Reverse Engineering of a KMM Portable Car Vacuum

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MCEN 5045: Design for Manufacturability
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Executive Summary

This comprehensive report examines the reverse engineering of a handheld wireless vacuum, a common household device aimed at providing convenient and efficient cleaning solutions. The analysis begins with an exploration of the economic driving factors influencing the product's design and manufacturing decisions. By understanding these financial motivations and limitations, we gain insight into the cost constraints and market demands that shape the vacuum's development.

Material selection is scrutinized to assess the strengths and weaknesses of the components used in the vacuum. This section highlights how the choice of materials impacts the device's performance, durability, and overall user experience. Through this analysis, we identify opportunities for improvement in material efficiency and cost-effectiveness.

A thorough investigation into the design flaws of the handheld vacuum reveals critical areas where the current model falls short. These flaws are documented with detailed observations, providing a foundation for potential enhancements. The discussion covers mechanical, electrical, and ergonomic aspects, ensuring a holistic evaluation of the device.

The report culminates in a redesign section that focuses on producing a vacuum with enhanced suction power, improved ease of manufacturing, and better material selection. Using data from our material analysis, we propose alternative materials that offer superior performance and durability. The redesign also considers manufacturing processes that can streamline production and reduce costs, thereby making the new model more economically viable.

In addition, the report outlines the steps involved in defining the system plant and selecting an appropriate controller for the vacuum. This phase is crucial for ensuring that the new design operates efficiently and meets performance standards. Our team has scheduled the first test of the redesigned system in two weeks, with plans for iterative refinement based on test results.

Product Description

The KMM Handheld Vacuum Cleaner is a cordless, rechargeable battery operated vacuum cleaner that can also act as a blower. Users activate the vacuum by pressing the power button. This activates the internal motor, and air is pulled in the nozzle on the front of the vacuum, and simultaneously blown out of a nozzle with a screen at the back of the vacuum. There is no speed or direction control.

The vacuum is shown with its attachments and charging cable in Figure 1. The intake nozzle of the vacuum is combined with the collection bin. A filter inside the collection bin prevents dirt and debris from being pulled inside of the vacuum. The collection bin can be easily removed and emptied by twisting it to unlock and pulling it off the front. The attachments simply slide over the nozzle at the front of the collection bin, or inside of the blower nozzle at the back of the device. The internal battery can be recharged by connecting an included USB-C cable to the charging port at the bottom of the handle.

The overall dimensions of the vacuum (with the collection bin attached) are 8.28 x 6.69 x 2.36 inches, with an overall weight of 0.73 pounds. Similar products generally cost somewhere between $30 and $100. The KMM Vacuum is listed at $43.99 on Amazon, near to the low end of the handheld cordless vacuum price range.

Figure 1: KMM Handheld Vacuum Cleaner with Attachments

This product was chosen for reverse engineering because of its simple construction and customer reviews that consistently describe a few of the same issues, such as poor suction, short product life, dirt and debris falling out of the collection bin, and a few other issues. We also set the goal of reducing the number of parts needed and to improve the assembly process.

Black and Glass Box Diagrams

As part of the analysis into the core functions of the vacuum, we generated a Black Box and Glass Box Diagram to break down the inputs and outputs of the overall device and some of its internal components. The vacuum's main inputs are electricity from a USB-C cable, inputs to a push button, and air flowing into the nozzle of the vacuum. After the vacuum is activated, it outputs air from the blower opening at the back of the vacuum, vibrations, sound, a small amount of heat, and light from an LED near the power button. A black box diagram that shows the inputs and outputs is shown in Figure 2.

Figure 2: Black Box Diagram of KMM Vacuum Cleaner

After analyzing the device from the outside, the vacuum was opened to determine which internal components used each of the inputs and where the outputs came from. Inside of the vacuum, there is a battery, DC electric motor, two LEDs (one near the power button; one near the charging port), a vacuum impeller, and a latching button switch. When the USB-C cable is plugged into the charging port, the LED closest to it flashes to indicate that it is charging the battery. After the switch is activated, the battery provides power to the DC motor and the LED near the power button. The motor drives the vacuum impeller, which pulls air in through the intake nozzle and pushes it out of the blower screen at the back of the device. A summary of the inputs and outputs for each of the main internal components were recorded in the Glass Box Diagram shown in Figure 3.

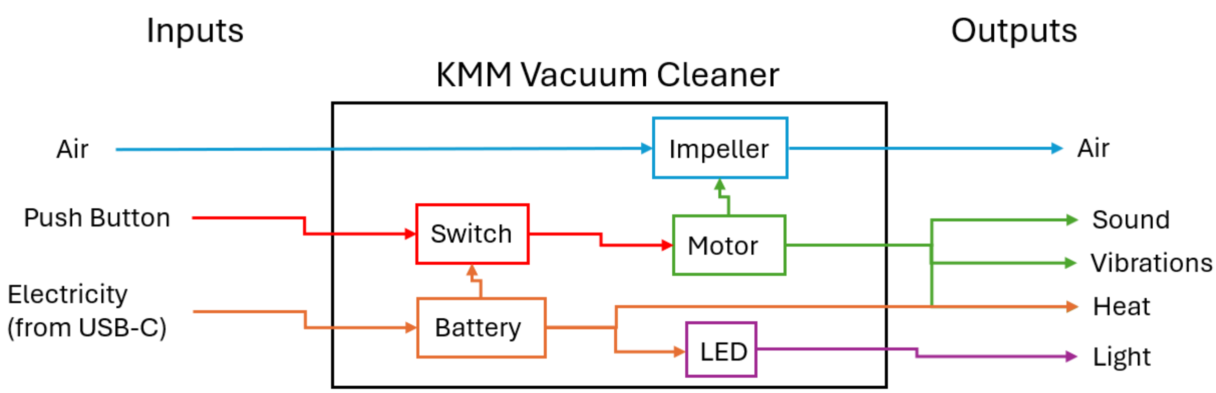


Figure 3: Glass Box Diagram of KMM Vacuum Cleaner

Gantt Chart

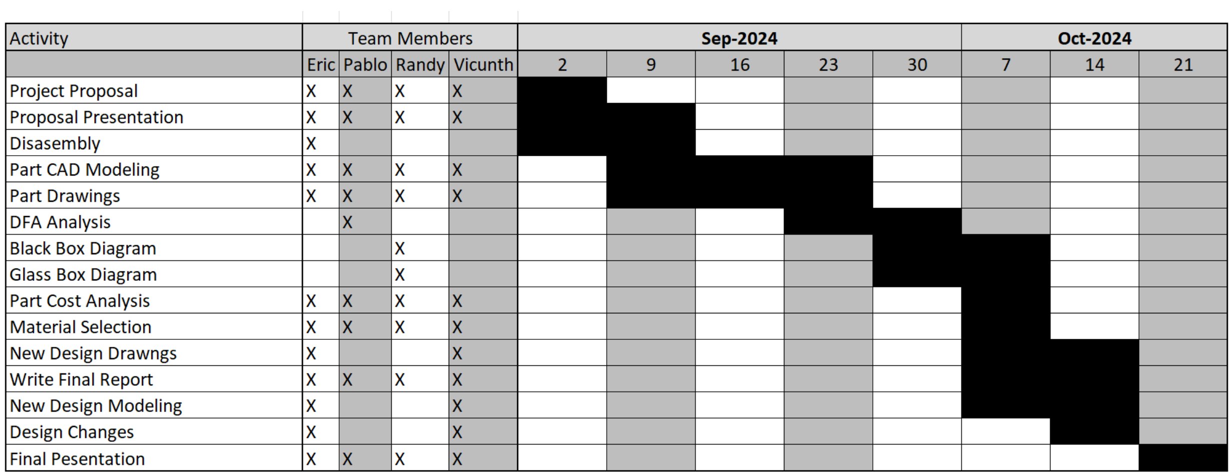


Figure 4: Gantt Chart

The successful completion of any team project hinges on effective planning and regular progress reviews to ensure tasks are completed satisfactorily and on time. Given the duration and the complexity of the reverse engineering process, our team initially devised a comprehensive execution plan, as outlined in Figure 4. This plan was visualized through a Gantt chart, which illustrated the timeline and the sequential tasks necessary for project completion.

After identifying all required tasks, our group allocated specific responsibilities to each team member, ensuring accountability and clarity. The Gantt chart not only displayed the start and end dates for each task but also helped us maintain our schedule and quickly identify any delays. It included scheduled team meetings, typically initiated at the commencement of significant tasks, to discuss required actions and review completed work. These meetings facilitated ongoing progress, ensuring tasks met both quality and timeliness standards.

By adhering to the Gantt chart devised at the project's onset, we aimed to fulfill all necessary steps for the successful reverse engineering of the vacuum. The structured timeline provided by the Gantt chart was instrumental in keeping the team focused and on track, fostering continuous progress towards our project goals.

Fishbone Diagram

The Fishbone Diagram shown in Figure 5 was created to analyze the Vacuum based on how each of its major components fit into assemblies. The Left Side Housing was chosen as the base part because most of the parts can be installed from the top down into this part. The main subassembly inside the vacuum consists of the circuitry and control components that drive the impeller. Most of the remaining components make up the housing assembly, which includes the Blower Screen Subassembly. The three components in the Blower Screen Subassembly can be put together separately before being installed in the base part, so they were assumed to be a single subassembly.

The Air Flow Components are parts that influence the movement of air within the vacuum based on their geometry. The collection bin and blower screen are included in other assemblies, but are also included here as they also make up the main inlet and outlet for the vacuum and blower. The impeller is the main component that influences airflow, excluding the motor that drives it. The Air filter prevents dust and debris from entering the main body of the vacuum (and potentially being blown out of the vacuum), but it also impedes air flow. These components were separated from the others as they uniquely influence the vacuum's capability compared to other parts.

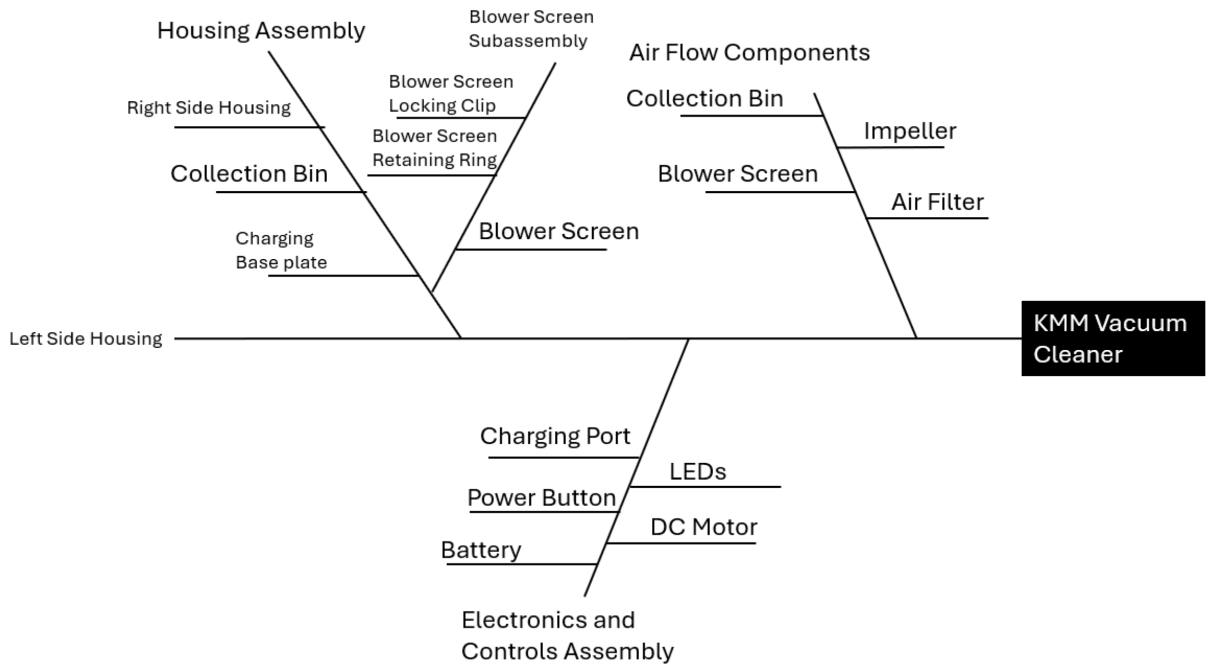


Figure 5: Fishbone Diagram of KMM Vacuum Cleaner

Patent Search

In order to better understand the design criteria for the original design as well as draw inspiration to base our redesigns of the KMM Vacuum Cleaner a patent search of similar products was conducted.

The patent US010433687B2 describes a product similar to the KMM Vacuum in the design idea of a pistol grip for a handheld vacuum instead of the traditional handheld vacuum design which more often than not has a handle at the top and is held as you would a leaf blower. This design feature gives the consumer a more natural feel when using the vacuum and the ability to reach tighter places. A major difference between the KMM vacuum and the one described in this patent is how both approach dust collection. The KMM vacuum uses a detachable bin that is mounted onto the vacuum housing, the patent describes a cyclonic separating unit that is part of the housing and uses a snap-fit latch to be cleaned out. This feature could serve as inspiration for a part reduction, however its complexity is a deterrent.

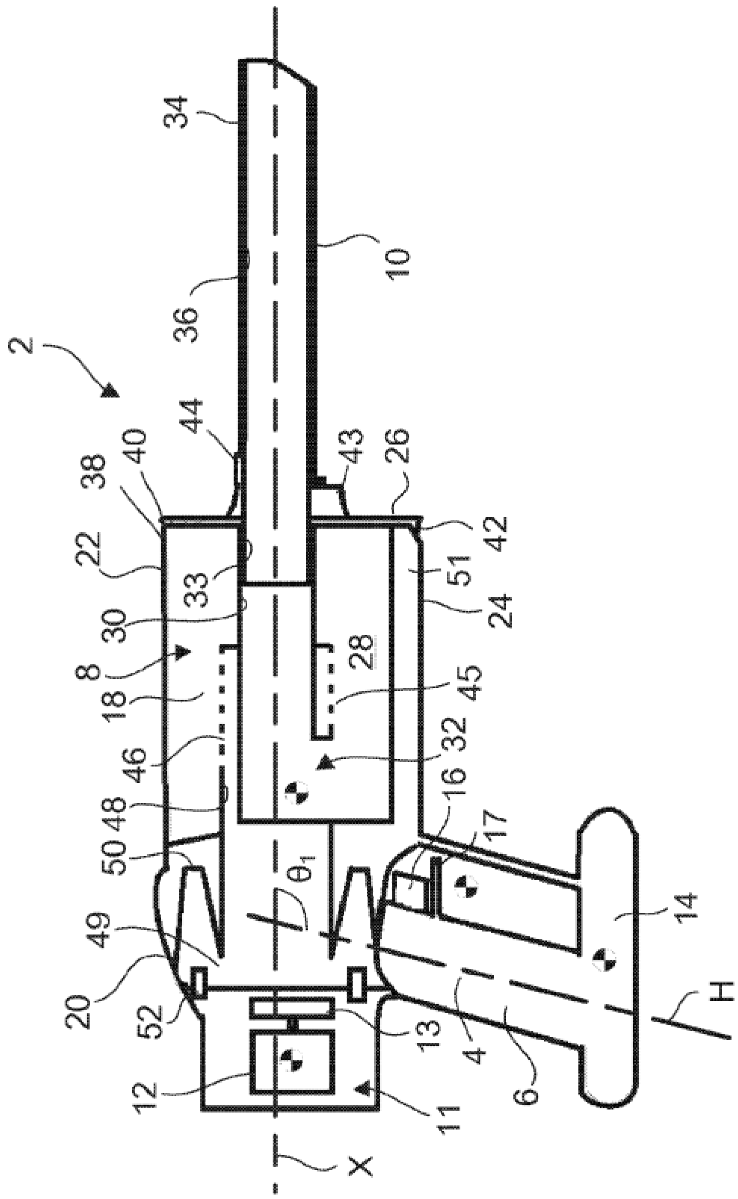


Figure 6: Sketch from US Patent #01059569B2

Another patent that served as a benchmark for the KMM vacuum was US008549704B2. This patent depicts a vacuum with an external bin for dust collection that uses a HEPA filter as a primary filter. The major difference is the addition of a filter cleaning device that is supposed to dislodge particles attached to the filter while the vacuum is being used, providing the user with the opportunity of using the vacuum for longer periods without having to remove the dust bin to clean out the filter. A drawing of the described filter cleaning part is shown below.

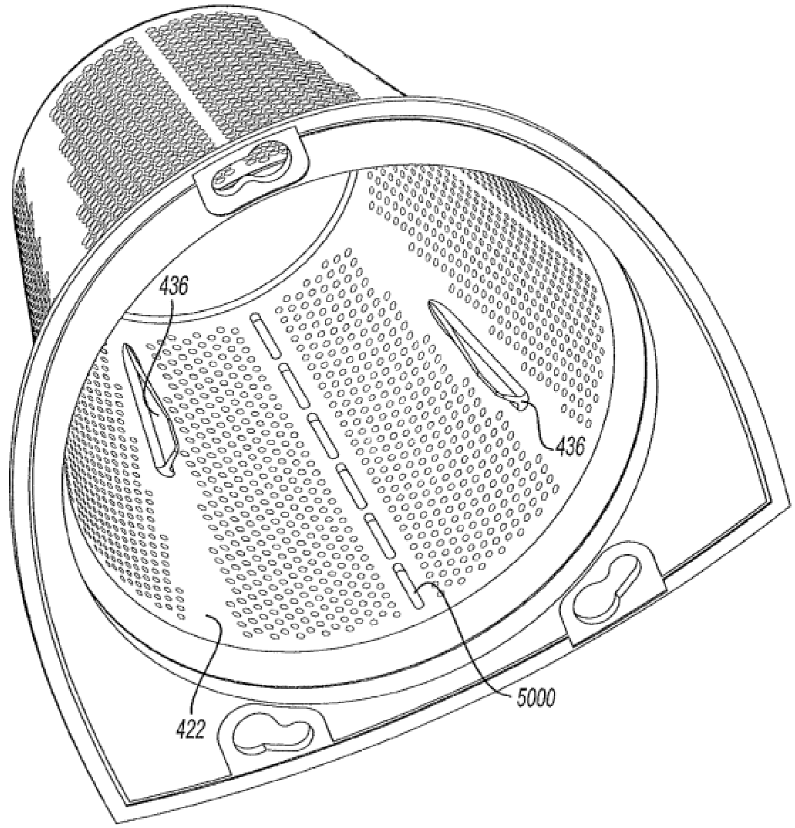


Figure 7: Sketch from US Patent #008549704B2

Design Documentation

After settling on reverse engineering the KMM car vacuum, one of the first steps we took was to take the vacuum apart, to examine the number of parts and potential for redesign. The vacuum had a total of 26 with 20 of them being unique parts. The team drafted a fishbone diagram seen above in Figure 5 with 3 assemblies and 1 minor subassembly.

The disassembly process showed the team the fallacies that the original design had in terms of design for manufacturability and assembly. The housing was held together by 6 screws that were difficult to set upon reassembly. The design of the housing's inner walls was very complex with groves that held the components in place but also groves that held no real purpose. The button had a spring and a cover that would shoot out when the top side of the housing was removed meaning they would have to be held down during assembly. The decomposition offered a lot of ideas for part reduction later discussed in the DFA analysis. The full part by part product decomposition is detailed below in Table 1.

Table 1: Product Decomposition

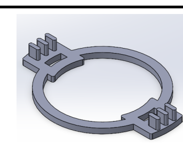
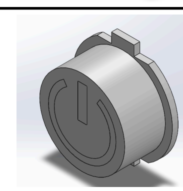
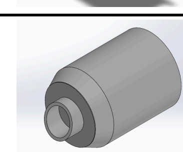
Product Decomposition

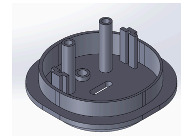
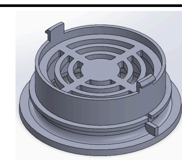
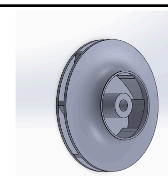
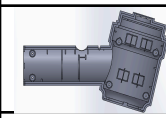
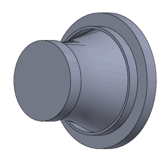
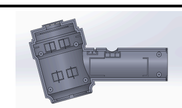
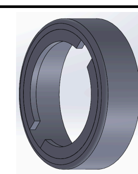
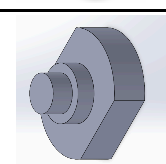
Design Organization: MCEN 5045	Date: 10/14/2024
Product Decomposed: KMM Car Vacuum	

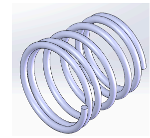
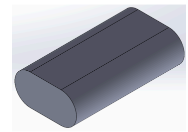
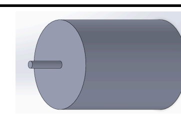
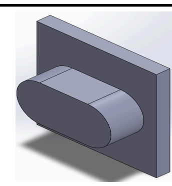
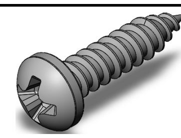
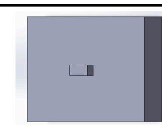
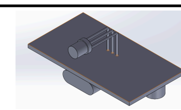
Description **This is a portable battery-powered car vacuum.**

How it works: The vacuum functions by pressing a button that activates a small electric motor that drives an impeller that generates a suction force that is meant to pick up small debris and dust. The dust is collected in a removable collection bin.

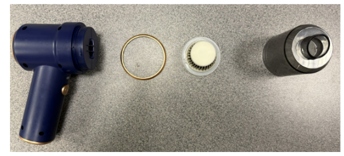
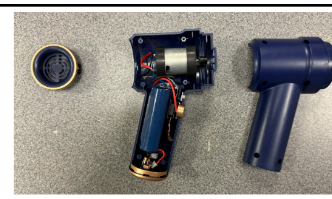
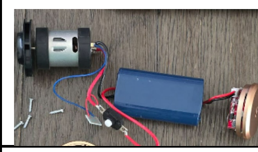
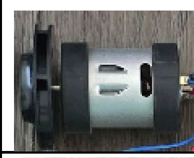
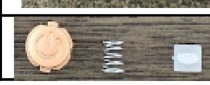
Parts:

Part #	Part Name	# Req'd	Material	Mfg Process	Image
RP001	Blower Screen Locking Clip	1	ABS	Injection Molding	
RP002	Power Button Cover	1	ABS	Injection Molding	
RP003	Dust Collection Bin	1	PC (Polycarbonate)	Injection Molding	

RP004	**Base Charging and LED Mount**	**1**	**ABS**	**Injection Molding**	
RP005	**Blower Screen**	**1**	**ABS**	**Injection Molding**	
RP006	**O-Ring Clip**	**1**	**ABS**	**Injection Molding**	
RP008	**Impeller**	**1**	**ABS**	**Injection Molding**	
RP009	**Housing (Right Half)**	**1**	**ABS**	**Injection Molding**	
RP010	**Air Filter**	**1**	**Various Materials**	**Off The Shelf**	
RP011	**Housing (Left Part)**	**1**	**ABS**	**Injection Molding**	
RP012	**Rubber Motor Cap**	**2**	**EVA**	**Injection Molding**	
RP014	**Blower Screen Retaining Ring**	**1**	**ABS**	**Injection Molding**	
RP015	**Power Button**	**1**	**Various Materials**	**Off The Shelf**	

RP017	**Power Button Spring**	**1**	**Spring Steel**	**Coiling**	
RP018	**XV LiPo Battery**	**1**	**Lithium-Ion Polymer**	**Off The Shelf**	
RP019	**Motor**	**1**	**Various Materials**	**Off The Shelf**	
RP020	**LED Cover**	**1**	**ABS**	**Injection Molding**	
RP021	**Screws**	**6**	**Steel**	**Thread Rolling**	
RP022	**LED**	**1**	**Various Materials**	**Off The Shelf**	
RP023	**Charging Circuit Board**	**1**	**Various Materials**	**Off the Shelf**	

Disassembly:

Step #	Procedure	Part #s removed	Image
1	Twist the collection bin off the housing, the air filter is pulled off the collection bin, and the O-ring is pulled off.	RP003, RP006, RP010	
2	The screws are unscrewed and pulled apart; the blower screen subassembly is pulled off the housing.	RP009, RP014, RP005, RP001	
3	The blower screen subassembly is taken apart by unclipping the retaining ring from the blower screen clip.	RP001, RP005, RP014	
4	Remove Electronics.	RP004, RP008, RP015, RP018, RP019, RP022, RP023	
5	Remove the impeller, and motor caps from the motor. The impeller was glued to the motor shaft had to be cut out.	RP008, RP012	
6	Remove the charging port board from the charging base.	RP004, RP023	
7	Remove the power button cover, LED cover, and spring from the housing.	RP002, RP020, RP017	

Full Assembly View

Figure 8 shows two CAD models of the assembly. A drawing of the assembly is also included in the appendix.

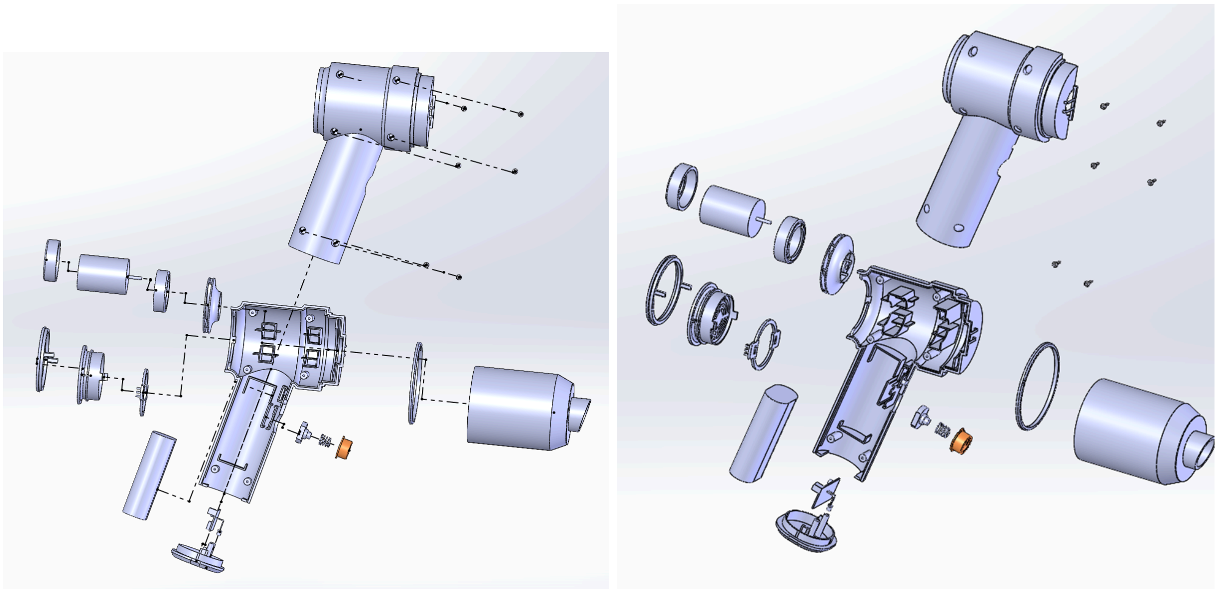


Figure 8: Assembly CAD Models

Design Changes

Power Button Part Reduction

The original design for the power button of the vacuum consisted of an analog button that was completely inside the housing, a spring placed on top of it, and an injection molded cover with the power symbol that the user would press to turn the vacuum on and off. As stated in the product decomposition section, the cover and spring had to be held down when assembled. The team's solution was to remove the cover and spring from the design altogether and modify the housing design so that the user could press the analog button to turn the vacuum on and off.
Collection cavity resizing

LED Part Reduction

The LED and LED cover were completely removed from our redesigned vacuum due to being a no-value-added feature. When using the vacuum the placement and size of the LED causes the user to completely cover the light that it is emitting. A positioning change was considered, however, it was not pursued because it would complicate the housing design and wiring arrangement.

Charging Base Reduction

The original base cap was designed to accommodate both a charging port and an indicator LED. To streamline the electronics and reduce the complexity of the base cap's geometry, the indicator LED was removed. This simplification not only reduced the number of electronic components needed but also made the design more straightforward. Furthermore, the upper surface of the base cap was extended to incorporate a press-fit lip. This modification enhanced the overall structural integrity by ensuring a secure fit for the housing, thus eliminating the need for additional fasteners. The redesign aimed to achieve a more efficient, easier-to-manufacture component without compromising functionality or reliability.

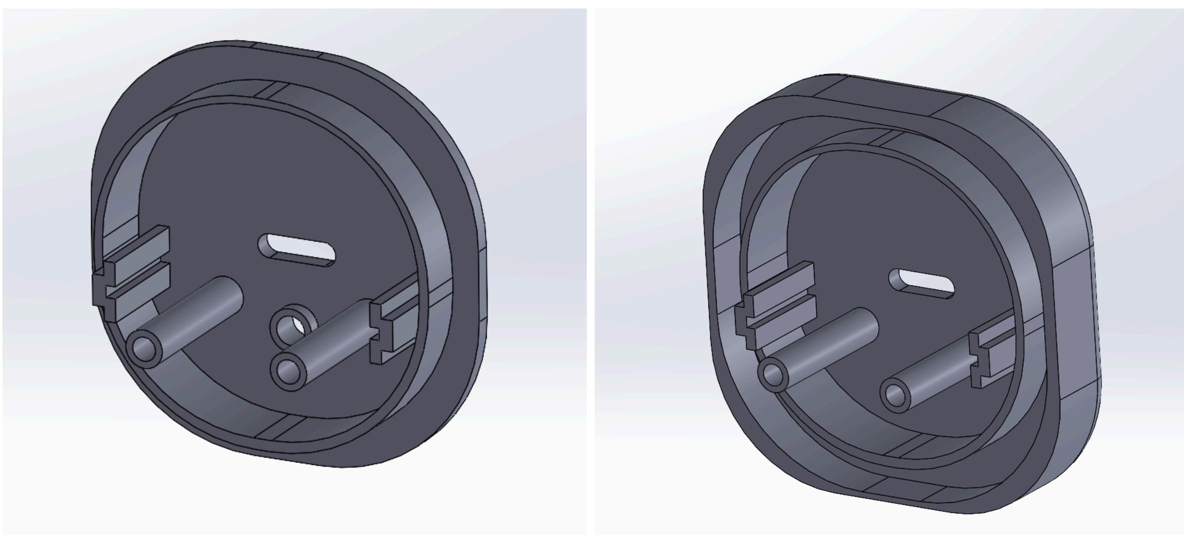


Figure 9: Original charging base (left) vs. new charging base (right)

Motor selection

The biggest complaint was the issue of low suction. This issue was tackled by identifying that the 380/385SH DC motor is the superior alternative. This motor was chosen due to its ability to provide 14,800 RPM, an increase of 8,300 rpm over the previous motor, significantly enhancing the vacuum's performance. Implementing this motor requires no changes to the existing housing as the motor only varies in its length by 0.12 inches. This change boosts the vacuum's efficiency and performance.

Blower Screen Integration

The Blower Screen was re-designed to eliminate the need for the Blower Screen Retaining Ring and Locking Clip. and reduce the complexity of the screen itself. In the original design, the retaining ring and the locking clip primarily exist to attach the Blower Screen to the vacuum housing. A ring molded in the blower screen interfaces with a circular rib inside of the vacuum housing. This ring can be expanded and fit into a groove in the housing wall, eliminating the need for 2 extra parts while still providing an attachment point for the removable nozzles that come with the vacuum. The nozzle attachments are slightly flexible, and are held inside of the main cylindrical portion of the blower screen by friction. All existing attachments will still function with the revised screen.

The original blower screen subassembly and the re-designed blower screen are shown in Figure X and Y.

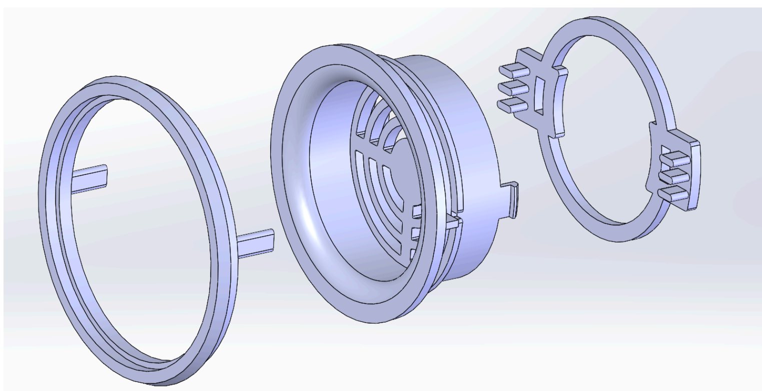


Figure 10: Original Blower Screen Subassembly

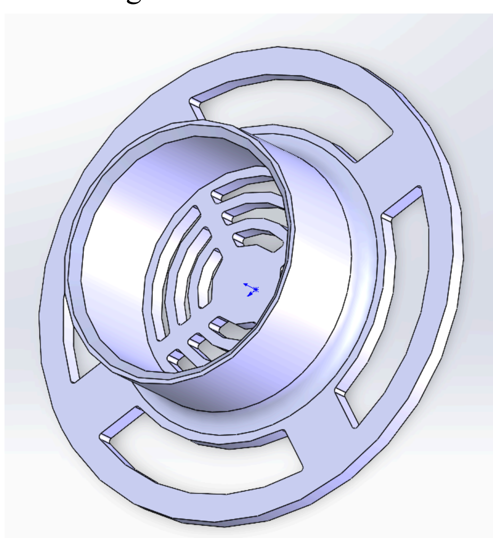


Figure 11: Blower Screen redesign

Simplification of Outer Shells

Instead of using screws, our team opted for cantilever snap-fits like the one shown in Figures A and B. This choice enhances the product's user-friendliness, as snap-fits allow for easier assembly and disassembly compared to traditional screws. From a manufacturing perspective, this approach also results in cost savings, increasing overall profitability.

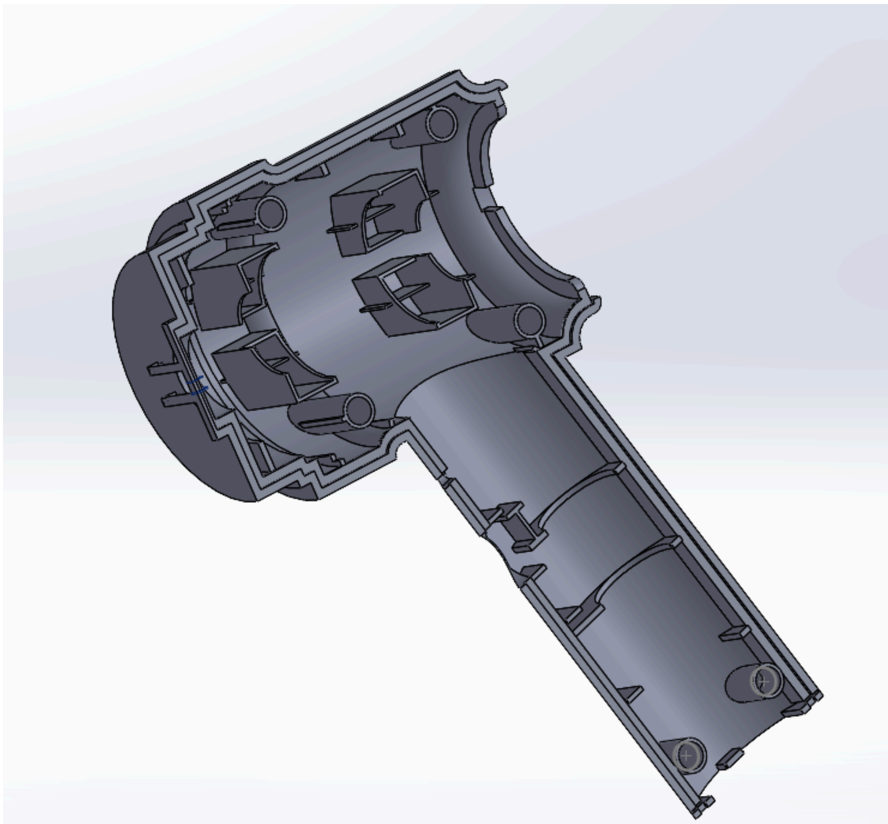


Figure 12: Modified Right Side Housing

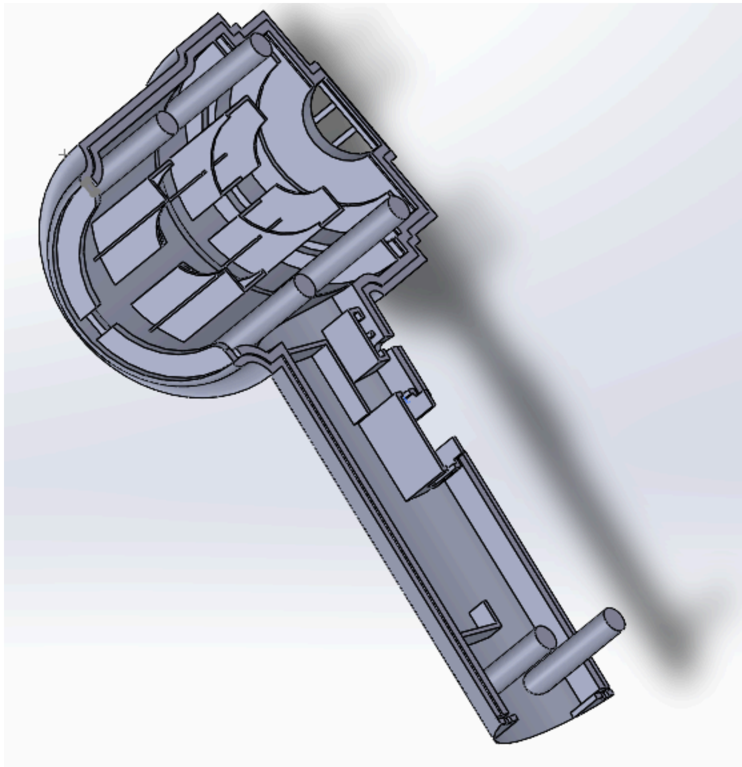


Figure 13: Modified Housing Left Side

Increasing Length of Collection Bin

The collection bin is compact, and our team believes this helps reduce the amount of dust buildup within the component. To improve its capacity and functionality, we decided to increase the size of the collection bin. This change offers additional benefits, such as reducing the frequency of emptying the bin, which enhances user convenience. The redesign aims to improve the overall efficiency of the vacuum by increasing dust-holding capacity while minimizing any impact on the vacuum's performance and suction power.

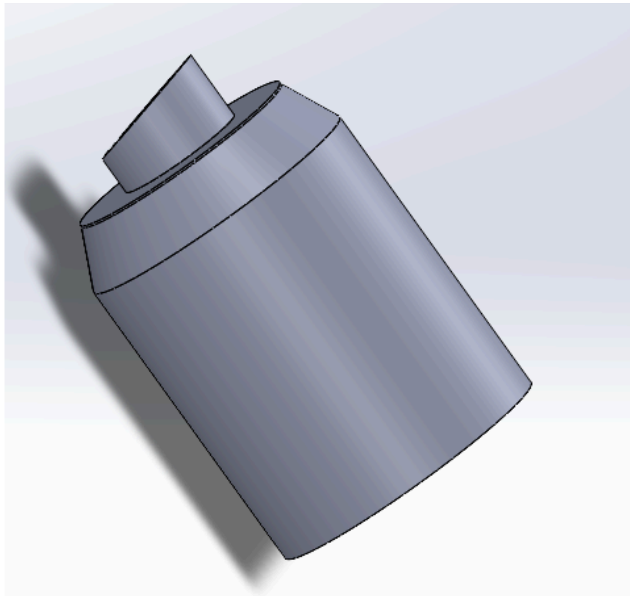


Figure 14: Original Collection Bin

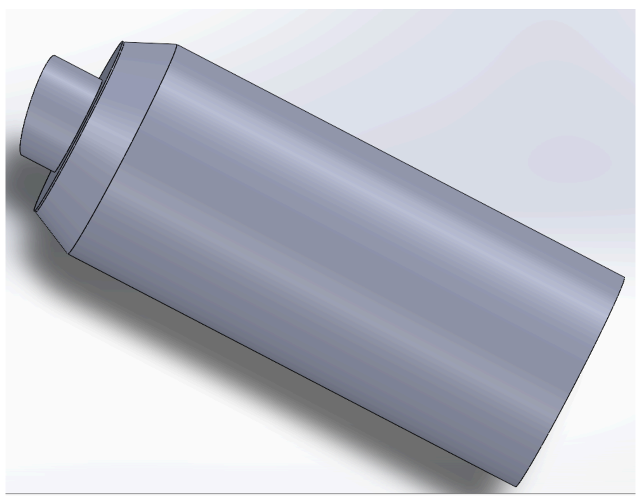


Figure 15: Modified Collection Bin

Bill of Materials for Redesign

Table 2: Redesign Bill of Materials

Part Number	QTY	Part Name	Material
RP003	1	Dust Collection Bin	PC (Polycarbonate)
RP004	1	Base Charging & LED Mount	ABS
RP005	1	Blower Screen	ABS
RP006	1	O-ring Clip	ABS
RP008	1	Impeller	ABS
RP009	1	Housing (Right Half)	ABS
RP010	1	Air Filter	ABS
RP011	1	Housing (Left Half)	ABS
RP012	2	Rubber Motor Cap	Rubber
RP015	1	Power Button	Various Materials
RP018	1	XV LiPo Battery	Lithium-ion Polymer
RP019	1	Motor	ABS
RO023	1	Charging Circuit Board	Various Materials

DFA Analysis & Comparison

After having completed a product decomposition and established the design changes. A DFA analysis was conducted on the original design and the redesigned products to help illustrate the quantitative effects that the redesign choices had.

Table 3: Initial DFA Analysis

DFA Analysis Worksheet																					
Assembly Name:	KMM Vacuum											**Team:**	Vacuum Redesign						**Date:**	10/9/2024	
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**
RP001	KMM Blower Screen Locking Clip	1	1	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP002	Power Button Cover	1	4	0	0	L	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RP003	KMM Blower Dust Collection Bin	1	3	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP004	KMM Base Charging and LED mount	1	3	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
RP005	Blower Screen	1	4	0	1	L	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RP006	O-Ring Clip	1	2	0	1	L	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0
RP008	Impeller	1	1	1	0	L	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
RP009	KMM Housing (right half)	1	19	1	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
RP010	Air Filter	1	1	0	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP011	KMM Housing (left half) (base part)	1	19	1	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
RP012	Rubber Motor Cap	2	6	0	1	L	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0
RP014	Blower Screen Retaining Ring	1	3	0	1	L	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0
RP015	Power Button	1	3	1	0	L	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
RP017	Power Button Spring	1	2	0	0	L	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0
RP018	XV LiPo Battery	1	2	1	0	H	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0
RP019	Motor	1	3	1	1	M	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
RP020	LED Cover	1	3	0	0	L	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
RP021	Screw	6	18	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP022	LED	1	3	0	0	L	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0
RP023	Charging circuit board	1	3	1	0	M	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	Totals	26	103	9	6	0	12	4	7	1	1	0	1	1	0	7	0	2	5	3	0
	Design for Assembly Metrics	**51.74939613**		**34.6%**	←Theor. Effy. Pract. Effy.→		**46.2%**	**1.22**		**0.22**			**1.00**				**1.11**				
	Targets	**30**		**60.0%**			**75.0%**	**1.00**		**0.20**			**0.75**				**1.00**				

Table 4: Final DFA Analysis

DFA Analysis Worksheet

Assembly Name: KMM Vacuum Redesigned Team: Vacuum Redesign Date: 10/9/2024

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
RP003	KMM Blower Dust Collection Bin	1	3	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP004	KMM Base Charging and LED mount	1	3	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
RP005	Blower Screen	1	2	0	1	L	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RP006	O-Ring Clip	1	2	0	1	L	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
RP008	Impeller	1	1	1	0	L	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
RP009	KMM Housing (right half)	1	10	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP010	Air Filter	1	1	0	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP011	KMM Housing (left half) (base part)	1	10	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RP012	Rubber Motor Cap	2	6	0	1	L	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0
RP015	Power Button	1	3	1	0	L	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
RP018	XV LiPo Battery	1	2	1	0	H	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0
RP019	Motor	1	3	1	1	M	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
RP023	Charging circuit board	1	3	1	0	M	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	Totals	14	49	9	5	0	12	1	4	0	1	0	0	0	0	5	0	0	4	2	0
	Design for Assembly Metrics	26.19160171		64.3%	←Theor. Effy. Pract. Effy.→		85.7%	0.56		0.11			0.56				0.67				

DFA Complexity Factor

The original design by KMM had 26 components and those components had 103 interfaces. This led to a design for assembly complexity factor of 51.74 not a high factor by any means but one the team felt could be improved on. In our redesigned model the team managed to bring down the number of parts to 14 and the number of interfaces to 43, which led to a complexity factor of 26.19 a number that surpassed our set target.

Functional Analysis

The theoretical minimum part count established by the team that is necessary to have a functioning vacuum was 9 components. The practical number of components to have a vacuum that is marketable and comfortable to use was 12. Comparing these numbers to the original component count, the theoretical efficiency was 34.6% and the practical efficiency was 46.2%. The team originally set the target to be 60% and 75% for theoretical and practical efficiency respectively. The redesigned model was successful in both of these goals achieving 64.3% and 85.7% theoretical and practical efficiencies respectively in the functional analysis portion of the DFA analysis.

Error Proofing

Approximately 15% of the total parts like the two rubber motor caps, power button spring, blower retaining ring, and LED cover are liable to be omitted during assembly and not be noticed until testing and inspection. 26% of the total number of parts can be assembled the wrong way around. After redesigns the rubber motor caps are the only unique part that can be omitted. The motor, battery, and impeller can still be assembled the wrong way around. This brought the error-proofing index from 1.22 to 0.44.

Handling

The small spring that loads the power button cover and the screws can be tangled and are small enough that are prone to be dropped when being handled. The O-ring, retaining ring, and LED can be considered fragile components. Totaling 7 components out of the 9 theoretical minimum parts equaling a 0.78 handling index. Since the redesigns eliminate the spring, screws, and consolidate the retaining ring into the blower screen it brings down the handling index to 0.11.

Insertion

The original design only had 3 insertion and alignment issues for assembly. The screws are not self-locating and are inserted into small indents on the housing making it difficult to insert them. The spring is the cause of the majority of the insertion issues it has to be held down and is resistant to insertion. The redesigned model eliminates both of these components bringing the insertion index down from 0.33 to 0.

Secondary Operations

The original design requires the housing to be screwed together. To remove this secondary operation, the redesign holds the top of the housing with the O-ring and the bottom charging base was changed to a snap-fit lid to hold the bottom of the housing together. All the electronic components are soldered together; the elimination of the LED is the only reduction in electronic components made in the redesign. Some components are spray-painted for the sake of aesthetics the team decided to keep this process; however, some of the parts were eliminated or consolidated onto other parts like the power button cover, and blower screen retaining ring. The secondary operations index was reduced from 1.22 to 0.67.

Materials Analysis

Many of the components in the KMM Vacuum are made of polymer materials. There are 4 main materials used. The Collection Bin is made of a clear polymer with a smoky-gray color, and the electric motor that drives the impeller is supported by 2 soft rubber-like rings that reduce vibrations. The main housing halves and blower screen are both made out of an opaque blue plastic with a matte finish. The remaining plastic components are made of opaque black plastics with a slightly more lustrous finish. Any exterior surfaces of any black plastic components were painted with a metallic bronze color for aesthetic purposes. The electronic components, fasteners, and Power Button Spring are not included in this material selection analysis, as they are likely either off-the-shelf components or custom manufactured by a subcontractor.

Environment and Loading Assumptions

To begin, a few assumptions were made about the vacuum and the environment it operates in. Since the vacuum is a small, handheld device that is not intended to impart force onto other objects, it is not expected to experience significant loads. However, it may be dropped on hard surfaces from distances of up to 6 feet, so the materials selected should be resistant to fracture. Many plastics and polymers would fit this criteria.

The vacuum is battery operated and marketed as a “car vacuum”, so it is likely that users will leave the vacuum in their car for cleaning small messes. As such, the vacuum could experience temperatures up to 140℉ as the car heats under the sun. The melting point of most plastics are well beyond this threshold, but the material used should stay rigid up to 150℉ to prevent any issues from arising, especially over time.

The average lifecycle of a vacuum cleaner is 5-10 years, so it is anticipated that the vacuum will not experience more than 20,000 activations throughout its lifecycle. 20,000 uses equates to over 5 uses per day for 10 years; a duty cycle which seems unlikely. Generally speaking, the vacuum is not expected to experience any drastic loads or conditions, so the primary driver of material selection for all parts will be the material cost.

Material Selections

When it is feasible to do so, standardizing materials across an assembly can lead to great benefits. Simplified supply chains, material inspection procedures, and easier material storage can all be realized by selecting consistent materials. For this reason, one of the goals in material selection is to use as few different materials as possible. The original designers of the KMM vacuum used 3 different types of plastic, one of which was transparent. The only transparent part was the dust collection bin, and it was likely made this way so that the user can see how full the bin is. This is a good design choice, so this part should be made out of a clear material.

The distinction between the other two types of plastic is less obvious. There is no apparent difference in the loads or conditions experienced by the two different types of parts, so it was decided that a simplified design should only use one type of plastic. The Left and Right Vacuum housing are the most exposed to the elements, most likely to experience loads or impacts, and largest out of all components in the assembly, so it was assumed that any material suitable for these components would also be suitable for the remaining parts.

The other plastic components could theoretically be made out of the same clear material that the collection bin is made of. Clear electronics like those shown in Figure 13 were first used in prisons in the 1970s and 1980s to prevent contraband from being smuggled into prisons, but also became common in the public market in the 1990s and early 2000s. However, as computers and other devices saw more widespread adoption, design trends changed and these styles of devices fell out of favor with consumers. For this reason, the remaining components should not be made of clear material to prevent the vacuum from appearing ”old” or “outdated”.

Figure 16: Examples of clear electronics

Finally, the rings that support the motor are made from a black, flexible material. This part reduces vibrations felt by the user and prevents the plastic columns that support the motor from slowly wearing down the columns. This material should be flexible enough that it conforms to the shape of the motor and support pillars while under a slight amount of tension to keep it wrapped around the motor. The material should also have a moderate hardness. It should be rigid enough that it effectively damps vibrations, but also soft enough to deform to the parts it interfaces with.

Left and Right Side Housings

The main function of these components is to contain or provide a mounting point for the rest of the components. They are the largest parts in the entire assembly, and will likely experience the largest loads of the entire assembly. Both housing halves are shown in Figure 14.

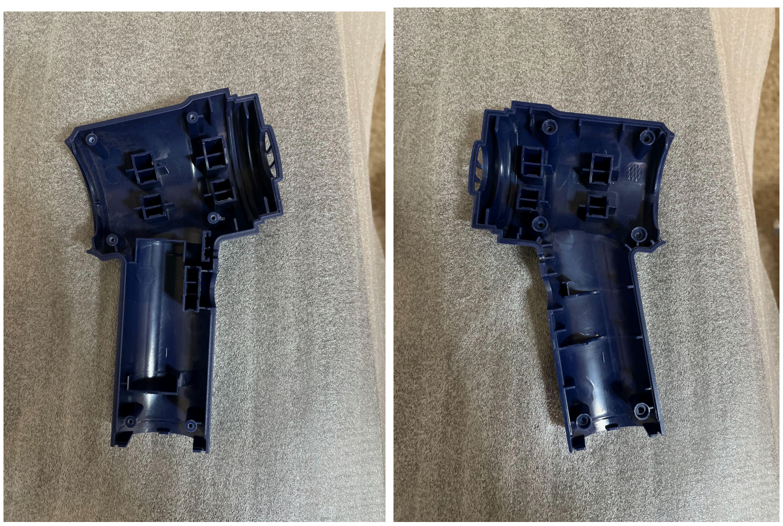


Figure 17: Left and Right Side Housings (PN:RP011 (left), RP009 (right))

Since the housing is also the part that is most likely to crack if dropped, an Ashby chart that plots Fracture toughness and Elastic Modulus was used to identify candidate materials. Hardness was chosen for analysis because it can influence how resistant a material is to scratching. Fewer scratches means there will be fewer opportunities for cracks to propagate. This chart is shown in Figure 15. The handle can be approximated as a beam under bending limited by displacement, so a material index of $M = K^2/E$ was chosen. As a result, ABS, PP, PTFE, and PC were identified as candidate materials. A weighted material index was then used to down-select from these materials.

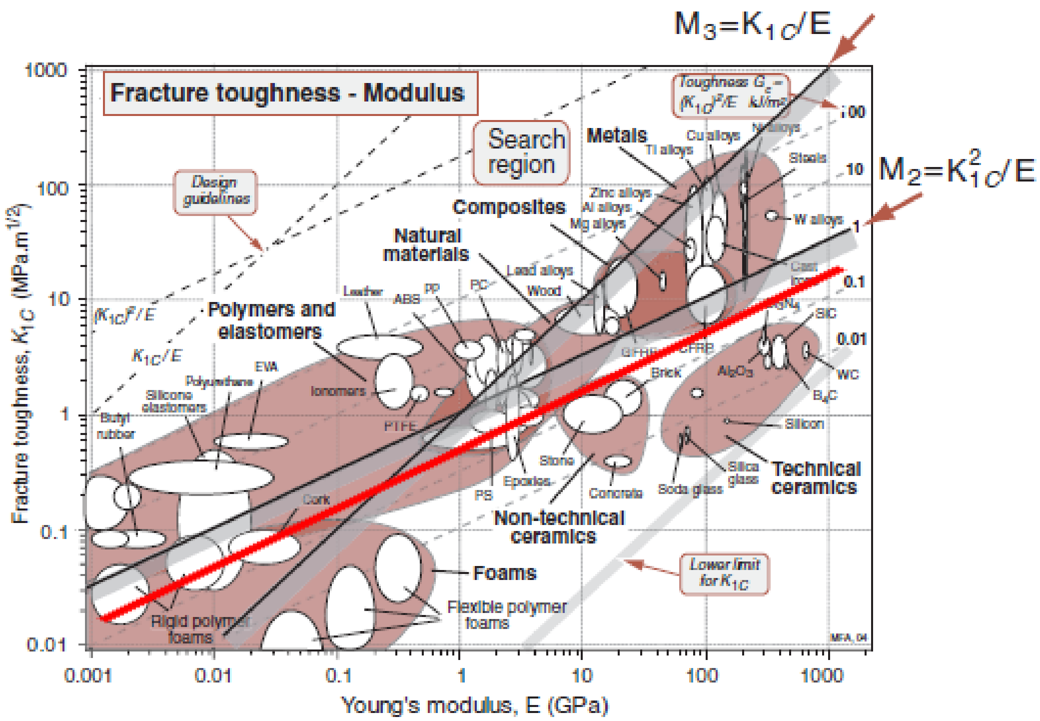


Figure 18: Ashby Chart for Fracture Toughness and Elastic Modulus

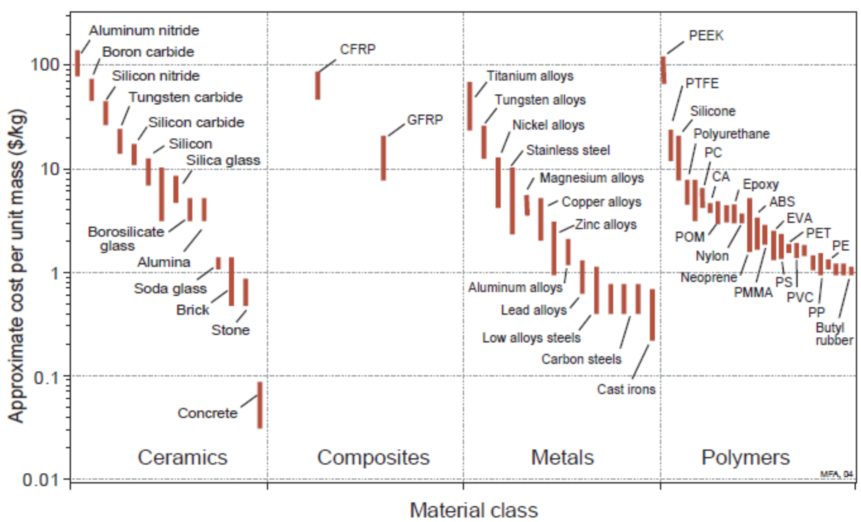


Figure 19: Approximate material cost comparison between material types

We analyzed the Elastic Modulus, Shore D hardness, Fracture Toughness, and cost of each material. The cost was estimated using the relative comparison chart shown in Figure 16, and the material properties were gathered from various sources; primarily MatWeb. The results of this weighted analysis are shown in Table 5. The properties were weighted as follows: Elastic modulus, 10%; Hardness, 10%; Cost, 50%, Fracture Toughness, 20%. PP failed the initial go/no-go check because it begins to soften at about 150℉, and may fail early if left in a hot environment. ABS ended up with the highest property index, and was selected as the best material for the vacuum. The material cost is low and the properties are suitable for the application.

Table 5: Weighted property index for Vacuum Housing

	GO/NO-GO	Elastic Modulus		Hardness		Cost		Fracture Toughness		weighted property index
Canidate Material	Begins Softening at > 150 F	ksi	β	Shore D	β	$/lb	β	MPa√m	β	γ
ABS	Y (200 F)	340	76%	100	100.00%	$1.00	80%	2.00	83.33%	0.74
PP	N (150 F)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PC	Y (300F)	450	100%	90	90.00%	$2.05	59%	2.40	100.00%	0.69
PTFE	Y (500F)	75	17%	55	55.00%	$5.00	0%	1.50	62.50%	0.20

Collection Bin

The collection bin (shown in Figure 17) is the only part of the entire assembly made of a clear substance. This allows users to see how full the collection bin is, and if it is properly removing debris. It interfaces with both of the housings and is held on by two small locking lugs. The Collection Bin is also an exterior part and is subject to the same environment as the housing, and must be resistant to cracking or shattering when dropped. For this reason, the same Ashby Chart and material index was used to identify materials for the Collection bin.

Figure 20: Collection bin (PN: RP003)

PMMA, ABS, PTFE and PC were identified as candidate materials. All metals were excluded automatically because the part needs to be clear. The same properties assessed for the vacuum housing were gathered for these 4 materials and assessed at the same weights in another weighted property, and the results are shown in Table 5. While ABS is included in both tables, the properties are different when applied to the collection bin. This is because ABS is opaque by default, but can be made transparent by adding Methyl Methacrylate (MMA) to the ABS as it is being processed. Doing so changes the properties of the material, increases cost, and manufacturing complexity.

Table 6: Weighted property index for Collection Bin

	GO/NO-GO		Elastic Modulus		Hardness		Cost		Fracture Toughness		weighted property index
Canidate Material	Begins Softening at > 150 F	Transparent	ksi	β	Shore D	β	$/lb	β	MPa√m	β	γ
PMMA	Y (185 F)	Y	490	100%	90	90.00%	$1.10	78%	0.50	20.83%	0.62
ABS	Y (200 F)	Y	180	37%	100	100.00%	$2.00	60%	2.00	83.33%	0.60
PC	Y (300 F)	Y	450	92%	90	90.00%	$2.05	59%	2.40	100.00%	0.68
PTFE	Y (500 F)	Y	75	15%	55	55.00%	$5.00	0%	1.50	62.50%	0.20

Based on the results in Table 6, PC is the best material for the Collection bin, followed by PMMA.

Motor Caps

A CAD model of the motor cap is shown in Figure 18. There are 2 motor caps used in the assembly, one at the front and back of the motor. They wrap around the diameter of the motor and reduce vibrations to the rest of the assembly. The caps were modeled as a spring based on how they interact with the motor and support pillars, so a material index of $\sigma_f^2/E\rho$ was selected and plotted on the Ashby chart shown in Figure 19.

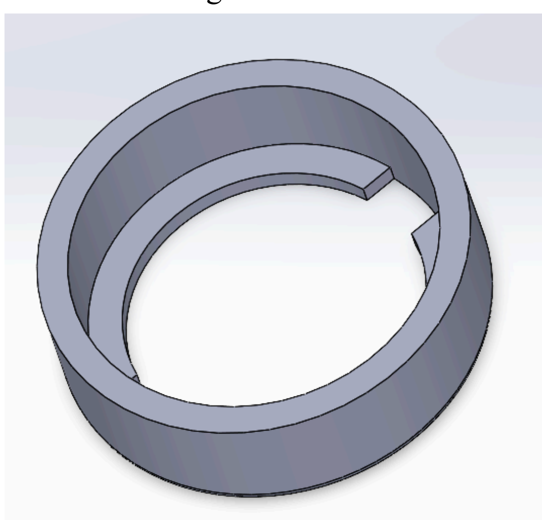


Figure 21: CAD model of Motor Cap

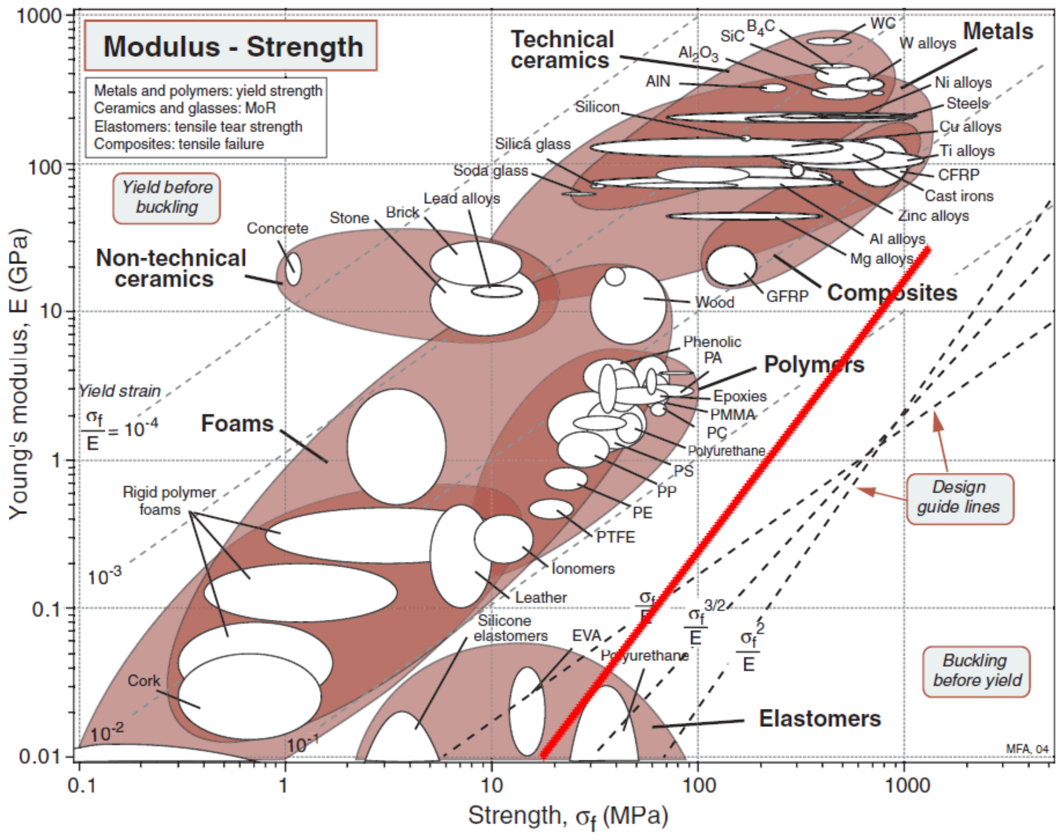


Figure 22: Ashby Chart for Yield Strength and Elastic Modulus

Figure FFF identifies some EVA, Silicone Elastomers, and cork as candidates. The Elastic Modulus, Shore D hardness, and cost per pound were measured and assessed in a weighted property index shown in Table 7 The elastic modulus was weighted at 10%, the Shore hardness at 20%, and the cost at 70%. The weighted property index identifies EVA as the superior material of those considered.

Table 7: Weighted Property index for Motor Caps

	GO/NO-GO	Elastic Modulus		Hardness		Cost		weighted property index
Canidate Material	Begins Softening at > 150 F	ksi	β	Shore D	β	$/lb	β	γ
EVA	Y (180 F)	15	100%	35.8	70.33%	$1.75	86%	0.84
Cork	Y (400F)	2.4	16%	15	29.47%	$5.50	55%	0.46
Silicone Elastomer	Y (260 F)	0.003	0%	50.9	100.00%	$12.15	0%	0.20

In summary, the results of the material selection analysis show that ABS should be chosen for all opaque plastic parts, PC should be used for the collection bin, and EVA should be used for the motor caps.

Manufacturing Analysis

Most of the unique components of the KMM vacuum are made of some form of plastic or polymer. Mold lines can be found on almost all of the original parts, meaning they were most likely injection molded. However, manufacturing analysis will still be completed to ensure that the most efficient process is selected. Our manufacturing analysis will be limited to the Right and Left side Housings (part number RP011 (left), and RP009 (right)). These are the largest and most complex parts in the entire assembly, and their manufacturing cost will likely drive the total manufacturing cost the most.

Manufacturing Assumptions

Data Available from Amazon indicated that the KMM Car Vacuum was selling approximately 10,000 units per month worldwide. Assuming that this vacuum is produced and sold for approximately 5 years before being replaced by an improved model, the total production run can be estimated at 600,000 units. The sale price of each vacuum is around $45. The two halves need to be highly standardized, and any two halves from a batch need to be able to fit together. These attributes indicate that a high-volume repetitive manufacturing operation would be ideal.

ABS was chosen as the material for these parts. Not only does it meet the required properties at a low cost, but ABS is also a commonly available, easy to manufacture material. There should be no difficulty in finding alternate sources of supply if needed.

Manufacturing Process Selection

With assumptions in place, candidate manufacturing processes can be identified. Figure UUU plots a few different manufacturing processes with their economical batch sizes. Based on the batch size alone, Extrusion, Blow Molding, and Injection molding stand out as candidates for manufacturing polymer parts. However, there are a few other polymer processing techniques that should be considered, like vacuum casting and compression molding. Vacuum casting is generally used for small production volumes, or to rapidly produce parts that will later be injection molded. Based on the expected production volume, this process can be eliminated.

Manufacturing processes are also limited by the types of geometry they can produce. Figure ABC and ABC1 in the appendix show which manufacturing processes can handle certain geometries. The alignment ribs, grooves, and screw alignment pillars make it so the housings are best described as an S4 part. Extrusion is not viable because the housings do not have a uniform cross section. Blow molding might work for the exterior surfaces, but would likely not work for the internal ribs. Injection and compression molding could be used to make the required shape.

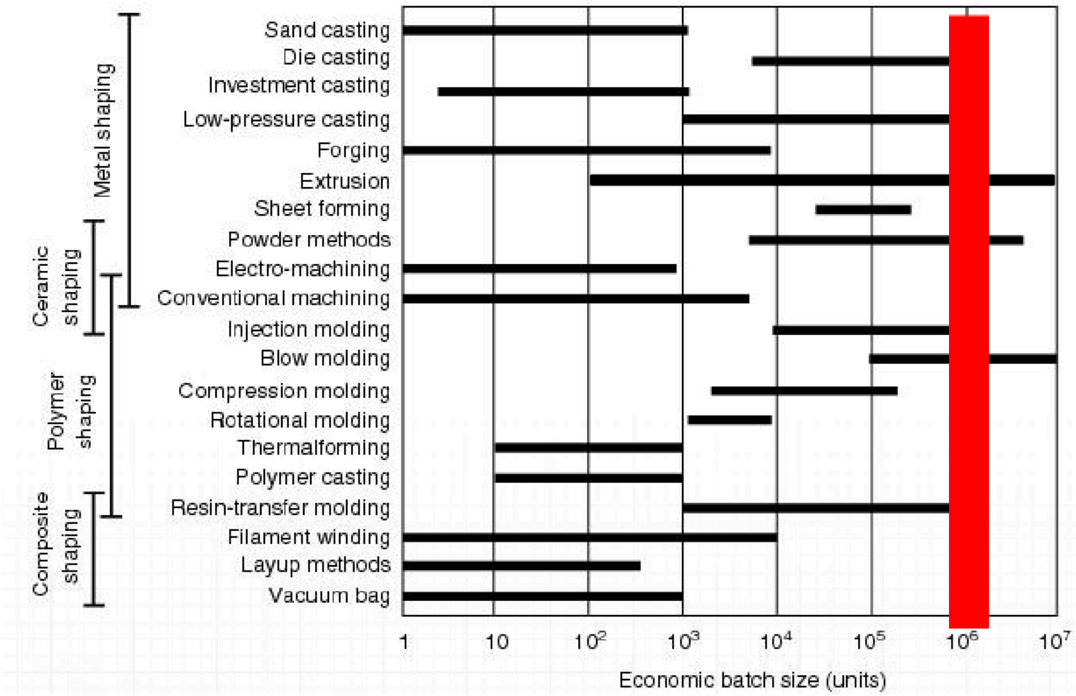


Figure 23: Candidate manufacturing processes based on batch size

Fundamentally, injection and compression molding are similar processes. In both cases, liquid plastic is forced into a negative mold of the intended part. The methods by which the plastic is forced are different. Compression molding uses high pressure to push heated material, while injection molding uses a long screw to compress and inject liquid plastic. The high pressure involved with compression molding could present a safety concern, and may also lead to deformation of small features. Injection molding is also a very low-waste process. This results in less material used, and the used material can be re-used in the molding process, resulting in less waste lost to the environment. Compression molding leads to more waste as more overflow is needed to completely fill a mold. This material can be recycled, but risks being contaminated and thrown away. To reduce material cost and mitigate potential environmental impacts, Injection molding should be used to manufacture the left and right side housings.

The batch size for most of the plastic parts in the assembly is expected to be the same size as the batch for the housings. For process and material handling standardization purposes, injection molding should be selected for all plastic parts in the assembly.

Economic Analysis

Understanding the design complexity, manufacturing process, and weight helps in obtaining an accurate cost estimate. A detailed cost analysis must be conducted for each part, with the depth of the analysis depending on the shape, design complexity, and size of the product.

Injection Molding

Most components in our part are injection molded. The cost of injection molding depends mostly on the mass of the product and complexity of Design. A steel mold is used for manufacturing. Due to the complexity of the process the price of each part is reduced if it is manufactured on a large scale.

The following equations and assumptions were used for obtaining Unit Cost:

A. **Material Cost:**

$$C_M = \frac{Mass\ of\ Material\ (m) -\ Cost\ of\ Material\ (cost/lb)}{1 - Fraction\ of\ Matrial\ lost\ in\ scrap}$$

B. **Labour Cost:**

$$C_L = \frac{Labour\ Cost(\$/lb)}{Production\ Rate(\frac{Units}{hr})}$$

Labour Cost ($/lb): $25 /Hour

Production Run (Units/hr): The production rate depends on the complexity and size of the product. For a more complex and large product like RP011, the production rate is around 30 parts/ hour and for RP003, which is considerably less complex, the rate is 50 parts/hour.

C. **Tooling Cost:**

$$C_T = \frac{Cost\ of\ Tooling\ (\$) \times Sets\ of\ Tooling\ Required}{Production\ Run(No.of\ Parts)}$$

$$Sets\ of\ Tooling\ Required = \frac{Production\ Run(No.of\ Parts)}{Life\ of\ Tooling}$$

Cost of Tooling($): Tooling cost depends on the complexity and Production rate. Based on these factors the tooling costs range between 10,000 to 60,000. For RP003, the cost is estimated to be 20,000 based on the complexity, Production rate and size of the product. For RP011 it is estimated to be around 50,000 based on the same factors.

Life of Tooling (Cost/lb): A steel mold usually lasts for 500,000 units.

Production Run (No. of Parts): Using the market estimate from Amazon around 10,000 units are bought a year we assumed a production run of 250,000 units.

D. **Equipment Cost:**

$$C_E = \left(\frac{1}{Production\ Rate(\frac{Units}{hr})}\right) \times \left(\frac{Capital\ Cost(\$)}{Load\ Factor \times (Capital\ Write\text{-}off\ Time)}\right) \times \boldsymbol{Load\ Sharing\ Factor}$$

Capital Cost ($): An Injection molding machine for a production run of this size costs around $100,000.

Capital Write-off Time: Assuming 5 years, 40 hours per week, 3 shifts per day, and 50 weeks per year.

Load Fraction: We assume there is one operator per machine.

Load Sharing Factor: We assume one machine per part.

E. **Overhead Cost (C_{OH}):**

$$Overhead\ Cost\ (C_{OH}) = \frac{Overhead\ Hourly\ Rate(\frac{\$}{hr})}{Life\ of\ Tooling}$$

Overhead Hourly Rate: $50 / Hour

F. **Total Unit Cost :**

The **Total Unit Cost (C_U)** is the sum of all these costs :

$$C_U = C_M + C_L + C_T + C_E + C_{OH}$$

A comprehensive unit cost analysis was conducted for both the original and redesigned equipment. The table below provides detailed information used in the cost estimation process. Grey-shaded cells in the table indicate the unit cost estimates that were calculated using the equations mentioned earlier.

Table 8: Unit Cost Analysis

Unit Cost Analysis								
COMPONENT	KMM Blower Screen Locking Clip	Power Button Cover	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)
Cost Element	RP001	RP002	RP003	RP004	RP005	RP006	RP008	RP009
Cost of Material (Cost/lb)	$1.000	$1.400	$1.000	$1.400	$1.800	$2.300	$3.600	$1.400
Fraction of process that is scrap	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Material (lb)	0.00198416	0.00202	0.15	0.00462	0.0127868	0.00284	0.00347	0.1
Unit Material Cost (C_M)	$0.002	$0.003	$0.158	$0.007	$0.024	$0.007	$0.005	$0.160
Labor Cost ($/lb)	25	15	25	15	25	15	15	$25.00
Production Rate (Units/hr)	75	120	50	120	60	180	120	30
Unit Labor Cost (C_L)	$0.333	$0.125	$0.500	$0.125	$0.417	$0.083	$0.125	$0.830
Cost of Tooling ($)	$20,000.00	50000	20000	50000	$50,000.00	20000	50000	$50,000.00
Production Run (No. of Parts)	250000	250000	250000	250000	250000	250000	250000	250000
Life of Tooling	300000	500000	500000	500000	300000	500000	500000	500000
Sets of Tooling Required	1	1	1	1	1	1	1	1
Unit Tooling Cost (C_T)	$0.080	$0.200	$0.080	$0.200	$0.200	$0.080	$0.200	$0.200
Capital cost	$1,00,000.000	$1,00,000.000	$10,00,000.000	$10,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000
Capital write-off time	30000	30000	30000	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1	1	1	1
Load Sharing Fraction	1	1	1	1	1	1	1	1
Unit Capital Cost (C_E)	$0.044	$0.028	$0.667	$0.278	$0.056	$0.019	$0.028	$0.110
Factory Overhead	50	50	50	50	50	50	50	50
Prodution Rate (Units/hr)	75	120	50	120	60	180	120	30
Unit Overhead Cost (C_{OH})	$0.667	$0.417	$1.000	$0.417	$0.833	$0.278	$0.417	$2.000
Total Unit Cost C_M+C_L+C_T+C_E+C_{OH}	$1.127	$0.772	$2.405	$1.026	$1.530	$0.467	$0.774	$3.300

Unit Cost Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen Retaining Ring	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Cost of Material (Cost/lb)	$2.700	$1.400	$0.900	$2.300	$1.400	$1.400	$1.300
Fraction of process that is scrap	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Material (lb)	0.03	0.1	0.1	0.004	0.002	0.004	0.00169
Unit Material Cost (C_M)	$0.160	$0.147	$0.095	$0.010	$0.003	$0.006	$0.002
Labor Cost ($/lb)	$25.00	25	25	25	25	25	15
Production Rate (Units/hr)	120	30	30	180	180	120	120
Unit Labor Cost (C_L)	$0.830	$0.833	$0.833	$0.139	$0.139	$0.208	$0.125
Cost of Tooling ($)	$50,000.00	50000	50000	15000	10000	20000	20000
Production Run (No. of Parts)	250000	250000	250000	250000	250000	250000	250000
Life of Tooling	1000000	500000	500000	500000	300000	250000	500000
Sets of Tooling Required	1	1	1	1	1	1	1
Unit Tooling Cost (C_T)	$0.200	$0.200	$0.200	$0.060	$0.040	$0.080	$0.080
Capital cost	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000
Capital write-off time	30000	30000	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1	1	1
Load Sharing Fraction	2	1	1	1	1	1	1
Unit Capital Cost (C_E)	$0.110	$0.111	$0.111	$0.019	$0.019	$0.028	$0.028
Factory Overhead	50	50	50	50	50	50	50
Prodution Rate (Units/hr)	120	30	30	180	180	120	120
Unit Overhead Cost (C_{OH})	$2.000	$1.667	$1.667	$0.278	$0.278	$0.417	$0.417
Total Unit Cost C_M+C_L+C_T+C_E+C_{OH}	$3.300	$2.958	$2.906	$0.505	$0.478	$0.739	$0.652

Redesign:

Unit Cost Analysis							
COMPONENT	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)	Air Filter
Cost Element	RP003	RP004	RP005	RP006	RP008	RP009	RP010
Cost of Material (Cost/lb)	$1.000	$1.400	$1.800	$2.300	$3.600	$1.400	$2.700
Fraction of process that is scrap	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Material (lb)	0.15	0.00462	0.0127868	0.00284	0.00347	0.1	0.03
Unit Material Cost (C_M)	$0.158	$0.007	$0.024	$0.007	$0.013	$0.147	$0.085
Labor Cost ($/lb)	25	15	25	15	15	$25.00	$25.00
Production Rate (Units/hr)	50	120	60	180	120	30	120
Unit Labor Cost (C_L)	$0.500	$0.125	$0.417	$0.083	$0.125	$0.833	$0.208
Cost of Tooling ($)	20000	50000	$50,000.00	20000	50000	$50,000.00	$50,000.00
Production Run (No. of Parts)	250000	250000	250000	250000	250000	250000	250000
Life of Tooling	500000	500000	300000	500000	500000	500000	1000000
Sets of Tooling Required	1	1	1	1	1	1	1
Unit Tooling Cost (C_T)	$0.080	$0.200	$0.200	$0.080	$0.200	$0.200	$0.200
Capital cost	$10,00,000.000	$10,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000
Capital write-off time	30000	30000	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1	1	1
Load Sharing Fraction	1	1	1	1	1	1	2
Unit Capital Cost (C_E)	$0.667	$0.278	$0.056	$0.019	$0.028	$0.111	$0.056
Factory Overhead	50	50	50	50	50	50	50
Prodution Rate (Units/hr)	50	120	60	180	120	30	120
Unit Overhead Cost (C_{OH})	$1.000	$0.417	$0.833	$0.278	$0.417	$1.667	$0.417
Total Unit Cost C_M+C_L+C_T+C_E+C_{OH}	$2.405	$1.026	$1.530	$0.467	$0.783	$2.958	$0.966

Unit Cost Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Cost of Material (Cost/lb)	$2.700	$1.400	$0.900	$2.300	$1.400	$1.400	$1.300
Fraction of process that is scrap	0.05	0.05	0.05	0.02	0.05	0.05	0.05
Mass of Material (lb)	0.03	0.1	0.1	0.004	0.002	0.004	0.00169
Unit Material Cost (C_M)	$0.085	$0.147	$0.095	$0.009	$0.003	$0.006	$0.002
Labor Cost ($/lb)	$25.00	25	25	25	25	25	15
Production Rate (Units/hr)	120	30	30	60	180	120	120
Unit Labor Cost (C_L)	$0.208	$0.833	$0.833	$0.417	$0.139	$0.208	$0.125
Cost of Tooling ($)	$50,000.00	50000	50000	15000	10000	20000	20000
Production Run (No. of Parts)	250000	250000	250000	250000	250000	250000	250000
Life of Tooling	1000000	500000	500000	500000	300000	250000	500000
Sets of Tooling Required	1	1	1	1	1	1	1
Unit Tooling Cost (C_T)	$0.200	$0.200	$0.200	$0.060	$0.040	$0.080	$0.080
Capital cost	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000	$1,00,000.000
Capital write-off time	30000	30000	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1	1	1
Load Sharing Fraction	2	1	1	1	1	1	1
Unit Capital Cost (C_E)	$0.056	$0.111	$0.111	$0.056	$0.019	$0.028	$0.028
Factory Overhead	50	50	50	50	50	50	50
Prodution Rate (Units/hr)	120	30	30	180	180	120	120
Unit Overhead Cost (C_{OH})	$0.417	$1.667	$1.667	$0.278	$0.278	$0.417	$0.417
Total Unit Cost C_M+C_L+C_T+C_E+C_{OH}	$0.966	$2.958	$2.906	$0.819	$0.478	$0.739	$0.652

Order of Magnitude(OME) Estimates:

This method was employed to roughly guess the price of each component using the 1:3:9 rule. The Material Cost, Manufacturing Cost, and Selling Price were calculated based on the Cost of Material (cost/lb), Mass of Material (m), and Fraction of Material lost in scrap using the following equations:

$$\textbf{\textit{Material Cost (\$)=Cost of Material}}\ (C_M)\textbf{\textit{(cost/lb) + Labour Cost}}\ (C_L)\ \textbf{\textit{(\$/hr)}}$$

$$\textbf{\textit{Manufacturing Cost (\$) = 3}} \times \textbf{\textit{Material Cost(\$)}}$$

$$\textbf{\textit{Selling Price (\$) =9}} \times \textbf{\textit{Material Cost(\$)}}$$

Table 9: OME Analysis

OME Analysis								
COMPONENT	KMM Blower Screen Locking Clip	Power Button Cover	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)
Cost Element	RP001	RP002	RP003	RP004	RP005	RP006	RP008	RP009
Mass of Material (lb)	$0.002	$0.003	$0.158	$0.007	$0.024	$0.007	$0.013	$0.147
Material Cost ($)	0.3354	0.1280	0.6579	0.1318	0.4409	0.0902	0.1381	0.9807
Manufacturing Cost ($)	1.0063	0.3839	1.9737	0.3954	1.3227	0.2706	0.4144	2.9421
Selling Price ($)	3.0188	1.1518	5.9211	1.1863	3.9680	0.8119	1.2433	8.8263

OME Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen Retaining Ring	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Mass of Material (lb)	0.013	0.147	0.085	0.147	0.095	0.010	0.003
Material Cost ($)	0.14	0.98	0.29	0.98	0.93	0.15	0.14
Manufacturing Cost ($)	0.41	2.94	0.88	2.94	2.78	0.45	0.43
Selling Price ($)	1.24	8.83	2.64	8.83	8.35	1.34	1.28

Redesign:

OME Analysis						
COMPONENT	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)
Cost Element	RP003	RP004	RP005	RP006	RP008	RP009
Mass of Material (lb)	$0.158	$0.007	$0.024	$0.007	$0.013	$0.147
Material Cost ($)	0.6579	0.1318	0.4409	0.0902	0.1381	0.9807
Manufacturing Cost ($)	1.9737	0.3954	1.3227	0.2706	0.4144	2.9421
Selling Price ($)	5.9211	1.1863	3.9680	0.8119	1.2433	8.8263

OME Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Mass of Material (lb)	0.085	0.147	0.095	0.009	0.003	0.006	0.002
Material Cost ($)	0.29	0.98	0.93	0.43	0.14	0.21	0.13
Manufacturing Cost ($)	0.88	2.94	2.78	1.28	0.43	0.64	0.38
Selling Price ($)	2.64	8.83	8.35	3.83	1.28	1.93	1.15

Stock Parts

This product consists of 6 stock parts, which are common components such as springs, batteries, screws, etc. These parts can be procured from manufacturers that produce them in large quantities. Since these materials are available in standardized sizes and specifications, producing them in-house would incur excess costs, making purchasing the more cost-effective option.

Table 10: Stock Parts

Stock Parts				
PART NO.	ELEMENT	Quantity	COST ($)	OVERALLCOST ($)
RP017	Power Button Spring	1	0.94	0.94
RP018	XV LiPo Battery	1	10	10
RP019	Motor	1	5	5
RP021	Screw	6	0.08	0.48

Resdesign:

Stock Parts				
PART NO.	ELEMENT	Quantity	COST ($)	OVERALLCOST ($)
RP018	XV LiPo Battery	1	10	10
RP019	Motor	1	5	5

Break-Even Product:

The analysis was carried out to determine the price at which each component should be sold in order to cover the cost of Manufacturing.

$$Break - Even\ Cost = \frac{Fixed\ Costs\ \left(\frac{\$}{Month}\right) + (5000\ units + Variable\ Cost))}{Fixed\ Costs\ \left(\frac{\$}{Month}\right)}$$

$$Variable\ Cost = C_M + C_L$$

Table 11: Break-Even Analysis

Break-Even Analysis								
COMPONENT	KMM Blower Screen Locking Clip	Power Button Cover	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)
Cost Element	RP001	RP002	RP003	RP004	RP005	RP006	RP008	RP009
Fixed Costs ($/month)	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00
Variable Costs ($)	$0.335	$0.128	$0.658	$0.132	$0.441	$0.090	$0.138	$0.981
Price to Break Even	$1.48	$1.18	$1.94	$1.19	$1.63	$1.13	$1.20	$2.40

Break-Even Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen Retaining Ring	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Fixed Costs ($/month)	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00
Variable Costs ($)	$0.294	$0.981	$0.928	$0.149	$0.142	$0.214	$0.127
Price to Break Even	$1.42	$2.40	$2.33	$1.21	$1.20	$1.31	$1.18

Redesign:

Break-Even Analysis						
COMPONENT	KMM Blower Dust Collection Bin	KMM Base Charging and LED mount	Blower Screen	O-Ring Clip	Impeller	KMM Housing (Right Half)
Cost Element	RP003	RP004	RP005	RP006	RP008	RP009
Fixed Costs ($/month)	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00
Variable Costs ($)	$0.658	$0.132	$0.441	$0.090	$0.138	$0.981
Price to Break even at	$1.94	$1.19	$1.63	$1.13	$1.20	$2.40

Break-Even Analysis							
COMPONENT	Air Filter	KMM Housing (left half) (base part)	Rubber Motor Cap	Blower Screen Retaining Ring	Power Button	LED Cover	Charging circuit board
Cost Element	RP010	RP011	RP012	RP014	RP015	RP020	RP023
Fixed Costs ($/month)	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00	$7,000.00
Variable Costs ($)	$0.294	$0.981	$0.928	$0.426	$0.142	$0.214	$0.127
Price to Break even at	$1.99	$2.38	$2.33	$1.83	$1.54	$1.61	$1.53

A table summarizing the Costs incurred for the Original and Redesigned Product is given below.

Table 12: Summary of Cost Estimates

Summary of Cost Estimates		
PART NO.	Original	Redesign
Unit Cost	$20.27	$18.69
OME	$58.63	$49.96
Stock Parts	$16.42	$15.00
Break-Even Cost	$23.20	$22.69

The product's listed price on Amazon is $43.99, so the production cost should be lower than that. Our analysis shows that the break-even price for the product is $23.20. This implies that the company is achieving a profit, assuming these materials were used.

The redesigns made the product more compact and did not significantly reduce the overall cost. The power button cover (with a unit cost of $0.772), the power button spring (costing $0.94), and the screws (costing $0.48) were removed. The Blower Screen Locking Clip and Retaining Ring were combined resulting in the entity Blower Screen.

Professional, Ethical, and Safety Issues

Safety Concerns with Initial Design

The main safety concern that exists with the KMM Vacuum is any harmful emissions or fires that could result from improper handling of the battery. One of the pictures included on the vacuum's Amazon page includes a caption that states the device should not be charged for 10 minutes after use to allow the battery to cool. This warning is shown in Figure 24. Ideally, the circuitry would be designed such that this is not an issue. Not only is this an unnecessary issue to have in the first place, notifying the user of it in a picture on a website or a line in the user manual is not sufficient. A warning should be molded in the plastic next to the charging port to ensure users are aware of this constraint.

This Vacuum is also specifically marketed as a “Car Vacuum Cleaner”, and there is a high probability that some users will simply keep the vacuum in their car. On hot, sunny days, the inside temperature of a car can easily pass 100°F in less than half an hour. While LiPo batteries have an operating temperature range of about 0-140°F, the combination of a hot car and heating from use may present an issue for some users.

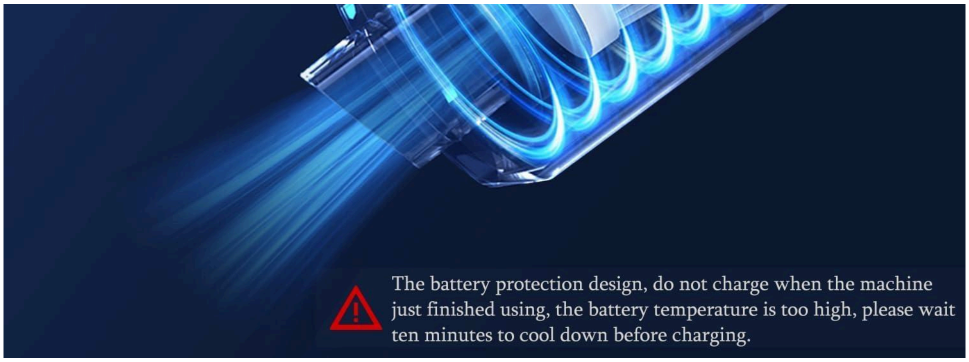


Figure 24: KMM Vacuum Battery Warning

Ethical Concerns

The primary ethical concern with the KMM Vacuum is more so a concern with KMM as a company. Very little visibility is provided into the company. A country of origin is difficult to locate, but the country of origin for many products listed on the company website is China. The address listed on the company’s website is 221B, Baker Street, Marylebone, London NW1 6XE, United Kingdom. 221B Baker Street is the fictional address of Sherlock Holmes, and the address listed is the location of the Sherlock Holmes Museum in London. The phone number provided is also not reachable. Even the meaning of the letters “KMM” is difficult to determine. Given the lack of available information and visibility into the company’s supply chain, manufacturing processes, and the low prices of the 110 different vacuum cleaners listed for sale on the company website, it seems likely that KMM exploits the low labor costs and lack of regulations in China to sell products at the lowest possible cost. KMM is also likely not the manufacturer or designer of these products, but rather a distributor or reseller. The overall lack of transparency exhibited by KMM presents a red flag to consumers and potential collaborators alike.

Conclusions

This reverse engineering project provides an extensive examination of a handheld vacuum, beginning with a detailed analysis of its design purpose and user intent. The project then advances to the deconstruction phase, where each component of the vacuum was meticulously modeled and evaluated. These parts underwent rigorous assessments focusing on several critical aspects, including manufacturability, material selection, economic feasibility, and assembly efficiency.

Through this deconstruction, a thorough understanding of the product's design and functionality was achieved. Each part's design and material choices were scrutinized to determine their impact on overall performance and production costs. The insights gained from these assessments were pivotal in identifying areas for improvement.

Following the comprehensive analysis, the project transitioned into the redesign phase, addressing significant customer concerns. These concerns were primarily centered around enhancing the vacuum’s collection bin capacity and improving suction strength. The redesign aimed to meet these demands while also simplifying the manufacturing process. This was accomplished by reducing the number of components and optimizing the geometry to facilitate easier and more cost-effective production. Additionally, the redesigned vacuum incorporated improved materials, further enhancing its durability and performance.

Overall, the project not only succeeded in refining the handheld vacuum's design to better meet user needs but also achieved a more efficient and economical manufacturing process. The result is a product that combines enhanced functionality with streamlined production, offering both superior performance and greater cost savings.

Appendix

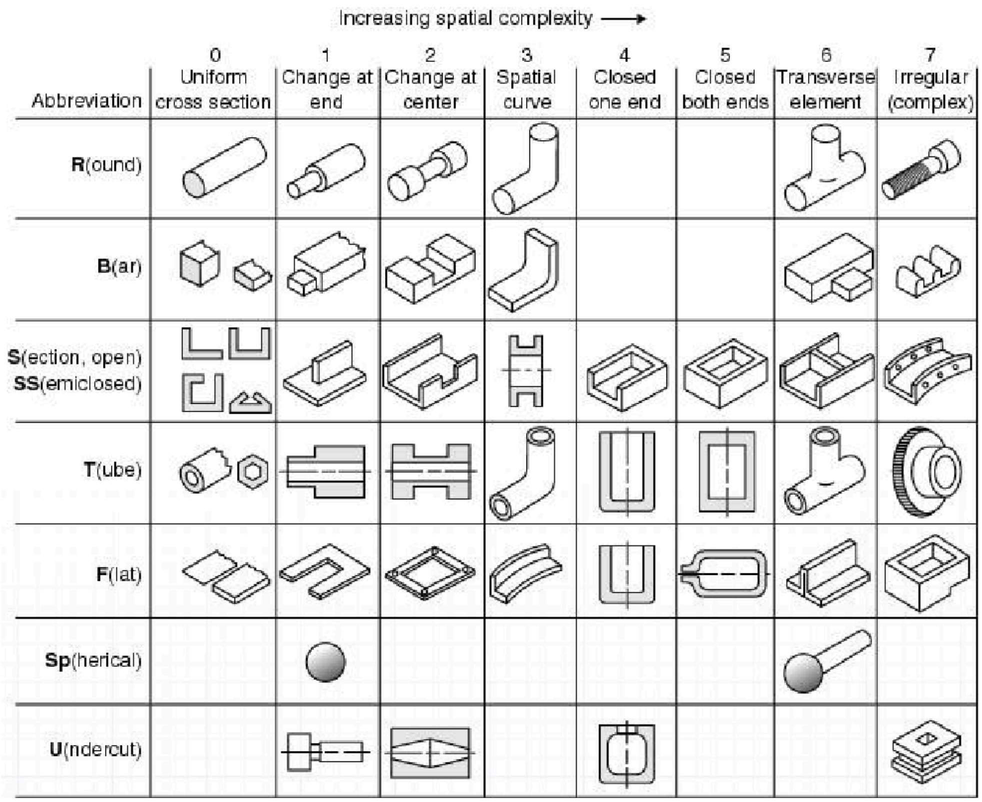


Figure 25: Part Complexity classification.

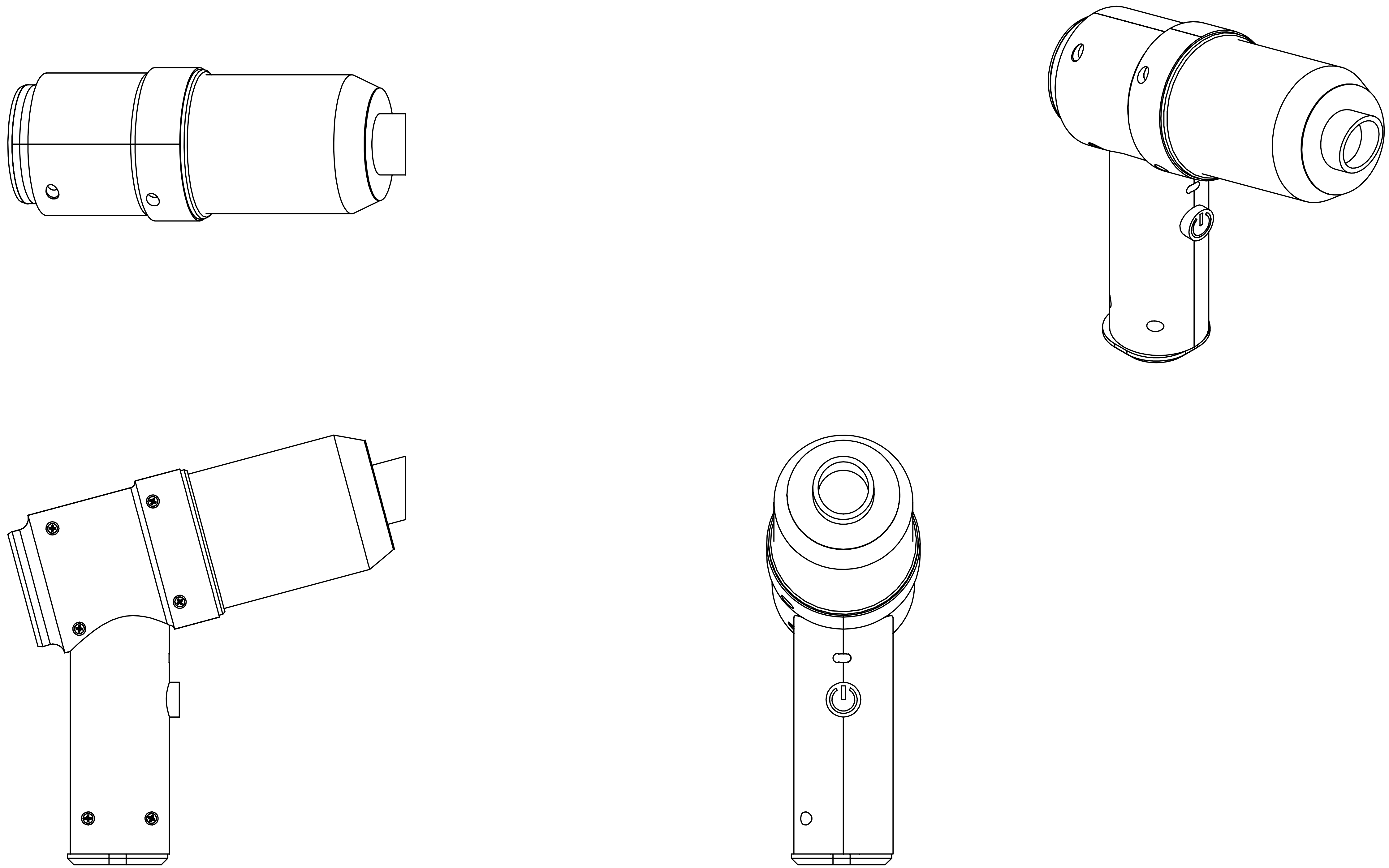
Ability of Manufacturing Processes to Produce Shapes

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	F4; 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 26: Ability of Manufacturing Processes to produce shapes

Original Assembly Drawings

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	10/15/2024

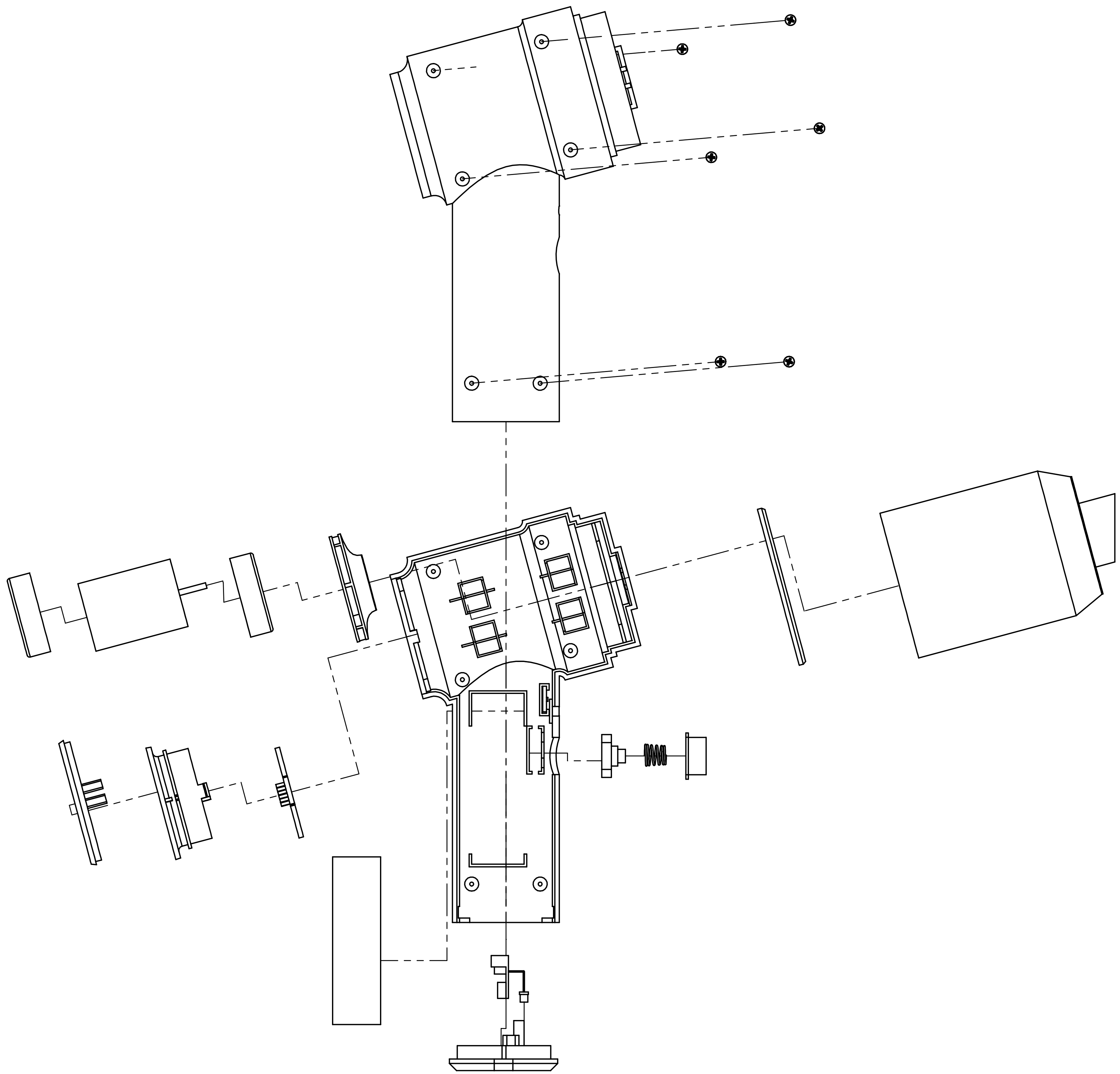


UNIVERSITY OF COLORADO 1876

DESCRIPTION
KMM VACUUM FULL ASSEMBLY

PN	REV		SHEET
N/A	A		1 of 2

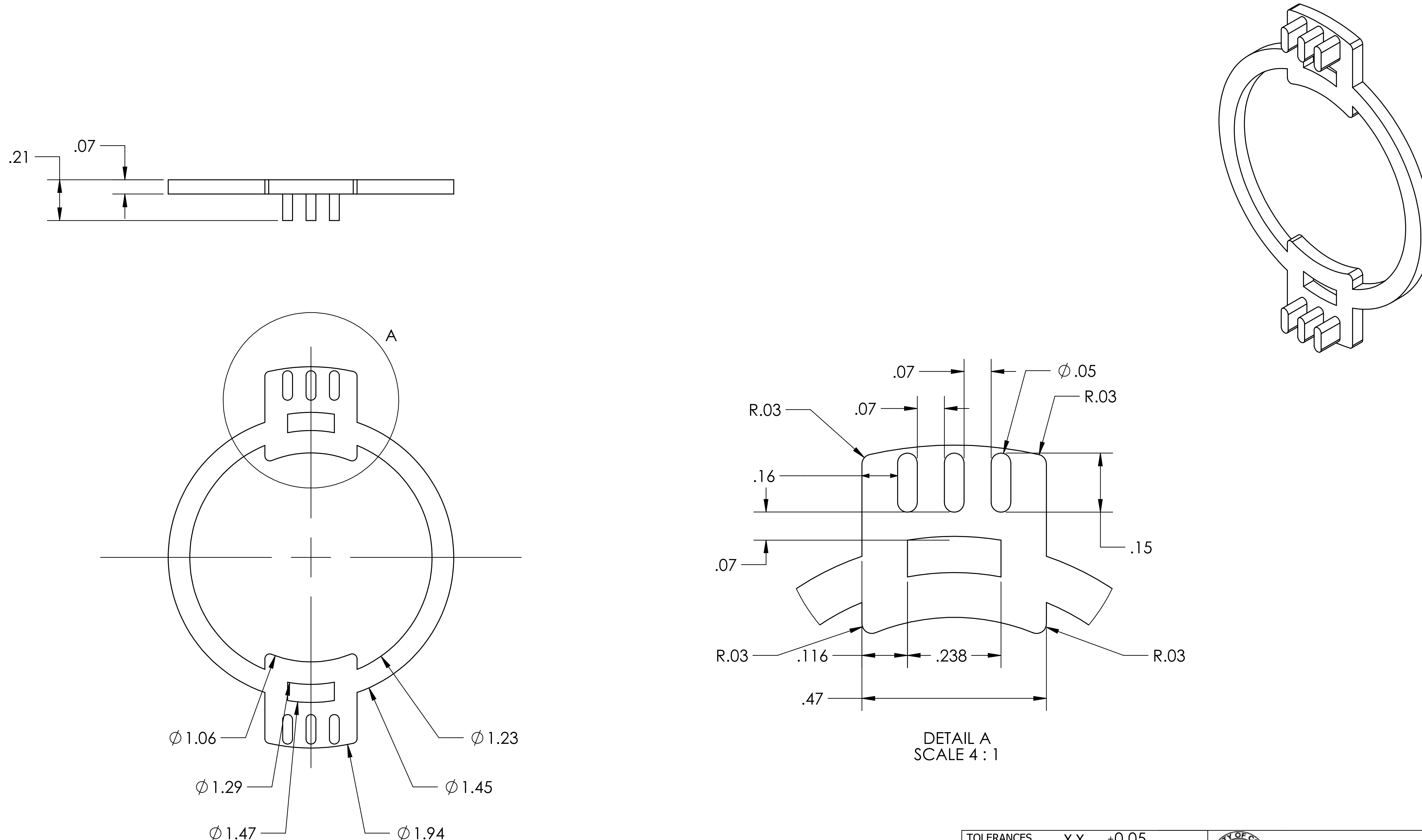
PROPRIETARY AND CONFIDENTIAL



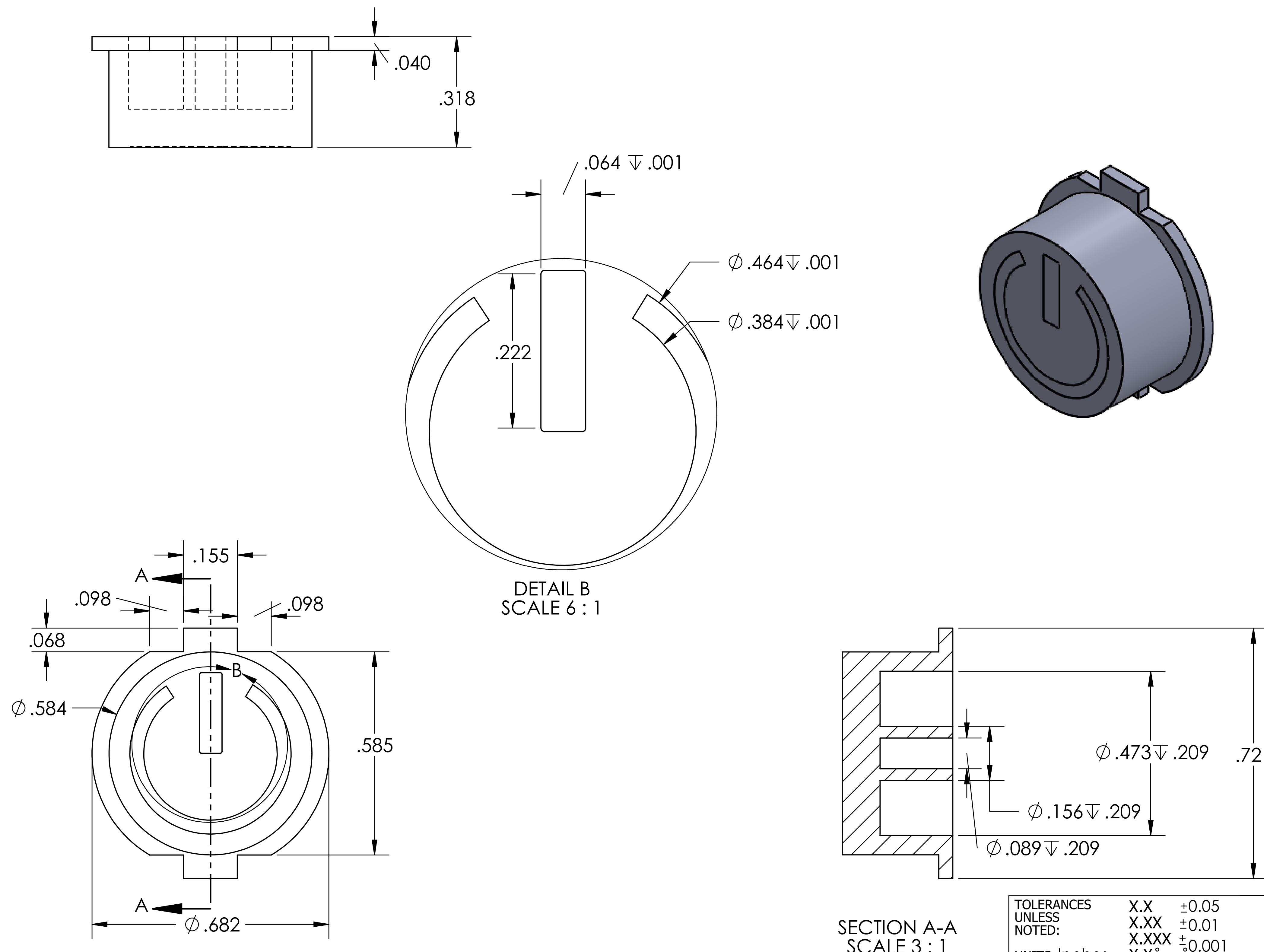
UNIVERSITY OF COLORADO

1111 ENGINEERING DRIVE
BOULDER, CO, 80309-0427

DESCRIPTION			
KMM VACUUM FULL ASSEMBLY			
PN N/A	REV A		SHEET 2 of 2



TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.001 X.X° °				
UNITS: Inches					
MATERIAL ABS		DESCRIPTION KMM Blower Screen Locking Clip			
FINISH Matte		PN RP001	REV A		SHEET 1 of 1



TOLERANCES UNLESS NOTED:	X.X X.XX X.XXX X.X°	±0.05 ±0.01 ±0.001 ±0
UNITS: Inches		
MATERIAL Thermoplastic	DESCRIPTION KMM Vacuum Power Button	
FINISH Paint	PN RP002	REV A	SHEET 1 of 1

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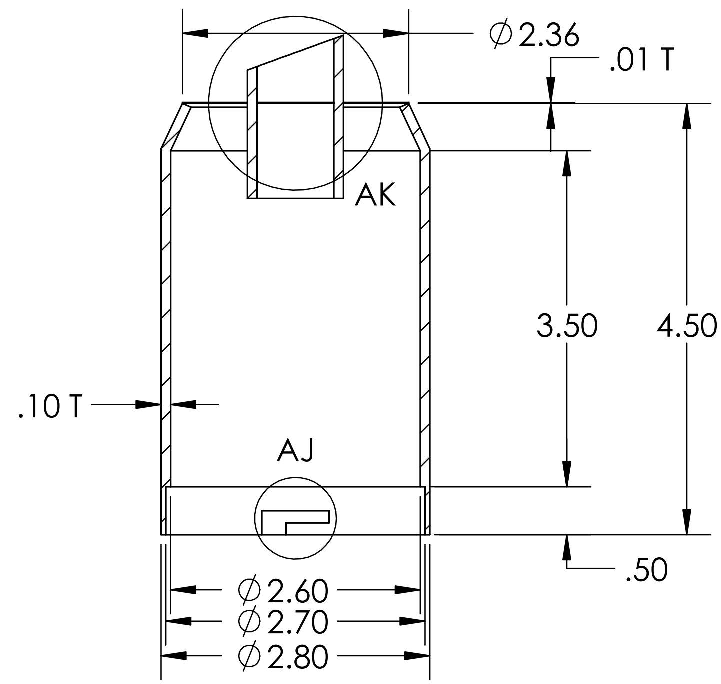
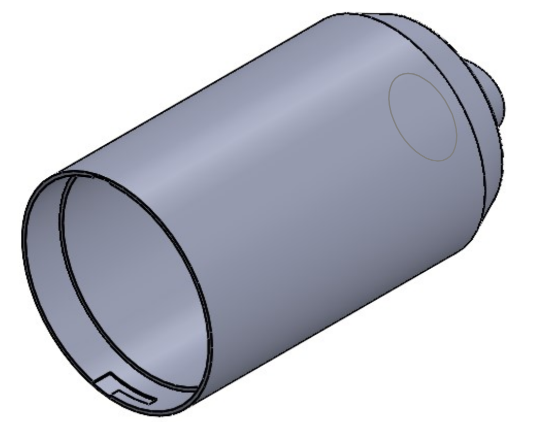
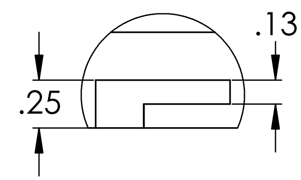
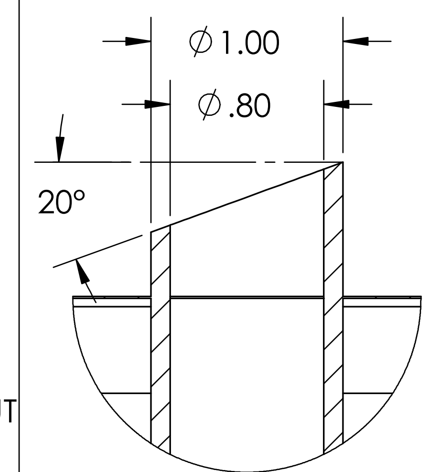


SECTION AH-AH

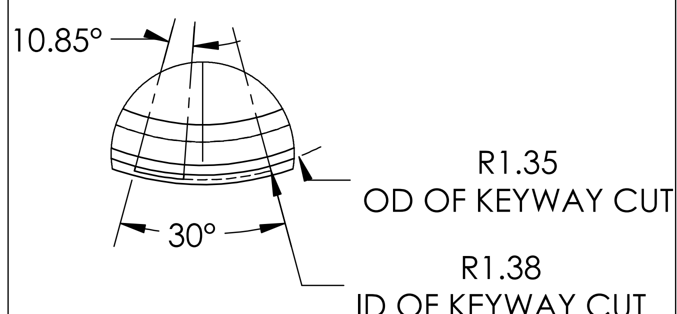




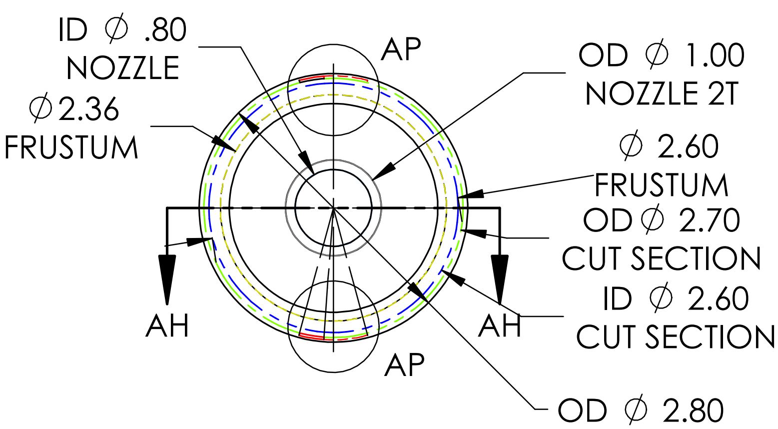
DETAIL AJ
SCALE 1 : 1



DETAIL AK
SCALE 1 : 1



DETAIL AP
SCALE 1 : 1



TOLERANCES UNLESS NOTED: UNITS:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.001 X.X° ±°			
MATERIAL THERMOPLASTIC		DESCRIPTION KMM BLOWER DUST COLLECTION BIN		
FINISH		PN RP003	REV A	SHEET 1 of 1

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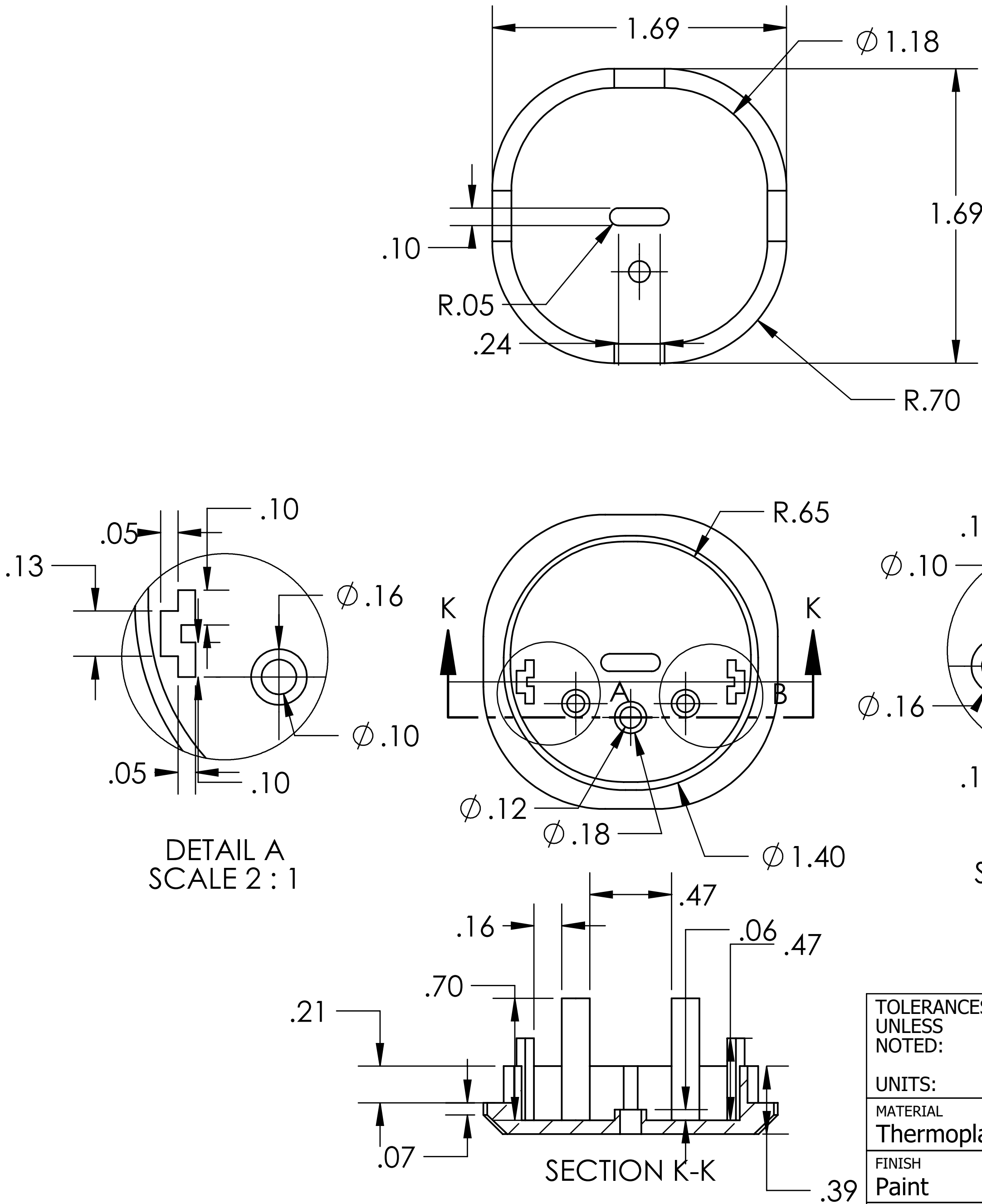

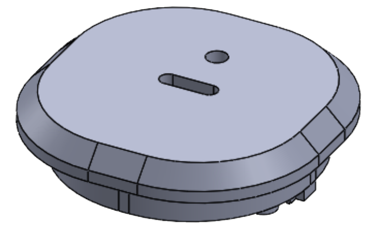

TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.001		
UNITS:	X.X° ± °		
MATERIAL Thermoplastic		DESCRIPTION KMM Base Charging and LED Mount	
FINISH Paint		PN RP004	REV A
			SHEET 1 of 1

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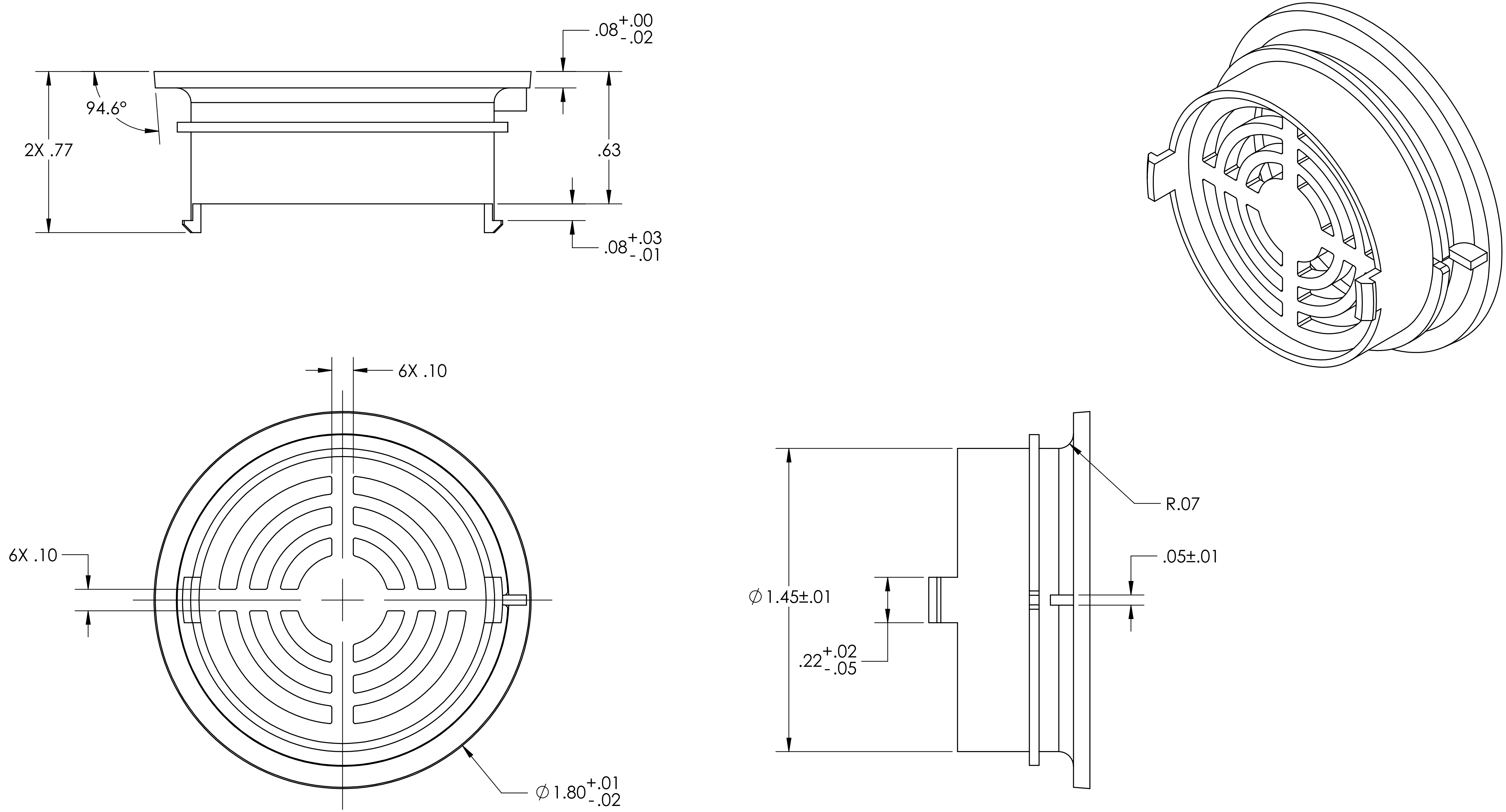
REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	9/16/2024



TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °
UNITS: INCHES	

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

MATERIAL: ABS	DESCRIPTION: BLOWER SCREEN
FINISH: MATTE	PN: RP005 · REV: A · SHEET: 1 of 4

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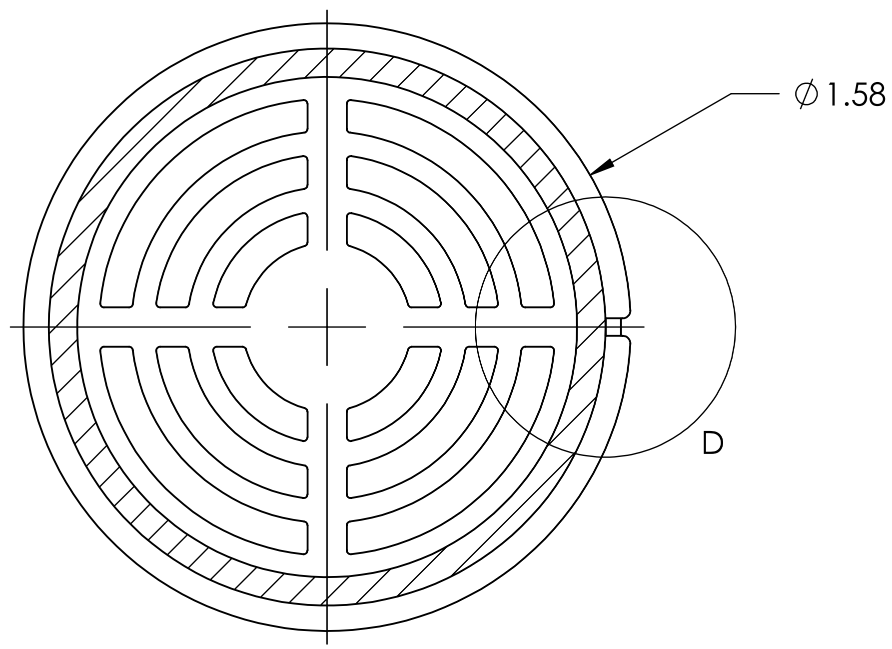
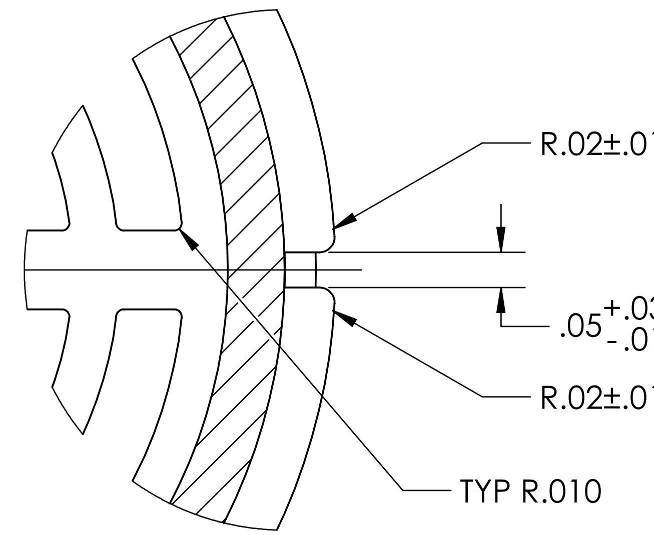
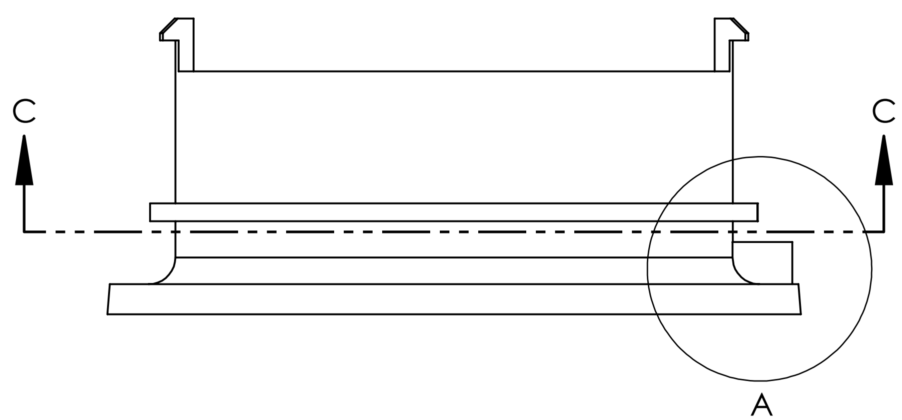
0.1

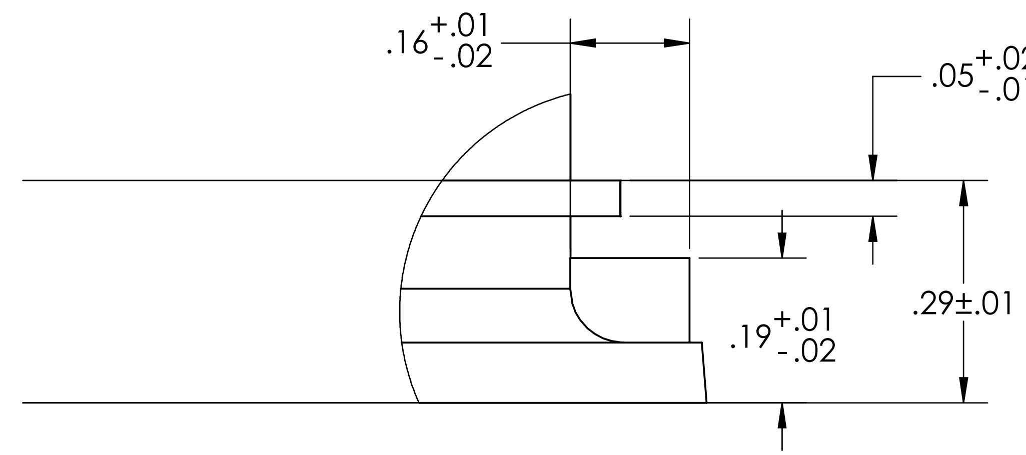


SECTION C-C



DETAIL D
SCALE 4 : 1





DETAIL A
SCALE 4 : 1

TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.02; X.XXX ± 0.005; X.X° ± °

UNITS:INCHES

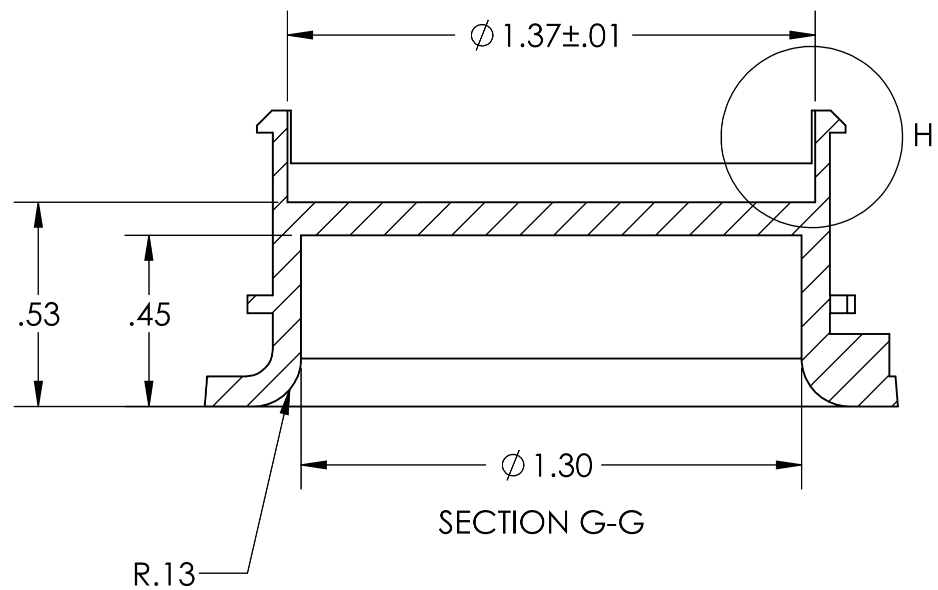
UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO, 80309-0427

MATERIAL
ABS

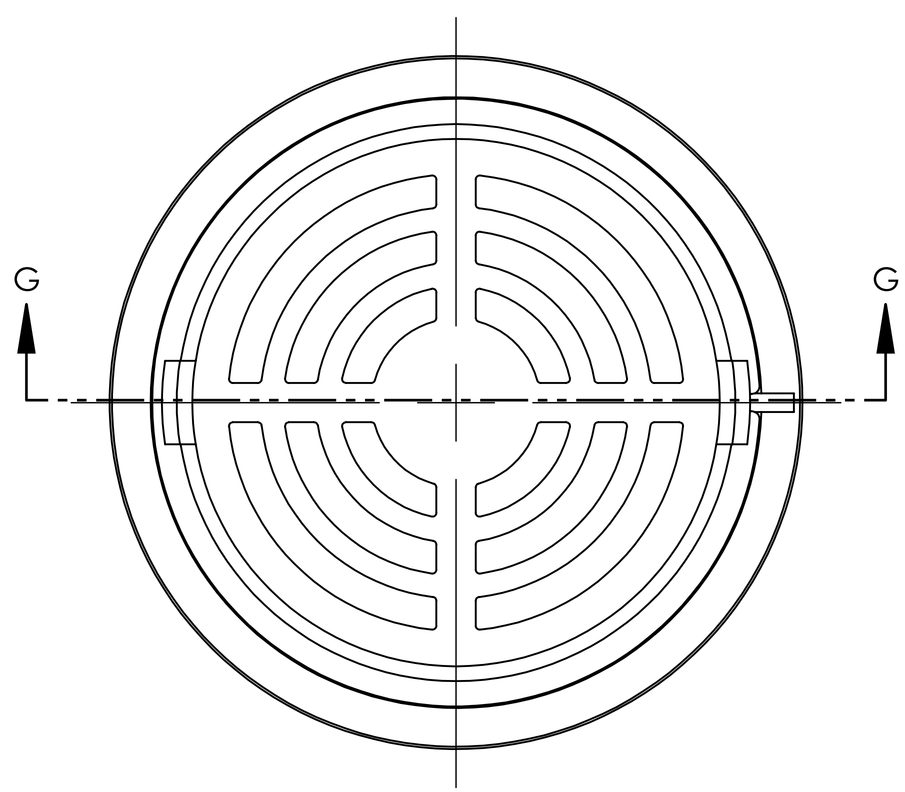
DESCRIPTION
BLOWER SCREEN

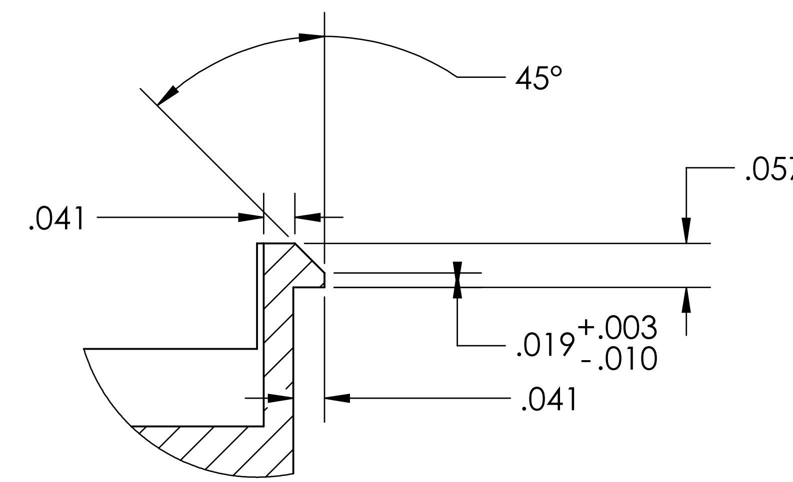
FINISH
MATTE

PN	REV	SHEET
RP005	A	2 of 4



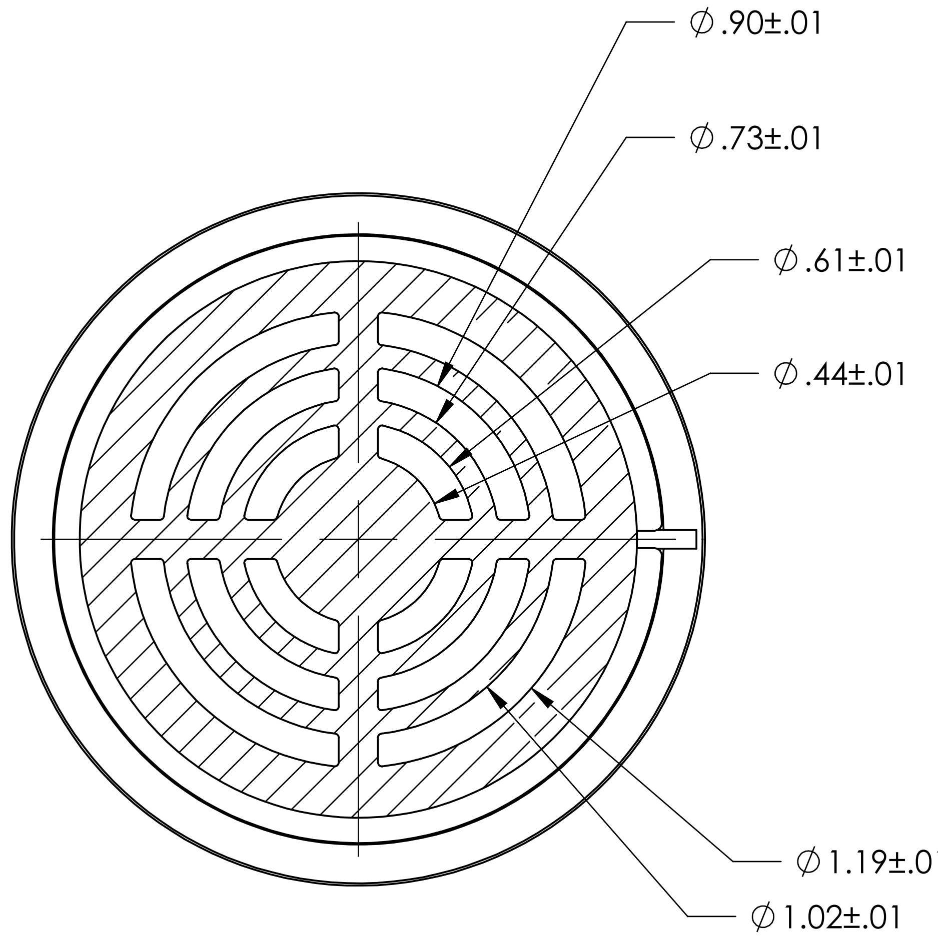
SECTION G-G





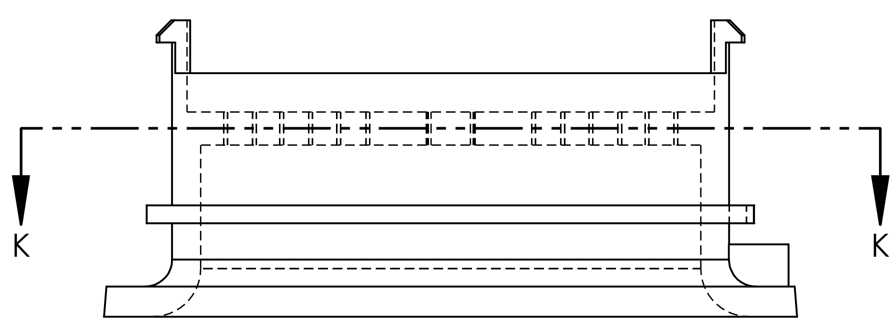
DETAIL H
SCALE 4 : 1

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427			
MATERIAL ABS		DESCRIPTION BLOWER SCREEN			
FINISH MATTE		PN RP005	REV A		SHEET 3 of 4



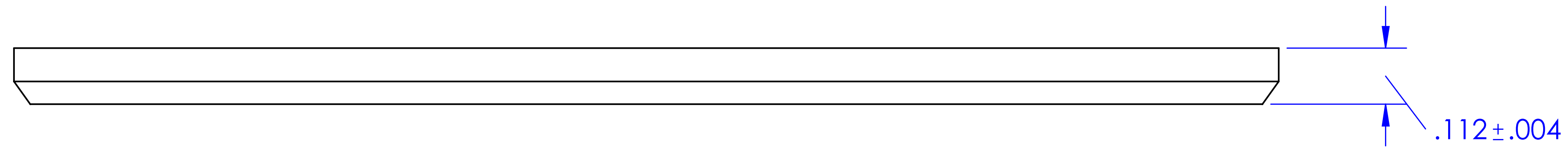
SECTION K-K

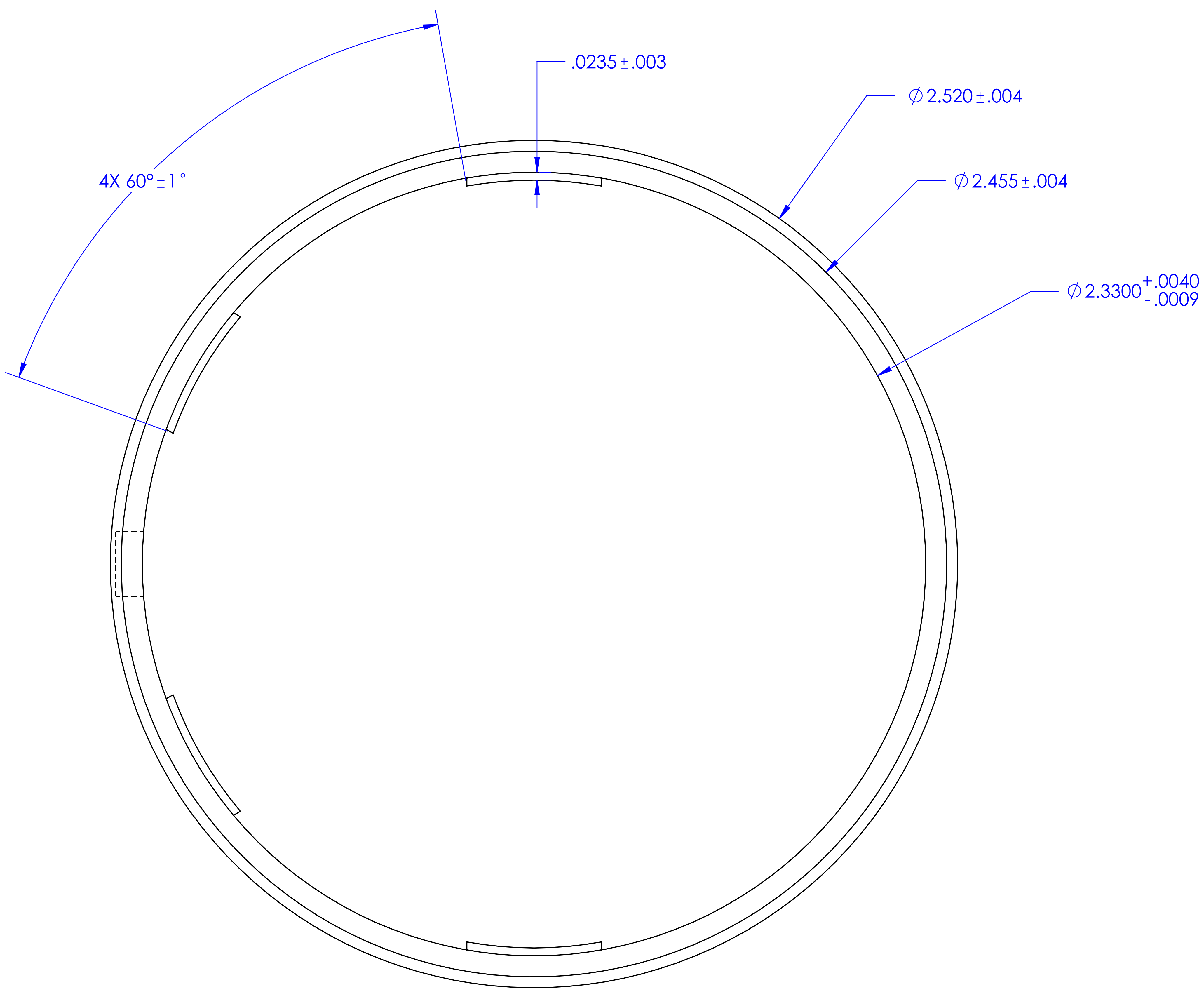
NOTE: CIRCULAR HOLES IN SCREEN GO THROUGH ALL SURFACES



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.1 X.XX ±0.02 X.XXX ±0.005 X.X° °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427		
MATERIAL ABS		DESCRIPTION BLOWER SCREEN		
FINISH MATTE		PN RP005	REV A	SHEET 4 of 4

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	Initial Prototype	9/17/2024	





TOLERANCES UNLESS NOTED: UNITS:	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.003 X.X° 1°		
MATERIAL ABS		DESCRIPTION O-Ring Clip	
FINISH MATTE		PN RP006	REV A · SHEET 1 of 3

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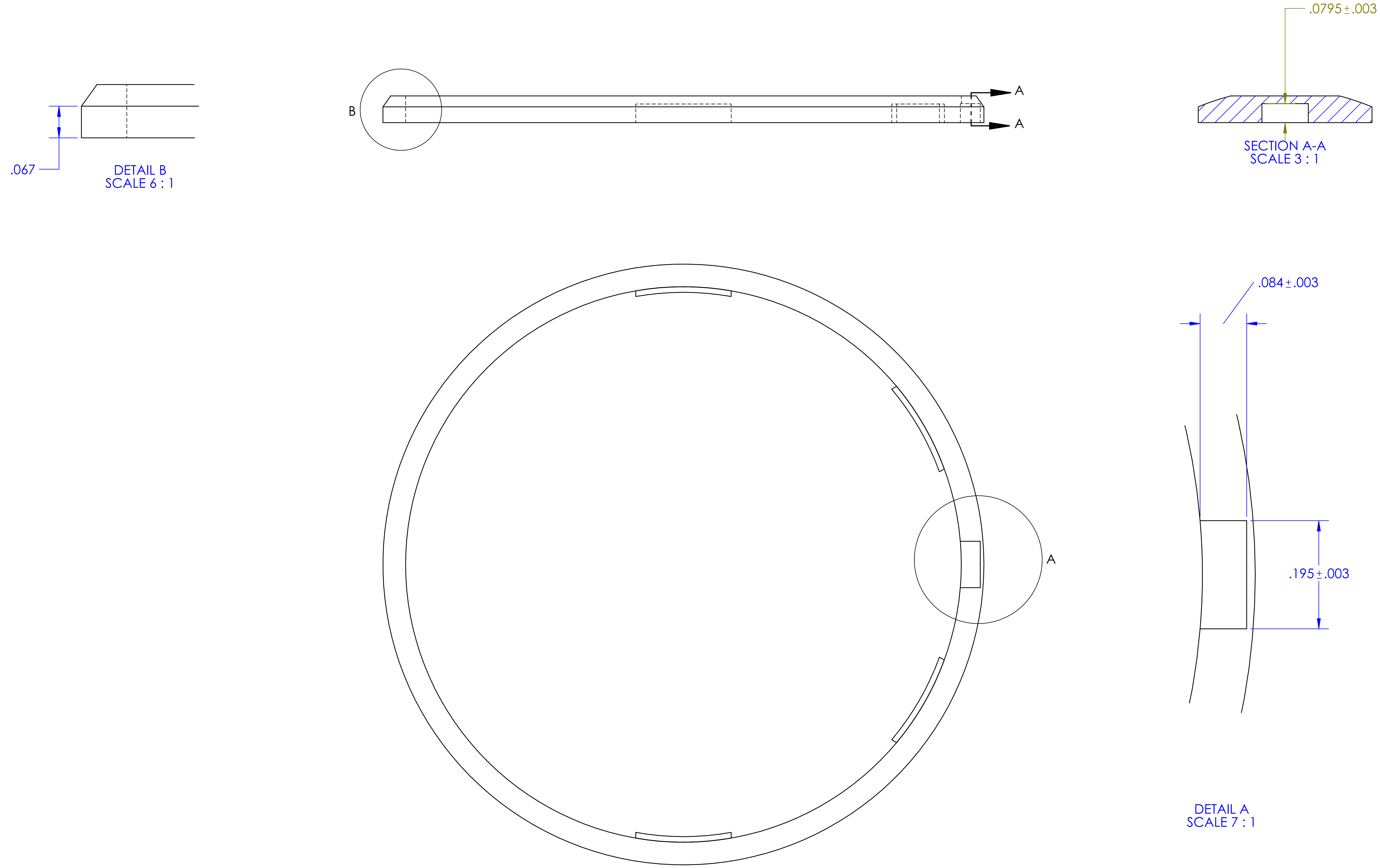
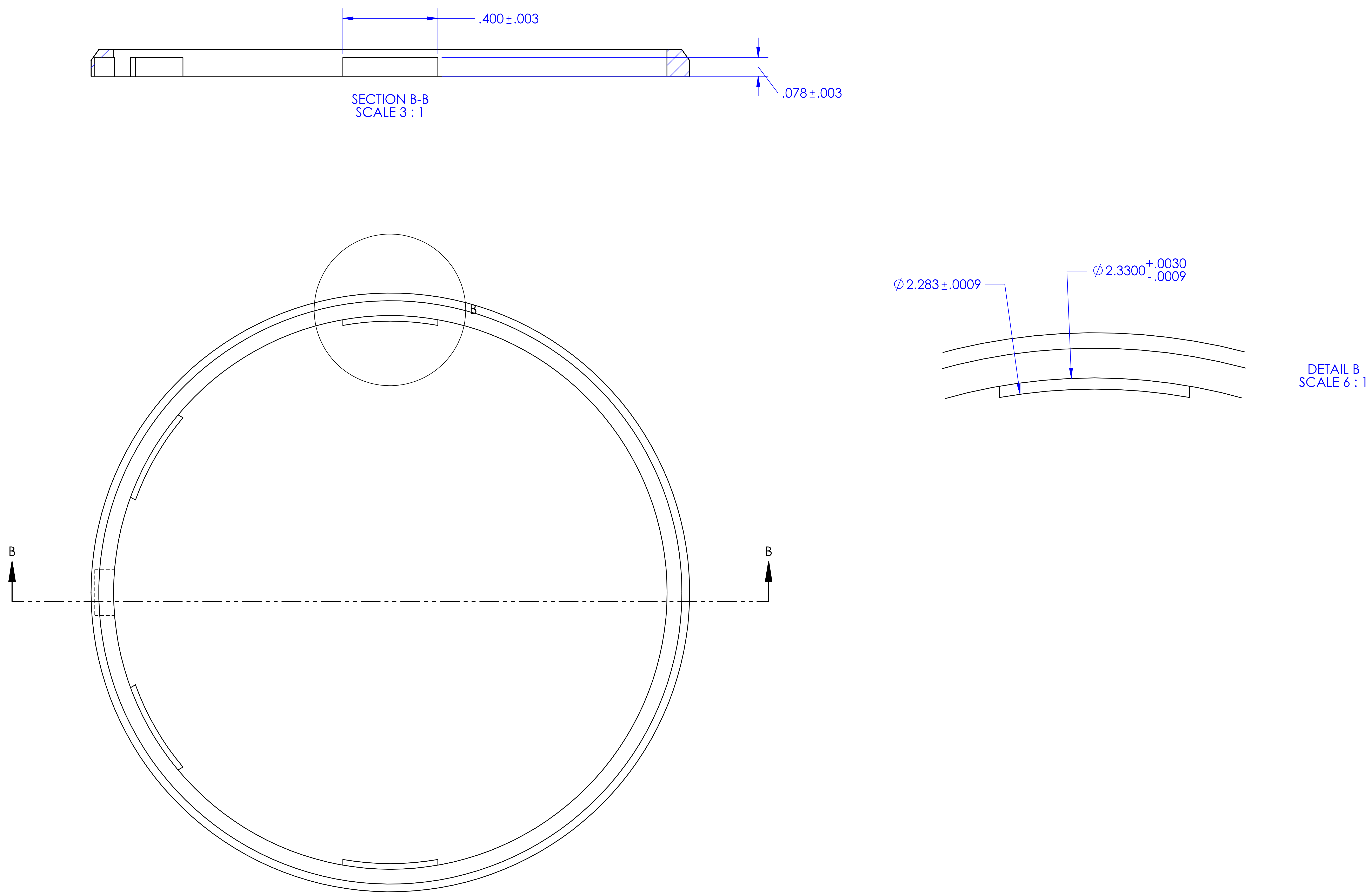


TOLERANCES UNLESS NOTED:	X.X ±0.1 X.XX ±0.02 X.XXX ±0.003 X.X° 1°	
UNITS:		
MATERIAL ABS	DESCRIPTION O-Ring Clip	
FINISH MATTE	PN RP006	REV A
		SHEET 2 of 3



TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.003 X.X° 1°	
UNITS:		
MATERIAL ABS	DESCRIPTION O-Ring Clip	
FINISH MATTE	PN RP006	REV A	SHEET 3 of 3

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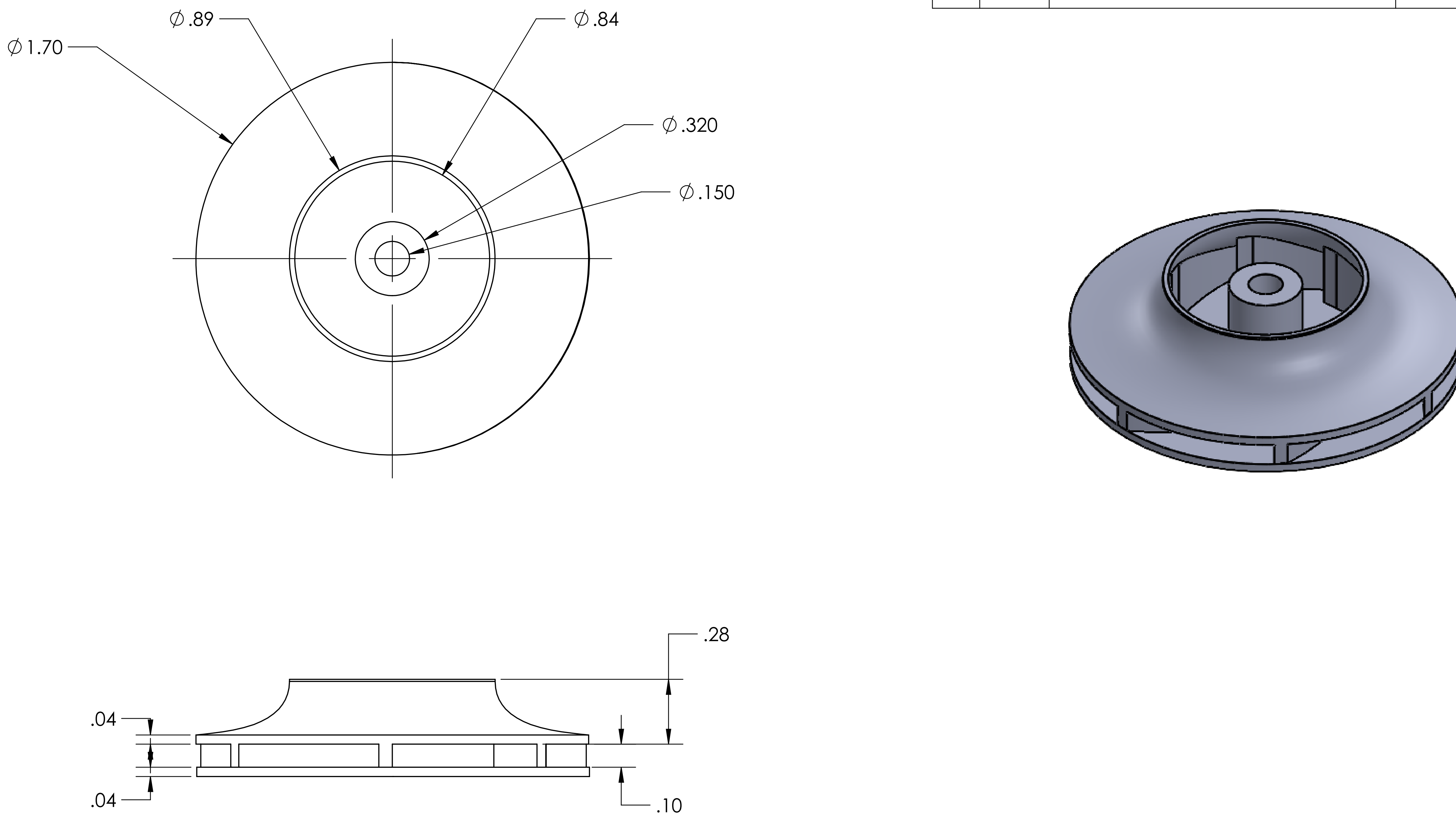
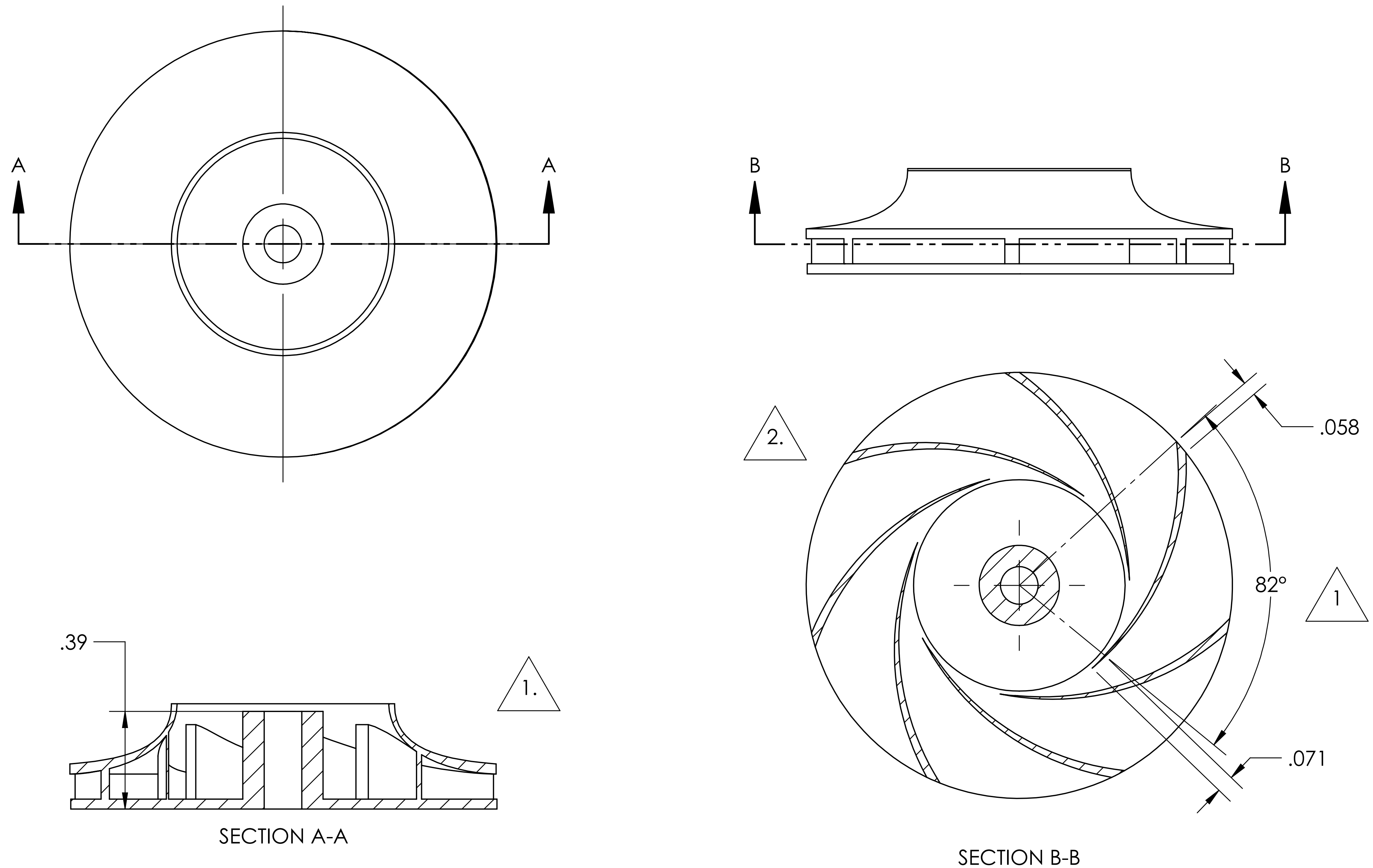


REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	Initial Draft	9/17/2024	

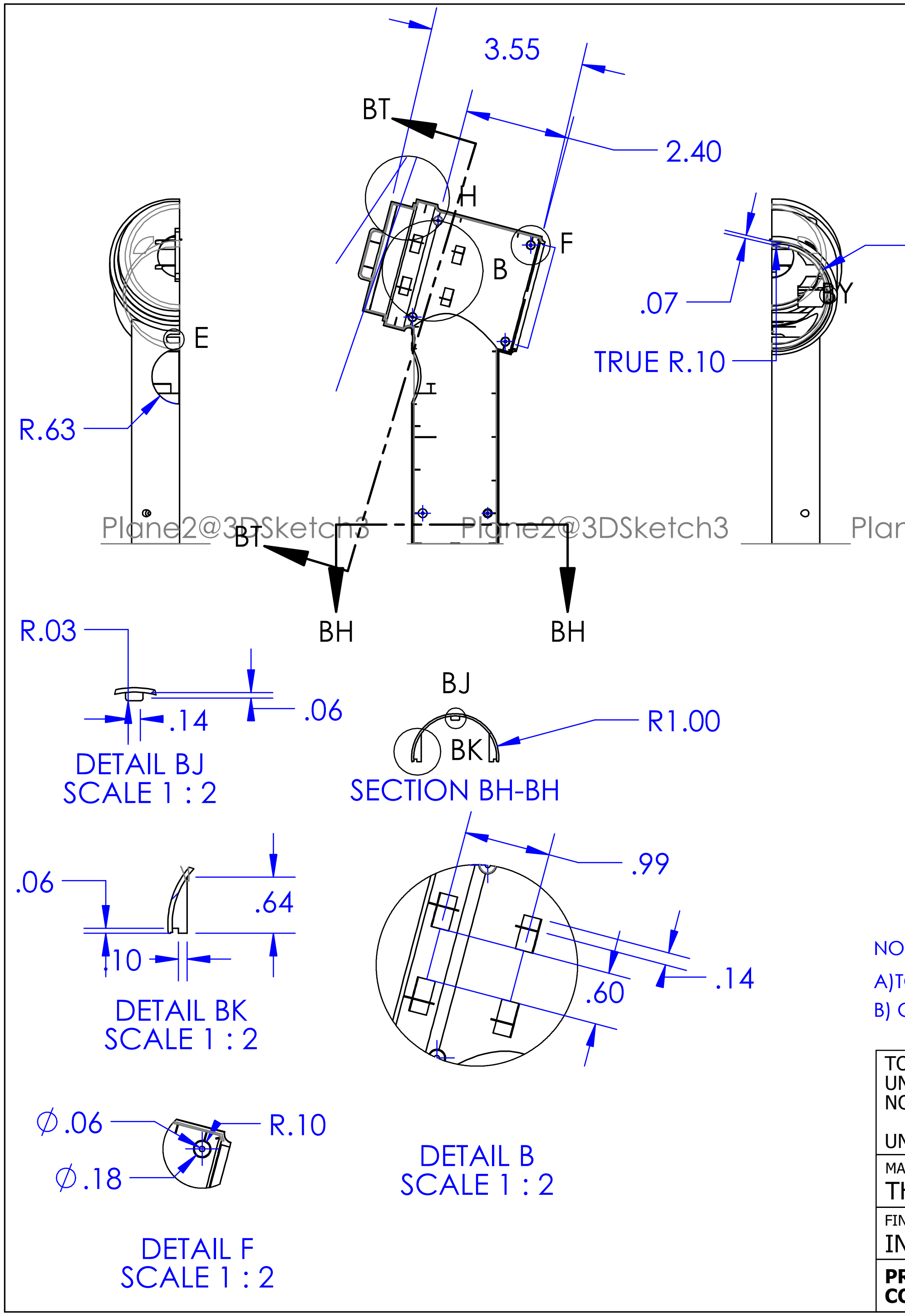
TOLERANCES UNLESS NOTED: X.X ± .1, X.XX ± .02, X.XXX ± .005, X.X° ± ° UNITS: INCHES	UNIVERSITY OF COLORADO 111 ENGINEERING DRIVE BOULDER, CO. 80309-0427		
MATERIAL ABS	DESCRIPTION Impeller		
FINISH MATTE	PN RP008	REV A	SHEET 1 of 2

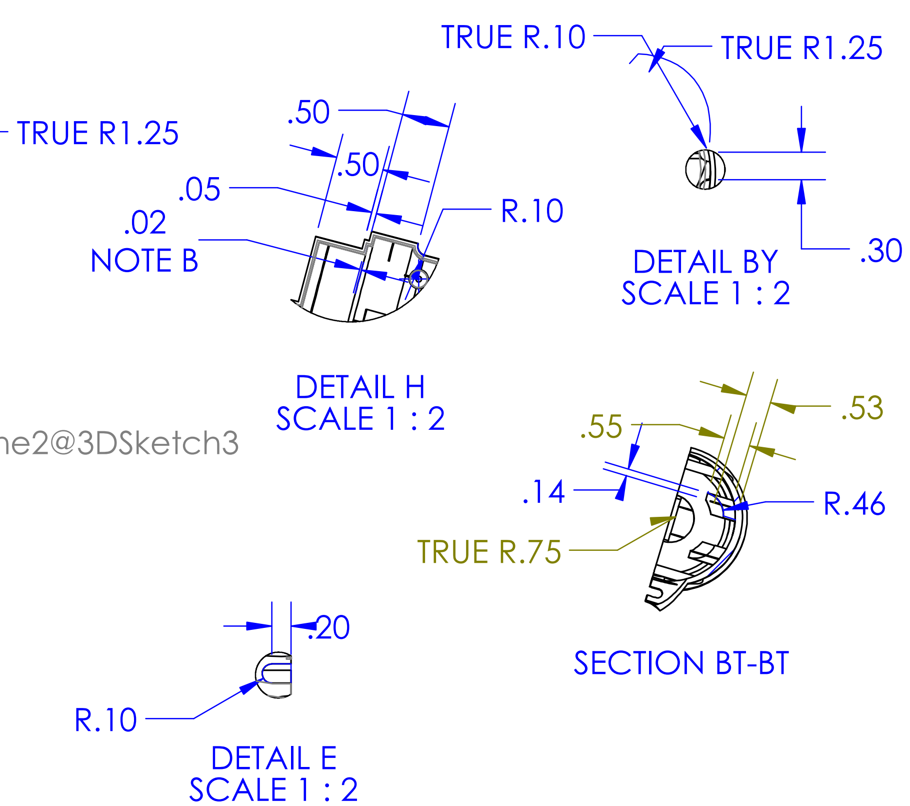


NOTES:
1) FAN BLADES START ON THE TOP OF THE BASE AND EXTEND TO THE BOTTOM OF THE ROOF
2) FAN BLADES ARE IDENTICAL AND EVENLY DISTRIBUTED AROUND THE CIRCUMFRENCE.
3)BLADES ARE CONSTRUCTED USING EDGE POINTS CONECTED WITH AN ARC WITH RADIUS 1.05 INCHES

TOLERANCES UNLESS NOTED: X.X ± .1; X.XX ± .02; X.XXX ± .005; X.X° ± .1 — UNITS: INCHES	UNIVERSITY OF COLORADO 111 ENGINEERING DRIVE BOULDER, CO. 80309-0427	
MATERIAL ABS	DESCRIPTION Impeller	
FINISH MATTE	PN RP008 · REV A	SHEET 2 of 2

REV	DESCRIPTION	DATE
A	INITIAL DRAWING	9/18/2024





NOTES:

A)TOLERANCE FOR INJECTION MOUNDING IS $\pm$.0.5

B) CUT TO ATTACH IT TO THE EXTRUDED SECTION OF THE LEFT SIDE

TOLERANCES UNLESS NOTED: UNITS:	X.X ± 0.1 X.XX ± 0.03 X.XXX ± 0.005 X.X° ± °	UNIVERSITY OF COLORADO 1876
MATERIAL THERMOPLASTIC		DESCRIPTION KMM HOUSING (RIGHT HALF)
FINISH INJECTION MOULDING		PN RPOO9 | REV A | SHEET 1 of 2

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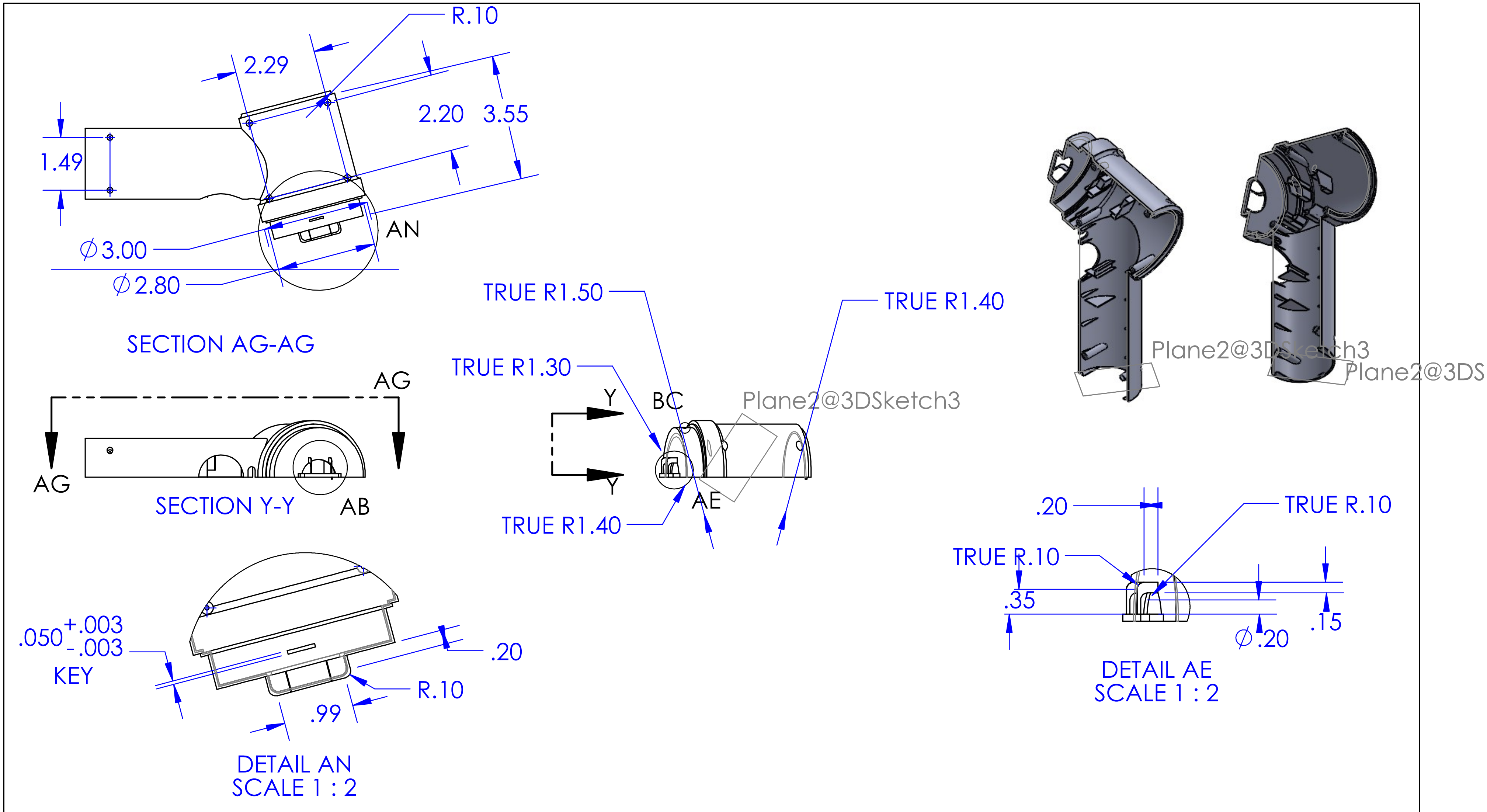

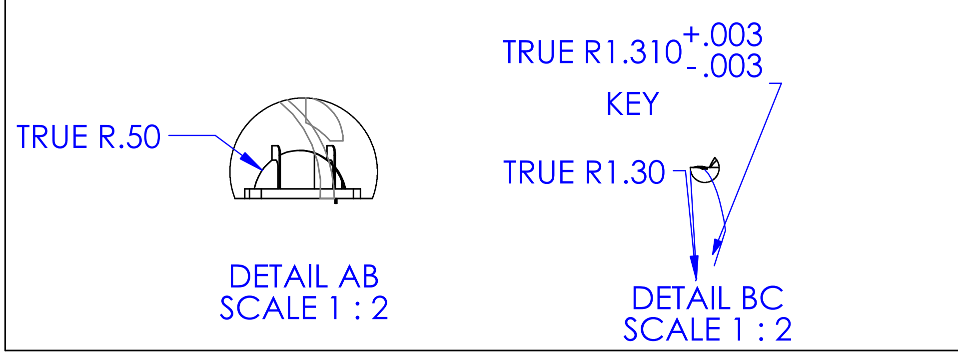

TOLERANCES UNLESS NOTED: X.X ±0.1; X.XX ±0.03; X.XXX ±0.005; UNITS: X.X° ±°	UNIVERSITY OF COLORADO 1876
MATERIAL THERMOPLASTIC	DESCRIPTION KMM HOUSING (RIGHT HALF)
FINISH INJECTION MOULDING	PN RPOO9 · REV A · SHEET 2 of 2

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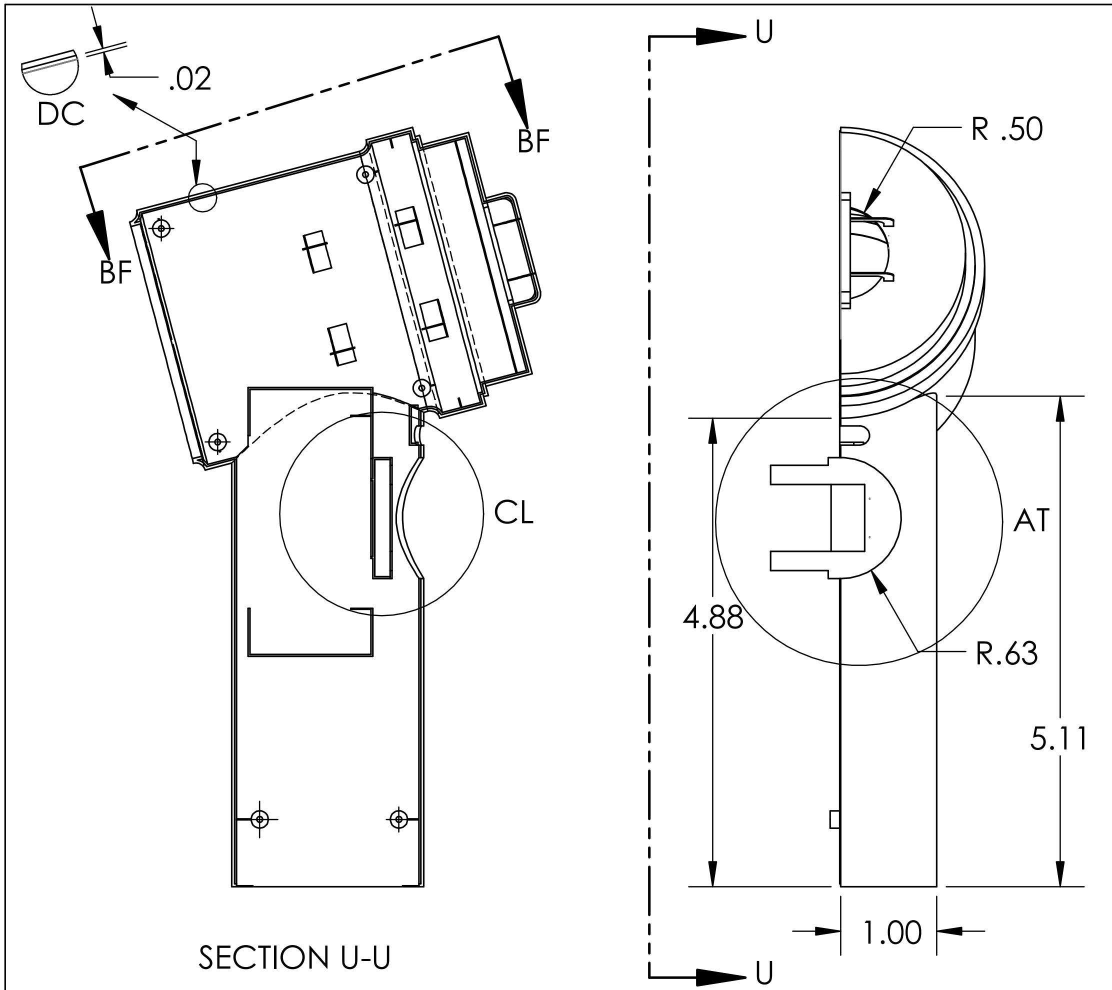
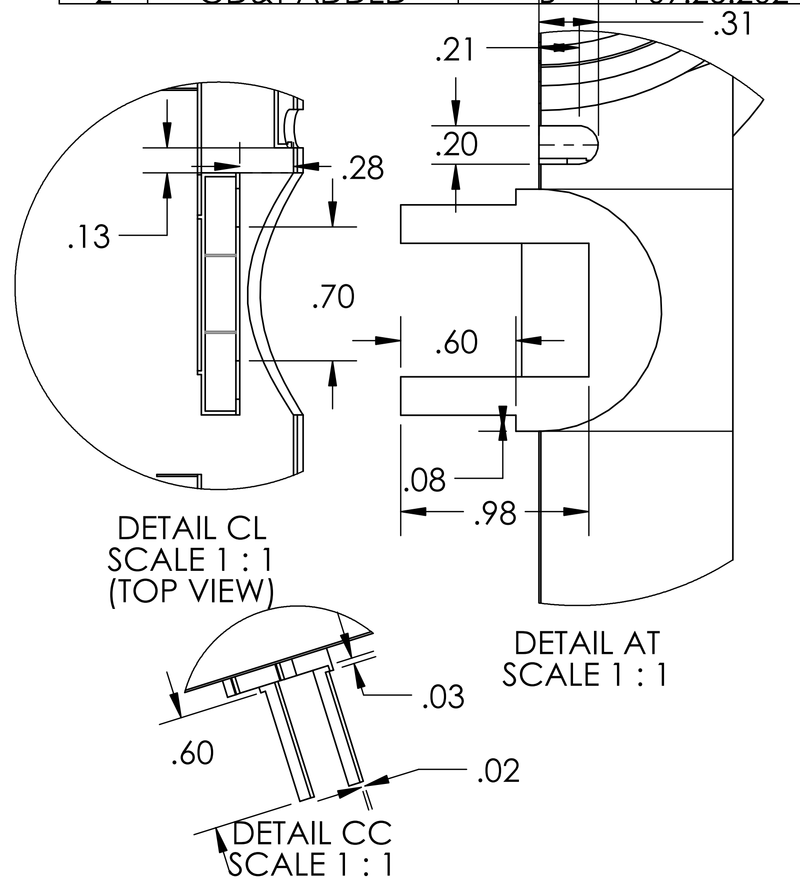
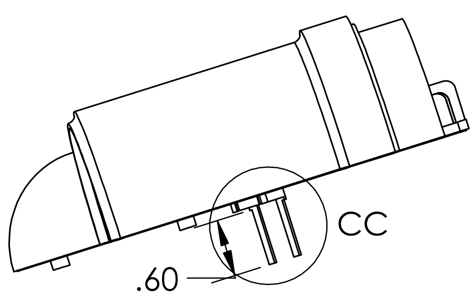
REVISIONS TABLE			
S.NO	DESCRIPTION	REV NO.	DATE
1	INITIAL DRAWING	A	09.23.2024
2	GD&T ADDED	B	09.25.2024





NOTES :

- DETAIL DC DISPLAYS THE EXTRUTION OF 0.1 INCHES. THIS ACTS A KEYWAY TO JOIN LEFT AND RIGHT SIDE OF THE VACUUM HOUSING (PART RP009).
- DETAIL CL, AT AND CC ARE MAIN INTERFACING FEATURES .IT IS THE HOUSING FOR THE POWER BUTTON (PART RP002).



SECTION BF-BF

TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.03; X.XXX ± 0.005; X.X° ± ° UNITS: INCHES	
MATERIAL THERMOPLASTIC	DESCRIPTION KMM VACUUM HOUSING(LEFT SIDE)
FINISH N/A	PN RP011 · REV B · SHEET 1 of 5

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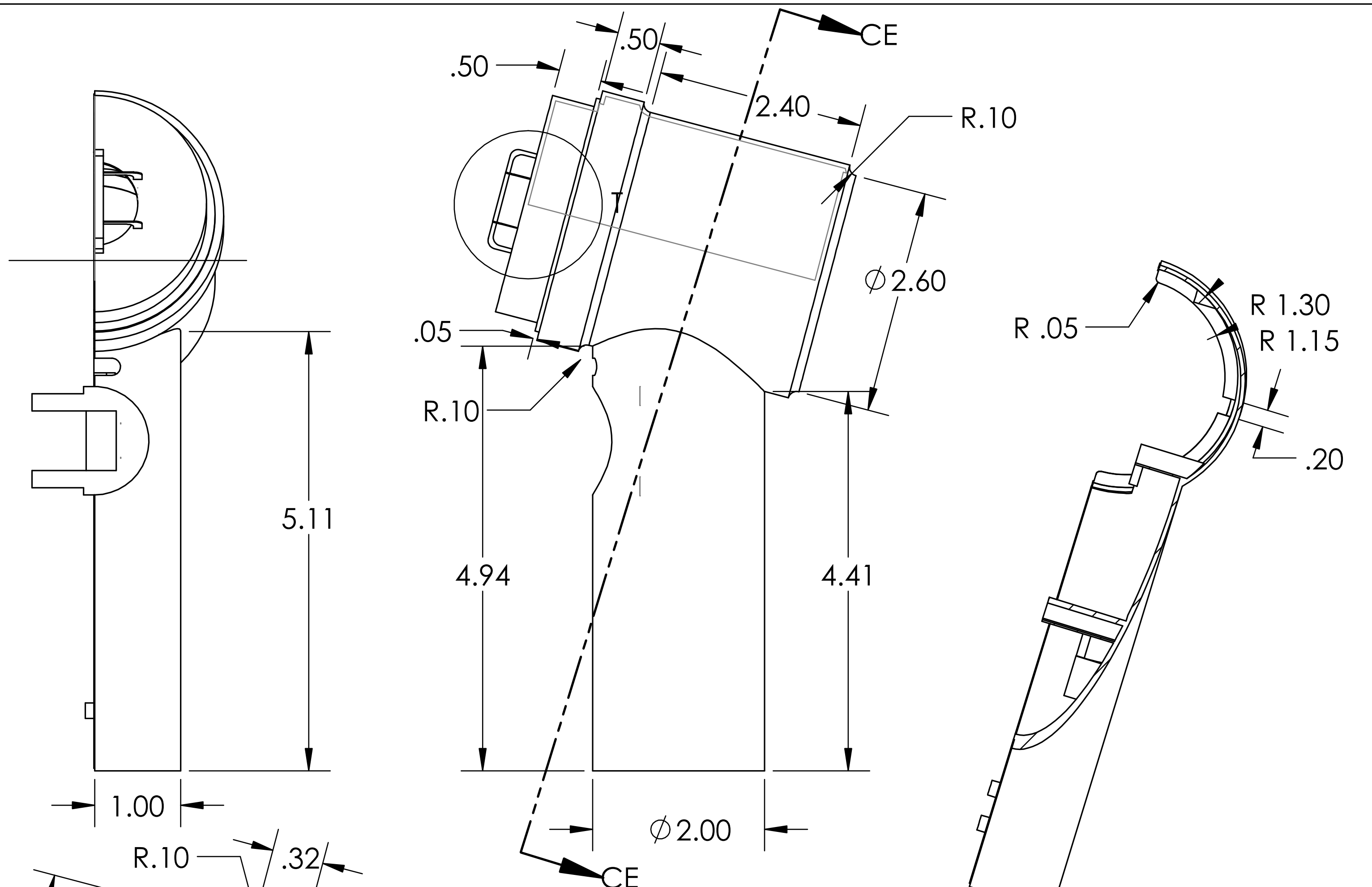
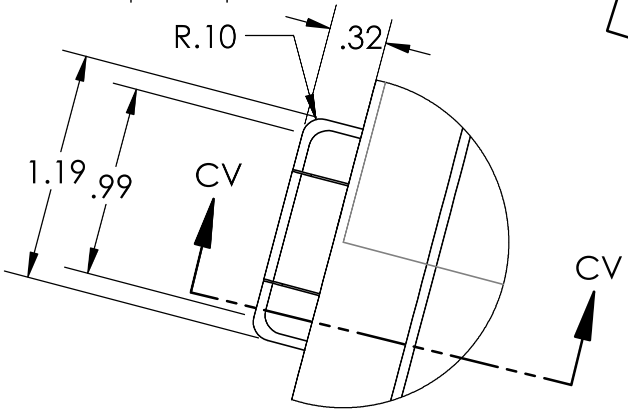
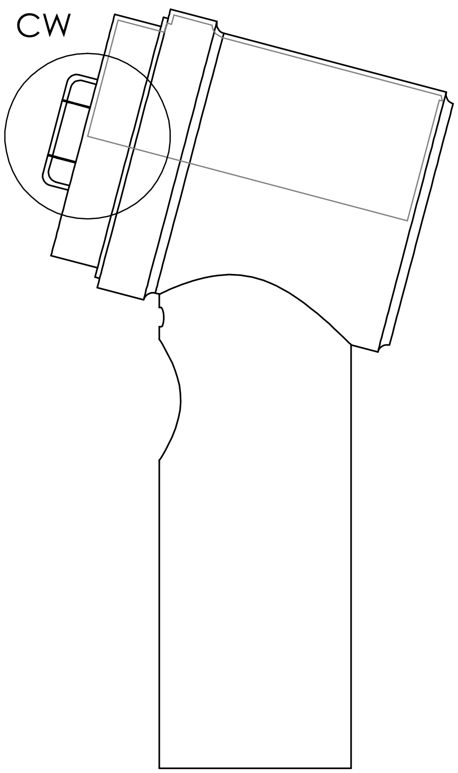


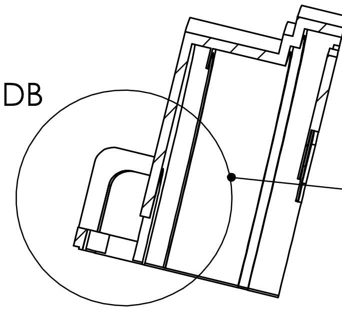
SECTION CE-CE



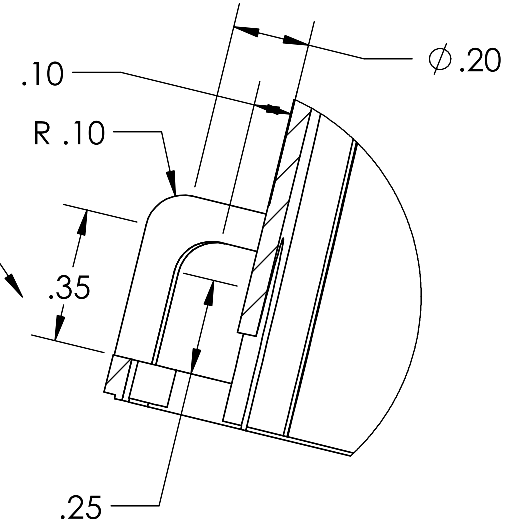
DETAIL T
SCALE 1 : 1

TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.03, X.XXX ± 0.005, X.X° ± ° UNITS: INCHES	
MATERIAL THERMOPLASTIC	DESCRIPTION KMM VACUUM HOUSING(LEFT SIDE)
FINISH N/A	PN RP011 · REV B · SHEET 2 of 5

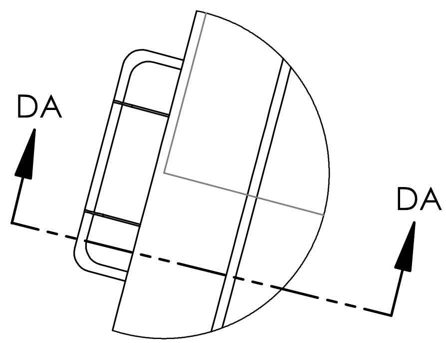




SECTION DA-DA
SCALE 1 : 1

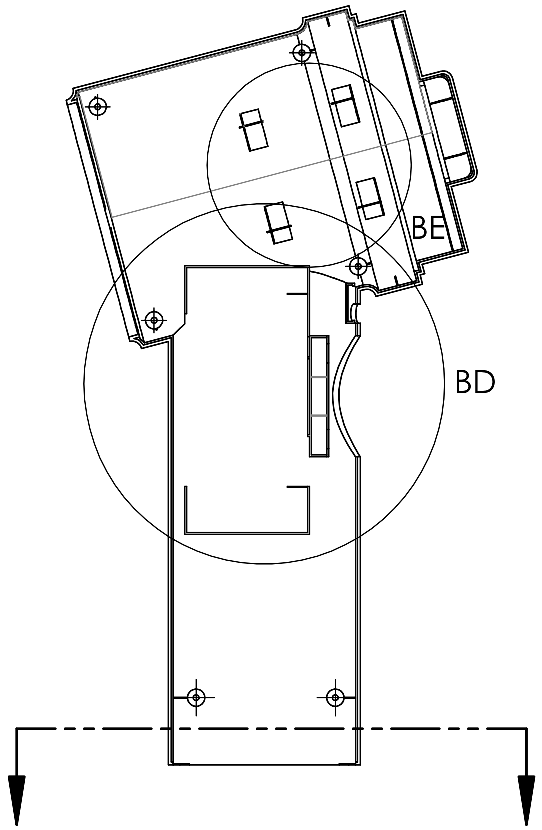


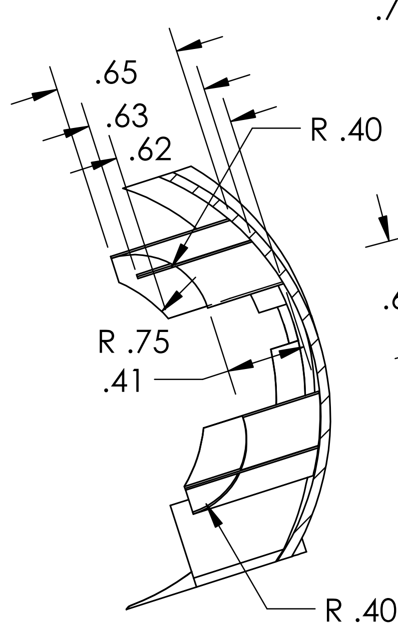
DETAIL DB
SCALE 2 : 1



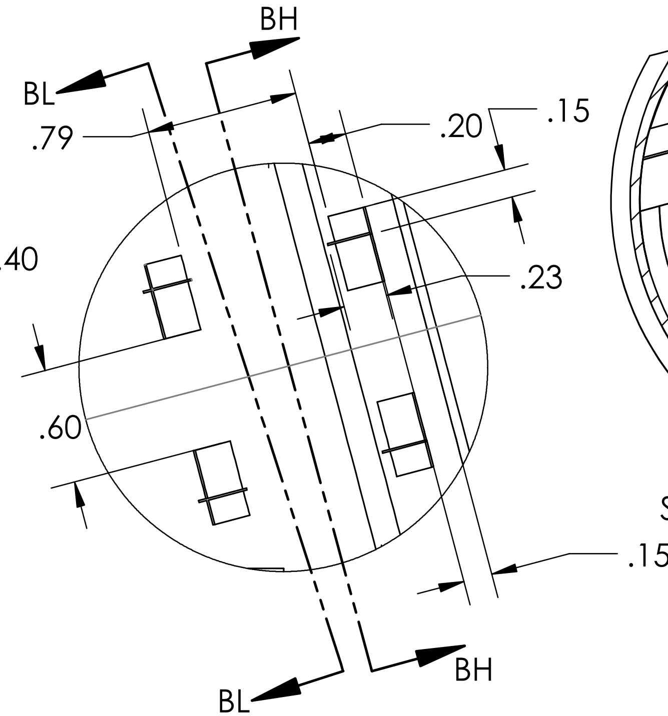
DETAIL CW
SCALE 1 : 1

TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.03; X.XXX ± 0.005; X.X° ± ° UNITS: INCHES				
MATERIAL THERMOPLASTIC	DESCRIPTION KMM VACUUM HOUSING(LEFT SIDE)			
FINISH N/A	PN RP011	REV B		SHEET 3 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.			

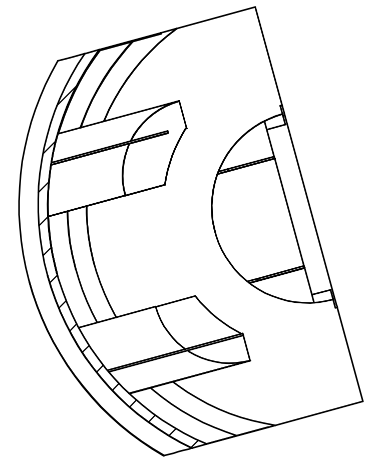




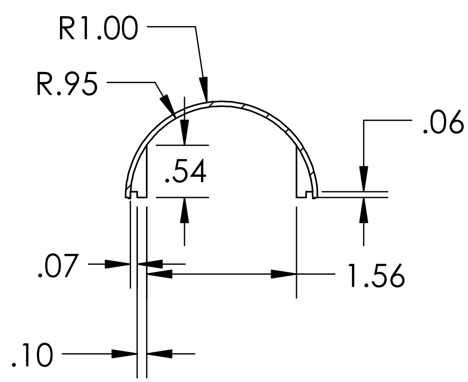
SECTION BL-BL
SCALE 1 : 1



DETAIL BE
SCALE 1 : 1



SECTION BH-BH
SCALE 1 : 1



SECTION BP-BP

NOTES :

- DETAIL 'BE' IS A MAIN INTERFACING FEATURES .IT IS THE HOUSING FOR THE MOTOR.
- SECTION BP-BP IS THE HOUSING FOR BASE CHARGING(PART RP004, RP009).

TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.03; X.XXX ± 0.005; X.X° ± 1° UNITS: INCHES			
MATERIAL THERMOPLASTIC	DESCRIPTION KMM VACUUM HOUSING(LEFT SIDE)		
FINISH N/A	PN RP011	REV B	SHEET 4 of 5

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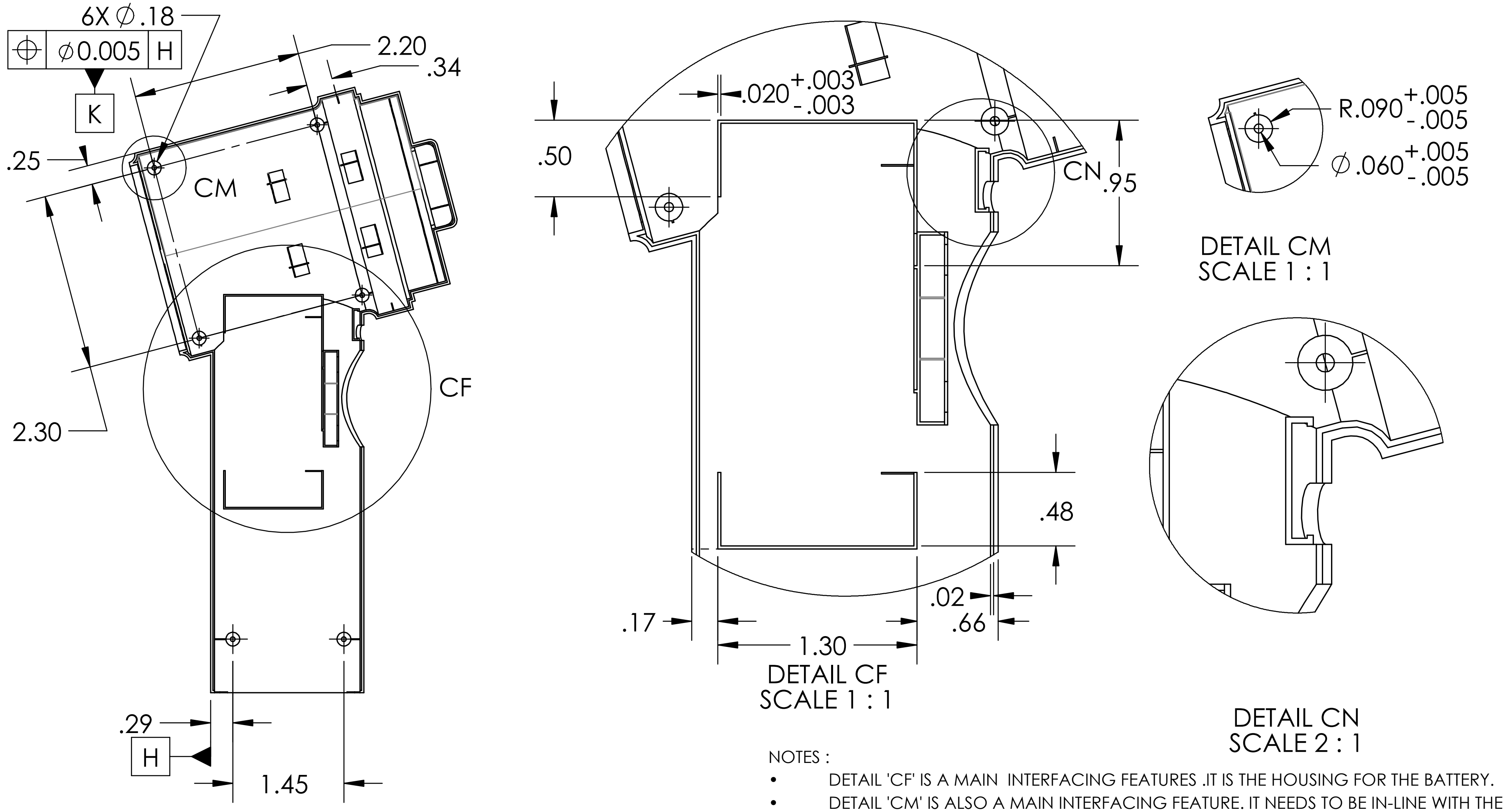
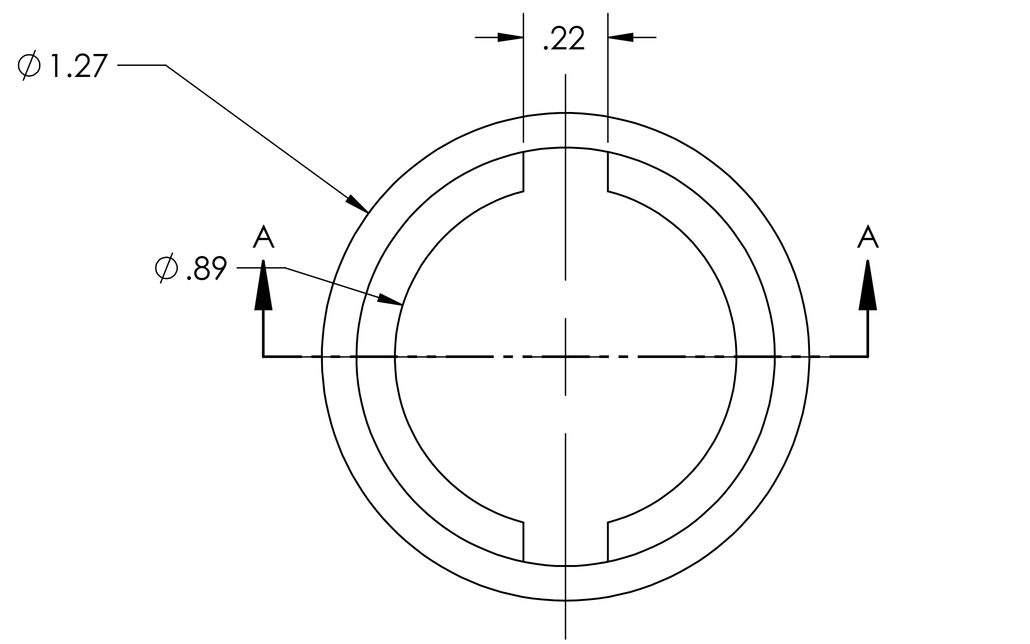


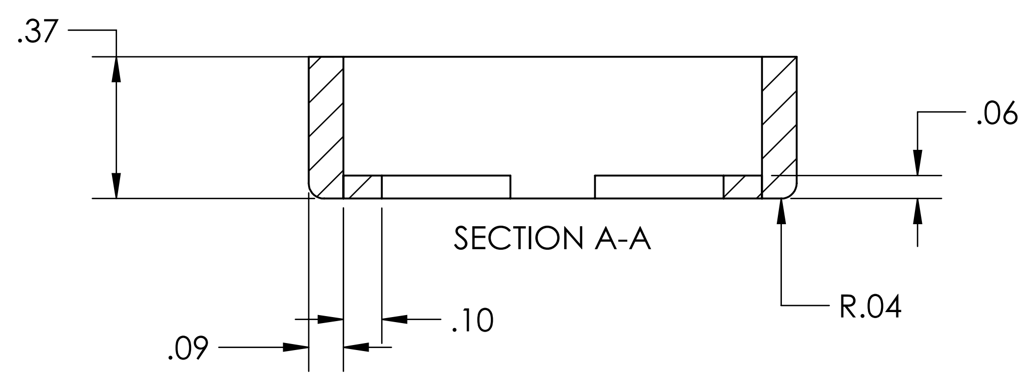
NOTES :

- DETAIL 'CF' IS A MAIN INTERFACING FEATURES .IT IS THE HOUSING FOR THE BATTERY.
- DETAIL 'CM' IS ALSO A MAIN INTERFACING FEATURE. IT NEEDS TO BE IN-LINE WITH THE HOLES IN THE RIGHT SIDE OF THE VACUUM HOUSING.THIS INTURN ASSURES A PROPER HOUSING OF THE PRODUCTS (WITH PART RP009).
- BY FIXING DATUM H WE MEASURE THE POSITION OF BOLT OF DIA 0.18.NOW BY FIXING THAT AS DATUM K, WE MEASURE THE ALIGNMENT OF THE ARRAY OF BOLTS.

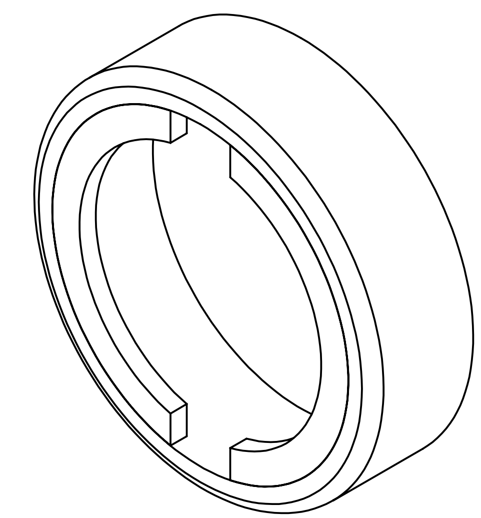
TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.1 X.XX ± 0.03 X.XXX ± 0.005 X.X° ± °		
MATERIAL THERMOPLASTIC		DESCRIPTION KMM VACUUM HOUSING(LEFT SIDE)	
FINISH N/A		PN RP011	REV B	SHEET 5 of 5

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





SECTION A-A

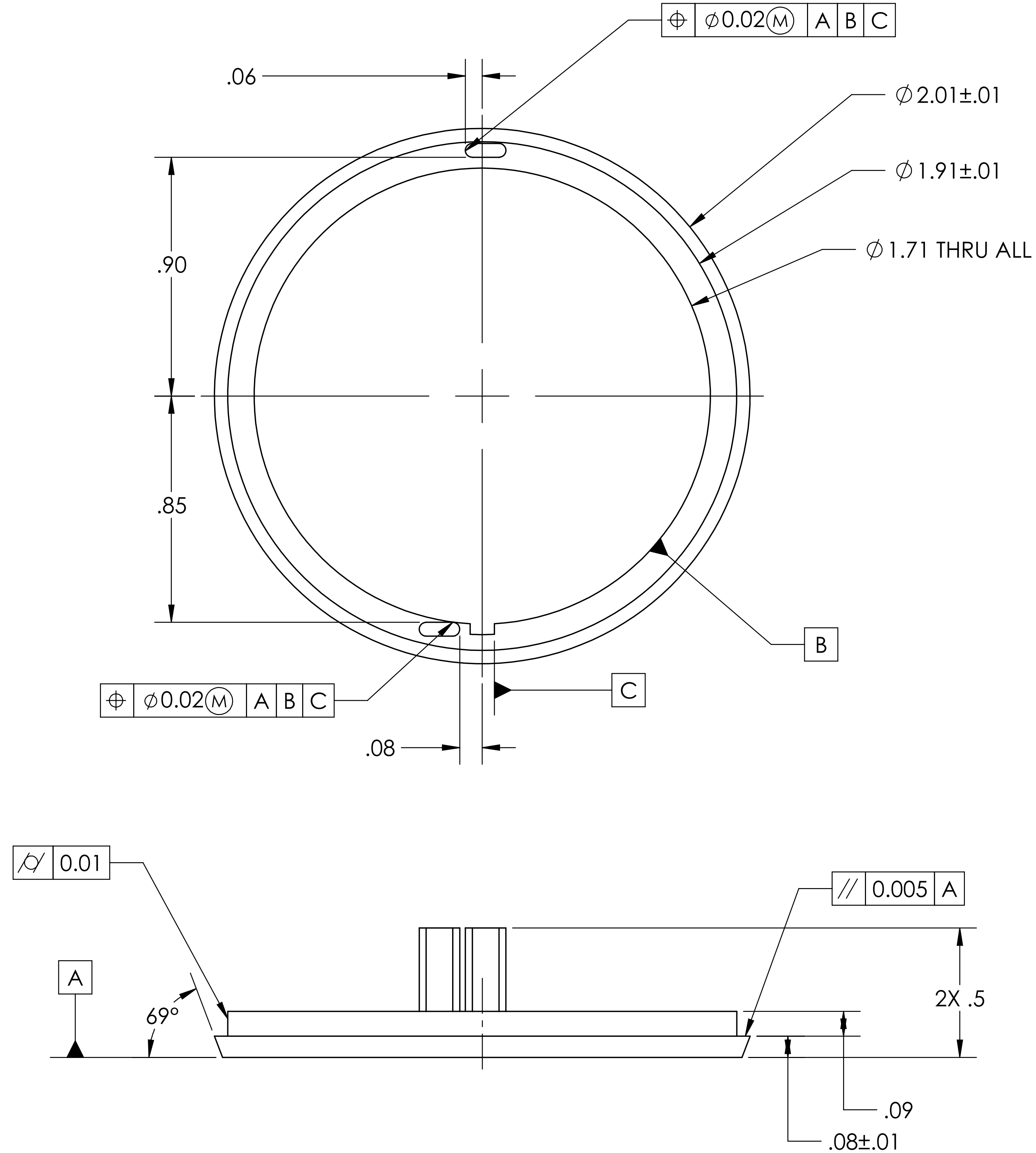


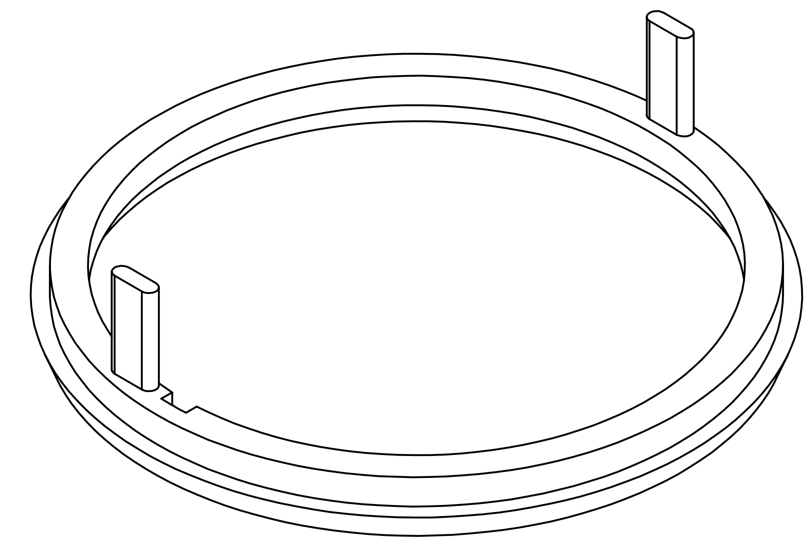
NOTES:

1. The lip that fixes the position of the cap in reference to the DC motor is a key feature. This lip should be measure to a thickness of at least 0.04 inches.
2. The thickness of the wall is another key feature that stablizes the position of the motor. The thickness should be inspected to have a minimum size of 0.07 inches.

TOLERANCES UNLESS NOTED: X.X ± 0.5; X.XX ± 0.02; X.XXX ± 0.001; X.X° ± ° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO. 80309-0427	
MATERIAL RUBBER	DESCRIPTION RUBBER MOTOR CAP	
FINISH MATTE	PN RP012 REV A	SHEET 1 of 1

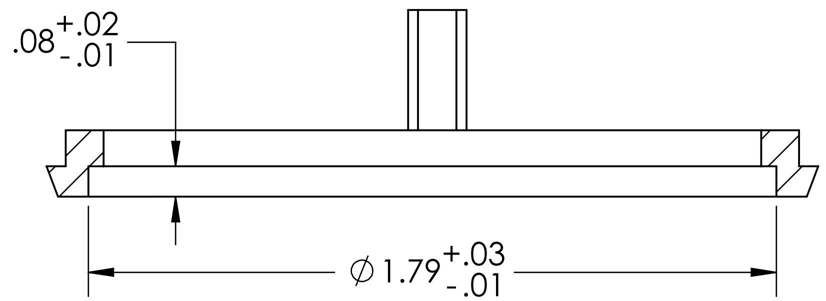
REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	9/21/2024
B	REPLACED NOTES WITH GD&T INFORMATION	9/24/2024



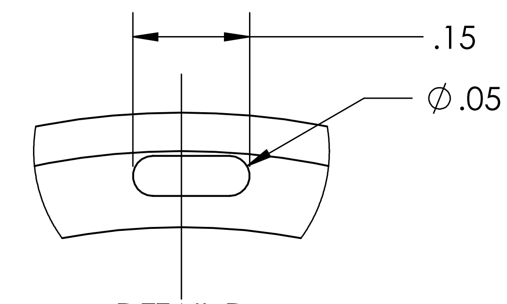


NOTES:
1. MIDDLE DIAMETER (Ø1.91) SHOWN IN TOP VIEW MUST FIT INSIDE OF HOLE AT BACK OF VACUUM OUTER SHELL (PARTS RP 009 AND RP011).

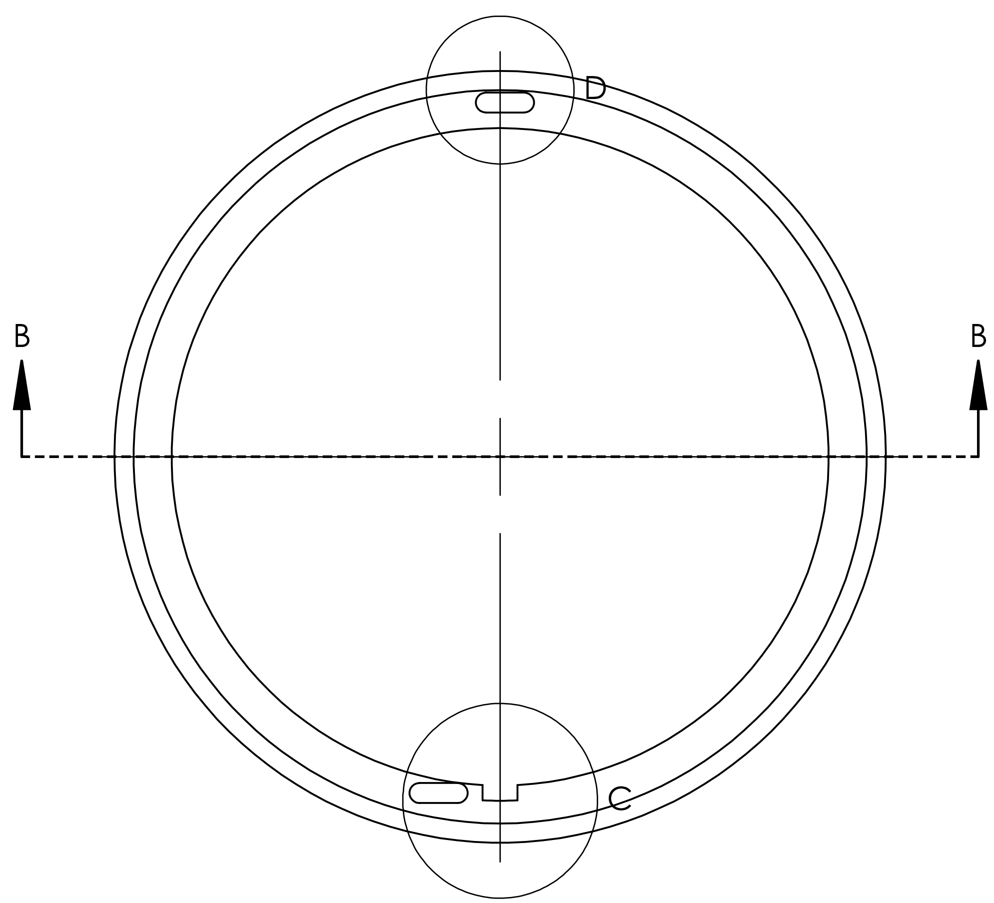
TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.02; X.XXX ± 0.005; X.X° ± °; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427	
MATERIAL ABS	DESCRIPTION BLOWER SCREEN RETAINING RING	
FINISH MATTE, PAINTED	PN RP014 · REV B	SHEET 1 of 2

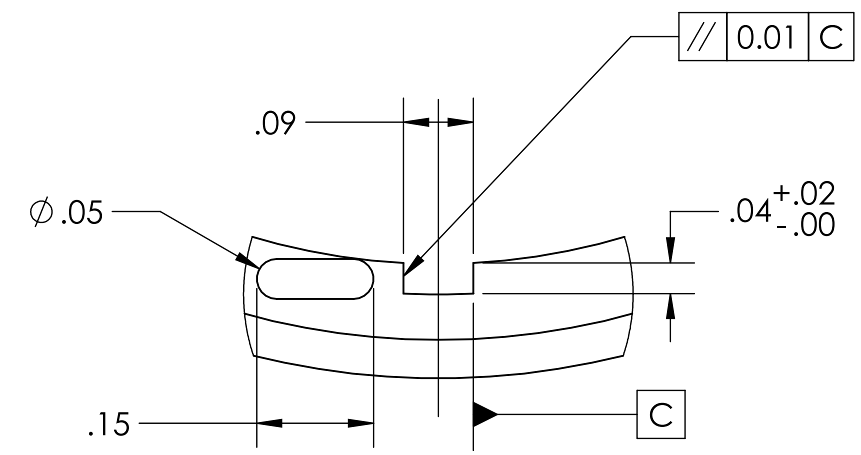


SECTION B-B



DETAIL D
SCALE 4 : 1





DETAIL C
SCALE 4 : 1

NOTES:

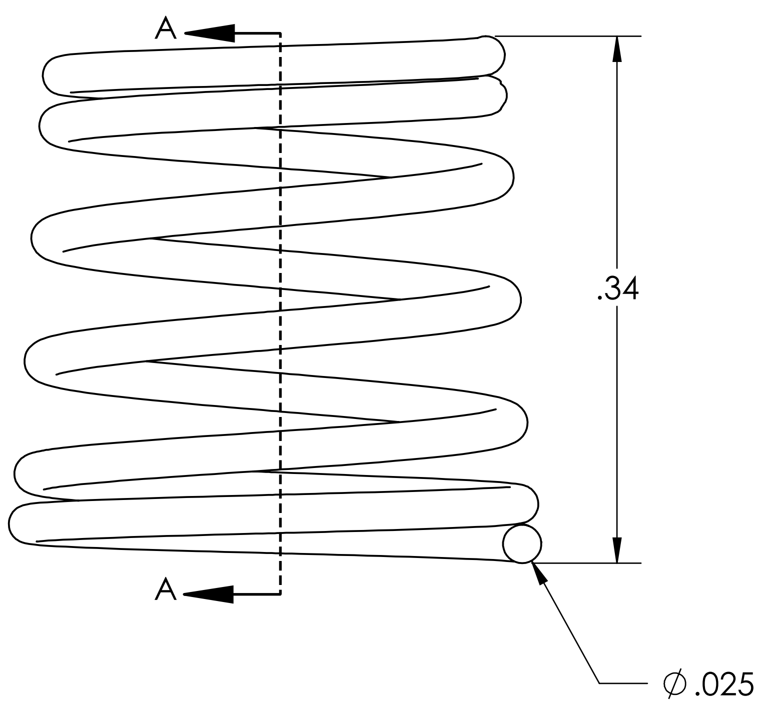
1. GROOVE SHOWN IN DETAIL C IS MAIN INTERFACING FEATURE. IT ALIGNS WITH RIB ON BLOWER SCREEN (PART NUMBER RP005) TO CONTROL ORIENTATION OF RETAINING RING.

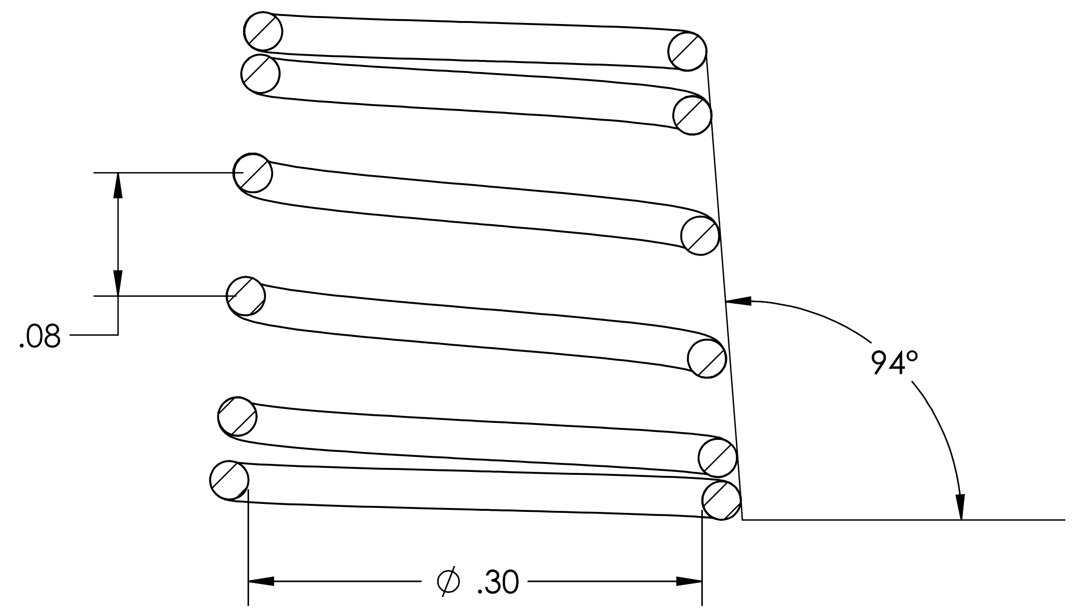
2. INNER DIAMETER OF RING SHOWN IN SECTION B INTERFACES WITH OUTER DIAMETER OF BLOWER SCREEN (PART NUMBER RP005).

TOLERANCES UNLESS NOTED:	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427			
UNITS: INCHES						
MATERIAL ABS			DESCRIPTION BLOWER SCREEN RETAINING RING			
FINISH MATTE, PAINTED			PN RP014	REV B		SHEET 2 of 2

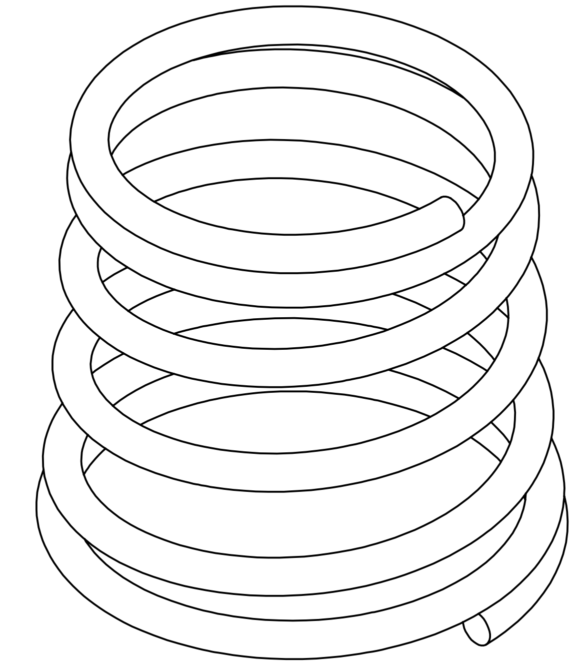
PROPRIETARY AND CONFIDENTIAL

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	10/1/2024





SECTION A-A



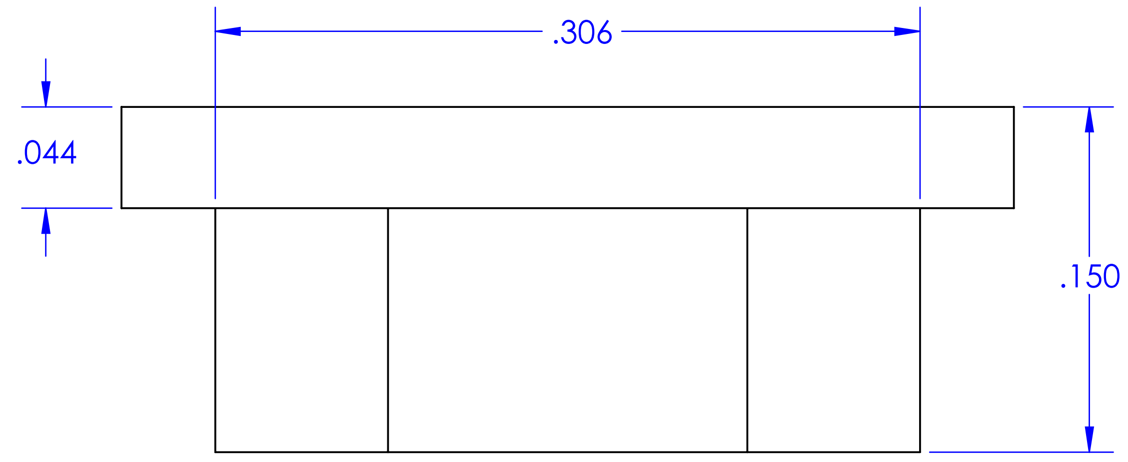
NOTES:

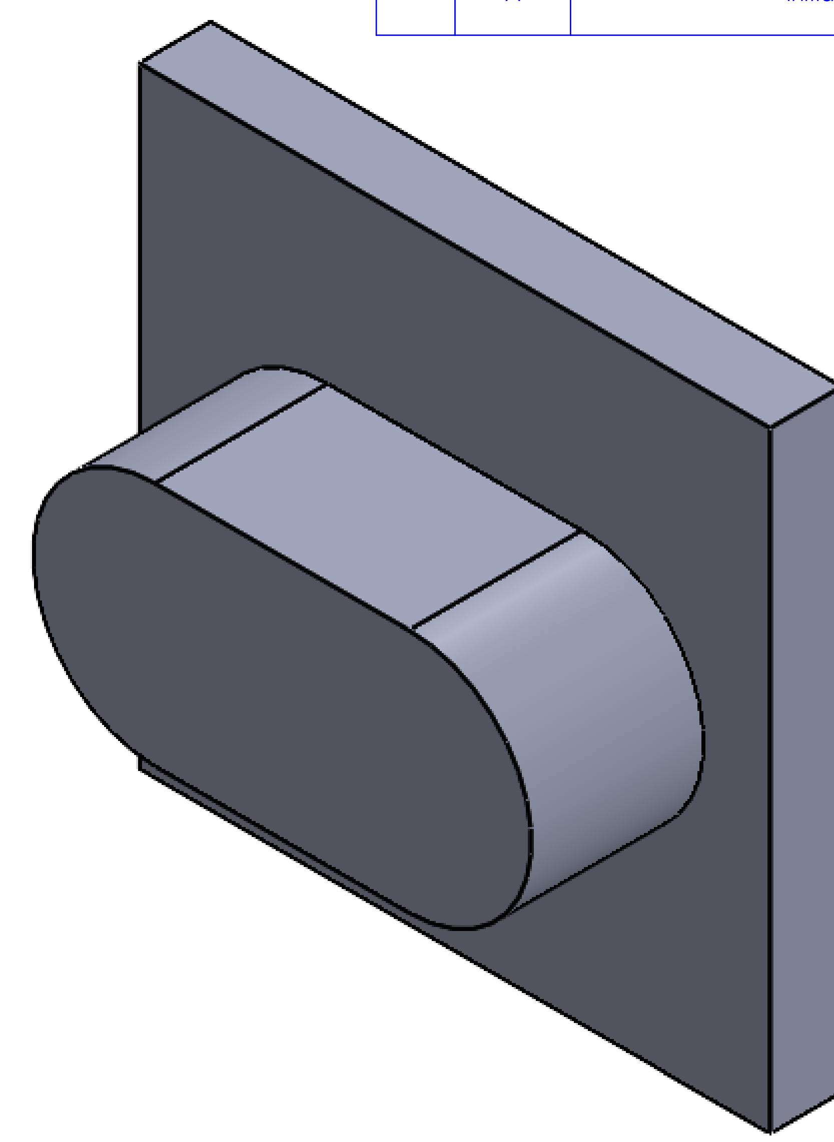
1. STANDARD SPRING PITCH IS 0.08 INCHES. ENDS OF SPRING ARE BENT FLAT AND CONTACT NEXT REVOLUTION OF WIRE.

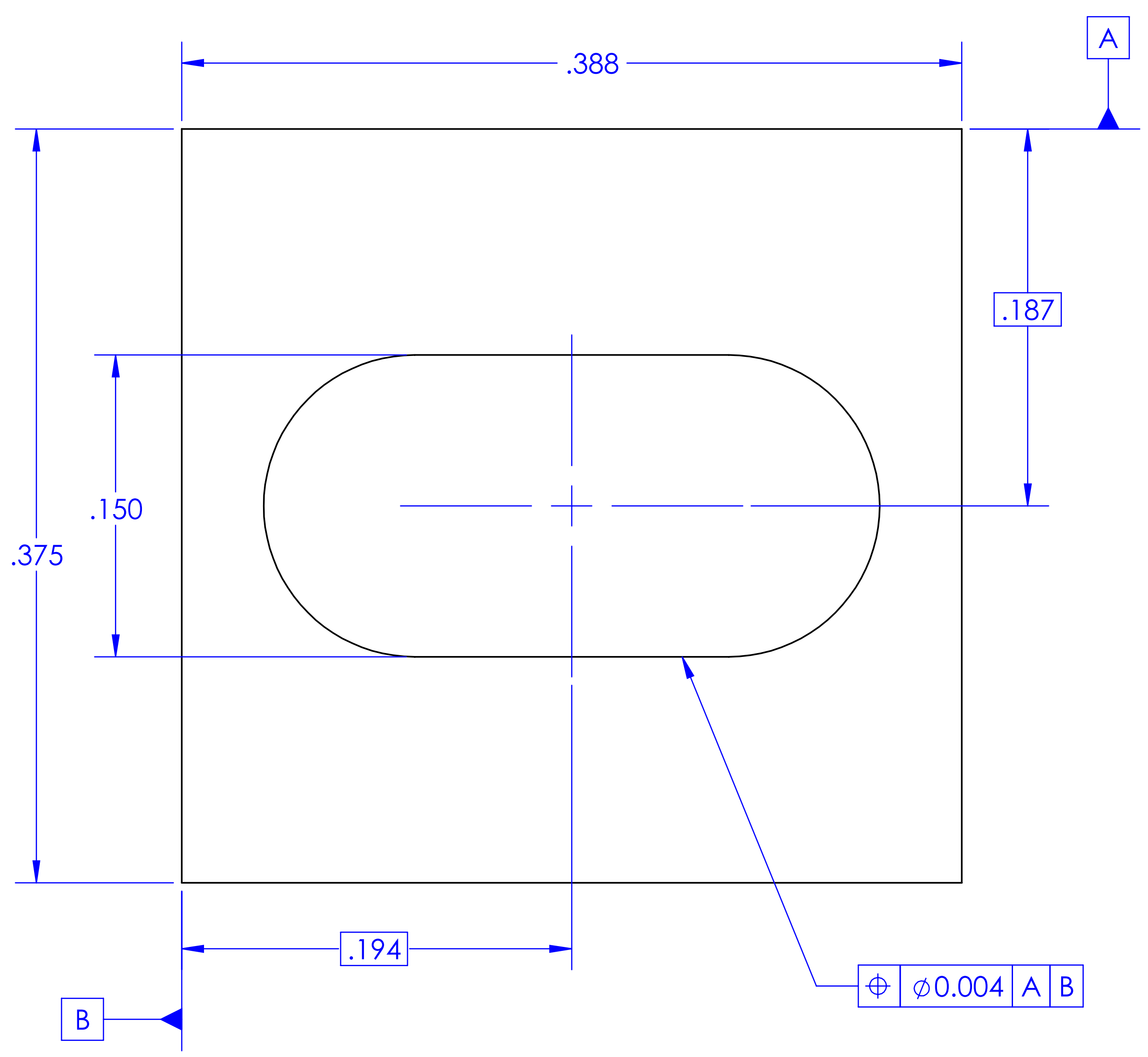
2. SPRING IS 6 REVOLUTIONS

TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427			
MATERIAL STEEL		DESCRIPTION POWER BUTTON SPRING			
FINISH COLD DRAWN WIRE		PN RP017	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				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	Initial Drawing	10/1/2024	





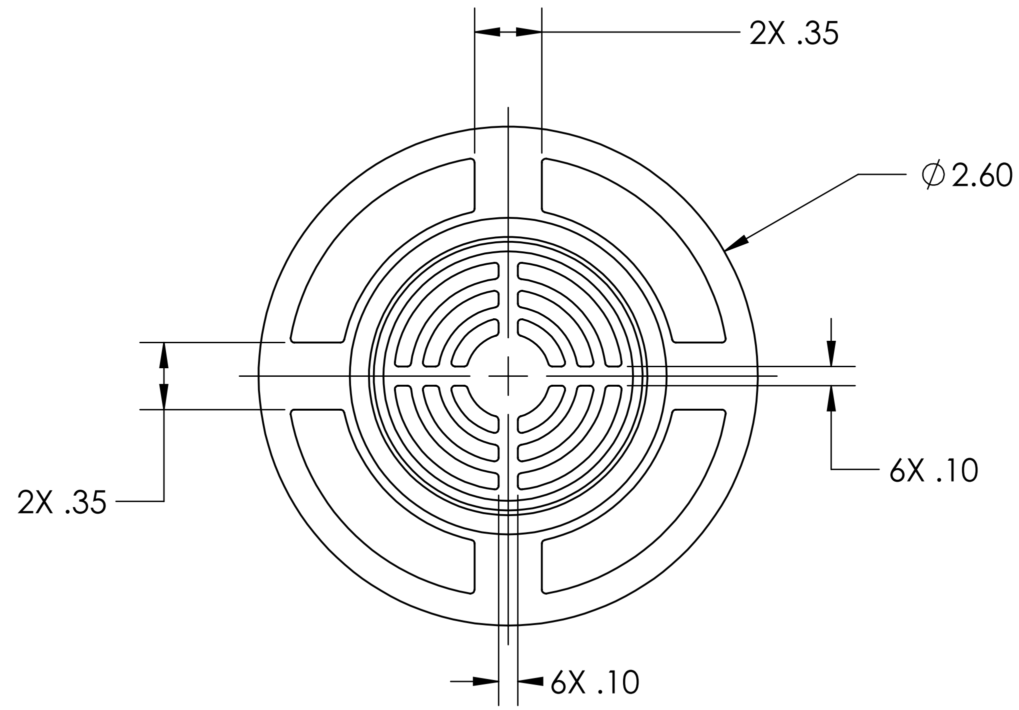


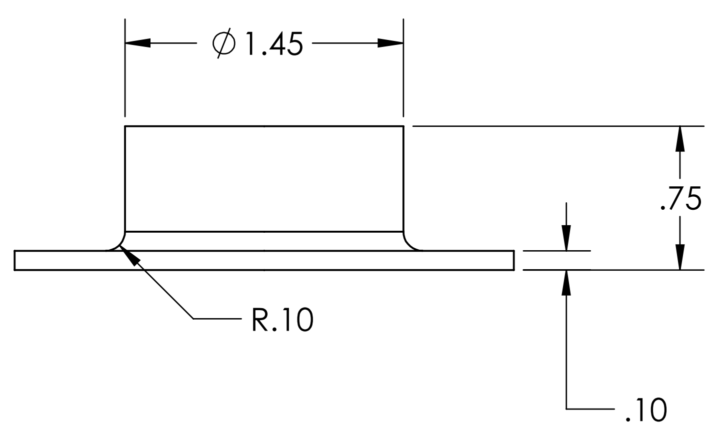
TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.02; X.XXX ± 0.004; X.X° 1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309
MATERIAL ABS	DESCRIPTION LED Cover
FINISH NONE	PN RP020 · REV A · SHEET 1 of 1

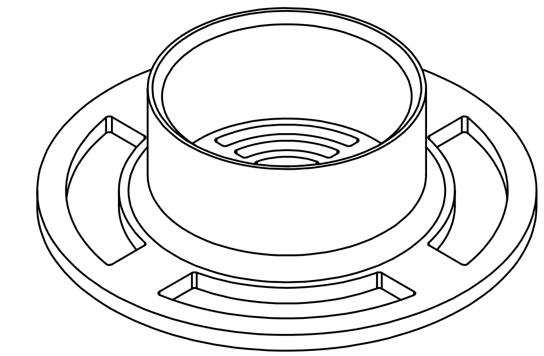
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF . ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT WRITTEN PERMISSION IS PROHIBITED.

Redesign Drawings

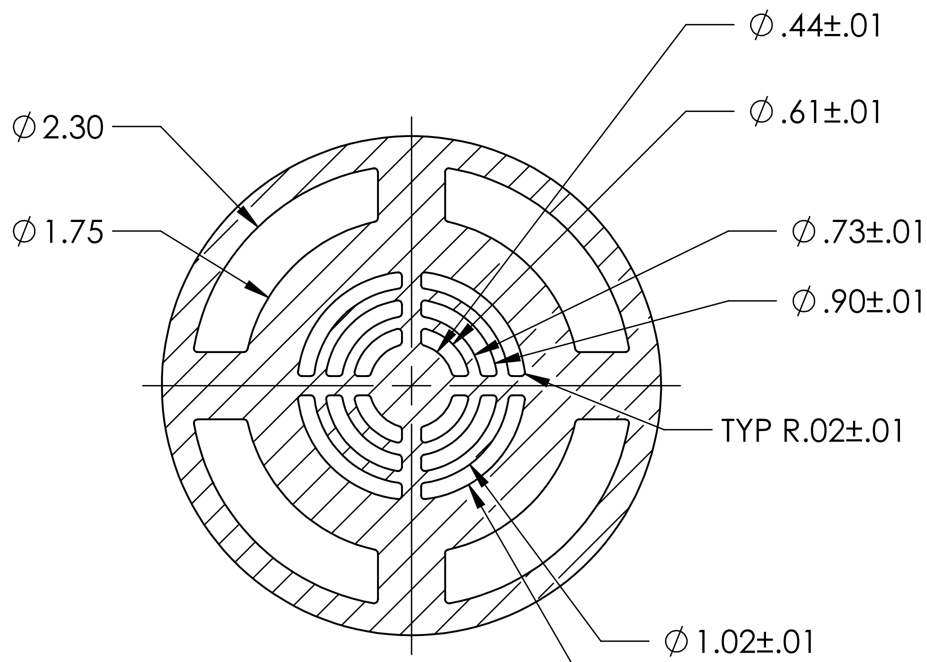
REV.	DESCRIPTION	DATE
A	Initial Drawing	10/6/2024





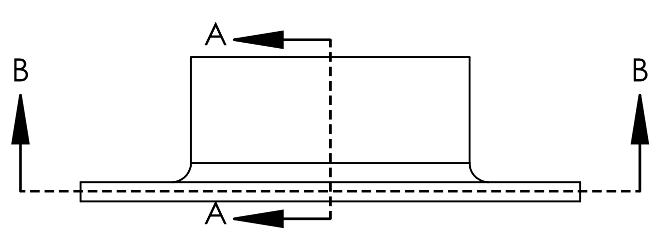


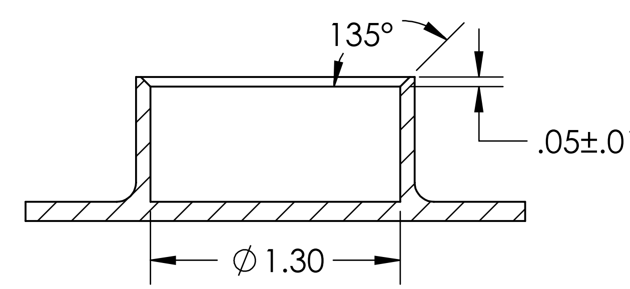
TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427
MATERIAL ABS		DESCRIPTION BLOWER SCREEN
FINISH MATTE		PN RD005 · REV A · SHEET 1 of 2



SECTION B-B

NOTE: CIRCULAR HOLES IN SCREEN GO THROUGH ALL SURFACES

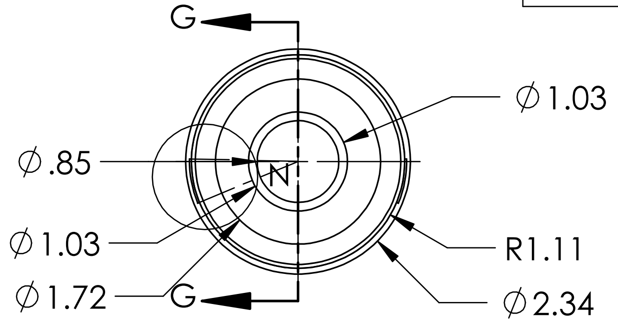


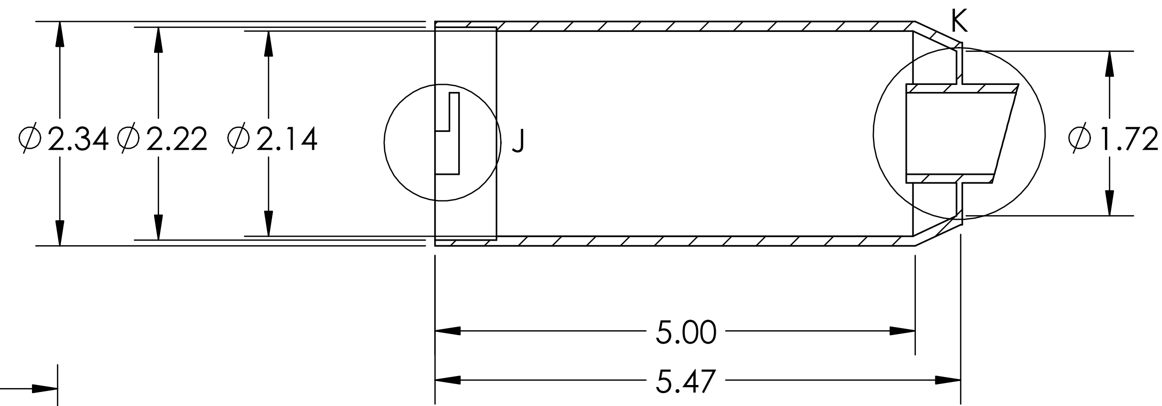


SECTION A-A

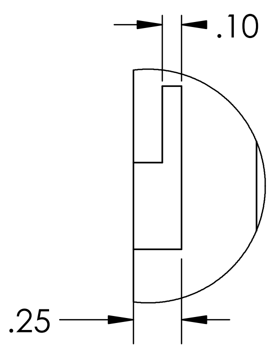
TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.02; X.XXX ± 0.005; X.X° ± ° — UNITS: INCHES	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO, 80309-0427
MATERIAL: ABS	DESCRIPTION: BLOWER SCREEN
FINISH: MATTE	PN: RD005 — REV: A — SHEET: 2 of 2

REVISION TABLE		
REVISION	DESCRIPTION	DATE
A	INITIAL DRAWING	09-11-2024
B	SUCTION HEAD LENGTH CHANGED	10-15-2024

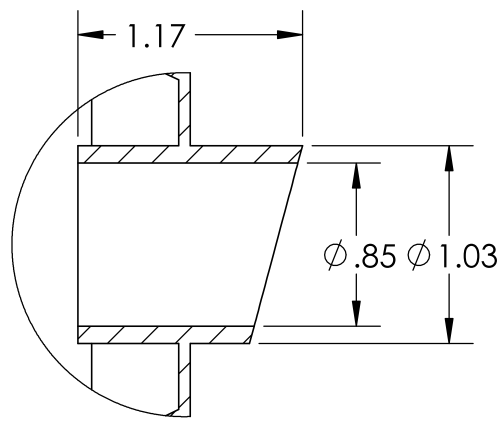




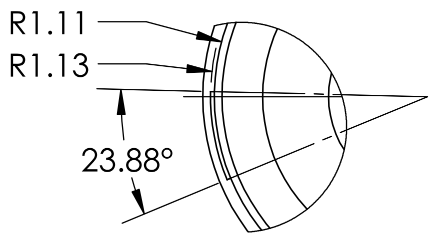
SECTION G-G



DETAIL J
SCALE 1 : 1



DETAIL K
SCALE 1 : 1

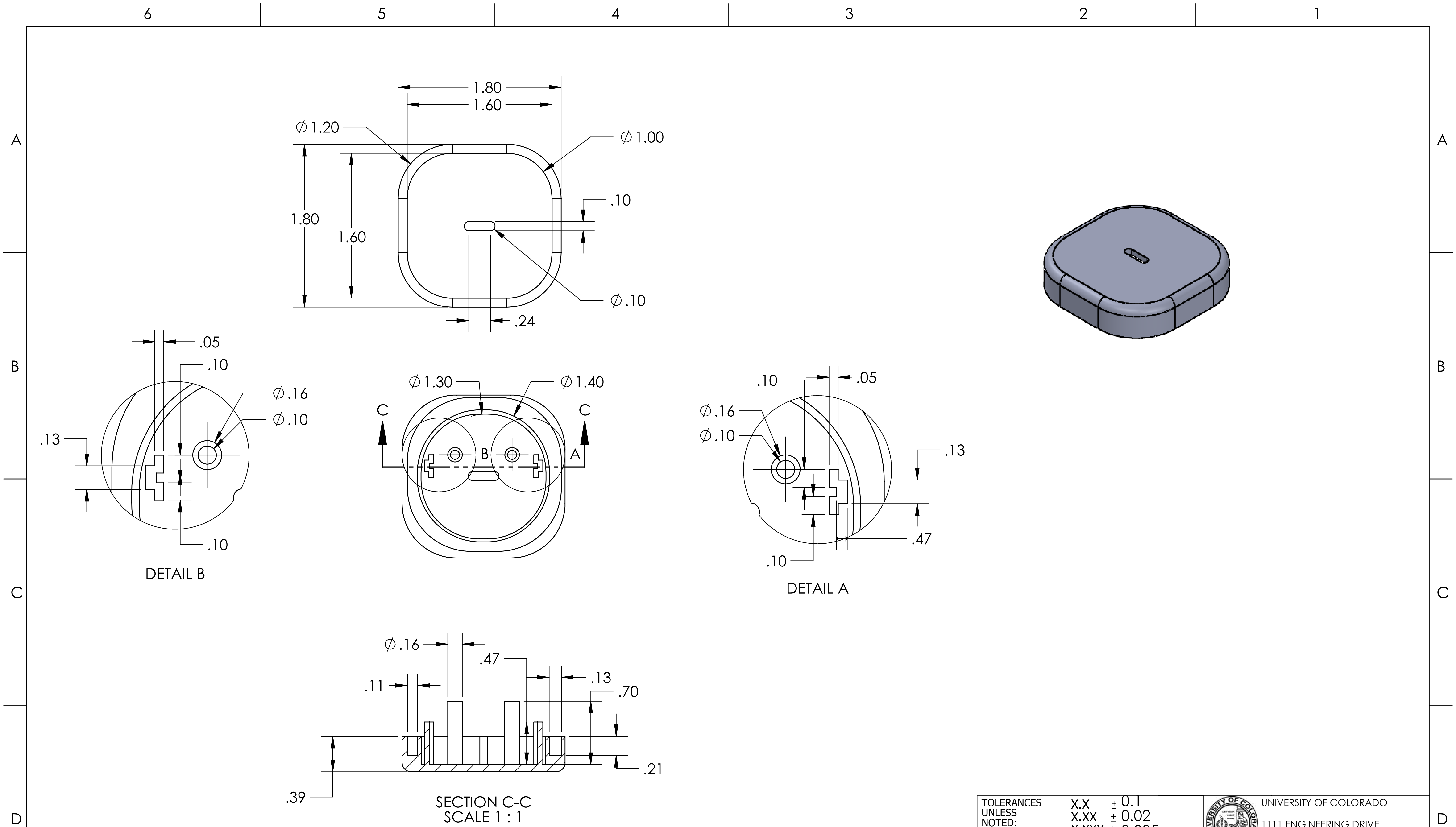


DETAIL N
SCALE 1 : 1

NOTES :

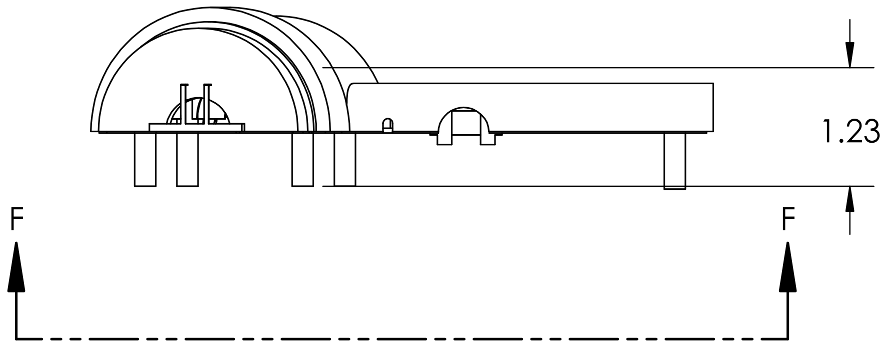
- Usual tolerance for injection molding: ±0.005 inches.
- Tolerance as mentioned in the title block unless specified separately.
- Detail J is a main interfacing unit that acts as a keyway to the housings (RP009 and RP011).

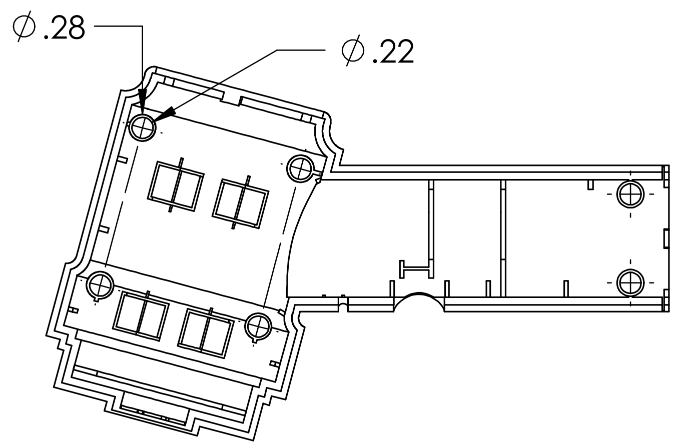
TOLERANCES UNLESS NOTED: UNITS:	X.X ± 0.1 X.XX ±0.01 X.XXX ±0.005 X.X° 0.1°			
MATERIAL THERMOPLASTIC		DESCRIPTION KMM BLOWER DUST COLLECTION BIN		
FINISH N/A		PN RP003	REV B	SHEET 1 of 1

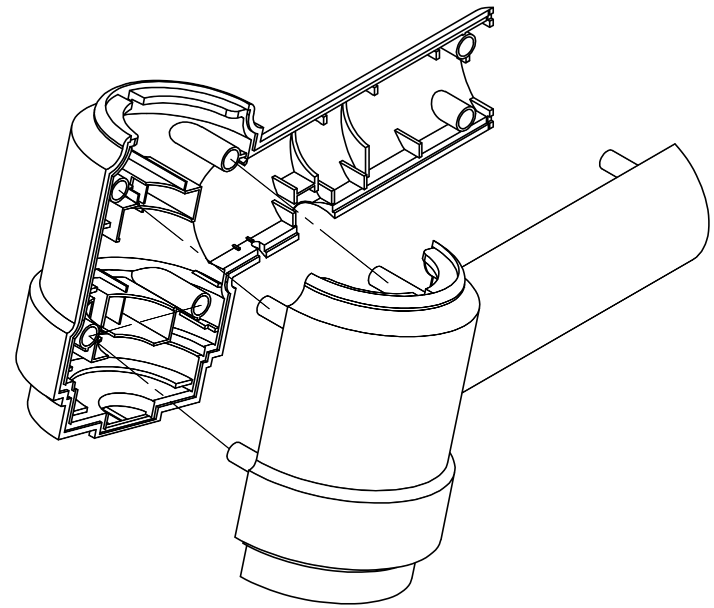


TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X°		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO. 80309-0427
MATERIAL Thermoplastic			DESCRIPTION KMM Base Charging and LED Mount
FINISH Paint	PN RD004	REV A	SHEET 1 of 1

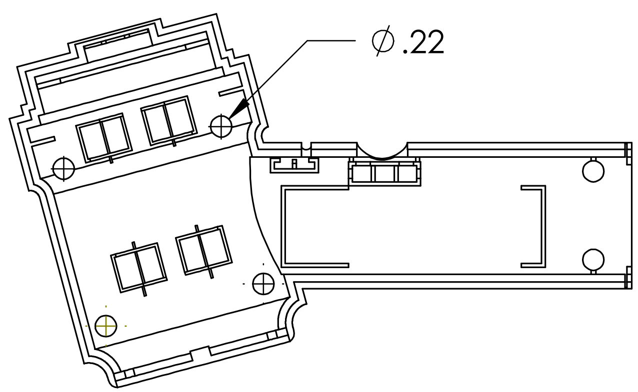
REVISIONS TABLE			
S.NO	DESCRIPTION	REV NO.	DATE
1	INITIAL DRAWING	A	10.15.2024







SECTION F-F



SECTION E-E
SCALE 1 : 2

NOTES :

- Cantilever snap-fits were added, and the screw setup was removed. The rest of the dimensions are the same. Please refer to drawings RP009 and RP011.
- Section F-F specifies how the snap-fit will be assembled.

TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.03, X.XXX ± 0.05, X.X° ± ° UNITS:				
MATERIAL THERMOPLASTIC	DESCRIPTION KMM HOUSING SNAP-FIT			
FINISH N/A	PN RP024	REV A		SHEET 1 of 1

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