws that hold the controller together. By

combining the separate left and right grips with the back plate and extending the screw access holes through the back plate decreased the part number and got rid of the two parts that had some resistances to insertion since.

This redesign decision with aid in manufacturability by combining three different parts into one full part. This also aids in assembly by exposing all the hidden fasteners, as well as providing a way to inspect that all fasteners have been placed when the controller is fully put together rather than just before the grip shells get snapped into place.

Conclusion:

The objective of the reverse engineering project was to systematically deconstruct a consumer product into its individual components, create detailed models of those components, and conduct a comprehensive design-for-manufacturing and assembly analysis of the product. The team selected the Microsoft Model 1697 Xbox One controller for this project due to its availability, as several units were already on hand for disassembly. Additionally, the team has extensive experience using this controller over the past decade. The well-established design of the Xbox controller serves as an ideal case study for examining effective design for manufacturing and assembly practices. The Xbox controller comprises a total of 36 unique parts, including commercially off-the-shelf (COTS) components. Given that the Xbox controller has undergone over 20 years of iterative design, there are limited opportunities for enhancing its manufacturability. The redesign focused on integrating components primarily intended for aesthetics into the main body of the controller. Specifically, this involved merging the left and right grips with the back frame to create a more streamlined structure. This integration will reduce the manufacturing and assembly time of the controller by decreasing the part count by two. While these changes may appear minor, Microsoft's high production volume means that even small efficiencies can accumulate rapidly due to economies of scale. With a product selected and a strategy in place, we commenced the reverse engineering process.

As the team disassembled the controller, it became evident just how much research and development Microsoft invested in the product. Reportedly, Microsoft allocated $100 million to the development of this controller, which clearly reflects the thoughtful design tailored for efficient manufacturing [1]. Most of the components are made from the same material (ABS) and produced using a uniform manufacturing process (injection molding), apart from the COTS parts, the d-pad spring, and the key mat. Upon disassembly, it became clear that nearly every component, aside from the COTS parts, is unique. Each button features a distinct set of alignment features that ensure only the correct button fits into its designated slot on the inner frame. This design facilitates assembly, as operators can easily verify the correct placement of each part. The specialized alignment features also prevent any possibility of incorrect assembly. Examining Microsoft's design for manufacturing and assembly efforts on the controller has provided significant insights and learning opportunities for the team.

Through the team's redesign efforts, the left and right grips were integrated with the back face of the controller, reducing the part count by two. This redesign does slightly alter the aesthetics of the controller, as the screw holes will now be visible. However, the screws will be recessed into the controller, minimizing their visual impact. Reducing the part count by two results in an estimated savings of $0.09 per controller. While this may seem minor on an individual basis, it

becomes significant when considering the volume of controllers sold annually. With this redesign, Microsoft stands to save approximately $90,000 for every million controllers produced. Additionally, since the two grips are injection molded, Microsoft would benefit from savings on tooling costs associated with two complex molds that include multiple lifters. The redesigned back face, which incorporates the grips, is not expected to significantly impact the tooling or material costs. Thus, the redesign of the controller was successful. Although the savings per part are modest, the large scale of production ensures that every cost reduction contributes meaningfully to overall savings.

This reverse engineering project provided the team with its first exposure to the process. By analyzing Microsoft's Xbox One Controller, the team gained valuable insights into design for manufacturing and assembly, highlighting the principles behind a well-designed, mass-produced product. This experience has been an excellent opportunity to apply theoretical concepts learned in class while engaging in our own design for manufacturing and assembly efforts.

Resources:

[1] https://www.statista.com/statistics/680526/global-xbox-gaming-consoles-unit-sales/#:~:text=Xbox%20X%2FS's%20predecessor%2C%20the,of%20its%20lifespan%20in%202020.&text=Designed%20by%20Microsoft%2C%20Xbox%20is,and%20the%20newest%20Xbox%20One.

[2] https://www.gamesindustry.biz/xbox-one-pad-cost-usd100-million-in-r-and-d-microsoft

[3] https://www.ziprecruiter.com/Salaries/Machinist-Salary#:~:text=How%20much%20does%20a%20Machinist,a%20Machinist%20on%20ZipRecruiter%20today.

[4] https://www.protolabs.com/materials/abs/#:~:text=Consumer%20electronics%3A%20ABS%20plastic%20is,it%20suitable%20for%20these%20applications.

[5] https://support.xbox.com/en-US/help/games-apps/game-setup-and-play/windows-10-healthy-gaming-guide

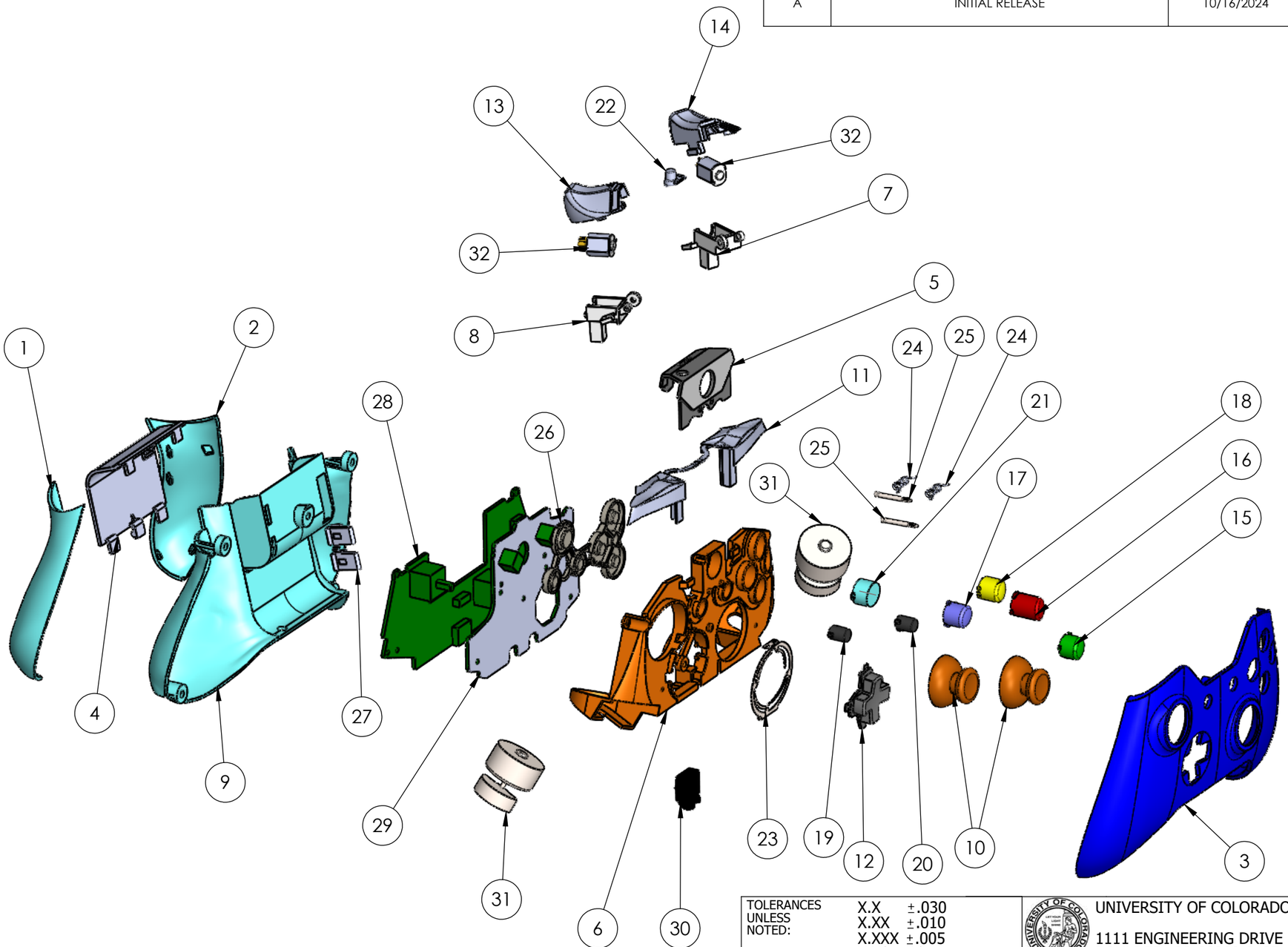
[6] https://www.gamesindustry.biz/xbox-one-pad-cost-usd100-million-in-r-and-d-microsoft

Appendix A – Engineering Drawings:

This appendix presents a comprehensive engineering drawing packet for the Xbox One controller, detailing all custom components used to an Xbox controller. The packet includes precise technical drawings, assembly diagrams, and annotations that outline critical dimensions and materials. These documents serve as essential resources for understanding the controller's engineering principles, facilitating accurate manufacturing and quality assurance processes.

ITEM NO.	PART NUMBER	QTY.
1	PN 101	1
2	PN 102	1
3	PN 103	1
4	PN 104	1
5	PN 105	1
6	PN 106	1
7	PN 107	1
8	PN 108	1
9	PN 109	1
10	PN 201	2
11	PN 202	1
12	PN 204	1
13	PN 205	1
14	PN 206	1
15	PN 207	1
16	PN 208	1
17	PN 209	1
18	PN 210	1
19	PN 211	1
20	PN 212	1
21	PN 213	1
22	PN 214	1
23	PN 301	1
24	PN 302	2
25	PN 303	2
26	PN 304	1
27	PN 401	1
28	PN 402	1
29	PN 403	1
30	PN 404	1
31	PN 405	2
32	PN 407	2

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/16/2024



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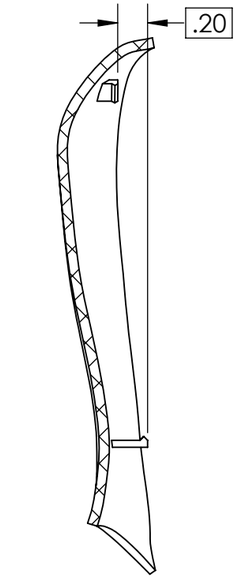
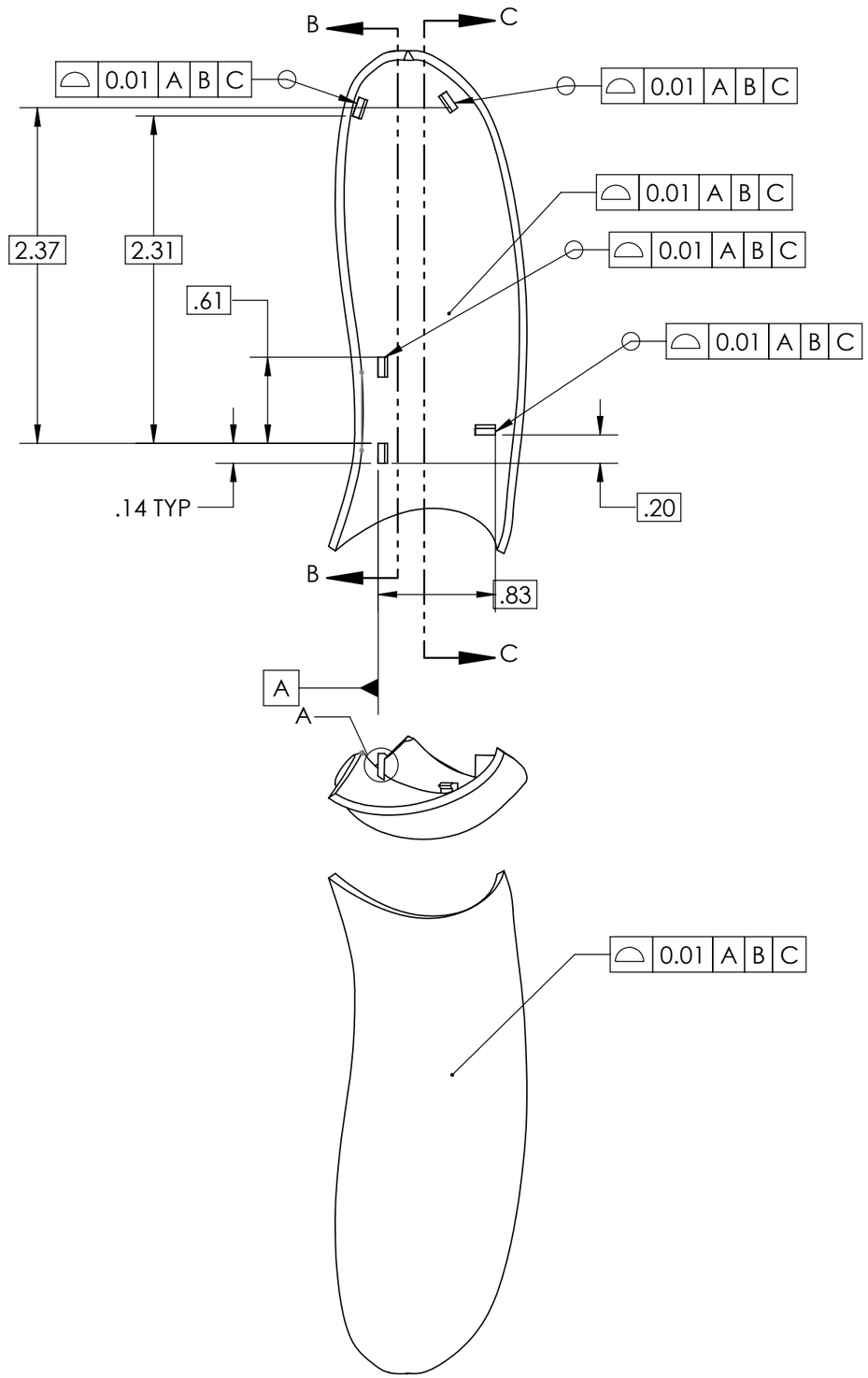
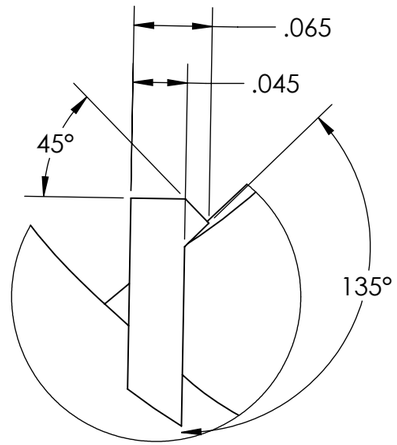
UNITS: INCH	X.X° 1°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL N/A		DESCRIPTION XBOX CONTROLLER ASSEMBLY		
FINISH N/A		PN 501	REV A	SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/8/2024

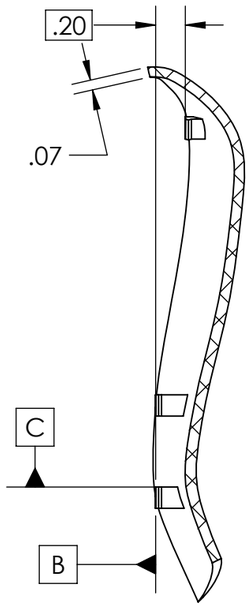


SECTION C-C





DETAIL A
SCALE 8 : 1
TYP 5 LOCATIONS

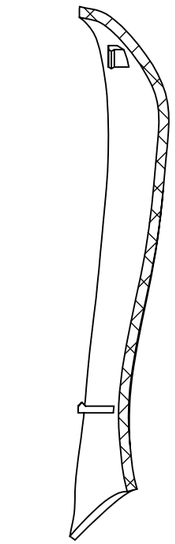


SECTION B-B

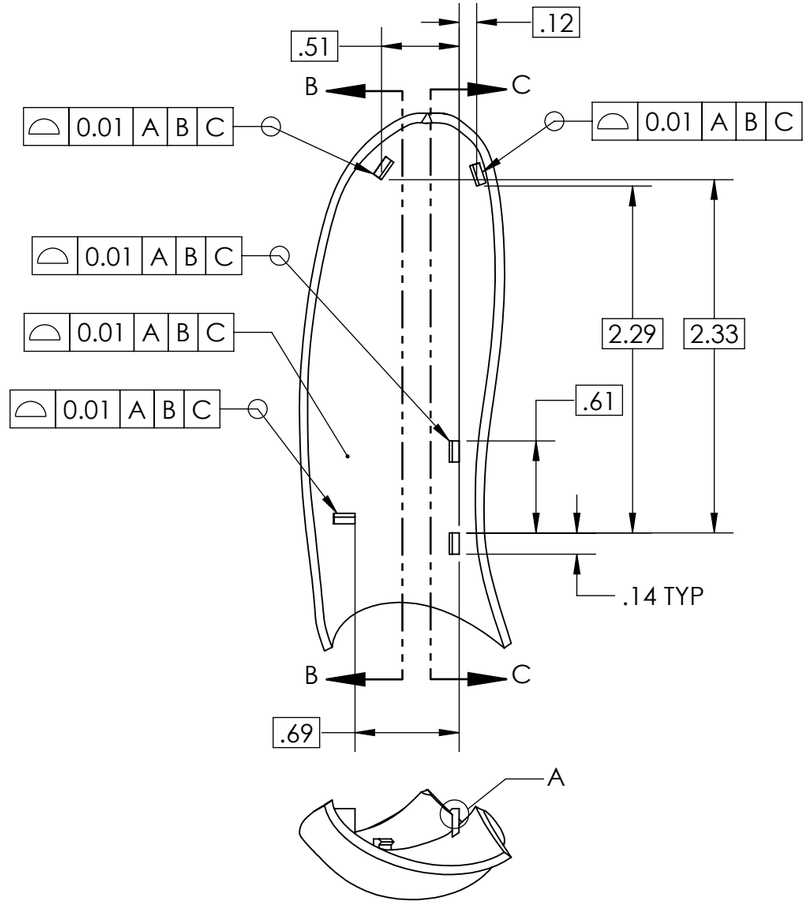
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 1°		
MATERIAL: ABS		DESCRIPTION: LEFT HAND GRIP	
FINISH: NONE		PN: 101	REV: A — SHEET: 1 of 1

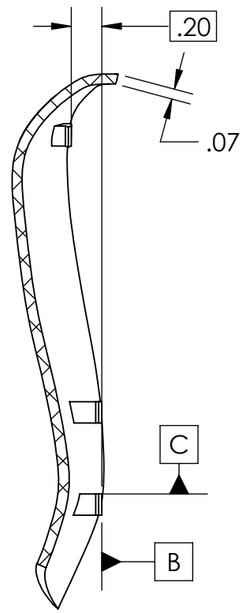
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/18/2024

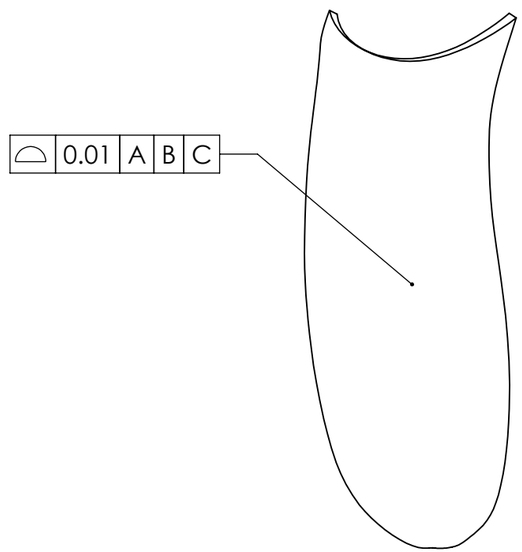


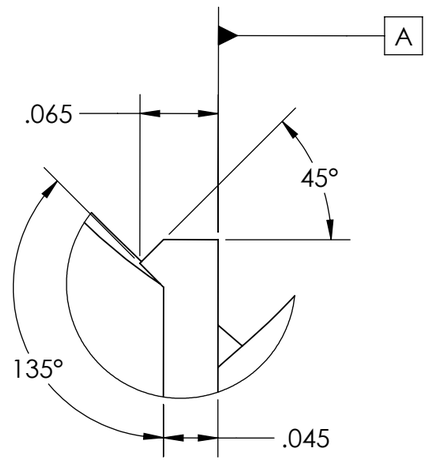
SECTION B-B





SECTION C-C





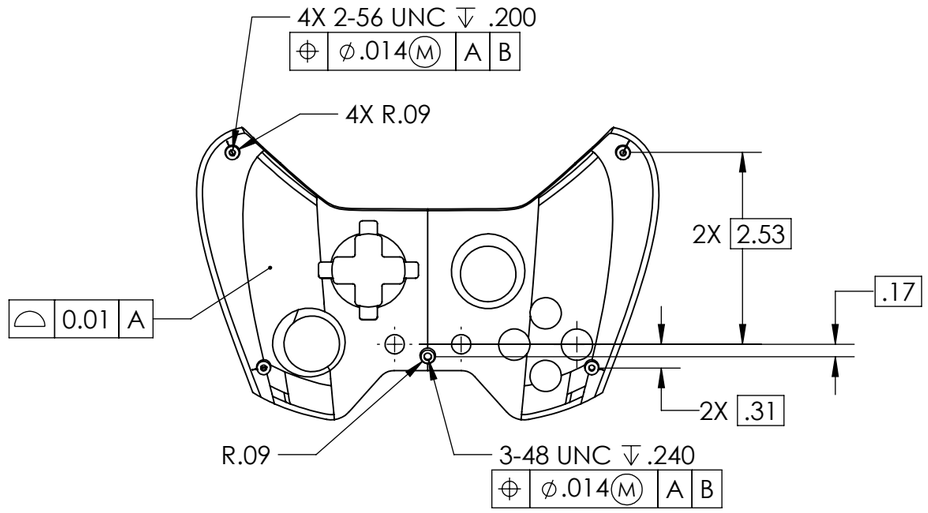
DETAIL A
SCALE 8 : 1
TYP 5 LOCATIONS

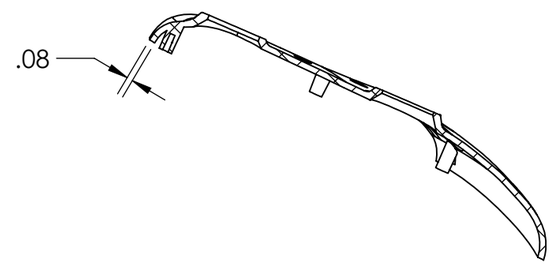
TOLERANCES UNLESS NOTED: X.X ±.030, X.XX ±.010, X.XXX ±.005, UNITS: INCH X.X° 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL: ABS	DESCRIPTION: LEFT GRIP		
FINISH: NONE	PN: 102	REV: A	SHEET: 1 of 1

NOTES:
1. THICKESS IS CONSISTENT ACROSS ENTIER PART
2. ANY UNSPECIFIED SURFACES SHALL MEET

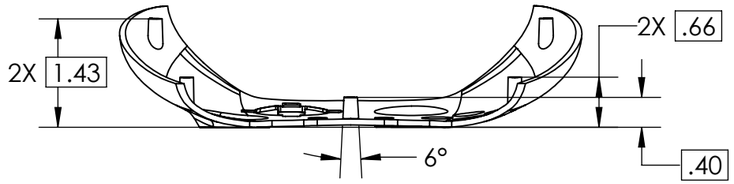
⌓	0.010	A	B

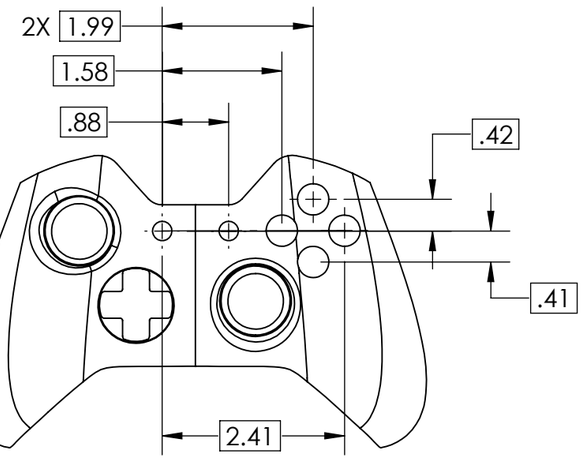
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024

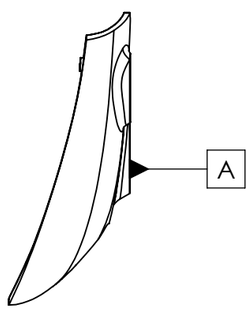


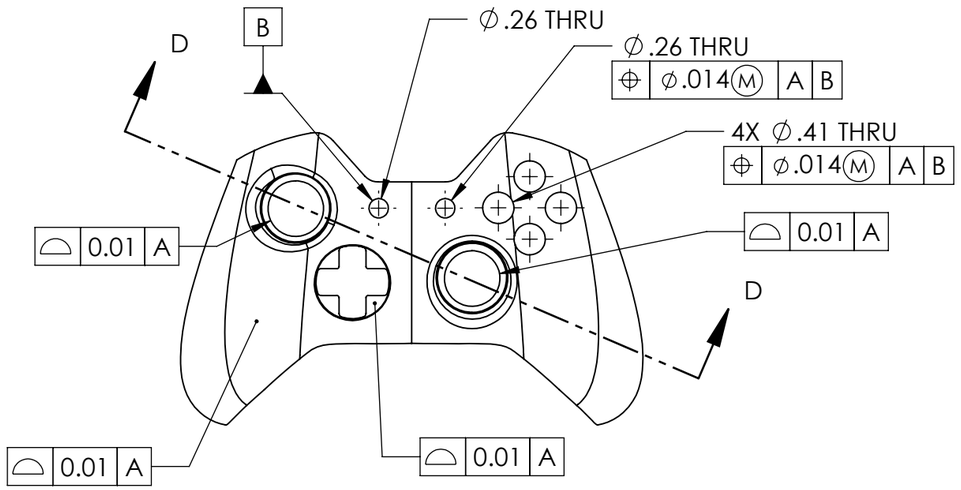


SECTION D-D



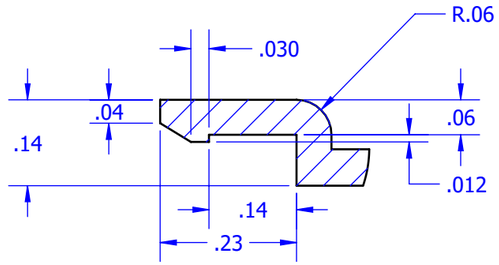




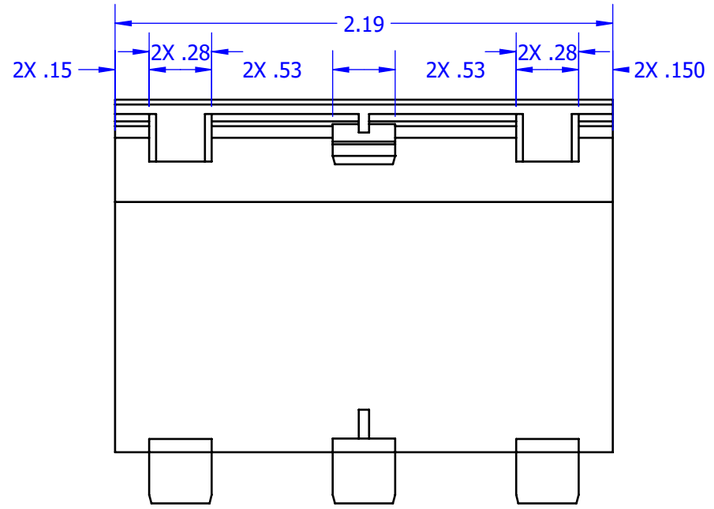


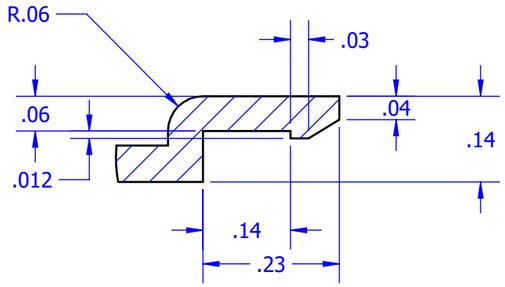
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS:	X.X° 1°		
MATERIAL ABS		DESCRIPTION FRONT PLATE	
FINISH NONE		PN 103	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/23/2024
B	ADDED SECOND SHEET, GD&T	9/25/2024

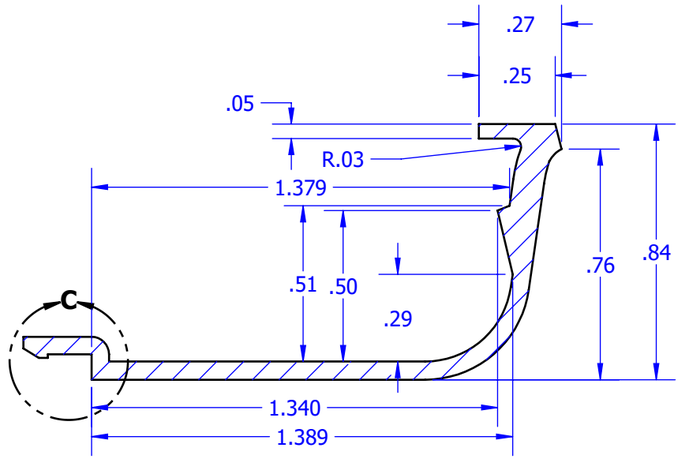


DETAIL C
SCALE 4 : 1

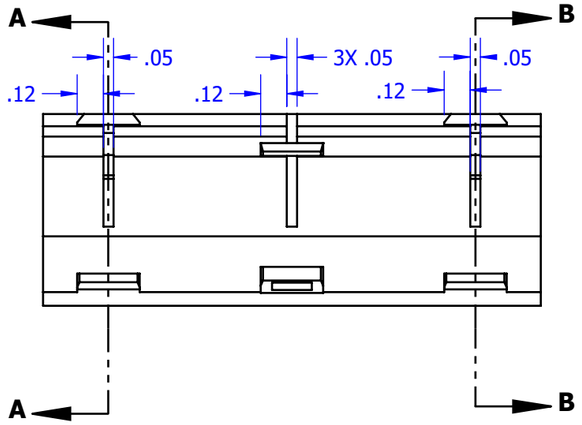


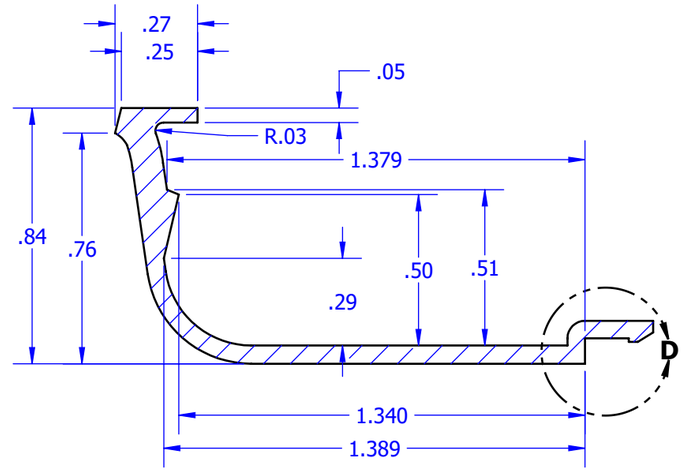


DETAIL D
SCALE 4 : 1

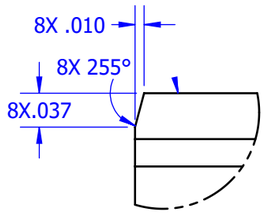


SECTION A-A

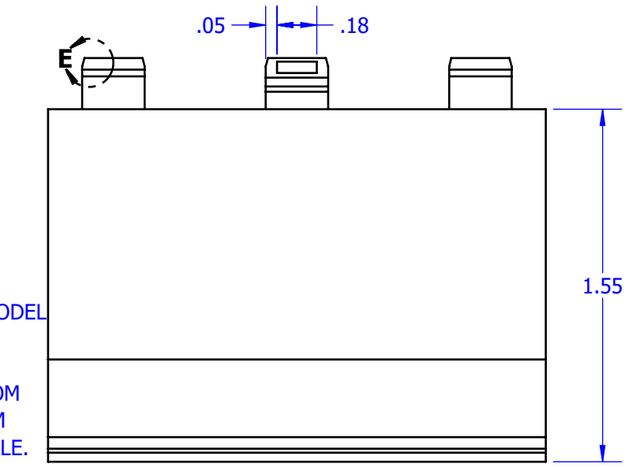




SECTION B-B

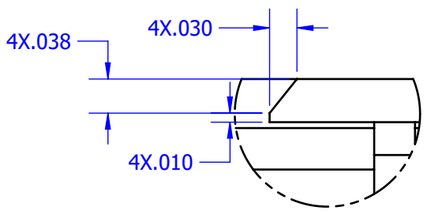


DETAIL E
SCALE 6 : 1

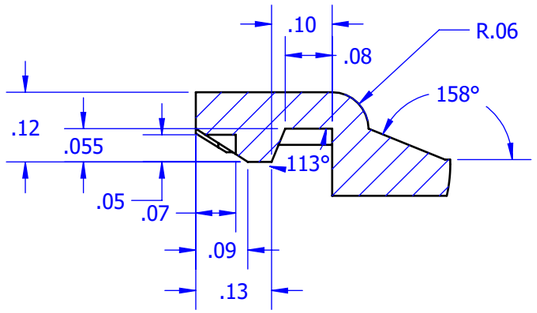


NOTES:
1. PARTIALLY DIMENSIONED DRAWING.
2. SURFACE PROFILE TO BE MANUFACTURED WITH 104.STEP REVISION B AS REFERENCE MODEL
3. CHAMFER SEEN IN DETAIL E TO BE APPLIED TO ALL TABS EXCEPT THOSE SEEN IN DETAIL J.
4. THE SURFACES HIGHLIGHTED IN SECTION G MAY VARY 0.01" IN EITHER DIRECTION FROM THE DIMENSIONS OUTLINED IN THE 3D MODEL. THIS MUST BE INSPECTED USING A CMM
5. SHEET 1 PRIMARY VIEWS 1.5:1 UNLESS SPECIFIED OTHERWISE. SECTION VIEWS 2:1 SCALE.

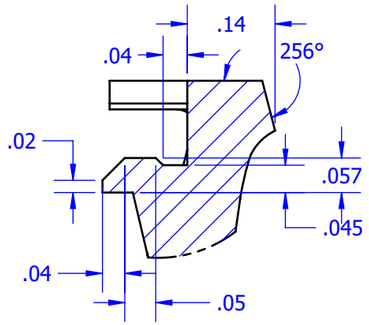
TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES	X.X° 0.5°	
MATERIAL: ABS, BLACK		DESCRIPTION: BATTERY DOOR
FINISH: NONE	PN: 104 / REV: A	SHEET: 1 of 2



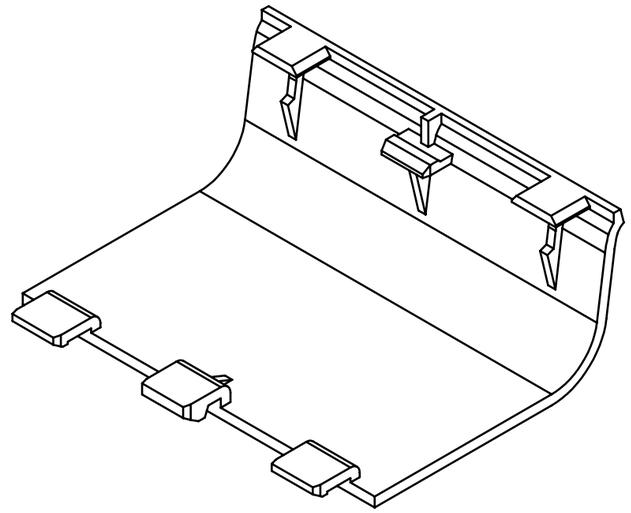
DETAIL J
SCALE 6 : 1

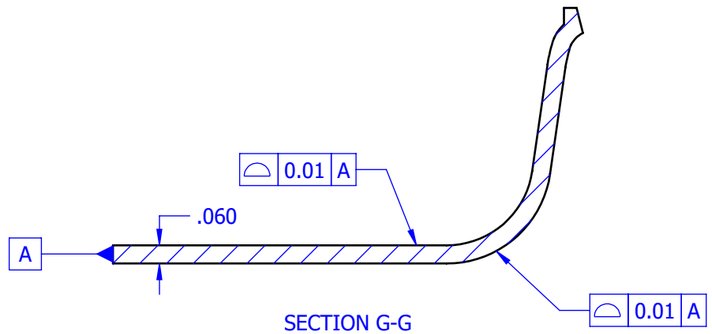


DETAIL H
SCALE 4 : 1

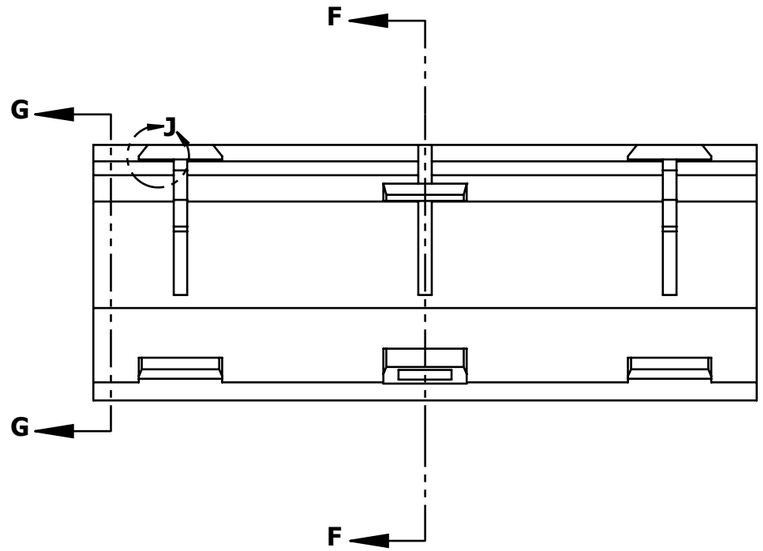


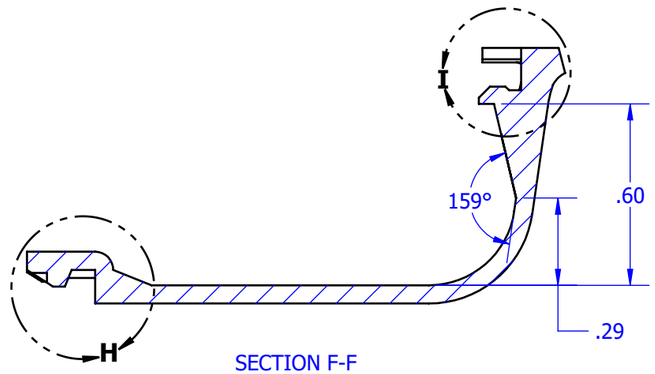
DETAIL I
SCALE 4 : 1





SECTION G-G





SECTION F-F

NOTES:

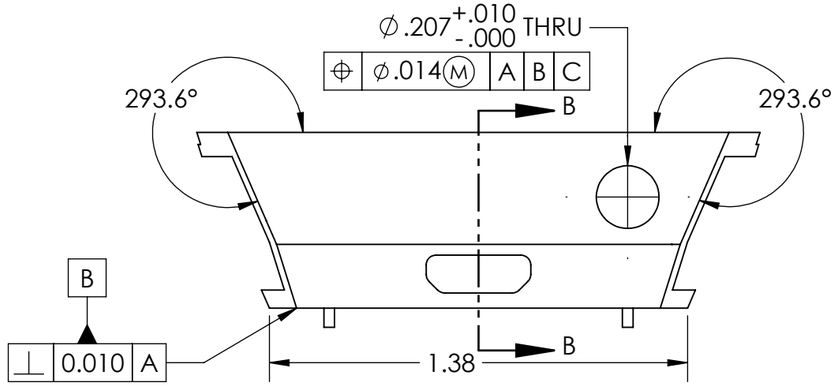
1. PARTIALLY DIMENSIONED DRAWING.
2. SURFACE PROFILE TO BE MANUFACTURED WITH 208.STEP REV 0 AS REFERENCE MODEL
3. CHAMFER SEEN IN DETAIL E TO BE APPLIED TO ALL TABS EXCEPT THOSE SEEN IN DETAIL J.
4. THE SURFACES HIGHLIGHTED IN SECTION G MAY VARY 0.01" IN EITHER DIRECTION FROM THE DIMENSIONS OUTLINED IN THE 3D MODEL. THIS MUST BE INSPECTED USING A CMM.
5. SHEET 2 SCALE IS 2:1 UNLESS SPECIFIED OTHERWISE.

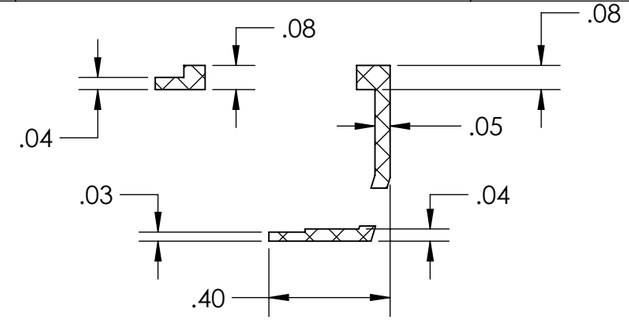
TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES	X.X° 0.5°	
MATERIAL: ABS, BLACK		DESCRIPTION: BATTERY DOOR
FINISH: NONE	PN: 104	REV: A / SHEET: 2 of 2

NOTES:

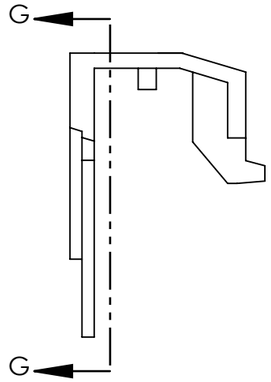
1. ALL RADII ARE .05 UNLESS OTHERWISE SPECIFIED

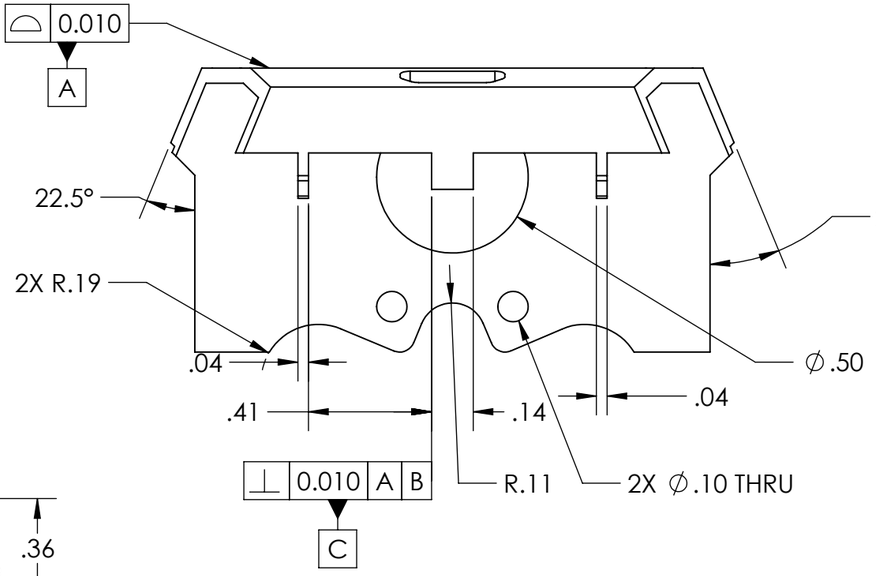
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/9/2024
B	UPDATED PROFILE	10/11/2024

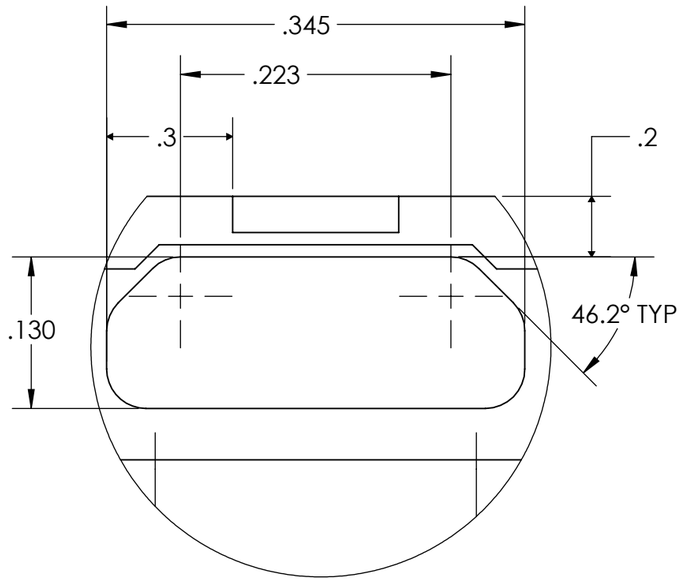




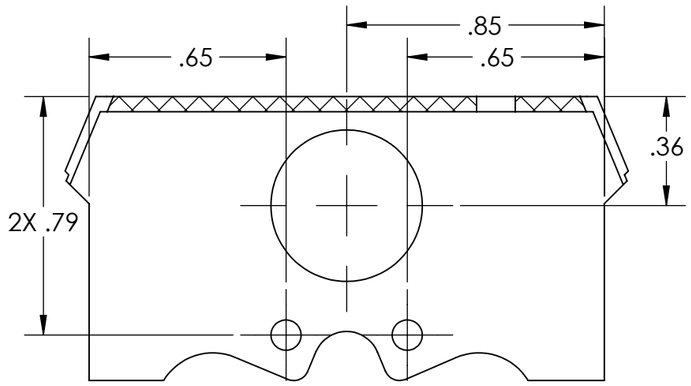
SECTION B-B
SLICE



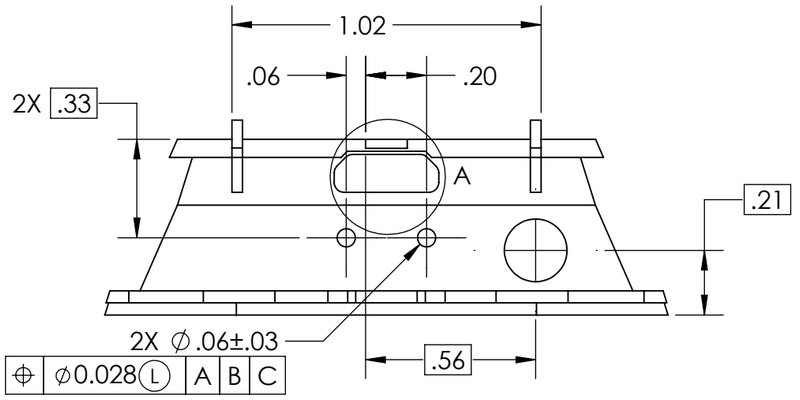




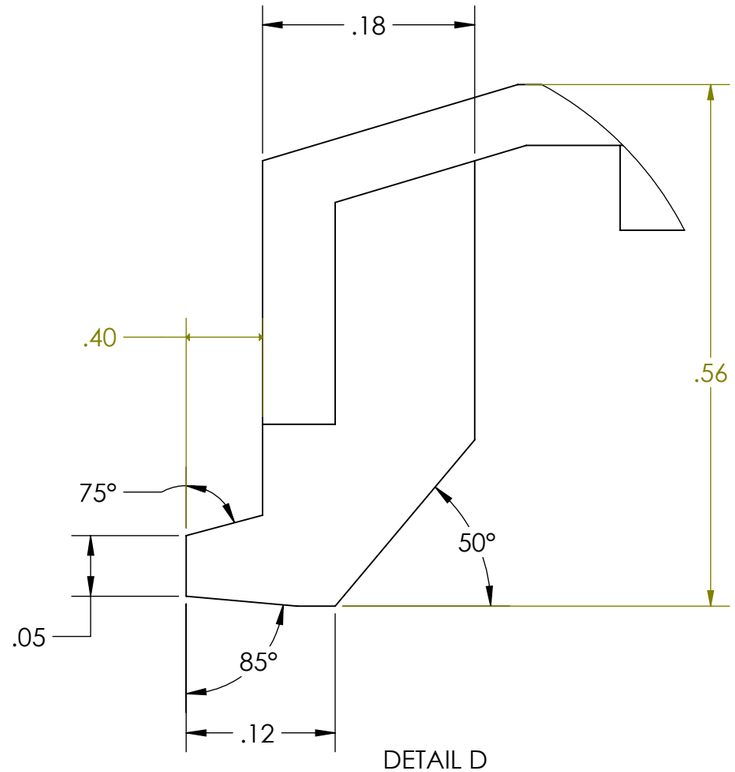
DETAIL A
SCALE 8 : 1



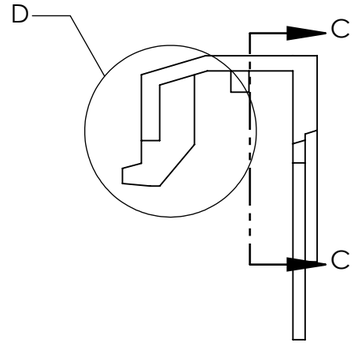
SECTION G-G

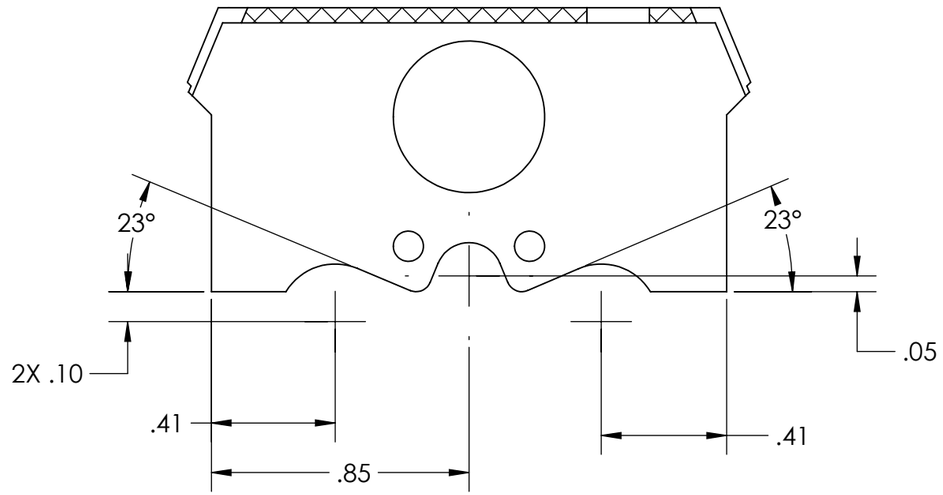


TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS: INCH	X.X° 1.0°				
MATERIAL ABS		DESCRIPTION SYNC BUTTON COVER			
FINISH NONE		PN 105	REV B		SHEET 1 of 2



DETAIL D
SCALE 8 : 1
TYP 2 PLACES





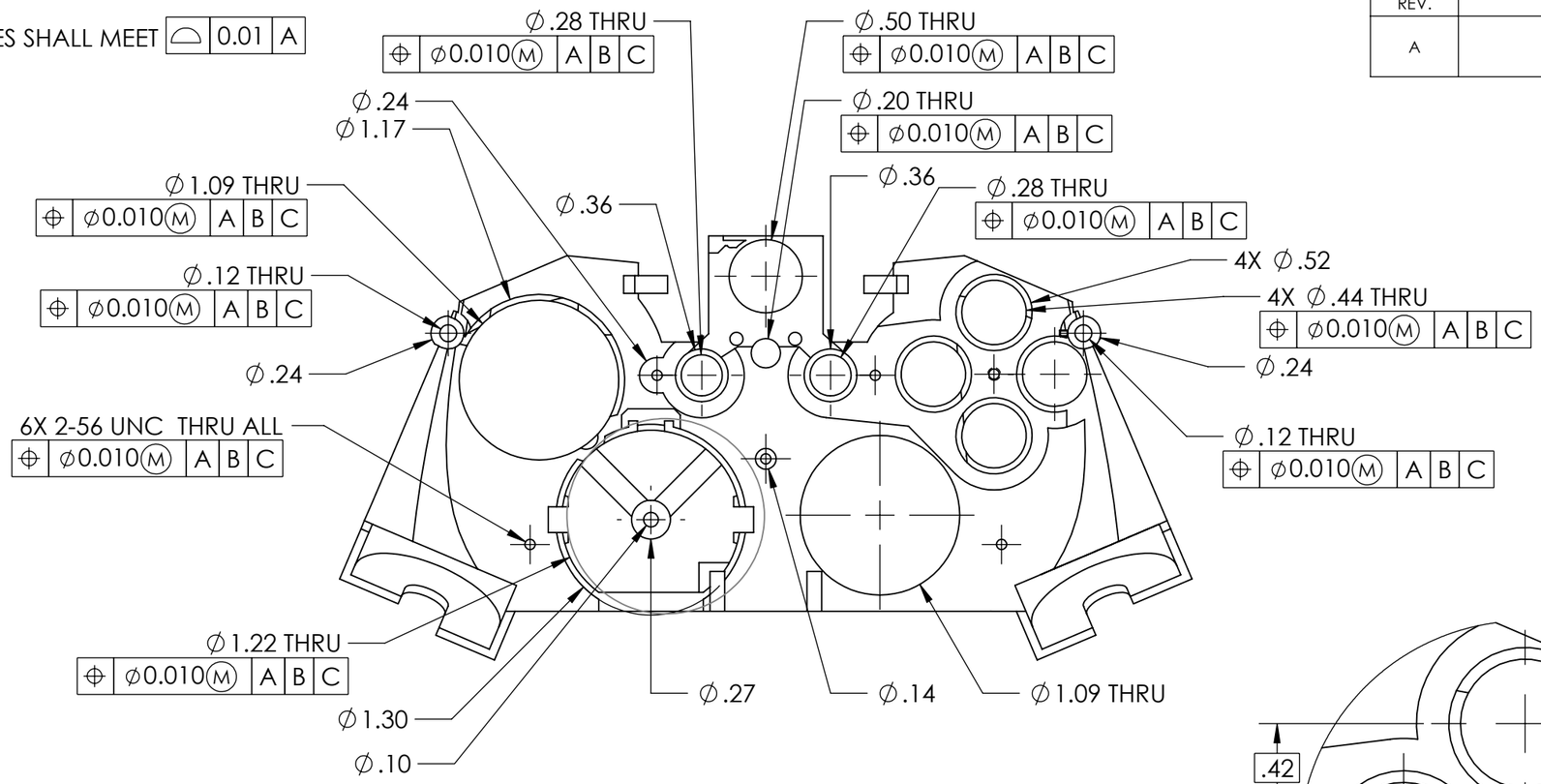
SECTION C-C

TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS:	X.X° 1°				
MATERIAL ABS		DESCRIPTION SYNC BUTTON COVER			
FINISH NONE		PN 105	REV B		SHEET 2 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.				

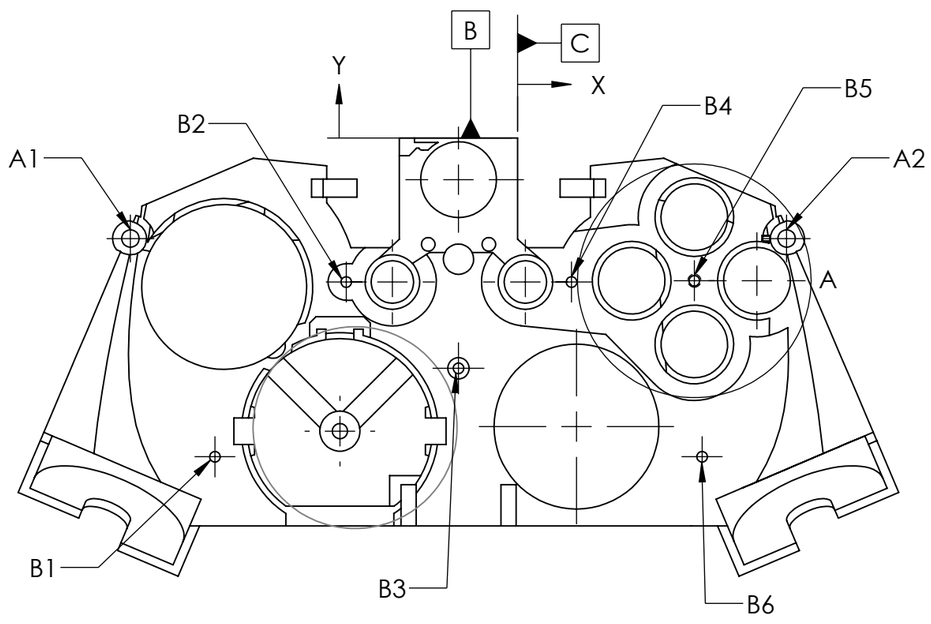
NOTES:

1. SURFACES SHALL MEET ⌓ 0.01 | A

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/15/2024

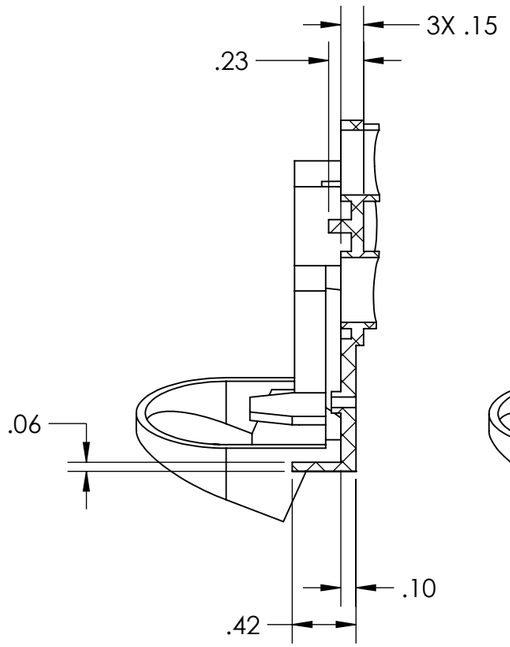


TAG	X LOC	Y LOC
A1	-2.56	-.66
A2	1.78	-.66
B1	-2.00	-2.10
B2	-1.13	-.95
B3	-.39	-1.52
B4	.36	-.95
B5	1.17	-.94
B6	1.22	-2.10

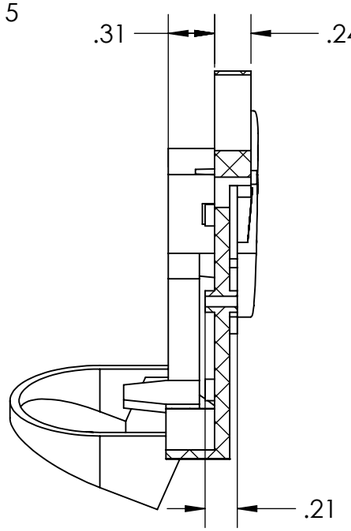


DETAIL A
SCALE 2 : 1

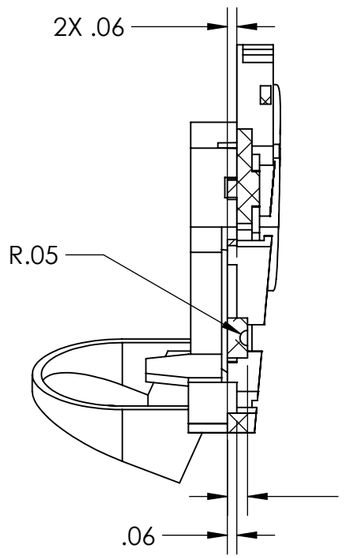
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO	
UNITS:	X.X° 1°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL: ABS		DESCRIPTION: FRAME	
FINISH: NONE		PN: 106	REV: A
			SHEET: 1 of 5



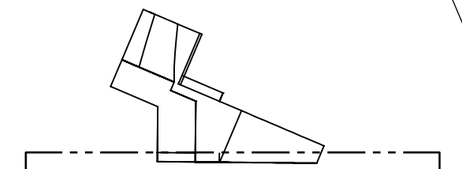
SECTION C-C



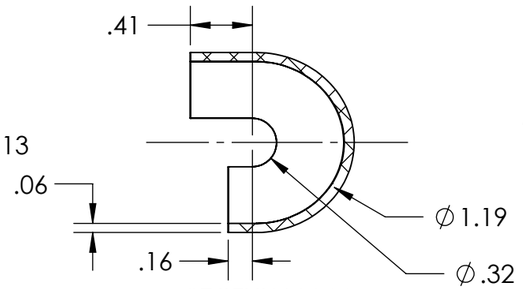
SECTION D-D



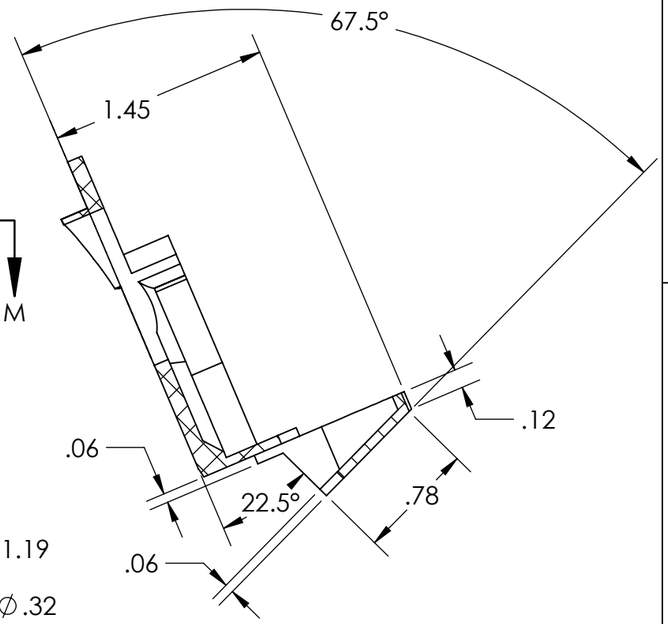
SECTION E-E



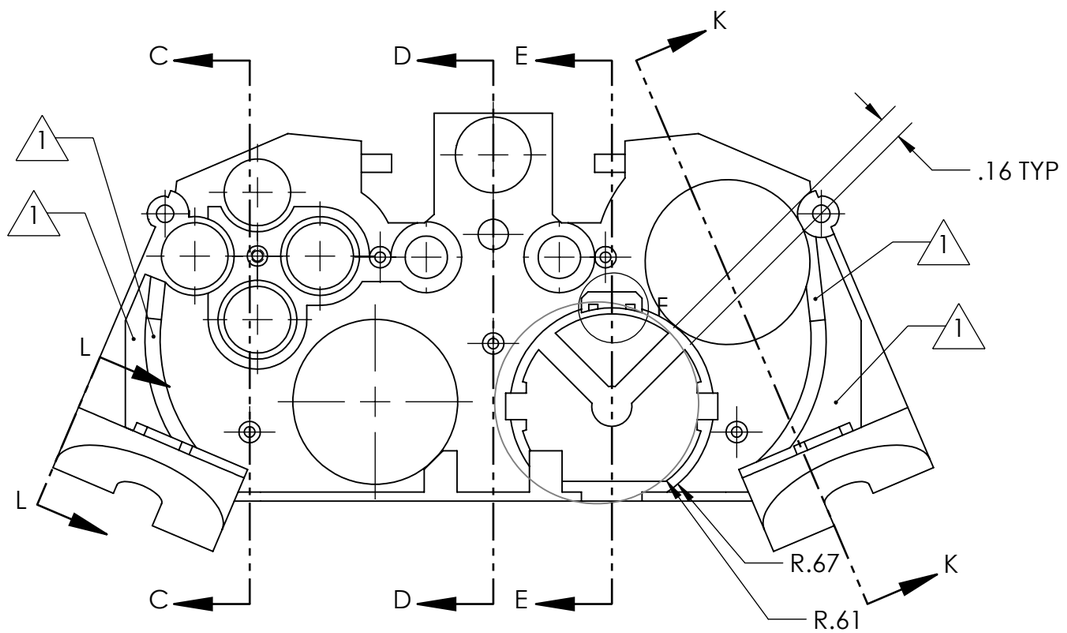
SECTION L-L

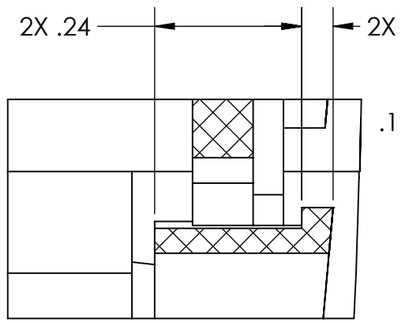


SECTION M-M
TYP BOTH SIDES

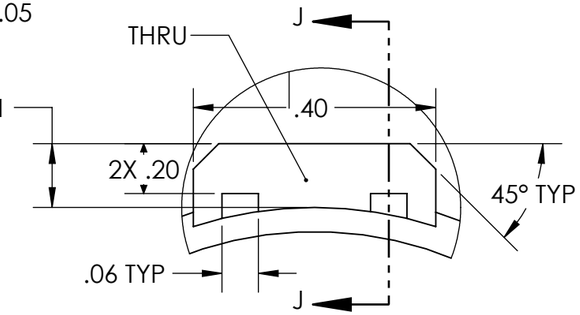


SECTION K-K
TYP BOTH SIDES





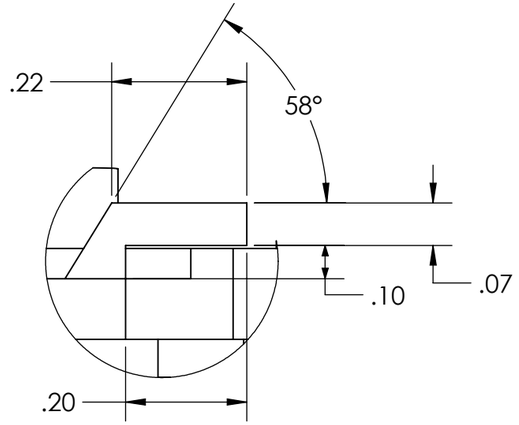
SECTION J-J
SCALE 4 : 1



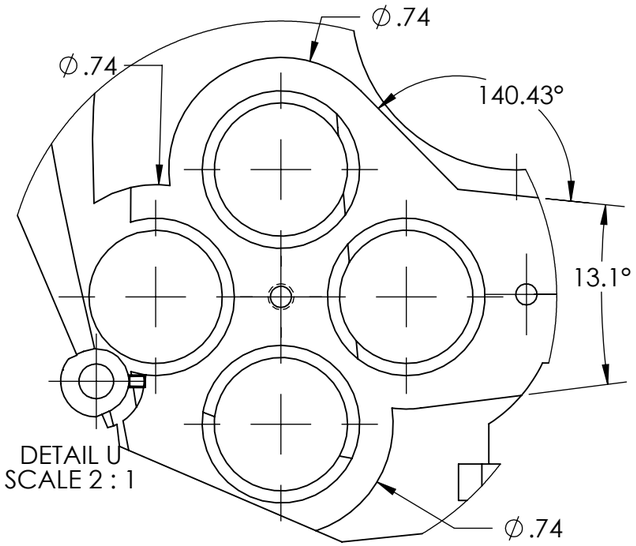
DETAIL F
SCALE 4 : 1

TOLERANCES UNLESS NOTED: X.X ±.030, X.XX ±.010, X.XXX ±.005	UNIVERSITY OF COLORADO		
UNITS: X.X° 1°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL: ABS	DESCRIPTION: FRAME		
FINISH: NONE	PN: 106	REV: A	SHEET: 2 of 5

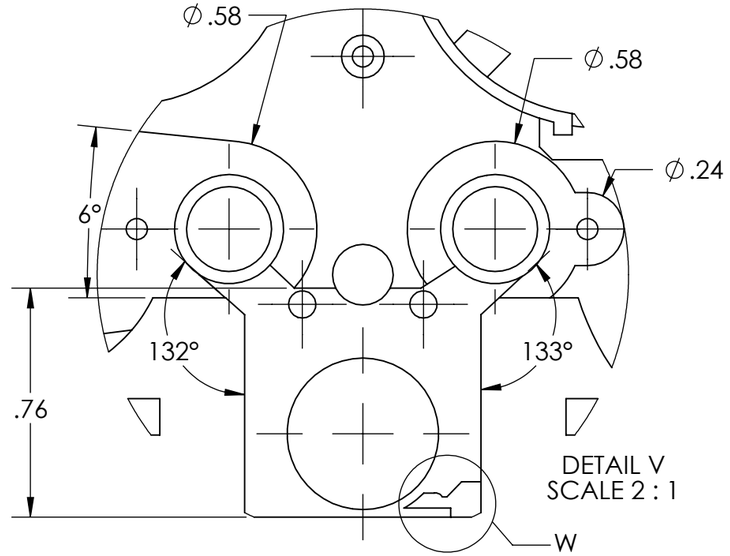
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.



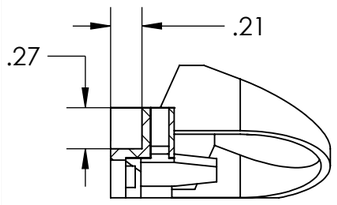
DETAIL N
SCALE 4 : 1
TYP BOTH SIDES



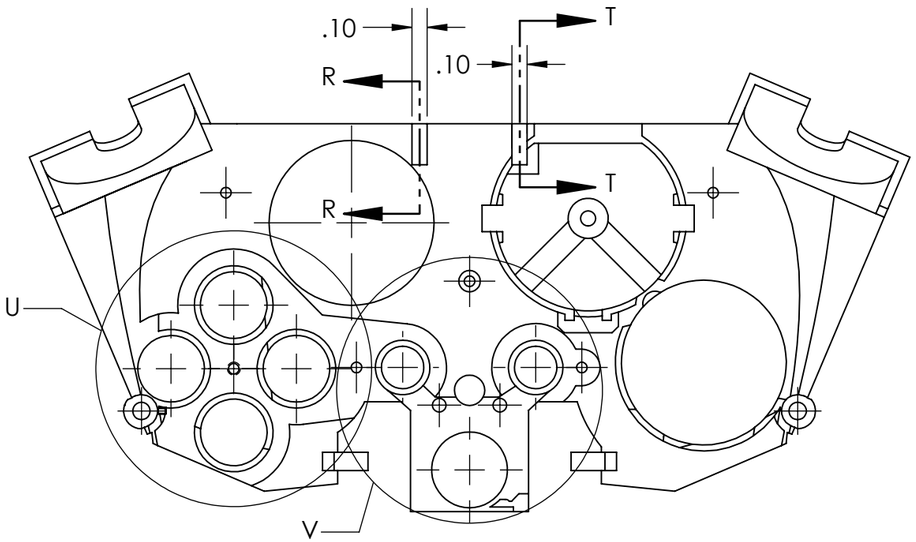
DETAIL U
SCALE 2 : 1

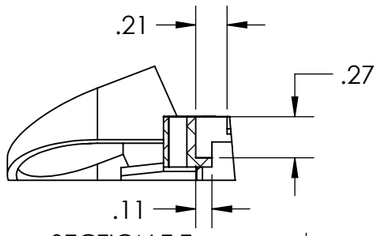


DETAIL V
SCALE 2 : 1

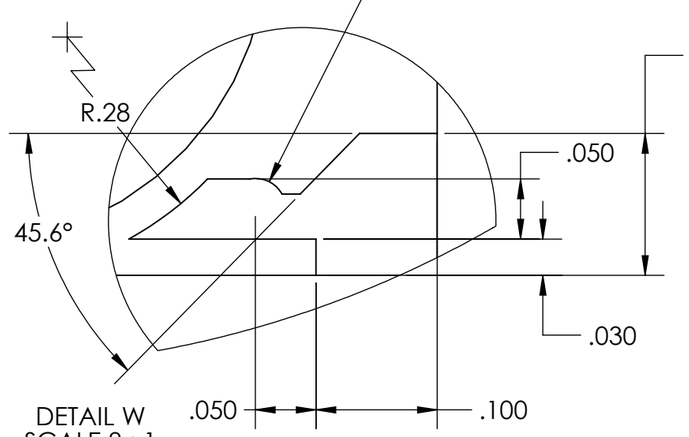


SECTION R-R

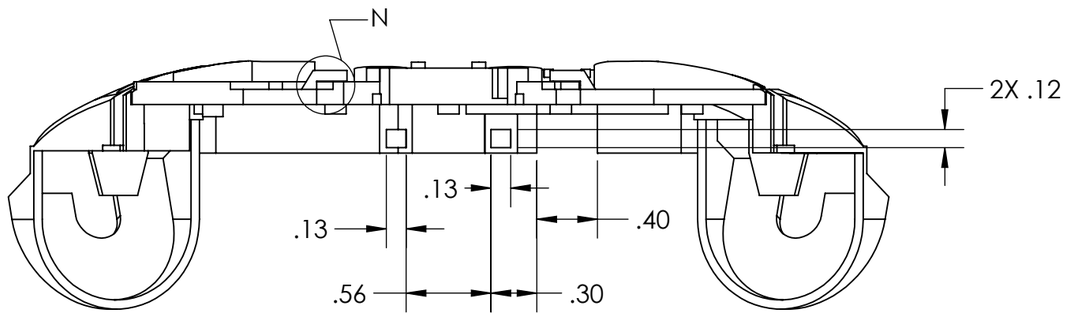




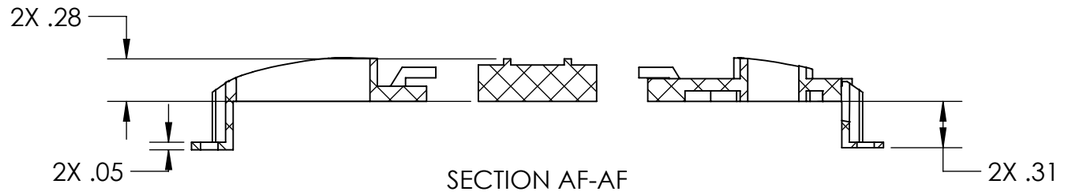
SECTION T-T



DETAIL W
SCALE 8 : 1



TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS:	X.X° 1°		
MATERIAL: ABS		DESCRIPTION: FRAME	
FINISH: NONE		PN: 106	REV: A
			SHEET: 3 of 5



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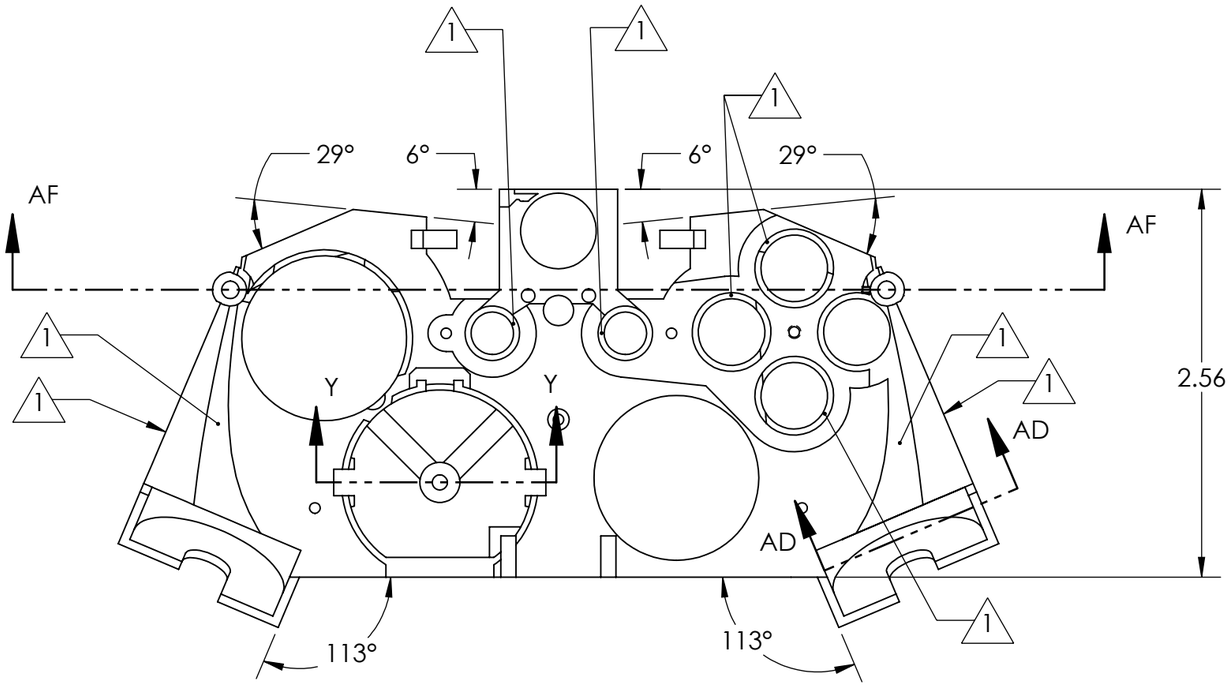
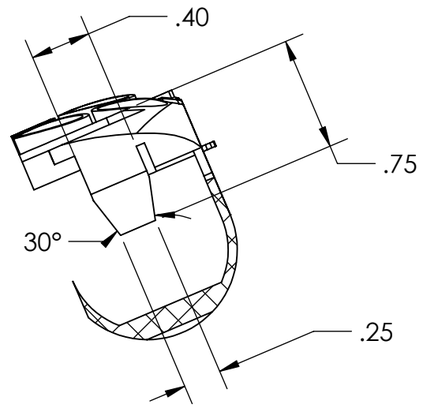
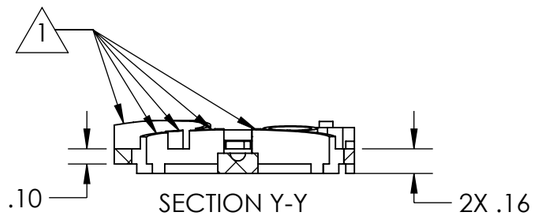




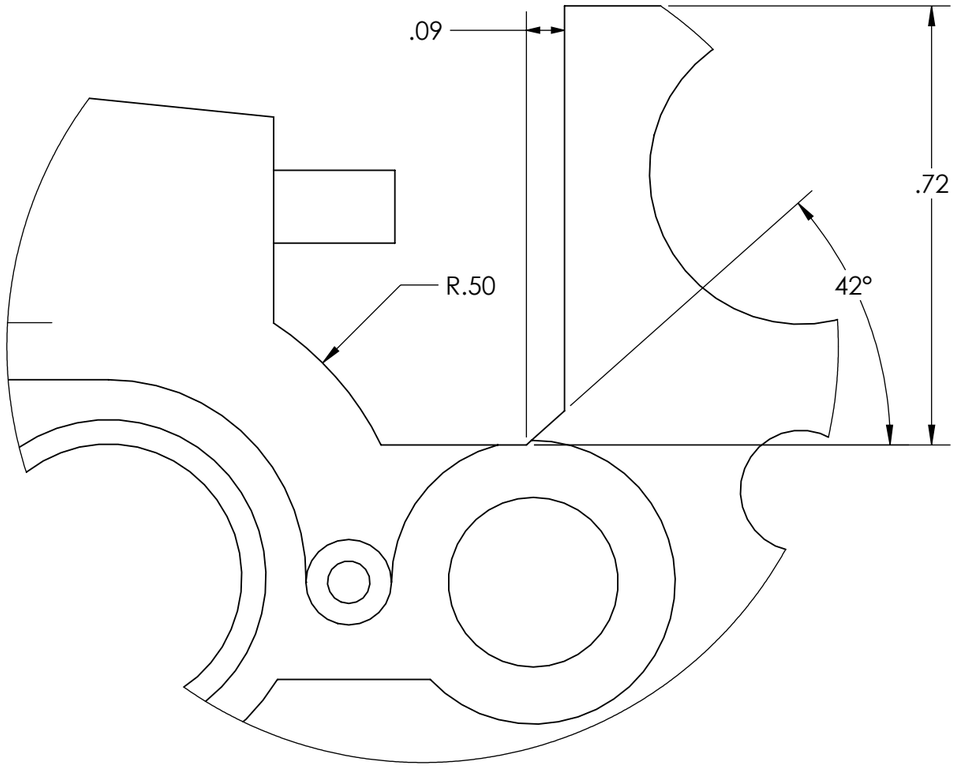
SECTION AD-AD
TYP BOTH SIDES



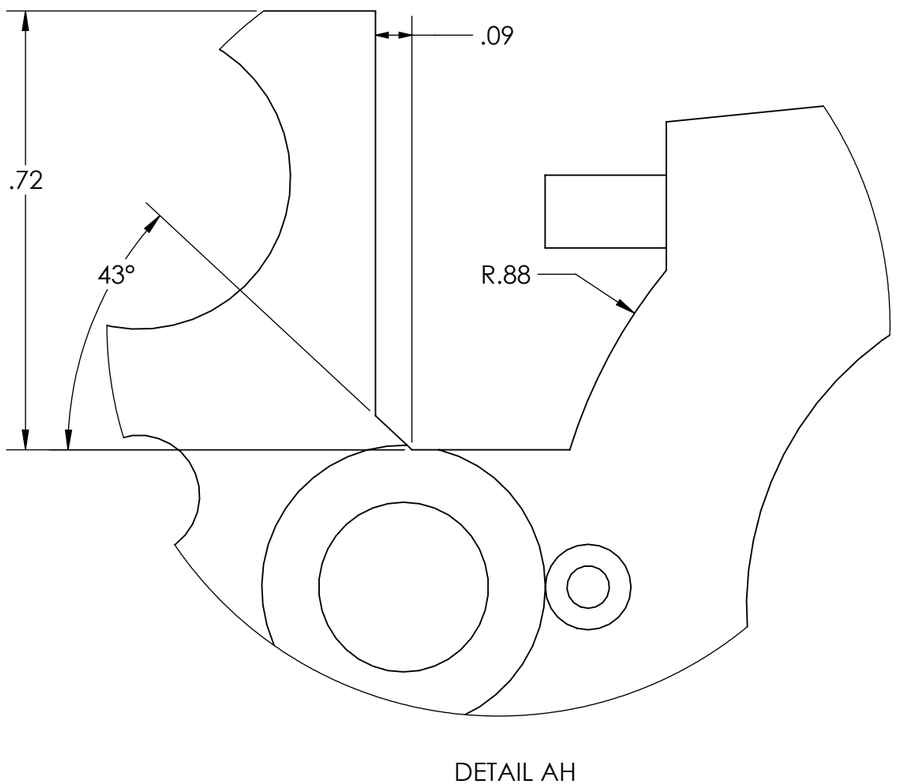
SECTION Y-Y

TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS:	X.X° 1°				
MATERIAL ABS		DESCRIPTION FRAME			
FINISH NONE		PN 106	REV A		SHEET 4 of 5

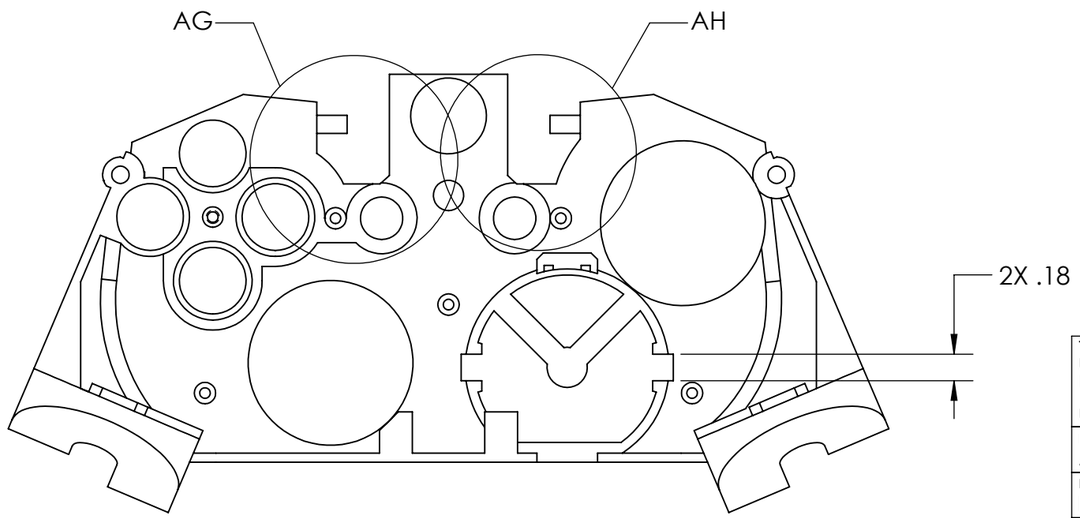
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.



DETAIL AG
SCALE 4 : 1

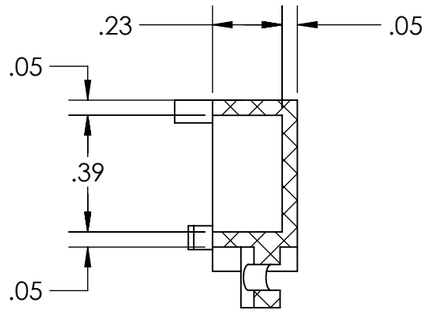


DETAIL AH
SCALE 4 : 1

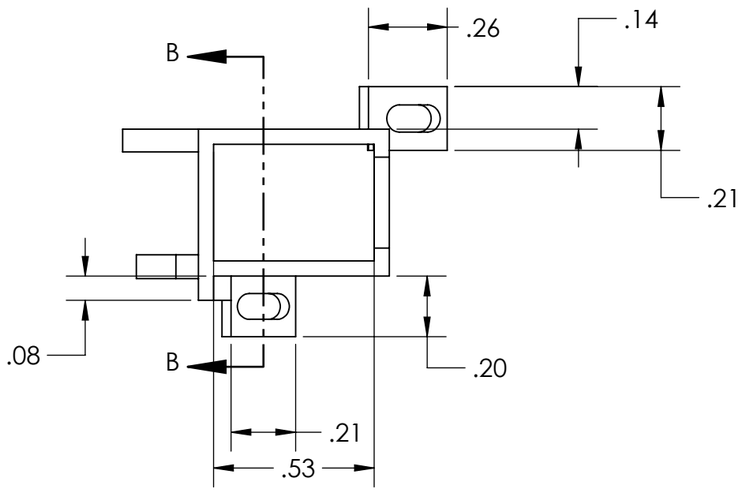


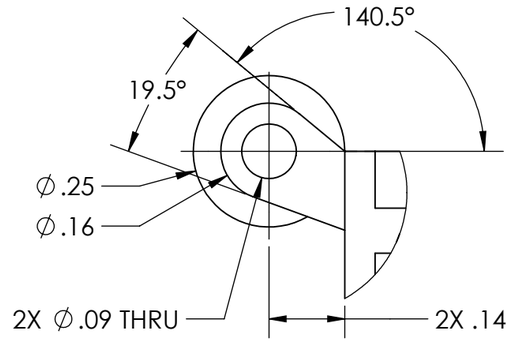
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS:	X.X° 1°				
MATERIAL ABS		DESCRIPTION FRAME			
FINISH NONE		PN 106	REV A		SHEET 5 of 5

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/15/2024

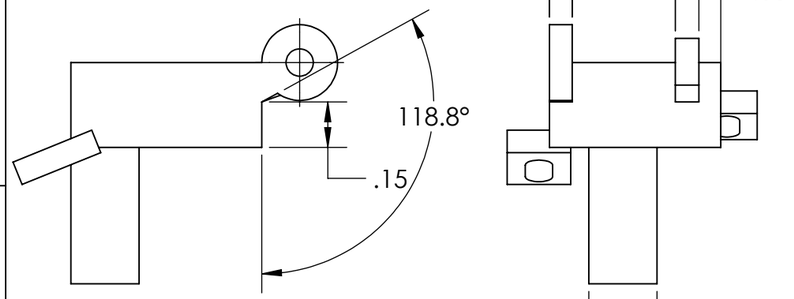


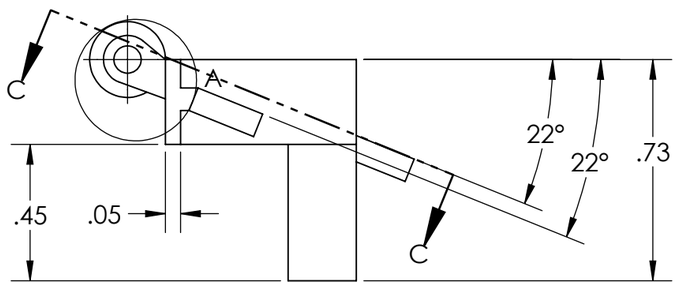
SECTION B-B

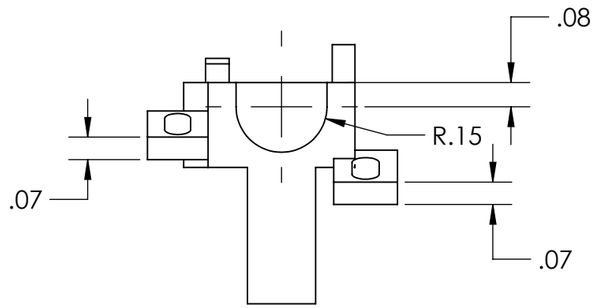


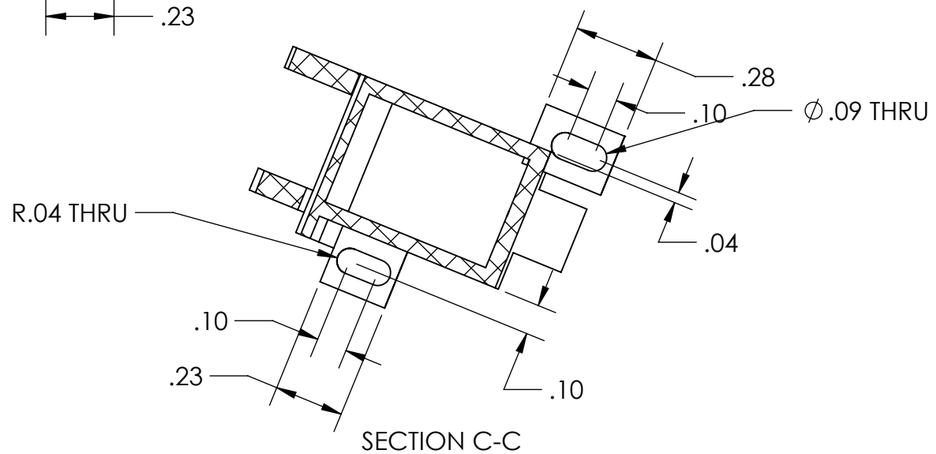


DETAIL A
SCALE 4 : 1





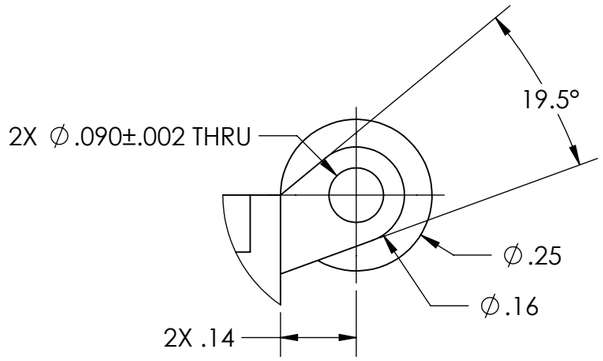




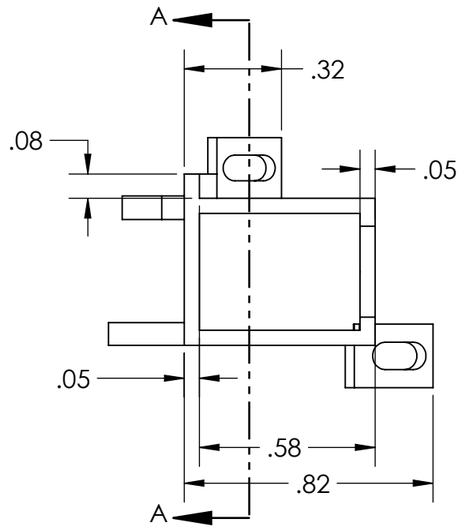
SECTION C-C

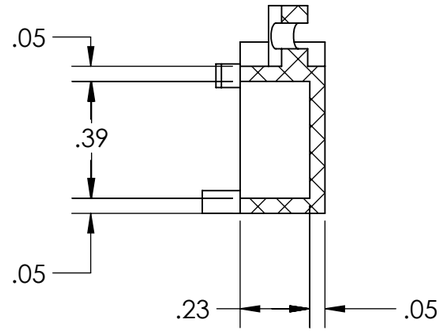
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
UNITS:	X.X° 1°			
MATERIAL ABS		DESCRIPTION RIGHT HAPTIC HOLDER		
FINISH NONE		PN 107	REV A	SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/18/2024

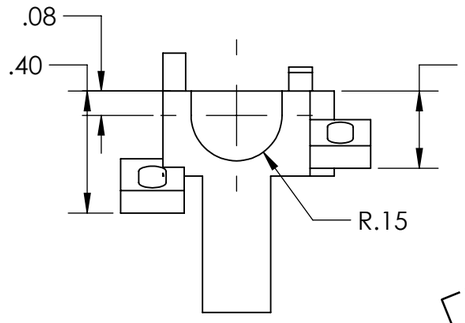


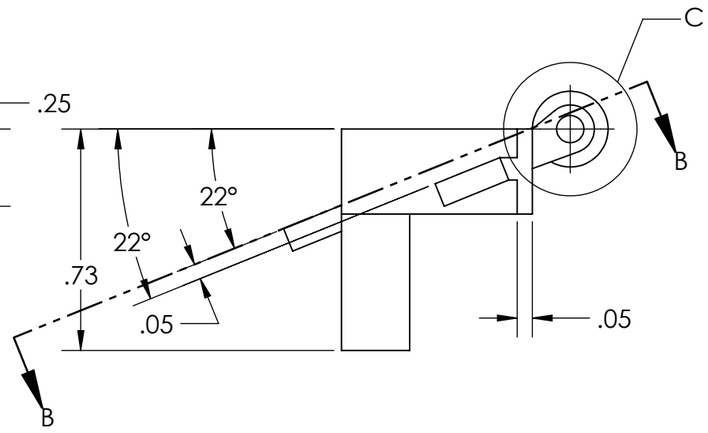
DETAIL C
SCALE 4 : 1

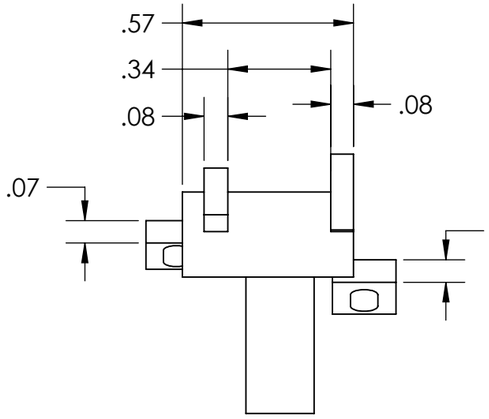


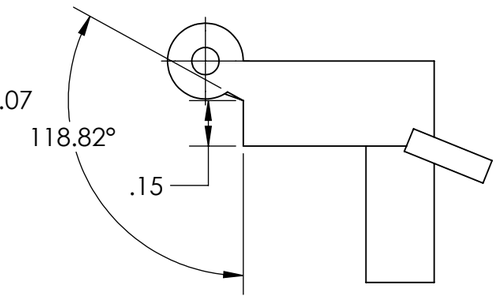


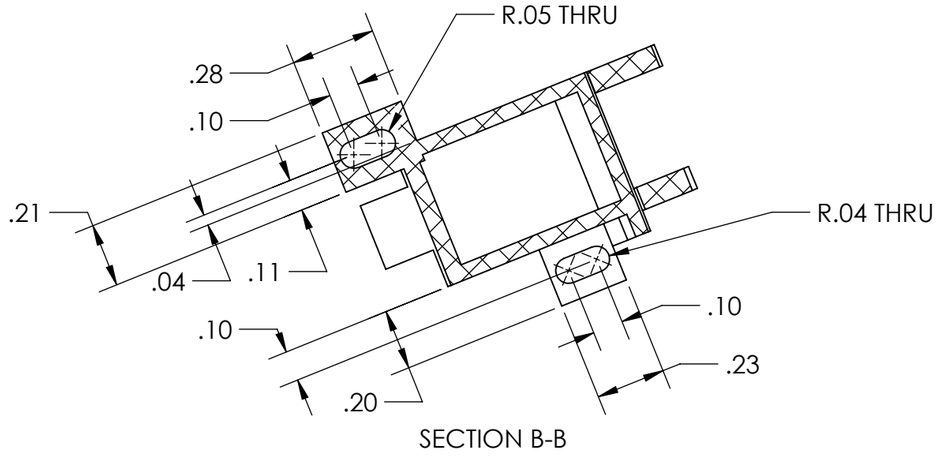
SECTION A-A







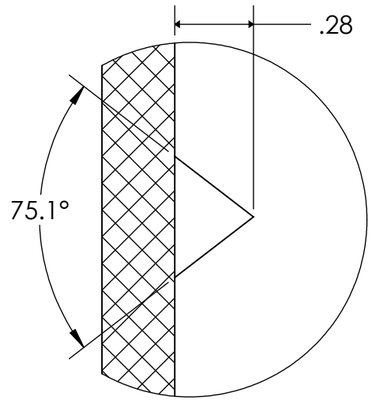




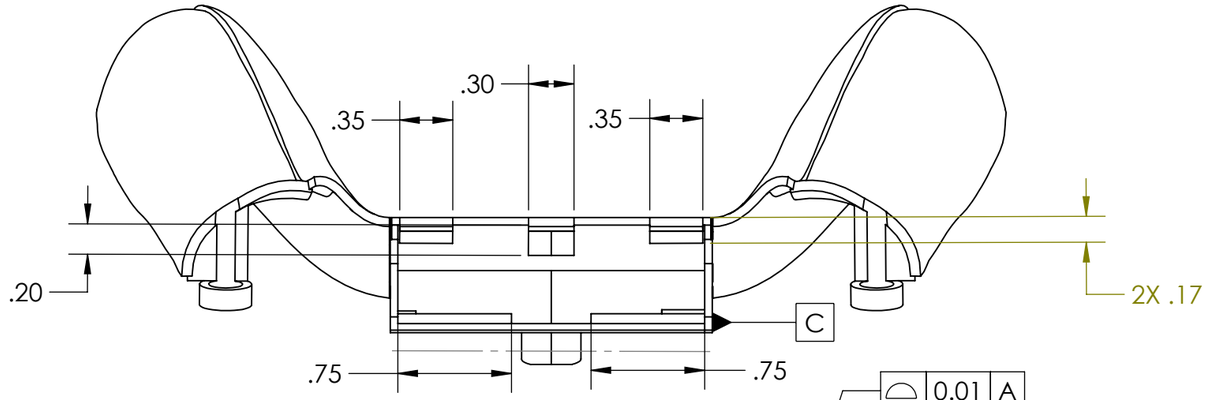
SECTION B-B

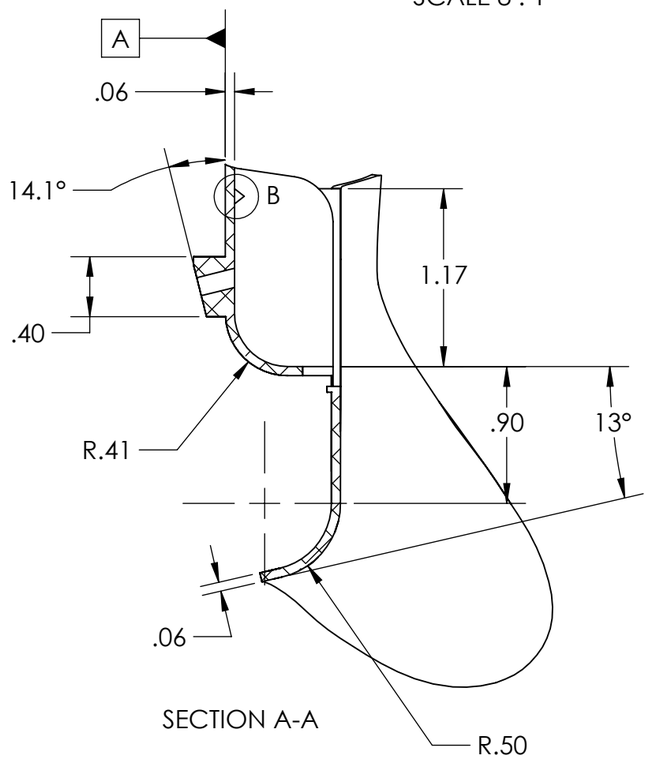
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCH	X.X° 1°		
MATERIAL: ABS		DESCRIPTION: LEFT HAPTIC HOLDER	
FINISH: NONE		PN: 108	REV: A
			SHEET: 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/14/2024

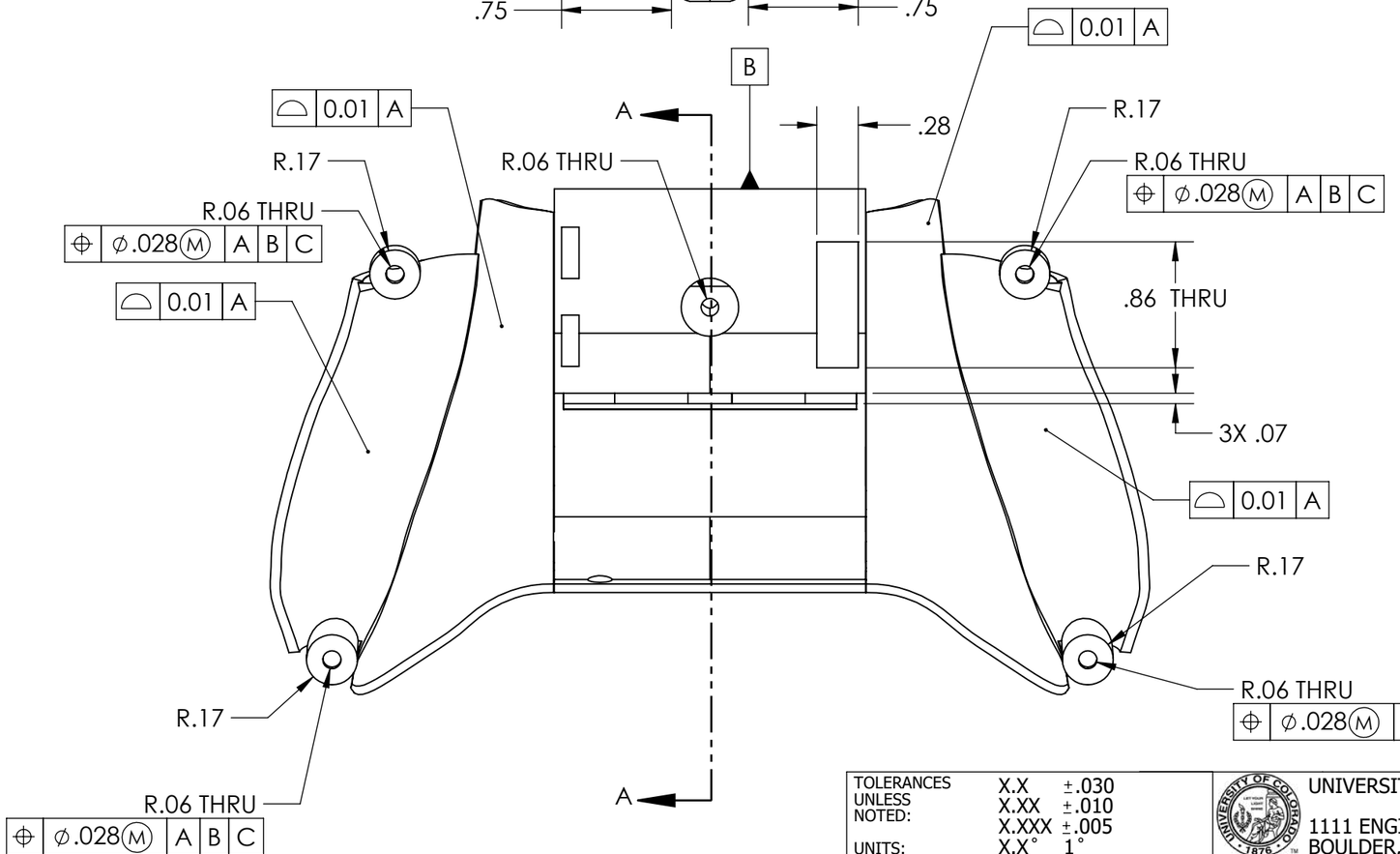


DETAIL B
SCALE 8 : 1

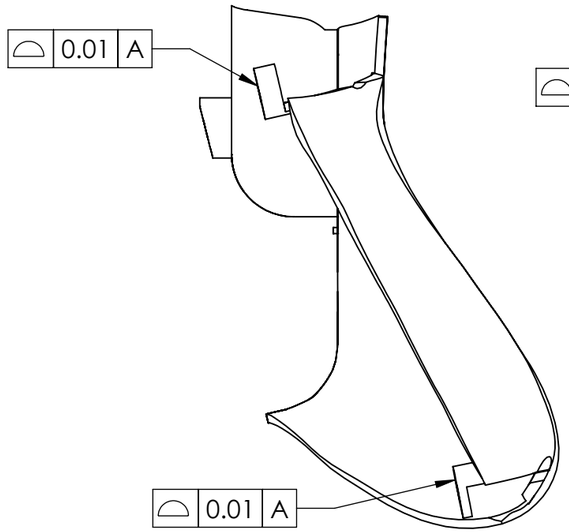


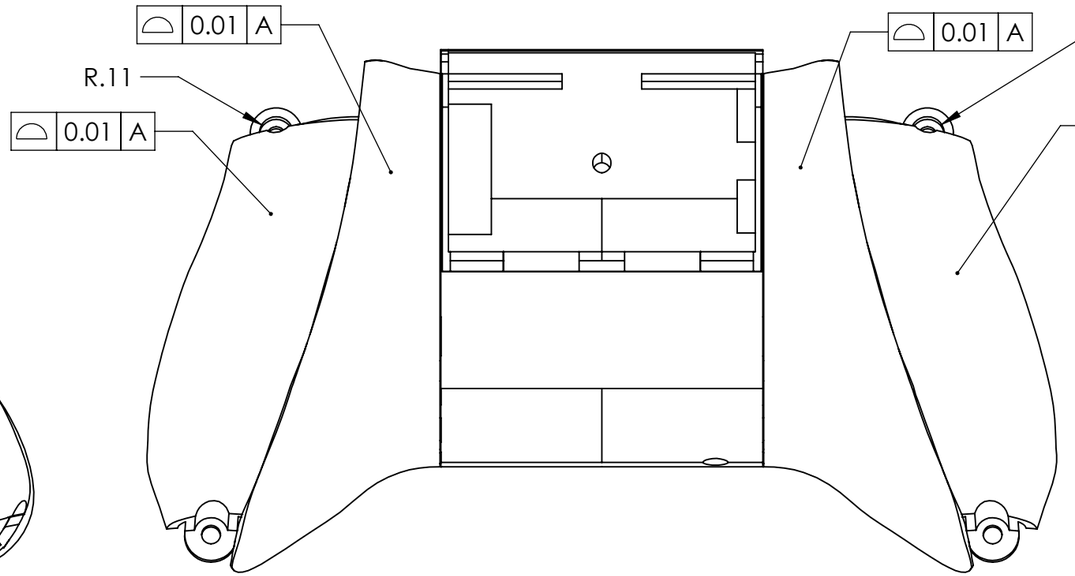


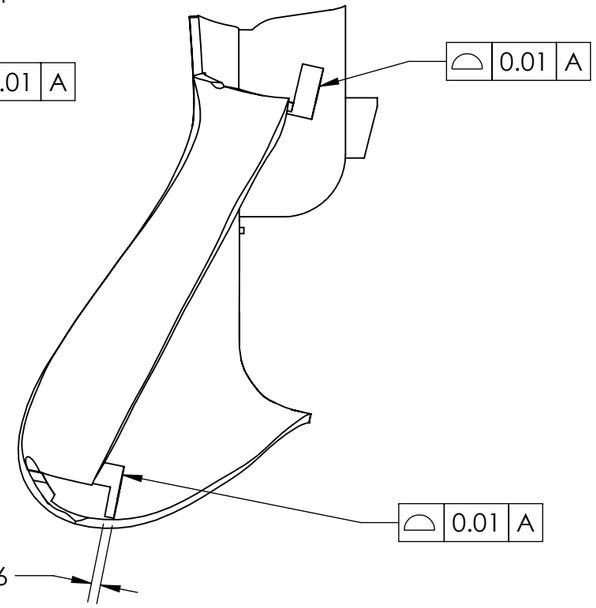
SECTION A-A

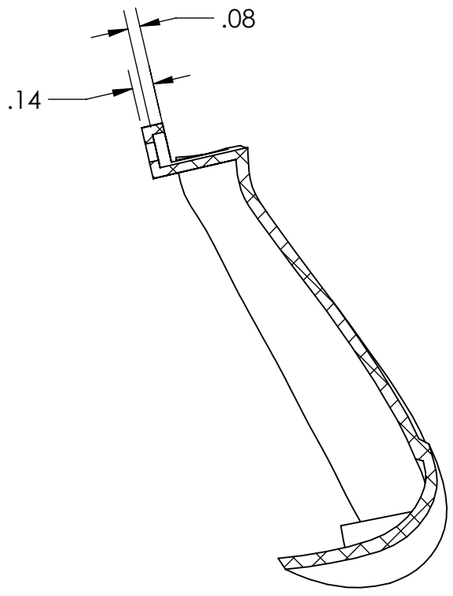


TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS:	X.X° 1°				
MATERIAL ABS		DESCRIPTION CONTROLLER BACK PLATE			
FINISH NONE		PN 109	REV A		SHEET 1 of 3

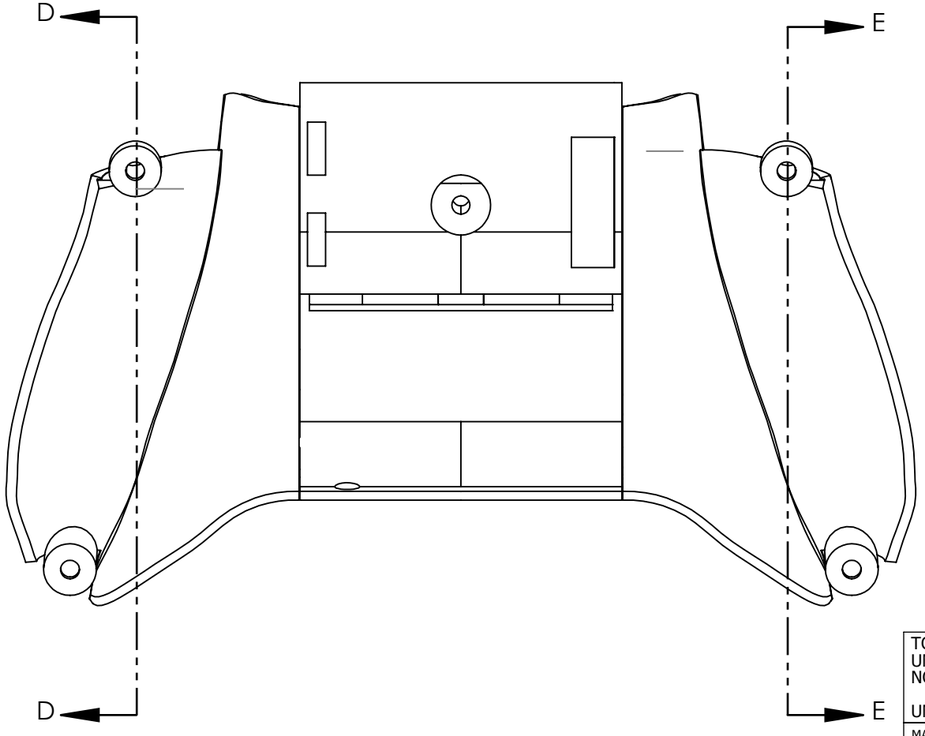


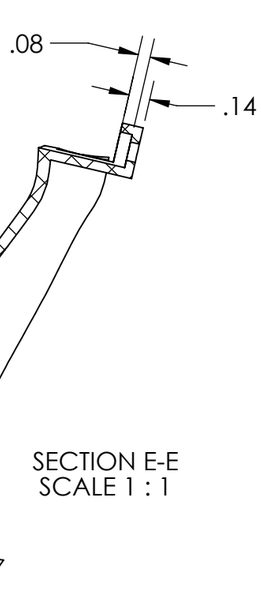






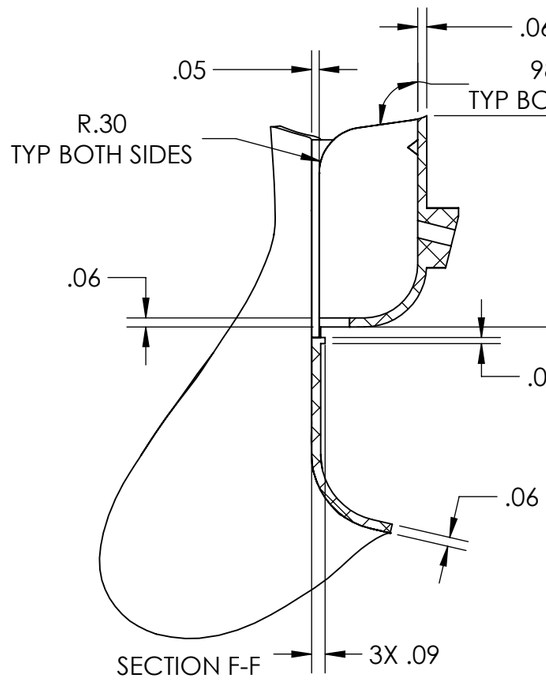
SECTION D-D
SCALE 1 : 1

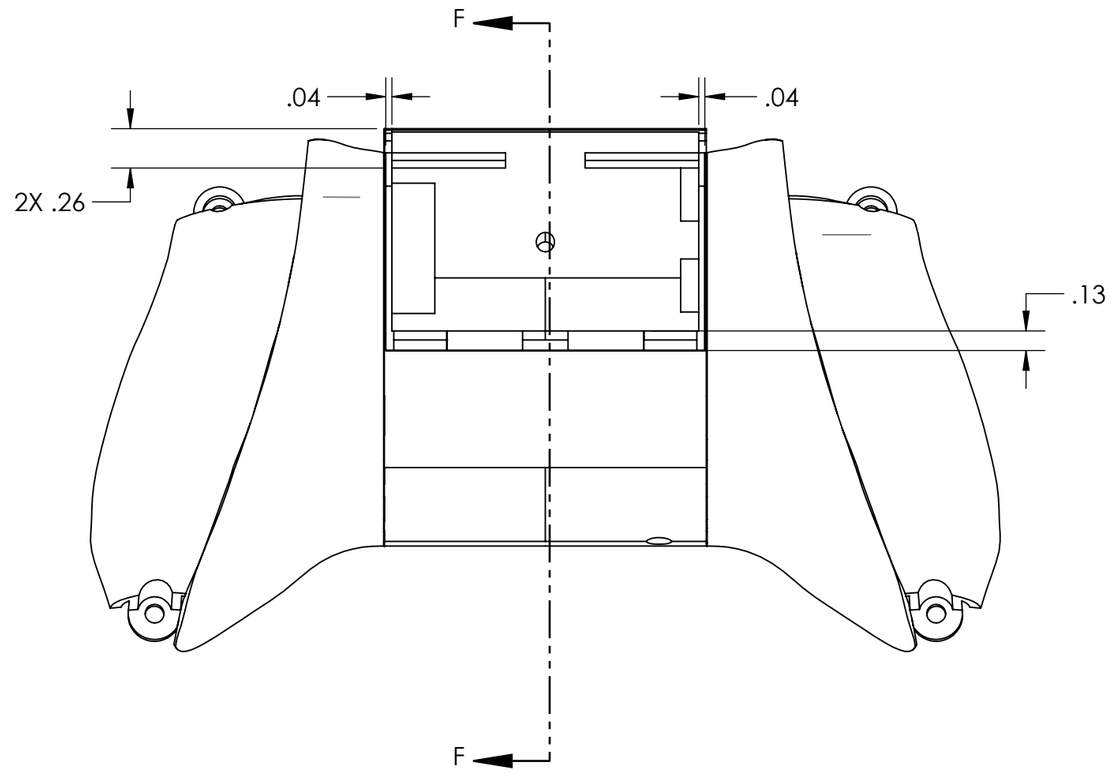




SECTION E-E
SCALE 1 : 1

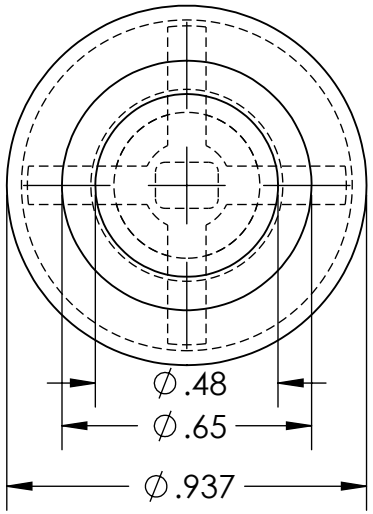
TOLERANCES UNLESS NOTED: UNITS:	X.X ±.030 X.XX ±.010 X.XXX ±.005 X.X° 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS		DESCRIPTION CONTROLLER BACK PLATE	
FINISH NONE		PN 109	REV A	SHEET 2 of 3
PROPRIETARY AND CONFIDENTIAL	THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.		

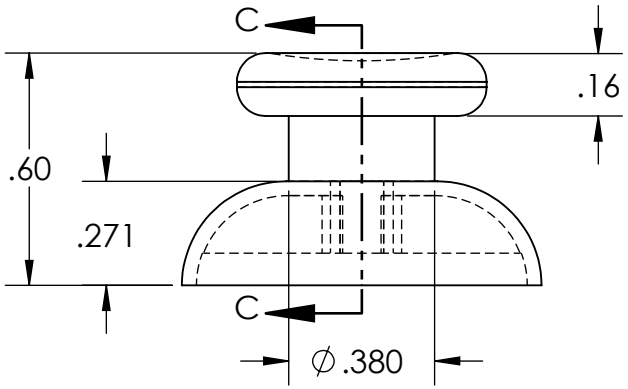


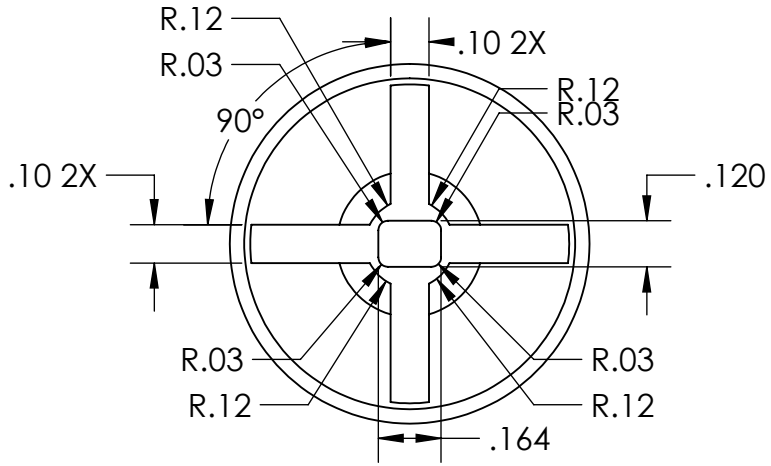


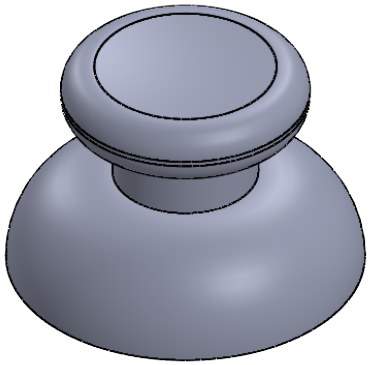
TOLERANCES UNLESS NOTED: X.X ±.030 X.XX ±.010 X.XXX ±.005 UNITS: X.X° 1°		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS		DESCRIPTION CONTROLLER BACK PLATE	
FINISH NONE		PN 109	REV A / SHEET 3 of 3
PROPRIETARY AND CONFIDENTIAL	THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.		

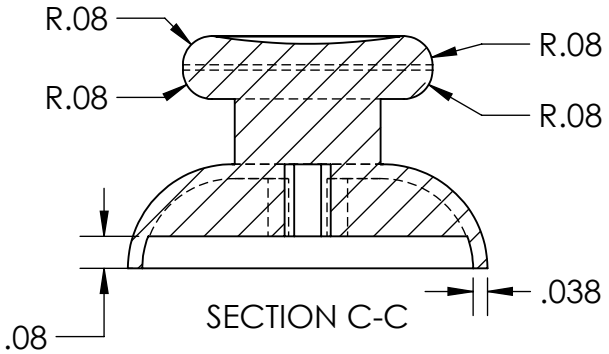
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/10/2024







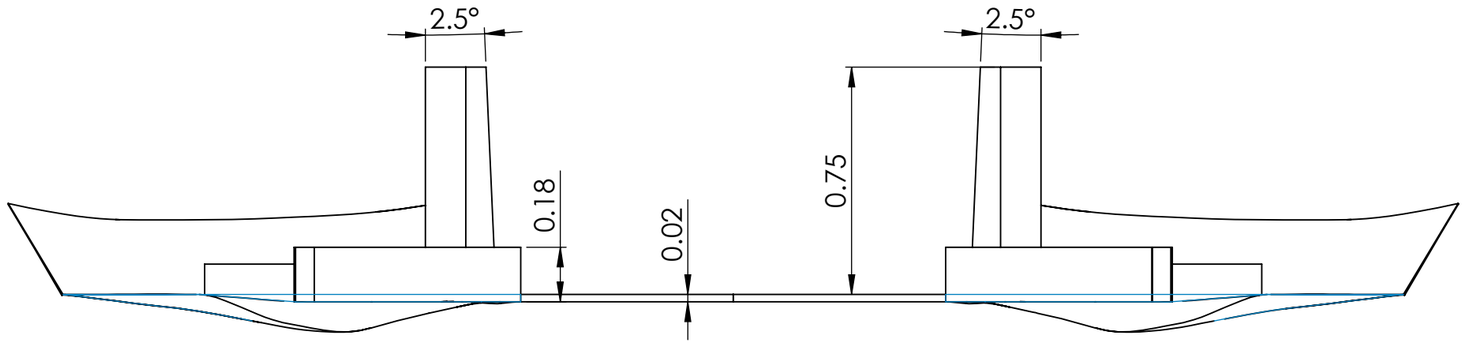


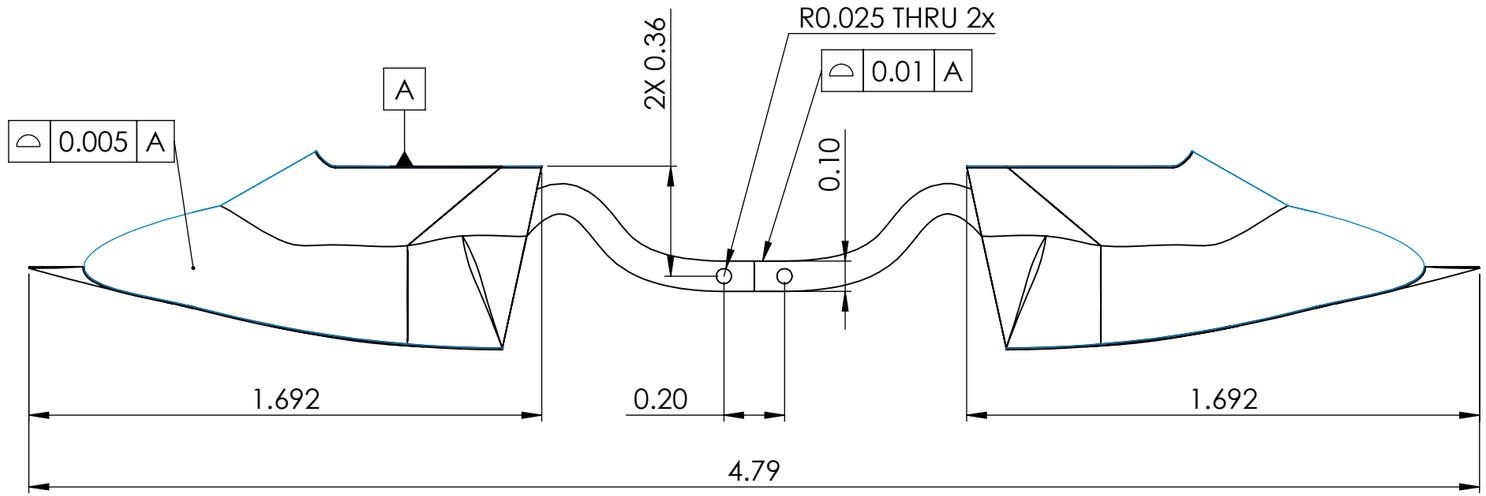


TOLERANCES UNLESS NOTED: X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 UNITS:INCHES X.X° ±0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427				
MATERIAL ABS	DESCRIPTION THUMBSTICK				
FINISH NONE	PN 201	REV A		SHEET 1 of 1	
PROPRIETARY AND CONFIDENTIAL	THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.				

NOTES:
1. REFERENCE MODEL PN 202 REV A FOR ALL UNSPECIFIED GEOMETRY
2. SURFACE PROFILES TO MATCH MODEL WITHIN 0.03"
3. RADII ARE 0.01" UNLESS OTHERWISE SPECIFIED

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/16/2024



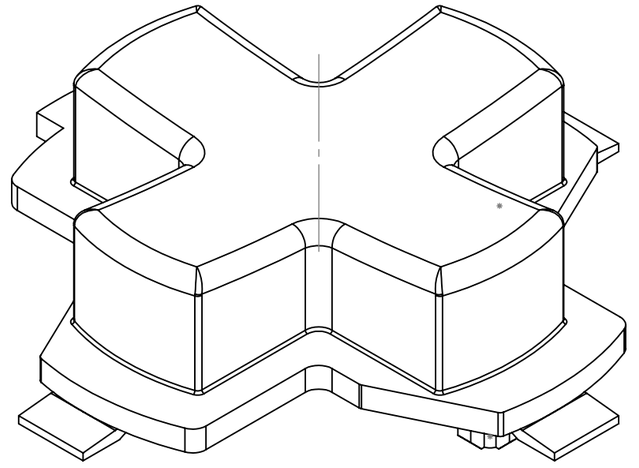


TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO		
UNITS:INCHES	X.X° ± 0.5°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL: ABS		DESCRIPTION: LEFT AND REIGHT BUMPER		
FINISH: NONE		PN: 202	REV: 1	SHEET: 1 of 1

NOTES:

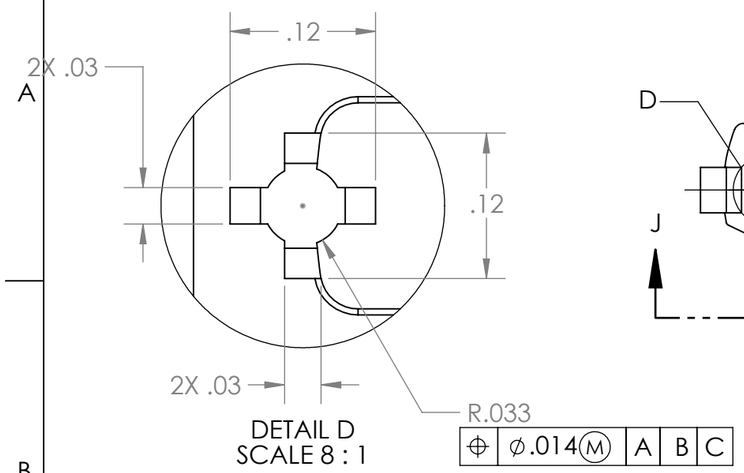
1. ALL CORNER RADII SHALL BE .010" UNLESS OTHERWISE SPECIFIED.

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/11/2024



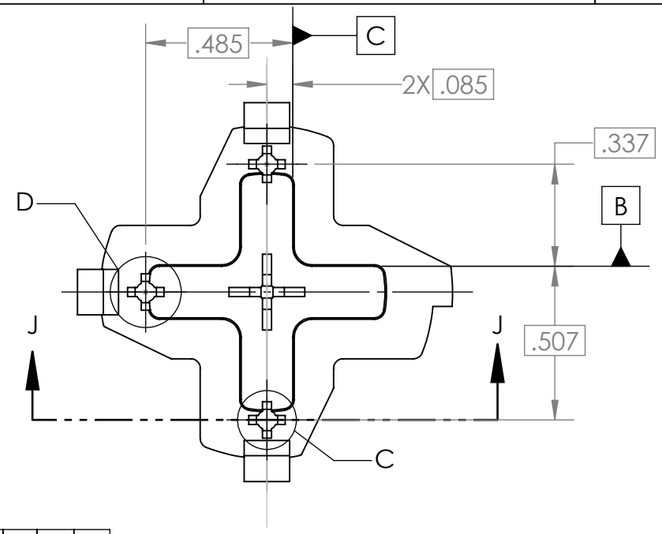
ISOMETRIC VIEW FOR REFERENCE ONLY

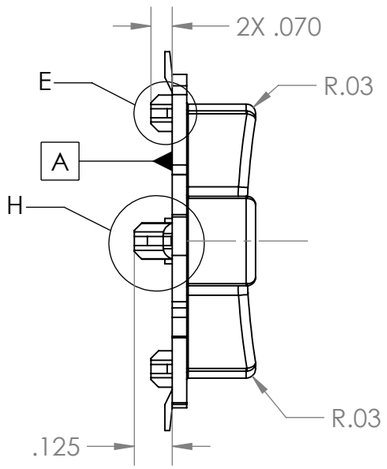
TOLERANCES UNLESS NOTED: X.X ±.030, X.XX ±.010, X.XXX ±.005		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: X.X° 1°			
MATERIAL: ABS		DESCRIPTION: D-PAD	
FINISH: NONE		PN: 204	REV: A / SHEET: 1 of 3

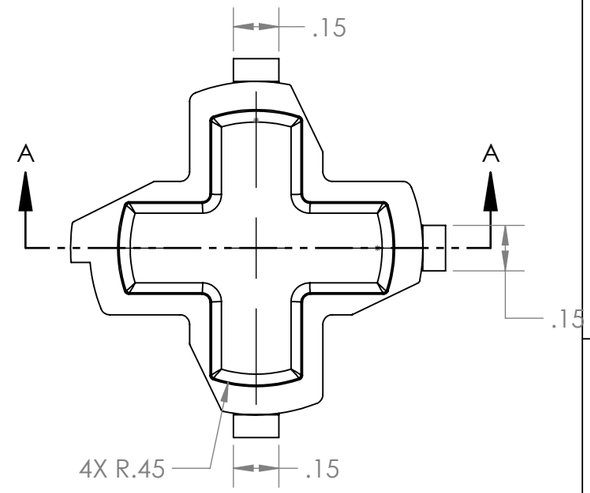


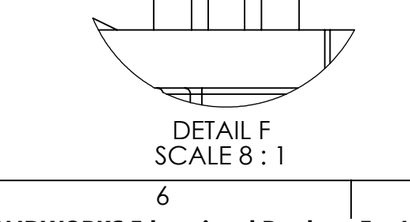
DETAIL D
SCALE 8 : 1

⌖	⌀.014 Ⓜ	A	B	C



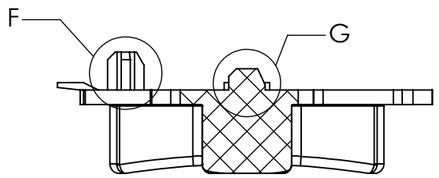




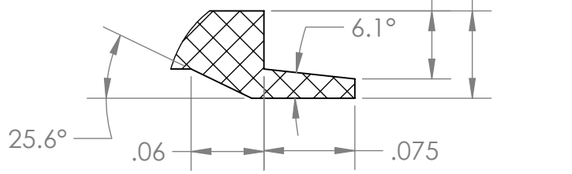


DETAIL C
SCALE 8 : 1
TYP 2 PLACES

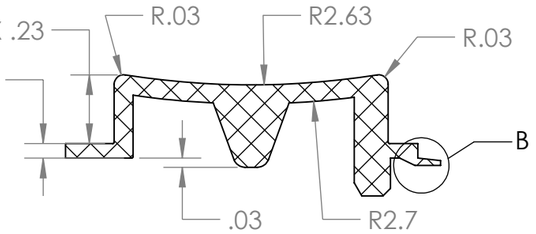
⌖	⌀.014 Ⓜ	A	B	C



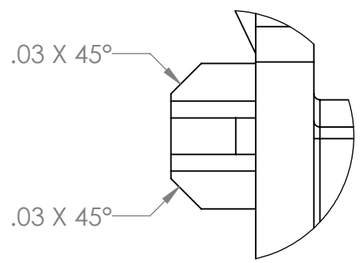
SECTION J-J



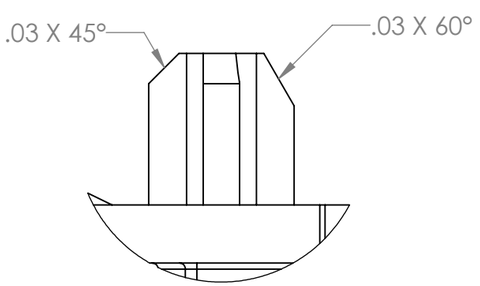
DETAIL B
SCALE 8 : 1
TYP 3 PLACES



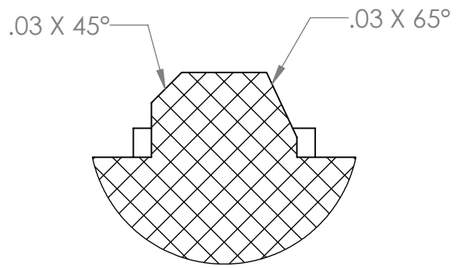
SECTION A-A
SLICE



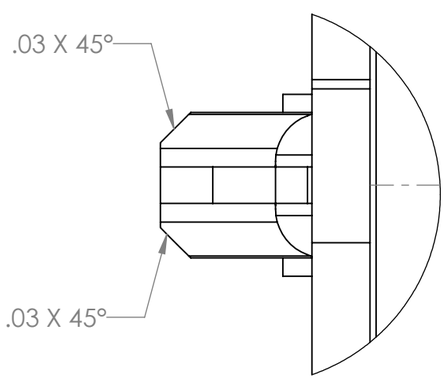
DETAIL E
SCALE 8 : 1
TYP 2 PLACES



DETAIL F
SCALE 8 : 1

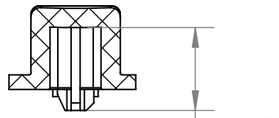


DETAIL G
SCALE 8 : 1
TYP 2 PLACES

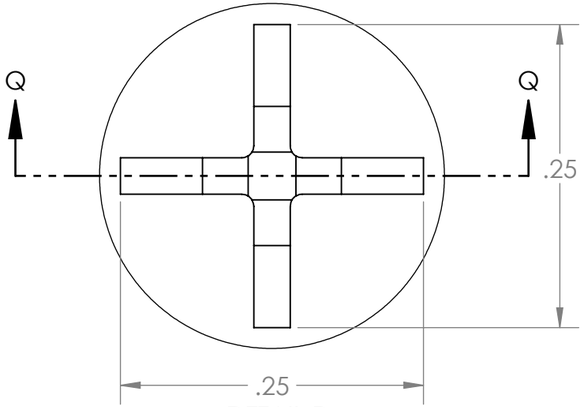


DETAIL H
SCALE 8 : 1

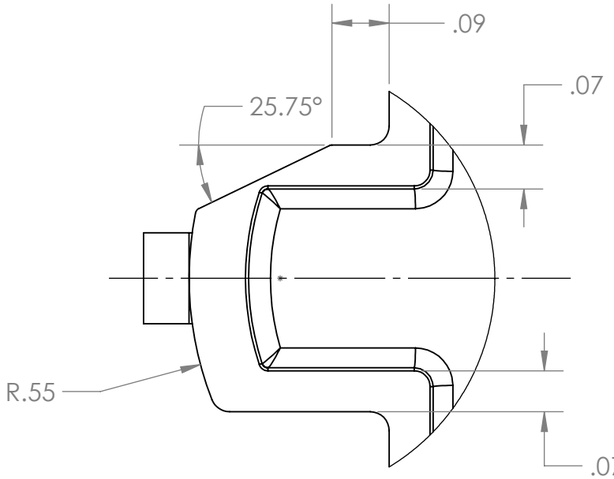
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO	
UNITS:	X.X° 1°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS		DESCRIPTION D-PAD	
FINISH NONE		PN 204	REV A
			SHEET 2 of 3



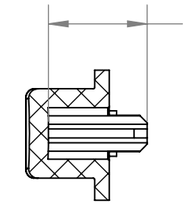
SECTION N-N
TYP 2 PLACES



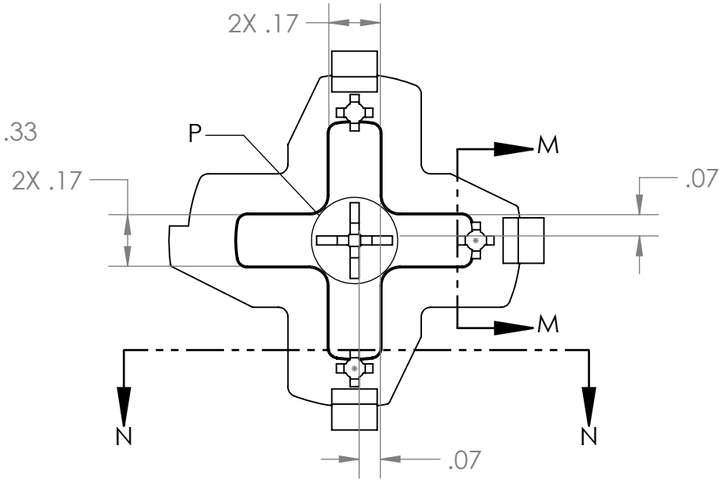
DETAIL P
SCALE 8 : 1

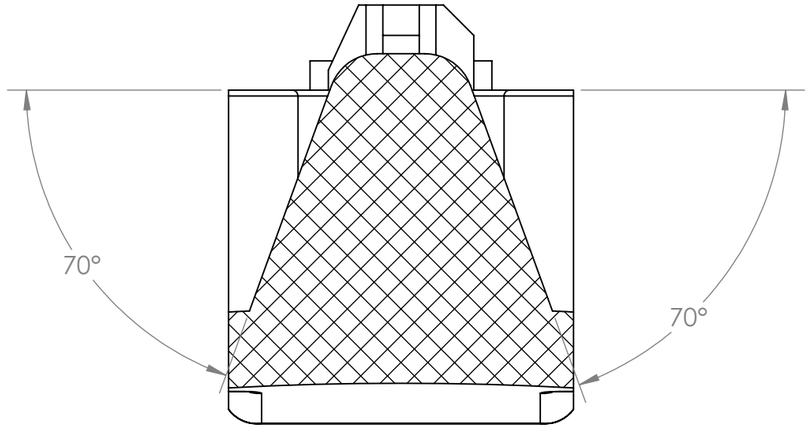


DETAIL L
SCALE 4 : 1
TYP 3 PLACES

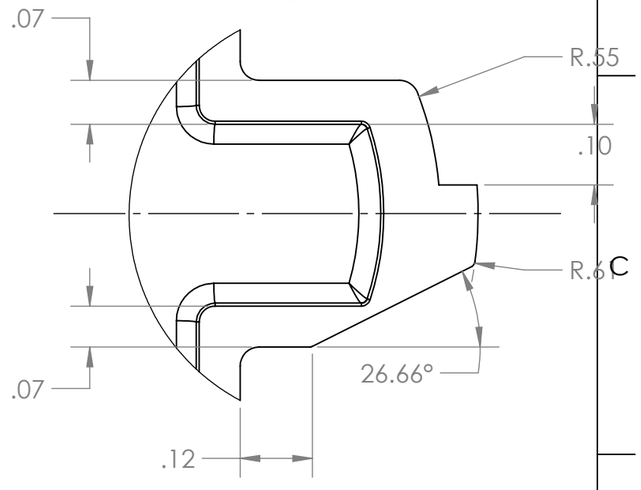


SECTION M-M

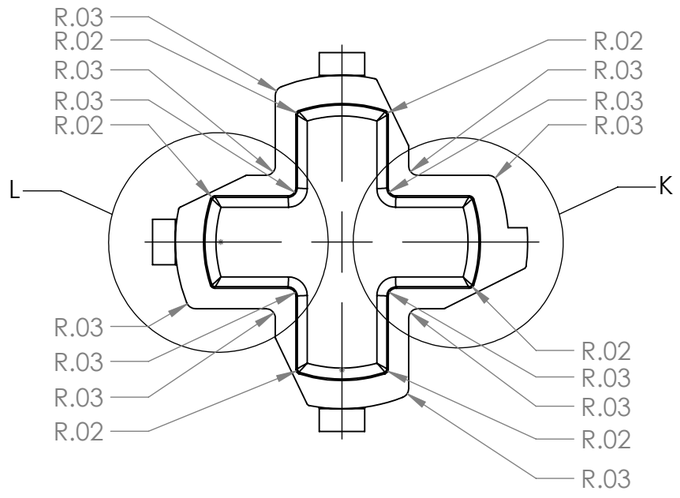


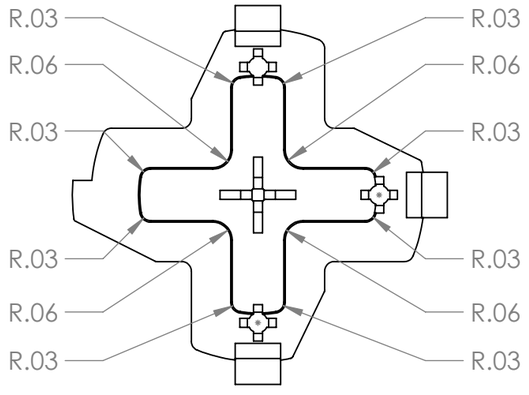


SECTION Q-Q
SCALE 8 : 1



DETAIL K
SCALE 4 : 1

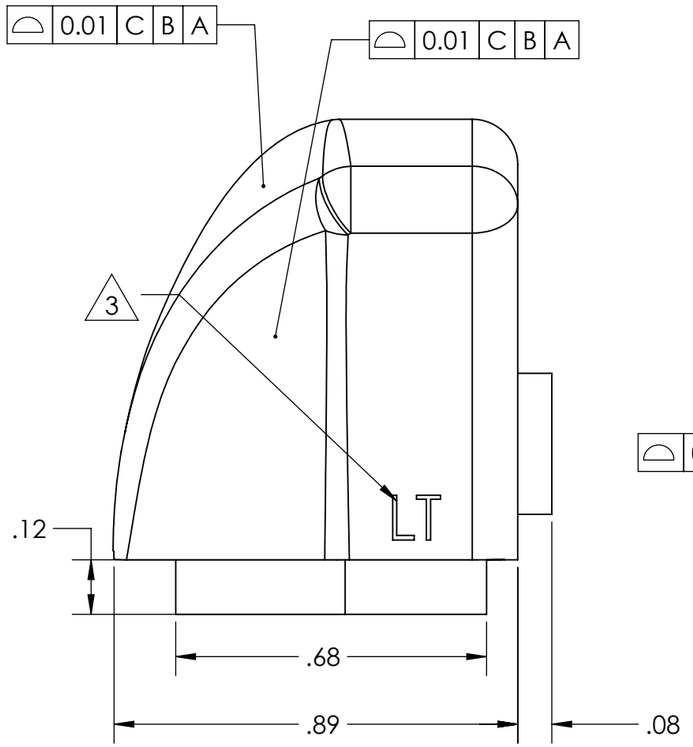


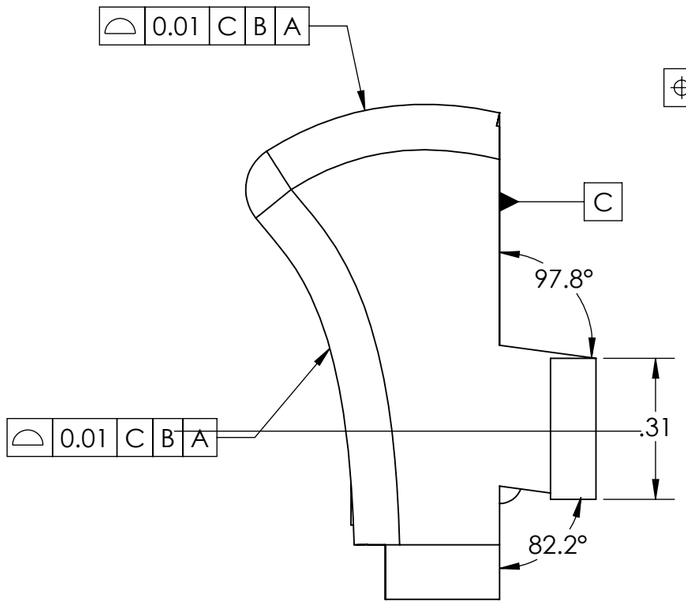


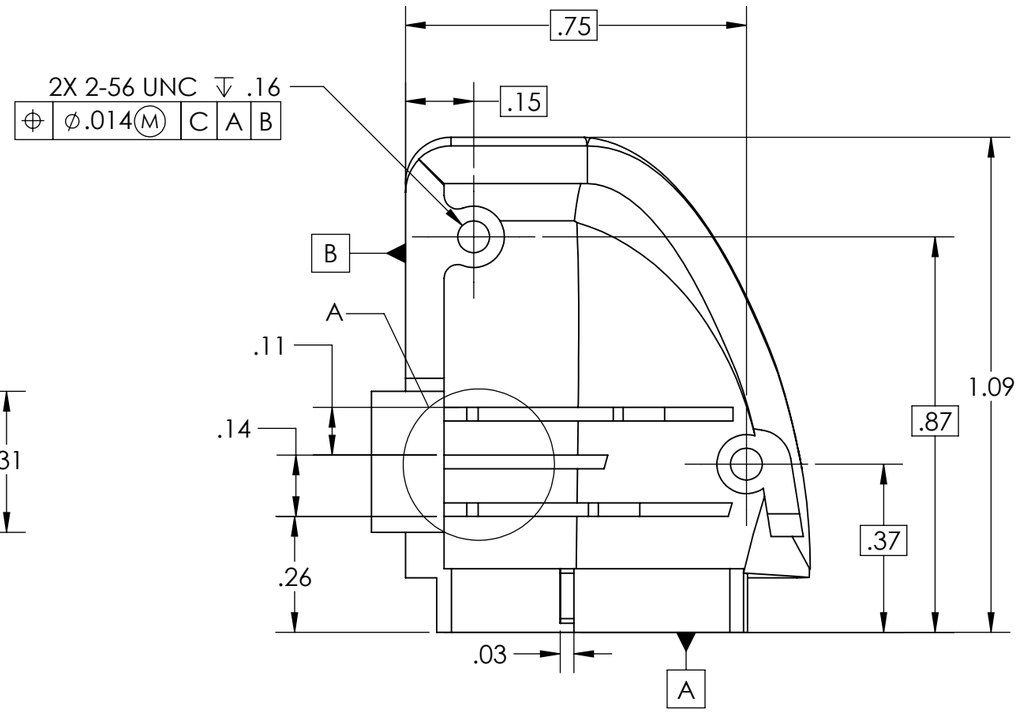
TOLERANCES UNLESS NOTED: X.X ±.030, X.XX ±.010, X.XXX ±.005 / UNITS: X.X° 1°	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427		
MATERIAL: ABS	DESCRIPTION: D-PAD		
FINISH: NONE	PN: 204	REV: A	SHEET: 3 of 3

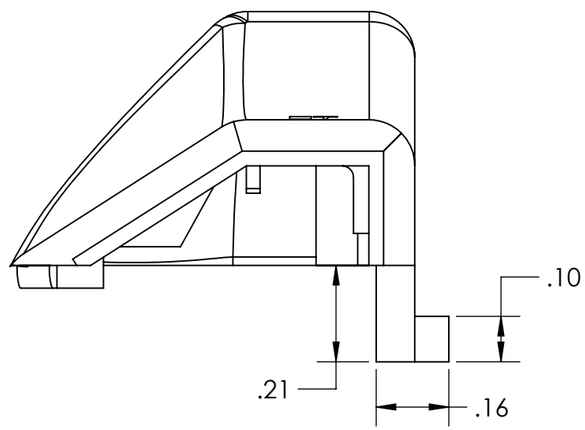
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

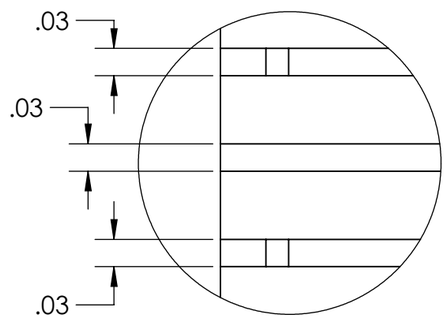
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/18/2024











DETAIL A
SCALE 6 : 1

NOTES:
1. REFERENCE MODEL PN 205 OF THE SAME REV FOR ALL UNSPECIFIED GEOMETRY
2. RADII ARE 0.01" UNLESS OTHERWISE SPECIFIED

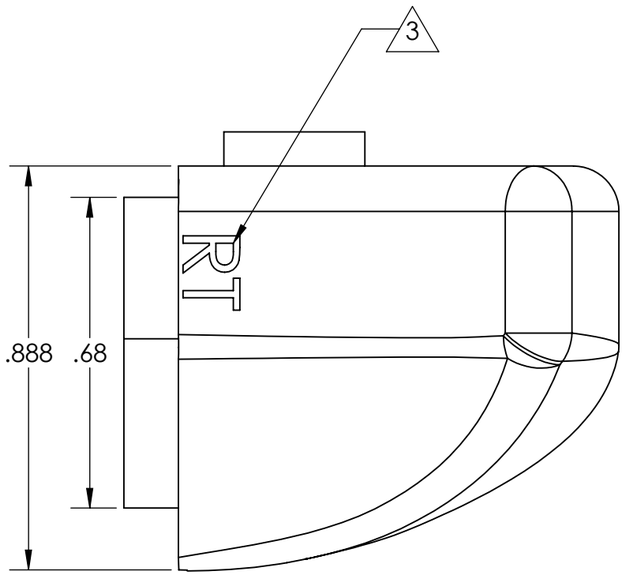
△3 DIPLAY TEXT APROXIMATELY AS SHOWN

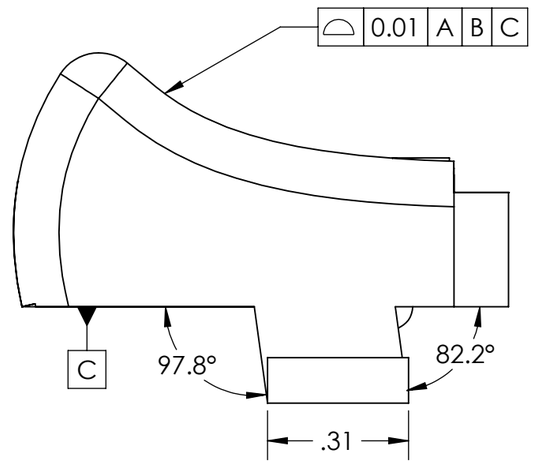
TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS:	X.X° 1°		
MATERIAL ABS		DESCRIPTION LEFT TRIGGER	
FINISH NONE		PN 205	REV A
			SHEET 1 of 1

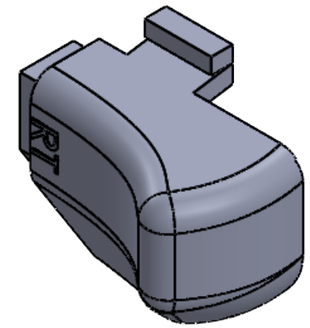
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

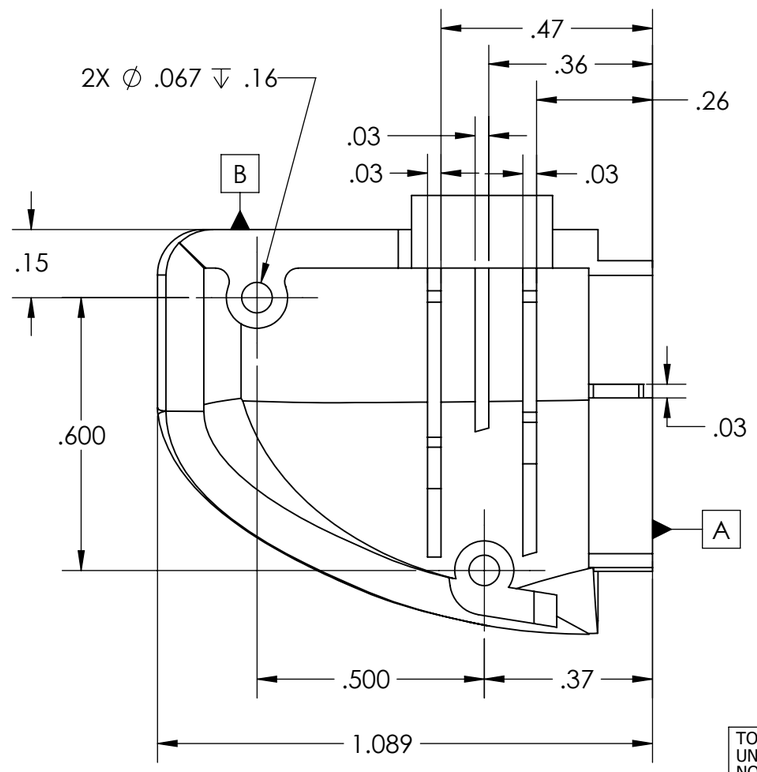
NOTES:
1. REFEERNCE MODEL 206 REV B FOR ALL UNSPECIFIED GEOMETRY
2. RADII ARE 0.01" UNLESS OTHERWISE SPECIFIED
3. DISPLAY TEXT APROXIMATELY AS SHOWN

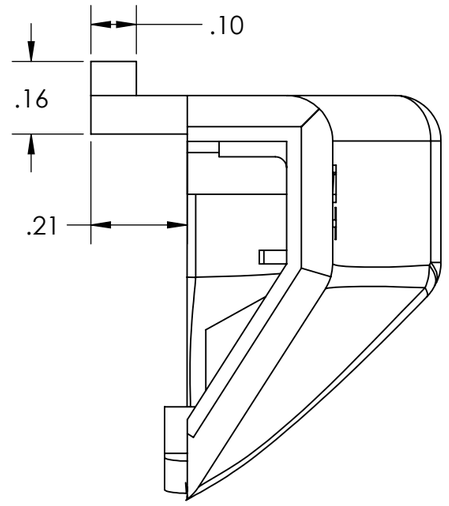
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/23/2024
B	UPDATED NOTES	10/18/2024





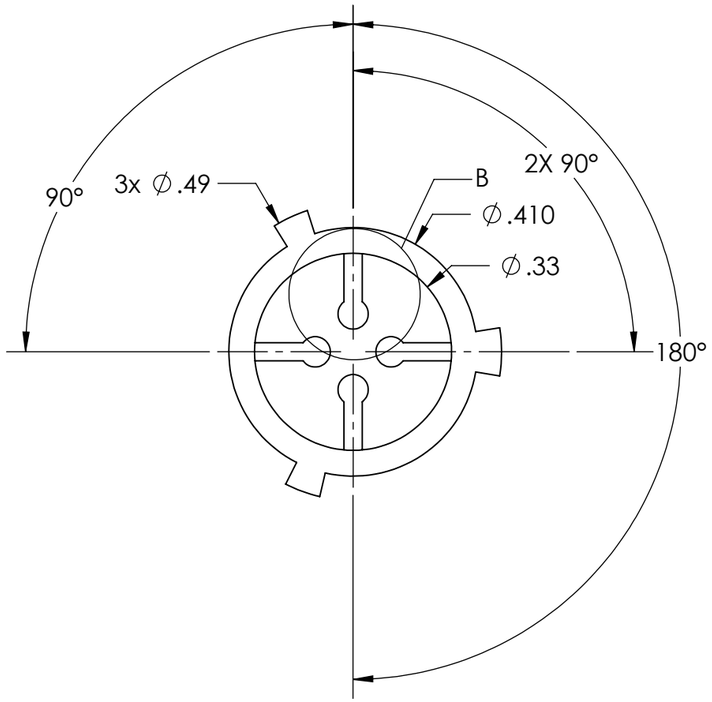


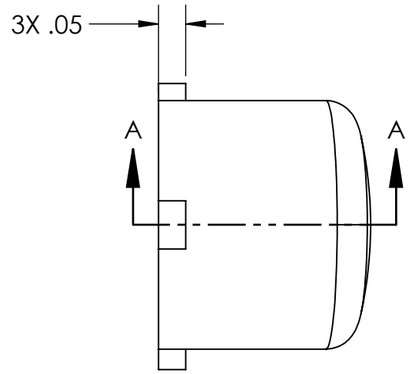


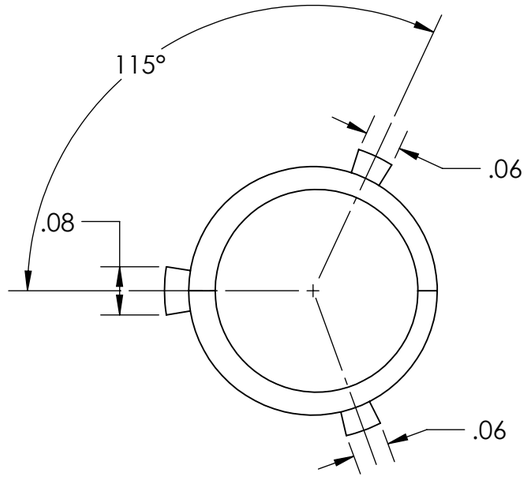


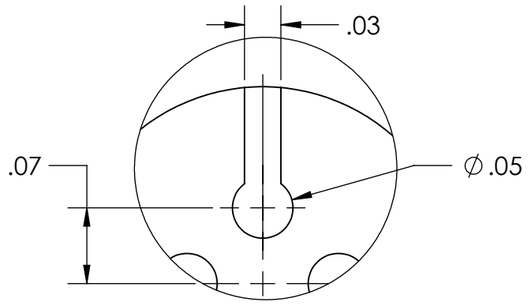
TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005 X.X° ± 0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL: ABS		DESCRIPTION: RIGHT TRIGGER	
FINISH: NONE		PN: 206	REV: B / SHEET: 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024

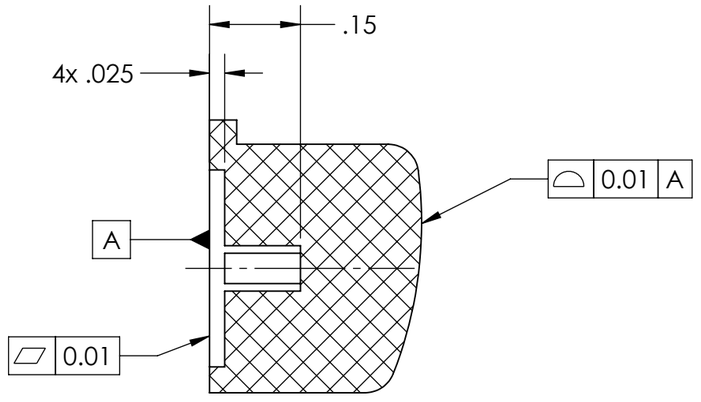




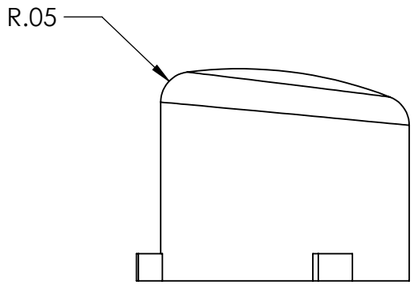




DETAIL B
SCALE 8 : 1
TYP 4 PLACES

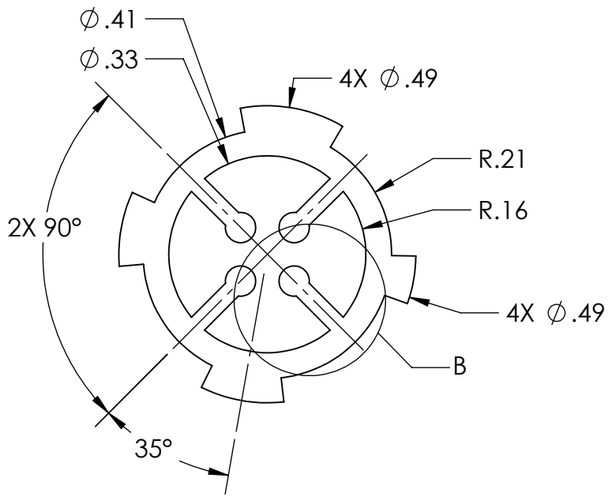


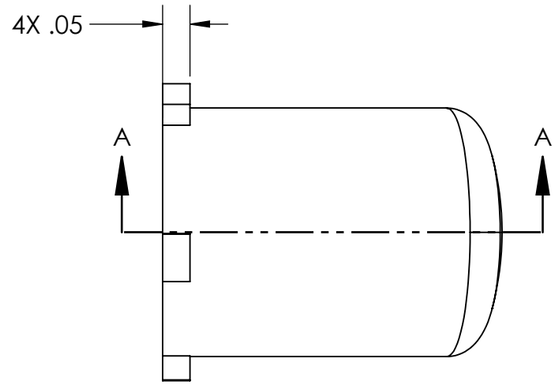
SECTION A-A

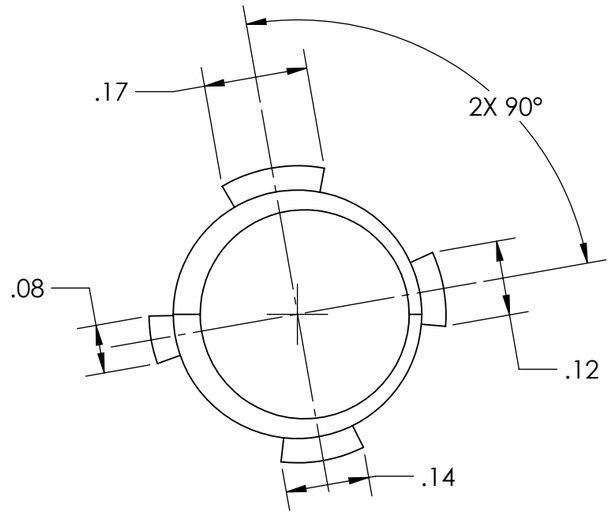


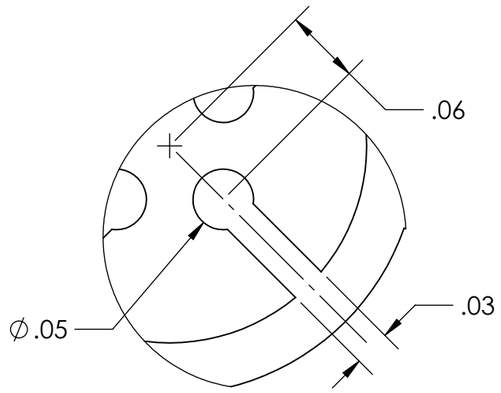
TOLERANCES UNLESS NOTED: X.X ±.030, X.XX ±.010, X.XXX ±.005; UNITS: X.X° 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL: ABS	DESCRIPTION: A BUTTON		
FINISH: NONE	PN: 207	REV: A	SHEET: 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024

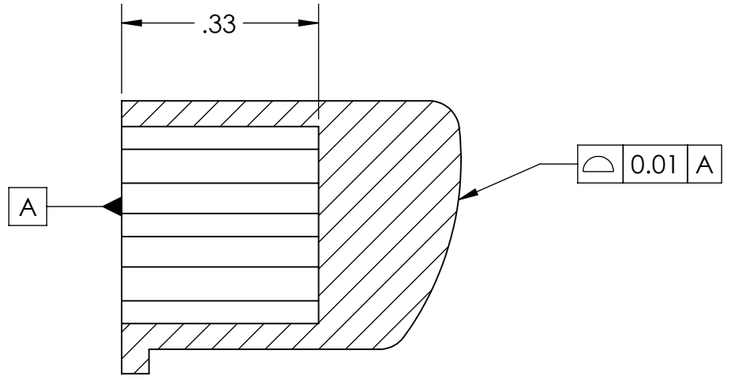




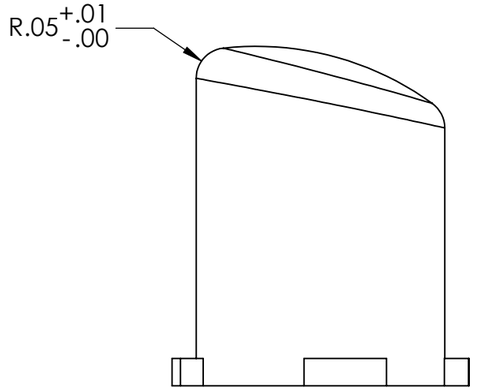




DETAIL B
SCALE 8 : 1
TYP 4 PLACES

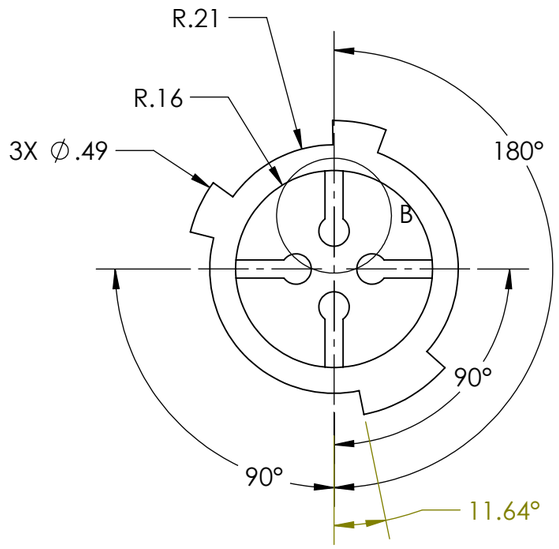


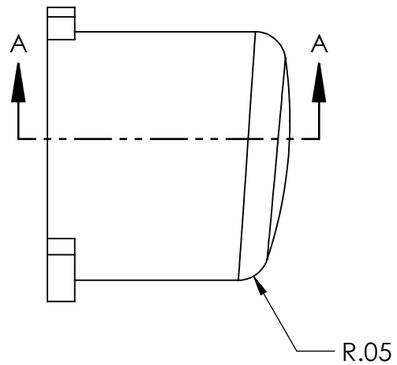
SECTION A-A

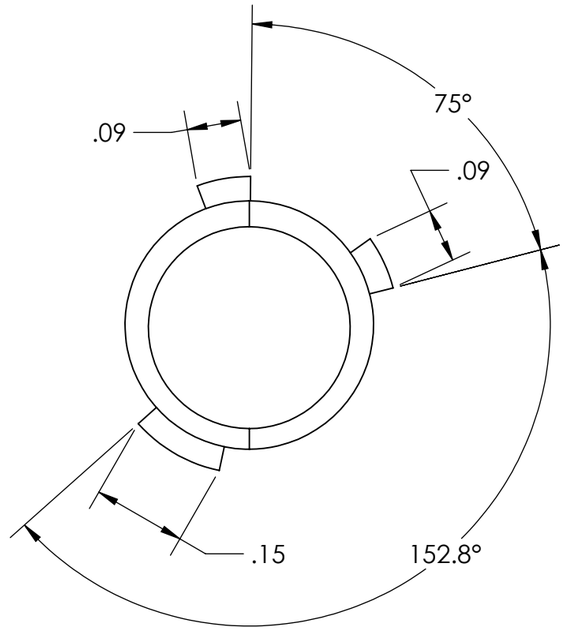


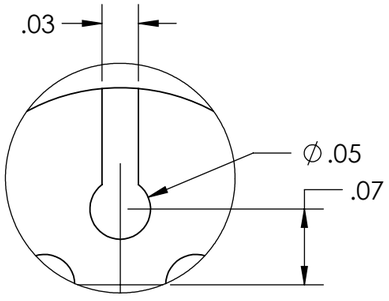
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS:	X.X° 1°				
MATERIAL ABS		DESCRIPTION B BUTTON			
FINISH NONE		PN 208	REV A		SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/14/2024

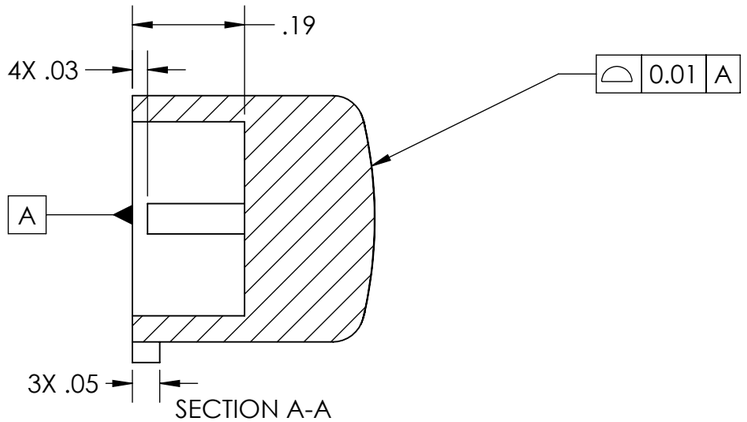








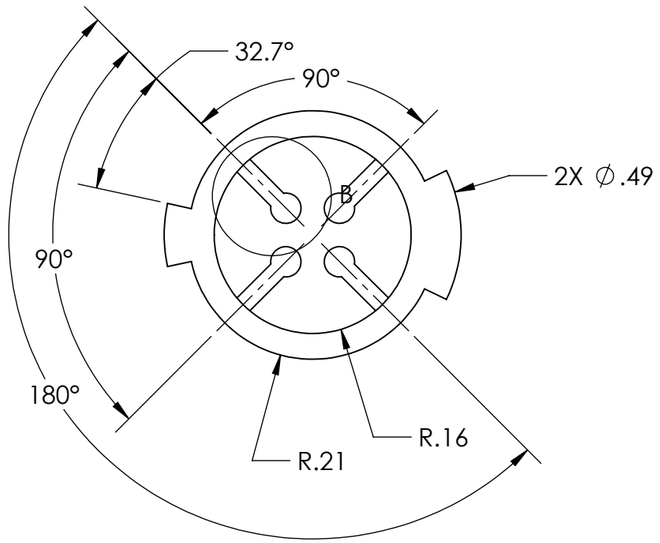
DETAIL B
SCALE 8 : 1
TYP 4 PLACES

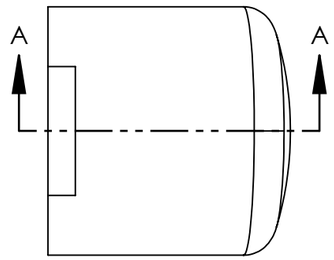


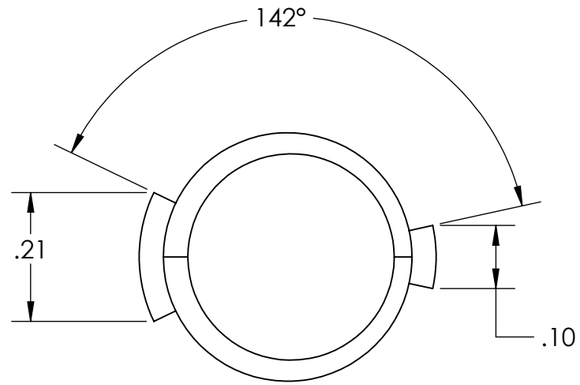
SECTION A-A

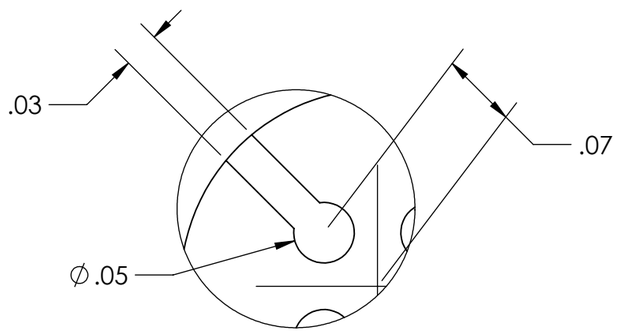
TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS:	X.X° 1°		
MATERIAL ABS		DESCRIPTION X BUTTON	
FINISH NONE		PN 209	REV A
			SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/14/2024

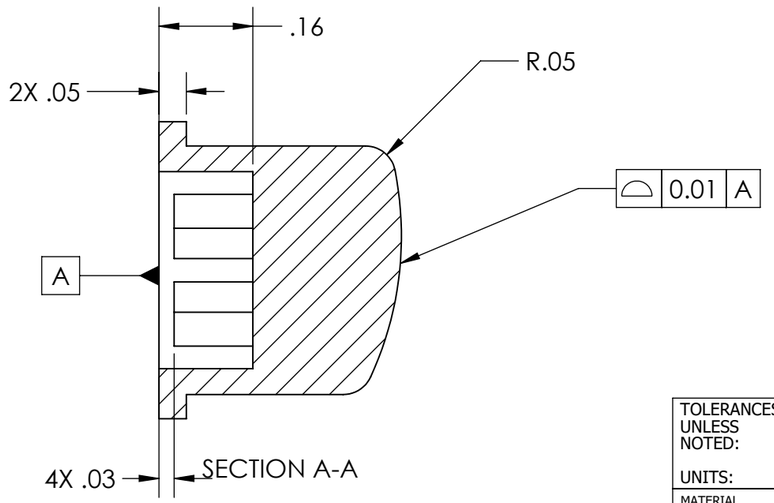






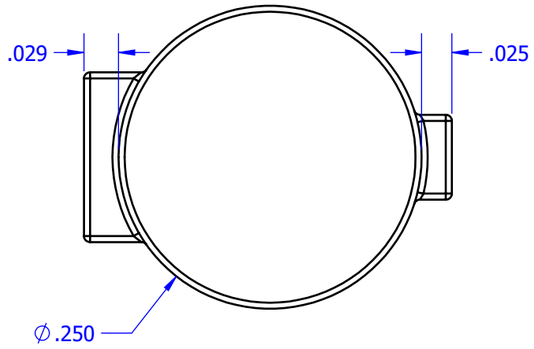


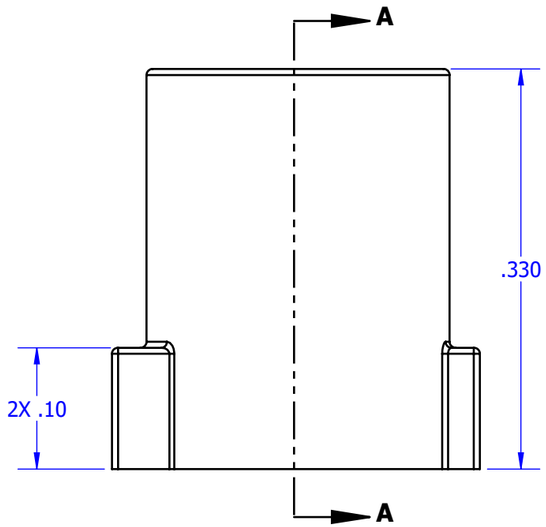
DETAIL B
SCALE 8 : 1
TYP 4 PLACES

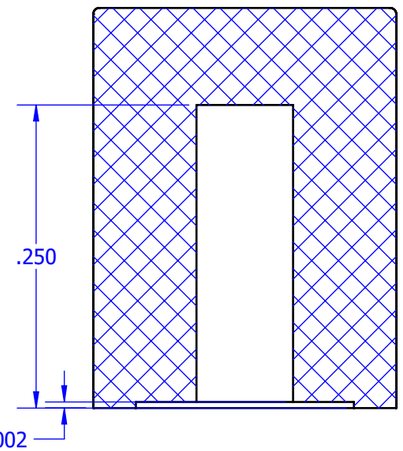


TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
UNITS:	X.X° 1°			
MATERIAL ABS		DESCRIPTION Y BUTTON		
FINISH NONE		PN 210	REV A	SHEET 1 of 1

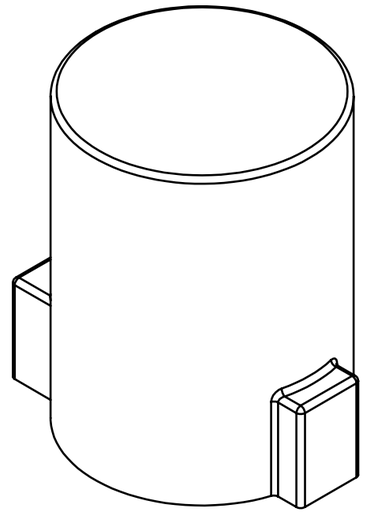
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/22/2024

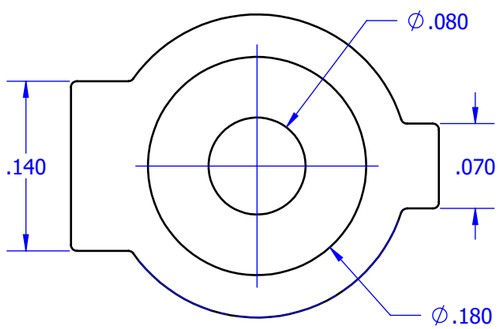






SECTION A-A

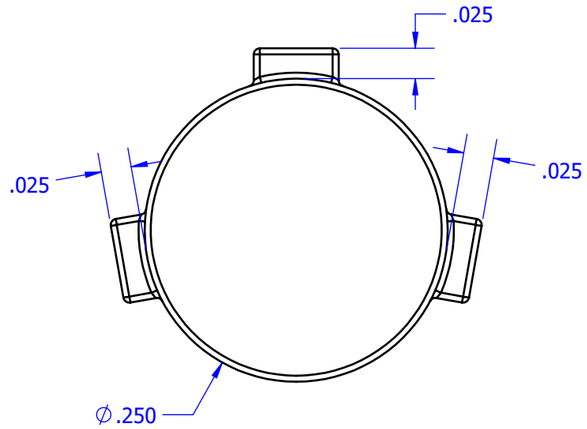


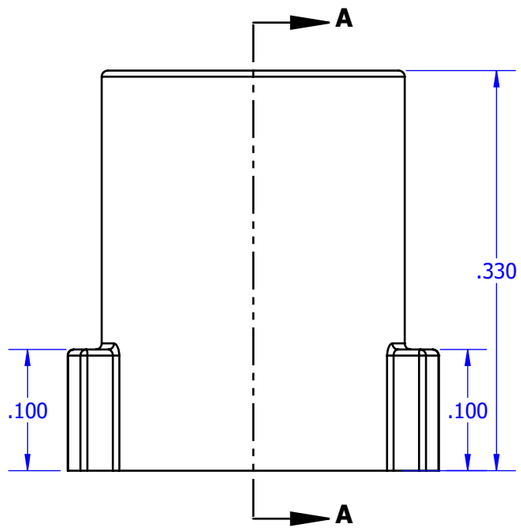


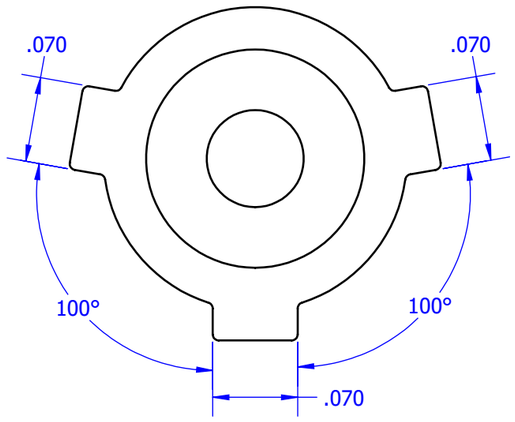
NOTES:
1. UNLESS OTHERWISE MARKED, ALL RADII ARE 0.005"

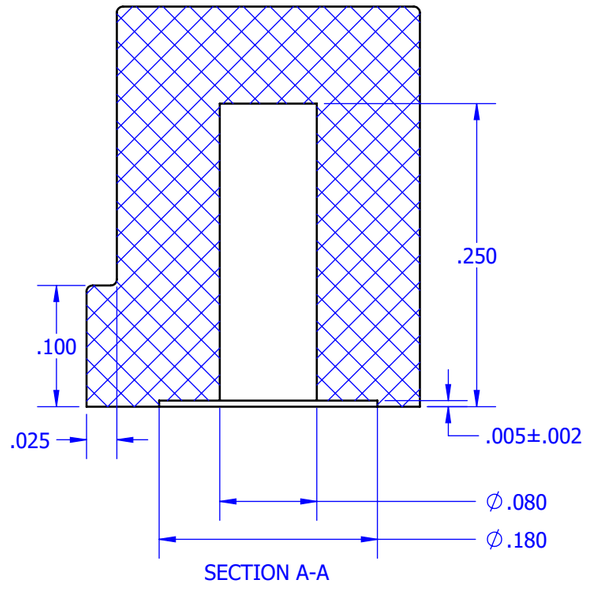
TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005	UNIVERSITY OF COLORADO LUKE JENSEN 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 0.5°		
MATERIAL: ABS		DESCRIPTION: VIEW BUTTON (SELECT)	
FINISH: NONE		PN: 211	REV: A / SHEET: 1 of 1

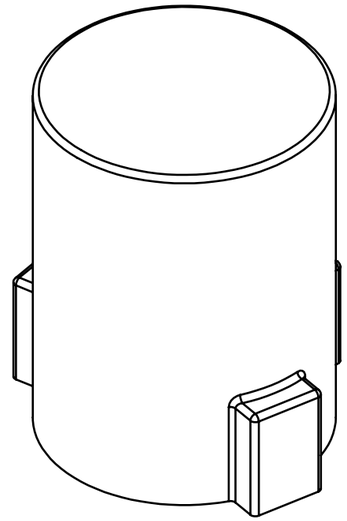
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/10/2024







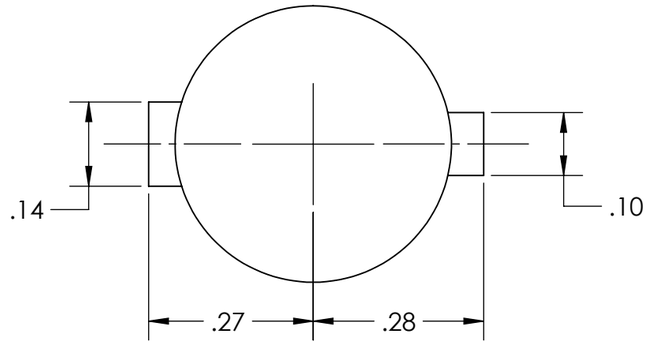


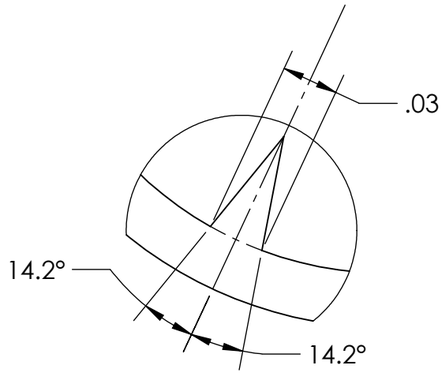


NOTES:
1. UNLESS OTHERWISE MARKED, ALL FILLETS ARE 0.005"

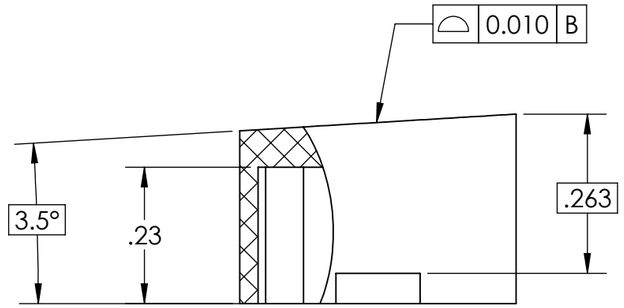
TOLERANCES UNLESS NOTED: X.X ± 0.05, X.XX ±0.01, X.XXX ±0.005, X.X° 0.5 °	UNIVERSITY OF COLORADO LUKE JENSEN 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES		
MATERIAL: ABS	DESCRIPTION: START BUTTON	
FINISH: NONE	PN: 212	REV: A / SHEET: 1 of 1

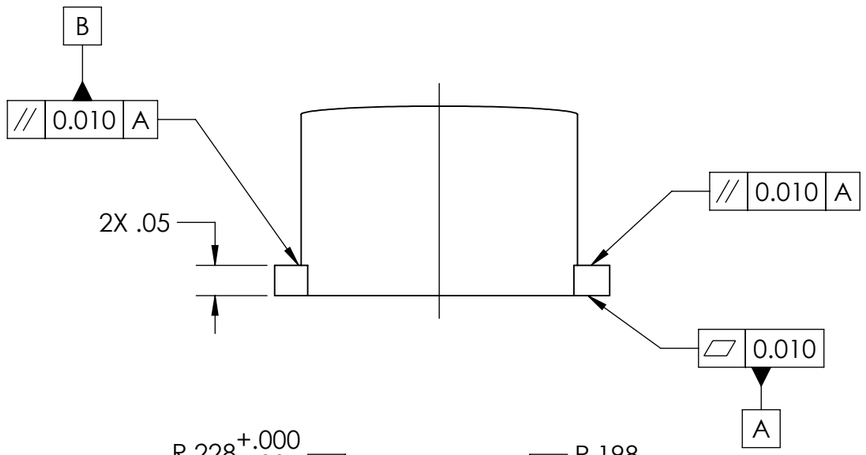
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/23/2024
B	UPDATED ANNOTATION TO INCLUDE GEOMETRIC TOLERANCES AND REVISED NOTE BLOCK. UPDATED MAIN BODY DIAMETER AND TRAVEL STOP HEIGHT. UPDATED PN.	9/23/2024
C	REMOVED NOTES	10/15/2024

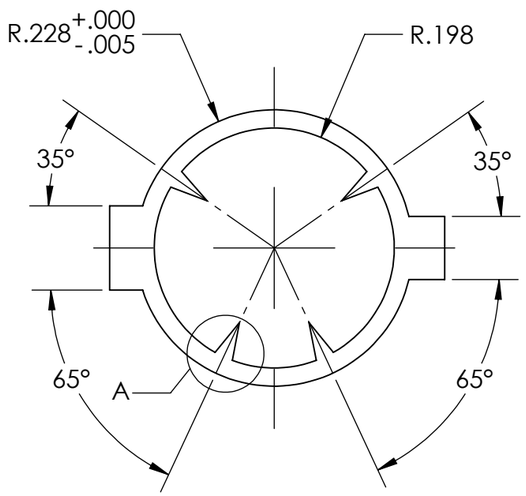




DETAIL A
SCALE 12 : 1
TYP 4 PLACES

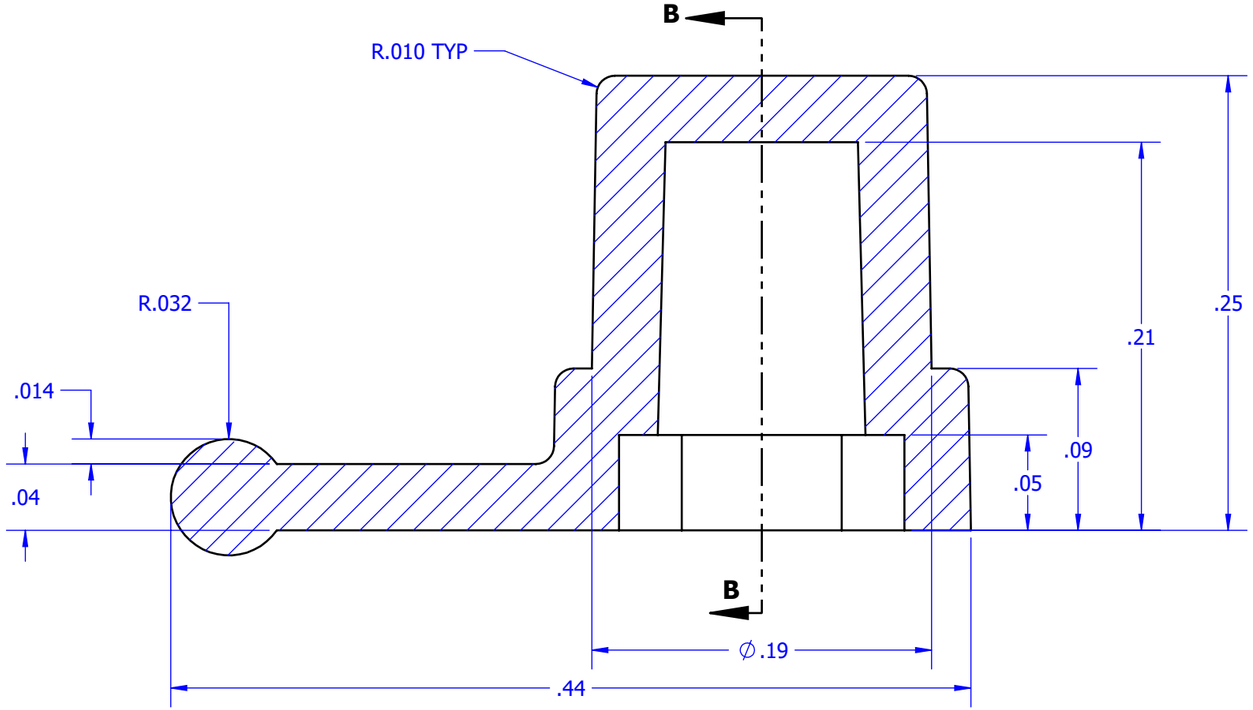


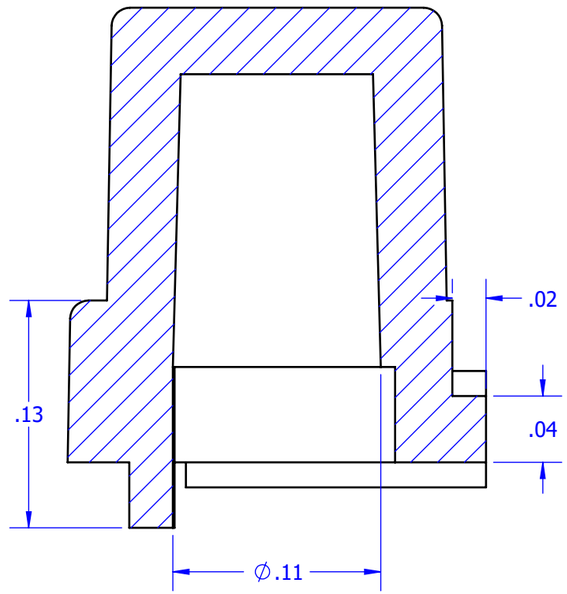




TOLERANCES UNLESS NOTED: X.X ± .030, X.XX ± .010, X.XXX ± .005, X.X° 1.0°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
UNITS: INCH			
MATERIAL: ABS	DESCRIPTION: XBOX BUTTON		
FINISH: NONE	PN: 213	REV: C	SHEET: 1 of 1

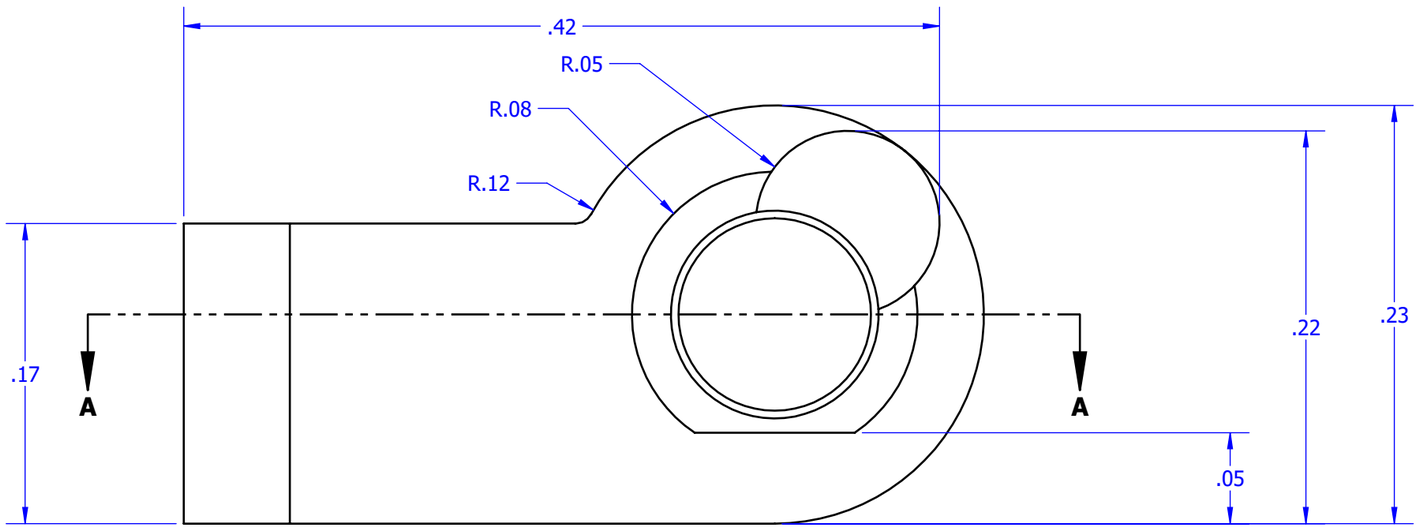
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/18/2024





SECTION B-B
SCALE 12 : 1

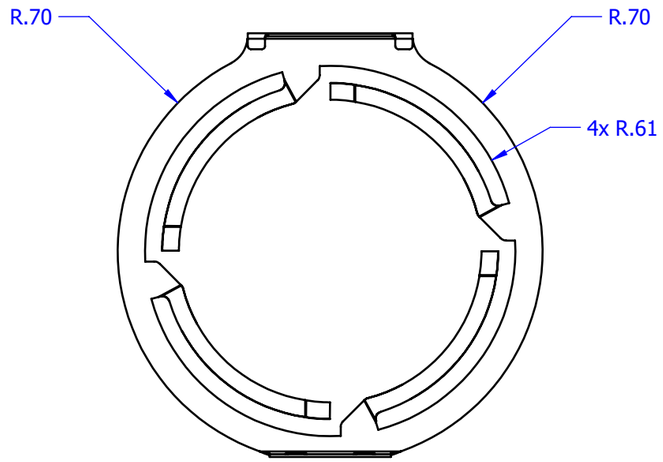
SECTION A-A
SCALE 12 : 1

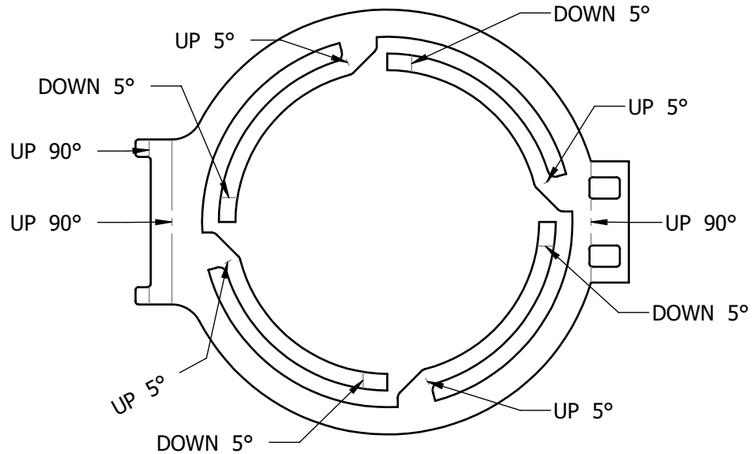


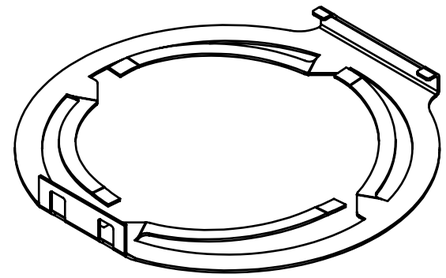
NOTES:
1. ALL DRAFT ANGLES 1 DEG. UNLESS SPECIFIED OTHERWISE.
2. DRAFT REMOVES MATERIAL.
3. 12:1 SCALE UNLESS SPECIFIED OTHERWISE.

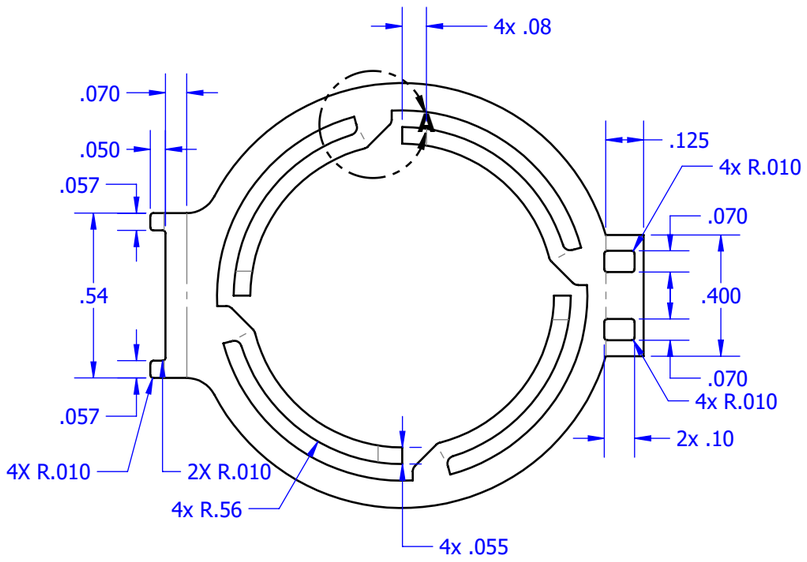
TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 0.5°		
MATERIAL: ABS, BLACK		DESCRIPTION: SYNC BUTTON	
FINISH: NONE		PN: 214	REV: A / SHEET: 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024

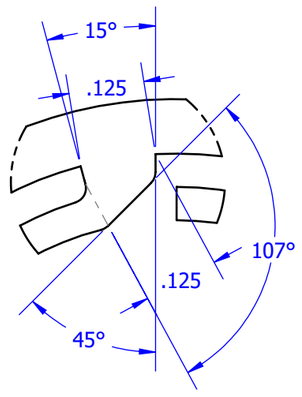








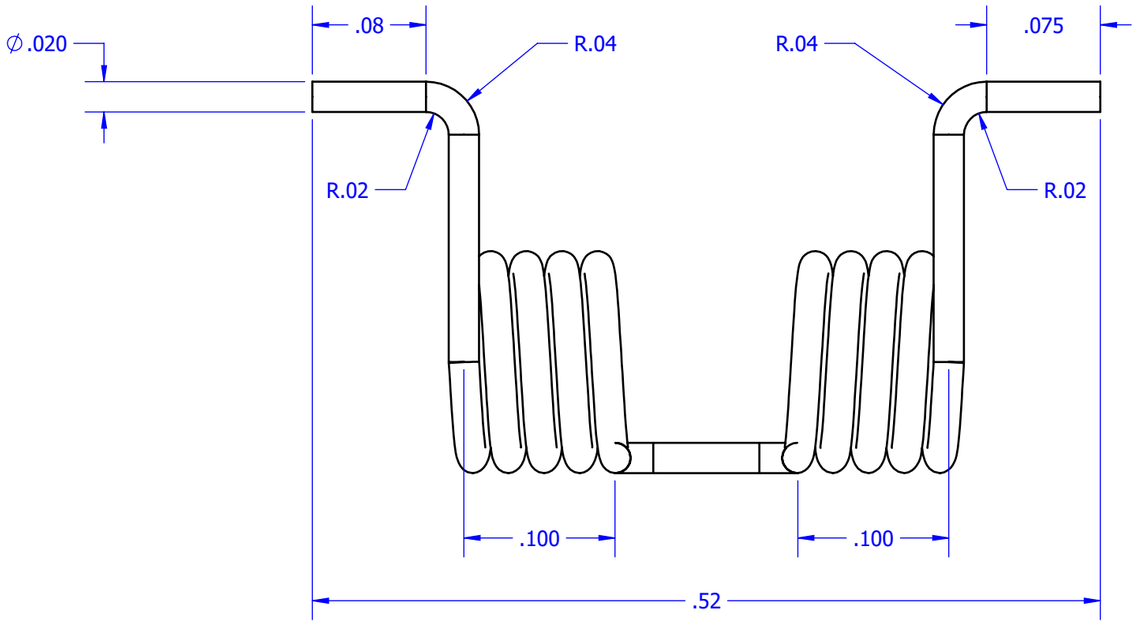
DETAIL A
SCALE 4 : 1

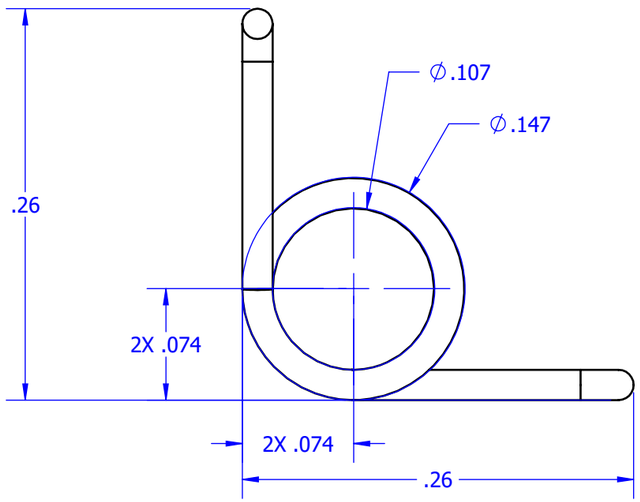


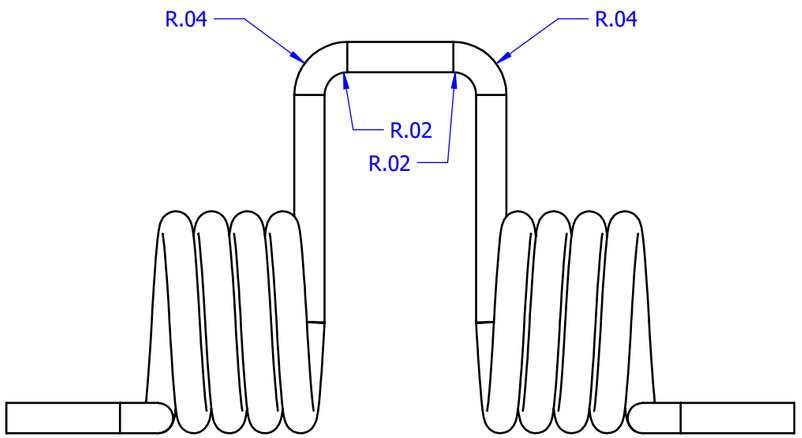
NOTES:
1. INNER ARMS ARE 4X RADIALLY SYMETRIC FEATURES
2. ALL RADII ARE 0.025" UNLESS OTHERWISE MARKED

TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005	UNIVERSITY OF COLORADO LUKE JENSEN 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 0.5°		
MATERIAL SPRING STEEL		DESCRIPTION DPAD SPRING	
FINISH NONE		PN 301	REV A
			SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/10/2024



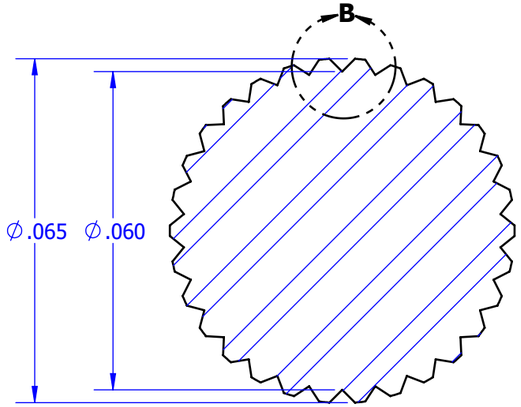




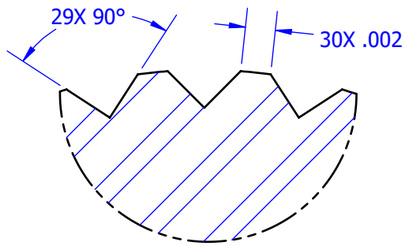
NOTES:
1. ALL DRAWING VIEWS 10:1 SCALE
2. SPRING WIRE DIAMETER IS UNIFORM, 0.020"
3. PITCH OF SPRING IS 0.024"
4. 4.25 REVOLUTIONS ON EACH SIDE.

TOLERANCES UNLESS NOTED: X.X ± 0.05, X.XX ± 0.01, X.XXX ± 0.005; UNITS: INCHES X.X° 0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL: SPRING STEEL	DESCRIPTION: TRIGGER SPRING		
FINISH: NONE	PN: 302	REV: A	SHEET: 1 of 1

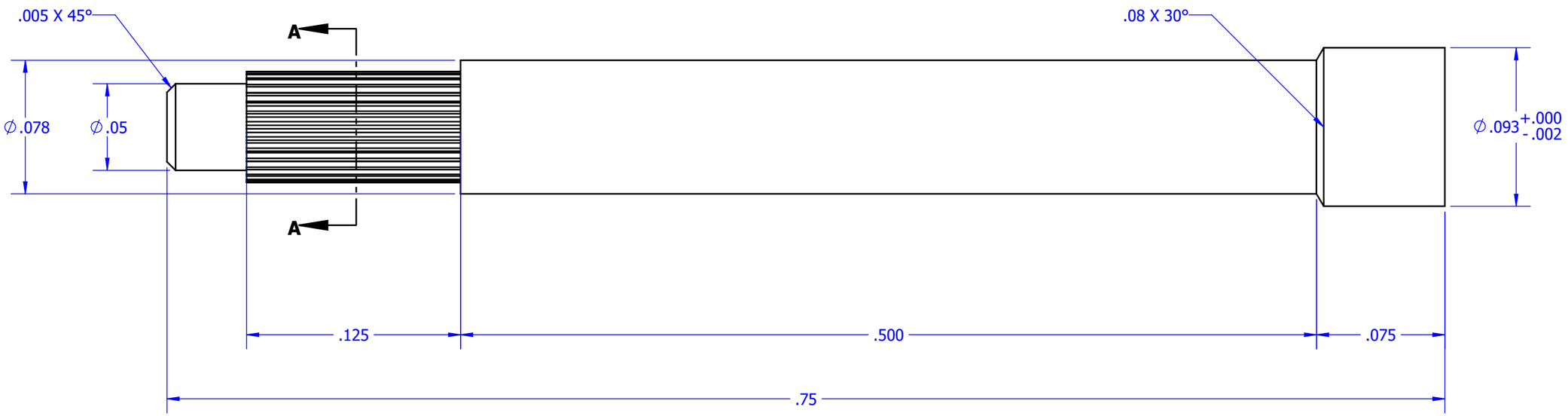
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/11/2024



SECTION A-A
SCALE 35 : 1



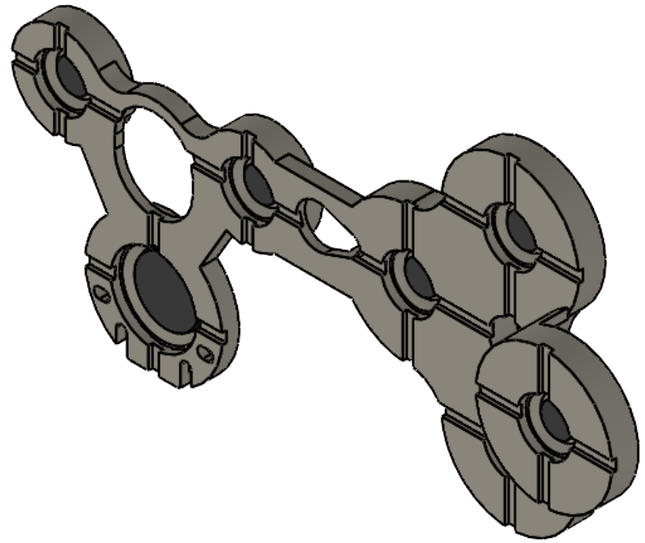
DETAIL B
SCALE 100 : 1

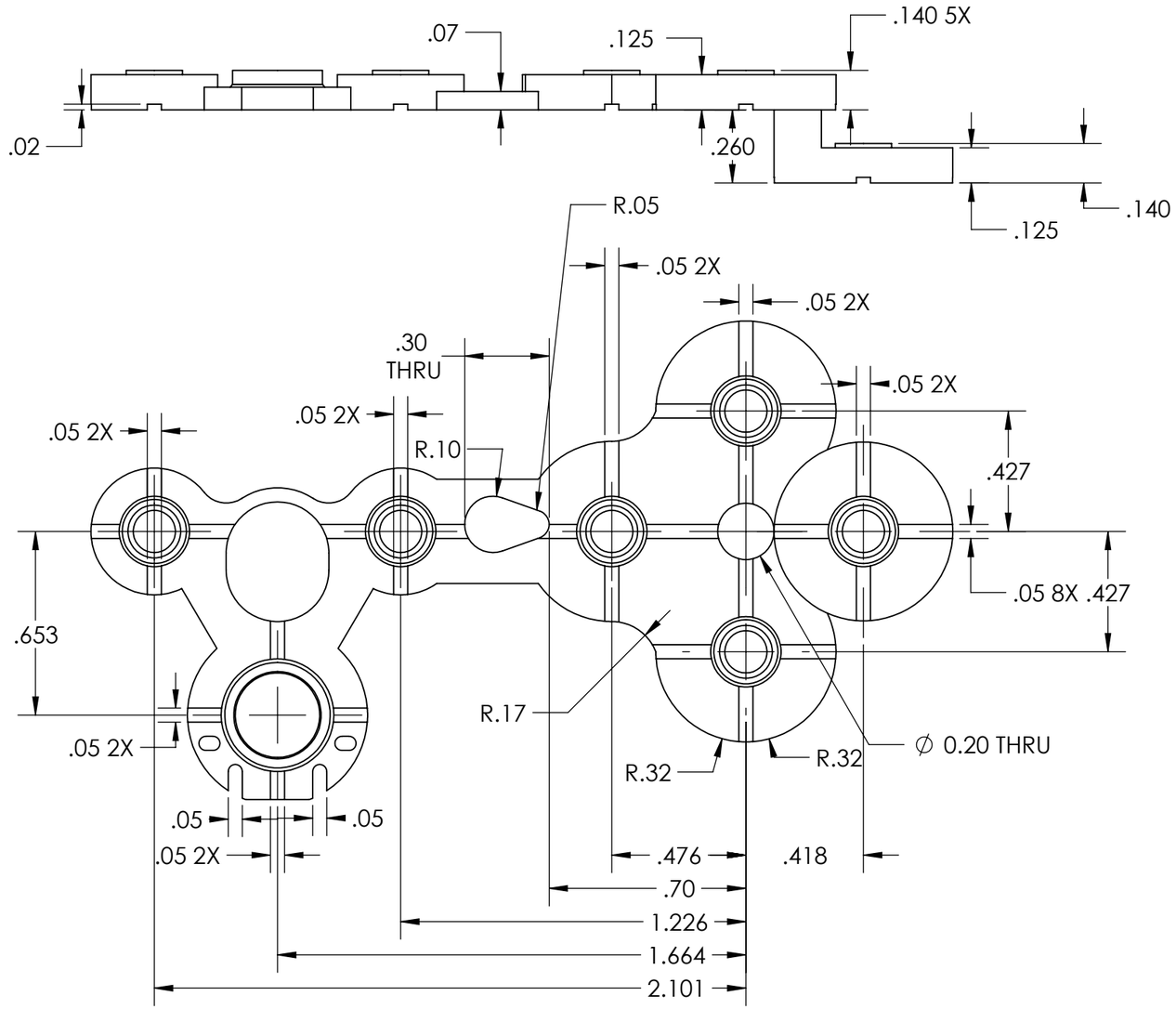


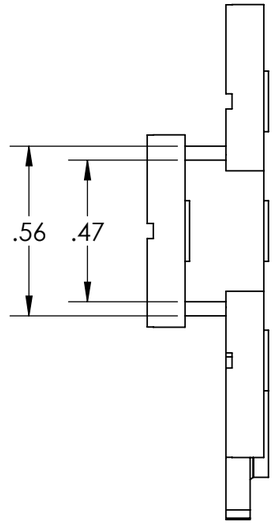
TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO	
UNITS: INCHES	X.X° 0.5°	1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL 304 SS		DESCRIPTION TRIGGER PIN	
FINISH NONE		PN 303	REV A
			SHEET 1 of 1

NOTES:
1. REFERENCE MODEL KEYMAT.SLDPRT FOR ANY UNSPECIFIED GEOMETRY
2. SIDEWALL IS 0.04" THICK UNLESS OTHERWISE SPECIFIED

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	09/17/2024

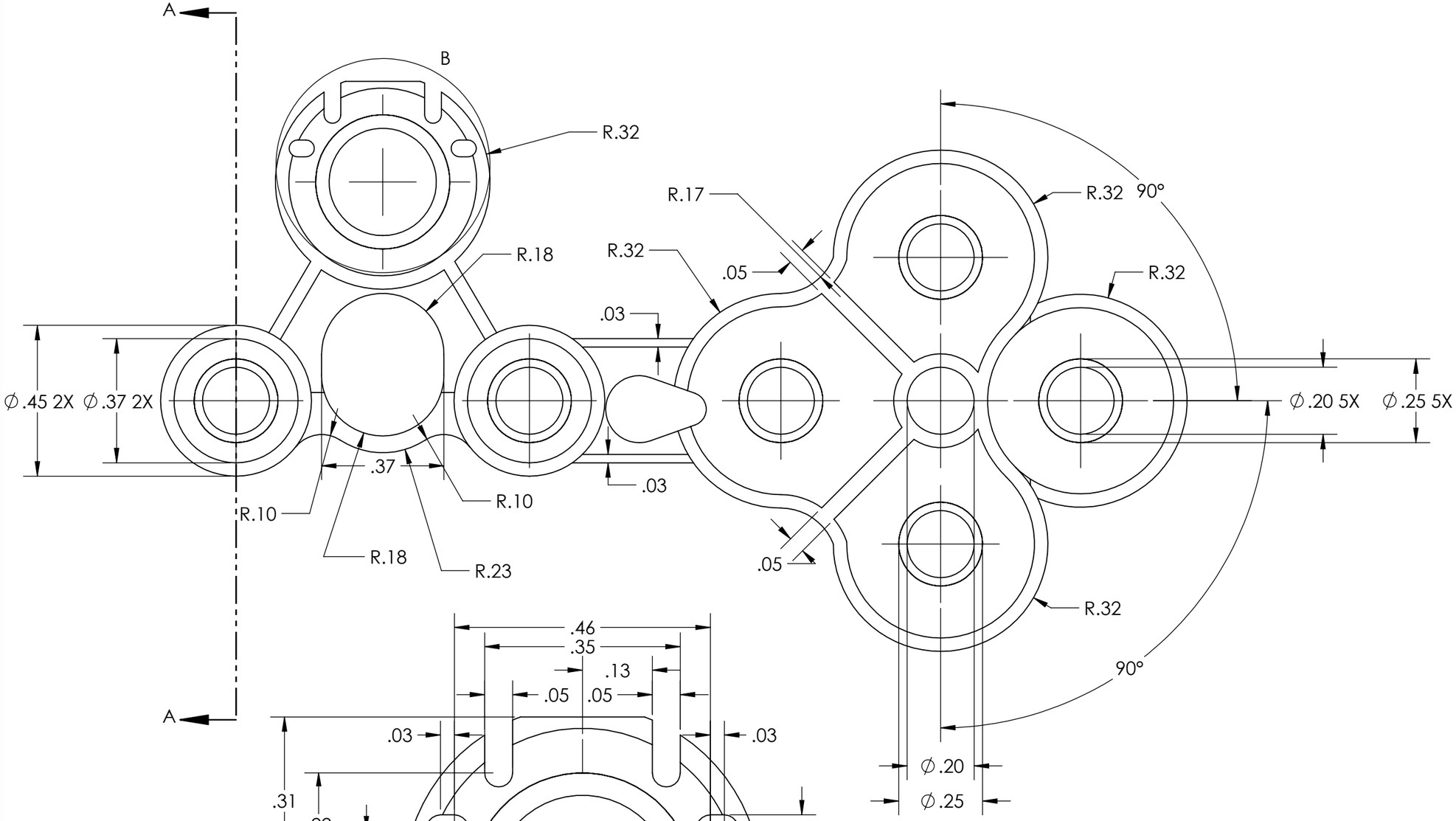


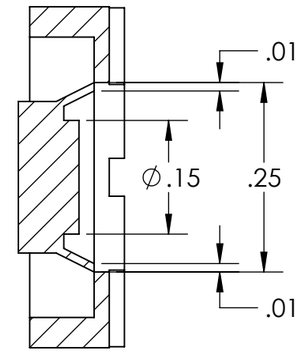




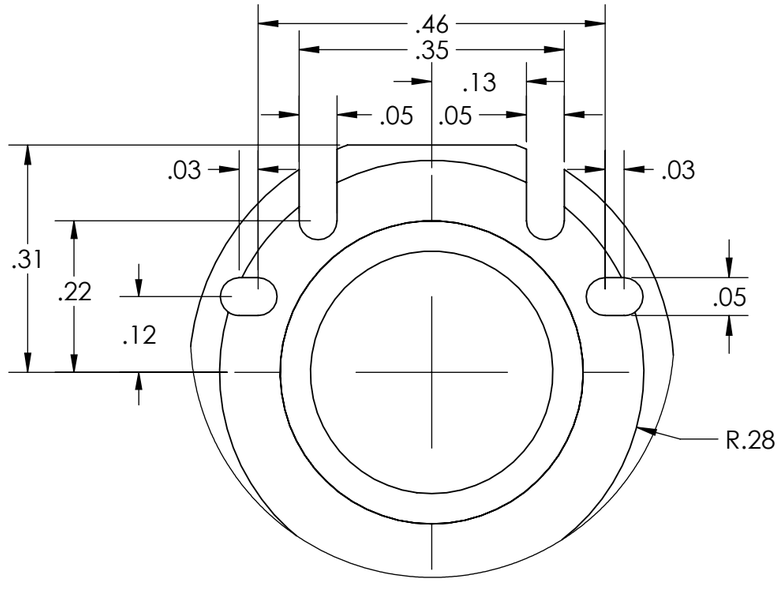
TOLERANCES UNLESS NOTED: X.X ± 0.05, X.XX ± 0.01, X.XXX ± 0.005, X.X° ± 0.5°				
UNITS: INCHES				
MATERIAL: SILICONE RUBBER		DESCRIPTION: KEYMAT		
FINISH: NONE	PN: 304	REV: A		SHEET: 1 of 2

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.





SECTION A-A
SCALE 5 : 1

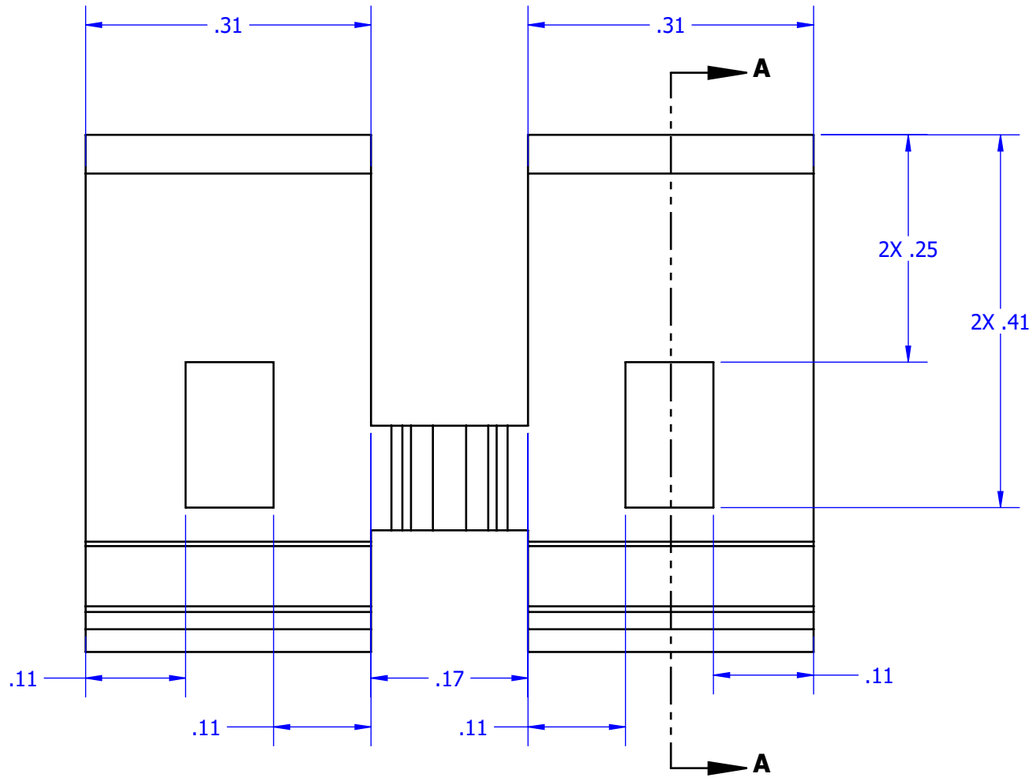


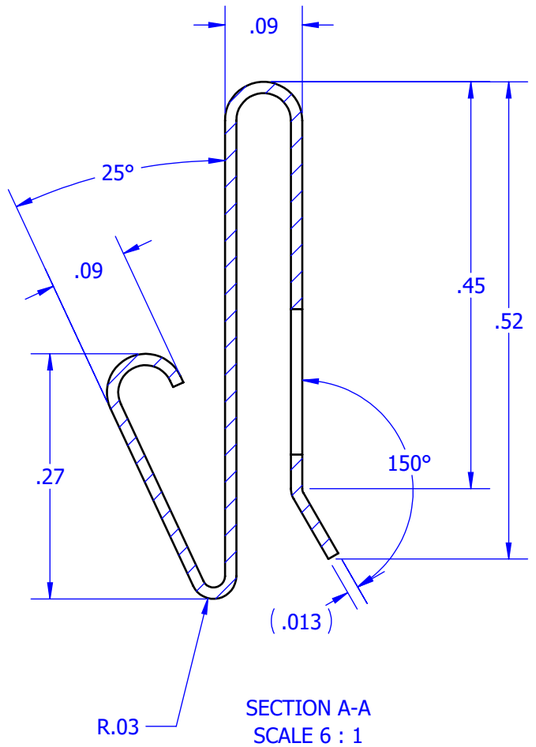
DETAIL B
SCALE 5 : 1

TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ±.05 X.XX ±.01 X.XXX ±.005 X.X° ±0.5°			
MATERIAL Silicone Rubber		DESCRIPTION Keymat		
FINISH N/A		PN 304	REV 1	SHEET 2 of 2

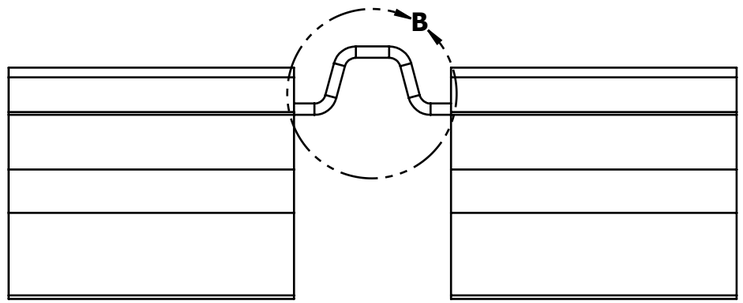
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

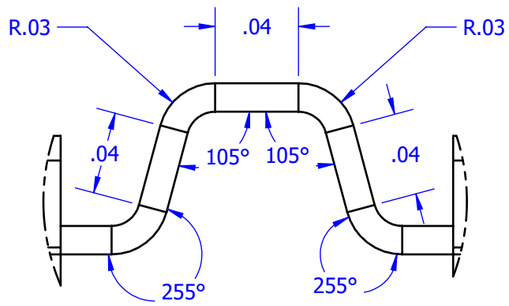
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/11/2024





SECTION A-A
SCALE 6 : 1

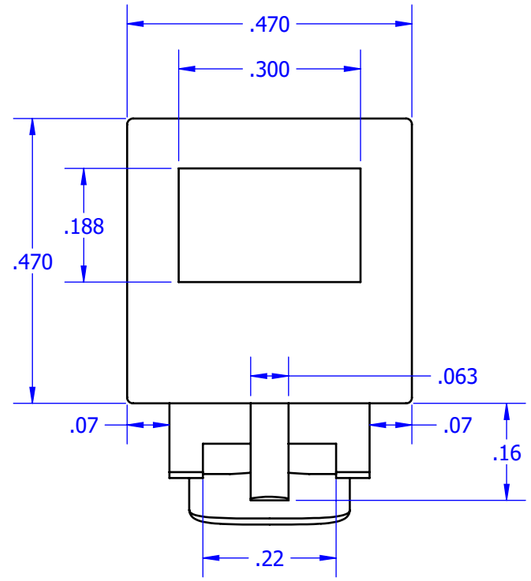


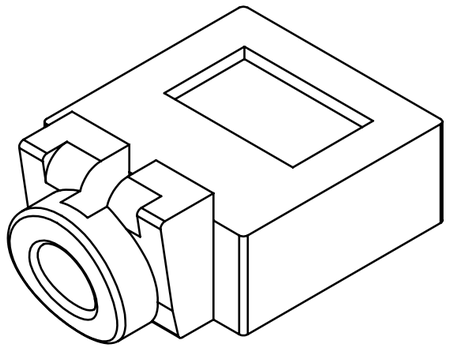


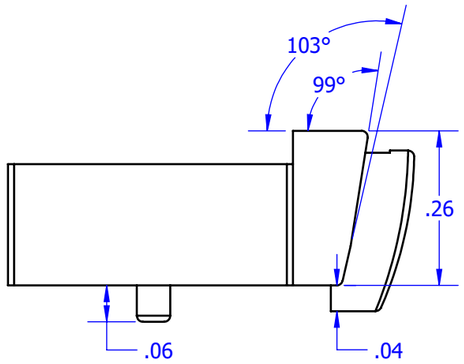
DETAIL B
SCALE 15 : 1

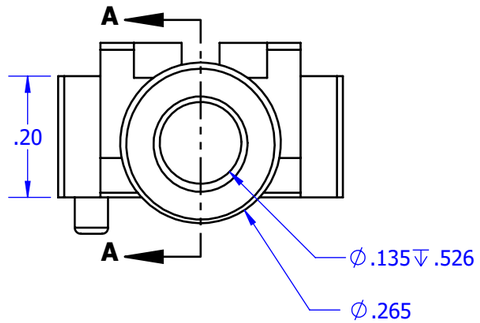
TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° ± 0.5 °		
MATERIAL 20 GA. SPRING STEEL		DESCRIPTION BATTERY TERMINALS	
FINISH NONE		PN 401	REV A
			SHEET 1 of 1

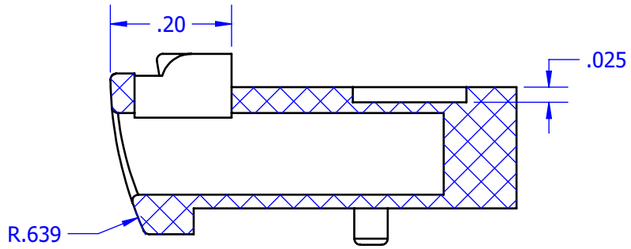
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024



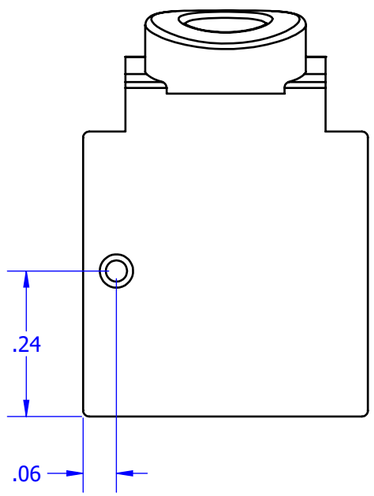








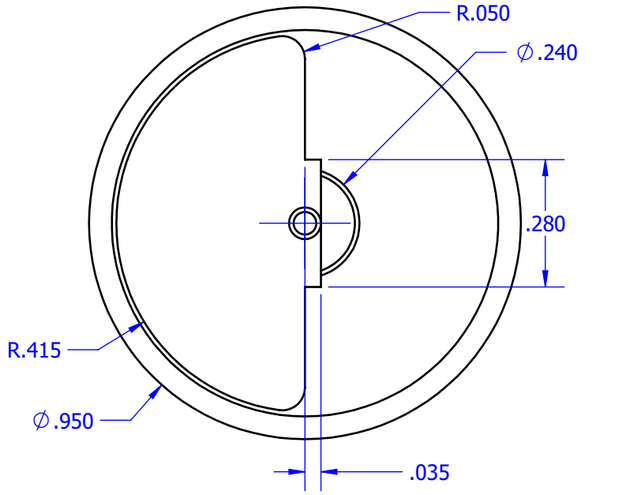
SECTION A-A

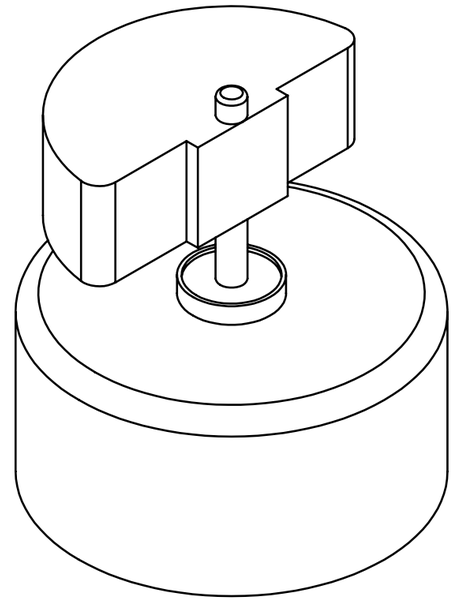


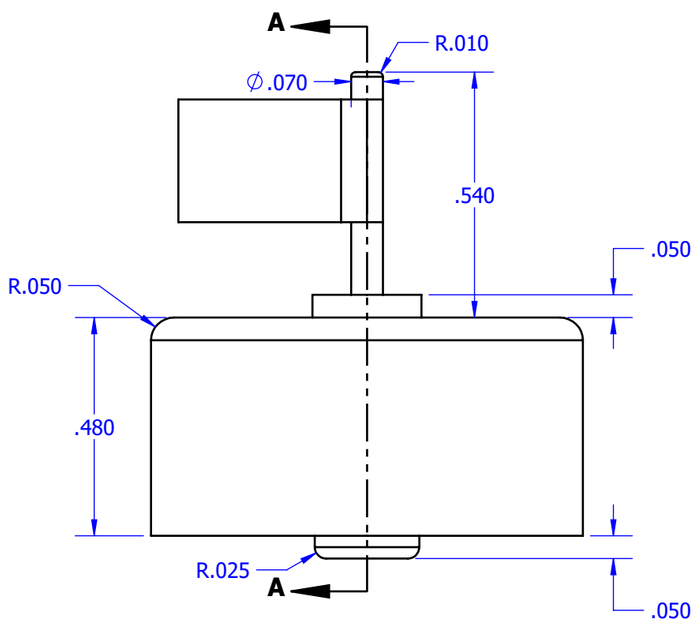
NOTES:
1. ALL FILLETS ARE 0.01" UNLESS OTHERWISE MARKED

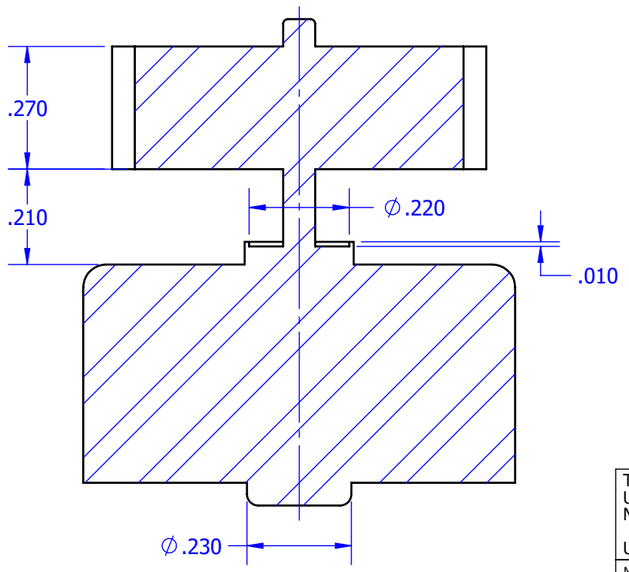
TOLERANCES UNLESS NOTED: X.X ±0.05, X.XX ±0.01, X.XXX ±0.005, UNITS: INCHES X.X° 0.5 °	UNIVERSITY OF COLORADO LUKE JENSEN 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS	DESCRIPTION HEADPHONE JACK	
FINISH NONE	PN 404	REV A / SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	9/17/2024





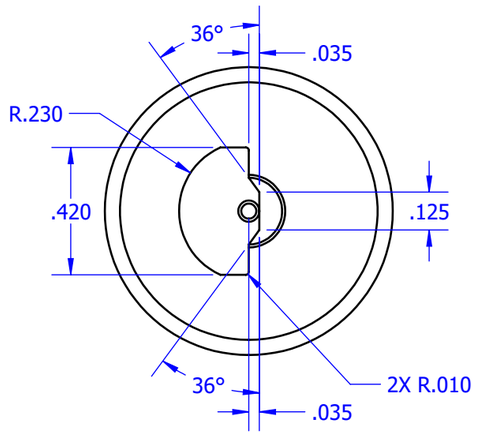


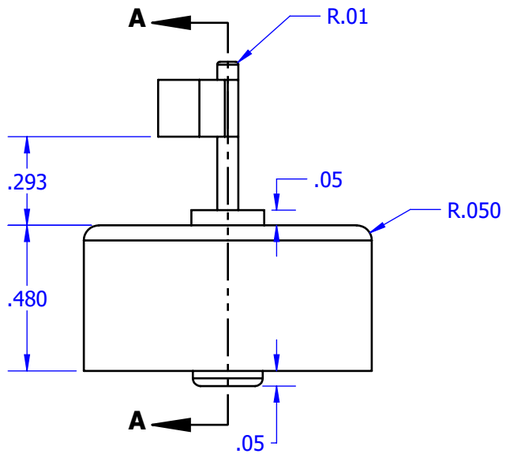


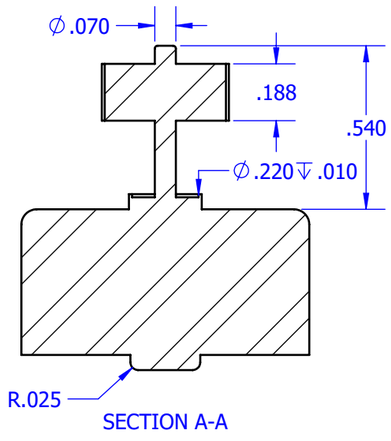
SECTION A-A
SCALE 3 : 1

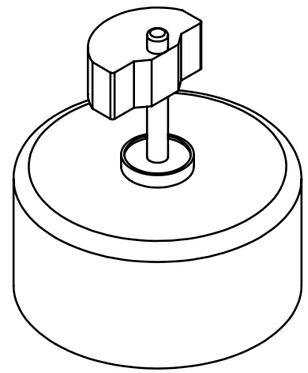
TOLERANCES UNLESS NOTED:	X.X ±0.1 X.XX ±0.05 X.XXX ±0.005	UNIVERSITY OF COLORADO LUKE JENSEN 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS: INCHES	X.X° 0.5 °		
MATERIAL STAINLESS STEEL		DESCRIPTION RUMBLE PACK LARGE	
FINISH NONE		PN 405	REV A
			SHEET 1 of 1

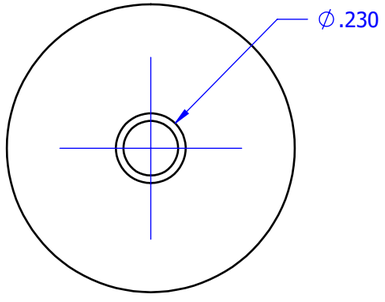
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/12/2024





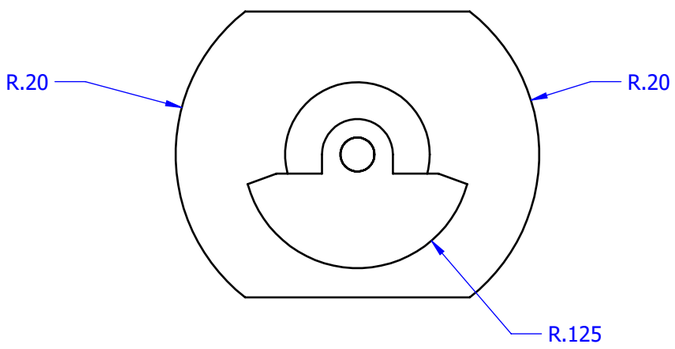


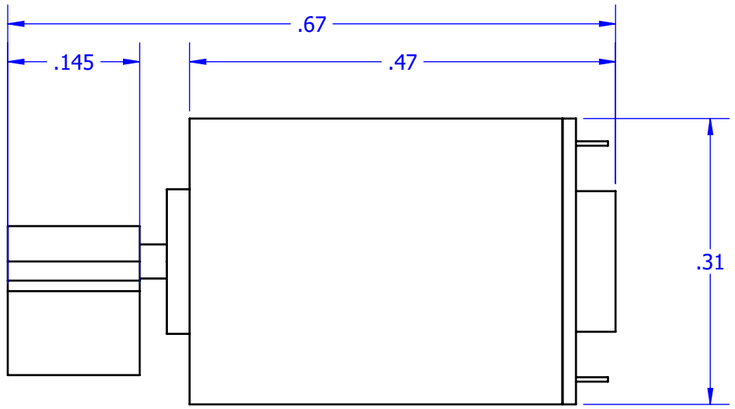


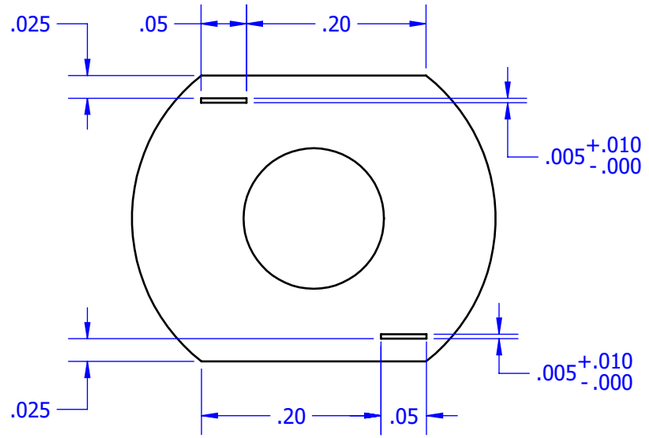


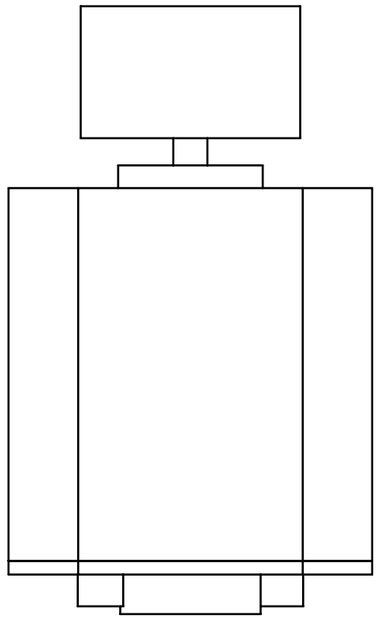
TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± .050 X.XX ± .010 X.XXX ± .005 X.X° 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
MATERIAL STAINLESS STEEL		DESCRIPTION RUMBLE PACK SMALL			
FINISH NONE		PN 406	REV A		SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/11/2024







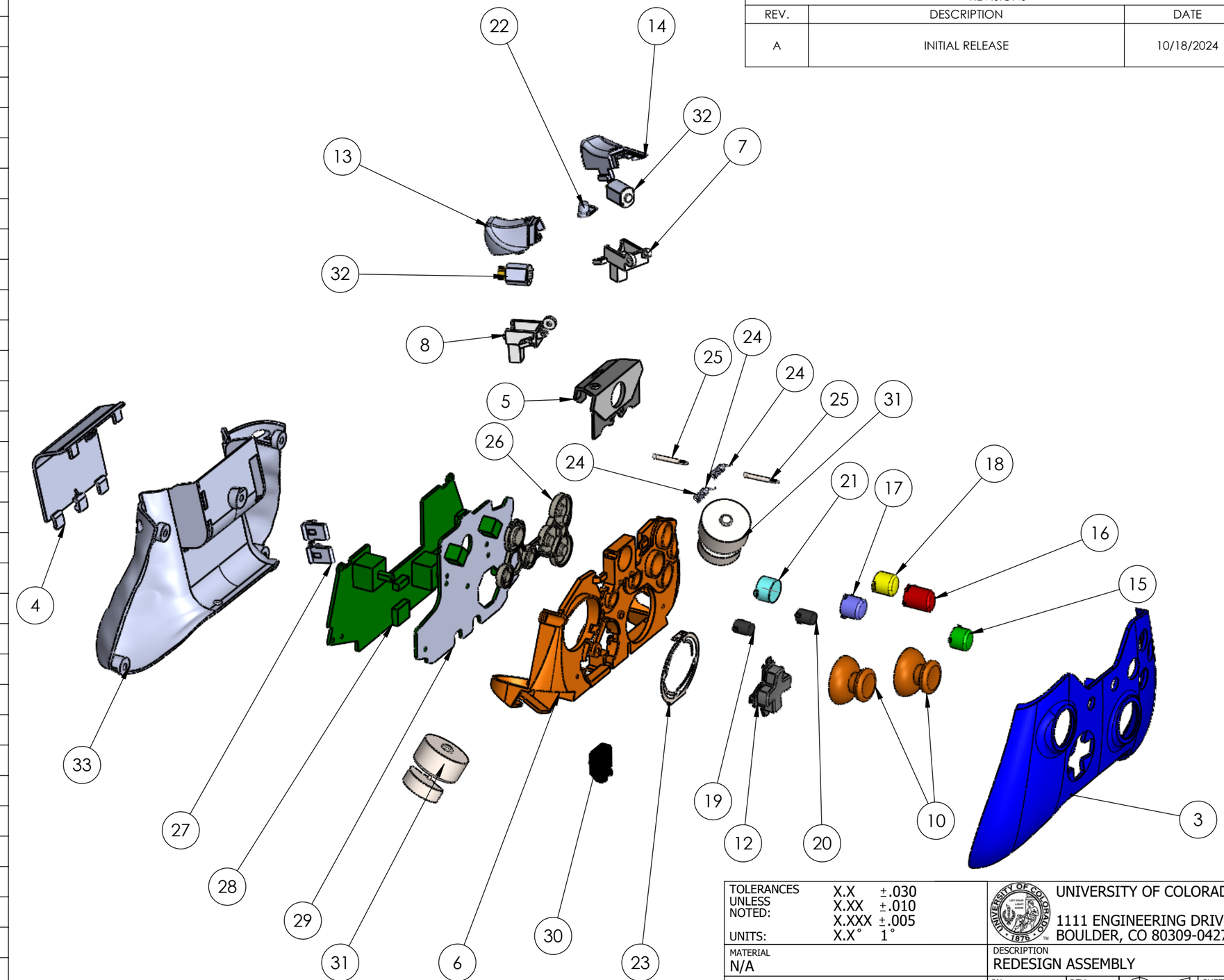


NOTE:
1. INCOMPLETE DRAWING OF ELECTRICAL COMPONENT.
REFER TO 407.STEP REV0 FOR ALL DIMENSIONS.

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005 X.X° 0.5°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ALUMINUM, BRASS, ABS		DESCRIPTION TRIGGER MOTOR	
FINISH NONE		PN 407	REV A SHEET 1 of 1

ITEM NO.	PART NUMBER	QTY.
1	PN 101	1
2	PN 102	1
3	PN 103	1
4	PN 104	1
5	PN 105	1
6	PN 106	1
7	PN 107	1
8	PN 108	1
9	PN 109	1
10	PN 201	2
11	PN 202	1
12	PN 204	1
13	PN 205	1
14	PN 206	1
15	PN 207	1
16	PN 208	1
17	PN 209	1
18	PN 210	1
19	PN 211	1
20	PN 212	1
21	PN 213	1
22	PN 214	1
23	PN 301	1
24	PN 302	2
25	PN 303	2
26	PN 304	1
27	PN 401	1
28	PN 402	1
29	PN 403	1
30	PN 404	1
31	PN 405	2
32	PN 407	2
33	PN 601	1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	10/18/2024



TOLERANCES UNLESS NOTED:	X.X ±.030 X.XX ±.010 X.XXX ±.005	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
UNITS:	X.X° 1°		
MATERIAL N/A		DESCRIPTION REDESIGN ASSEMBLY	
FINISH N/A		PN 602	REV A	SHEET 1 of 1