Final Design Project: Chocolate Winnowing Machine

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MCEN 5045: Design for Manufacturability
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December 02, 2024

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Executive Summary

The design project aimed to develop an innovative cacao winnower with an integrated vacuum blower, providing a cost-effective solution that surpasses existing market alternatives. The primary objective was to create a winnower that is not only more affordable but also uniquely equipped with a built-in vacuum, a feature absent in current market offerings. Through careful consideration of materials and manufacturing processes, the project achieved both performance and economic objectives.

Material selection was a critical aspect of the design process, utilizing an Ashby chart to evaluate and identify the optimal materials for each component based on criteria such as Young's modulus, density, and cost. Polypropylene (PP) was selected for the blower housing and collection bins due to its low cost and suitable mechanical properties. The platform for mounting components utilized 301 stainless steel, chosen for its cost-effectiveness, appropriate density, and satisfactory structural integrity. The separator column was made from polyethylene (PE), which provided an excellent balance of stiffness, hardness, and cost, while also being dishwasher and food safe. The impeller was constructed from polystyrene (PS) for its high stiffness and durability. The manufacturing processes involved Selective Laser Sintering (SLS) for the PP, PE, and PS components, and laser cutting for the 301 stainless steel housing.

The integrated vacuum blower significantly enhances the separation efficiency by effectively removing lighter husks from the heavier cacao nibs, ensuring a cleaner and more precise separation process. This feature, unique to our design, sets it apart from other winnowers on the market. By streamlining the winnowing process, the integrated vacuum blower reduces manual intervention and increases overall throughput, leading to higher productivity. The design's user-friendly nature ensures that operators can quickly and efficiently manage the winnowing process with minimal downtime.

The comprehensive approach to material selection and manufacturing resulted in a cacao winnower that not only meets but exceeds performance expectations. The unit price of $441.80 makes it a highly competitive option, providing a cheaper alternative with superior functionality. This design sets a new standard for winnowing solutions in the industry, offering a versatile and valuable tool for cacao producers, from small-scale farmers to larger processing facilities. This innovative approach not only supports the needs of various stakeholders but also demonstrates a significant advancement in cacao processing technology, ensuring reliability, efficiency, and cost savings.

Introduction

In the process of preparing chocolate, cacao beans are separated from the cacao fruit, fermented, dehydrated, roasted, and crushed before being ground into fine powders used in chocolate production. The individual cacao beans are covered in a thin husk that must be removed before the crushed mixture is used in chocolate. Removing the husk improves the quality and flavor of the chocolate produced.

For comparison, the thin red husk that covers a peanut inside of its shell is similar in size and weight to the husk of a cacao bean. Cacao fruits are about 12 inches long by 4 inches wide, and can have 20 to 50 cacao beans inside a single fruit. An open cacao fruit is shown alongside an image of crushed peanuts for comparison in Figure 1. The beans are initially coated in a slimy white substance that is gradually reduced into a thin husk through the fermenting, dehydrating, and roasting processes. Cacao beans after the roasting process are shown in Figure 2. These beans are then crushed into small pieces known as nibs. At this stage, the nibs are still mixed with the thin shells that encase them.

Figure 1: Peanut shells and husks compared to Cacao Fruit [1]

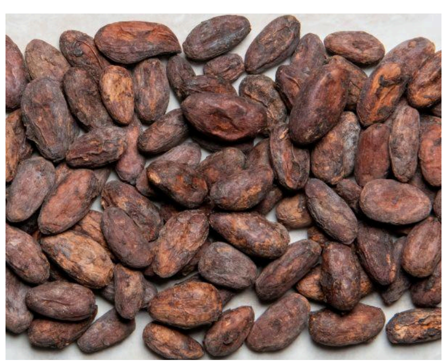

Figure 2: Roasted Cacao Beans [2]

Winnowing is a method of separating heavier components in a mixture from lighter components using wind or other air currents. This is an important step in the processing of many dry goods, such as grain, because it allows chaff and other contaminants to be removed from the desired product. Cacao nibs are much heavier compared to the cacao husks, so this technique is often used to filter the mixture. The outer shell of the cacao fruit is similar in density to the cacao nibs, but the outer shell's size makes it easy to separate by hand before this step. The final outputs of this process are the separated shells and nibs shown in Figure 3.

Figure 3: Cacao husks [3] (left) and Cacao nibs [4] (right)

Chocolate produced at industrial scale uses large machines very similar to those used to clean grain and other dry goods. When hobbyists make chocolate at home, the batch sizes are generally small enough that the husks can be separated by hand or by dropping the mixture in front of a fan without creating a significant mess. Artisan chocolatiers and small candy stores that make their own chocolate fall into an unfortunate middle ground where the batch sizes are too large for the "at-home" methods, but are not large enough to justify the expense of industrial scale machines. Some devices are designed to meet this particular need, but they are generally very rudimentary and expensive for the materials they use. We decided to design a new machine that meets this need while minimizing cost. To minimize the overall part count and complexity, the project is limited to a winnowing machine that takes in a crushed nib and shell mixture and separates the two components.

Goals

The goal for this project was to lower the barrier to entry into craft chocolate making, as you will see in the market analysis the existing products are on average well above $1000. This product aims to stay below that threshold by minimizing the complexity of the design. We strive to achieve this by reducing the number of manufacturing processes utilized to create the product, minimizing part count, and standardizing materials used wherever possible. Additionally, the design should be simple enough that a customer can assemble and maintain it. The ease of assembly is important because it can greatly reduce shipping costs, and the ease-of-maintenance aspect seems lacking from competitors' designs.

Market Analysis

Target Market

The target market for the cacao winnowing machine described in this report is the middle ground between hobbyists making chocolate at home and industrial-scale production of chocolate. Industrial scale chocolate producers may still be interested in the device to prepare and test smaller batches of new recipes. According to IBISWorld.com, there were an estimated 3,206 chocolate production businesses in the US in 2023 [5]. Assuming that there is a similar number of chocolate production businesses per capita in Canada and Mexico, there are an additional estimated 1,600 chocolate shops across the US, Canada, and Mexico that may be interested in the machine this report describes.

Existing Products

We conducted an analysis of winnowing machines that are already commercially available to develop design criteria and set economic targets. One of the first devices we came across was the Sylph Winnower, sold by Chocolate Alchemy (shown in Figure 4). The design is very simple and incorporates mostly off-the-shelf components. The mixture of cacao nibs and husks is poured into a food-safe PVC pipe network that is connected to a 5 gallon bucket. The lid of the bucket has an attachment point for a standard 2” vacuum hose. The manufacturer recommends a 6.5 hp Shop Vac for use with this winnower (sold separately). The air flow and negative pressure caused by the vacuum is controlled by a metal cover that pivots over an opening in the lid, allowing more air to enter the system. The price of this device is $285, and it is estimated that it can process 1 lb/min of roasted and crushed cacao beans.

Figure 4: Sylph Winnower

The next devices we analyzed were the Cocoatown Basic Winnower and Deluxe Winnowers, shown in Figure 5. Both devices are primarily made of stainless steel and are rated to process 20-50 lbs of cracked cacao beans in a single pass with a loss rate of less than 0.05%. Additionally, the stainless steel column is described by the manufacturer as “elegant” and suitable for display in front of customers and demonstrations of the winnowing process. The primary design difference between the two is that the basic winnower incorporates an off-the shelf vacuum to separate the husks and a valve to alter air flow, but the Deluxe version uses an integrated vacuum with electronic speed control to control the internal flow rate. The basic version has a sale price of $1,950 and the deluxe is listed for $2,250.

Figure 5: Cocoatown Basic (left) and Deluxe (right) Winnower

The last device we analyzed was the Aether Winnower, also from Chocolate Alchemy (shown in Figure 6). The design is hand-built from stainless steel, food-safe PVC, and clear polycarbonate in the husk collection chamber. The unique feature of this device is that it is also designed to crack roasted cacao beans using a Champion Juicer (sold separately). This device also requires the user to purchase a 6.5 hp Shop Vac to use, and has an estimated processing rate of 55-65 lbs per hour. The Aether Winnower is listed for $2,650 (plus $250-$400 in shipping in the US).

Figure 6: Aether Winnower

Across all of these devices, there are a few common trends. Many of the winnowers offered by Chocolate Alchemy are very simple in their construction, and appear easy to replicate with common hardware store components. Another common trend is the need for an external vacuum or other device to separate husks and nibs. The prices appear high for the size of the devices and the materials used, but the target market for these devices is generally very small. It is likely, if not outright stated, that the parts used in many of these winnowers are hand made for each order, driving up the production cost. All components that interact with the mixture directly are made of food safe materials.

Patent Search

Winnowing is a very old technique of separating chaff from grain. There are records dating back to at least 1500 BC of farmers winnowing grain in ancient Egypt [10], and the process is likely as old as agriculture itself. Winnowing was traditionally done by hand, with workers throwing baskets of grain into the air and relying on wind to carry away the lighter chaff. Machines for winnowing first appeared in Scotland in 1737, and further improved during the Industrial Revolution. Many modern patents surrounding the winnowing process surround mechanisms inside of combine harvesters.

US Patent # 9,426,943 (sketch shown in Figure 7, dated August 2016) describes a series of oscillating and vibrating pans used to keep grain and chaff suspended in an airstream as they move rearward in the combine. After being separated from the Straw, the grain falls from the oscillating thresher pan (labeled 228) onto the cascade pan (250). A fan generates an airstream that blows away the chaff and directs the grain to fall onto the sieve (251). A second airstream to separate any additional chaff. A second sieve under 251 further filters the grain before it falls in a collection pan. This patent specifically covers the use of vibrating rubber sheets (284 and 288) to keep the grain suspended in front of the airstream for longer, ideally forcing more chaff to be blown away before the grain falls through the sieves as normal.

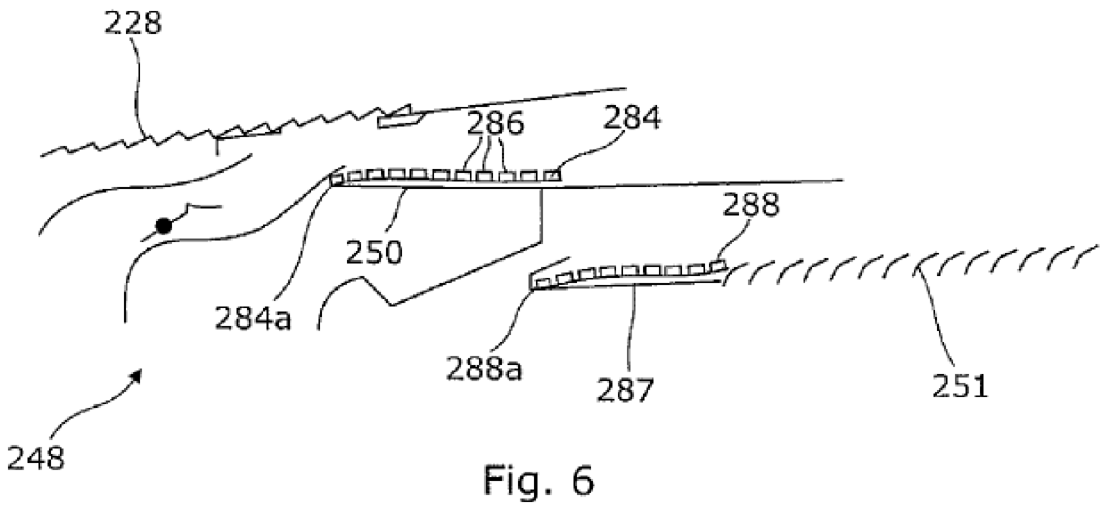

Figure 7: Sketch from US Patent # 9,426,943 [8]

US patent # 762,705 (filed in June 1904) describes a machine that combines the crushing (or nibbing), grading, and winnowing process. The crushed beans are raised by an endless bucket elevator (labeled as 11) and poured through a duct (12) into a rotating grader (14). The beans and husks pass through the grader and fall into another duct (17) which directs them to the winnowing chamber (15). The fan (23) creates a vacuum inside the winnowing chamber that pulls the lighter shells out of the mixture, and the cacao nibs ultimately fall out of the machine through the openings at 22. While the main goal of this machine is to reduce the cost and floor space of the entire cacao handling process, its approach to winnowing is unique in that it uses a vacuum to remove the husks instead of blowing air through the mixture.

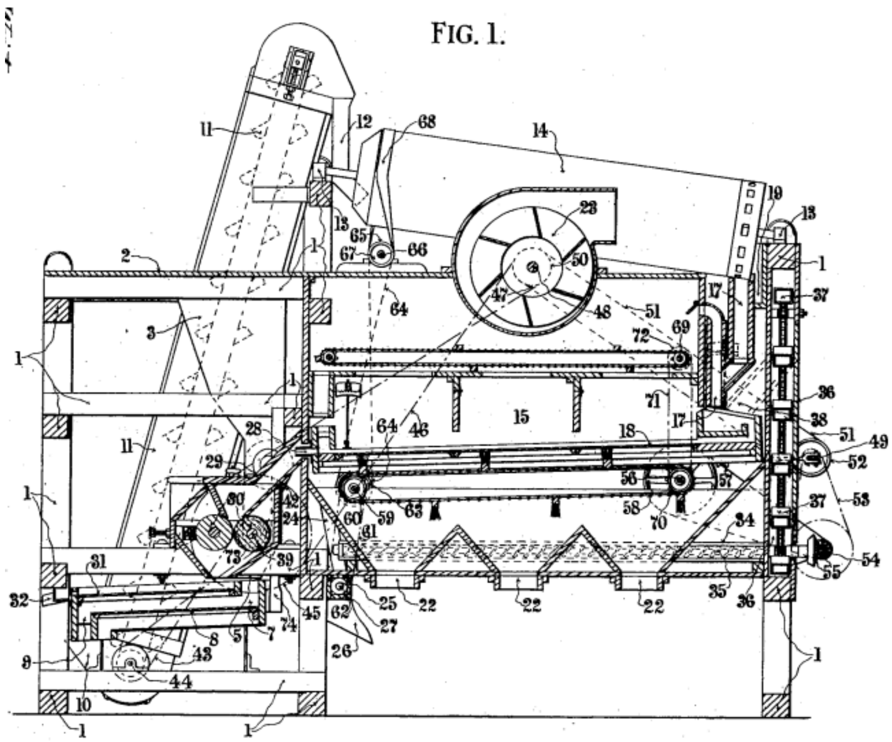

Figure 8: Drawing from US Patent #762,705 [9]

Product Description

From our analysis of existing winnowing machines, the basic requirements and design space started to take shape. Before developing specific concepts or mechanisms to satisfy the requirements, the inputs, outputs, and basic functions of the device were broken down into their basic forms.

Black and Glass Box Diagrams

The system is limited to the winnowing process, so the main inputs will be a mixture of crushed cacao beans and husks. An air current can be used to separate the lighter cacao husks from the nibs when the mixture is falling or suspended in the air. To further refine the inputs and outputs of the system, a Black Box diagram, shown in Figure 9, was generated that broke down the inputs and outputs of a machine that would be able to effectively separate the mixture.

Figure 9: Cacao Winnowing Machine Black Box Diagram

The Black Box Diagram was further refined into a Glass Box diagram, shown in Figure 10. The motor is powered after a switch is activated, and the motor's speed is controlled by an off the shelf potentiometer. The motor drives an impeller that creates an air current that flows through the separator column. While this air current is flowing, the Cacao mixture will be dropped into the separator as well. The air current will carry the husks into a separate duct in the separator while the nibs fall through the column into a collection bin. The motor will release some amount of sound, vibrations, and heat. These byproducts are not essential, but are mostly unavoidable.

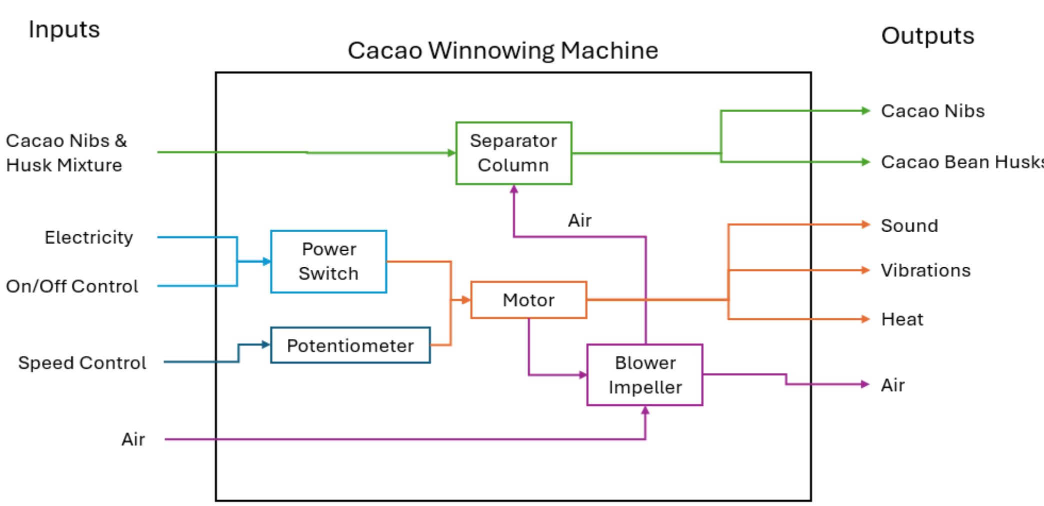

Figure 10: Cacao Winnowing Machine Glass Box Diagram

Fishbone Diagram

The fishbone diagram for the cacao winnower project outlines three primary branches: Electronics, Housing, and Vacuum Blower. Each branch is critical to the overall functionality and efficiency of the design. The Electronics branch includes components such as the BLDC motor, potentiometer, power switch, and DC power adapter, which collectively manage the electrical control and power distribution necessary for the winnower's operation. The Housing branch comprises the structural elements, including the left base, right base, legs, and separator column, providing the foundational support and stability needed to accommodate the various components and ensure the machine's integrity. The Vacuum Blower branch features the impeller, blower housing left, blower housing right, and blower standoff, which are integral to creating the necessary airflow for effective separation of cacao nibs from husks. Together, these components form a cohesive and efficient system that enhances the winnowing process, ensuring a superior and cost-effective solution for cacao producers.

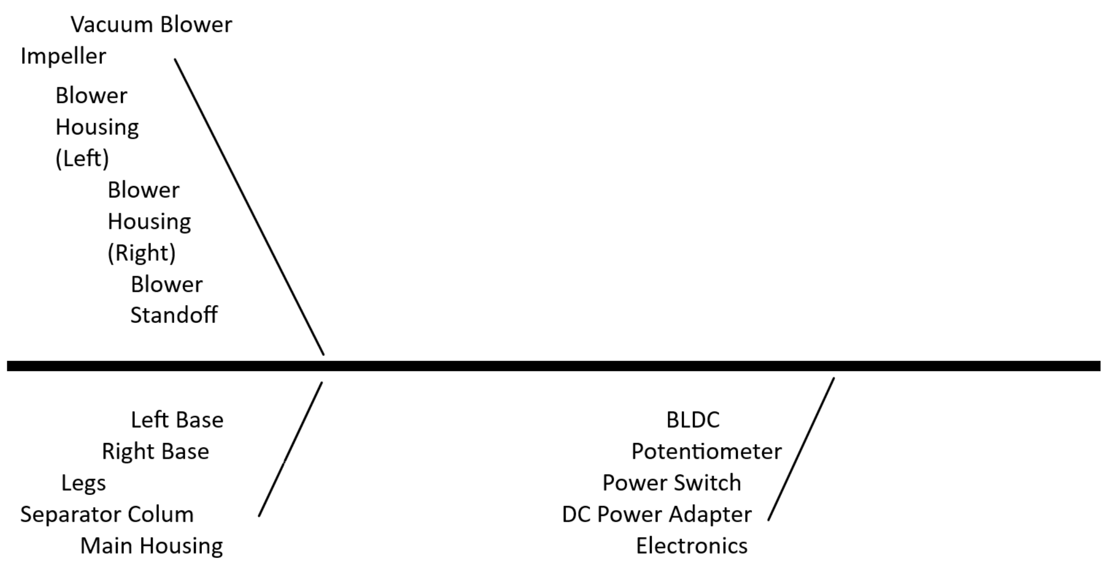

Figure 11: Fishbone Diagram

Gantt Chart

To ensure that our project remained on schedule and all tasks were completed in a timely manner, we utilized a Gantt chart. This tool allowed us to effectively plan, coordinate, and monitor the various stages of the project, providing a clear visual representation of the timeline and dependencies. By regularly updating and referring to the Gantt chart, we were able to identify potential bottlenecks, allocate resources efficiently, and maintain a steady progression towards our project milestones. The Gantt chart was instrumental in keeping the team organized and ensuring that we met our deadlines.

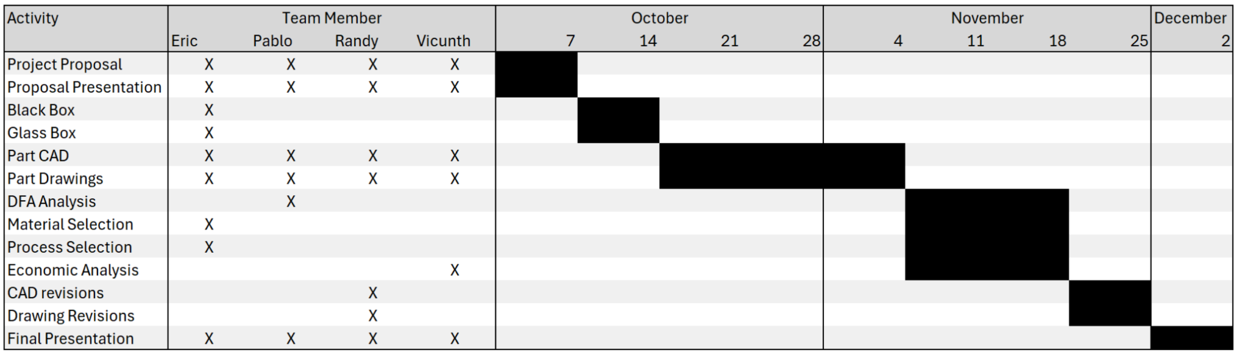

Figure 12: Gantt Chart

Design Development

Concept Development

At the start of the project, the goal was to create an all-in-one winnowing machine that would take in full, un-crushed roasted cacao beans. The project scope was eventually reduced to only the winnowing process. Figure 13 shows a sketch of the original concept development. The different critical functions were separated into simplified glass boxes to help choose methods for accomplishing each step. It was initially decided that the design would leverage gravity to pass the cacao mixture in front of a vacuum that would pull the husks away. Because the crushing step was placed outside the scope of the design, there was no need to lift the crushed mixture to the top of the collection bin. The mixture could be fed directly into the top of the separating area, eliminating the need for an additional function and mechanism.

The design also needs to incorporate some sort of control to raise or lower the power of the vacuum or blower used to filter the husks from the mixture. Many similar products on the market use mechanical valves to tune the amount of air let into the system, while others use electronics to control the speed of the vacuum/blower motor. It was decided that electronic speed control would be more repeatable and easier to use than a mechanical valve, as the results of “turning up” the motor are likely more obvious to the user. Increasing the speed of the motor will increase the air speed in the system, ideally causing more husks to be removed. To properly tune the machine for a particular mixture of cacao nibs and husks, a human operator will need to add a mixture to the machine with the motor set at a specific speed, then assess the contents of the cacao nibs and husk collection bins. If there are too many husks in the nib collection bin, the motor speed should be increased to create a stronger air stream. If there are too many nibs in the husk collection bin, the speed should be reduced. Different cacao grinding tools and techniques may result in slightly different mixtures, so this process may need to be repeated for different mixtures. An electronic speed control dial will make it easier for users to quickly return the motor to a known speed for a particular mixture.

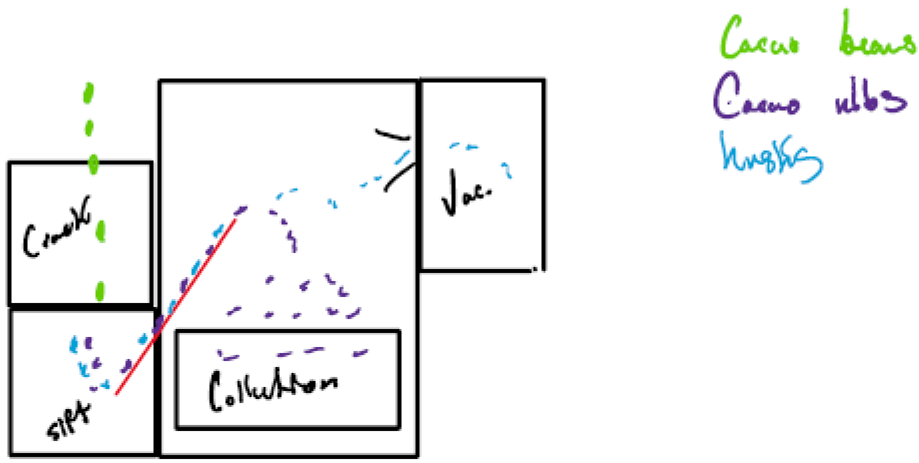

Figure 13: Concept Development Sketch

First Concept

The first draft implementation of this concept is displayed in Figure 14. A mixture of Cacao nibs and husks fills a hopper on top of the assembly. A simple valve prevents the mixture from falling before the vacuum is activated. The mixture falls from the hopper into a converging-diverging nozzle into the Separator Column, and passes a junction where the husks are pulled from the mixture by a vacuum. The cacao nibs are comparatively much heavier than the cacao husks and are much harder for the vacuum to redirect, so they continue falling into the collection bin. The nozzle ensures that there is empty space in the separator column for the husks to move through and into the cyclone filter. This filter was inspired by a cyclone sediment filter, often used for things like sawdust in wood workshops. An example of a cyclone filter is shown in Figure 15. A vacuum on top of the cyclone (not pictured in Figure 14 or 15) pulls in a mixture of air and light particles from a duct that is tangent to the cylindrical walls of the cyclone. The particles strike the inside walls as they swirl around the cyclone, causing them to lose their momentum and ultimately fall into the collection bin at the base. The air is pulled out of the cyclone through a column in the center. Using a cyclone filter rather than a traditional mesh filter prevents the filter from being plugged and stopping air from flowing. Allowing continuous air flow is critical for a winnowing machine, because the air flow drives the separating process.

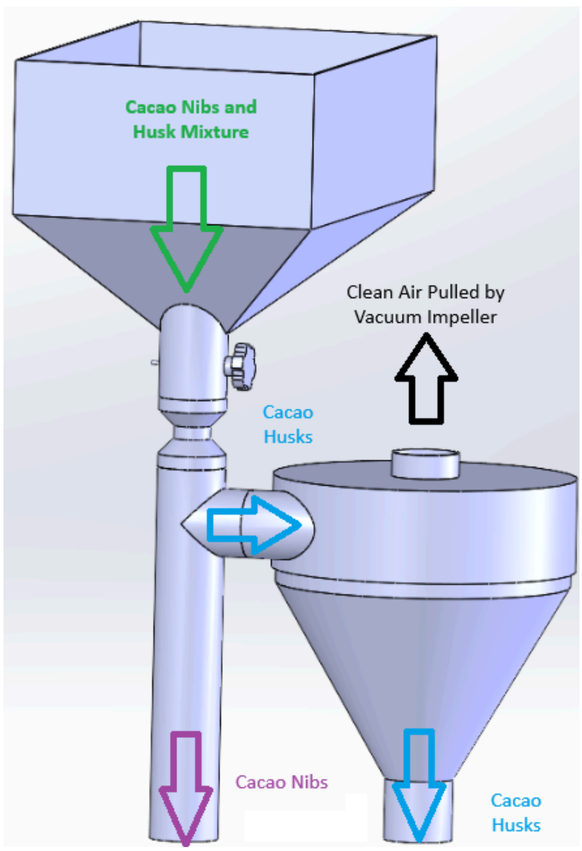

Figure 14: First Concept Draft Model

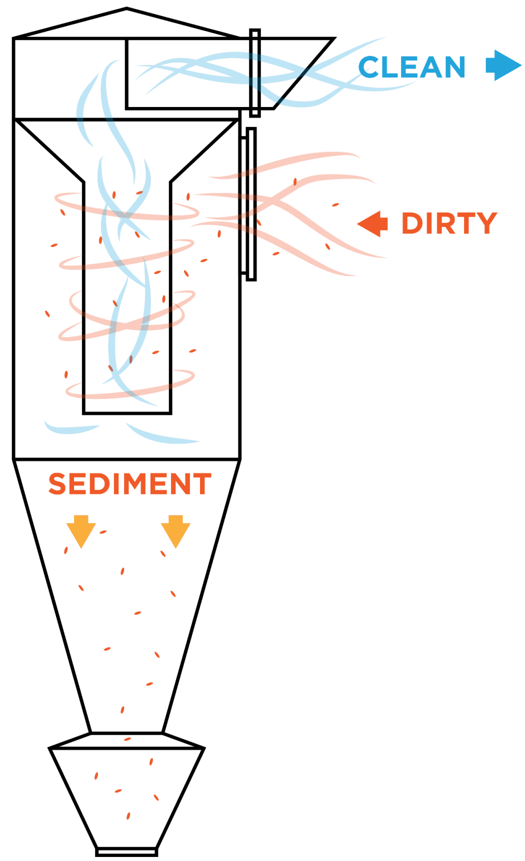

Figure 15: Cyclone Sediment Filter [6]

Revised Concept

The first draft of the design would have required a large number of parts, and some of them may have been difficult to manufacture. The second draft of the design, shown in Figure 16 has a number of changes incorporated that make it much simpler. Firstly, the hopper on top of the device was eliminated. The cacao mixture would likely fall through the converging/diverging nozzle within a few minutes, almost as fast as the mixture can be added to the hopper. If so, the mixture can be fed into a funnel on the top of the separator column by a human operator or an interface with a cacao bean crushing machine without making the overall process significantly slower or manually intensive. Additionally, the vacuum was removed in favor of a blower. Using a blower to push the husks out of the cacao mixture eliminates the need for the cyclone filter, as there is no risk of the husks getting pulled into a vacuum impeller. However, the cacao husks need to be pushed into a sealed container or into a mesh filter to prevent them from scattering around the working area. Using a blower increases the complexity of the junction in the separator column, but the two curved ducts can be identical, duplicated parts. The changes overall result in a significant part reduction and reduces the overall complexity of the design.

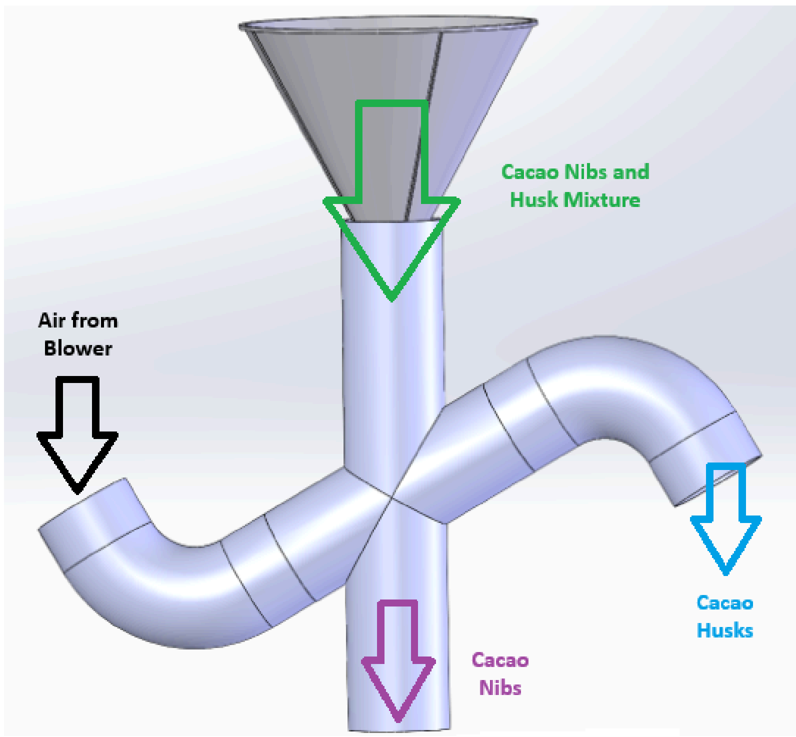

Figure 16: Revised Concept Model

Final Concept

To reduce the complexity of the separator column and ducts, it was decided that the separator column and ducting assembly should be replaced with fewer parts. Additionally, due to the small market for chocolate winnowing machines, the parts should be able to be manufactured with low-volume production methods. This design is intended to reduce the number of secondary manufacturing processes necessary to produce the parts. The updated design is shown in Figure 17. A cover with integrated snap fits latches over the main separator column. This removable cover makes it easier for users to open the assembly for cleaning or any other maintenance. The separator column fits flush against the base and is attached by snap rivets that can be installed by hand. By opening the separator column directly into the collection bins, the amount of dust and husks that will be blown around the work area is reduced. A perforated sheet is also included to reduce the likelihood that any cacao pieces will fall into the blower duct. This concept reduces the separator column to 2 parts, the column and its cover, while still allowing a blower to separate the mixture.

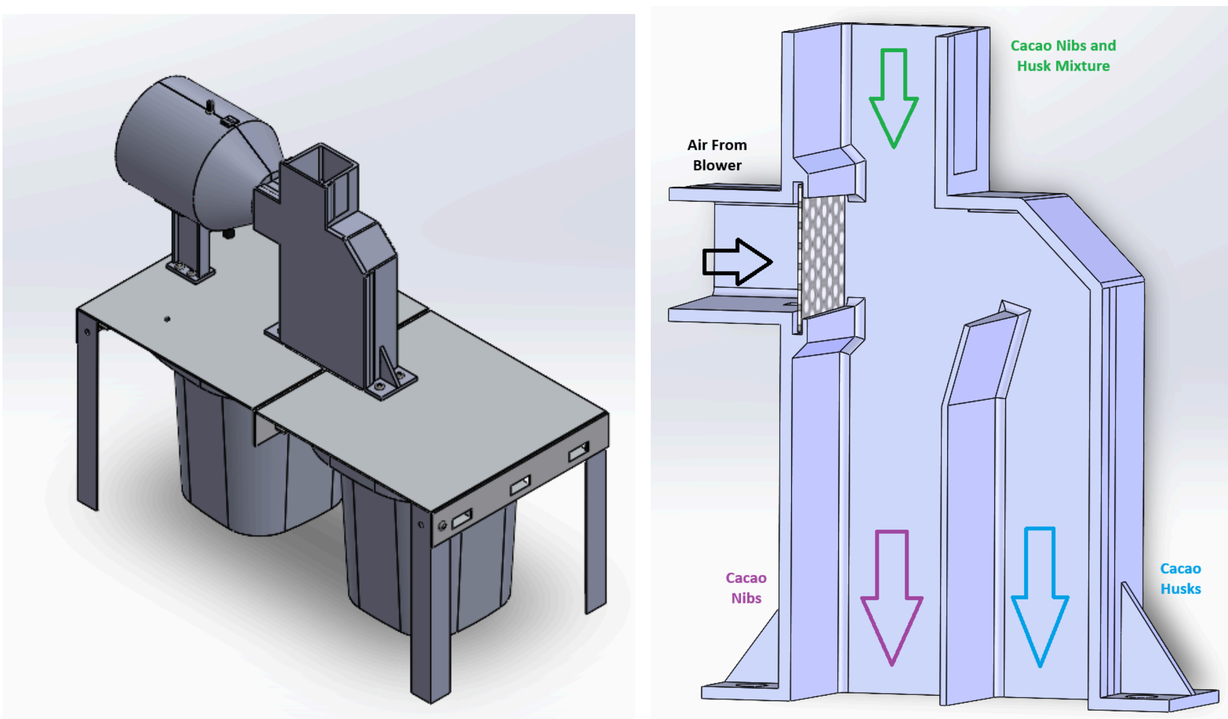

Figure 17: Final Concept Model

DFA Analysis

During the design process, a major consideration was the product's design for assembly; this meant an emphasis on reducing parts by minimizing the number of fasteners used and using snap-fits. A DFA analysis entails comparing various design iterations to display a quantitative improvement made through design changes. The two design iterations used in the DFA analysis were based on the final concept detailed above with the major difference being the choice of fastener used to hold the separator housing and blower stand to the base. This choice affected the DFA complexity factor, functional analysis, insertion index, and secondary operations index. All of these effects will be discussed further in this section. Fastener choice did not have any effect on the error proofing and handling index.

DFA Complexity Factor

The first iteration called for the use of bolts, washers, and nuts as the fasteners of choice, this added 14 nuts and bolts respectively, and 22 washers which made the fasteners alone 68% of the total number of parts of the entire product. The group agreed that this was a poor design choice and argued for the use of snap-fits incorporated directly into the design of the separator housing and blower stand to eliminate the need for external fasteners. However, incorporating snap-fits was ultimately chosen against due to the additional complexity it would add to the already complex model of the separator housing. Instead, The group decided to use plastic snap rivets, adding only 14 parts to the design. These snap rivets can be installed by hand, but require a tool for removal. The results of this analysis are seen below in Figure 18, the original design consisted of 73 parts, 142 interfaces with a complexity factor of 101.81, with the choice of snap rivets all of those design characteristics were approximately halved to 37 parts, 86 interfaces with a complexity factor 56.41.

DFA Analysis Worksheet

Assembly Name: Winnower

Part Number	Part Name	DFA Complexity: Number of Parts (Np)	DFA Complexity: Number of Interfaces (Ni)
W01	Impeller	1	1
W02	BLDC	1	2
W03	Blower Housing	2	12
W04	Blower Clips	2	2
W05	Seperator Column	1	9
W06	Seperator Cover	1	2
W07	Collection Bin	2	2
W08	Female Power Adapter	1	2
W09	Potentiometer	1	2
W10	Switch Blower	1	2
W11	Box (Left)	1	4
W12	Box (Right)	1	4
W13	Bolts	14	24
W14	Washers	22	32
W15	Nuts	14	16
W16	Blower Stand	1	7
W18	Blower Screen	1	1
W20	Legs	6	18
	Totals	73	142
	Design for Assembly Metrics	101.8135551	

DFA Analysis Worksheet

Assembly Name: Winnower

Part Number	Part Name	DFA Complexity: Number of Parts (Np)	DFA Complexity: Number of Interfaces (Ni)
W01	Impeller	1	1
W02	BLDC	1	2
W03	Blower Housing	2	12
W04	Blower Clips	2	2
W05	Seperator Column	1	9
W06	Seperator Cover	1	2
W07	Collection Bin	2	2
W08	Female Power Adapter	1	2
W09	Potentiometer	1	2
W10	Switch Blower	1	2
W11	Box (Left)	1	4
W12	Box (Right)	1	4
W16	Blower Stand	1	7
W18	Blower Screen	1	1
W19	Snap Rivets	14	16
W20	Legs	6	18
	Totals	37	86
	Design for Assembly Metrics	56.4092191	

Table 1: DFA Complexity Factor Results

Functional Analysis

The functional analysis revealed the efficiency improvements that the choice to use snap rivets in the overall design had. Theoretically, a winnower could consist only of 4 parts; a blower in itself a theoretical 3 part minimum, and a collection bin to hold the desired nibs with the husks flying in all directions. To have a winnower that separates the nibs from the husks in a closed environment and keeps the husks from flying everywhere the practical minimum part count was set at 11 parts. This meant that the original nuts and bolts option had a theoretical efficiency of a mere 5.5% and a practical efficiency of 15.1%. The snap rivets option doubled the efficiency having 10.8% and 29.7% theoretical and practical efficiency respectively.

DFA Analysis Worksheet
Assembly Name:

Part Number	Part Name	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part
		Functional Analysis / Redesign Opportunity			
W01	Impeller	1	1	H	1
W02	BLDC	1	1	L	1
W03	Blower Housing	1	1	H	1
W04	Blower Clips	0	1	L	0
W05	Seperator Column	0	1	M	1
W06	Seperator Cover	0	1	M	1
W07	Collection Bin	1	1	L	2
W08	Female Power Adapter	0	1	L	1
W09	Potentiometer	0	1	L	1
W10	Switch Blower	0	1	L	1
W11	Box (Left)	0	0	M	0
W12	Box (Right)	0	0	M	0
W13	Bolts	0	1	L	0
W14	Washers	0	1	L	0
W15	Nuts	0	1	L	0
W16	Blower Stand	0	1	L	1
W18	Blower Screen	0	1	L	0
W20	Legs	0	0	L	0
	Totals	4	15	0	11
	Design for Assembly Metrics	5.5%	←Theor. Effy. Pract. Effy.→		15.1%

DFA Analysis Worksheet
Assembly Name:

Part Number	Part Name	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part
		Functional Analysis / Redesign Opportunity			
W01	Impeller	1	1	H	1
W02	BLDC	1	1	L	1
W03	Blower Housing	1	1	H	1
W04	Blower Clips	0	1	L	0
W05	Seperator Column	0	1	M	1
W06	Seperator Cover	0	1	M	1
W07	Collection Bin	1	1	L	2
W08	Female Power Adapter	0	1	L	1
W09	Potentiometer	0	1	L	1
W10	Switch Blower	0	1	L	1
W11	Box (Left)	0	0	M	0
W12	Box (Right)	0	0	M	0
W16	Blower Stand	0	1	L	1
W18	Blower Screen	0	1	L	0
W19	Snap Rivets	0	1	L	0
W20	Legs	0	1	l	0
	Totals	4	14	0	11
	Design for Assembly Metrics	10.8%	←Theor. Effy. Pract. Effy.→		29.7%

Table 2: Functional Analysis Result

Error Proofing

As stated above, the error proofing index was not changed by the fastener choice. However, it was not null as several parts could be omitted or assembled in the incorrect direction. 8 potential errors were registered by the team leading to the error proofing index to be 2.00.

Handling

The handling index was the smallest registered in the DFA analysis for this product at only 0.25 for both design iterations. The sole potential problem that the team could envision was the fragility of the Blower Clips that hold the blower housing together due to the small size and material of this component.

Insertion

Although the assembly step of inserting the blower stand and separator column is likely to be passed down to the customer to minimize shipping volume the insertion index must be considered. The customer would want a product that is simple to assemble, the first option requires the washer and nut at the bottom of the assembly to be held while the bolt is being screwed, and if the collection bins are already inserted into the base, the space is obstructed to conduct this step. The snap rivets avoid both of these problems, however there might be insertion resistance due to the nature of the snap-fit. This results in the first option having an insertion index of 3.25 and the second option having an insertion index of 2.50.

DFA Analysis Worksheet

Assembly Name: Cacao Winnower

Part		Insertion			
Part Number	Part Name	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility
W01	Impeller	0	1	0	0
W02	BLDC	0	1	0	0
W03	Blower Housing	0	1	0	0
W04	Blower Clips	1	0	1	1
W05	Seperator Column	0	1	0	0
W06	Seperator Cover	0	0	0	0
W07	Collection Bin	0	0	0	0
W08	Female Power Adapter	0	0	0	0
W09	Potentiometer	1	0	0	0
W10	Switch Blower	1	0	0	0
W11	Box (Left)	0	0	0	0
W12	Box (Right)	0	0	0	0
W13	Bolts	0	0	0	0
W14	Washers	0	1	0	1
W15	Nuts	0	1	0	1
W16	Blower Stand	0	0	0	0
W18	Blower Screen	0	0	0	0
	Totals	3	6	1	3
	Design for Assembly Metrics	3.25			

DFA Analysis Worksheet

Assembly Name: Cacao Winnower

Part		Insertion			
Part Number	Part Name	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility
W01	Impeller	0	1	0	0
W02	BLDC	0	1	0	0
W03	Blower Housing	0	1	0	0
W04	Blower Clips	1	0	1	1
W05	Seperator Column	0	1	0	0
W06	Seperator Cover	0	0	0	0
W07	Collection Bin	0	0	0	0
W08	Female Power Adapter	0	0	0	0
W09	Potentiometer	1	0	0	0
W10	Switch Blower	1	0	0	0
W11	Box (Left)	0	0	0	0
W12	Box (Right)	0	0	0	0
W16	Blower Stand	0	0	0	0
W18	Blower Screen	0	0	0	0
W19	Snap Rivets	0	0	1	0
	Totals	3	4	2	1
	Design for Assembly Metrics	2.50			

Table 3: Insertion Index Result

Secondary Operations

As mentioned before the fastening of the base to the blower stand and separator will be left to the customer, however secondary operations that require a tool need to be considered since the tool will either need to be supplied adding cost to the product or expect for the customer to have their own which for our target audience of chocolatiers this might not be the case. The first option requires screwing a bolt into a nut 8 times which leads to a secondary operation index of 3.25 compared to the snap rivets option with an index of 2.75 since the snap rivets can be pushed in by hand.

DFA Analysis Worksheet
Assembly Name: Cac Date: 11/4/2024

Part Number	Part Name	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
W01	Impeller	0	0	0	0	0
W02	BLDC	0	0	1	0	0
W03	Blower Housing	0	0	0	0	0
W04	Blower Clips	0	0	0	0	0
W05	Seperator Column	0	0	0	1	0
W06	Seperator Cover	0	0	0	1	0
W07	Collection Bin	0	0	0	1	0
W08	Female Power Adapter	0	0	1	0	0
W09	Potentiometer	0	0	1	0	0
W10	Switch Blower	0	0	1	0	0
W11	Box (Left)	0	1	1	0	0
W12	Box (Right)	0	1	1	0	0
W13	Bolts	0	1	0	0	0
W14	Washers	0	0	0	0	0
W15	Nuts	0	1	0	0	0
W16	Blower Stand	0	0	0	0	0
W18	Blower Screen	0	0	0	0	0
	Totals	0	4	6	3	0
	Design for Assembly Metrics	3.25				

DFA Analysis Worksheet
Assembly Name: Cac Date: 11/4/2024

Part Number	Part Name	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
W01	Impeller	0	0	0	0	0
W02	BLDC	0	0	1	0	0
W03	Blower Housing	0	0	0	0	0
W04	Blower Clips	0	0	0	0	0
W05	Seperator Column	0	0	0	1	0
W06	Seperator Cover	0	0	0	1	0
W07	Collection Bin	0	0	0	1	0
W08	Female Power Adapter	0	0	1	0	0
W09	Potentiometer	0	0	1	0	0
W10	Switch Blower	0	0	1	0	0
W11	Box (Left)	0	1	1	0	0
W12	Box (Right)	0	1	1	0	0
W16	Blower Stand	0	0	0	0	0
W18	Blower Screen	0	0	0	0	0
W19	Snap Rivets	0	0	0	0	0
	Totals	0	2	6	3	0
	Design for Assembly Metrics	2.75				

Table 4: Secondary Operations Index

Tertiary Operation

To ensure that the plastic components of the cacao winnower meet FDA food safety standards for commercial use, a tertiary operation involving the application of Max CLR food-safe epoxy will be conducted. Max CLR is an FDA-compliant, food-safe epoxy that provides a durable, non-toxic coating, making it suitable for use in food processing equipment. After the initial manufacturing process, each plastic component, including those made from Polypropylene (PP), Polyethylene (PE), and Polystyrene (PS), will undergo a thorough cleaning to remove any residues. Following this, the eoxy will be evenly applied to the surface of each component, ensuring complete coverage. Once applied, the epoxy will cure according to the manufacturer's specifications, resulting in a hard, glossy finish that is both food-safe and resistant to wear and tear. This additional step is crucial in guaranteeing that all plastic parts of the winnower comply with stringent food safety regulations, thereby ensuring the equipment is safe for commercial use in the cacao processing industry.

Material Analysis

This part of the report provides an overview of the material selection process for various designed components, including a vacuum blower housing, a platform for component mounting and structural support, collection bins, a separator column, and an impeller. The criteria for selection included factors such as Young's modulus, density, cost, and specific application requirements. The selected materials were chosen based on their performance across these criteria, ensuring they meet the specific needs of each project.

Blower Housing

Criteria and Weighting

The selection criteria for the blower housing of a vacuum included Young's modulus, density, and cost. Among these, the cost of the material was given the highest weight, followed by density and Young's modulus. This prioritization ensured that the chosen material would be cost-effective while still providing the necessary structural properties.

Selected Material: Polypropylene (PP)

Polypropylene (PP) was selected as the optimal material for the blower housing. PP offers a balanced combination of low cost, suitable density, and satisfactory Young's modulus. Its cost-effectiveness ensures budget efficiency, while its physical properties provide the necessary structural integrity and lightweight characteristics. This makes PP an excellent choice for the blower housing, aligning well with the project requirements.

Boxes (Main Housing)

Criteria and Weighting

For the design project involving the creation of a platform to mount components and provide structural support, the selection criteria were based on Young's modulus, density, and the cost of a 12" by 12" plate. The cost of the material was weighted the highest, followed by density and Young's modulus.

Selected Material: 301 Stainless Steel

301 stainless steel was chosen as the optimal material for the platform. The selection was driven by its cost-effectiveness, suitable density, and satisfactoryYoung's modulus. This combination ensures that the platform is both economical and capable of providing the necessary structural support and stability required for the project.

Collection Bins

Criteria and Motivation

The material selection for collection bins was highly motivated by the cheapness of the material. The criteria also included density and Young's modulus to ensure practicality and performance.

Selected Material: Polypropylene (PP)

Polypropylene (PP) was selected for the collection bins due to its low cost, low density, and average Young's modulus. These characteristics make the bins lighter and easier to handle while ensuring they are economical and practical for everyday use. PP’s suitability for Stereolithography (SLS) 3D printing also adds to its efficiency in production.

Separator Column

Criteria and Weighting

For the separator column, the criteria included Young's modulus, Rockwell hardness, and cost, with the material needing to be dishwasher safe and food safe. The material selection was weighted with cost as the highest priority, followed by density and Young's modulus.

Selected Material: Polyethylene (PE)

Polyethylene (PE) was chosen as the optimal material for the separator column. PE offered higher than average scores in Young's modulus, Rockwell hardness, and cost when compared to alternatives such as ABS, PS, 304 Stainless Steel, and 356 Aluminum. PE’s attributes of being dishwasher safe and food safe were crucial for the application, ensuring reliability and compliance with the project’s safety and functionality requirements.

Impeller

Criteria and Performance

The material for the impeller was selected based on its Young's modulus and Rockwell hardness. The goal was to find a material that provided high stiffness and resistance to wear.

Selected Material: Polystyrene (PS)

Polystyrene (PS) was selected for the impeller due to its high Young's modulus and Rockwell hardness, indicating excellent stiffness and structural integrity. These properties are critical for efficient impeller performance and durability under operational conditions. PS’s suitability for SLS 3D printing further enhances its practicality for production.

The material selection for each designed component was meticulously evaluated based on specific criteria relevant to their applications. The chosen materials—Polypropylene (PP), 301 Stainless Steel, Polyethylene (PE), and Polystyrene (PS)—provide a balanced combination of cost-effectiveness, structural integrity, and compliance with specific requirements. These selections ensure that the project will meet the performance goals while remaining economical and practical for production.

Manufacturing Process Analysis

Impeller

The impeller for the vacuum blower will be manufactured using Selective Laser Sintering (SLS), a 3D printing technology that uses a high-power laser to sinter powdered material into solid parts. The process begins with designing the impeller using CAD software, ensuring all dimensions and specifications meet the design requirements. The design file is then uploaded to the SLS printer, where a laser selectively fuses powdered Polystyrene (PS) layer by layer to form the impeller. After printing, the impeller is cleaned to remove any excess powder and then undergoes a post-processing step to enhance its mechanical properties.

Blower Housing

The blower housing, which consists of two parts (left and right), will also be manufactured using SLS. Similar to the impeller, the housing components are designed using CAD software and printed layer by layer using the SLS printer. Post-printing, the parts are cleaned to remove any loose powder and then undergo a post-processing treatment to ensure durability and precision. The two halves of the blower housing are then assembled together with the impeller and secured in place using appropriate fasteners.

Separator Column

The separator column, integral to the housing, will be produced using SLS. This component is designed with precise dimensions to fit seamlessly with other parts of the machine. The SLS process ensures that the column is accurate and robust, providing the necessary structural support and functionality. After printing and post-processing, the separator column is inspected for any imperfections and then integrated into the main housing assembly.

Collection Bins

The collection bins are manufactured using Polypropylene (PP) due to its cost-effectiveness and suitable mechanical properties. The bins are designed to be lightweight and durable, ensuring ease of handling and longevity. The SLS process is used to print the bins, with a focus on achieving precise dimensions and smooth surfaces. After printing, the bins undergo post-processing and inspection to ensure they meet the design specifications and can securely fit into the winnower assembly.

Vacuum Blower

The vacuum blower assembly includes the impeller, blower housing (left and right), and blower standoff. Each component is designed to work in harmony to create the necessary airflow for the winnowing process. The impeller and blower housings are printed using SLS, cleaned to remove excess powder, and post-processed. The blower standoff, also produced via SLS, is designed to provide the necessary spacing and support for the blower assembly. Once all components are printed and processed, they are assembled together with precise alignment to ensure optimal performance of the vacuum blower.

Boxes (Main Housing)

The boxes forming the main housing of the winnower are made from a sheet of 301 stainless steel (SS). The stainless steel sheet is first prepared by cleaning and ensuring it is free from any contaminants. It is then laser cut to include all necessary holes and tabs required for the design. Laser cutting provides high precision and clean edges, ensuring the boxes fit perfectly into the overall assembly. After cutting, the pieces are inspected for accuracy and any sharp edges are deburred. The stainless steel boxes are then assembled, providing a durable and corrosion-resistant housing for the winnower.

Legs (Structural Support)

The legs of the machine are fabricated from 6061 aluminum (AL), a material known for its strength and lightweight properties. Stock aluminum extrusions are used, which are cut to a length of 8 inches using a precision saw. Two holes are then drilled into each leg for mounting purposes. The aluminum legs are then inspected for any defects and prepared for assembly with the main housing. This ensures that the machine has a stable and robust foundation, capable of supporting all other components securely.

In conclusion, the manufacturing process for the vacuum winnower components involves a combination of advanced 3D printing technologies like Selective Laser Sintering (SLS) and traditional machining techniques. By using SLS for the majority of parts and laser cutting for the stainless steel housing, the design achieves a balance of precision, durability, and cost-effectiveness. The integration of these manufacturing methods ensures that the final product meets all performance and structural requirements, providing a high-quality solution for cacao winnowing.

Economic Analysis

Most components in our product are SLS printed, with a few exceptions, such as those that are plasma cut and welded. The manufacturing costs of these processes largely depend on factors like mass, design complexity, and the volume of products to be produced. These processes are well-suited for low-scale manufacturing but are not ideal for mass production. Given that only

1000 units of these products are sold annually and based on data from the Fine Chocolate Industry Association (FCIA), these were the most optimal manufacturing options.

UNIT COST ANALYSIS

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

1. Material Cost:

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

2. Labor Cost:

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

Labour Cost ($/lb):

- **SLS Printing :** $25 /Hour
- **Plasma Cutting :** $30/Hour
- **Plasma Cutting and Welding(GMAW) :** $35/Hour

Production Rate (Units/hr):

The production rate of parts depends largely on their size and complexity, with variations based on the manufacturing process. Below is an analysis of the production rates for various processes:

SLS Printing:
The production rate for SLS printing typically ranges from 20 to 30 parts per hour, which is influenced by the complexity and size of the product. For example, components such as

W01 (Impeller) and W17 (Blower Clips) are relatively small but feature intricate contours, resulting in slower production rates. On the other hand, larger components like W05 (Separator Column), W06 (Separator Cover), and W07 (Collection Box) have lower production rates due to their size and additional post-processing requirements.

Plasma Cutting and Welding:
Components like W11 and W12 are both plasma cut and welded, while W18 (Blower Screen) is solely plasma cut. The production rate for these components is approximately 10 units per hour, which is influenced by the material properties. Stainless steel grades SS301 and SS304, which are used for perforated sheets, take significantly longer to cut compared to plastics. Additionally, the size and precision requirements for components like W11, W12, and W19 further contribute to the reduced production efficiency.

3. Tooling Cost:

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

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

A. *Cost of Tooling ($):*

Below is an analysis of the Cost of Tooling($) for various processes:

SLS Printing:

SLS printing is generally considered a cost-effective process, particularly for low-volume production. The primary costs involved include the resin and the operation of the machine. The cost of resin is approximately $200, in addition to the cost of the materials used for printing. This makes SLS printing an affordable option, especially for small-scale or prototyping applications

Plasma Cutting:

Plasma cutting is a more expensive process due to the specialized equipment required to handle thicker materials such as stainless steel. The cost of tooling setup for plasma cutting is estimated at approximately $3,000.

Welding:

The tooling costs for welding, particularly for Gas Metal Arc Welding (GMAW), vary based on the size of the components being welded. The setup cost for welding is typically around $2,000, influenced by the materials used and the complexity of the welds required.

B. ***Life of Tooling (Cost/lb):***

SLS Printing:

SLS printing does not require significant tooling aside from the 3D printer and CAD file. Therefore, the tooling cost is typically listed as N/A. The production process is mostly reliant on the use of digital models, making it a relatively low-cost option in terms of tooling.

Plasma Cutting:

Plasma cutting tools have an estimated life of approximately 1,000 units. To meet production demands, typically 3 sets of plasma cutting machines are required, ensuring consistent operation and minimizing downtime.

Welding:

The life of welding tools is contingent upon the size and complexity of the components being welded. Larger parts generally require more frequent tool maintenance or replacement. The tooling life for welding is estimated based on usage and the frequency of welding sessions required for each component.

Production Run (No. of Parts): Based on data from IBISWorld.com, approximately 1000 units of this machine are sold annually. Since the market for this product is relatively stable without any drastic sales increases, we have assumed a production run of 3,000 units.

4. . Equipment Cost:

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

A. ***Capital Cost ($):***
   - **SLS Printing:** $5,500
   - **Plasma Cutting:** $11,000
   - **Plasma Cutting and Welding (GMAW):** $5,500

B. ***Capital Write-off Time:***

Assuming 5 years, 40 hours per week, 3 shifts per day, and 50 weeks per year.

C. ***Load Fraction:***

We assume one operator per machine**.**

D. ***Load Sharing Factor:***

We assume one machine per part.

5. Overhead Cost (C_{OH}):

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

Overhead Hourly Rate: $50 / Hour

6. 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 the equipment. The table below provides detailed information used in the cost estimation process. Grey-shaded cells in the table indicate unit cost estimates that were calculated using the equations mentioned earlier.

Unit Cost Analysis					
COMPONENT	Impeller	Blower Housing	Blower Clips	Separator Column	Separator Cover
Process	SLA PRINTING	SLA PRINTING	SLA PRINTING	SLA PRINTING	SLA PRINTING
Material	PS	PP	PP	PE	PE
Cost Element	W01	W03	W04	W05	W06
Cost of Material (Cost/lb)	$1.500	$1.800	$1.800	$1.500	$1.800
Fraction of process that is scrap	0.05	0.05	0.05	0.05	0.05
Mass of Material (lb)	1.7	0.38	0.1	0.413	0.135
Unit Material Cost (C_M)	$2.684	$0.720	$0.189	$0.652	$0.256
Labor Cost ($/lb)	$25.00	$25.00	$25.00	$25.00	$25.00
Production Rate (Units/hr)	30	20	30	30	30
Unit Labor Cost (C_L)	$0.833	$1.250	$0.833	$0.833	$0.833
Cost of Tooling ($)	$200.00	$200.00	$200.00	$200.00	$200.00
Production Run (No. of Parts)	3000	3000	3000	3000	3000
Life of Tooling	NA	N/A	N/A	N/A	N/A
Sets of Tooling Required	NA	N/A	N/A	N/A	N/A
Unit Tooling Cost (C_T)	$0.067	$0.067	$0.067	$0.067	$0.067
Capital cost	$5,500.000	$5,500.000	$5,500.000	$5,500.000	$5,500.000
Capital write-off time	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1
Load Sharing Fraction	1	1	1	1	1
Unit Capital Cost (C_E)	$0.006	$0.009	$0.006	$0.006	$0.006
Factory Overhead	50	50	50	50	50
Prodution Rate (Units/hr)	30	20	30	30	30
Unit Overhead Cost (C_{OH})	$1.667	$2.500	$1.667	$1.667	$1.667
Quantity	1	2	2	1	1
Total Unit Cost C_M+C_L+C_T+C_E+$C_($	$5.257	$4.546	$2.762	$3.225	$2.829

Table 5: Unit Cost Analysis 1

Unit Cost Analysis						
COMPONENT	Collection Bin	Box (Left)	Box (Right)	Blower Stand	Blower Screen	Blower Legs
Process	SLA PRINTING	PLASMA CUTTING + WELDING	PLASMA CUTTING + WELDING	SLA PRINTING	PLASMA CUTTING	PLASMA CUTTING+WELDING
Material	PP	SS301	SS301	AL 60661	PERFORATED SHEET - SS304	AL 60661
Cost Element	W07	W11	W12	W16	W18	W20
Cost of Material (Cost/lb)	$1.800	$6.500	$6.500	$2.500	$31.000	$2.500
Fraction of process that is scrap	0.05	0.05	0.05	0.05	0.05	0.05
Mass of Material (lb)	0.419	2	2	0.8	0.028	0.5
Unit Material Cost (C_M)	$0.794	$13.684	$13.684	$2.105	$0.914	$1.316
Labor Cost ($/lb)	$20.00	$35.00	$35.00	$25.00	$30.00	$35.00
Production Rate (Units/hr)	20	10	10	20	15	10
Unit Labor Cost (C_L)	$1.000	$3.500	$3.500	$1.250	$2.000	$3.500
Cost of Tooling ($)	$200.00	$5,000.00	$5,000.00	$200.00	$3,000.00	$5,000.00
Production Run (No. of Parts)	3000	3000	3000	3000	3000	3000
Life of Tooling	N/A	1000	1000	N/A	1000	N/A
Sets of Tooling Required	N/A	3	3	N/A	3	N/A
Unit Tooling Cost (C_T)	$0.067	$5.000	$5.000	$0.067	$3.000	$1.667
Capital cost	$4,500.000	$11,000.000	$11,000.000	$5,500.000	$5,300.000	$11,000.000
Capital write-off time	30000	30000	30000	30000	30000	30000
Load Fraction	1	1	1	1	1	1
Load Sharing Fraction	1	1	1	1	1	1
Unit Capital Cost (C_E)	$0.008	$0.037	$0.037	$0.009	$0.012	$0.037
Factory Overhead	50	60	60	50	60	60
Prodution Rate (Units/hr)	20	10	10	20	15	10
Unit Overhead Cost (C_{OH})	$2.500	$6.000	$6.000	$2.500	$4.000	$6.000
Quantity	2	1	1	1	1	1
Total Unit Cost C_M+C_L+C_T+C_E+$C_($	$4.368	$28.221	$28.221	$5.931	$9.925	$12.519

Table 6: Unit Cost Analysis 2

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:

Material Cost ($)=Cost of Material ($C_M$)(cost/lb) + Labour Cost (C_L) ($/hr)

Manufacturing Cost ($) = 3 ×Material Cost($)

Selling Price ($) =9 ×Material Cost($)

OME Analysis					
COMPONENT	Impeller	Blower Housing	Blower Clips	Separator Column	Separator Cover
Cost Element	W01				
Quantity	1	2	2	1	1
Mass of Material (lb)	1.7	0.38	0.1	0.413	0.135
Material Cost ($)	3.5175	1.9700	1.0228	1.4854	1.0891
Manufacturing Cost ($)	10.5526	11.8200	6.1368	4.4563	3.2674
Selling Price ($)	31.6579	35.4600	18.4105	13.3689	9.8021

Table 7: Approximate Order of Magnitude Estimate 1

OME Analysis						
COMPONENT	Collection Bin	Box (Left)	Box (Right)	Blower Stand	Blower Screen	Blower Legs
Cost Element	W07	W11	W12	W16	W18	W20
Quantity	2	1	1	1	1	1
Mass of Material (lb)	0.419	2	2	0.8	0.028	0.5
Material Cost ($)	1.7939	17.1842	17.1842	3.3553	2.9137	4.8158
Manufacturing Cost ($)	10.7634	51.5526	51.5526	10.0658	8.7411	14.4474
Selling Price ($)	32.2901	154.6579	154.6579	30.1974	26.2232	43.3421

Table 8: Approximate Order of Magnitude Estimate 2

Stock Parts:

This product consists of four stock parts, which are common components such as bolts, DC motors, potentiometers, 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.

Stock Parts				
PART NO.	ELEMENT	Quantity	COST ($)	OVERALLCOST ($)
W02	BLDC	1	17.99	$17.99
W08	FEMALE POWER ADAPTER	1	1.8	$1.80
W09	POTENTIOMETER	1	1.99	$1.99
W10	SWITCH	1	1.5	$1.50
W19	SNAP RIVETS	14	0.3218	$4.51

Table 9: Stock Parts Cost Summary

Break-Even Point

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

$$\boldsymbol{Break-Even\ Quantity} = \frac{\boldsymbol{Fixed\ Costs}\left(\frac{\$}{\boldsymbol{Month}}\right)}{\boldsymbol{Selling\ Price}(\$) - (\boldsymbol{Quantity} * \boldsymbol{Variable\ Cost}}$$

$$\boldsymbol{Variable\ Cost}(\$) = \boldsymbol{C_M} + \boldsymbol{C_L}$$

$$\boldsymbol{Selling\ Price}(\$) = \boldsymbol{3} \times \boldsymbol{Quantity} \times \boldsymbol{C_U}$$

Break-Even Analysis					
COMPONENT	Impeller	Blower Housing	Blower Clips	Separator Column	Separator Cover
Cost Element	W01	W03	W04	W05	W06
Quantity	1	2	2	1	1
Fixed Costs ($/month)	$5,500.00	$5,500.00	$5,500.00	$5,500.00	$5,500.00
Variable Costs ($)	$5.257	$4.546	$2.762	$3.225	$2.829
Selling Price ($)	$15.771	$27.275	$16.574	$9.675	$8.486
Break-Even Quantity	523.11	302.47	497.78	852.74	972.22

Table 10: Break Even Analysis Estimates 1

Break-Even Analysis						
COMPONENT	Collection Bin	Box (Left)	Box (Right)	Blower Stand	Blower Screen	Blower Legs
Cost Element	W07	W11	W12	W16	W18	W20
Quantity	2	1	1	1	1	1
Fixed Costs ($/month)	$5,500.00	$5,500.00	$5,500.00	$5,500.00	$5,500.00	$5,500.00
Variable Costs ($)	$4.368	$28.221	$28.221	$5.931	$9.925	$12.519
Selling Price ($)	$26.208	$84.663	$84.663	$17.793	$29.776	$37.557
Break-Even Quantity	314.78	97.45	97.45	463.66	277.07	219.66

Table 11: Break Even Analysis Estimates 2

Summary

A table summarizing the Costs incurred for the product is given below.

Summary of Cost Estimates	
PART NO.	Original
Unit Cost ($)	$107.80
OME ($)	$550.07
Stock Parts ($)	$27.79
Overall Selling Price ($)	$441.80
Break-Even Quantity	420

Table 12: Summary of Economic Analysis

$$\boldsymbol{Overall\ Selling\ Price}(\$) = \boldsymbol{Selling\ Price}(\$) + (\mathbf{3}\ \times \boldsymbol{Stock\ Parts}(\$))$$

The product's listed price on the official website cocoatown.com is $2250. However, our manufactured version achieves a Break-Even Quantity of 420 units at a selling price of $441.80 per unit, approximately $1808.2 less than the listed price. Despite the cost reduction, our product maintains high-quality standards, making it competitive in the market. This pricing advantage could expand accessibility, particularly in the household segment, potentially driving significant sales growth.

Professional, Ethical, and Safety Issues

Initially, safety concerns such as sharp edges, pinching or crushing injuries, and hair or loose clothing getting caught in moving parts surfaced. The main moving part is the blower impeller, so the blower housing was designed to minimize the number and size of any openings that could be used to access any possible points of injury. The blower housing was designed to place the impeller over 3 inches away from any inlets, and openings in the housing are small enough that the risk of injury is low. An operator could potentially catch their hand in the gap between the collection bin and the base, but it is highly unlikely that the forces involved would be significant enough to cause serious injury.

The major remaining safety concern with this device is the risk of inhaling airborne particles. Even if small particles are made of non-toxic materials, inhaling particles as small as 2.5 micrometers has been linked to aggravated asthma, decreased lung function, and irritation of the lungs and airway [7]. The particles from the cacao crushing process are much larger than those that are associated with inhalation hazards, but it is possible that a small number of small particles become airborne. Most of the air from the blower is directed downwards into collection bins, and some particles could escape through small gaps in between the collection bins and base. When the operator tunes the speed of the motor for optimal separation, they can also observe if any particles escape and alter the motor's speed accordingly.

Conclusion

The design and development of the innovative cacao winnower with an integrated vacuum blower have successfully met the objectives of providing a more cost-effective and efficient solution compared to existing market alternatives. The unique integration of the vacuum blower enhances the separation process, ensuring a cleaner and more precise winnowing operation. This project highlights the potential for significant improvements in productivity and cost savings for chocolate producers.

The integrated vacuum blower significantly improves the separation efficiency by effectively removing lighter husks from the heavier cacao nibs, ensuring a cleaner and more precise separation process. This feature, unique to our design, sets it apart from other winnowers on the market. By streamlining the winnowing process, the integrated vacuum blower reduces manual intervention and increases overall throughput, leading to higher productivity. The design's user-friendly nature ensures that operators can quickly and efficiently manage the winnowing process with minimal downtime.

This project demonstrates how thoughtful design and material selection can lead to innovative solutions that address specific industry needs. Our cacao winnower with an integrated vacuum blower is not only more affordable but also more efficient than existing market alternatives. The combination of cost-effectiveness, structural integrity, and enhanced functionality makes our design a valuable tool for improving cacao production processes. The success of this project underscores the importance of multidisciplinary approaches in engineering design, combining material science, mechanical design, and practical considerations to create superior products.

Overall, this innovative approach not only supports the needs of small-scale chocolate producers but also scales up to meet the demands of moderate sized processing facilities. The winnower's design aligns with the goals of improving productivity, reducing costs, and enhancing the quality of the final product. By providing a cheaper alternative with superior functionality, our cacao winnower sets a new standard for winnowing solutions in the industry, offering a versatile and valuable tool for the cacao production community.

Acknowledgements

We would like to thank Mr. Dan Riffel for his guidance throughout the Fall 2024 semester. It has been a great pleasure to learn from his experience.

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Appendix

Appendix 1 Material Selection Ashby Chart

For the material selection process, we initially utilized an Ashby chart to identify and evaluate potential candidate materials. The Ashby chart is a valuable tool in materials science, allowing us to plot and compare critical properties such as Young's modulus, density, and cost on a single graph. This visual representation facilitated a systematic and informed approach to material selection, enabling us to efficiently narrow down the list of materials that best met our project's criteria. By using the Ashby chart, we ensured that our decisions were data-driven and optimized for performance and cost-effectiveness. The Ashby chart used in our analysis will be shown below.

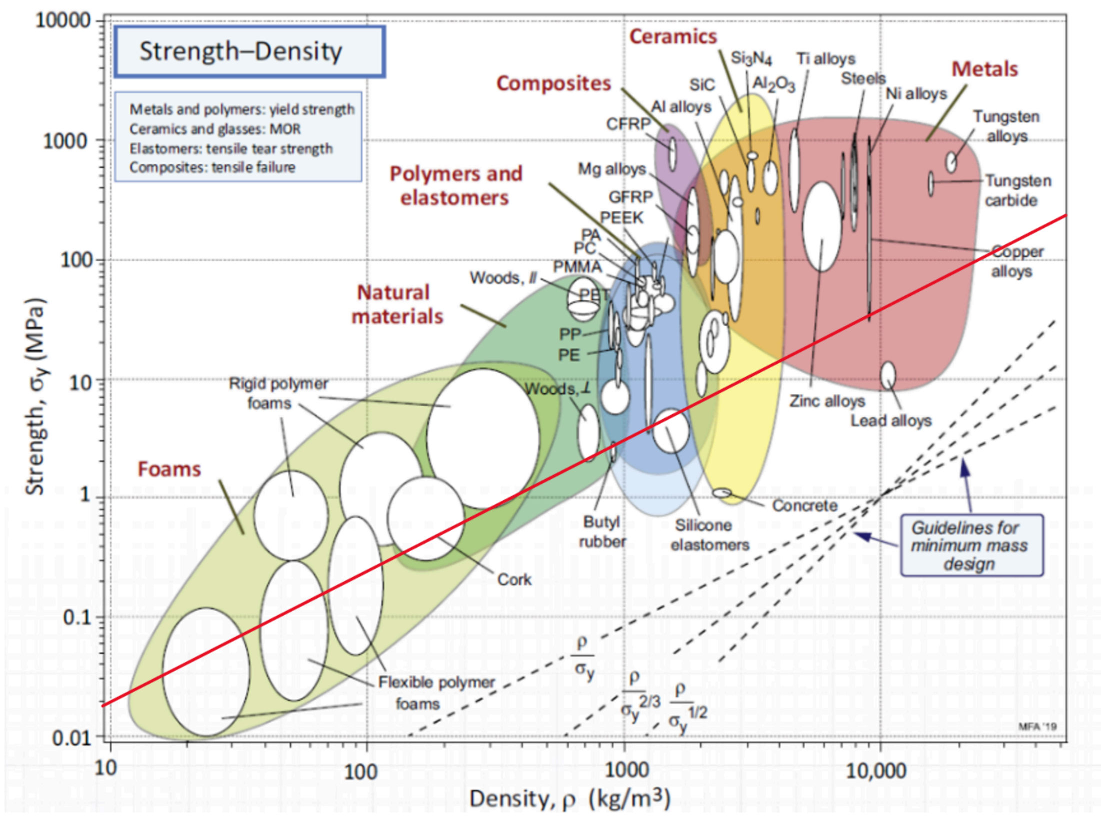
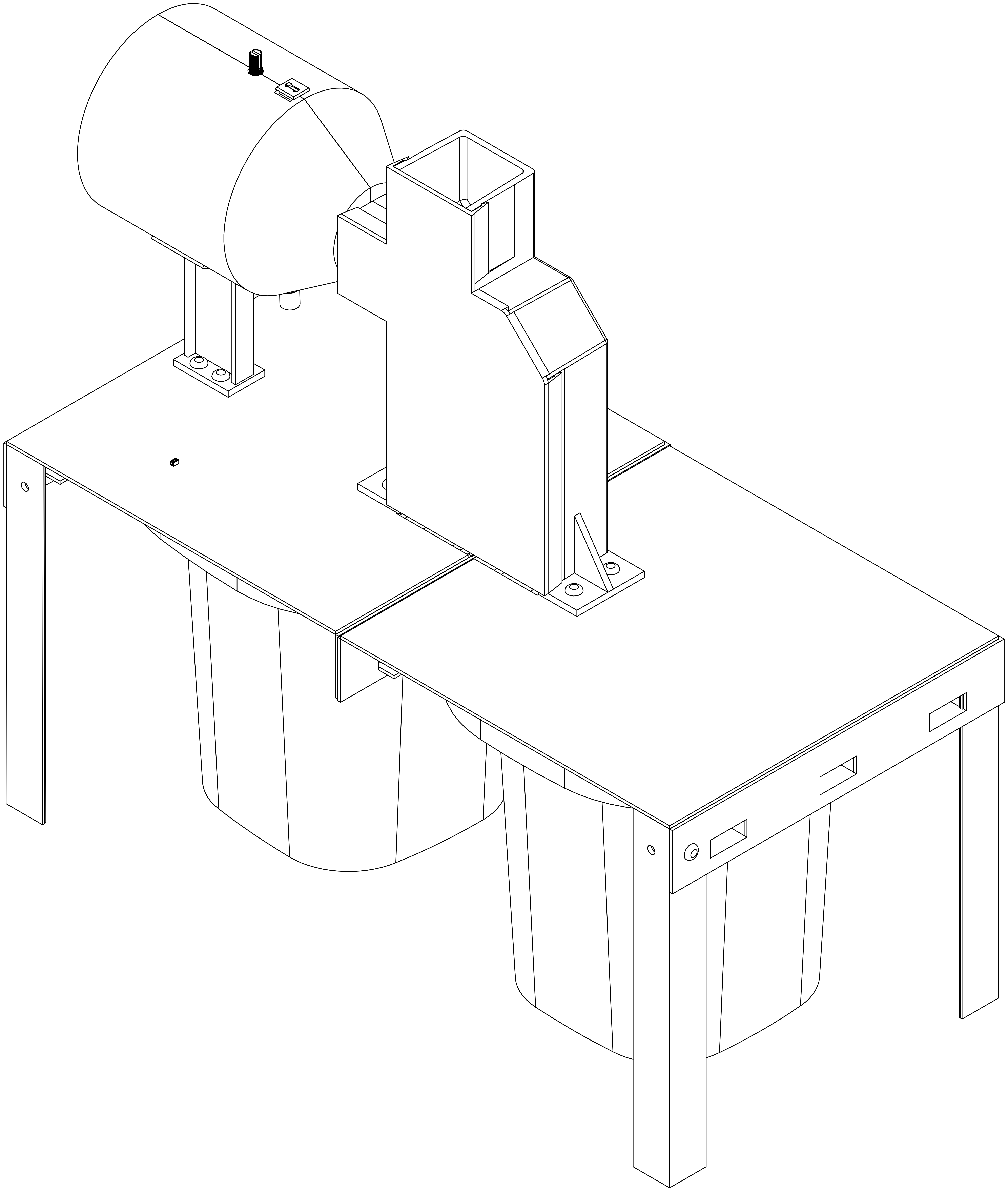


Figure 18: Ashby Chart

Engineering Drawings

REV.	DESCRIPTION	DATE
A	Initial Creation	12/1/2024



UNIVERSITY OF COLORADO

1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION		
Assembly		
PN Asm-01	REV A	SHEET 1 of 2

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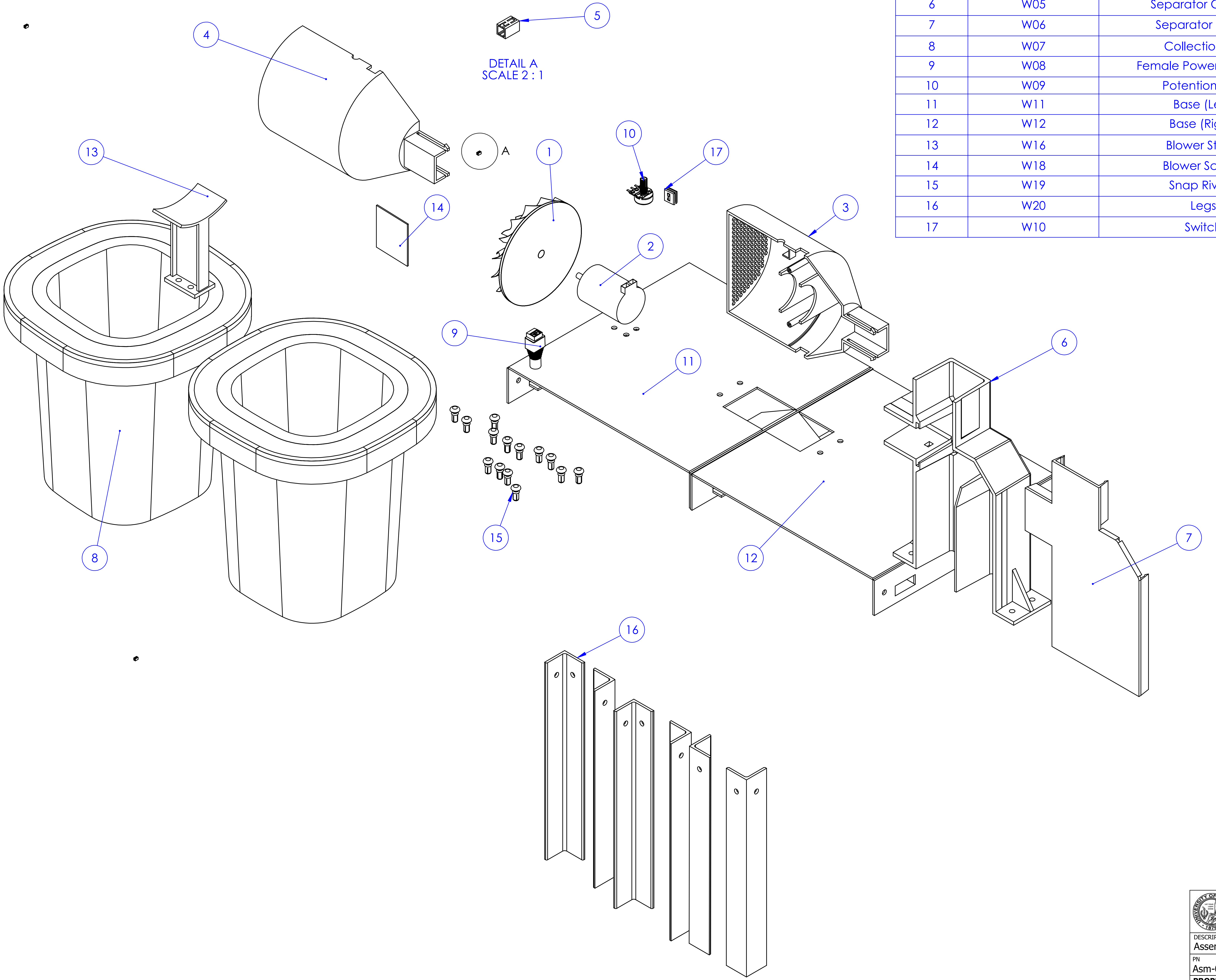
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	W01	Impeller	1
2	W02	Brushless Motor	1
3	W03-A	Blower Housing Side A	1
4	W03-B	Blower Housing Side B	1
5	W04	Blower Clips	2
6	W05	Separator Column	1
7	W06	Separator Cover	1
8	W07	Collection Bin	1
9	W08	Female Power Adapter	1
10	W09	Potentiometer	1
11	W11	Base (Left)	1
12	W12	Base (Right)	1
13	W16	Blower Stand	1
14	W18	Blower Screen	1
15	W19	Snap Rivets	14
16	W20	Legs	6
17	W10	Switch	1

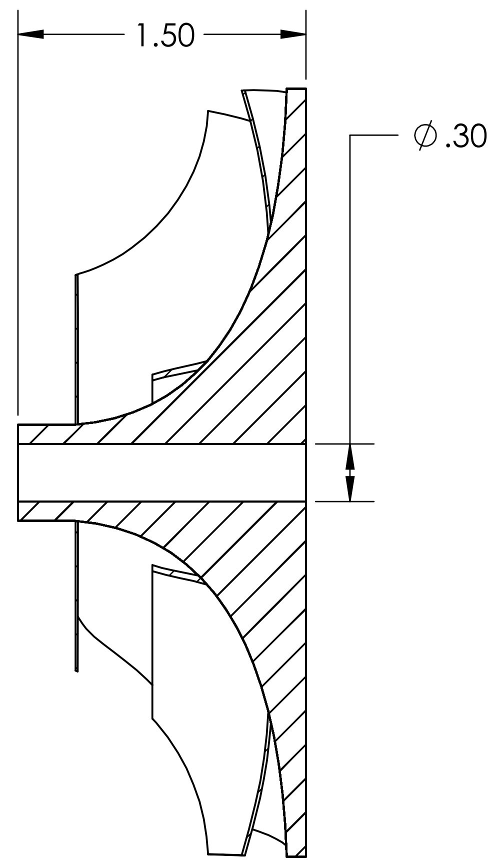


UNIVERSITY OF COLORADO
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

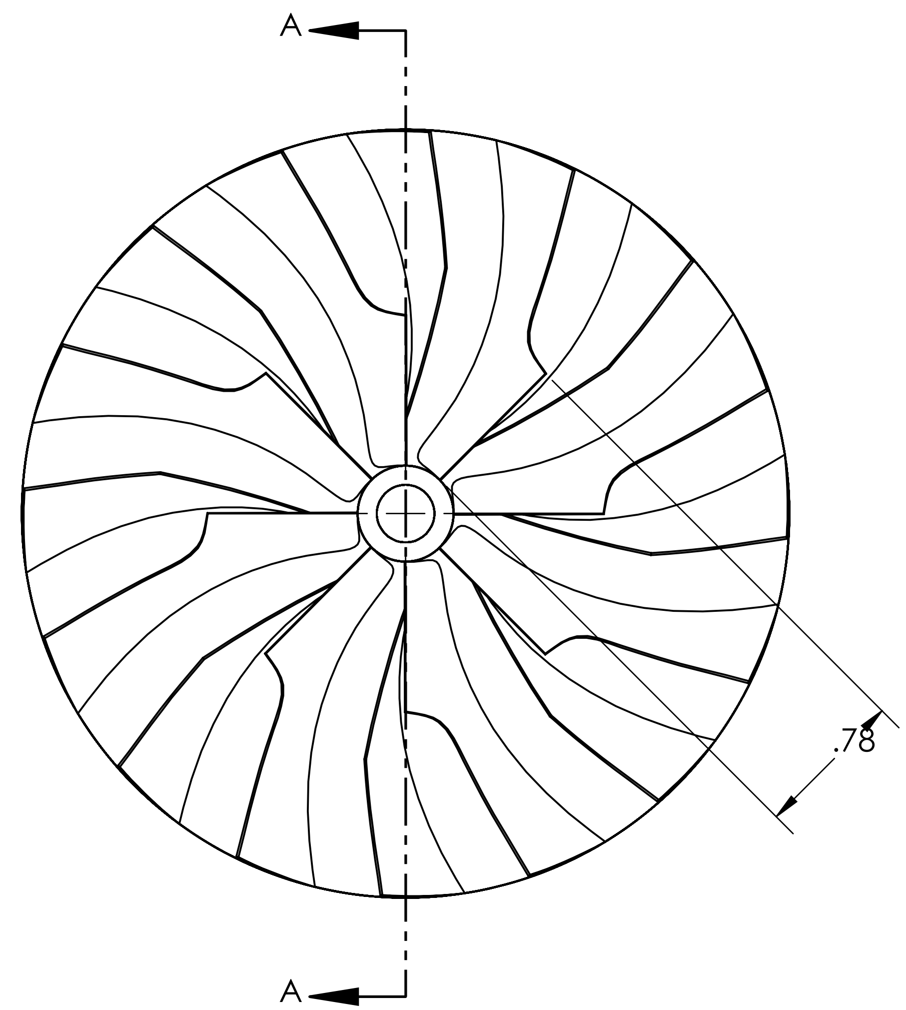
DESCRIPTION			
Assembly			
PN: Asm-01	REV: A		SHEET: 2 of 2

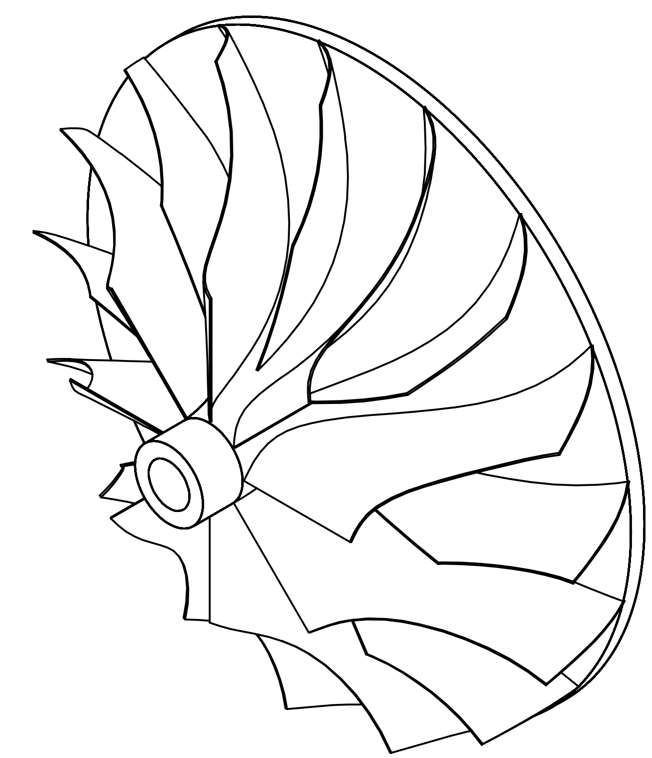
PROPRIETARY AND CONFIDENTIAL

REV.	DESCRIPTION	DATE
A	INIITAL DRAWING	111/20/2024

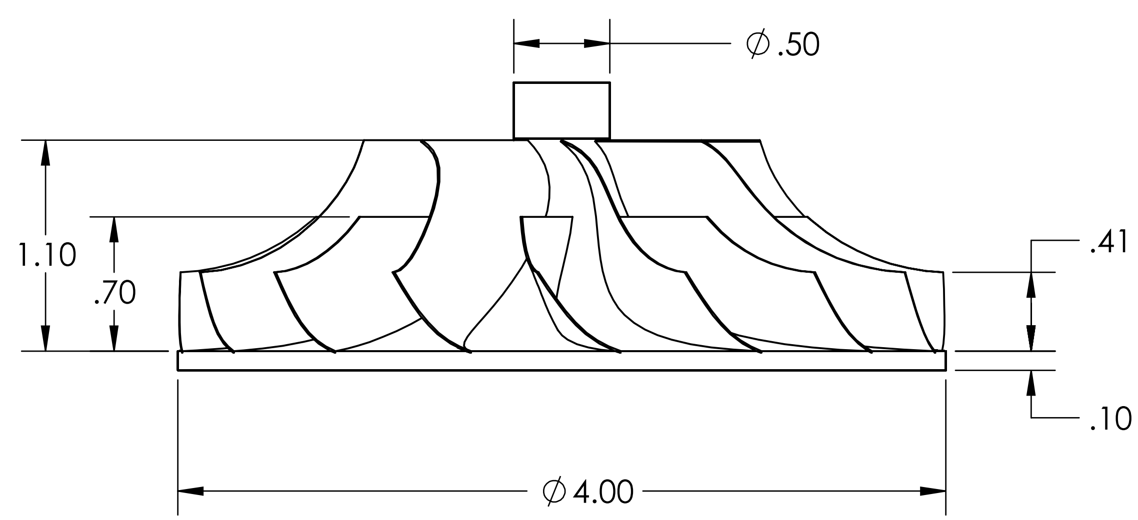


SECTION A-A





NOTE: 8 LARGE FINS AND 8 SMALL FINS.
DIMENSIONS FOR EACH FIN ARE TYPICAL FOR ALL SIMILAR FINS



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 POLYPROPYLENE		DESCRIPTION IMPELLER	
FINISH MATTE		PN W01	REV A; SHEET 1 of 1

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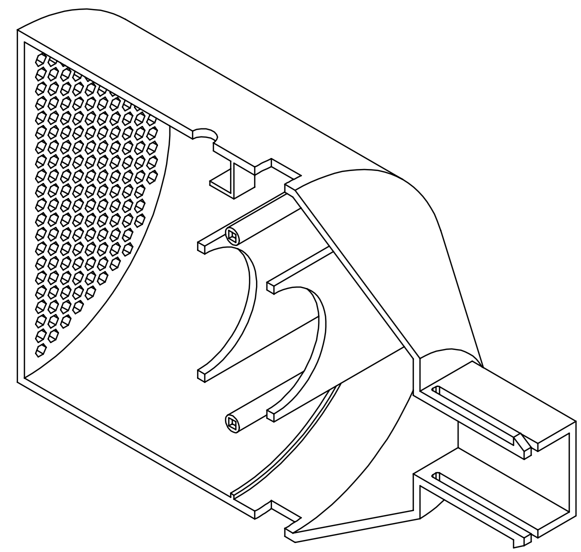
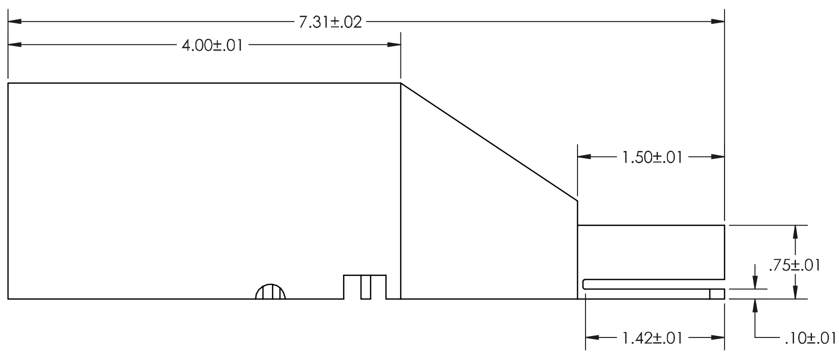
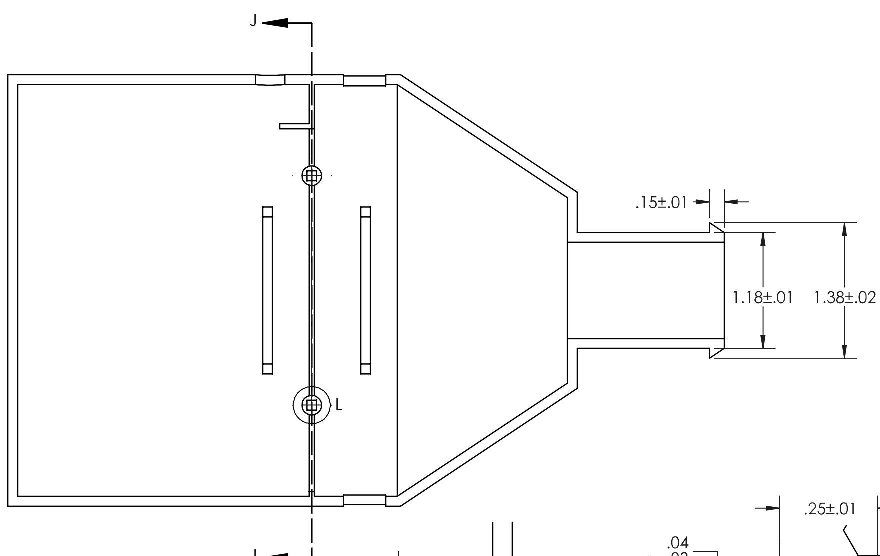
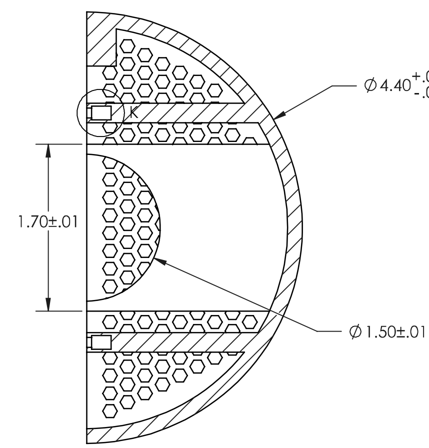
REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	11/15/2024
B	CHANGED SUPPORTS TO INCLUDE SNAP FITS	11/20/2024

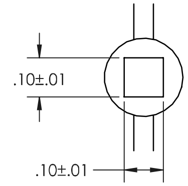








SECTION J-J



DETAIL L
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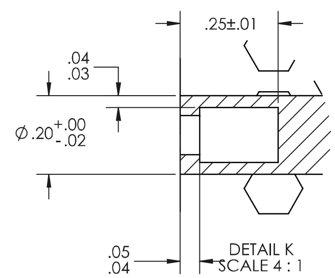
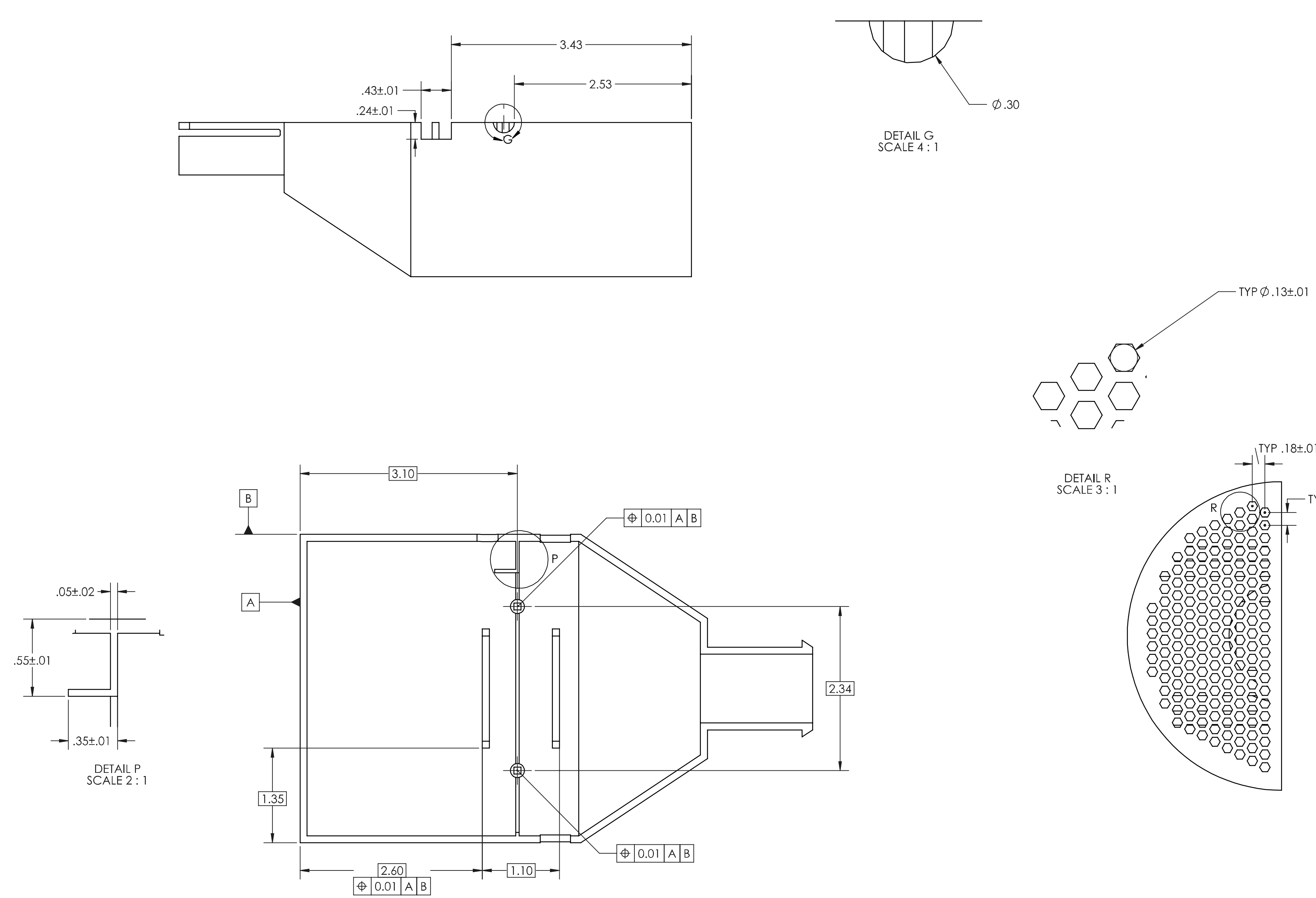


DETAIL K
SCALE 4 : 1

NOTES:
1. ALL WALL THICKNESSES ARE 0.10 INCHES UNLESS SPECIFIED
2. FEATURES ON DETAIL K ARE SYMMETRIC ACROSS THE MIDPLANE OF THE PART

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 POLYPROPYLENE	DESCRIPTION BLOWER HOUSING	
FINISH MATTE	PN W03-A	REV B; SHEET 1 of 2



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 POLYPROPYLENE		DESCRIPTION BLOWER HOUSING	
FINISH MATTE		PN W03-A	REV B · SHEET 2 of 2

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REV.	DESCRIPTION	DATE
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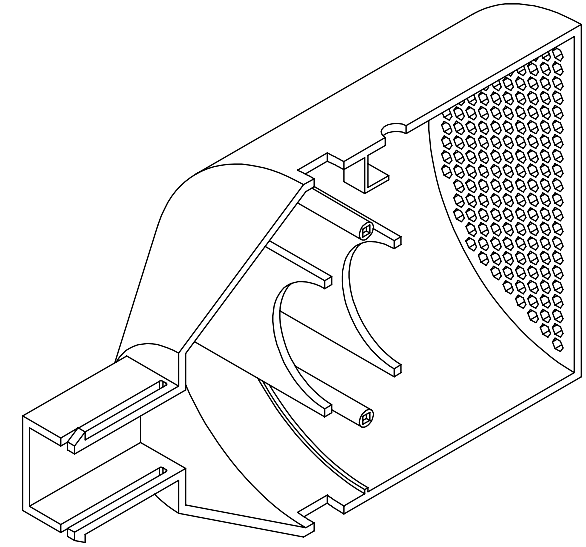
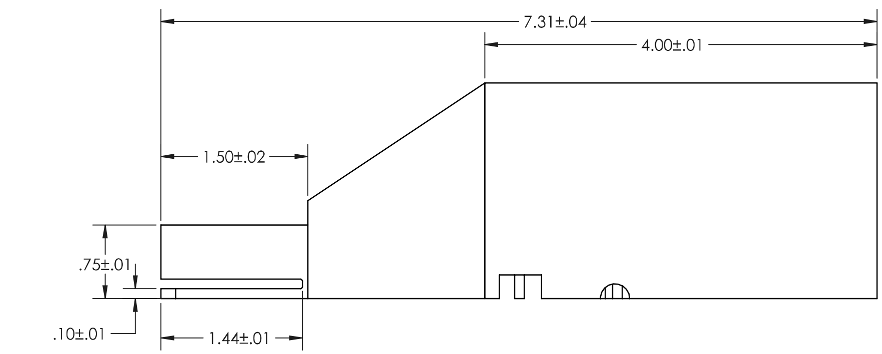
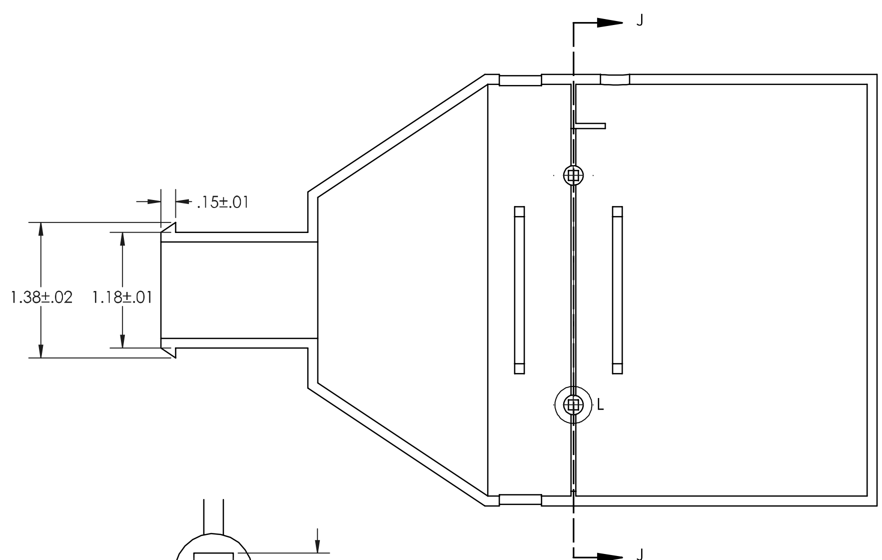
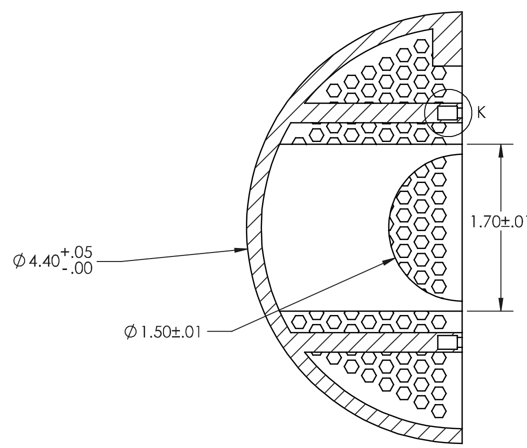
B	MIRRORED PART	11/16/2024
C	CHANGED SUPPORTS TO INCLUDE SNAP FITS	11/20/2024









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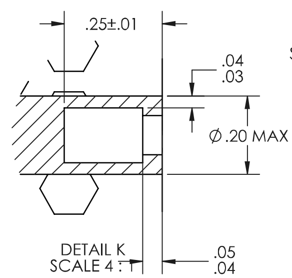
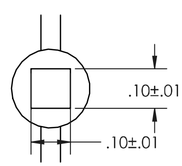


DETAIL K
SCALE 4 : 1

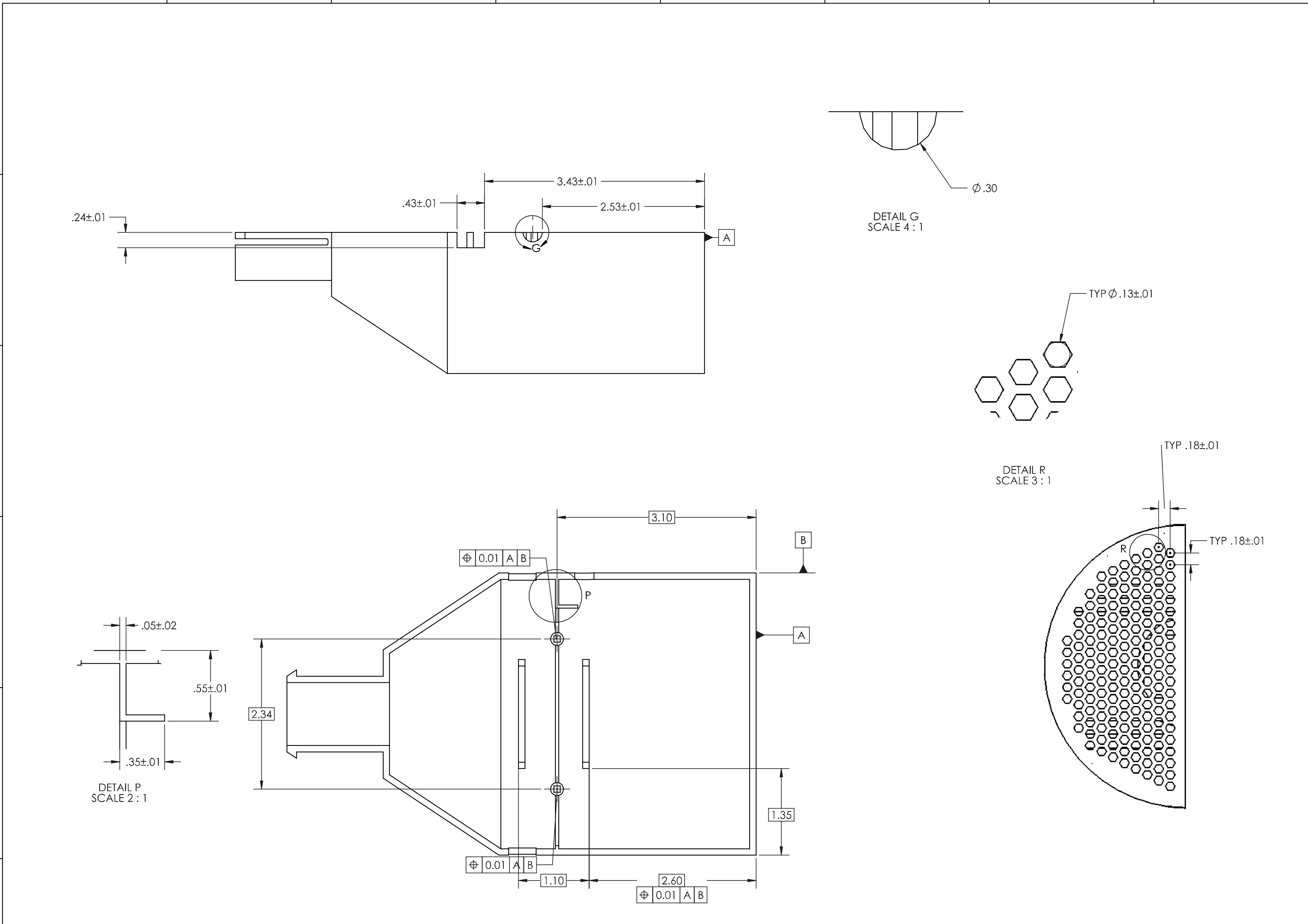


DETAIL L
SCALE 4 : 1

NOTES:

1. ALL WALL THICKNESSES ARE 0.10 INCHES UNLESS SPECIFIED
2. FEATURES ON DETAIL K ARE SYMMETRIC ACROSS THE MIDPLANE OF THE PART

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: POLYPROPYLENE		DESCRIPTION: BLOWER HOUSING
FINISH: MATTE		PN: W03-B; REV: C; SHEET: 1 of 2



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 POLYPROPYLENE		DESCRIPTION BLOWER HOUSING
FINISH MATTE		PN W03-B · REV C · SHEET 2 of 2

REV.	DESCRIPTION	DATE
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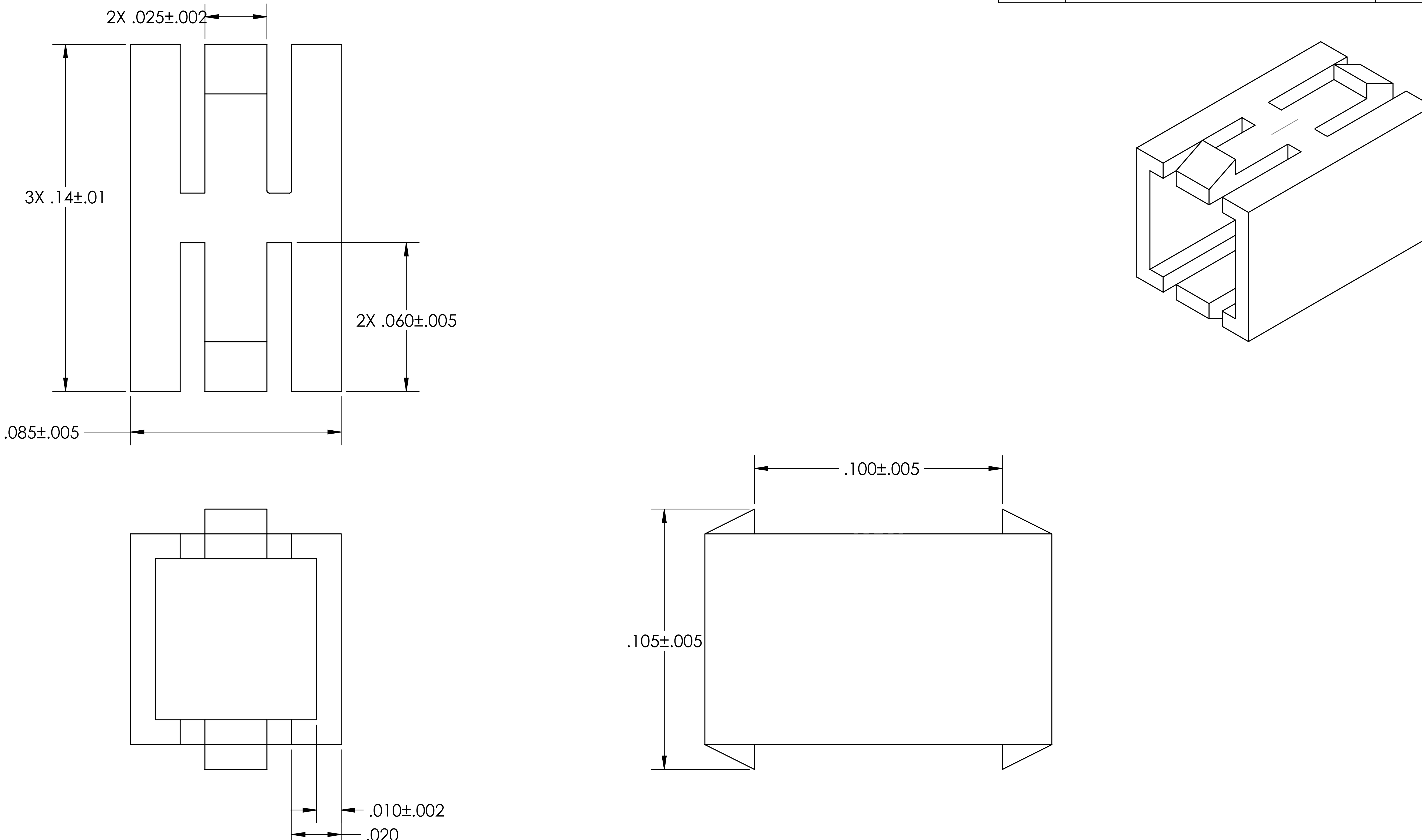

Inches

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 POLYPROPYLENE		DESCRIPTION BLOWER CLIP
FINISH MATTE	PN W04	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
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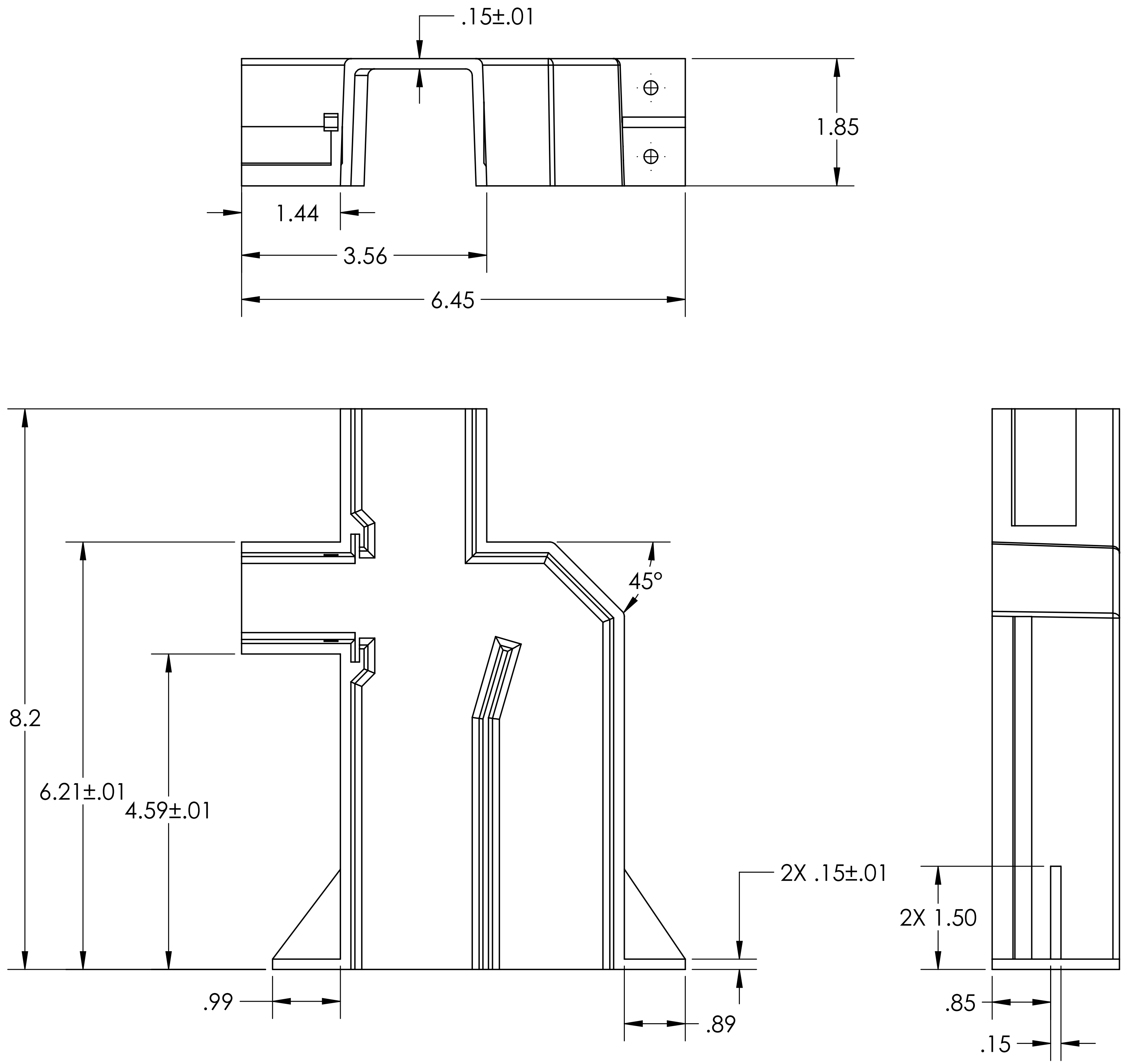

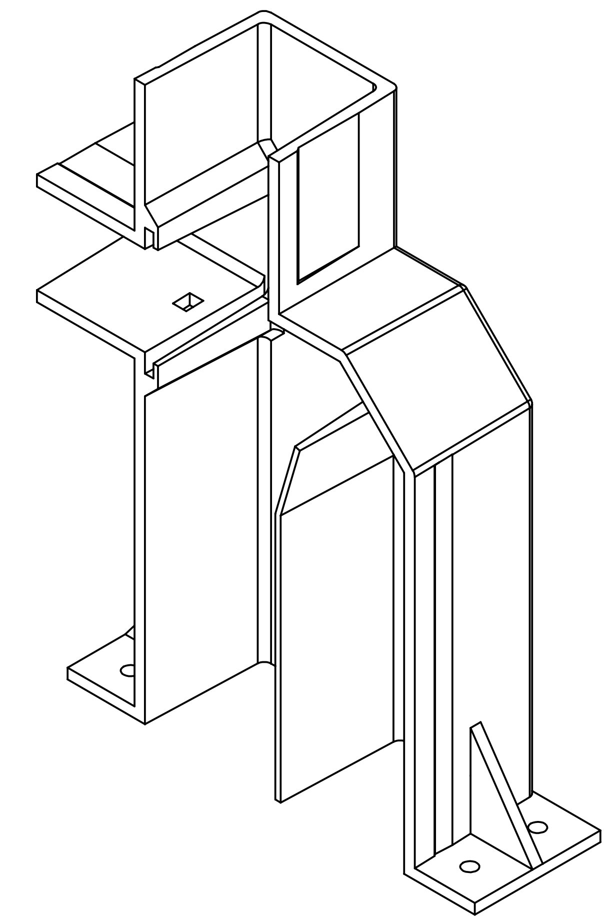

NOTE: EDGE RADIUS IS 0.10 INCHES UNLESS OTHERWISE SPECIFIED

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 POLYETHYLENE		DESCRIPTION SEPARATOR COLUMN
FINISH MATTE		PN W05 · REV A · SHEET 1 of 4

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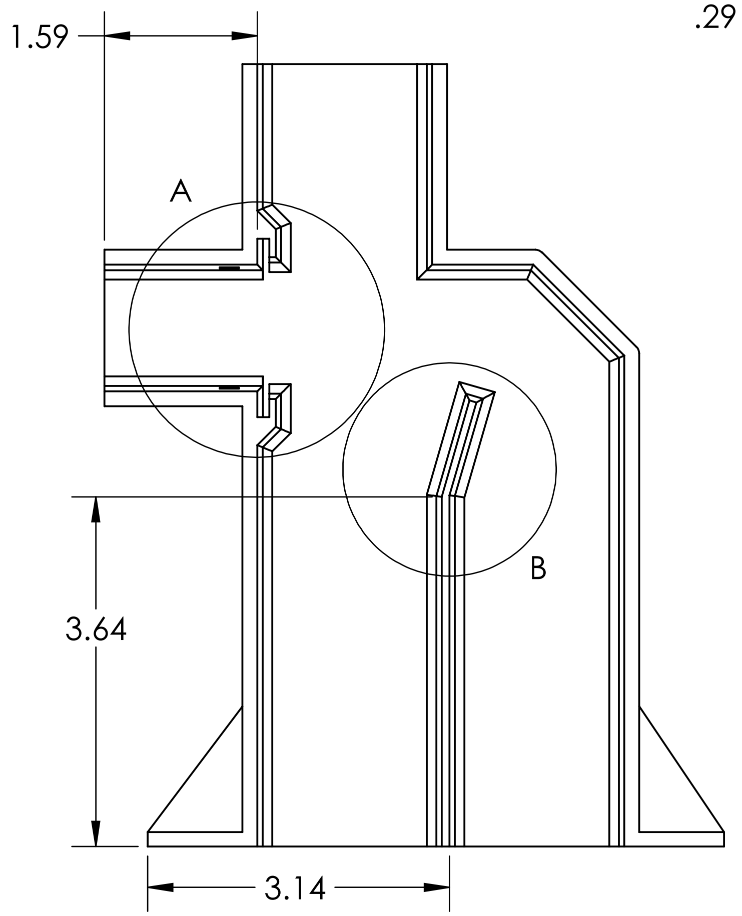
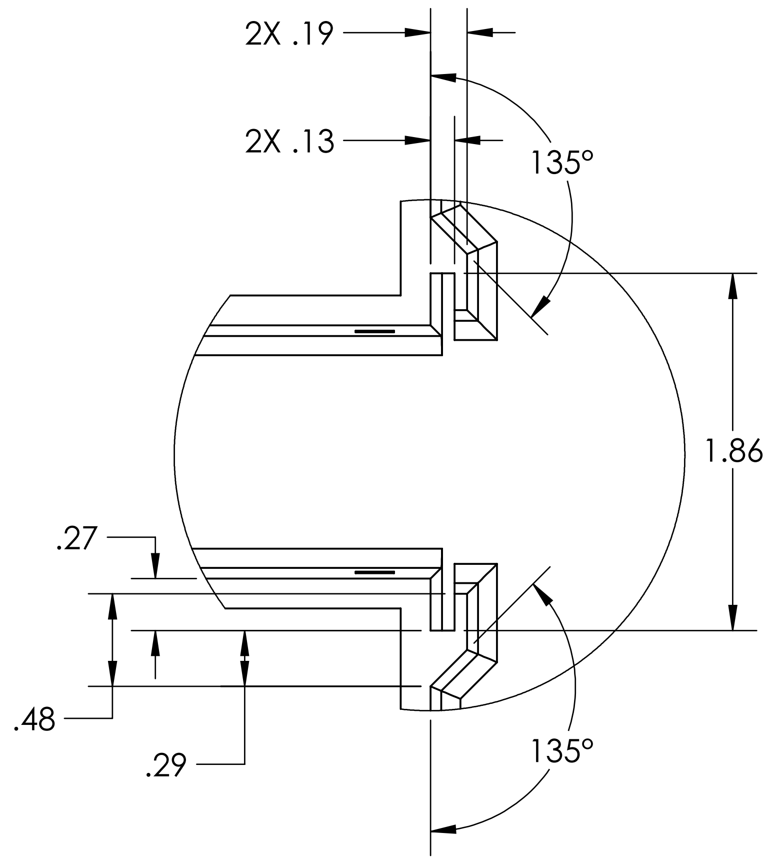
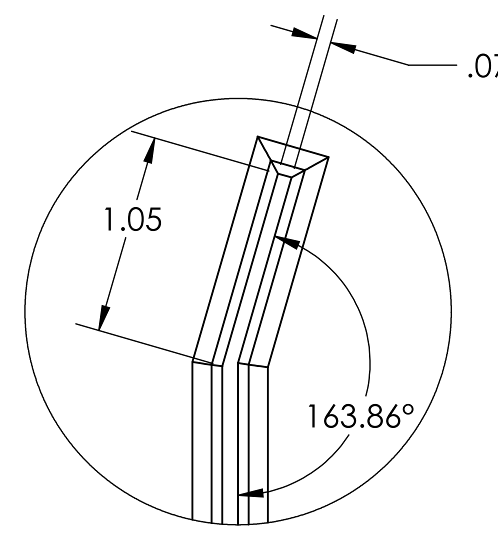
NOTE: DIMENSIONS FOR SCREEN HOLDERS SHOWN IN DETAIL A ARE TYP FOR BOTH HOLDERS





DETAIL A
SCALE 1 : 1



DETAIL B
SCALE 1 : 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 POLYETHYLENE	DESCRIPTION SEPARATOR COLUMN	
FINISH MATTE	PN W05 · REV A	SHEET 2 of 4

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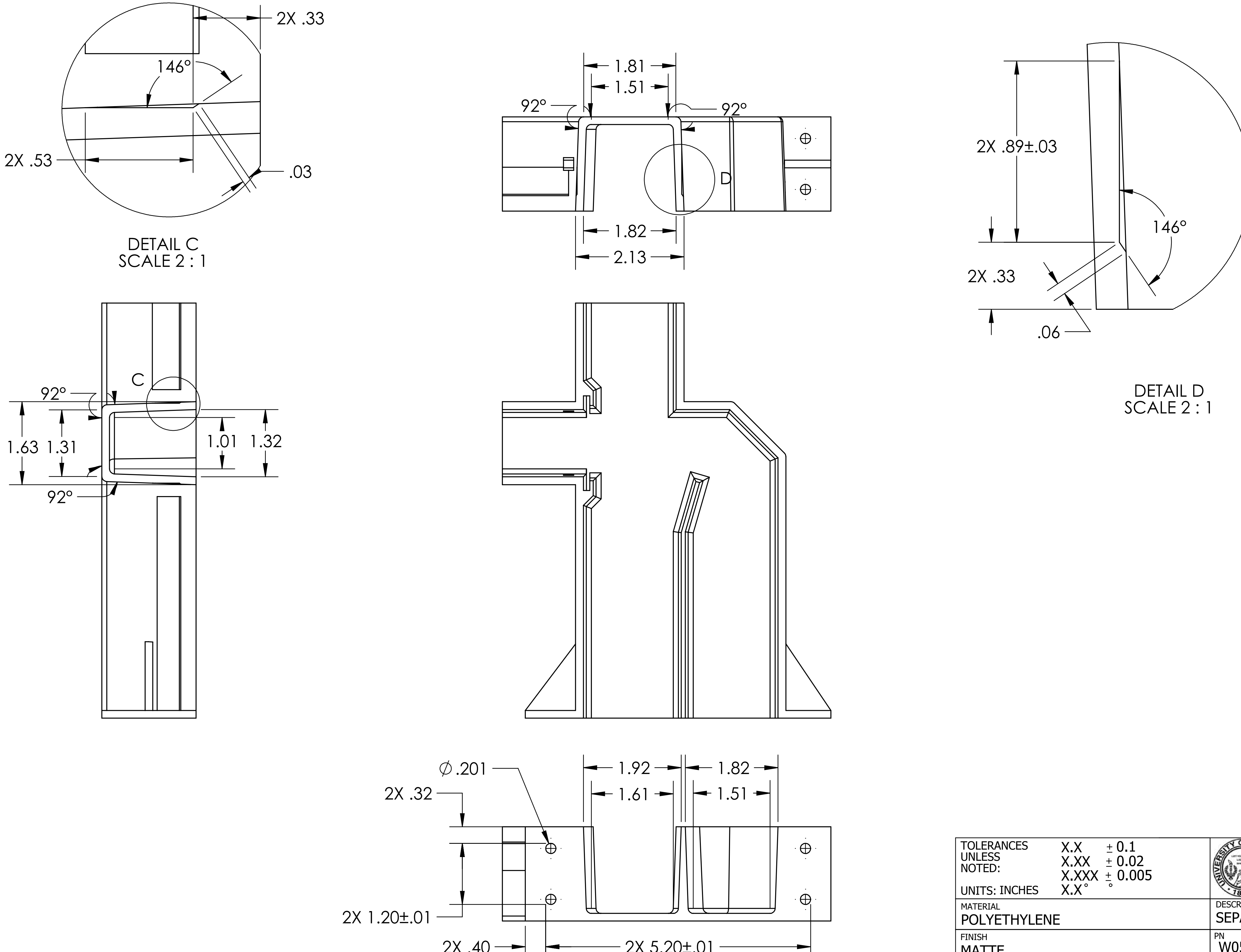

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± °	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427	
MATERIAL POLYETHYLENE		DESCRIPTION SEPARATOR COLUMN	
FINISH MATTE		PN W05	REV A
		SHEET 3 of 4	

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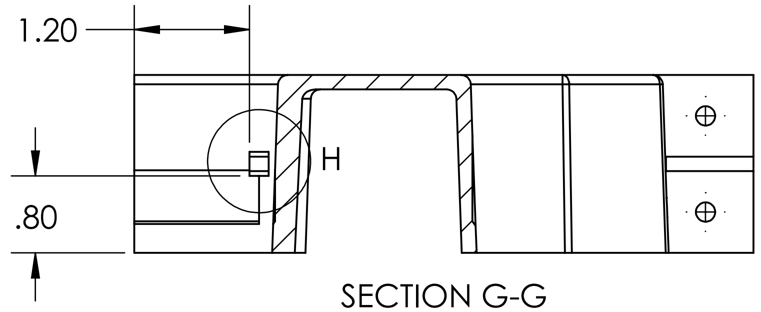

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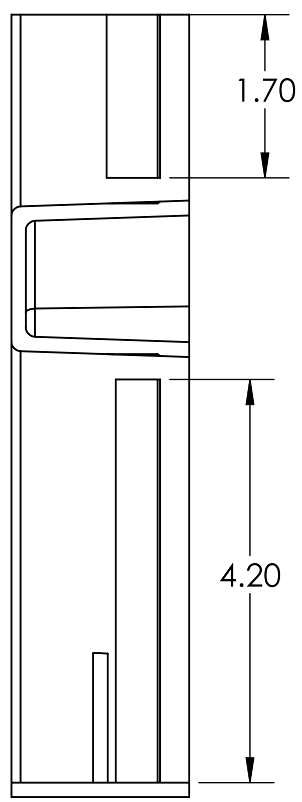

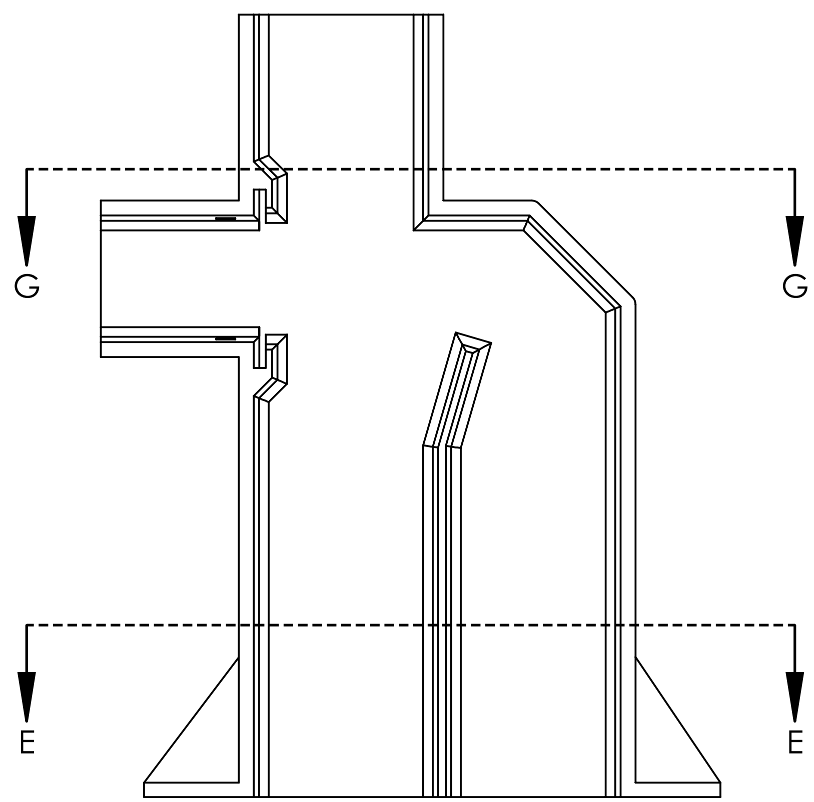

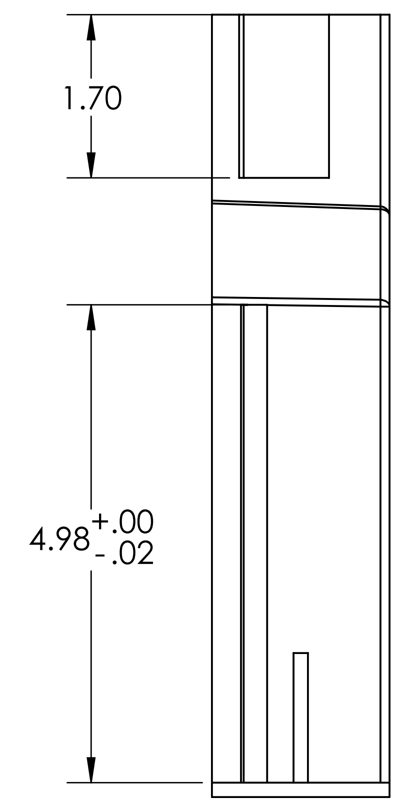

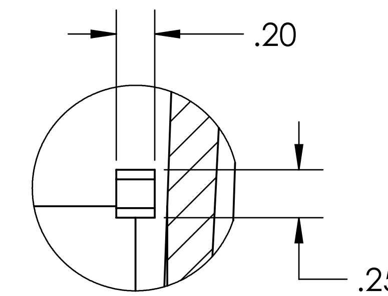

DETAIL H
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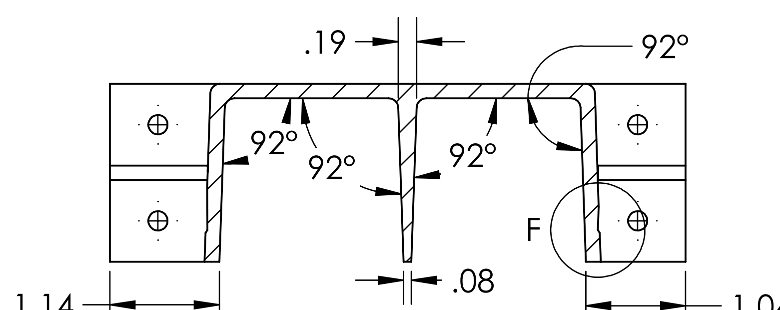

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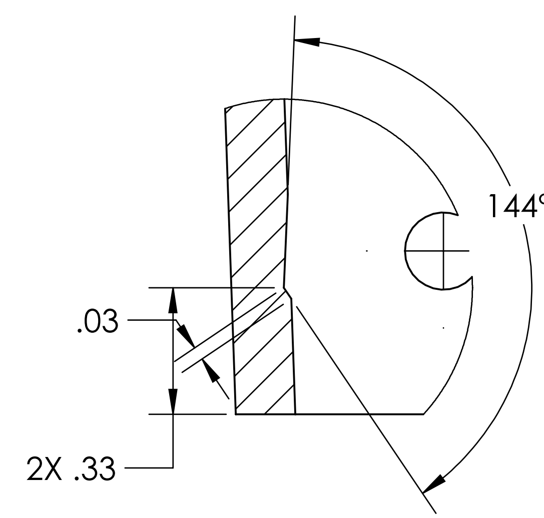
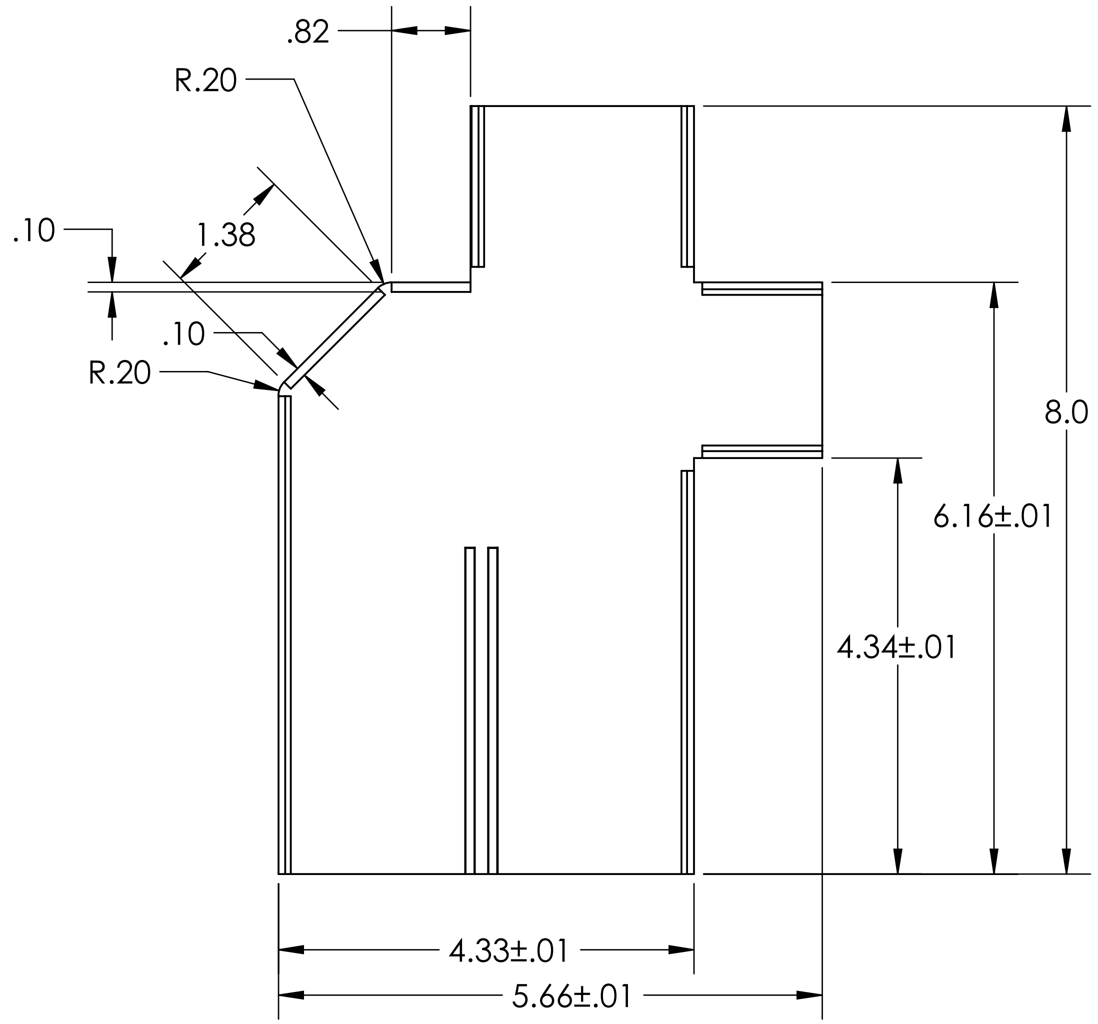


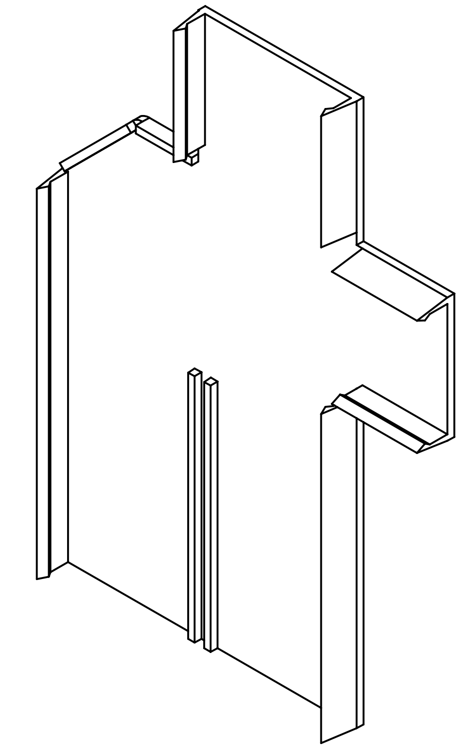
DETAIL F
SCALE 2 : 1

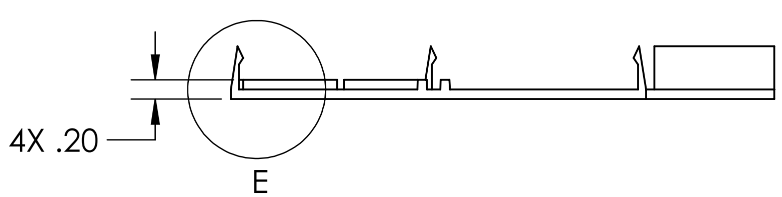
NOTE: DIMENSIONS FOR SNAP FIT GROOVE SHOWN IN DETAIL F ARE TYP FOR BOTH SIDES OF COLUMN

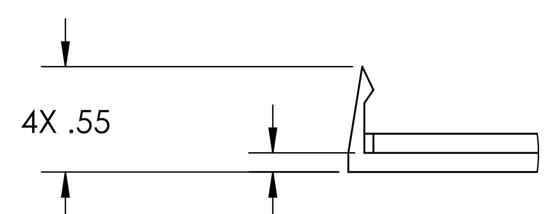
TOLERANCES UNLESS NOTED: X.X ±0.1, X.XX ±0.02, X.XXX ±0.005, X.X° ±° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427	
MATERIAL POLYETHYLENE		DESCRIPTION SEPARATOR COLUMN	
FINISH MATTE	PN W05	REV A	SHEET 4 of 4

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	11/17/2024



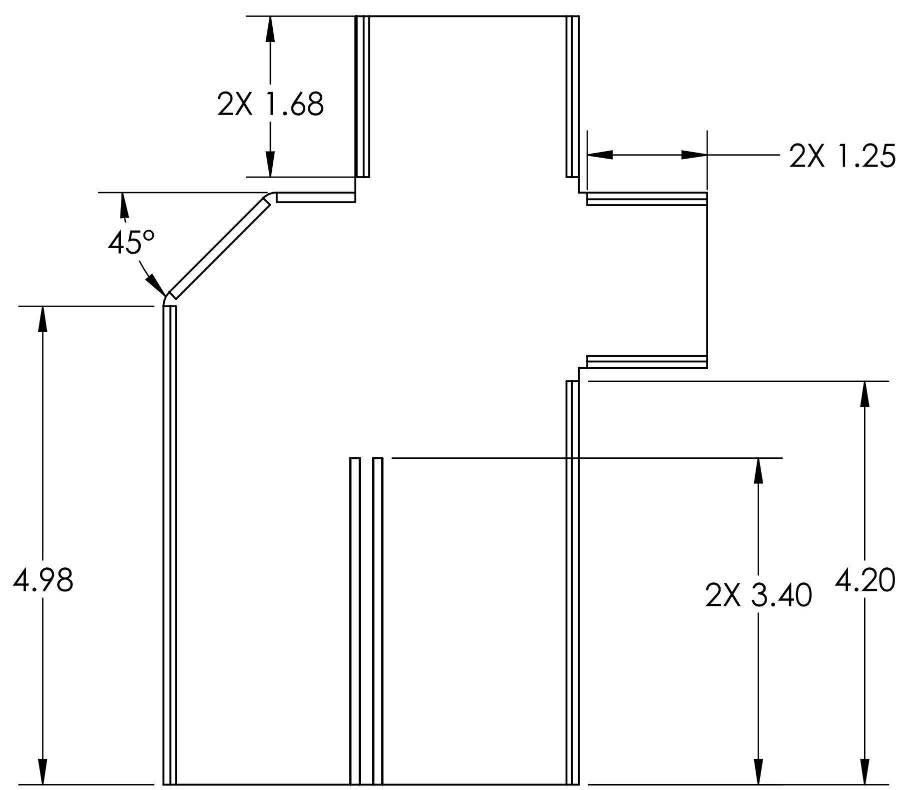


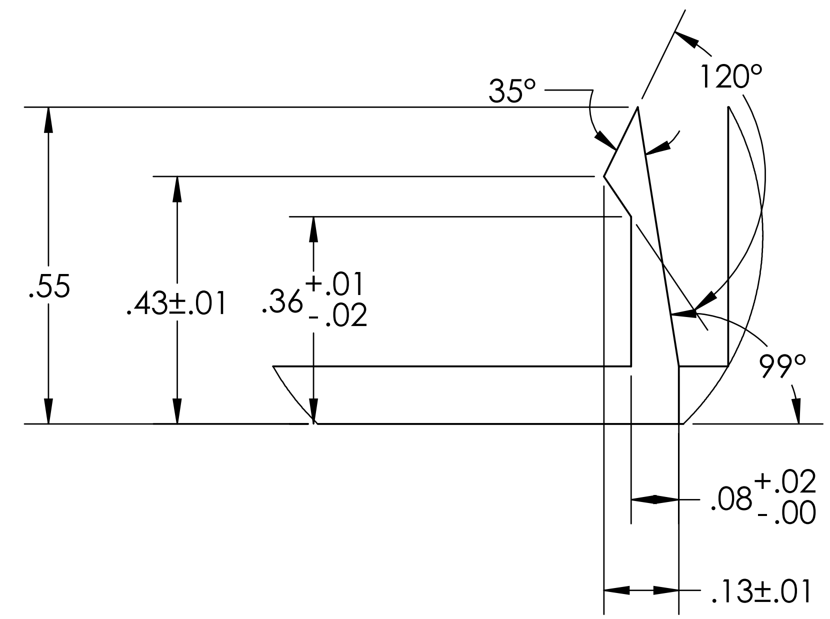




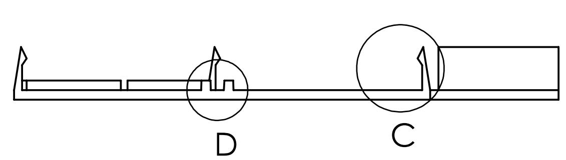
DETAIL E
SCALE 1 : 1

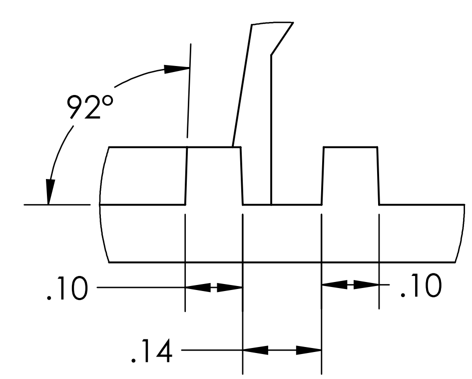
TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.02; X.XXX ± 0.005; X.X° ± ° UNITS: INCHES		UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427
MATERIAL POLYETHYLENE		DESCRIPTION SEPARATOR COLUMN COVER
FINISH MATTE		PN W06 · REV A · SHEET 1 of 2





DETAIL C
SCALE 3 : 1



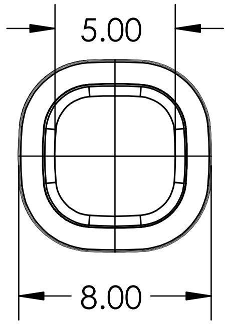


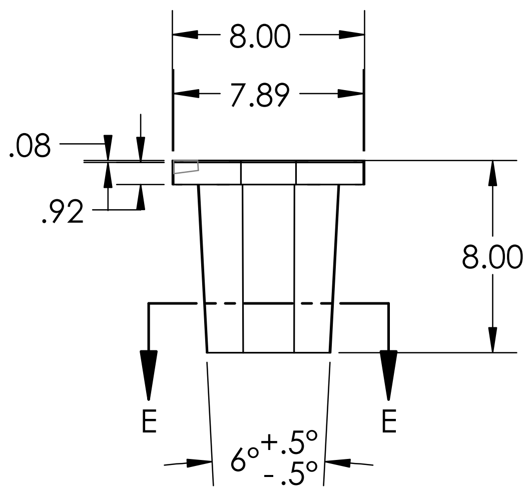
DETAIL D
SCALE 3 : 1

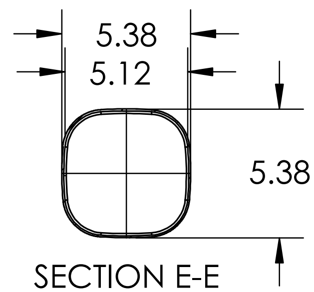
NOTE: DIMENSIONS ON SNAP FIT SHOWN IN DETAIL C ARE TYPICAL FOR ALL SNAP FITS.

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 POLYETHYLENE		DESCRIPTION SEPARATOR COLUMN COVER
FINISH MATTE	PN W06	REV A; SHEET 2 of 2

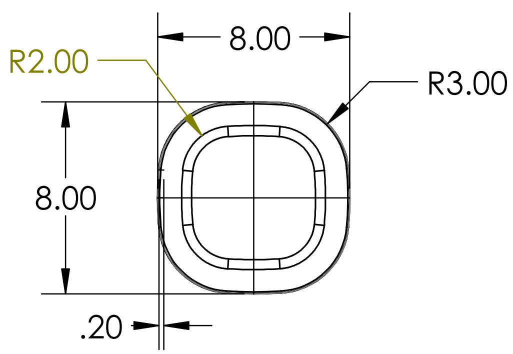
REV.	DESCRIPTION	DATE
A	INIITAL DRAWING	11/17/2024

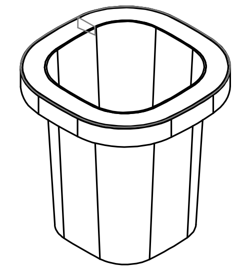






SECTION E-E

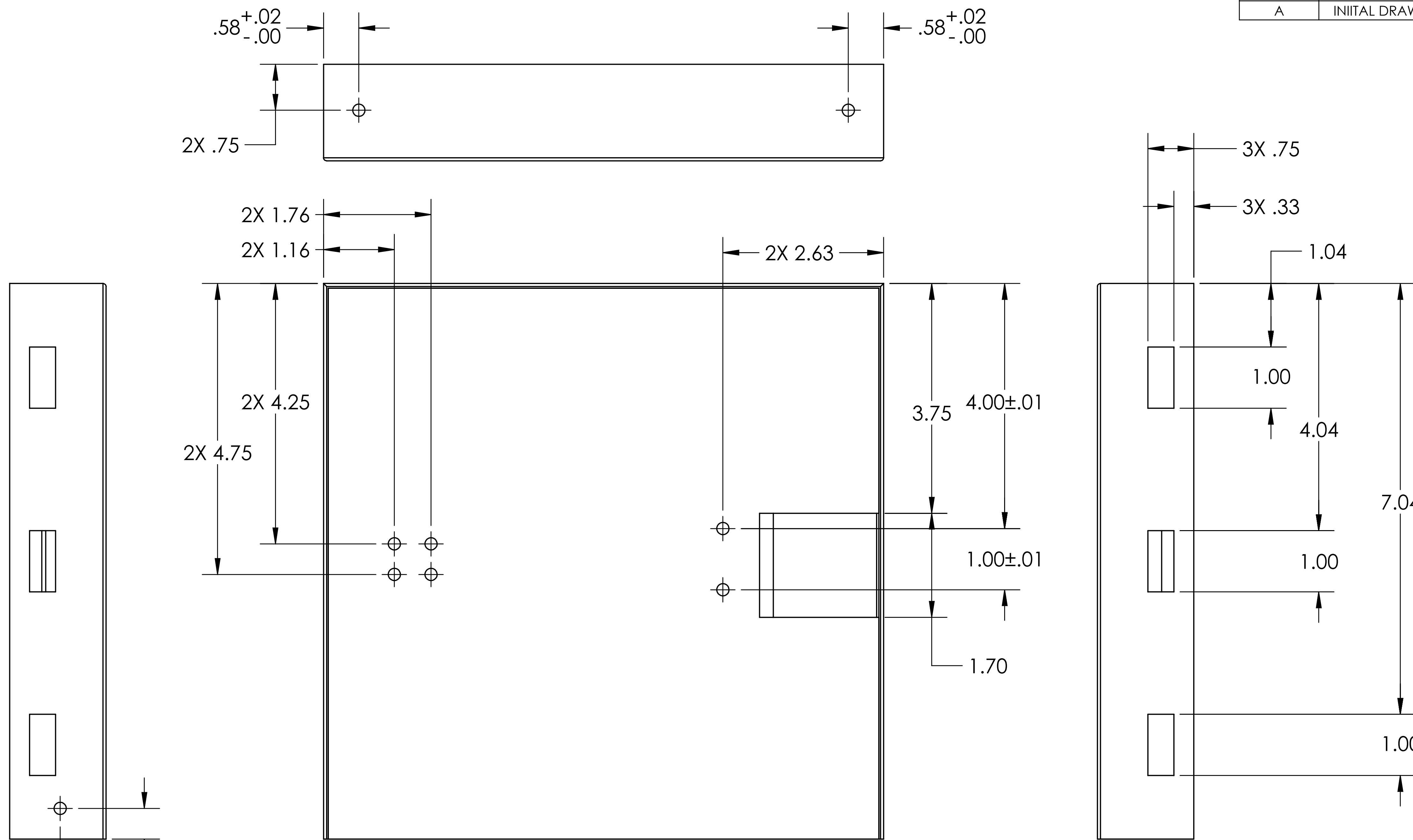


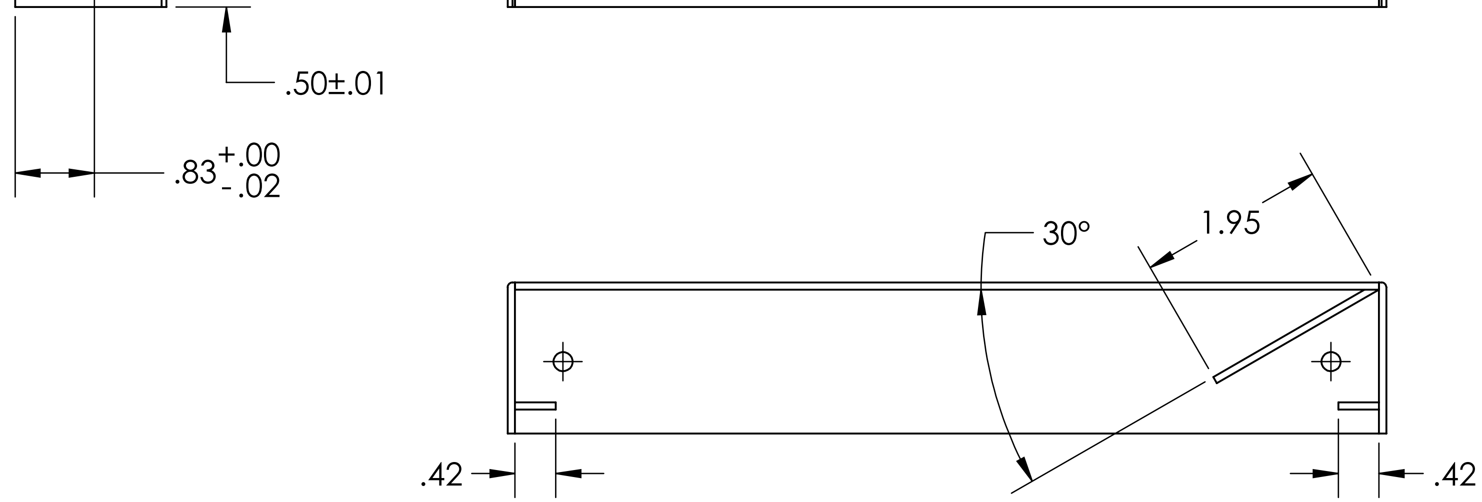


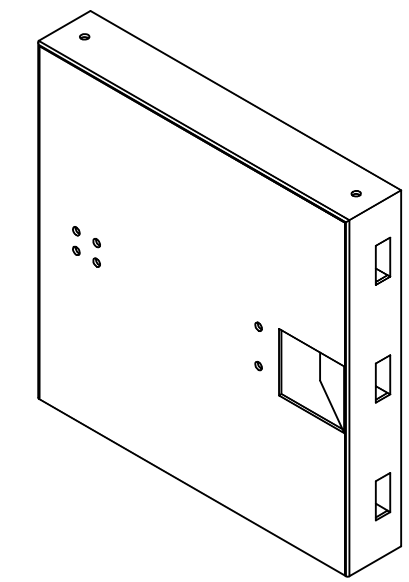
Notes:
- The thickness of all walls is 0.08 inches unless specified.

TOLERANCES UNLESS NOTED: X.X ± 0.1; X.XX ± 0.01; X.XXX ± 0.005; X.X° ° 0.5; UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO, 80309-0427	
MATERIAL POLYPROPYLENE	DESCRIPTION COLLECTION BIN	
FINISH N/A	PN W07 / REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INIITAL DRAWING	11/19/2024





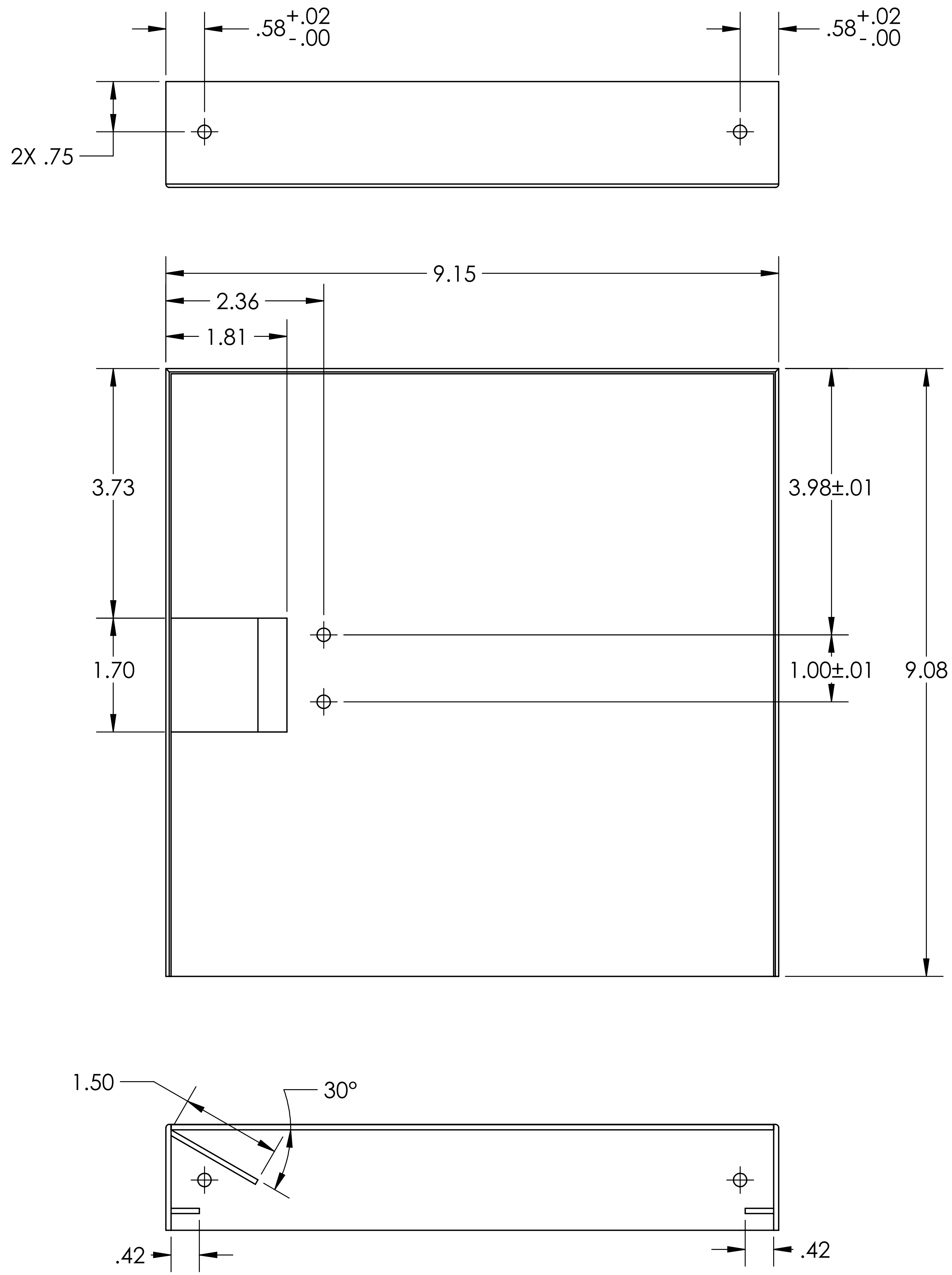


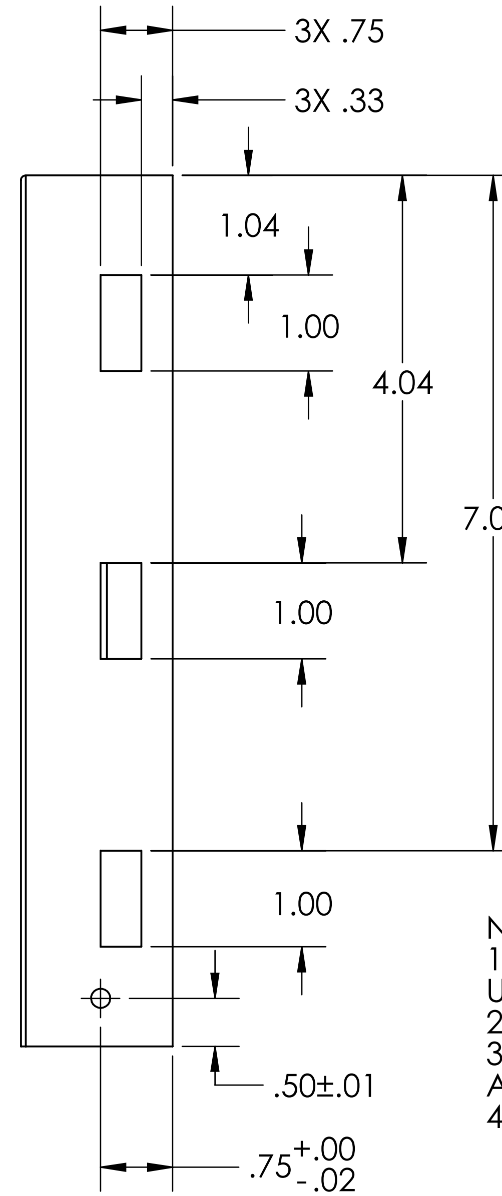
SCALE: 1:4

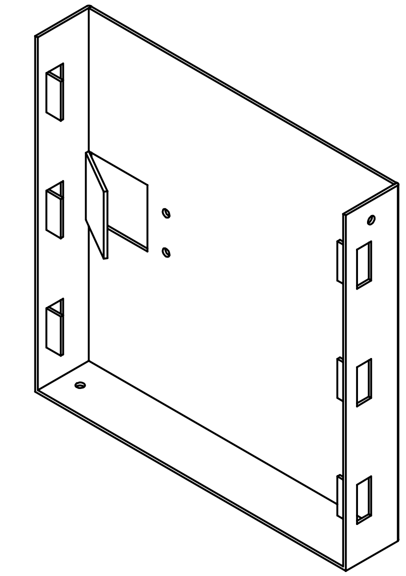
NOTES:
1. ALL CIRCULAR HOLE DIAMETERS ARE Ø 0.20 INCHES UNLESS OTHERWISE SPECIFIED
2. STEEL THICKNESS IS 0.08 INCHES
3. DIMENSIONS FOR THREE RECTANGULAR HOLES ON RIGHT AND LEFT SIDES OF BASE ARE SYMMETRIC
4. BEND RADIUS IS NOT CRITICAL, BUT MUST BE LESS THAN 0.25

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 301 STAINLESS STEEL	DESCRIPTION LEFT TOP OF BASE
FINISH MATTE	PN W11 / REV A / SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	11/19/2024







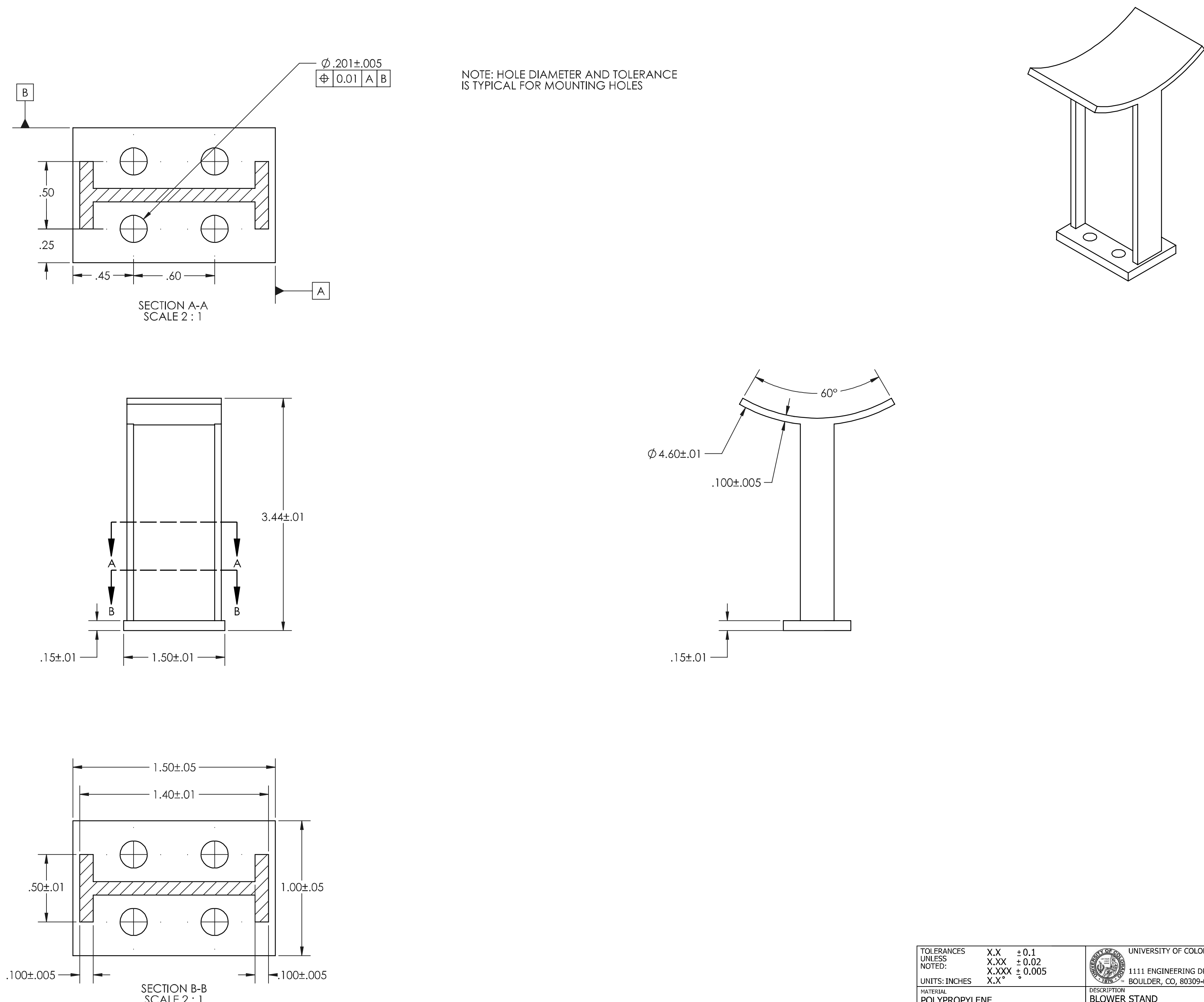
SCALE: 1:4

NOTES:
1. ALL CIRCULAR HOLE DIAMETERS ARE Ø 0.20 INCHES UNLESS OTHERWISE SPECIFIED
2. STEEL THICKNESS IS 0.08 INCHES
3. DIMENSIONS FOR THREE RECTANGULAR HOLES ON RIGHT AND LEFT SIDES OF BASE ARE SYMMETRIC
4. BEND RADIUS IS NOT CRITICAL, BUT MUST BE LESS THAN 0.25

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 301 STAINLESS STEEL	DESCRIPTION RIGHT TOP OF BASE	
FINISH MATTE	PN W12 · REV A	SHEET 1 of 1

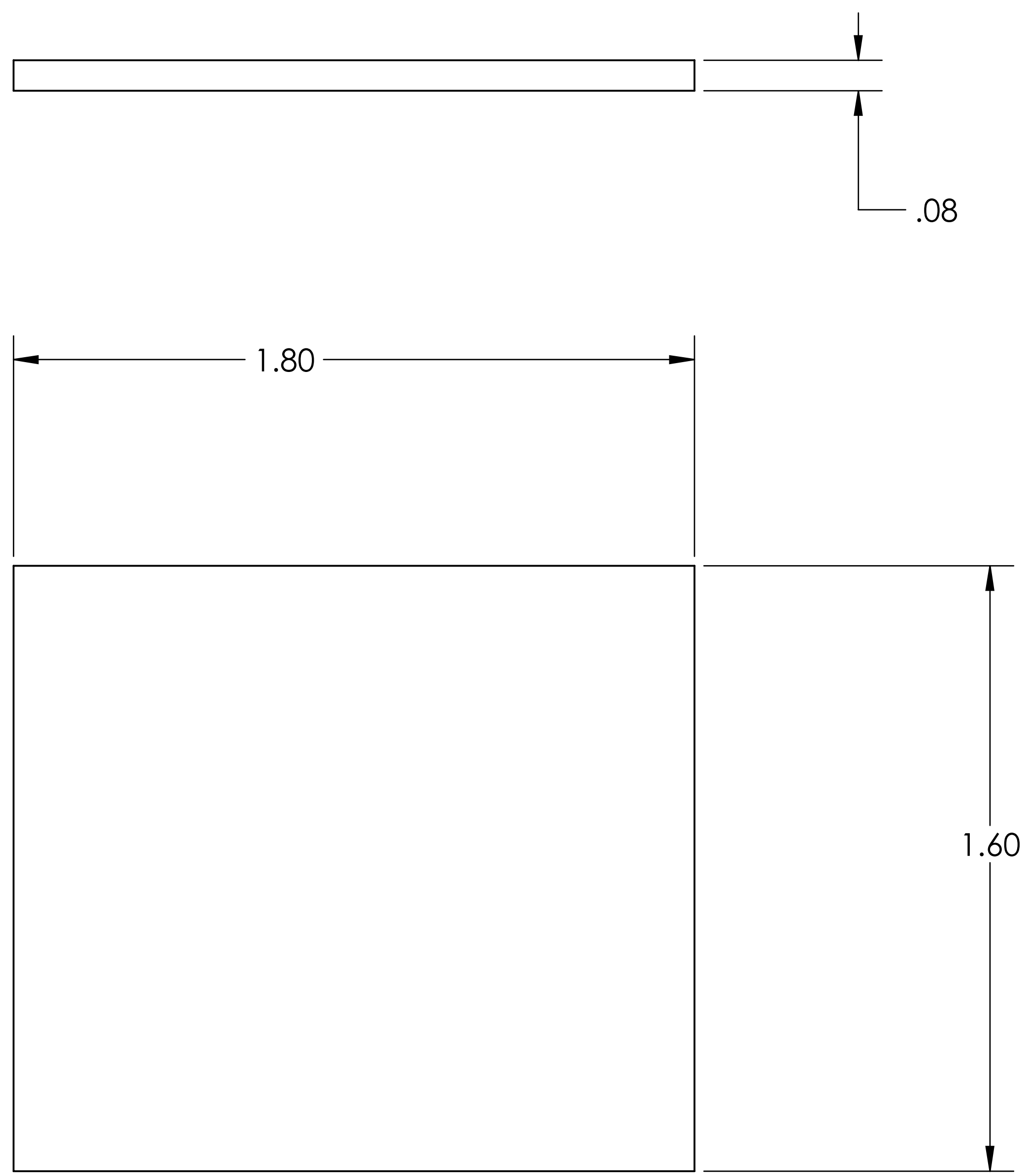
REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	11/16/2024

NOTE: HOLE DIAMETER AND TOLERANCE
IS TYPICAL FOR MOUNTING HOLES



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 POLYPROPYLENE		DESCRIPTION BLOWER STAND
FINISH MATTE		PN W16 · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	11/26/2024

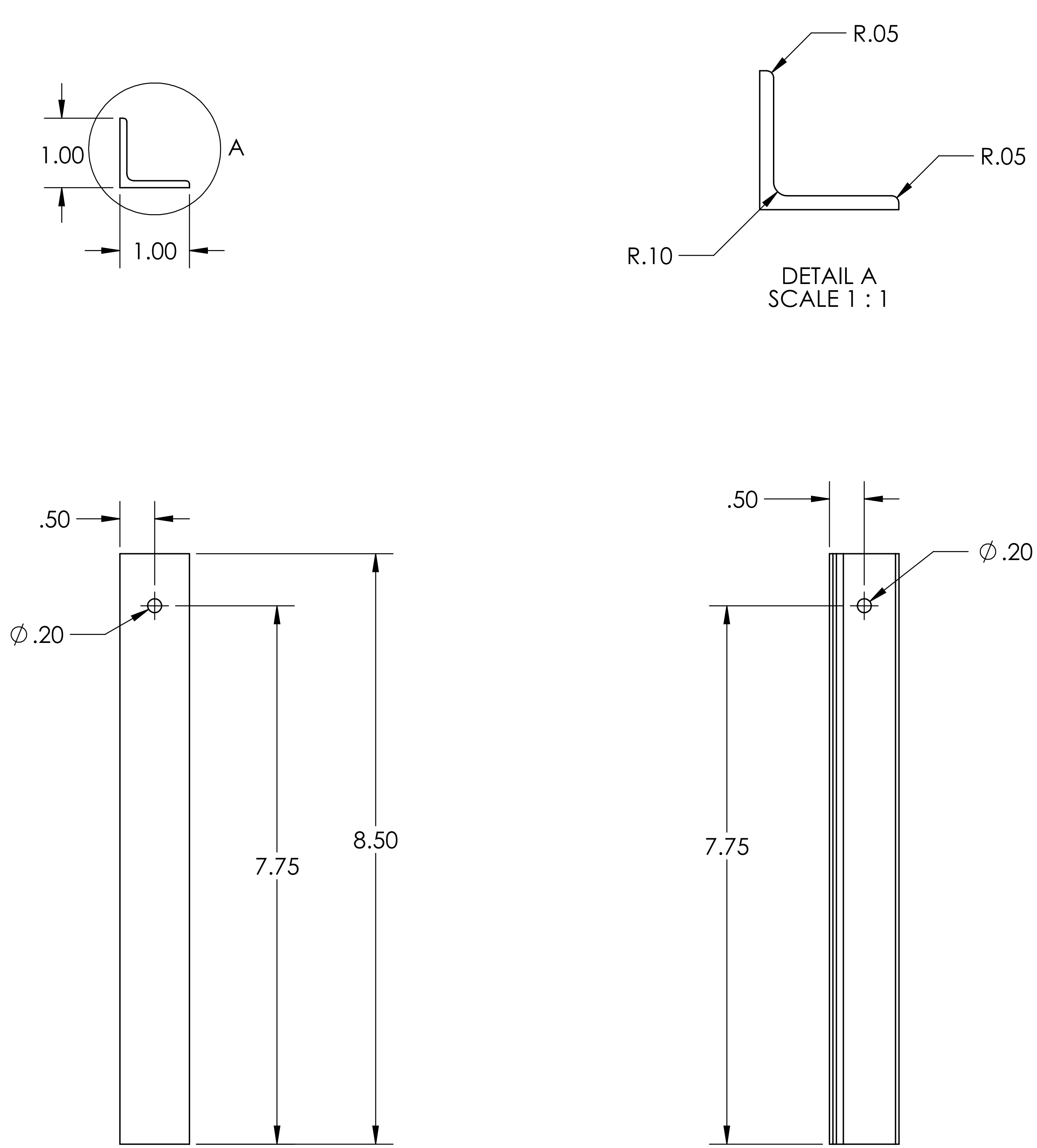


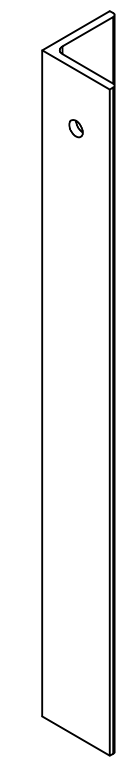
NOTE: SHEET IS CUT TO SPECIFIED SIZE FROM STAINLESS STEEL MESH SHEET.

MCMASTER-CARR 85385T21
- MESH OF 0.08 INCH STAINLESS STEEL WIRE
- 0.253 INCH HOLES
- 58% OPEN AREA

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 304 STAINLESS STEEL	DESCRIPTION BLOWER SCREEN
FINISH AS STOCK	PN W18 — REV A — SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL DRAWING	12/1/2024





NOTES: LEGS ARE CUT FROM 6061 ALUMINUM EXTRUSION
MCMASTERCARR ID 8982K39

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 6061 ALUMINUM		DESCRIPTION BASE LEG	
FINISH MATTE	PN W20	REV A	SHEET 1 of 1