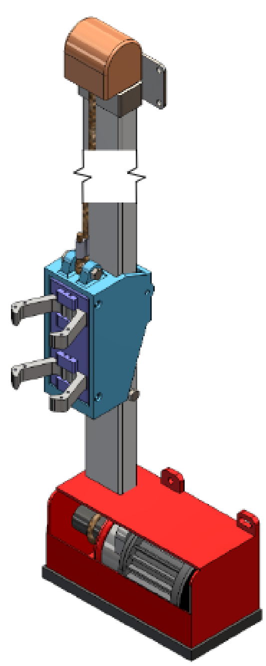
University of Colorado Boulder

Mechanical Engineering

Final Project Report

MCEN 5045 - Design for Manufacturability

Automated Vertical Bike Storage



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1. Executive Summary

Indoor bicycle storage consistently serves as a hindrance to the daily lives of many. Whether one's storage system is clunky, inconvenient or even non-existent, there needs to be a better way to store one's bike safely, efficiently, and in a space-optimized manner. Thus the creation of an automated vertical bike storage system would both meet this niche and provide users with the relief that they so earnestly seek.

Our team began this design in Advanced Product Design last semester and had a few existing prototypes on hand to iterate off of and build upon. At the beginning, there was a focus on better understanding the product, so black box and glass box diagrams were generated along with traditional project management tasks.

With that completed, an initial DFA was conducted and definite indicators of improvements were made known. As a team, we concentrated our efforts on overall part reduction, the incorporation of embedded features, minimizing secondary operations, and increased ease of assembly. In addition to the DFA, initial material and manufacturing process selections were made. For manufacturing processes, the focus was on limiting variations to be able to minimize vendors, bolstering relations, and thus enhancing overall product quality. Materials were selected based upon the few types of manufacturing processes that were being used, and these, too, were chosen based upon a criteria of consistency and minimal variation. An economic analysis was conducted to determine where excessive costs had been allocated and how to better cut down on cost.

A number of design changes were conducted to improve DFMA factors across the board. The primary design change involved a major part reduction of the lifting assembly where the assembly decreased from 33 parts to 9 total parts. In addition, the part was redesigned so as to be able to be injection molded, with a focus on incorporating specific locating features for the required springs and hardware. Another change involved the election to use a motor rather than a counterweight pulley system to achieve the desired lifting capability. The final design modification of note was to change the design of the Sleeve to allow it to be fabricated using sheet metal bending rather than machining.

DFA metrics clearly show large-scale improvements from the original design to the improved one. Some of the more notable metric improvements were a decrease in part count by 45%, a decrease in secondary operations by 20%, and a decrease in insertion metrics by 30%. In addition, the overall design cost decreased by 40%. The total system cost was $106.18 which resulted in a profit of $43.82 per unit. With an annual sales quantity of 50,000 units, the annual profit comes out to be $2,191,107.45. While not all metrics were met and economic improvements could be made, the overall design shows great promise and potential.

Overall, these design changes resulted in drastically improved DFA metrics, decreased cost and adhered more strictly to best DFM practices. These modifications have allowed the product to both function better and created a system that can be assembled more efficiently both in the manufacturing facility as well as by the user. The product is in a position where it could, with some additional tweaks, pose as a legitimate contender in the realm of indoor bicycle storage.

2. Design Problem and Objectives

The creation of a new product to fill a specific need in the marketplace can be difficult and typically revolves around a number of major factors, such as functionality, cost, and manufacturability, to determine if the product will be successfully launched. The intent of this project was to devise a novel product of our group's selection and iterate upon the design with a focus on ensuring the product was something that could readily be manufactured and assembled. Physical models and prototypes were not the aim of this project; rather, our team focused on modeling the system in CAD, creating associated drawings from which the components would be manufactured, and incorporating improvements to DFMA metrics throughout the design process. A fair bit of strength analysis was also conducted to ensure that the product could withstand the required loading conditions associated with its function and to determine the longevity of the product.

In the following sections (Sections 3 through 7) a full introduction of the product will be made as well as additional insight into many of the design intents of this automated vertical bike storage system.

3. Product Description

The product that our team elected to design was an automated vertical bike stand. This idea was engendered last semester in the Advanced Product Design course at CU. The motivation for this creation revolved around the need for a more space-conscious and efficient manner in which to store one's bike indoors. There are countless bike storage solutions available on the market, yet a few concerns always seem to remain prevalent. The prevailing issue touches upon a trade off between space optimization and ease of storage. It is true that a number of bike storage solutions generally available to the public are quite easy to use and efficient; for example, the standard outdoor bike rack located outside of parks and grocery stores. It truly is simple to wheel one's bike up to the rack, gently lift the front tire over the rack and settle it in place; however, this solution is far from space conscious. Most people, even those with large garages attached to their homes, can hardly afford to use that much space to store their bicycles.

In contrast, there are a myriad of space-efficient storage solutions available on the market. These usually take the form of being wall mounted. Whether vertical or horizontal in orientation, these solutions allow one to maximize the use of space in their homes while creating an area in which to store one's bike. The issue here is the difficulty of insertion and removal of one's bike, especially if the bike in question is an electric bicycle. The mass and form factor of a bicycle can make it extremely cumbersome to lift/handle, so it can be onerous to load and unload one's bike from these wall-mounted storage solutions.

Thus, the ideal solution to this problem would be to devise a product with a solution set that accounts for both of these issues – vertical bike storage with an automatic lifting mechanism.

Our automated vertical bike storage system consists of a six foot long piece of hollow tubing which mounts to the wall via a sleeve component and serves as a lifting guide. At the base of this tubing, a motor located within its respective housing, for safety and ease of use purposes, is connected to a pulley system via nylon rope. The rope spools and unspools directly from the motor, runs through the interior of the hollow tubing around a pulley and attaches to lifting componentry of the assembly. This sub assembly consists of a number of integrated components that allow for the bicycle to be gripped securely when pressure is applied to the front face while also simultaneously shifting into an unlocked position so as to allow the motor to lift the bike. Once the user engages the clamping mechanism, a spring-loaded roller on the bottom of the lifting mechanism applies just enough force to ensure that the bike rack is lifted out of the slot and able to move along the length of the guide tubing. At this point, the bicycle is fully engaged and self-stable, so the user can then press the button on the motor, which activates the motor and allows the bike to be lifted freely into the air along the length of the guide tubing until the unit reaches its maximum ascent where the motor shuts off and the combination of forces of the rope's tension and the bicycle's center of gravity securely constrain the bicycle in place.

In a similar fashion, the bicycle can be lowered back to the floor by reversing the direction of the motor, pressing the button, and gently guiding the rear tire outward from the system as the bicycle makes contact with the ground. Once the lifting component is lowered to the appropriate position, the bike tire is then released automatically and can be removed from the bike storage.

This automated vertical bike storage solution will be commercially available for purchase in bike shops, large retailers, as well as online suppliers such as Amazon. The price point for this bike storage solution is set at $150 per unit. It is designed to be sold in a kit that includes the required mounting hardware, such as screws and drywall anchors. The kit will be mostly assembled, but the customer will need to assemble a couple of components, such as sliding the rectangular tubing (P/N 001) into the Sleeve (P/N 016), to ensure that the system works properly within the user's space. For more information on the individual components of this system, please refer to Appendix A at the end of this report.

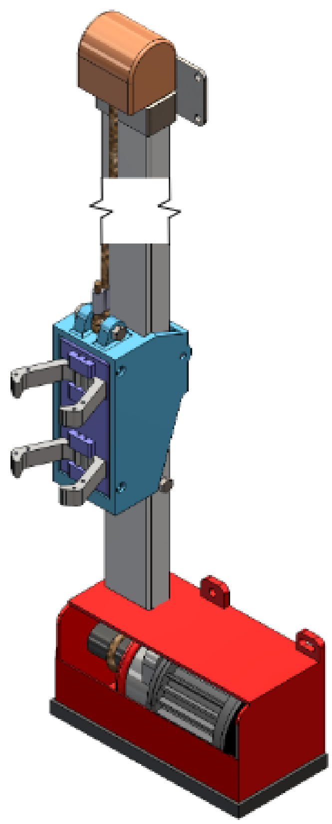


Figure 1 - Automated Vertical Bike Storage System

4. Patent Search

An integral part of designing a new product is to conduct a patent search to ensure that no existing patents have already been approved for the same or similar product. Using a few different websites/databases, a thorough search was conducted to validate this concern. A few patents do indeed exist for vertical bike storage solutions and there were similar ideas that were patented for the automated lifting component of this design; however, there were no patents that took both of these key concepts into consideration. Thus, it is safe to assume that our idea is a novel one and worth pursuing for the intent of this project.

5. Gantt Chart

Time management is a key factor in all successful projects, regardless of academic or professional context. To better account for all of the time constraints associated with the design of our automated vertical bike storage system, we created a Gantt chart to clearly assign tasks and deadlines to each of the team members. Unlike the reverse engineering project where assignment deadlines were a large factor in determining the ultimate project time table, this project's timeline was at our sole discretion.

The overall time frame of this project began in March with a quick turnaround of April 25th when reports were due. Due to the lack of course-directed deadlines for each of the components of this project, the critical path of this Gantt chart is not incredibly long. The fact that this product idea stemmed from APD also afforded our team a little more flexibility of schedule then other teams due to the fact that our idea had already been generated.

Some of the most critical and time consuming components of the project's design revolved around design changes associated with material and process selection. While we attempted to anticipate what the ideal manufacturing process would be and which materials would be associated with those, it took quite a bit of time to react to and make the associated design changes required to ensure part manufacturability. See Figure 2 below for additional details:

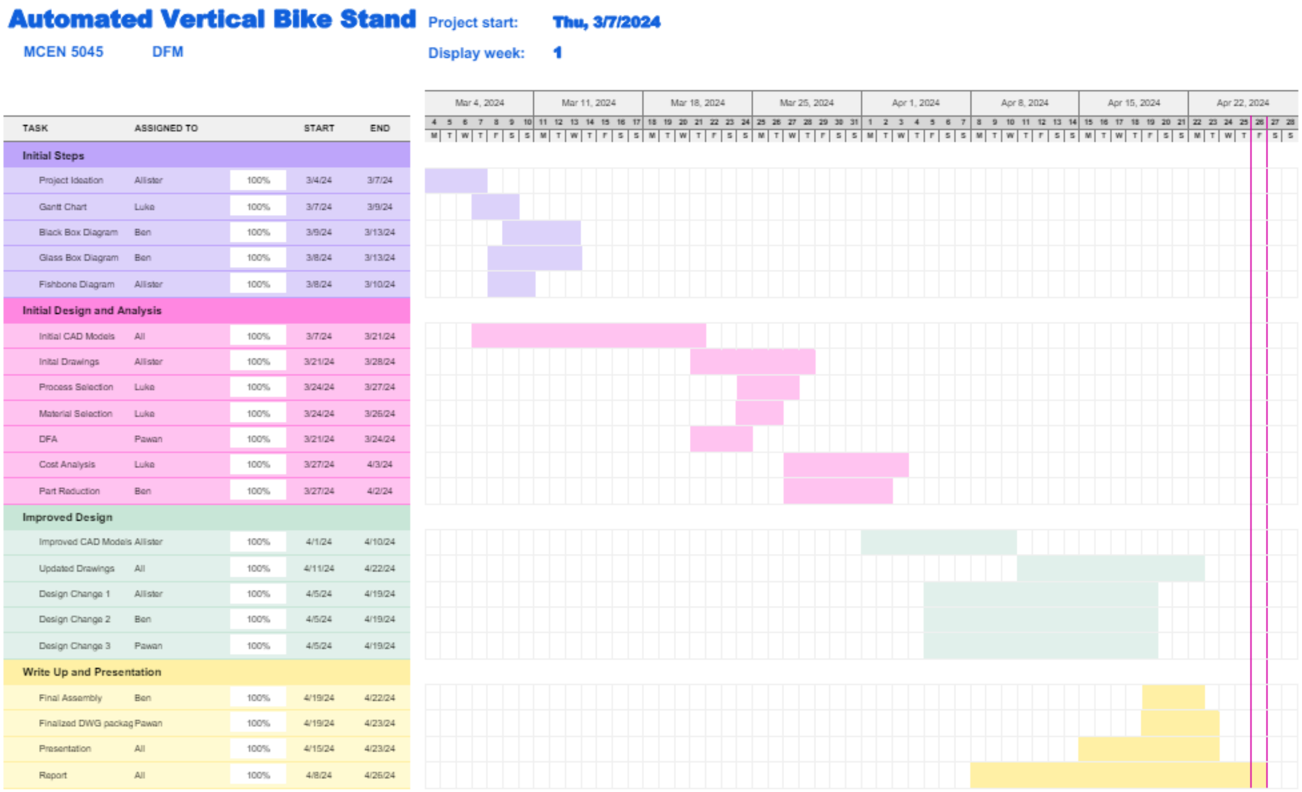


Figure 2 - Gantt Chart

6. Black Box Diagram

The Black Box diagram is a simple, visual representation of the inputs and outputs of the system. It clearly shows, to the viewer, what forms of input correlate with which types of output. For the automated vertical bike stand that we designed, the black box conveys that when the bicycle is pushed into the lifting componentry of the system, the locking mechanism engages, and the bike becomes secured or attached to the bike stand. In addition, a combination of electrical power from a standard outlet and the activation of the motor will allow the bike to be both lifted into the air and lowered to the ground. Reference Figure 3 below for more information.

Figure 3 - Black Box Diagram

7. Glass Box Diagram

The Glass Box diagram serves to expand upon the concepts described in the Black Box Diagram by clarifying how the inputs reach their output state. For example, the Glass Box diagram clarifies that when the bike is engaged on the stand, springs actuate, which cause the tire to be clamped and be secured in place. Additional information can be found in Figure 4 below.

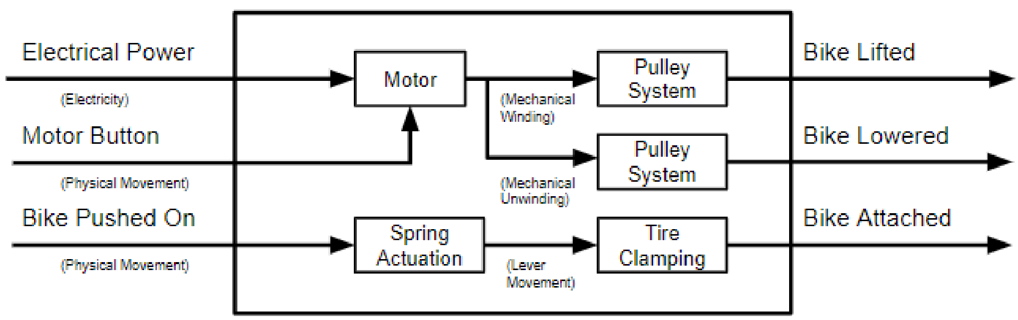


Figure 4 - Glass Box Diagram

8. Fishbone Diagram

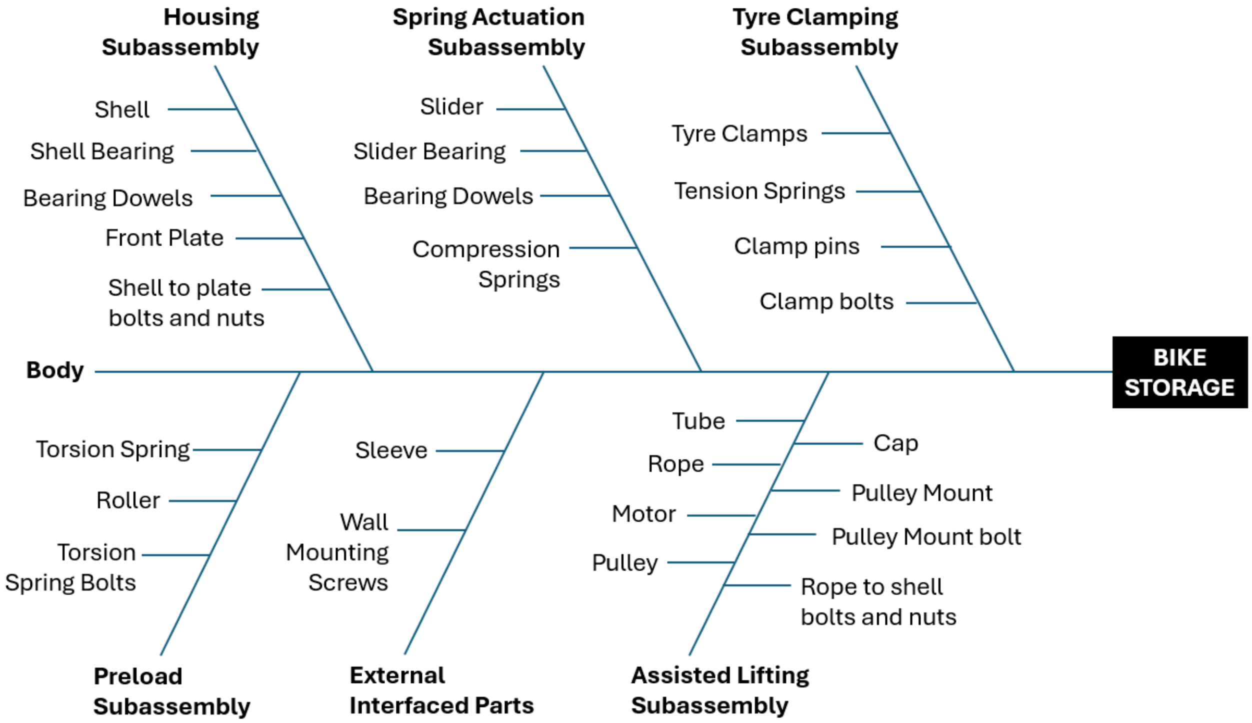


Figure 5 - Fishbone Diagram

The components of the automated bike stand can be divided into different subassemblies. A fishbone diagram, shown in Figure 5, helps to understand the relationship between these individual components and subassemblies. The head of the fishbone diagram represents the product name. The central spine represents the body, the ribs attached to the spine represent the subassemblies, and the horizontal lines branching out from the ribs represent each individual component part of the hair clipper. The detailed breakdown of the components and subassemblies is discussed in the following section.

9. Detailed Design Documentation

The Detailed Design section of the report will comprise the majority of the report and discuss factors such as Initial prototype, Design for Assembly, Design for Manufacturability, Design Changes, Material Selection, Economic Analysis, and Process Selection. Refer Table of Contents sections 9-21 for additional information. Let's first look at the design and working of the subassemblies and components referenced in the fishbone diagram.

9.1. Final Design: Subassemblies and Components

Shell Housing and Internal Components:

The main subassembly of the design consists of a Shell (P/N 002) which houses the spring actuation and tire clamping mechanisms. The components of the Spring Actuation sub assembly consists of a Slider (P/N 003) that is free to slide within the Shell. Both the Shell and the Slider have bearings (P/N 004) secured with dowels (P/N 005 and 006) which roll along the length of the Tube (P/N 001). The Slider is pushed against the Tube with the help of Compression Springs (P/N 007). The other end of the Compression Springs interface with the Front Plate (P/N 008). The Front Plate is bolted to the Shell with two bolts. To the Front plate is attached the clamping mechanism which consists of four Tire Clamps (P/N 004), Tension Springs (P/N 010) that keep the clamp in the open position, Clamp pins (P/N 011) to secure the Clamp to the Front plate and also provide a pivot point, and finally bolts to mount the springs to the clamp. The figure below shows the internal components of the Shell Housing and its interface with the Tube. Table 3 lists the individual components with part numbers and material used.

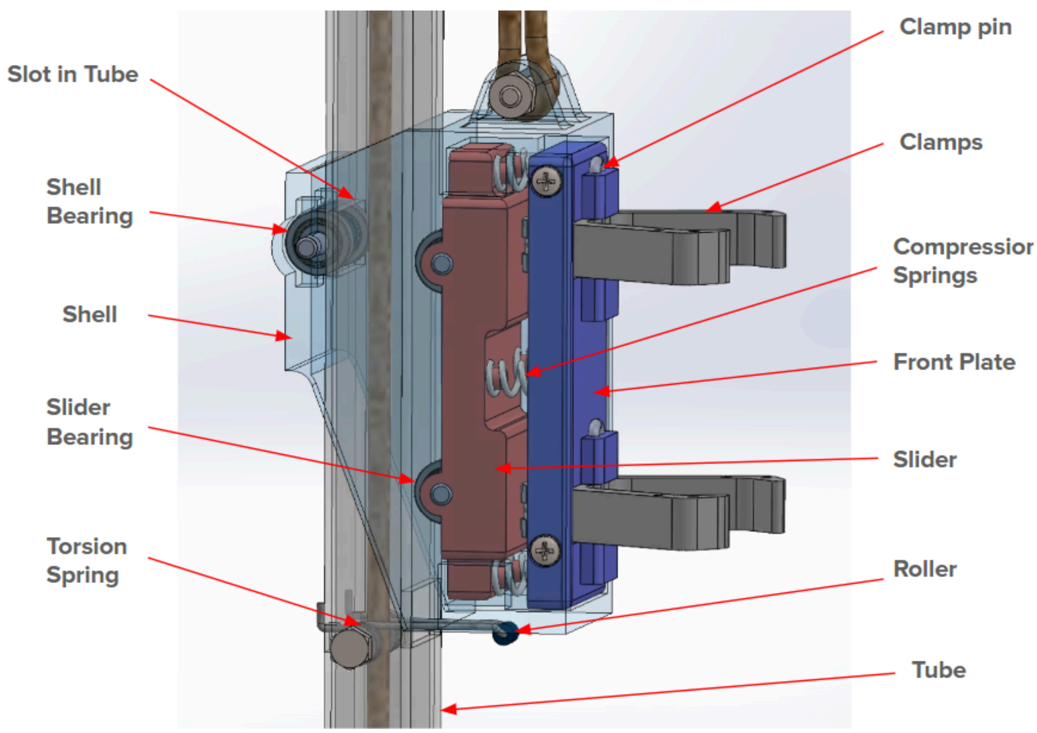


Figure 6 - Shell Housing Sub Assembly and Interface with Tube

The basic working principle of the clamping mechanism is that the user has to push the front wheel of the bike into the clamp housing. The housing is secured at the desired position, that is the height along the Tube with a slot for the shell bearing in the Tube itself, near about the center of the wheel, so that the frontmost face of the tire comes in contact with the Front Plate of the Mechanism. Once the user has applied a certain minimum push force, the compression springs compress and allow the Shell to slide in reference to the stationary Tube. This action pushes the shell bearing outside the Tube slot. At the same time, as the shell slides in, the clamps attached to the front plate also slide in and come in contact with the slider surface and due to a cam action the clamps close and secure the front wheel of the bike.

Preload Subassembly:

Once the tire is clamped with the help of the clamps it's not really secured yet, as the compression springs are in compression, there is nothing to stop it from launching the bike out when the users release the bike. This is where the Torsion Spring (P/N 012) comes into action. Refer to the figure 6 above. All the while when the bike is within the slot, the torsion spring being in the pre compressed state applied an upward force on the shell. The slot in the Tube allowed the shell bearings to rest in it to not allow the mechanism to shoot upwards. However, once the user pushes the bike tire inside, the shell bearing leaves the slot and the torsion spring pushes the complete mechanism about an inch upwards. This does two things, firstly the wheel is securely clamped as the only way to unclamp the wheels is to take the bearing back into the slot, and secondly the user has a clear visual understanding that the wheel is properly mounted onto the bike stand.

Automated Lifting Subassembly:

As seen in the figure 7 below, The automated lifting is achieved with the help of a Motor (P/N 015). Once the bike is secured to the clamps, with the press of a button the mechanism is lifted to the vertical position. The Rope (P/N 014) from the spool of the motor goes through the Tube and around the Pulley (P/N 017) right at the top and back down to the Shell lifting mount. The Tube is held vertical with a Sleeve (P/N 016) which is screwed into the wall.

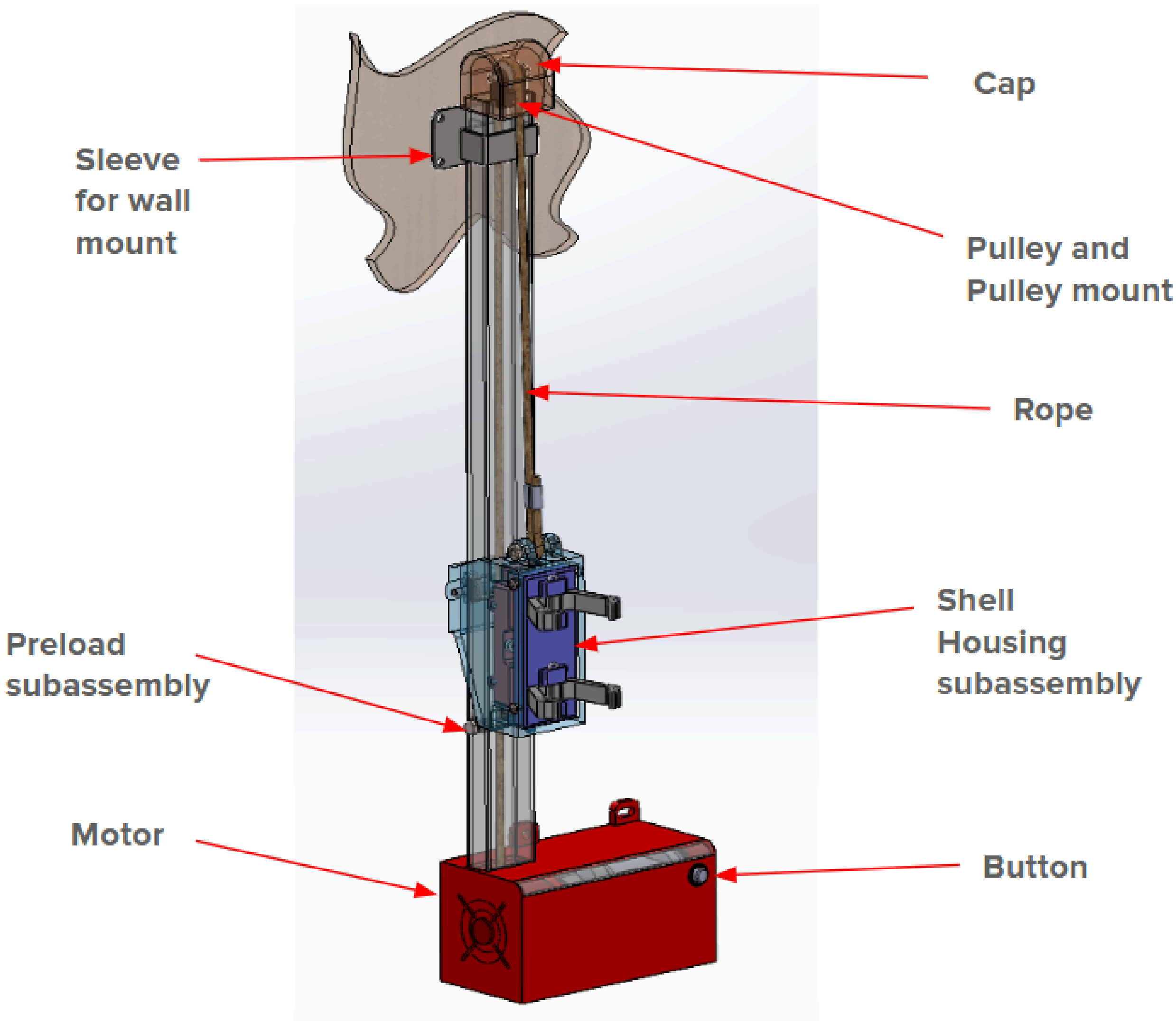


Figure 7 - Automated Lifting components

Similarly, the bike can be lowered by pressing the motor button. During the lowering action the bike would be lowered to about the height of the slot in the Tube. At that point, the torsion springs will stop the bike from just launching off the bike stand by holding the tire about an inch above the ground or slot. This is also a safety feature inbuilt in the mechanism. The Cap (P/N 010) keeps the pulley covered and provides safety. The safety feature will be discussed in detail in the Human Factors and Safety section.

9.2. Initial Design

In order to understand the final design decisions, we need to understand the initial design. As mentioned earlier, the final design came about after reconsidering the initial prototype design from our Advanced Product Design class last semester.

Figure 8 - Initial Prototype

The figure above shows a bike mounted in a vertical position to our prototype. The initial design or prototype (see figures 8 and 9) consisted of a similar clamping mechanism as our final design along with an assisted lifting mechanism. The shell, slider, front plate, clamps and clamps were all 3D printed. The mechanism used tension springs instead of compression springs for the spring actuation once the front tire was pushed onto the mechanism. Instead of a Tube we had a 6 feet 2x4 wood piece along which the mechanism rolled with the help of bearings. The assisted lifting mechanism included a counterweight of 15 lbs or 20 lbs depending on the weight of the bike. The grooves in the wood, within which the shell bearings rolled, kept the mechanism in place. We had a double pulley system at the top. We used a nylon rope to connect the counterweight to the shell. Once the user pushed the bike into the clamp mechanism, the shell bearing would leave the groove, and the bike would be instantaneously hoisted to the vertical position.

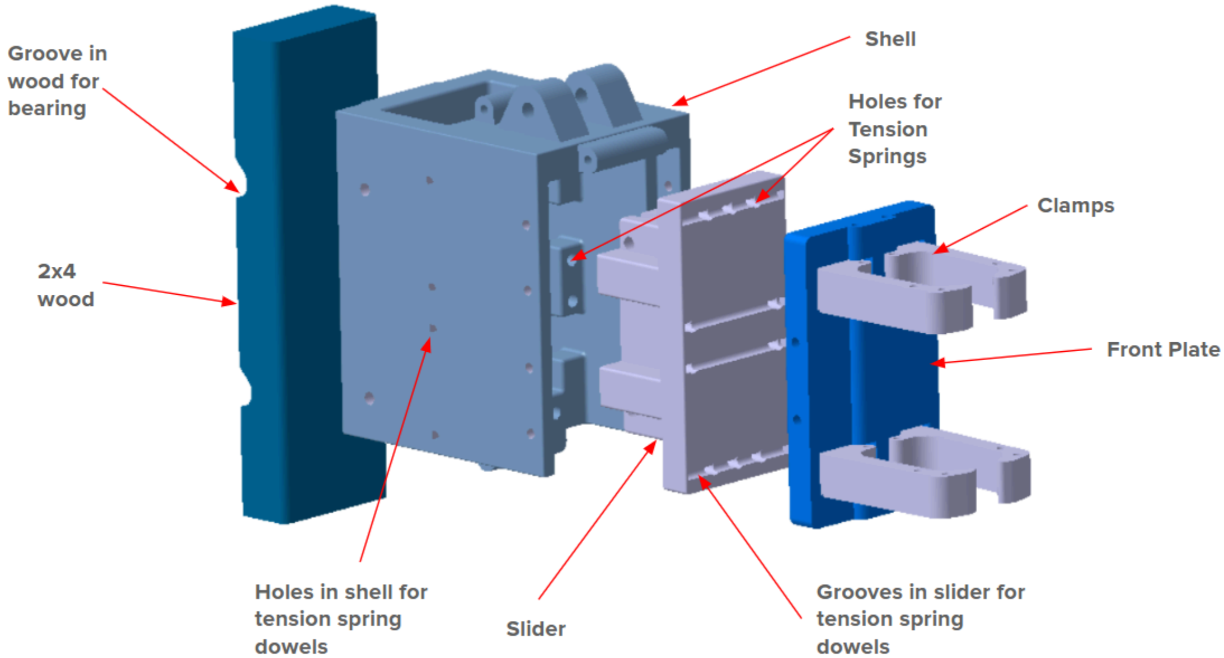


Figure 9 - Initial Prototype Clamping subassembly

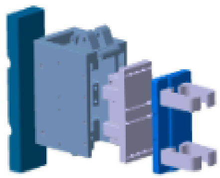
10. DFA Analysis - Initial Design

An initial DFA analysis was carried out based on the design we developed in the Advanced Product Design course. In this design, we had a total of 99 components associated with a total of 320 interfaces. The complexity of various components highlights there was a serious need for effective assembly improvements. Based on the analysis, we found that there are many possibilities to improve the assembly by eliminating various parts and fasteners. Table-1 shows the initial DFA analysis that gave us information on the interaction between components and sub-assemblies, and allowed us to identify areas for improvement.

DFA Analysis Worksheet

Assembly Name: Bike Storage | **Team:** Group 6 | **Date:** 4/23/2024

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



Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name	Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/ Omit Part	Assemble Part Wrong Way Around	Tangle, Nest, or Stick Together	Flexible, Fragile, Sharp or Slippery	Pliers, Tweezers, or Magnifying Glass Needed	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility	Re-orient Workpiece	Screw, Drill, Twist, Rivet, Bend, or Crimp	Weld, Solder, or Glue	Paint, Lube, Heat, Apply Liquid or Gas	Test, Measure or Adjust
	Housing Subassembly																				
	Shell 1	1	30	1	0	H	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Shell 2	1	30	1	0	H	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Shell bolts and nuts	12	24	0	0	L	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0
	Shell Bearings	4	8	1	0	L	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0
	Shell Bearing Dowels	4	8	1	1	L	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0
	Tension Spring dowels	6	14	1	0	L	1	1	0	0	0	0	1	1	0	0	1	1	0	0	0
	Front Plate	1	10	1	0	H	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Shell to Plate bolts	2	6	0	0	L	1	1	0	0	0	0	1	1	0	0	1	1	0	0	0
	Part 102 bolt nuts	2	4	0	0	L	1	1	0	0	0	0	1	1	0	0	1	1	0	0	0
	Sring Actuation Subassembly																				
	Slider	1	23	1	0	H	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Slider Bearings	4	8	1	0	L	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0
	Slider Bearing Dowels	4	8	1	1	L	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0
	Tension Springs	10	20	1	0	L	1	1	0	1	0	1	1	1	0	1	1	1	0	0	0
	Tension spring dowels	4	14	1	1	L	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0
	Tyre Clamping Subassembly																				
	Tyre Clamps	4	16	1	0	M	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Tension Springs	2	4	1	0	L	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0
	Clamp pins	4	4	1	1	L	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0
	Clamp bolts and nuts	8	20	1	0	L	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	Assisted Lifting Subassembly																				
	Wood 2x4	1	16	1	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rope	1	4	1	0	L	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	Counter weight	1	1	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulley	2	4	0	1	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Pulley Mount	2	4	0	1	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Pulley mount bolt	2	4	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Rope to Shell bolt	1	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Part 104 bolt nuts	1	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Sleeve screws	4	8	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	External Interface Parts																				
	Sleeve	2	8	1	1	M	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
	Wall mounting screws	8	16	0	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Totals	99	320	19	8	0	23	10	0	4	1	2	11	12	4	4	8	22	0	0	0
	Design for Assembly Metrics	177.99		19.2%	←Theor. Effy. Pract. Effy.→		23.2%	0.53		0.37			1.63				1.58				
	Targets	80		60.0%			60.0%	0.25		0.25			1.00				1.00				

Table 1 - Initial Design for Assembly Analysis Worksheet

10.1 DFA complexity factor

Our initial design had a total of 99(Np) components and 320(Ni) interfaces. The DFA analysis sheet has components arranged in the order of assembly. Using the formula in equation 1, we can calculate the complexity factor of 177.99 associated with the initial design. As we can see in the DFA sheet, most of the interfaces are present in the Housing Assembly, with a total of 134 interfaces. We decided to achieve the target factor 40 with the design improvements that we will be making in this project.

$$complexity\ factor = \sqrt{(Np \times Ni)} \quad (1)$$

10.2 Functional Analysis

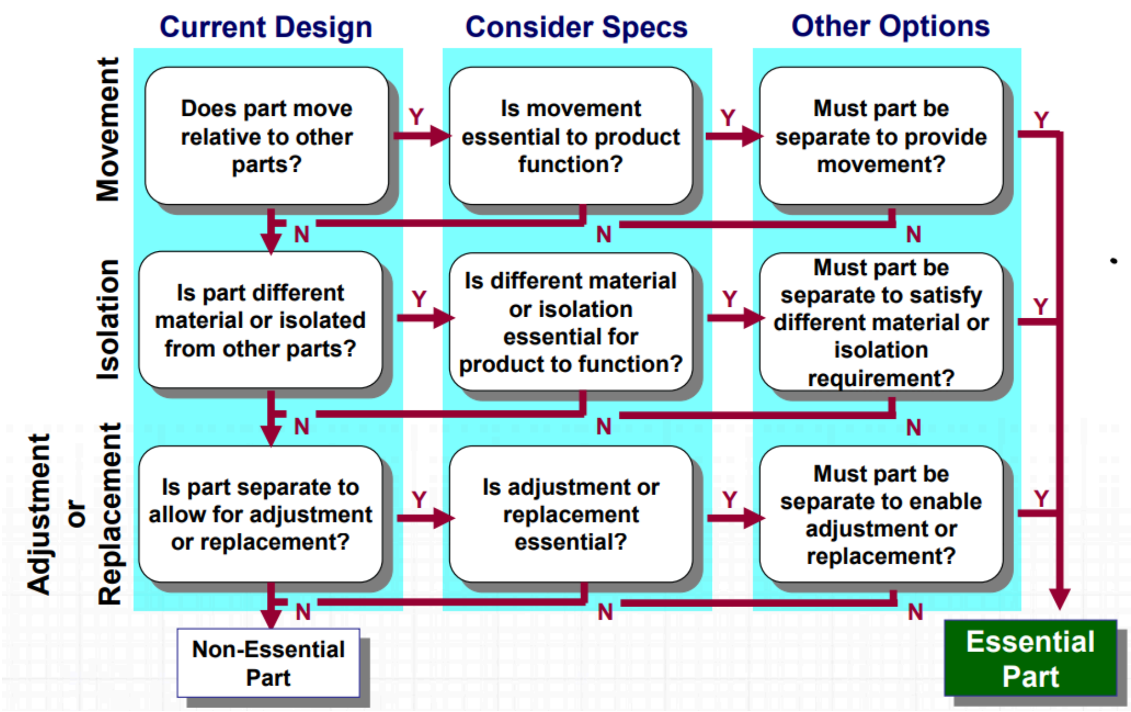


Figure 10 - Functional Analysis Diagram

Finding which components can be practically and theoretically standardized is the primary aim of the functional analysis. According to the flowchart shown above, any component in the assembly can be considered an essential or non-essential component, and then we can practically identify the essentiality depending upon its actual function. The equation shown below can be used to find practical and theoretical efficiencies. We found out that our assembly had 19 theoretical minimum components and 23 practical minimum components, therefore, the corresponding efficiencies came out to be 19.5% and 23.2%, respectively.

$$Theoretical\ part\ count\ efficiency = \frac{Theoretical\ minimum\ part\ count}{Total\ number\ of\ parts} \tag{2}$$

$$Practical\ part\ count\ efficiency = \frac{Practical\ minimum\ part\ count}{Total\ number\ of\ parts} \tag{3}$$

10.3 Error Proofing

Error proofing involves finding possible errors that may occur during the assembly of the components. Potential errors that may arise during the assembly process include wrong assembly of components and/or completely missing the components to assemble. One possible way to address this problem is by error proofing the assembly process or the components. The initial design had a total of 10 components that the assembly technician might assemble incorrectly or completely omit. Therefore, from the formula shown below, the Error Factor came out to be 0.53. Our objective after improving the design was to achieve a target Error Factor of 0.25.

$$Error\ Factor = \frac{Assembled\ wrong\ part/omitted\ part + Assembled\ part\ wrong\ way\ around}{Theoretical\ Minimum\ part\ count} \tag{4}$$

10.4 Handling

Handling is primarily a measure of the ease with which the components or fasteners can be handled during the assembly. Understanding the potential problems associated with the handling of the components while assembling is crucial to saving time and energy. The factors associated with handling are the number of hands required to assemble or grab a component or fastener if it is tiny, slippery, flexible, or sharp, which will impact how the components are handled. Our initial design had 7 components that fell into this category, which led to a handling factor of 0.37, and we aimed to achieve 0.25 through redesign.

10.5 Insertion

In order to measure the level of ease or difficulty to assemble a specific component, we use this insertion factor. This factor is determined by the level of difficulty in aligning the component, whether it needs a hold down to keep it in place, or the level of accessibility and visibility. Our initial design had a lot of bearings, dowels and springs which were difficult to align and assemble. While assembling the spring, there was considerable resistance to insertion due to obstructed access. We had a total of 31 components that had these issue mentioned, there using the formula shown below, we calculated insertion factor of 1.63.

$$insertion\ factor = \frac{difficult\ to\ align\ parts + holding\ required + resistance\ to\ insertion + obstructed\ access}{Theoretical\ Minimum\ \#\ parts} \quad (5)$$

10.6 Secondary Operations

Due to the difficulties in insertion of components such as springs and dowels, we had to perform secondary operation such as reorienting the workpiece. Many components required screwing and twisting, which also added to the secondary operation to perform while assembling. Our design had 30 components that required some secondary operations to assemble it into the product, this led to a secondary operations factor of 1.58.

11. Design Changes

After a thorough analysis of the product in its initial prototype state, it became clear that a few major design improvements could be made to ensure that the parts were less expensive, more readily manufacturable and more easily assembled. The manner in which we did this was by focusing on DFA metrics such as reducing part count, consolidating the numbers and types of materials and manufacturing processes selected, and designing built-in features to enhance ease of assembly. The primary objective of these design modifications, however, was to decrease the overall cost of the system, thereby making the product more profitable for each unit that was purchased.

11.1. Design Change 1 - Shell Housing Sub Assembly Redesign

Having had the prototype built, we had first hand experience with the assembly and manufacturing process. A major redesign was needed for the shell and the internal components. Firstly, the initial shell design was such that it was impossible to manufacture. As you can see in the below figure 11, the shell on the left has internal wall features that cannot be machined or injection molded. Since this was a prototype, having it 3D printed was the idea. However, if the part was printed as is, it would be, if not impossible, very difficult at best to remove the supports from within the shell. Hence, for fabricating this part we had to split the shell in two halves as seen in the below figure 11. The internal wall features were required for the tension spring dowel placement, which made the assembly bulky as we had to add one more wall feature for the slider for placing the dowels. Another issue with this design was that, in order to place the dowels for the springs, the assembler would have to guess the location of the spring loop hole for the dowel to pass through for the side towards the bearing. This assembly design was a big frustration for assemblers because of so many hidden locations within the shell that had to be reached to install the internal components.

To have it mass manufactured, we needed to redesign it such that we could eliminate this assembly nightmare. When testing the prototype, we realized a need for just one set of bearings on the shell side, which saved a lot of material. We switched to compression springs which made our life easy by eliminating all the dowels needed for the tension springs. We had features to the slider and front plate as seen in the figure 12 below to assist in assembling. Switch to compression springs, majorly improved the shell and slider design by getting rid of two internal walls, one on the shell and other on the slider, making the assembly very compact. This elimination of internal walls made it possible to manufacture the shell in one piece using injection molding. We were able to provide uniform wall thickness and sufficient drafts for injection molding. Elimination of dowels also minimized the side action required during molding. And lastly, the complete assembly can be done with a Top Down assembly sequence, with minimum reorientation, making assembly a seamless process.

Figure 11 - Initial shell design (top left), final shell design (top right), and shell and slider prototype with tension springs and dowels (bottom)

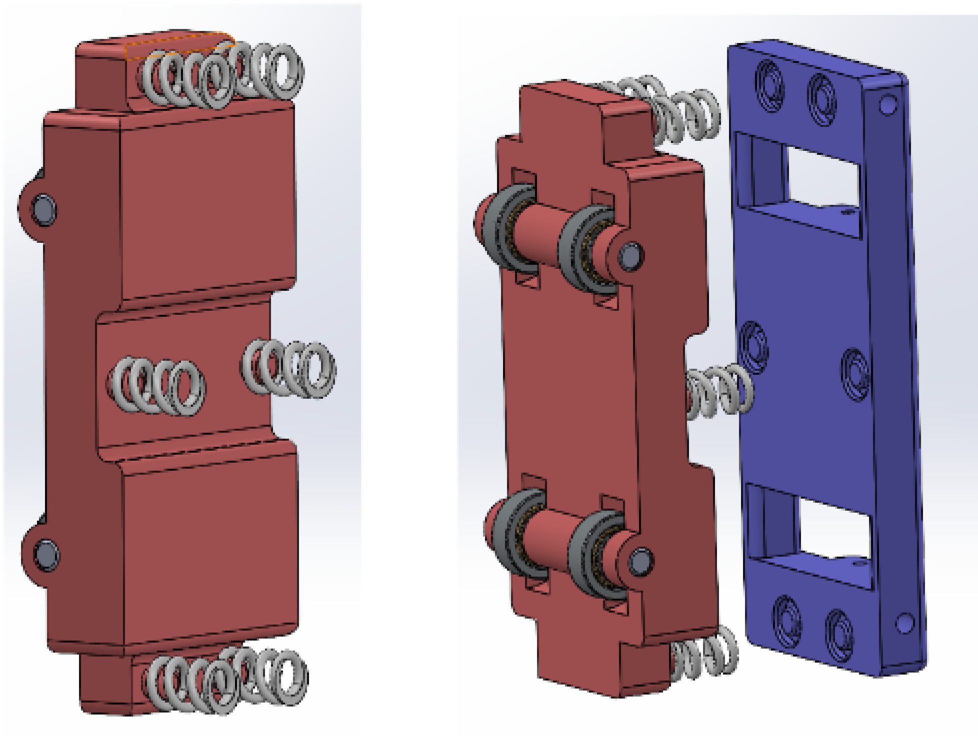


Figure 12 - Slider and Front plate features for compression spring assembly

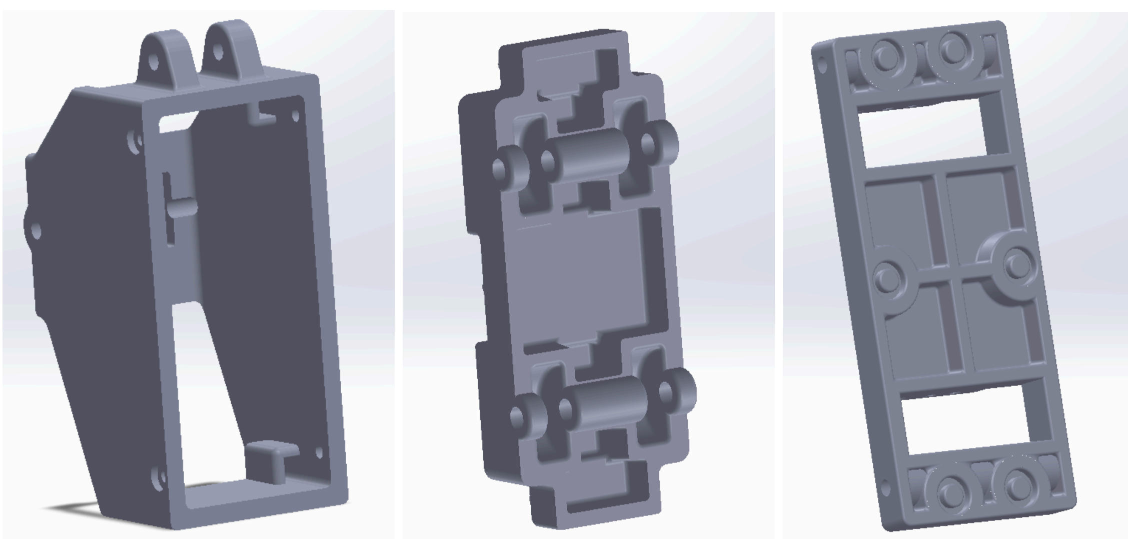


Figure 13 - Injection molded shell, slider and front plate having features for uniform thickness

These design changes reduced the part count from 33 to 9 parts which includes elimination of all mounting bolts to attach the two part shell of the prototype, four dowels, all tension spring dowels. We also reduced the spring count, two bearings and two fasteners for shell to plate mounting. We drastically improved the insertion and handling metrics as will be discussed in the final DFA analysis section. The major injection molded parts shown in the figure 13 above have appropriate internal drafts and hollow features for injection molding. In essence the redesign of the shell made it possible to manufacture and seamlessly manufacture the shell housing assembly.

11.2. Design Change 2 - Assisted lifting to Automated lifting

Another major design change involved the method the bike would be lifted to its vertical position. Our initial prototype incorporated a double pulley and counterweight system. There were a number of issues with this setup. First, the counterweight requires a space of its own for its vertical translatory motion. The space required for this motion extends about a foot from the wall, and only beyond that can you mount your bike stand. This takes away the purpose of having a space efficient bike storage when you need considerable space for the bike stand itself. Another problem with this system was that the user would have to adjust the counterweight for their bike weight, so there can not be a simple fixed weight in the system. Varying bike weights also has different results with the assisted lifting experience, with a heavier counterweight than the bike meaning easier loading but more difficult unloading. Yet another issue would be the complexity of installation itself, and safety associated with it. Having 30 pounds in weight not installed properly would be detrimental. And lastly, the weight of the system would be twice or even thrice of what it is now, from increasing the cost of manufacturing, to cost of transportation. This needed to change.

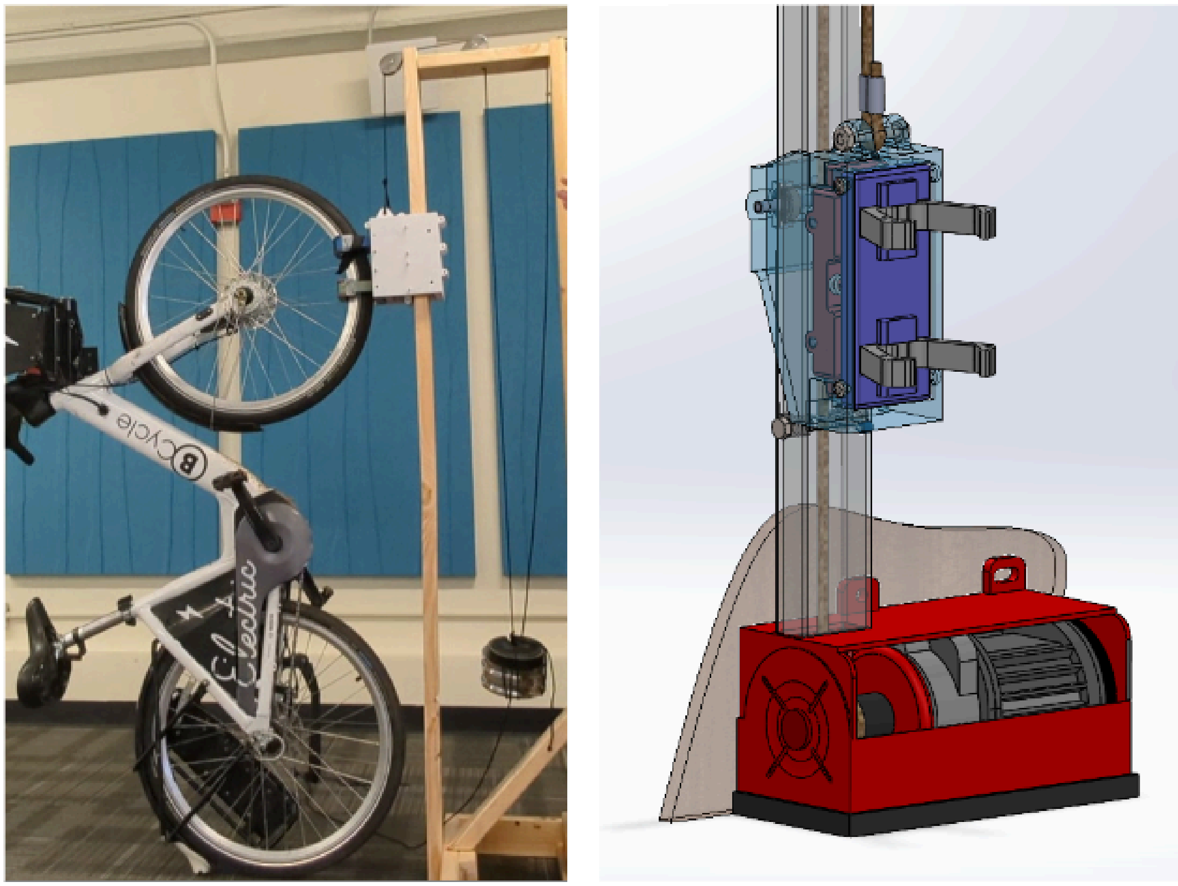


Figure 14 - Counterweight (assisted) lifting vs Motorized (automated) lifting

The solution to this is to replace the counterweight with a motor that would take comparatively minimal space, and also to replace the 2x4 wood with an aluminum tube for passing the rope through the tube to the pulley on top. The motor controls can be simply adjusted to varying bike weights, and programmed for consistency in loading and unloading, where the user doesn't have to worry about even touching the bike once it is mounted in place. The user experience would be constant with all bike users, and the Installation is much less complex and free of the fear of a 30 lb weight falling from 6 feet above ground. The entire setup only weighs about 20 lbs, which means less transportation cost and consistency in the product for all bike weights. An automated system not only makes the user experience of the product seamless, but also solves every issue with the previous system.

11.3. Design Change 3

In the initial design (see figure 15), we decided to manufacture the wall mounted sleeve by cutting from a stock rectangular tube, laser cutting the other two plates, and then welding them together. This will require us to design a welding fixture, which will in turn increase the cost of manufacturing. Furthermore, this method will reduce the overall material waste.

After careful consideration, we decided to switch the manufacturing of the Sleeve to a single sheet metal plate shown in figure 16. We decided to propose a change wherein we will be manufacturing this component using sheet metal bending. We will first laser cut the plate to required thickness and then we can perform a bending operation. This method not only simplifies the manufacturing by eliminating secondary operation and associated fixture design and its manufacturing, but it also maintains consistency of the manufacturing process.

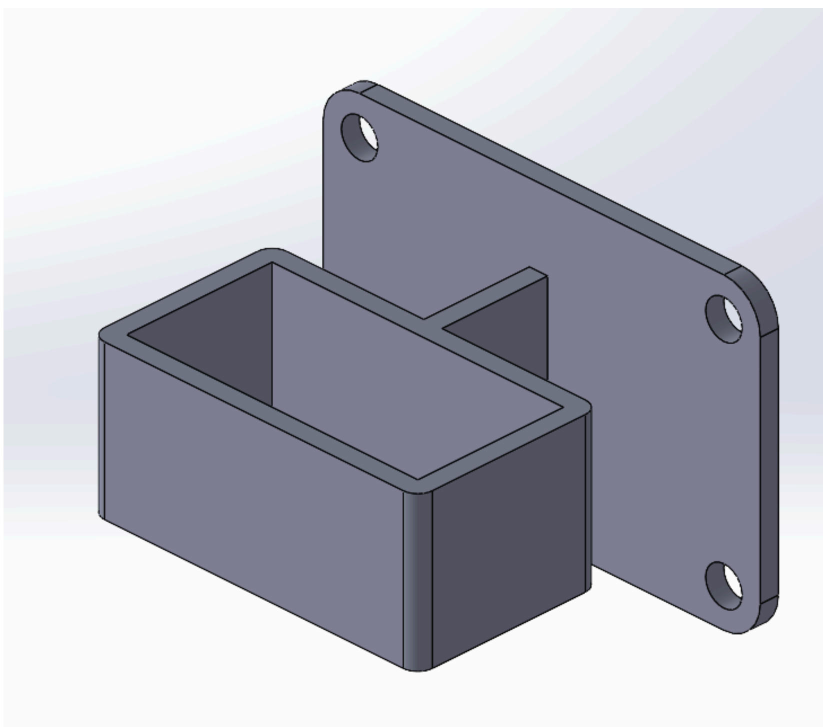


Figure 15: Initial Sleeve Design

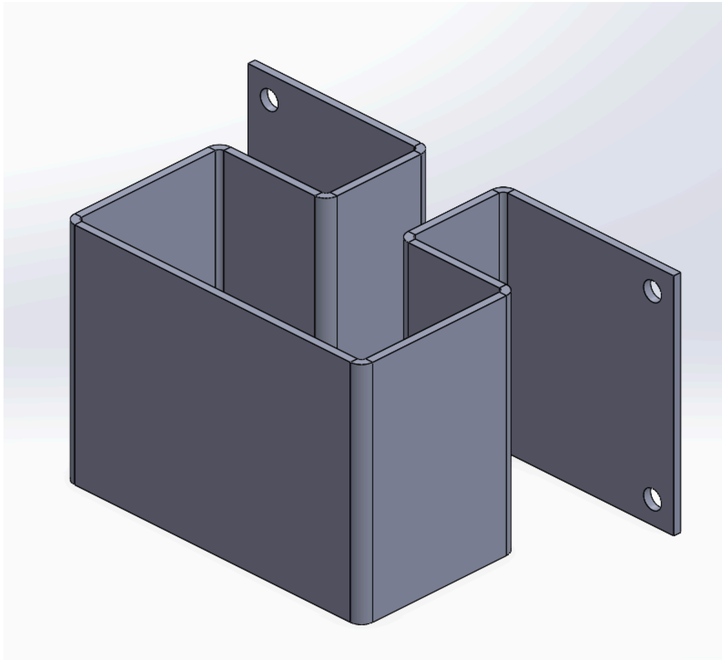


Figure 16: Redesigned Sleeve

12. Engineering Specifications of Product

Model	ABLP-007
Electric Specs.	120 V, 60 Hz
Motor Power	150 Watts
Lift Weight	60 lbs
Lift Speed	0.5 ft/sec
Bike wheel size range	24-28 inch
Spatial Volume	6 cubic feet
Dimensions	1.6" H x 2.1" W x 6" L
Weight	20 lbs

Table 2: Engineering Specifications of Product

The above table lists the product specs of the automated vertical bike stand. The automated bike stand is capable of lifting bikes weights of up to 60 lbs. The average road bike weighs about 15-20 lbs and an average electric bike weighs about 50-55 lbs. Hence, our target was to include all bike weights. We needed a motor that would have high torque and low speed. The calculated motor power for the max bike weight and lift speed came out to 150 watts. The assembly is placed on the floor and mounted to the wall, occupying less than one square feet of floor space and less than 6 cubic feet of volume. It is a highly compact system with an automated lifting ability.

13. Calculation and Analysis

13.1 Motor Power Rating Calculation

With the upward lift speed of 0.5 feet per sec and a force of 60 lbs considering lift weight of the bike, we get a power requirement of, *Power = Force * Velocity = 42 Watts.* Considering a motor power factor of 0.7 we get a Motor Power rating of 60 watts. We plan to have multiple lift speeds in the future reaching a maximum of 1 foot per second. Hence, that would mean a motor power rating of 120 watts is required at minimum. We selected a 150 W motor for our lifting mechanism.

13.2 Spring Constant Calculations

Compression Spring:

As per our prototype testing, the force required to engage the clamping mechanism should be about 2 lb force. The mechanism must displace 0.25 inches within the mousing for the clamp to engage. We have six springs resisting this force. The spring constant comes out to be, *k = Force / (No. of springs * displacement) = 1.34 lb/in.* For our purpose we chose a spring constant between 1.3-1.5 lb/in which ranges from 1.95 lb to 2.25 lb force requirement, which are acceptable.

Tension Spring:

As per our prototype testing, the springs used in the mechanism were sufficient to disengage the bike when the mechanism shell bearing goes back in the tube slot. The force required to open the claw should be sufficient enough to overcome any friction between the claw and the front plate and the cam action required using a 2 lb force. For our purpose we chose a spring constant of 1.5-2 lb/in which matched our prototype value.

Torsion Spring:

The torsion spring should make the mechanism deflect about an inch when the shell bearing leaves the slot in the tube. The length of the torsion spring arm is 1.6 inches. Having it spring up an inch would require a torsional rotation of 40 degrees. The weight at this point would be the front end of the bike lifted above ground, that is 30 lbs force. The spring constant is calculated as *k = Torque / radial displacement = (30 lbs * 1.6 in) / 40 deg. = 1.2 in.lbs/deg.* The spring constant chosen was 1.2-1.5 in.lbs/deg.

13.3 Finite Element Analysis(FEA)

Even though the parts that carry the max load were tested with 3D printed parts with an infill of as minimum as 20%, we still felt it would be beneficial to have analysis done for critical components, namely the clamps, front plate, shell, and pulley mount. We did FEA for these components. The load applied on these components was considered taking a Factor of Safety of 1.5, i.e since we are designing the product that can lift a 60lb bike, we have designed it to lift a 90 lb weight.

1. Shell: Material- ABS

Boundary Conditions:

Loads: The weight of the bike is completely taken by the clamp which is transferred to the shell through the Front Plate. The front plate is bolted at four locations and it also rests on the inner lower surface as shown in the figure below. The force applied is distributed across these 5 contact surfaces.

Supports: The shell is fixed at the mounting lifting mount cylindrical surface. We have given roller support to the inner side walls as there are components inside the shell which restrict the inward deflection.

Results:

a) Max Stress = 17.49 MPa (Max Allowable Stress = 45 MPa)
b) Max Deformation = 1.5mm

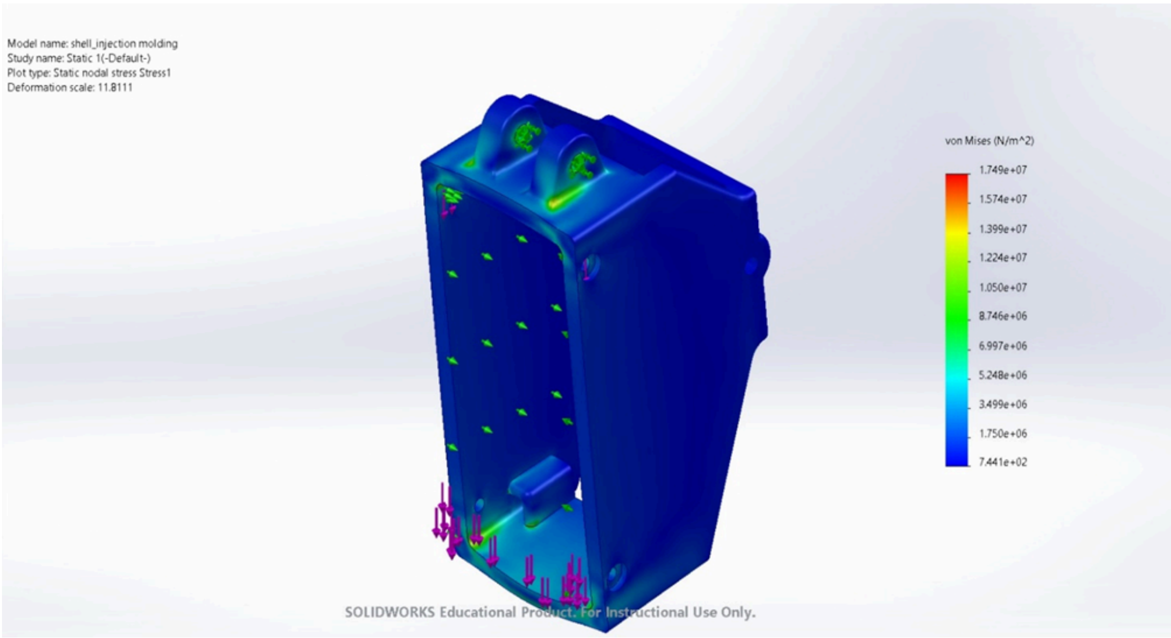


Figure 17: Shell FEA - Stresses

2. Front Plate: Material - ABS

Boundary Conditions:

Loads: The weight of the bike is completely transferred by the clamp to the Front Plate evenly at the two surfaces in contact with the clamp as shown in the figure below.

Fixed Supports: The mounting interfaces between the front and the shell, i.e. the cylindrical surfaces for bolting.

Results:

a) Max Stress = 30.12 MPa (Max Allowable Stress = 45MPa)

b) Max Deformation = 0.03mm

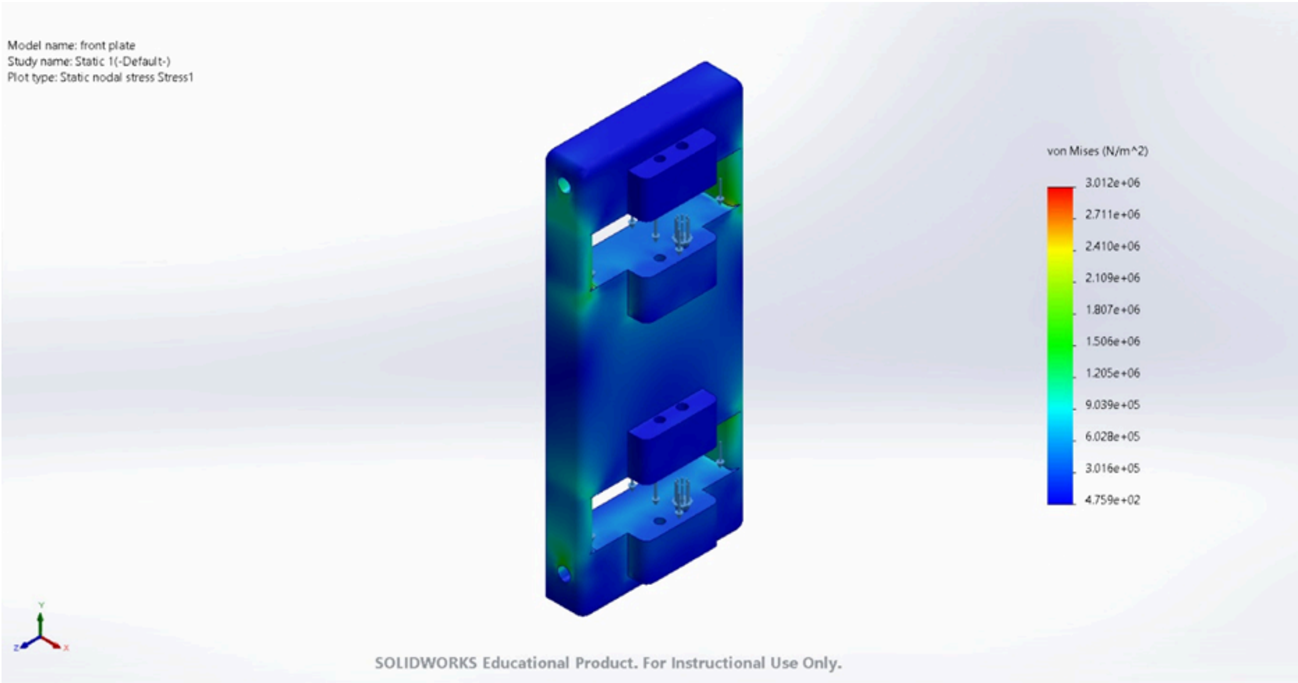


Figure 18: Front Plate FEA - Stresses

3. Tyre Clamp: Material - ABS

Boundary Conditions:

Loads: The weight of the bike is completely applied on the contact area of the wheel's rim and the clamp as shown in the figure below.

Fixed Support: The Clamp is mounted on the front plate and has a contact area as shown in the figure below.

Result:

a) Max Stress = 41.69 MPa (Max Allowable Stress = 45MPa)

b) Max Deformation = 1.3mm

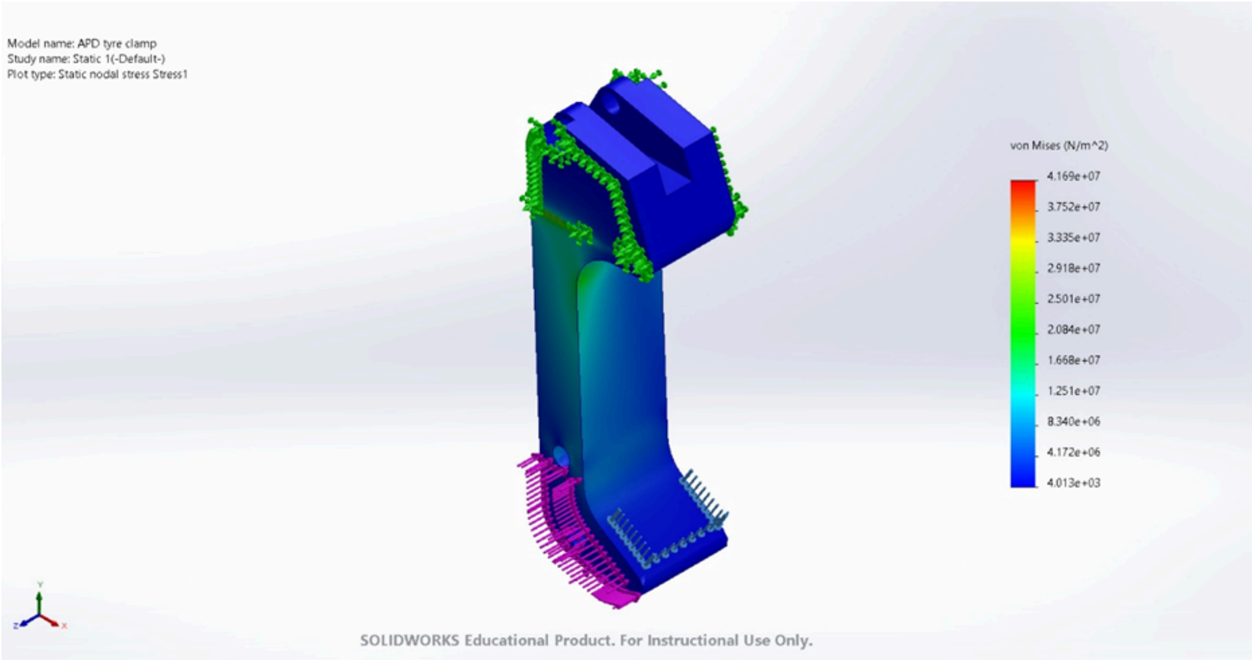


Figure 19: Clamp FEA - Stresses

4. Pulley Mount: Material - Aluminum

Boundary Conditions:

Loads: The pulley is mounted on this pulley mount through the bolt. The load of the bike and tension in the rope on the other side is transferred from the pulley to the inner cylindrical surface through the bolt.

Fixed Support: The mount is fixed on the tube using a bolt, hence the cylindrical surface is fixed as shown in the figure below.

Result:

a) Max Stress = 21.26 MPa (Max Allowable Stress = 214 MPa)

b) Max Deformation = 9.04e-3 mm

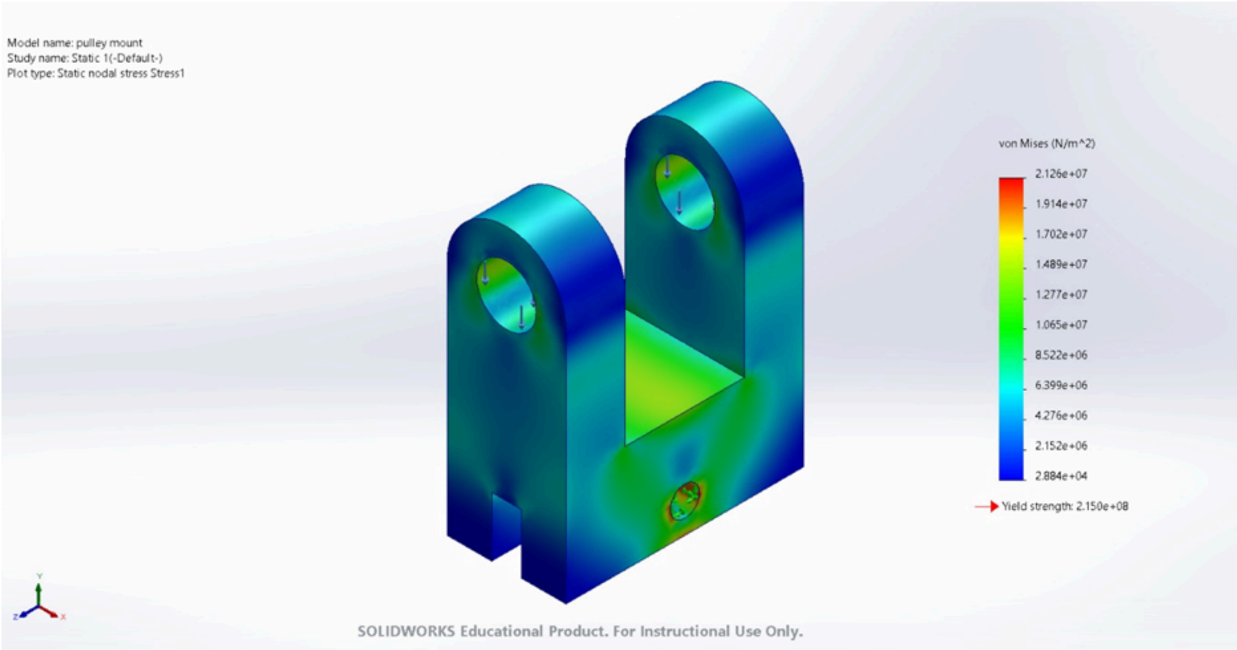


Figure 20: Pulley Mount FEA - Stresses

14. Process Selection:

A driving design intent of the team involved minimizing the different types of manufacturing processes used to produce the vertical bike stand. The team's overall goal was to limit the number of different types of manufacturing processes to three, thereby reducing cost and ideally, reducing variability within material selection as well.

The first step in this methodology, then, was to divide the components into custom and COTS parts, and then determine the structural requirements and/or nature of each custom component. For each component that would bear high loads, the determination was made to select a process that would allow for a metallic material to be used. For any remaining components, specifically those with larger profiles, complex form factors, and increased mass, the team opted for injection molding as the manufacturing process.

After reviewing the part list and the base requirements of each component, we determined that 002 - Shell, 003 - Slider, 008 - Front Plate, 009- Tire Clamps, 013 - Roller, and 019 - Cap would all be designed so as to be injection molded. After conducting additional analysis, it was determined that the loading on these parts was either relatively insignificant or non-existent. Also, during the prototyping phase of this project, a number of these parts were manufactured via Additive Manufacturing, 3D printing specifically, with only a 20% infill. These parts were cycled more than 100 times with no signs of wear or deformation, thus indicating that the use of injection molded plastics would be adequate to meet our design intent.

As for cost considerations, while the tooling for injection molding typically costs in the range of $100,000, the cost of material and decreased weight of parts, compared to metal fabricated components, confirms that the selection of injection molding is suitable from an economic perspective. Additionally, with an annual production run of 50,000 units, injection molding would also meet needs based on a production quantity basis. Refer to Figure 21 below.

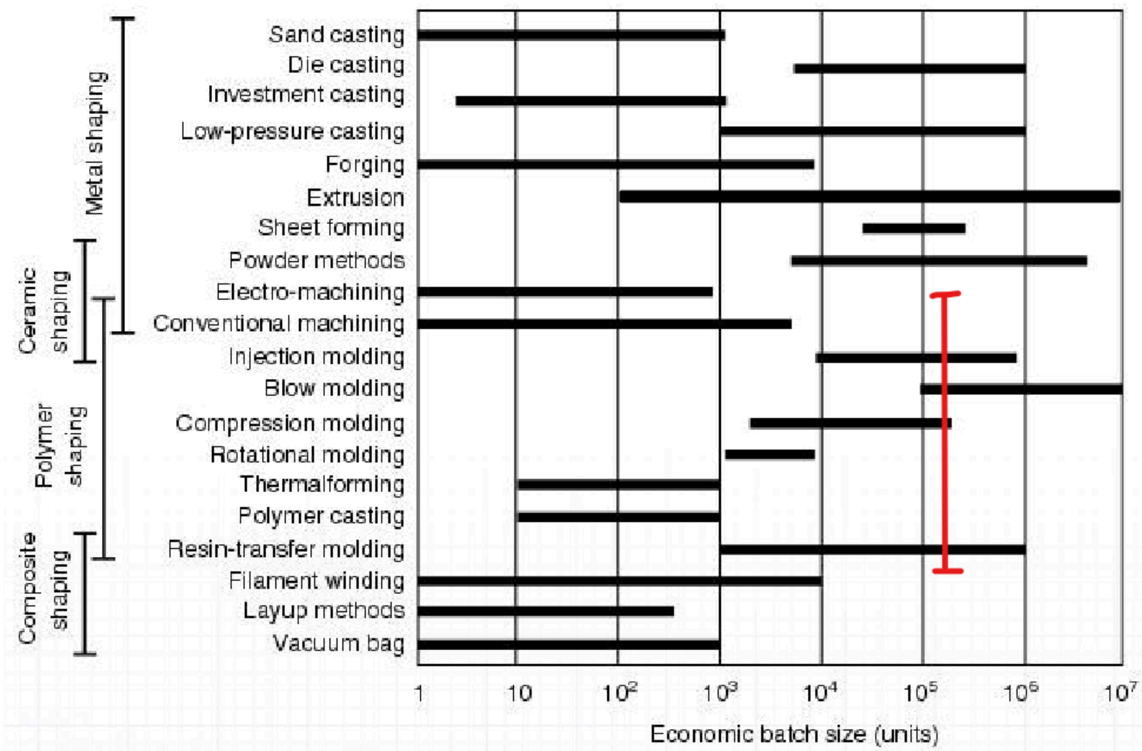


Figure 21 : Batch Size vs MFG process

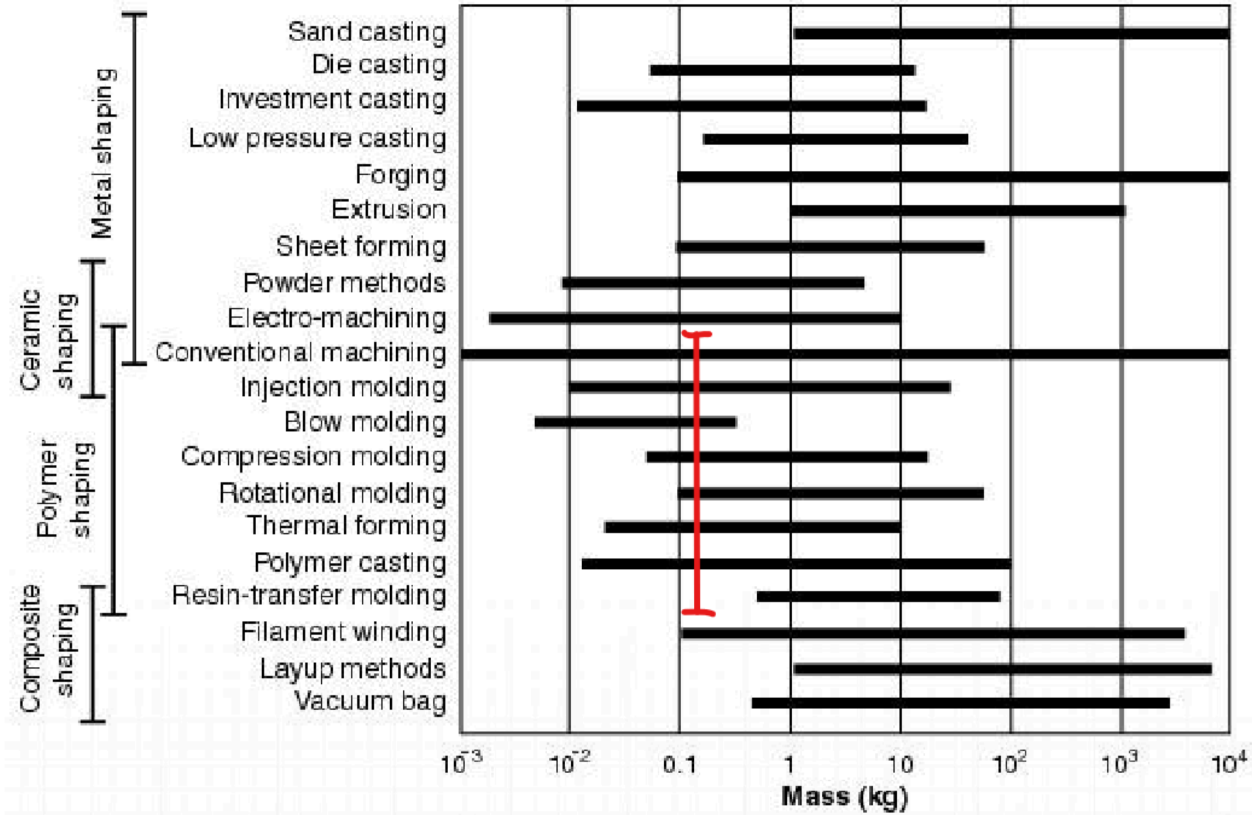


Figure 22 - Mass vs Mfg process at Mass < 1lb

The remaining components were determined to be manufactured using a metal as a material of choice due to either structural or ease of manufacture considerations, thus the remaining processes to be considered were sheet metal bending, machining, casting, and forging. Looking at these parts holistically, we identified two other primary components (015 - Motor Housing and 016 - Sleeve) that were not load bearing and could readily be fabricated from sheet metal bending. The plan for these components would be to purchase large sheet stock of a specific alloy/temper and cut to size using the precision of laser cutting. In fact, it was determined that all metallic components that came from stock sizes would be laser cut due to the high tolerances of the laser. These sheet metal components would then be bent to meet the necessary drawing standards.

Finally, the last remaining components of note were 001 - 1 x 2 x 0.125 Tube and 018 - Pulley Mount. The tubing would require secondary operations beyond that of laser cutting to size to get it to the correct form factor to fit in the motor housing, so machining was a natural fit for that. The largest concern with 018 - Pulley mount was that at its max loading condition, the connection point securing 017 - Pulley to 018 - Pulley Mount would support twice the weight of the bicycle which could lead to compressive or bearing failure if weaker material or sheet metal were used. Thus, the decision was made to machine 018 - Pulley mount to ensure that it was more than robust enough to withstand its more severe loading conditions and to ensure that it would be durable enough to withstand high cycle counts as well.

15. Material Selection

As mentioned in the previous section, our team decided to hone in on a specific few manufacturing processes based on product requirements and then use those selected processes to determine the materials for each of the components. The Table below indicates the material selection for all custom components:

Part Number	Part Name	Qty	Material Selection	Manufacturing method	Mass (lbs)
*001	1x2x0.125 Tube	1	6063 Al	Lasercut/Machining from stock tubing	4.60
*002	Shell	1	ABS	Injection Molding	0.48
*003	Slider	1	ABS	Injection Molding	0.23
*004	0.75"OD Bearing	6	304 Stainless Steel	COTS	0.002
*005	Shell Bearing Dowel	1	304 Stainless Steel	Cut and chamfer from shock	0.04
*006	Slider Bearing Dowel	2	304 Stainless Steel	Cut and chamfer from shock	0.03
*007	Compression Spring	6	304 Stainless Steel	COTS	0.005
*008	Front Plate	1	ABS	Injection Molding	0.18
*009	Tyre Clamps	4	ABS	Injection Molding	0.02
*010	Tension Spring	2	304 Stainless Steel	COTS	0.001
*011	Clamp Pin	2	304 Stainless Steel	Wire bending	0.01
*012	Torsion Spring	1	304 Stainless Steel	COTS	0.02
*013	Roller	1	ABS	Injection Molding	0.001
*014	Rope	1	Nylon	Nylon stock	0.28
*015	Motor & Housing	1	Stainless Steel 14 ga	Plate lasercut & welding	1.0
*016	Sleeve	1	Stainless Steel 14 ga	Plate bending & stamping	0.47
*017	Pulley	1	Aluminium	COTS	0.05
*018	Pulley Mount	1	6063 Al	Machining	0.10
*019	Cap	1	ABS	Injection Molding	0.15

Table 3 - Material Selection

In addition, for each component, an Ashby chart, as seen in the figure below, was created and consulted to determine which potential materials would be appropriate for our applications; however, since we were focused on more of a manufacturing process-driven methodology, the Ashby chart was limited to material class/type for each case. For example Figure 23 below is indicative of a beam in tension, which is a comparison of Young's modulus to the density of the material, specifically $E^{1/2}/\rho$. The index line shown in the bottom right corner was transposed onto the graph overlapping with a known, good material, thus allowing for additional suitable materials.

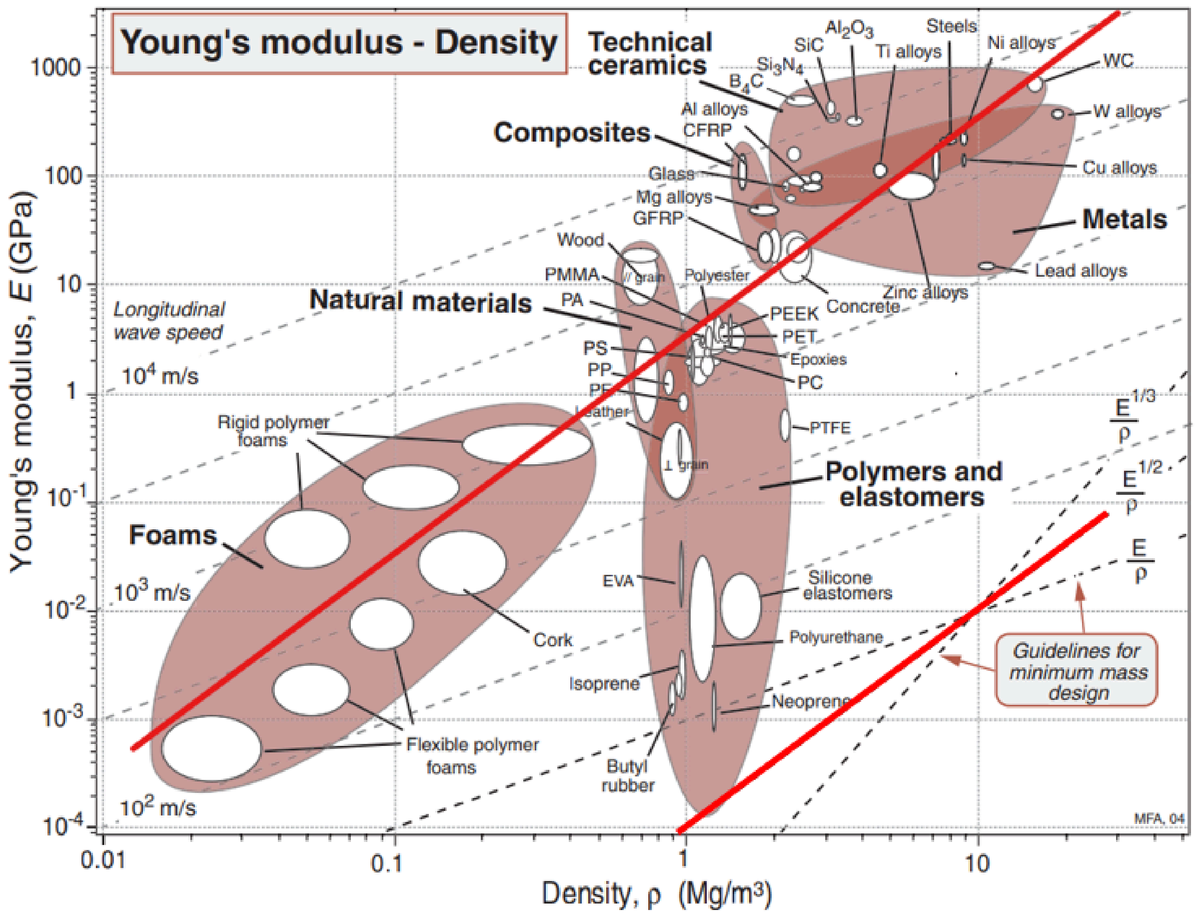


Figure 23 - Ashby Chart depicting Stiffness vs Density

For the injection molded parts, there were a few potential options such as ABS, ABS-PC, Nylon, and HDPE; however, ultimately the group elected to opt for ABS since it is extremely common, easily accessible and pretty inexpensive.

The sheet metal components are not designed to be load bearing and essentially are used to secure the system to the wall in a constrained state. With that in mind, it was determined that the usage of 14 gauge 304 Stainless steel would be ideal. 304 stainless steel was chosen for its resistance to corrosion, good material properties and relatively low expense. While some users may elect to use the system in their homes, many will install it in their garage which does not always have the best insulation and/or weather proofing. By electing to use 304 stainless steel, the system itself will be better able to withstand the effects of time and last longer. The choice of using 14 gauge was made based on previous experience with this thickness of stainless steel and its overall rigidity. While the 015 - Motor Housing and 016 - Sleeve are not structural in nature, it is important for the user to feel confident in the security of these parts and for them to be robust in the case of abuse/misuse.

The final components that required a material determination were 01 - 1 x 2 x 0.125 Tube and 018 - Pulley Mount. Since the team determined that the tubing should be six (6) feet in length, we realized that the part would be very large and heavy, despite the fact that the tubing would be hollow. This weight factor motivated us to steer away from steels and focus on aluminum due to its lightweight nature and relatively low cost. Research determined that 6063 Al was both strong and very readily machinable. In addition, commercially available tubing in 6063 Al of the correct dimensions was available at a reasonable price, so the team decided to pursue 6063 Al as the ideal choice for this component.

As for 018 - Pulley Mount, the driving factors for this material selection were cost, strength, and machinability. Once again, 6063 Al proved to be a great candidate for these criteria due to the fact that it can easily withstand the required loading conditions and it is one of the easiest alloys of aluminum to machine overall.

COTS Parts:

For the dowels, springs, pins, fasteners, etc, the thought process was to focus on consistency of material selection and focus on corrosion resistance to ensure product longevity. Thus, the ideal would be to use COTs parts made of 304 stainless steel, but if, in the future, the team were able to increase in cost savings by selecting a different material for these commercial parts, that would certainly be a consideration that the team would be willing to look into.

16. Economic analysis

A comprehensive cost analysis of each component of the system was conducted to get a better understanding of the value of the selected manufacturing processes and to determine the amount of profit that could be made on the product as a whole. By evaluating the sum of each component's material cost, labor cost, tooling cost, equipment cost, and overhead costs, the unit cost for each component was determined. See below equations:

Material Cost	$C_M = \frac{mc_m}{1-f}$
Labor Cost	$C_L = \frac{c_w}{n'}$
Tooling Cost	$C_T = \frac{c_t k}{n}$
Equipment Cost	$C_E = \left(\frac{1}{n'}\right)\left(\frac{c_e}{Lt_{wo}}\right)q$
Overhead Costs	$C_{OH} = c_{OH}/n'$

Figure 24 : Cost Analysis Equations

Tables 4-7 below clearly portray the cost analysis for each component:

Part Number	001	002	003	004	005	006
Part Name	1x2x0.125 Tube	Shell	Slider	0.75"OD Bearing	Shell Bearing Dowel	Slider Bearing Dowel
Manufacturing Process	Laser Cut Stock Tubing	Injection Molding	Injection Molding	COTS	Machine from stock	Machine from stock
Material	304 Stainless Steel	ABS	ABS	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
m Weight of part [lb]	13.63	0.48	0.23	0.002	0.04	0.03
c_m Cost of material [$/lb]	$10.00	$1.30	$1.30	$1.30	$10.00	$10.00
Cost of material reference source	QAvD_BwE&gclsrc=aw.ds	tic-injection-molds-cost				ealed-cold-finish/pid/4473
f Fraction of material that ends up as scrap	0.01	0.05	0.05	0.2	0.05	0.05
C_M Material cost [$/unit]	**$137.68**	**$0.657**	**$0.315**	**$0.003**	**$0.421**	**$0.316**
C_L Labor cost [$/unit]	**$0.50**	**$0.83**	**$0.83**	**$0.42**	**$0.42**	**$0.42**
C_T Tooling cost [$/unit]	**$0.03**	**$0.05**	**$0.05**	**$0.05**	**$0.03**	**$0.03**
C_E Equipment cost [$/unit]	**$0.152**	**$0.167**	**$0.167**	**$0.001**	**$0.004**	**$0.007**
C_OH Overhead costs [$/unit]	**$1.20**	**$2.00**	**$2.00**	**$1.00**	**$1.00**	**$1.00**
C_U Unit cost [$/unit]	**$139.55**	**$3.71**	**$3.36**	**$1.47**	**$1.87**	**$1.76**
OME Manufacturing cost [$/unit]	**$413.03**	**$1.971**	**$0.944**	**$0.010**	**$1.263**	**$0.947**
OME Price [$/unit]	**$1,239.09**	**$5.912**	**$2.833**	**$0.029**	**$3.789**	**$2.842**
P Sales price to break even [$/unit]	**$139.20**	**$3.54**	**$3.20**	**$0.49**	**$0.96**	**$0.92**
Unit Build Price	$206.68					
Sale Price	$150.00					
Profit per Unit	-$56.68					
Annual Revenue	$7,500,000.00					
Net Gain	-$2,834,145.08					

Table 4 Cost Analysis Part 1

Part Number	007	008	009	010	011	012
Part Name	Compression Spring	Front Plate	Tire Clamps	Tension Spring	Clamp Pin	Torsion Spring
Manufacturing Process	COTS	Injection Molding	Injection Molding	COTS	Wire bending	COTS
Material	304 Stainless Steel	ABS	ABS	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
C_M Material cost [$/unit]	**$0.051**	**$0.246**	**$0.027**	**$0.010**	**$0.111**	**$0.202**
C_L Labor cost [$/unit]	**$0.42**	**$0.83**	**$0.83**	**$0.42**	**$0.63**	**$0.42**
C_T Tooling cost [$/unit]	**$0.01**	**$0.05**	**$0.05**	**$0.01**	**$0.13**	**$0.01**
C_E Equipment cost [$/unit]	**$0.001**	**$0.167**	**$0.333**	**$0.001**	**$0.125**	**$0.001**
C_OH Overhead costs [$/unit]	**$1.00**	**$2.00**	**$2.00**	**$1.00**	**$1.50**	**$1.00**
C_U Unit cost [$/unit]	**$1.47**	**$3.30**	**$3.24**	**$1.43**	**$2.49**	**$1.62**
OME Manufacturing cost [$/uni	**$0.152**	**$0.739**	**$0.082**	**$0.030**	**$0.333**	**$0.606**
OME Price [$/unit]	**$0.455**	**$2.217**	**$0.246**	**$0.091**	**$1.000**	**$1.818**
P Sales price to break even [$/	**$0.49**	**$3.13**	**$4.91**	**$0.45**	**$2.86**	**$0.64**

Table 5 Cost Analysis part 2

Part Number	013	014	015	016	017	018	019
Part Name	Roller	Rope	Motor & Housing	Sleeve	Pulley	Pulley Mount	Cap
Manufacturing Process	Injection Molding	Cut from Stock	ate lasercut & welding	Plate bending & stam	COTS	Machined	Injection molded
Material	ABS	Nylon	14 Ga Stainless Steel	14 Ga Stainless Steel	304 Stainless Steel	304 Stainless Steel	ABS
C_M Material cost [$/unit]	$0.001	$0.343	$13.333	$6.267	$0.505	$1.333	$0.205
C_L Labor cost [$/unit]	$0.83	$0.42	$0.83	$0.83	$0.42	$0.83	$0.83
C_T Tooling cost [$/unit]	$0.05	$0.00	$0.03	$0.03	$0.01	$0.50	$0.05
C_E Equipment cost [$/unit]	$0.208	$0.002	$0.505	$0.842	$0.001	$0.104	$0.093
C_OH Overhead costs [$/unit]	$2.00	$1.00	$2.00	$2.00	$1.00	$2.00	$2.00
C_U Unit cost [$/unit]	$3.09	$1.76	$16.70	$9.97	$1.93	$4.77	$3.18
OME Manufacturing cost [$/uni	$0.004	$1.030	$40.000	$18.800	$1.515	$4.000	$0.616
OME Price [$/unit]	$0.012	$3.089	$120.000	$56.400	$4.545	$12.000	$1.847
P Sales price to break even [$/	$2.88	$0.80	$16.19	$9.13	$0.95	$4.67	$3.09

Table 6 Cost Analysis part 3

The above three tables, when compiled together, give a clear picture of the costs of the component parts within the system. From the table, it can be deduced that either the material or the overhead cost comprise the major driving factor for the cost of a component. Specifically for components that are lightweight and/or injection molded, the overhead cost is the key factor in determining the overall unit cost for that particular component. In contrast, the custom metal components have a very high material cost, which accounts for a large percentage of the overall system cost.

Table 4 demonstrates that the overall unit cost would be $206.68, which, with a desired sale price of $150, makes this product far from profitable. When the team dove into this deeper, it was determined that the price of the 1 x 2 x 1.125 tubing (P/N 001) accounted for nearly 70% of the overall system cost. The primary reason for this extreme price differential when compared to other components was due to the fact that this tubing needed to be six (6) feet in length, making it the heaviest component in the system by far. The original plan was to continue to use 304 Stainless Steel whenever possible; however, this price point was far too high to justify. After doing some additional research, it was determined that 6063 Al would be a much cheaper, yet equally as functional fit for this application. After modifying the material to 6063 Al, the weight of the tubing decreased by over 50% to 4.6 lbs. This lower weight resulted in a material cost of $37, which is nearly $100 in savings per unit sold. See Table 7 below for additional information.

Part Number	001	002	003	004	005	006
Part Name	1x2x0.125 Tube	Shell	Slider	0.75"OD Bearing	Shell Bearing Dowel	Slider Bearing Dowel
Manufacturing Process	Laser Cut Stock Tubing	Injection Molding	Injection Molding	COTS	Machine from stock	Machine from stock
Material	6063 Al	ABS	ABS	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
m Weight of part [lb]	4.6	0.48	0.23	0.002	0.04	0.03
c_m Cost of material [$/lb]	$8.00	$1.30	$1.30	$1.30	$10.00	$10.00
Cost of material reference source	QAvD_BwE&gclsrc=aw.ds	tic-injection-molds-cost				iealed-cold-finish/pid/4473
f Fraction of material that ends up as scrap	0.01	0.05	0.05	0.2	0.05	0.05
C_M Material cost [$/unit]	**$37.17**	**$0.657**	**$0.315**	**$0.003**	**$0.421**	**$0.316**
C_L Labor cost [$/unit]	**$0.50**	**$0.83**	**$0.83**	**$0.42**	**$0.42**	**$0.42**
C_T Tooling cost [$/unit]	**$0.03**	**$0.05**	**$0.05**	**$0.05**	**$0.03**	**$0.03**
C_E Equipment cost [$/unit]	**$0.152**	**$0.167**	**$0.167**	**$0.001**	**$0.004**	**$0.007**
C_OH Overhead costs [$/unit]	**$1.20**	**$2.00**	**$2.00**	**$1.00**	**$1.00**	**$1.00**
C_U Unit cost [$/unit]	**$39.05**	**$3.71**	**$3.36**	**$1.47**	**$1.87**	**$1.76**
OME Manufacturing cost [$/unit]	**$111.52**	**$1.971**	**$0.944**	**$0.010**	**$1.263**	**$0.947**
OME Price [$/unit]	**$334.55**	**$5.912**	**$2.833**	**$0.029**	**$3.789**	**$2.842**
P Sales price to break even [$/unit]	**$38.70**	**$3.54**	**$3.20**	**$0.49**	**$0.96**	**$0.92**
Unit Build Price	$106.18					
Sale Price	$150.00					
Profit per Unit	$43.82					
Annual Revenue	$7,500,000.00					
Net Gain	$2,191,107.45					

Table 7 - Improved Cost Analysis

By substituting the material, the overall Unit build price decreased to $106.18 which leaves a profit of $43.82 per unit. With the intention of selling 50,000 of these automated vertical bike stands in a year, that yields an annual revenue of $7,500,000 and a profit of $2,191,107.45 annually. It is also important to note that in the process of making this change, a commercial variant of the P/N 001 rectangular tubing was found at a cost that was even cheaper than the value in the cost estimate; thus, by purchasing these in bulk, there is even greater potential of the product yielding even higher profit margins.

It is important to note that this economic analysis is based only on the preliminary efforts made by the team in overall product development. We are confident that given more time and design iterations, we would be able to bring the overall system cost down resulting in an even more profitable product.

17. DFA Analysis for Redesign

DFA Analysis Worksheet

Assembly Name: Bike Storage | Team: Group 6 | Date: 4/23/2024

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

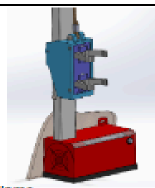
Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name 	Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if not already standard)	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/ Omit Part	Assemble Part Wrong Way Around	Tangle, Nest, or Stick Together	Flexible, Fragile, Sharp or Slippery	Pliers, Tweezers, or Magnifying Glass Needed	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Access/ Visibility	Re-orient Workpiece	Screw, Drill, Twist, Rivet, Bend, or Crimp	Weld, Solder, or Glue	Paint, Lube, Heat, Apply Liquid or Gas	Test, Measure or Adjust
	Housing Subassembly																				
002	Shell	1	7	1	0	M	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
004	Shell Bearings	2	4	0	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
005	Shell Bearing Dowels	1	2	0	1	L	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
008	Front Plate	1	15	1	0	M	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
102	Shell to Plate bolts	2	4	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
202	Part 102 bolt nuts	2	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Sring Actuation Subassembly																				
003	Slider	1	13	1	0	M	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
004	Slider Bearings	4	8	0	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
006	Slider Bearing Dowels	2	4	0	1	L	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
007	Compression Springs	6	12	1	1	L	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tyre Clamping Subassembly																				
009	Tyre Clamps	4	16	1	1	M	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
010	Tension Springs	2	4	0	1	L	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
011	Clamp pins	2	6	1	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
101	Clamp bolts	4	8	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Preload Subassembly																				
012	Torsion Spring	1	4	1	1	L	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
013	Roller	1	2	0	1	L	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
103	Torsion Spring bolts	2	4	0	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Assisted Lifting Subassembly																				
001	Tube	1	12	1	0	L	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0
014	Rope	1	3	1	0	L	1	0	0	1	1	0	1	1	0	1	0	1	0	0	0
015	Motor	1	4	1	0	H	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0
017	Pulley	1	2	1	1	L	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
018	Pulley Mount	1	3	0	1	L	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0
019	Cap	1	1	0	1	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
101	Pulley mount bolt	1	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
104	Rope to Shell bolt	1	2	0	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
204	Part 104 bolt nuts	1	2	0	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	External Interface Parts																				
016	Sleeve	1	5	1	1	L	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0
020	Power Cord	1	1	1	0	L	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0
105	Wall mounting screws	6	6	1	0	L	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Totals	55	158	14	12	0	23	5	0	3	2	0	4	6	3	1	1	14	2	1	0
	Design for Assembly Metrics	93.22		25.5%	←Theor. Effy. Pract. Effy.→		41.8%	0.36		0.36			1.00				1.29				
	Targets	80		60.0%			60.0%	0.30		0.30			1.00				1.00				

Table 8 DFA Analysis for Redesigned System

In order to evaluate the impact of design improvements on the assembly, we performed the DFA analysis once again and analyzed the outcomes to check whether we achieved the targets. Through the design improvements, we were able to eliminate a considerable amount of parts in total, As you can see in Table 9, we were able to reduce the total number of parts from 99 to 55, which in turn reduced the number of interfaces from 320 to 158; therefore, there was an approximately 45% reduction in the total number of parts and interfaces. The complexity factor was also reduced from 178 to 93.2 . There was also an increase in the theoretical and practical efficiencies from 19.25% to 25.5% and 23.2% to 41.8% respectively. For the Error proofing and handling factor, we were able to improve these metrics by a small margin, but we were not able to achieve the target that we had set. The major problem associated with our initial design was insertion and secondary operation, and we did considerably well to be able to reduce these factors. Due to design improvements that led to the elimination of a few springs and dowels, we were able to reduce the insertion factor from 1.63 to 1 and reduce the secondary operation by about 18%.

18. Human Factors, Safety and Ethical Considerations

Designing an Automatic Vertical Bike Stand involves considering various human factors, which will ensure that the product is user-friendly, safe, and can be used by a wide range of users. The height of the clamping mechanism is such that any user can push their bike securely and turn on the motor. We have considered various bike tyre sizes and types so that a wide range of users can use our product. Clear instruction manual will also be provided to assemble, and the manual will guide the users to use our product effectively.

While designing the Automatic Vertical Bike Stand, we took into account various safety considerations. In order to secure the bike to the mechanism, the user needs to push the bike with enough force in order to initiate clamping action. Due to the torsion spring below the mechanism, the entire assembly will be pushed slightly up only when the front wheel of the bike is clamped securely (i.e., when the bearings are out of the slot in the tube). Hence, the user knows if the bike is secure enough to turn on the motor. Also, the clamp will only release the front wheel if the bearings are in the slots. Therefore, the bike won’t fall off when it is clamped securely. Another safety feature is associated with the motor having an inbuilt brake so that the bike won't fall off when the motor is off. We have also provided a safety cap for the pulley so that no one can accidentally put their fingers in the pulley, which can cause serious injury when the motor is on. This pulley also somewhat serves the purpose of aesthetics in the design.

While manufacturing our product, we will be considering the highest labor standards by ensuring fair wages, a safe working environment, and reasonable working hours for all employees. Additionally, we will maintain complete transparency and honesty while marketing our product. The commitment to maintain ethical practices and transparency is a key factor in building trust with our prospective users.

19. Conclusion

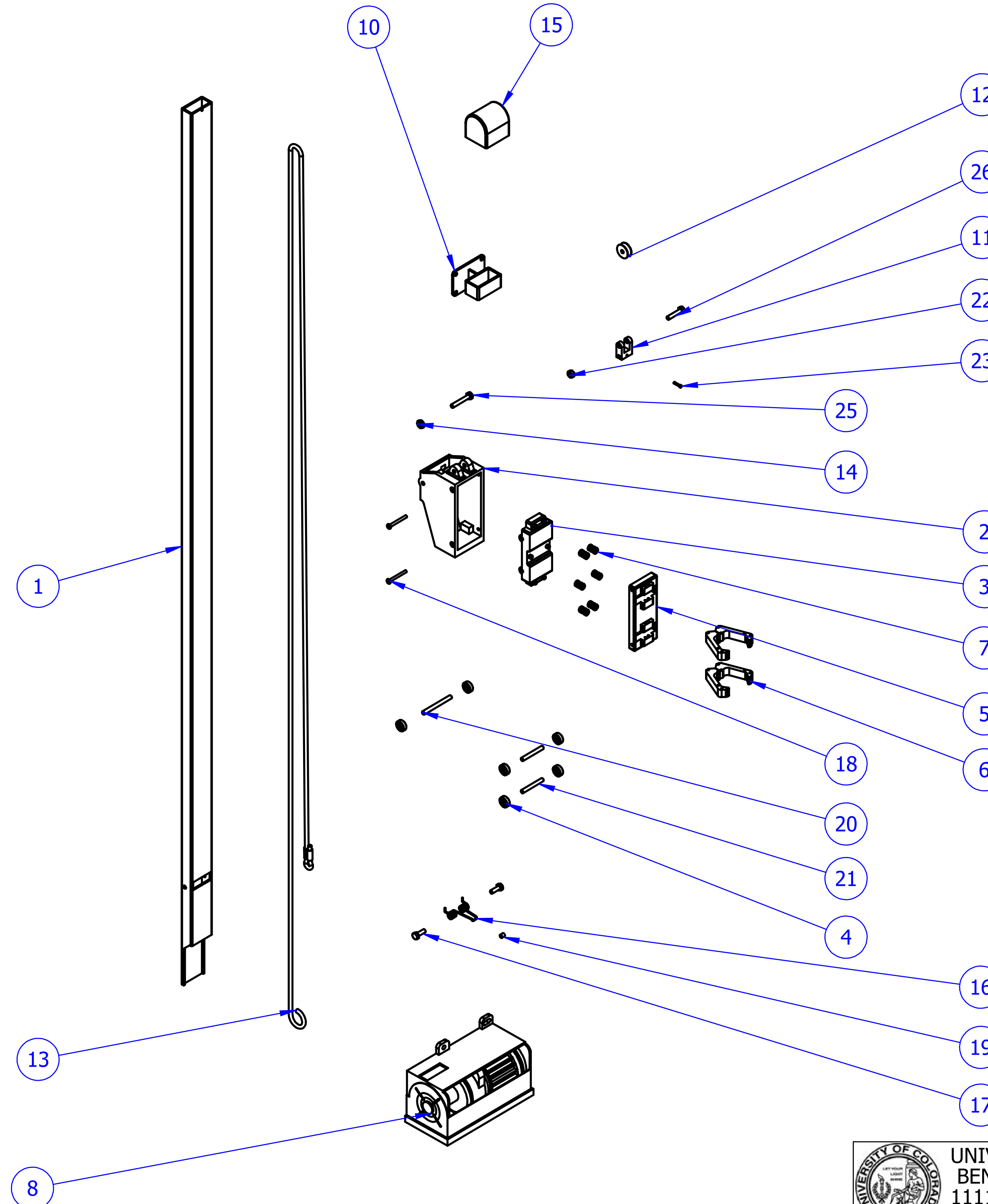
In conclusion, the development of the Automated Vertical Bike Storage System resulted in some major component design improvements, increased manufacturing process consistency, and decreased product cost. By evaluating this product from the perspective of Design for Manufacturing and Assembly, the product was able to be improved in countless ways. For example, a focus on uniformity of manufacturing process allowed our team to limit the number of processes to three, thereby limiting the number of vendors and enhancing overall product quality. Specific design changes ensured that the product could be more readily assembled by technician and consumer alike. The focus on utilizing injection molded parts decreased overall component cost significantly as did the usage of and modification of additional off the shelf components. While the product certainly has additional design iterations and considerations to be made, it has improved tremendously as a result of the efforts made in this project. It may not be quite ready to be manufactured and introduced into the market, but it has the potential to be a serious contender as a leading bike storage solution.

20. Appendix A - Individual drawings and Assembly Drawing with BOM

Refer drawings below.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	001	1X2X0.125 TUBE	1
2	002	SHELL	1
3	003	SLIDER	1
4	004	0.75 IN OD BEARING	6
5	008	FRONT PLATE	1
6	009	TIRE CLAMP	4
7	007	COMPRESSION SPRING	6
8	015	MOTOR AND HOUSING	1
9	010	TENSION SPRING	2
10	016	SLEEVE	1
11	018	PULLEY MOUNT	1
12	017	PULLEY	1
13	014	ROPE	1
14	HHJNUT 0.2500-20-D-N		1
15	019	CAP	1
16	012	TORSION SPRING	1
17	HBOLT 0.2500-28x0.75x0.75-N		2
18	CR-BHMS 0.164-36x1.625x1-N		2
19	013	ROLLER	1
20	005	SHELL BEARING DOWEL	1
21	006	SLIDER BEARING DOWEL	2
22	HNUT 0.2500-20-D-N		1
23	CR-FIMS 0.112-48x0.5625x0.5625-N		1
24	CR-FIMS 0.112-48x0.5x0.5-N		4
25	HBOLT 0.2500-20x1.625x0.75-N		1
26	HBOLT 0.2500-20x1.25x0.75-N		1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/23/2024
B	ADDED PNS TO BOM	4/25/2024

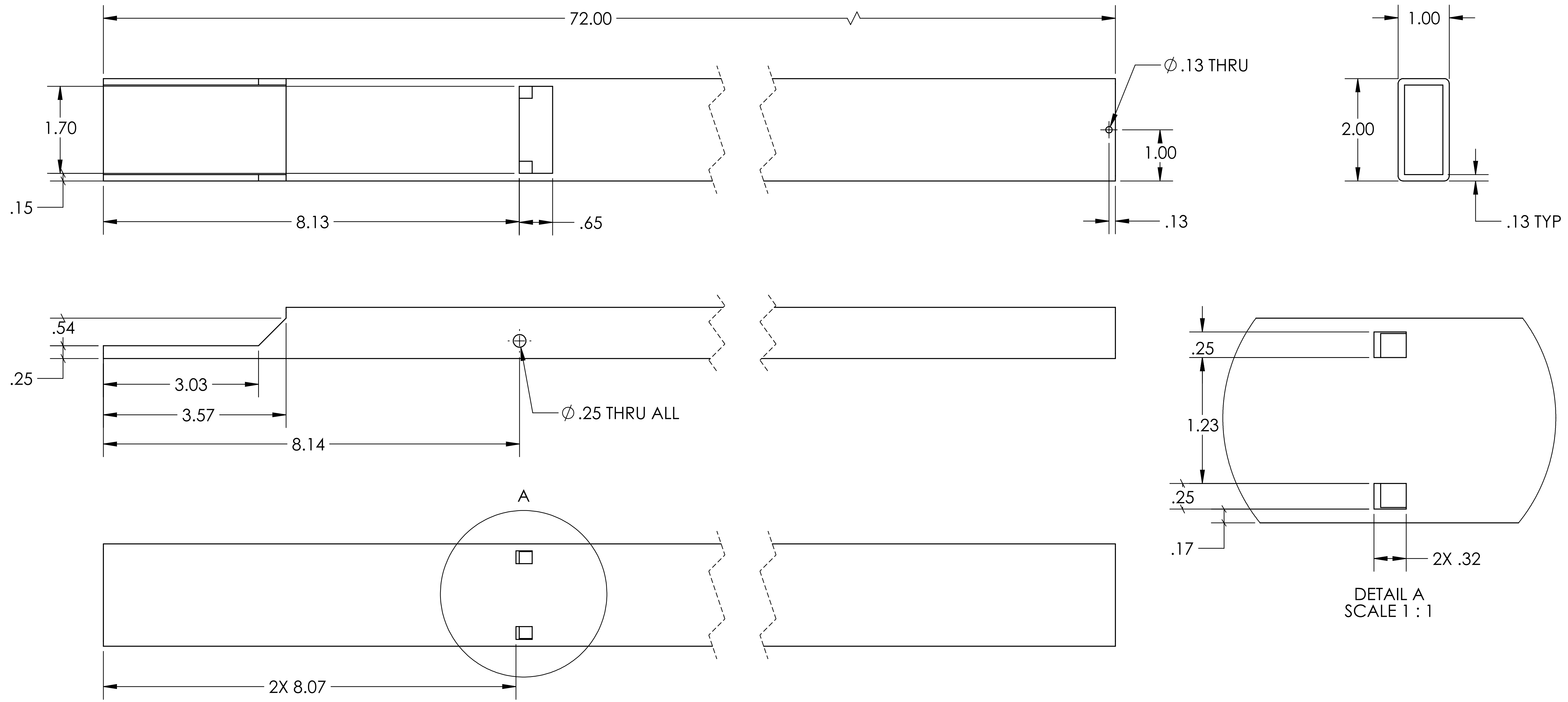


UNIVERSITY OF COLORADO
BEN ERICKSON
1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION
ASSEMBLY

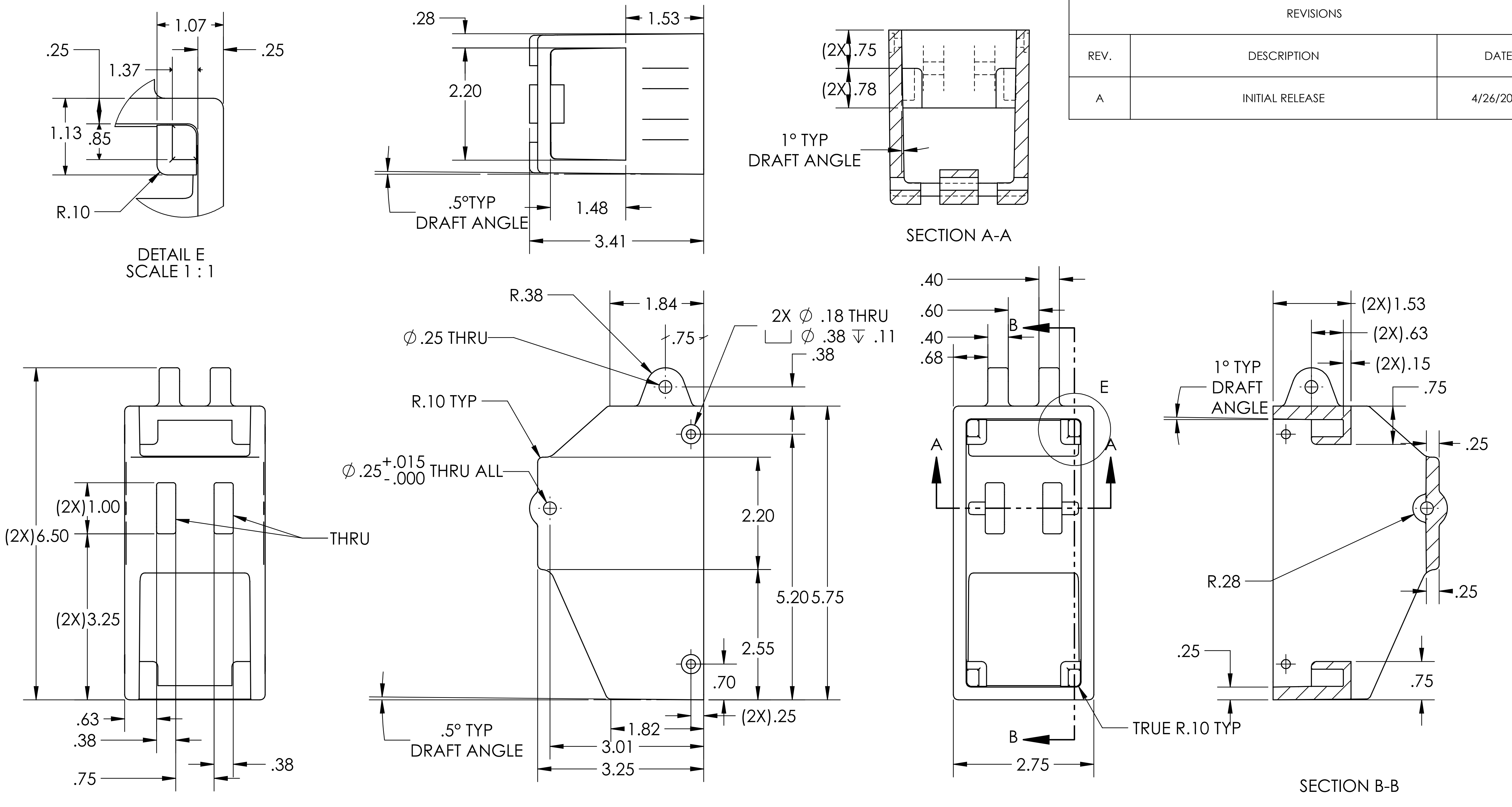
PN	REV	SHEET
000	B	1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 1:2
2. REMOVE ALL BURRS

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL AL 6063		DESCRIPTION TUBE
FINISH NONE		PN 001 · REV A · SHEET 1 of 1



REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024

NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 1:2
2. REMOVE ALL BURRS

TOLERANCES UNLESS NOTED: X.X ±0.05; X.XX ±0.01; X.XXX ±0.005; X.X° °0.5; UNITS: INCHES	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL: ABS	DESCRIPTION: SHELL	
FINISH: NONE	PN: 002	REV: A; SHEET: 1 of 1

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REVISIONS		
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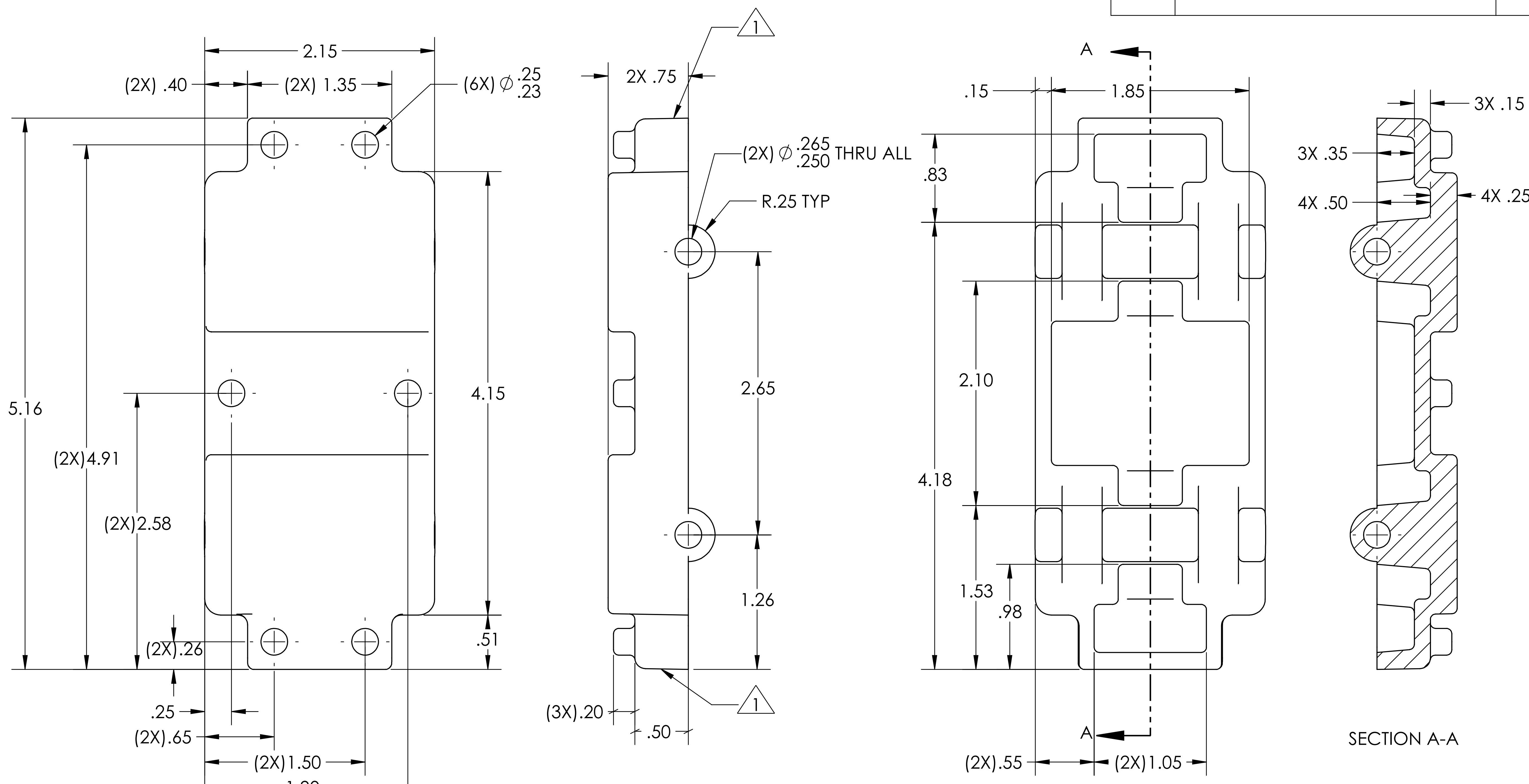
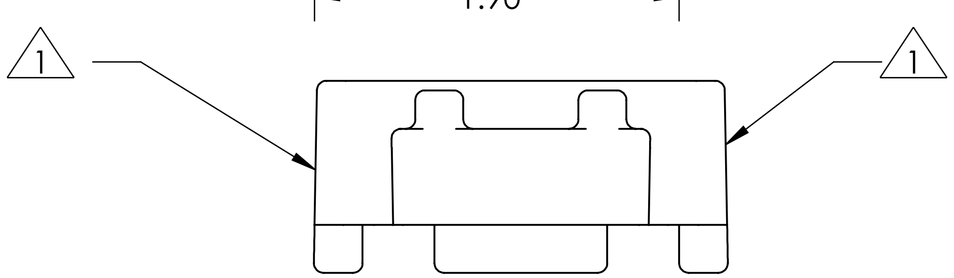
A	INITIAL RELEASE	4/26/2024





NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 1:1
2. REMOVE ALL BURRS
3. 1 REPRESENTS 1DEG° DRAFT ANGLE
3. ALL POCKETS HAVE 5DEG° DRAFT ANGLE

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL ABS		DESCRIPTION SLIDER
FINISH NONE		PN 003 · REV A · SHEET 1 of 1

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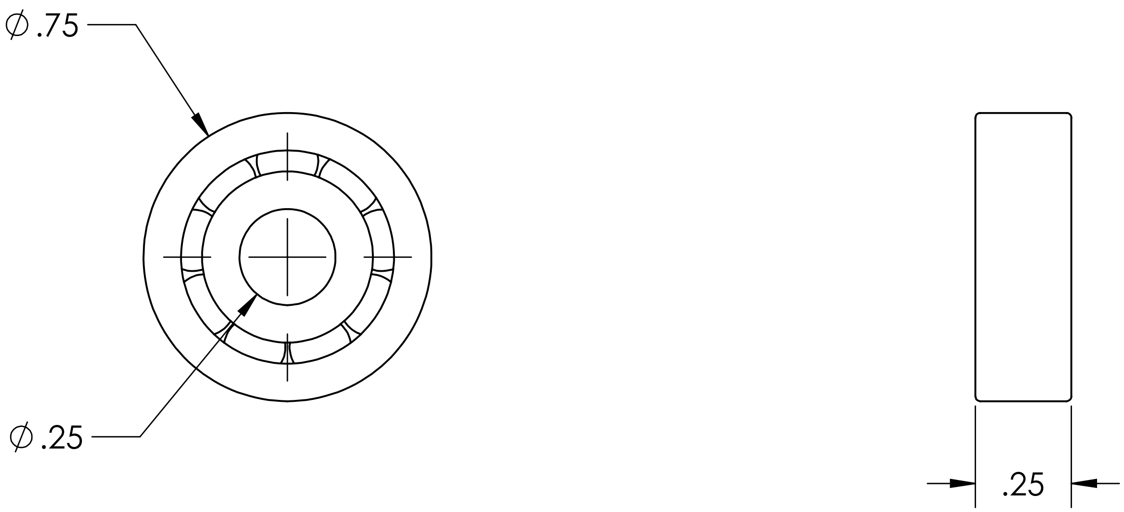
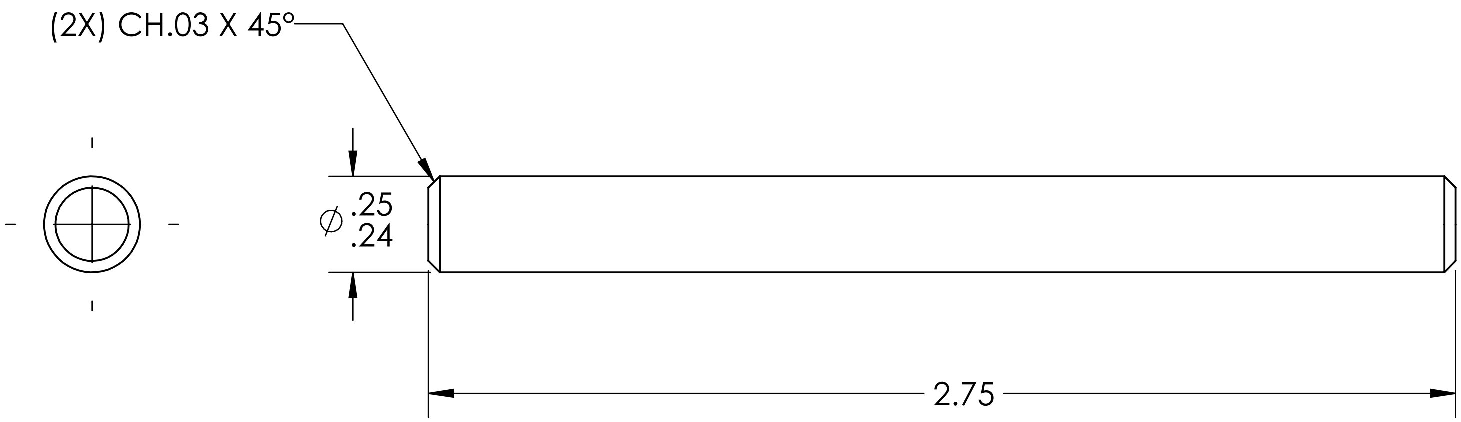


NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 1:2
2. REMOVE ALL BURRS

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL -		DESCRIPTION BEARING	
FINISH -		PN 004	REV A
SHEET 1 of 1			

REVISIONS		
REV.	DESCRIPTION	DATE
A	INTIAL RELEASE	4/25/2024

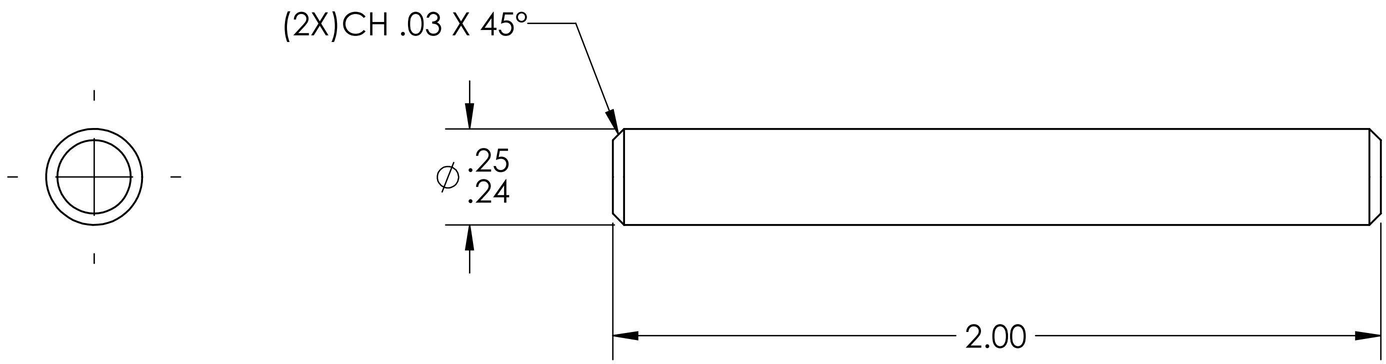


NOTES:

1. UNLESS OTHERWISE SPECIFIED SCALE 2:1
2. REMOVE ALL BURRS

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL STAINLESS STEEL		DESCRIPTION SHELL BEARING DOWEL	
FINISH NONE		PN 005	REV A
			SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/25/2024



NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 2:1
2. REMOVE ALL BURRS

TOLERANCES UNLESS NOTED: X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5 UNITS: INCHES		UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL STAINLESS STEEL		DESCRIPTION SLIDER BEARING DOWEL		
FINISH NONE		PN 006	REV A	SHEET 1 of 1

REVISIONS		
REV.	DESCRIPTION	DATE
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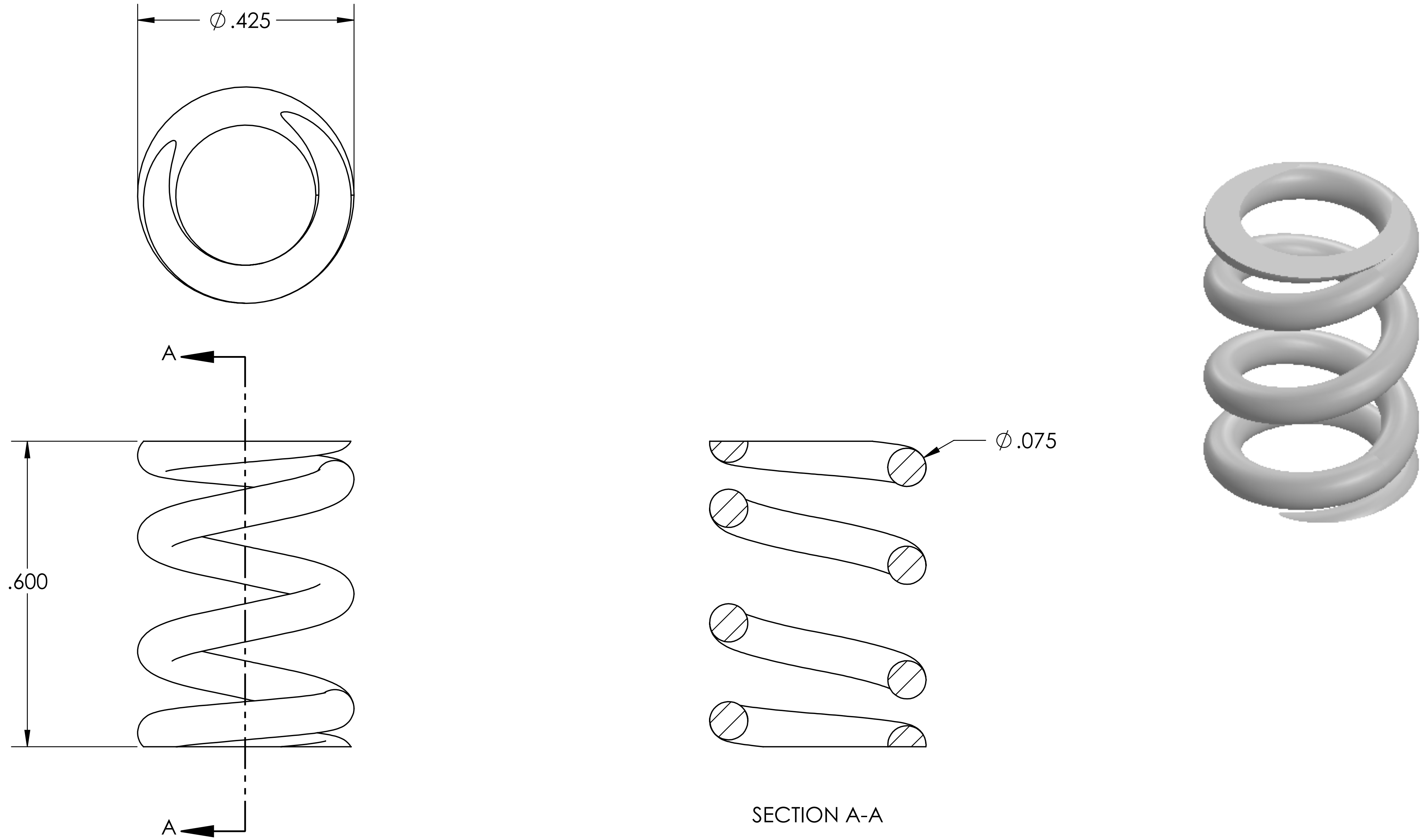
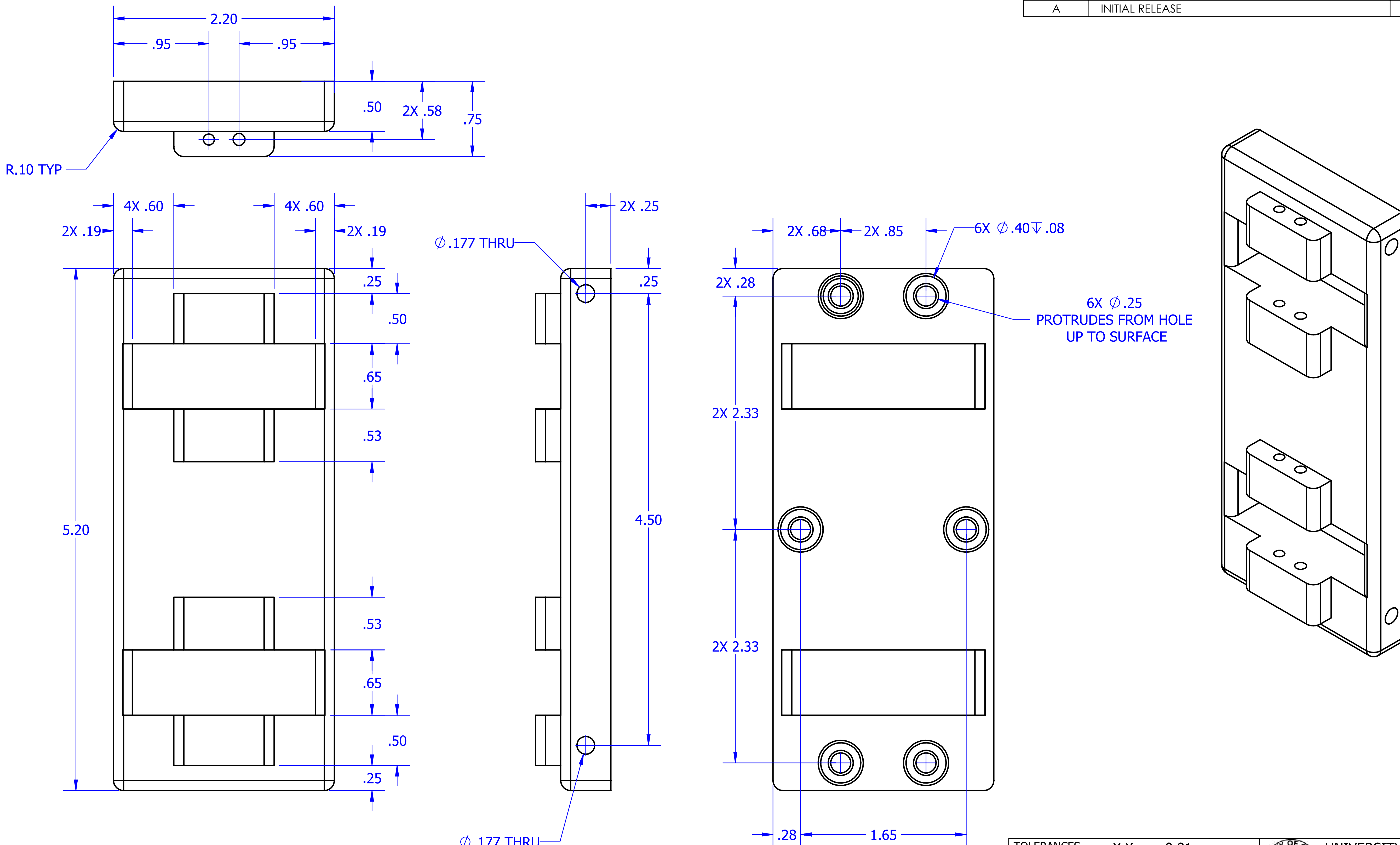


NOTES:

1. UNLESS OTHERWISE SPECIFIED SCALE 4:1
2. SPRING CONSTANT SHALL EB BETWEEN 1.3 - 1.5 LB/IN

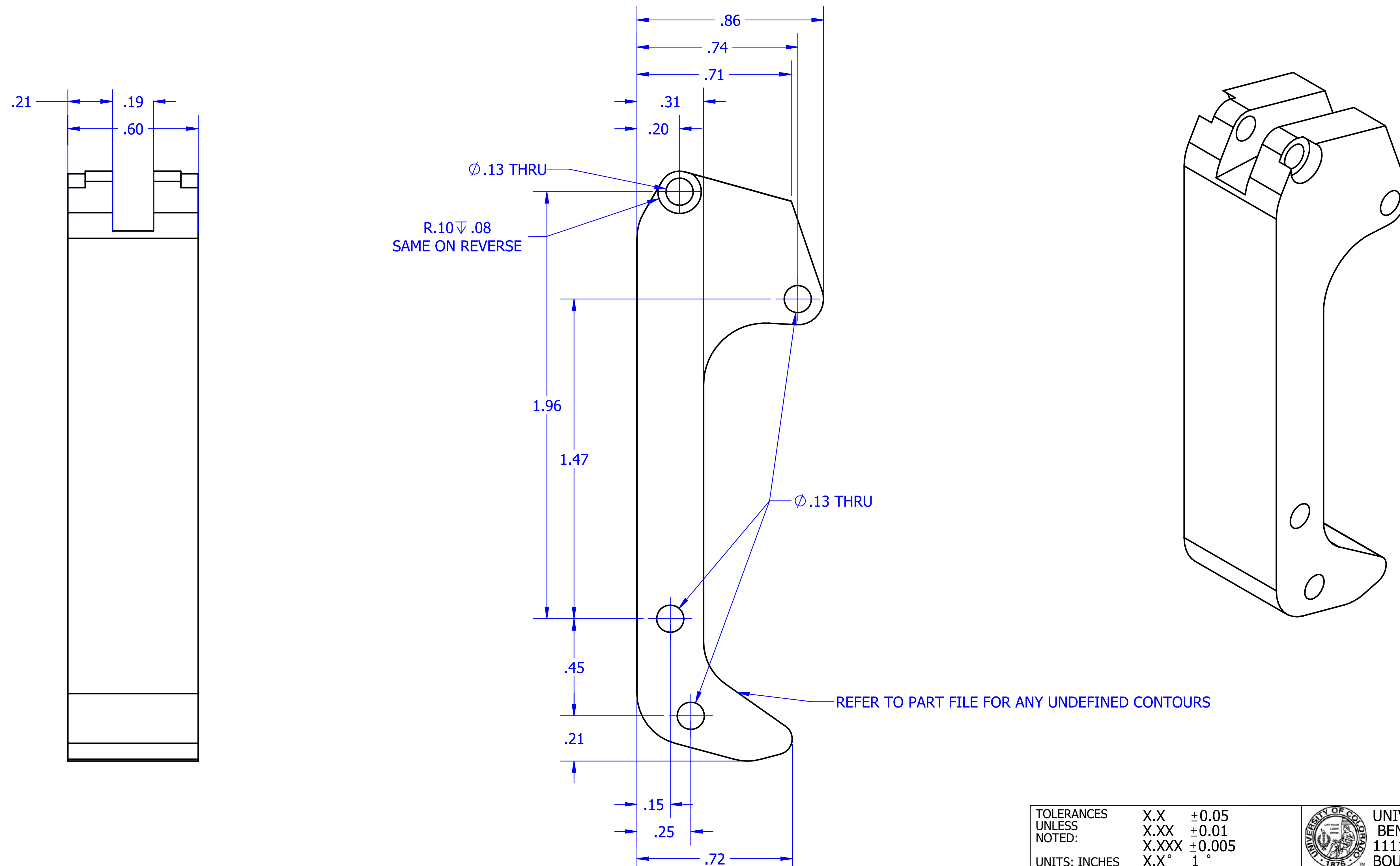
TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005 X.X° ± 0.5°	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309	
UNITS: INCHES			
MATERIAL STAINLESS STEEL		DESCRIPTION COMPRESSION SPRING	
FINISH NONE		PN 007	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



TOLERANCES UNLESS NOTED: X.X ±0.01; X.XX ±0.05; X.XXX ±0.005; X.X° 1°. UNITS: INCHES		UNIVERSITY OF COLORADO BEN ERICKSON 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL ABS		DESCRIPTION FRONT PLATE
FINISH NONE	PN 008 / REV A	SHEET 1 of 1

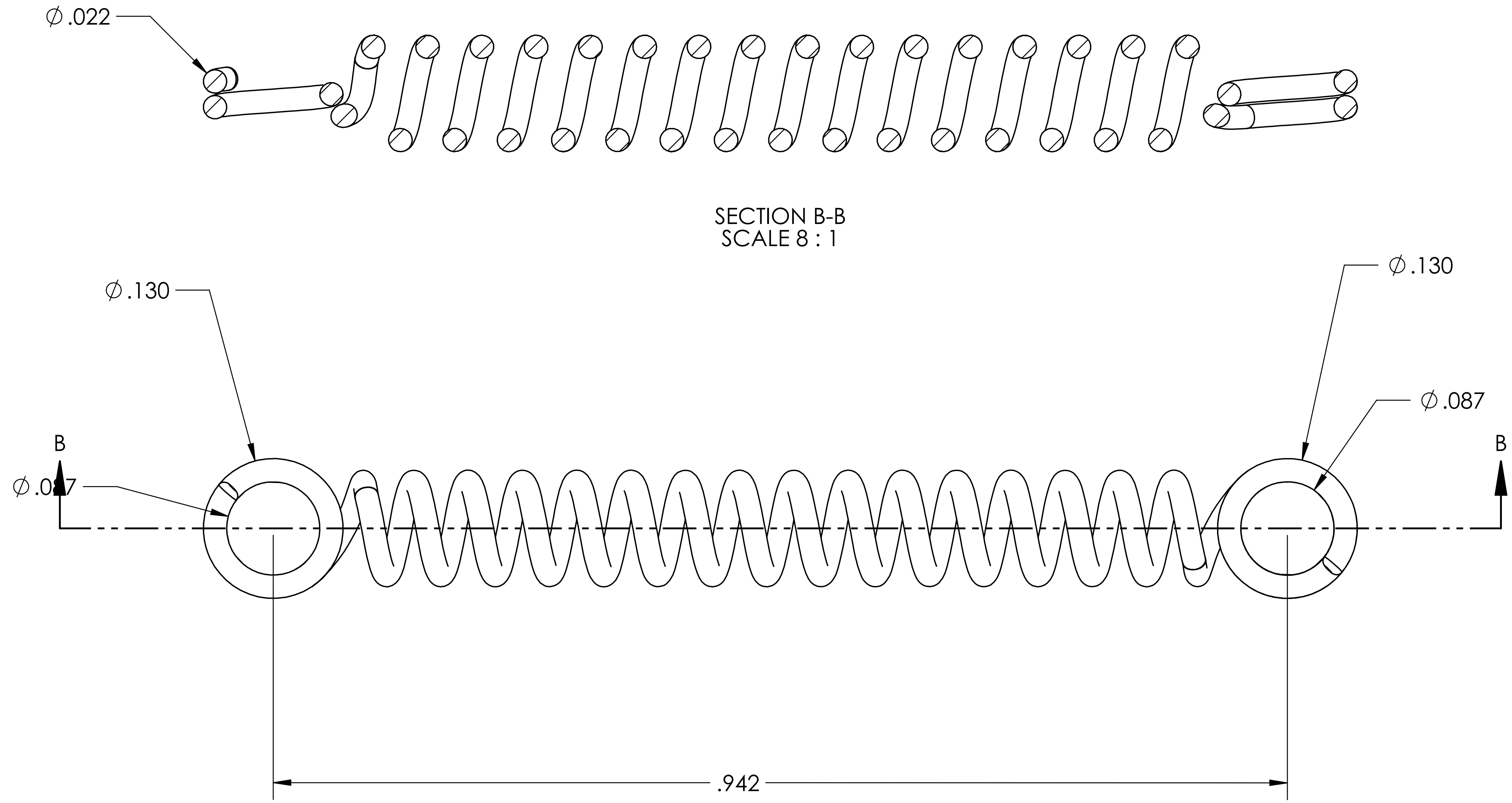
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005	UNIVERSITY OF COLORADO BEN ERICKSON 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
UNITS: INCHES	X.X° 1°				
MATERIAL ABS		DESCRIPTION TIRE CLAMP			
FINISH NONE		PN 009	REV A		SHEET 1 of 1

PROPRIETARY AND CONFIDENTIAL

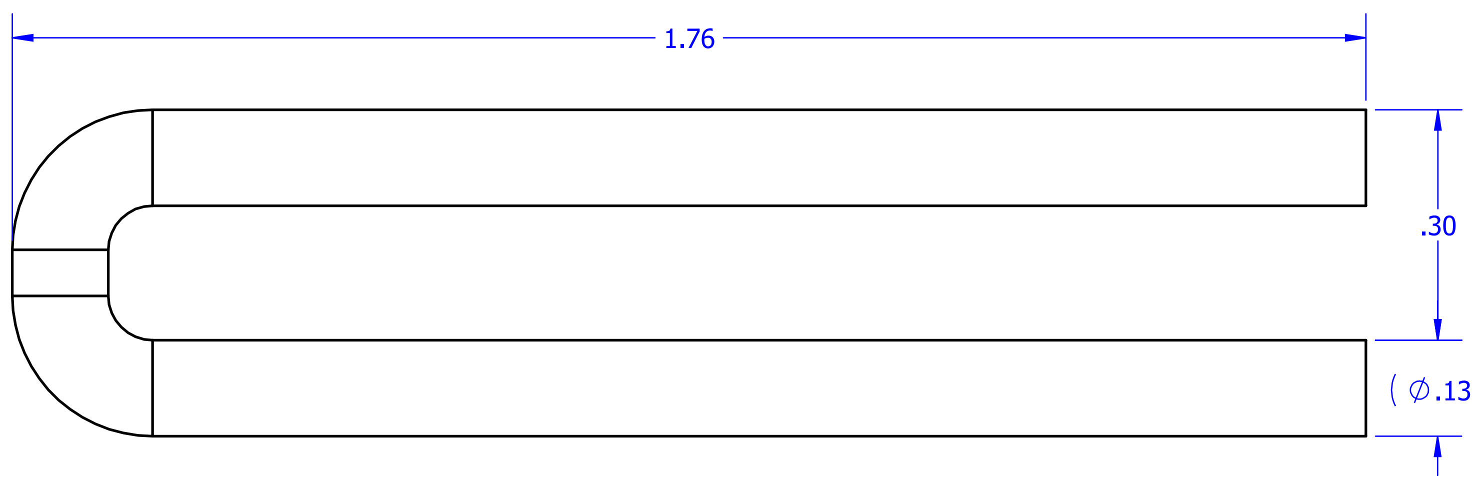
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024

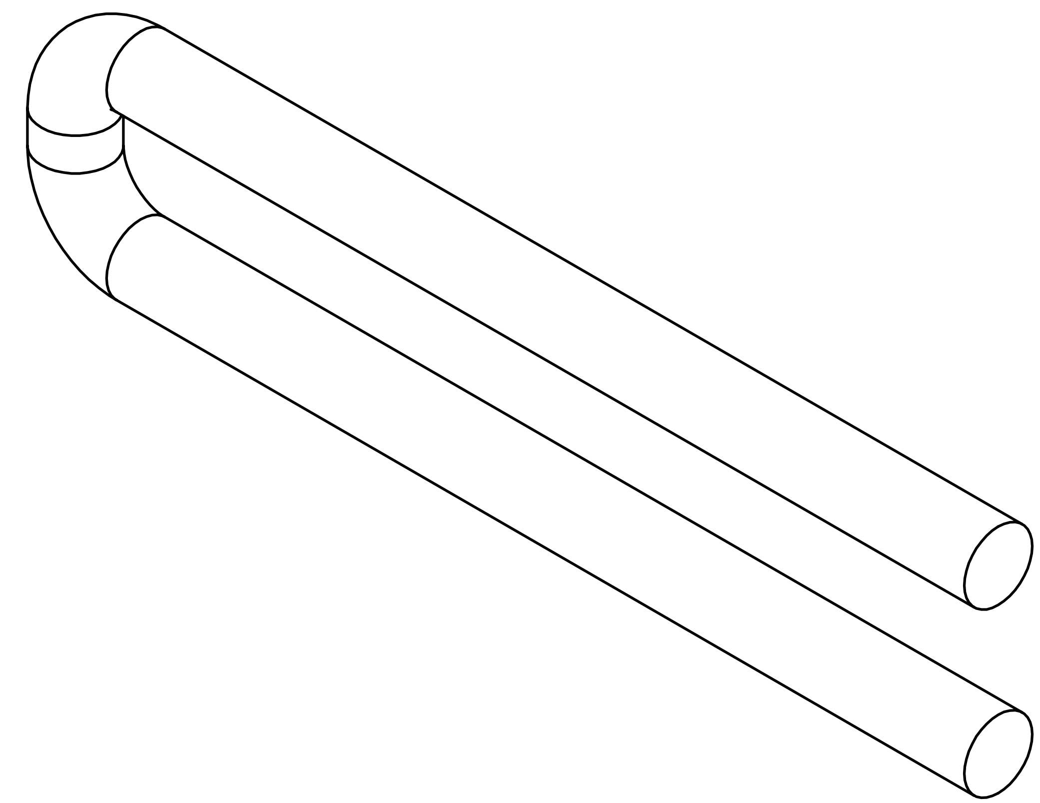


NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 8:1
2. SPRING CONSTANT SHALL EB BETWEEN 1.5 - 2 LB/IN

TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005 X.X° ± 0.5°	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309
UNITS: INCHES		
MATERIAL STAINLESS STEEL		DESCRIPTION TENSION SPRING
FINISH NONE		PN 010 · REV A · SHEET 1 of 1

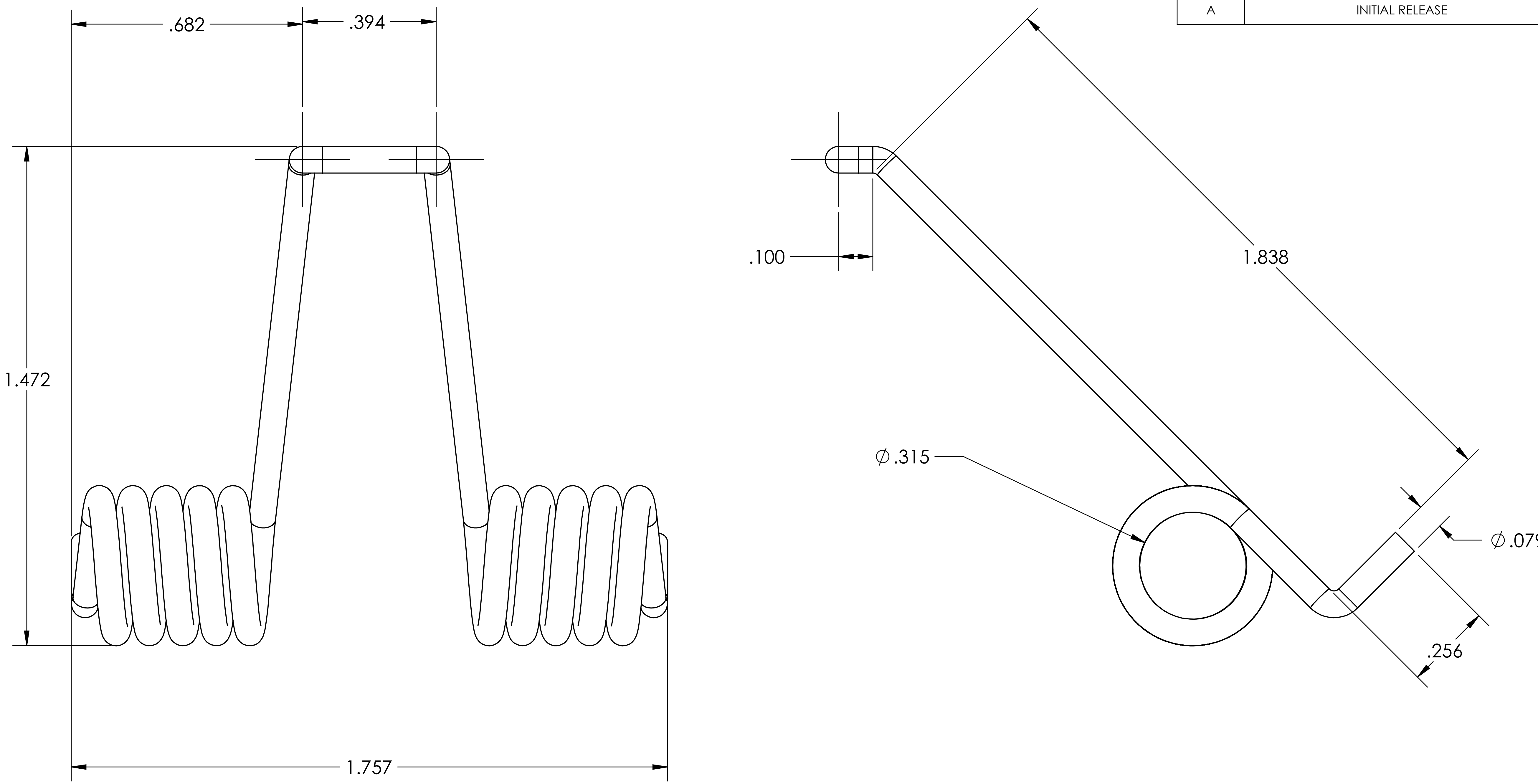
REV.	DESCRIPTION	DATE
A	INTIAL RELEASE	4/26/2024





TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005	UNIVERSITY OF COLORADO BEN ERICKSON 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES	X.X° 1°	
MATERIAL STAINLESS STEEL 304 1/8" WIRE		DESCRIPTION CLAMP PIN
FINISH NONE		PN 011 · REV A · SHEET 1 of 1

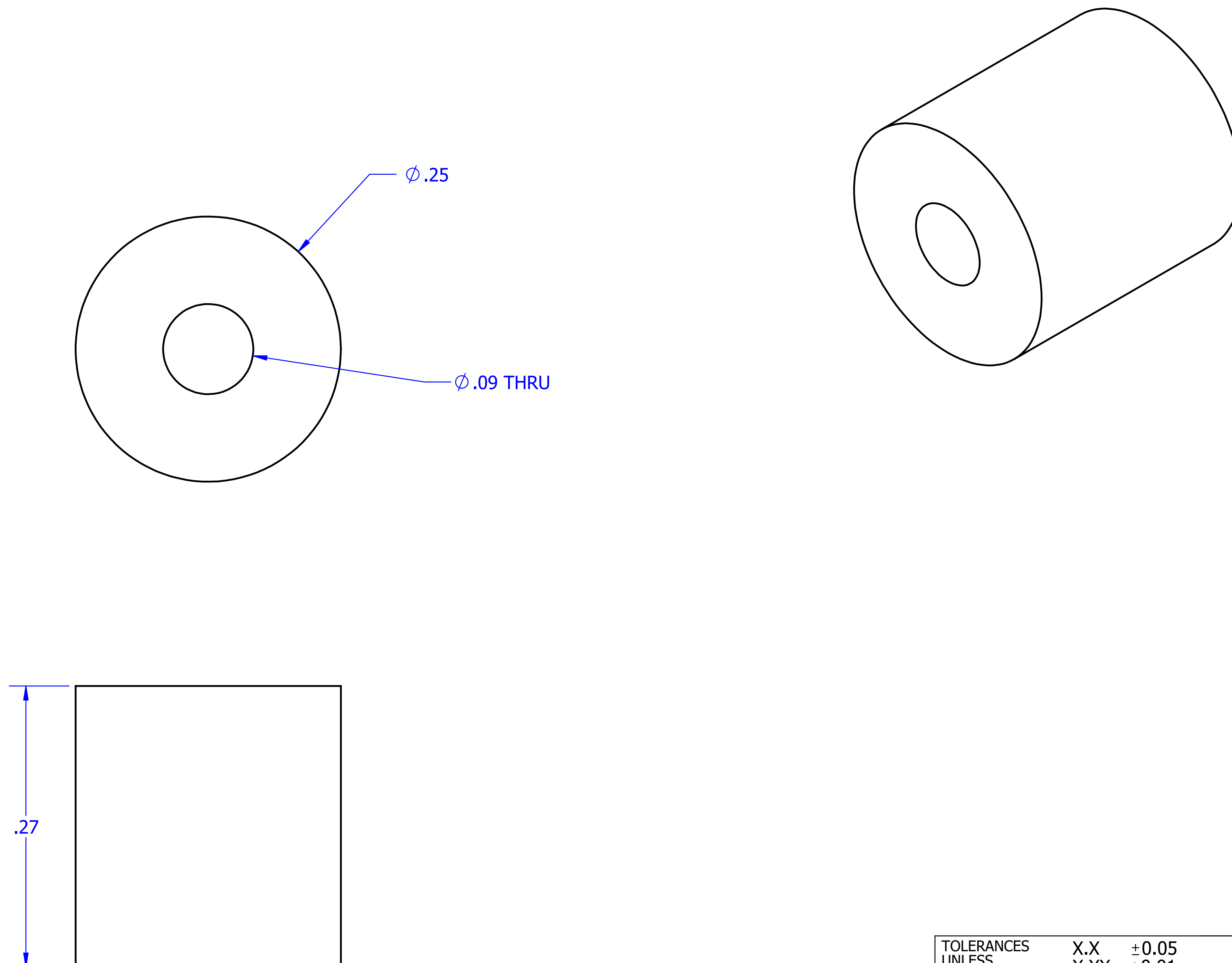
REVISIONS		
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 3:1
2. SPRING CONSTANT SHALL EB BETWEEN 1.2 - 1.5 IN.LBS/DEG

TOLERANCES UNLESS NOTED:	X.X ± 0.05 X.XX ± 0.01 X.XXX ± 0.005 X.X° ± 0.5°	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309
UNITS: INCHES		
MATERIAL STAINLESS STEEL		DESCRIPTION TORSION SPRING
FINISH NONE	PN 012	REV A — SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITAL RELEASE	4/26/2024



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° 1 °	UNIVERSITY OF COLORADO BEN ERICKSON 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL ABS		DESCRIPTION ROLLER
FINISH NONE		PN 013 · REV A · SHEET 1 of 1

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REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024

1 ROPE DIAMETER TO BE 0.25 INCHES. OVERALL LENGTH IS TO BE 140+/- 5 INCHES

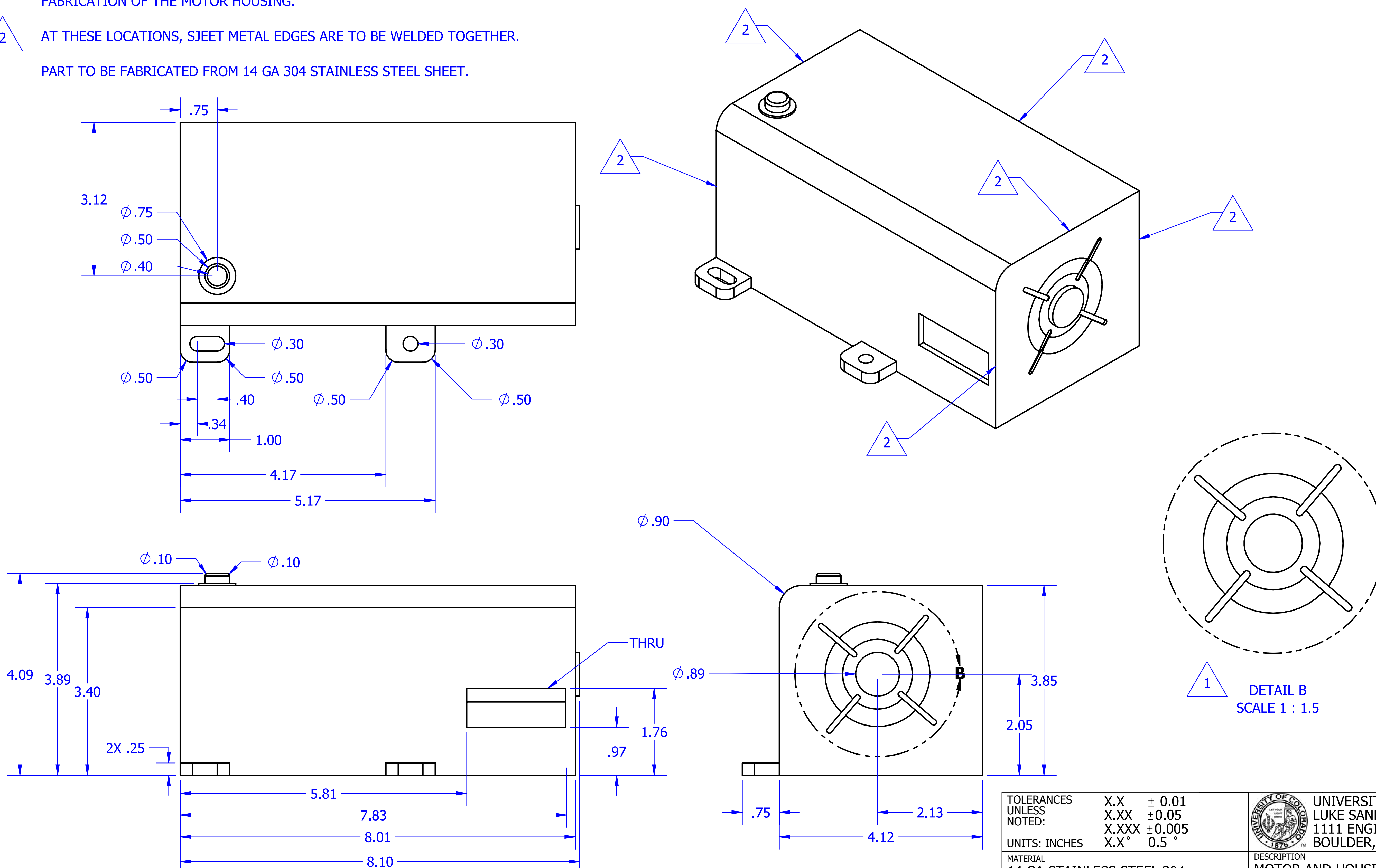
TOLERANCES UNLESS NOTED:	X.X ± 0.5 X.XX ±0.1 X.XXX ±0.05 X.X° 1 °	UNIVERSITY OF COLORADO LUKE SANFORD 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL NYLON		DESCRIPTION ROPE
FINISH NONE		PN 014 · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024

1. THE FEATURES SHOWN HERE (DETAIL B) ARE PART OF THE COTS MOTOR AND NOT RELEVANT TO THE FABRICATION OF THE MOTOR HOUSING.

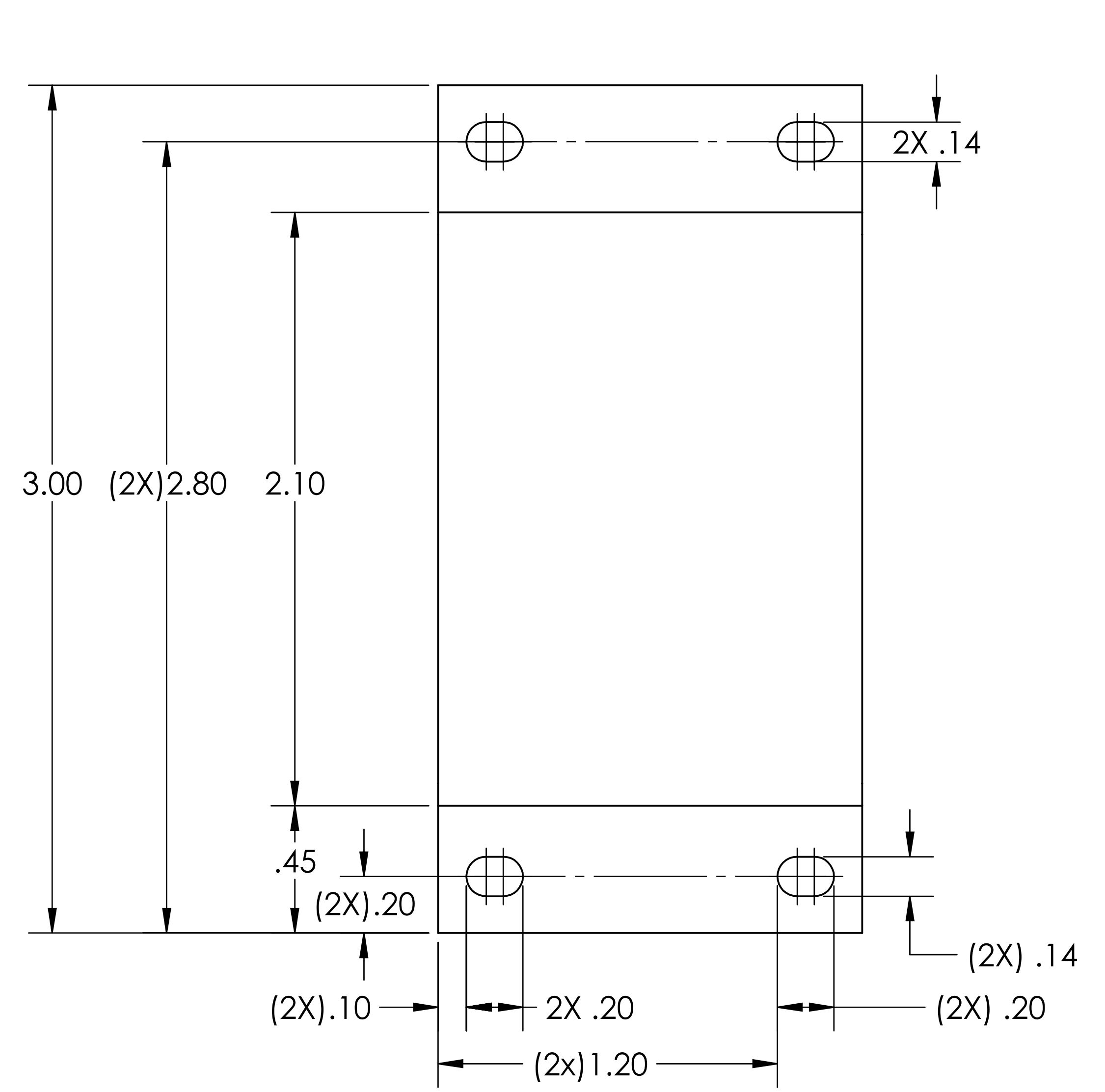
2. AT THESE LOCATIONS, SJEET METAL EDGES ARE TO BE WELDED TOGETHER.

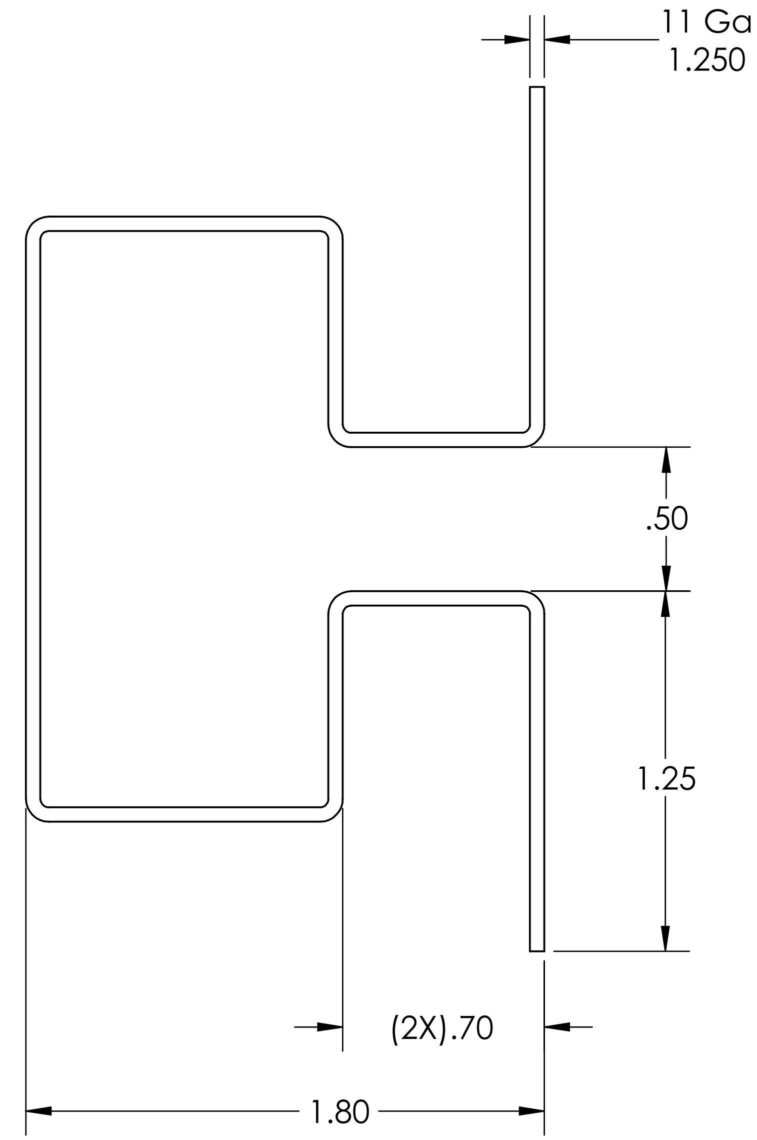
PART TO BE FABRICATED FROM 14 GA 304 STAINLESS STEEL SHEET.

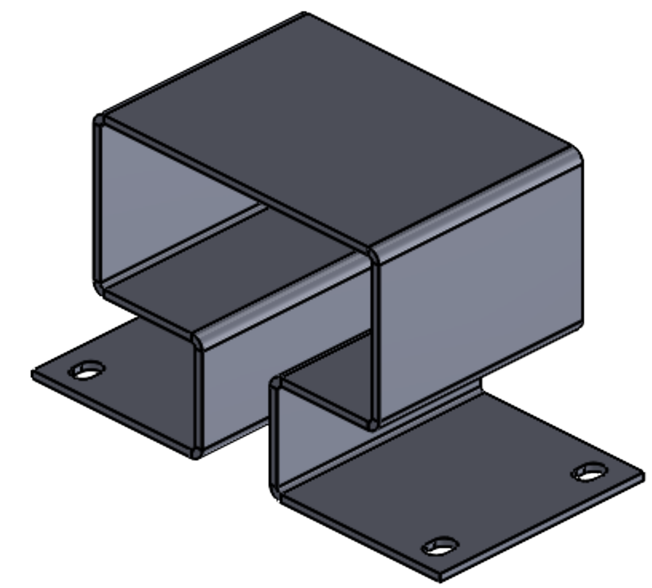


TOLERANCES UNLESS NOTED: X.X ± 0.01, X.XX ±0.05, X.XXX ±0.005, X.X° 0.5° UNITS: INCHES		UNIVERSITY OF COLORADO LUKE SANFORD 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL 14 GA STAINLESS STEEL 304		DESCRIPTION MOTOR AND HOUSING
FINISH NONE	PN motor REV A	SHEET 1 of 1

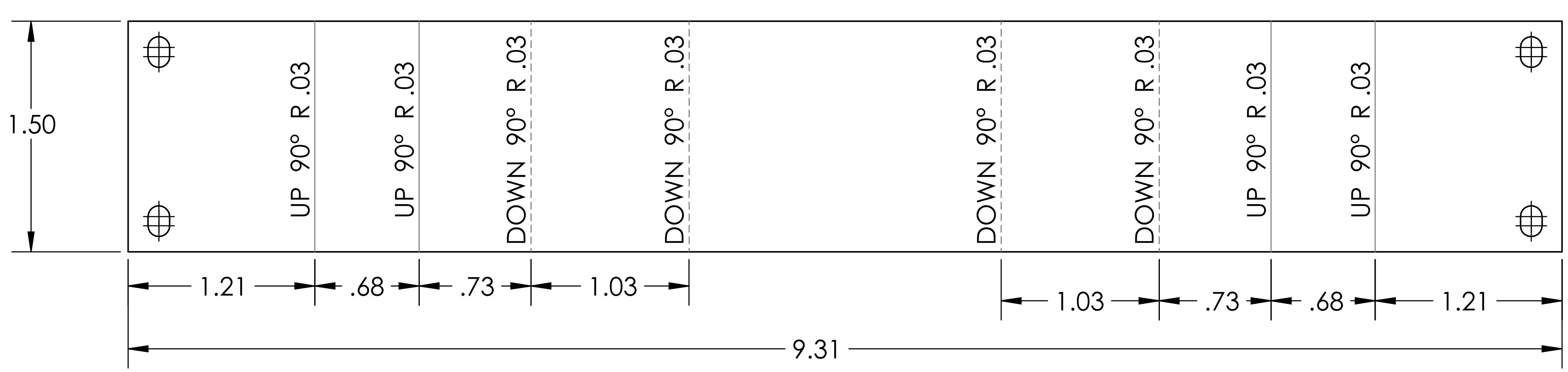
REVISIONS		
REV.	DESCRIPTION	DATE
A	iNITIAL RELEASE	4/25/2024







ISOMETRIC VIEW
SCALE : 1:1

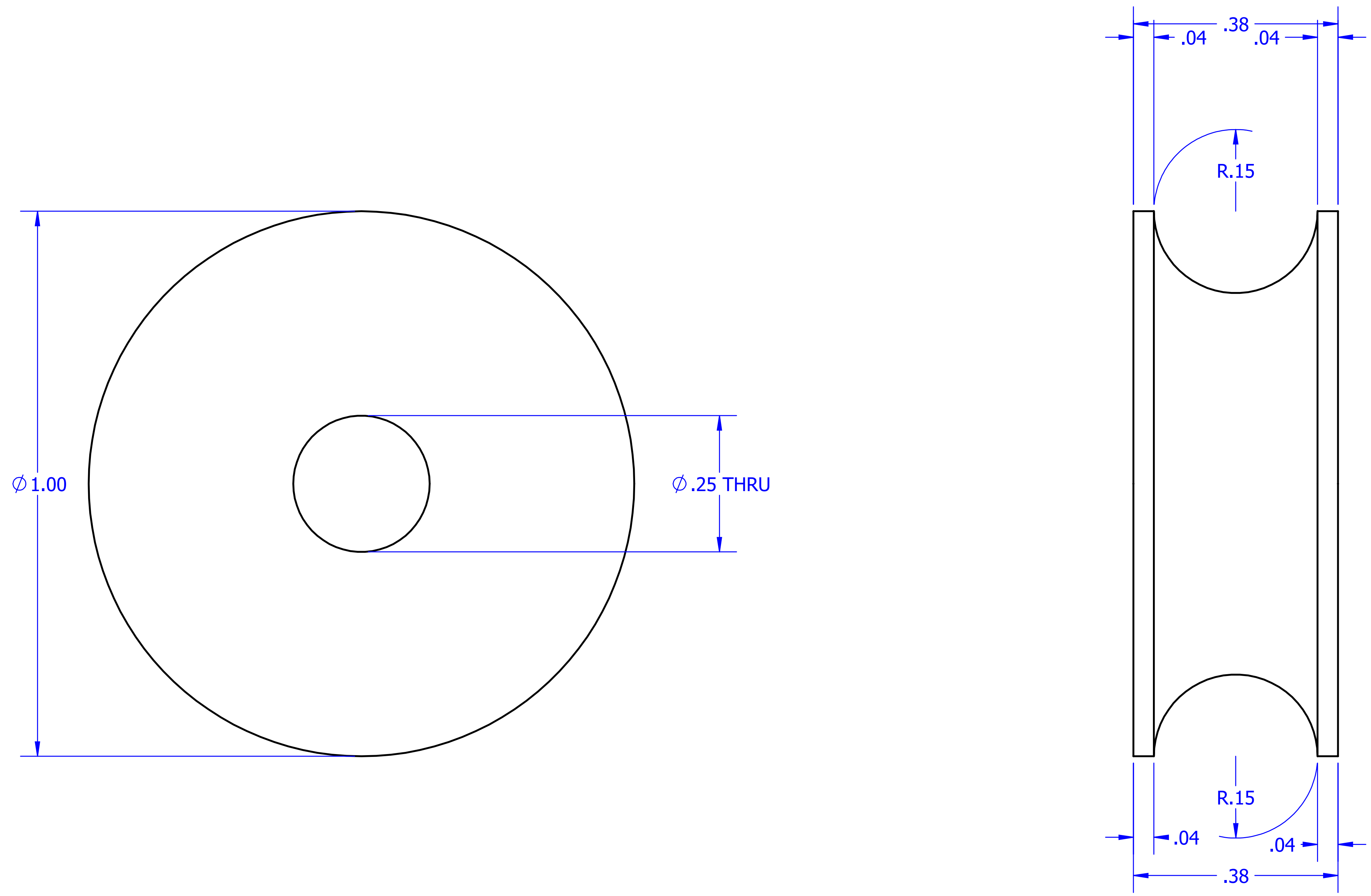


FLATTEN VIEW
SCALE : 1:1

NOTES:
1. UNLESS OTHERWISE SPECIFIED SCALE 3:2
2. REMOVE ALL BURRS

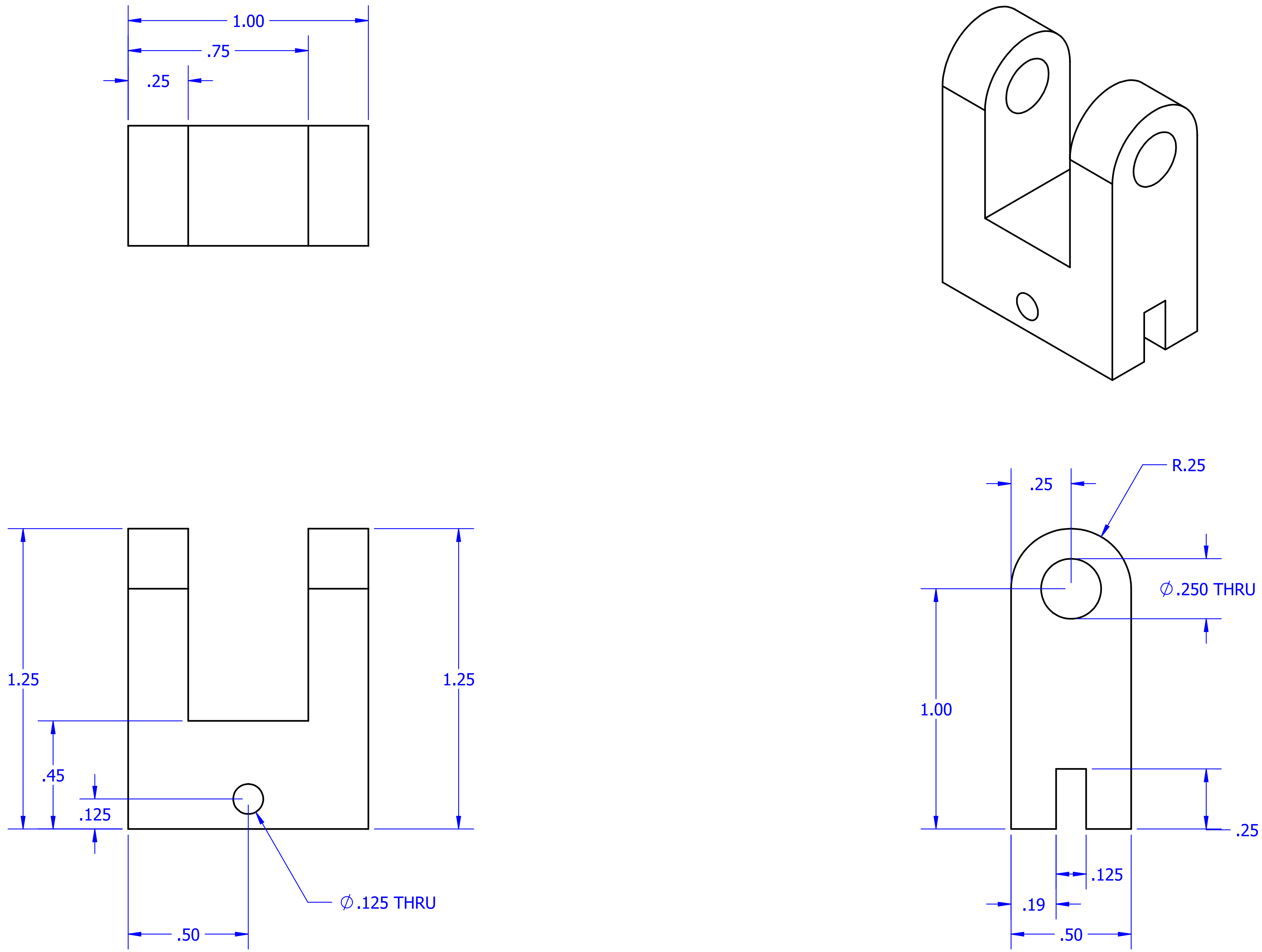
TOLERANCES UNLESS NOTED:	X.X ±0.05 X.XX ±0.01 X.XXX ±0.005 X.X° °0.5	UNIVERSITY OF COLORADO MCEN 5045 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL STAINLESS STEEL 304 14 GA		DESCRIPTION SLEEVE
FINISH NONE		PN 016 · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.5 X.XX ±0.1 X.XXX ±0.05 X.X° 1°	UNIVERSITY OF COLORADO LUKE SANFORD 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL 6063 AL		DESCRIPTION PULLEY		
FINISH N/A		PN 017	REV A	SHEET 1 of 1

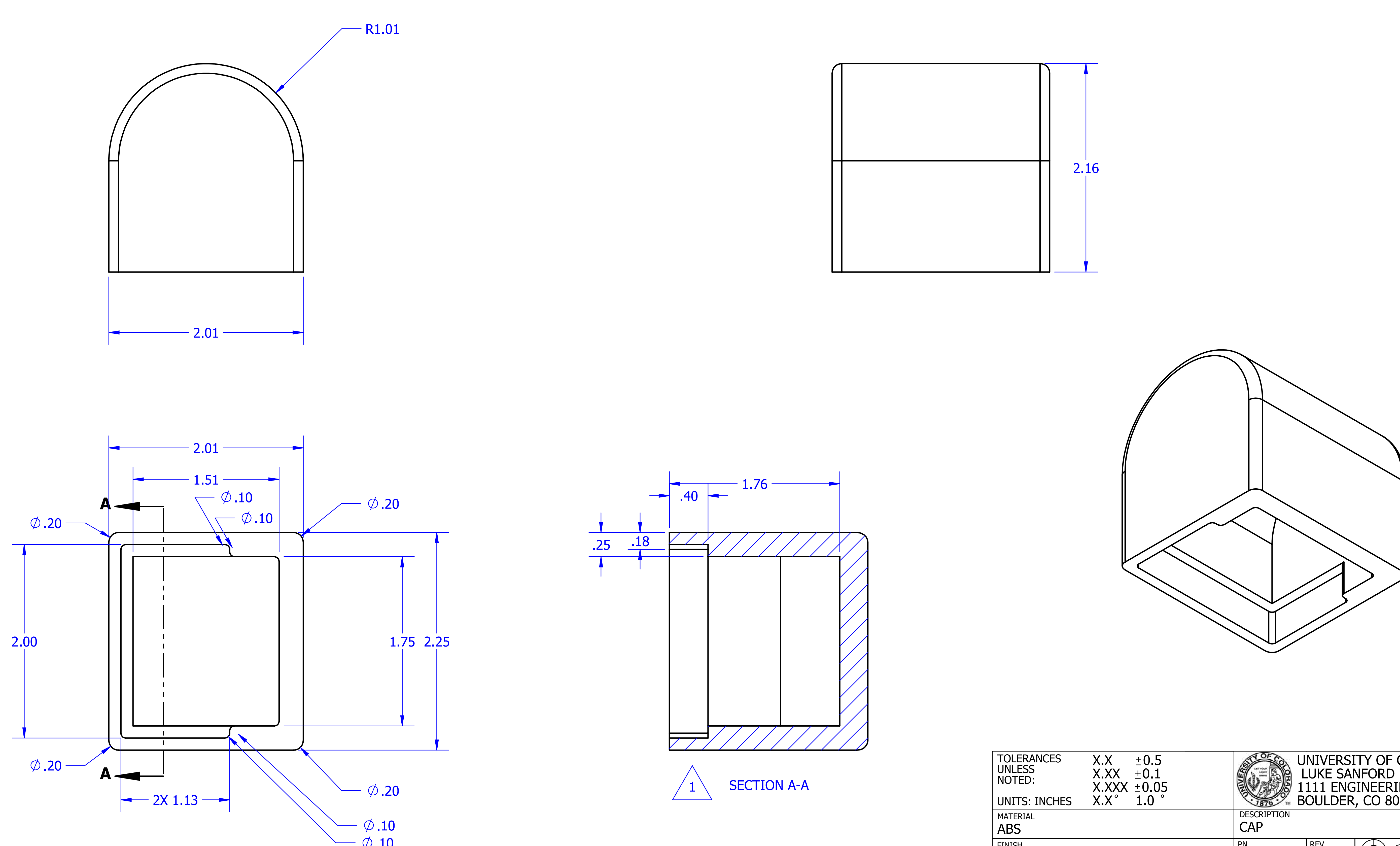
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024



TOLERANCES UNLESS NOTED:	X.X ±0.5 X.XX ±0.1 X.XXX ±0.05 X.X° 1°		UNIVERSITY OF COLORADO LUKE SANFORD 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES			
MATERIAL 304 STAINLESS STEEL			DESCRIPTION PULLEY MOUNT
FINISH NONE	PN 018	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	4/26/2024

1 DRAFT ANGLE TO BE 1.0 DEGREES



SECTION A-A

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ±0.5 X.XX ±0.1 X.XXX ±0.05 X.X° 1.0°	UNIVERSITY OF COLORADO LUKE SANFORD 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS		DESCRIPTION CAP	
FINISH NONE		PN 019	REV A
			SHEET 1 of 1

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