Reverse Engineering Project: All-Terrain Toy Car

Section No: 001

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MCEN 5045: Design for Manufacturability

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EXECUTIVE SUMMARY

This report goes over the objective and description in reverse engineering an all-terrain toy car, specifically "Trix Trux Monster Trucks That Flip, Climb and Zip - Line Powerful 4 Wheel Drive" (seen in Figure 1) for MCEN 5045: Design for Manufacturability. The goal of this project is to understand the key elements involved in modifying existing product design to improve either functionality, manufacturing processes, assembly processes, or overall consumer satisfaction. The team is comprised of three people whose names and contact information are in Table 1.

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Table 1. Contact Information for the team.

Figure 1. The all-terrain toy car that will be disassembled for the project.

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I. DESIGN PROBLEM AND OBJECTIVES

In order to understand the process of reverse engineering a commercial product, the team chose a monster toy truck advertised to climb, flip, and zip-line an accompanying obstacle course. This product has 18 individual parts that can be manufactured by a number of different ways that the team analyzed. This item was also selected because it is very inexpensive, both in cost and price of the product. The purpose of this project is to understand how a product like ours is manufactured, look for areas of improvement in design, assembly, or manufacturability, and enact those design changes.

The team has disassembled the monster toy car and organized the parts into various subassemblies. Research into costs and manufacturing processes associated with each individual component has been done. Design modifications were then made to reduce total assembly cost, improve functionality of the car to do its functions as advertised, and improve overall manufacturability. These results can be seen later in this report. Furthermore, the team will begin to model each individual component, as well as begin to understand the assembly process for the all-terrain toy car.

II. GANTT CHART AND PROJECT SCHEDULE

The project schedule was largely driven by weekly assignments assigned by professor Dan Riffell as well as weekly lecture content. Although weekly assignments mainly centered around computer-aided drawings, the team stayed composed and created deliverables each week to break up the project into manageable components. From the very start, after team formation and a conversation with professor Dan Riffell, it was emphasized and advised that we start early and- that, we start early. That advice has rung true and we had started the report by the second week, as seen in Figure 2. Drawings and modelling components were started in week 2 and completed in week 3, design for assembly analysis was done in week four, CAD modelling of changed parts were done in week 4 and 5, and end deliverables were done by week 6. In addition to the gantt chart, the team met each week before or after class to assign deliverables and stayed additional time if needed for tasks that were more efficiently done as a team. Project conception took a total of 6 weeks and the team was able to achieve the following project within the set specifications and requirements.

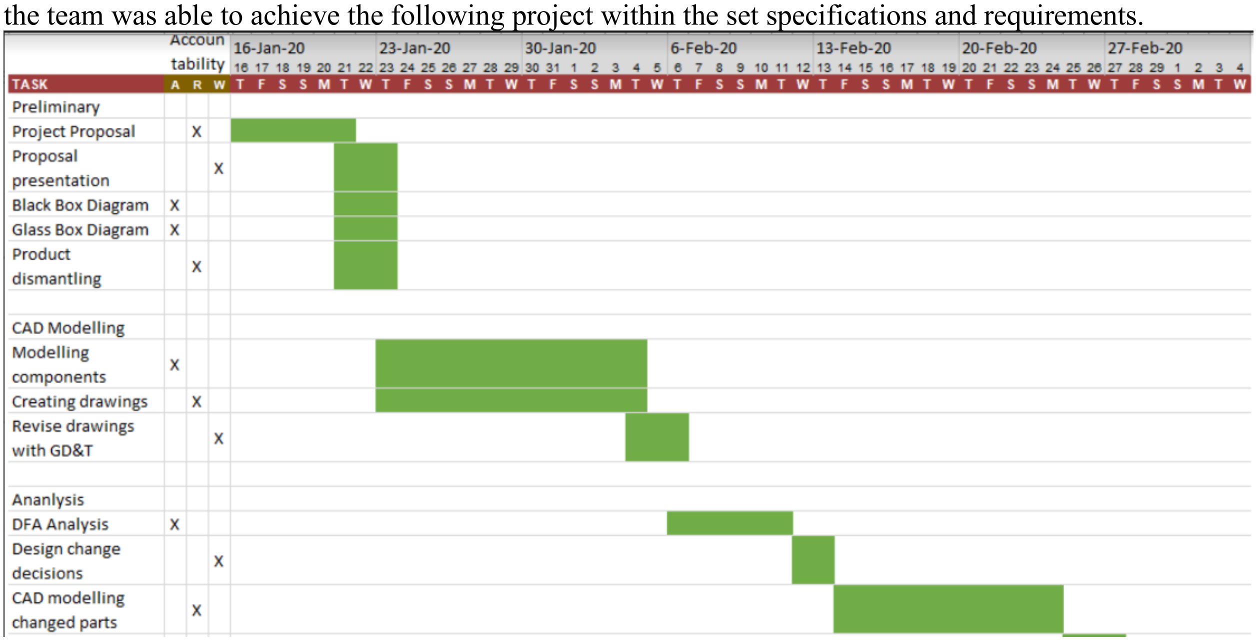


Figure 2. Gantt Chart

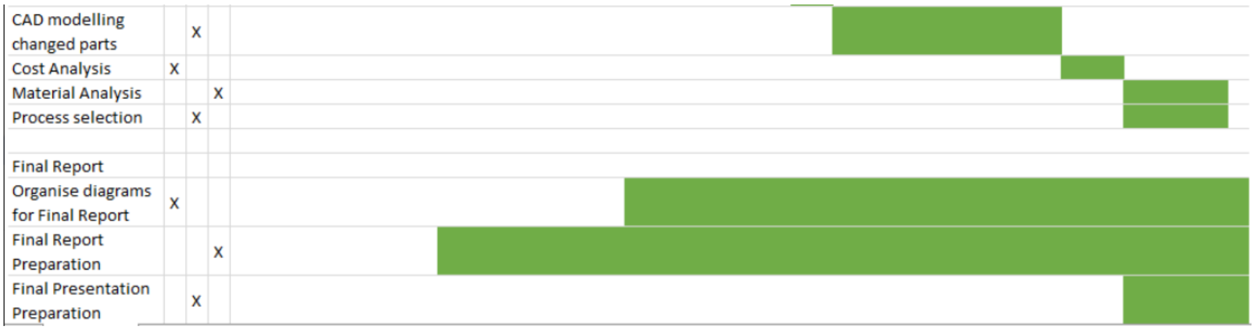


Figure 2. Gantt Chart (Cont.)

III. PRODUCT SELECTION AND DESCRIPTION

Product selection ran through numerous different considerations such as a card shuffler, a mechanical coin holder, a gaming controller, a bag sealer, a flashlight, a bucket vacuum cleaner, a trimmer, a rice cooker, a Living Solutions desk fask, an adjustable desk lamp, a remote controlled car, and a JVC player. The Trix Trux Monster Truck was selected because the number of components it had, meeting the required 15, as it had 18 in total not including the fasteners. Furthermore, the toy truck had various different complex components that would prove challenging in modeling and provide a sufficient amount of CAD experience for the team. Although complex, multiple components lacked functionality, namely the wheels, which could not complete the obstacle course that the product included without falling from the zip-line, coming off the tracks, or being stuck in the wave portion of the course. Also by initial observation, the car lacked a kill-switch as it ran continuously unless turned off manually with a switch, the car itself seemed slightly too big for the course, the battery pack was cumbersome, and numerous components like the car spoiler could benefit from snap-fits to improve assembly cost. Many of these frustrations were seconded in online product reviews, even though the toy car and the included obstacle course was priced at an inexpensive, or rather, cheap $15.00 (made in China). These faults helped the team finalize their choice in product, over the other named products, as it would produce the most amount of design changes and gained engineering experience.

IV. PRODUCT FUNCTIONALITY FAULTS

With the main objective of this project being the team's execution in its design changes to make the toy car operational as advertised, an overview of the current faults of the product is provided at each obstacle within the course.

Track and Underside of Bottom Cover Interface

The Car is first placed on the straight track plastic tubing (figure 3) as seen below in the bottom right of the picture, it should slot nicely with the bottom cover (part 3033, as seen in figure 4). However, this plastic tube, much like a thicker and wider straw, does not shape entirely to the bottom design of the battery cover. This design oversight allows for the toy car often come off the track or travel through it at inconsistent speeds.

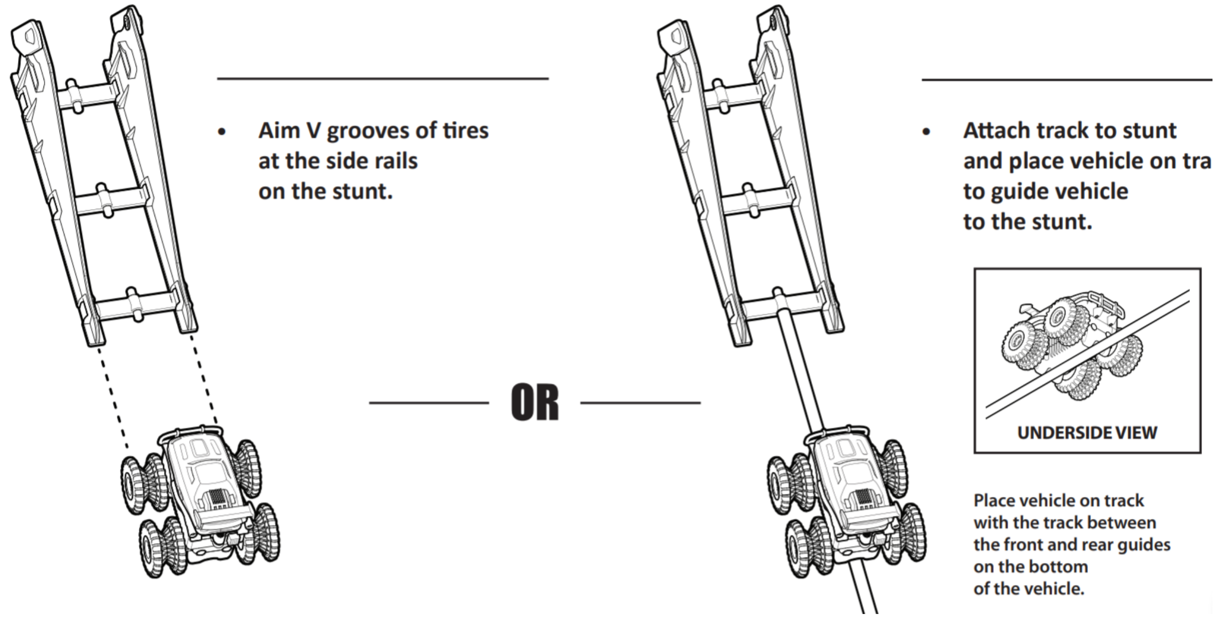


Figure 3. Plastic tubing track that guides the track

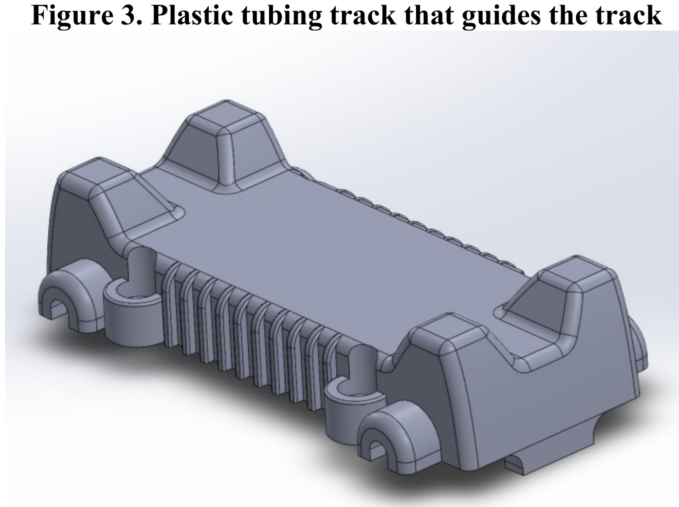


Figure 4. CAD of the bottom case done (flipped), the middle opening is where the track runs across

Monster Ramp Stunt

Upon going up the monster ramp, the wheels have a sub-par success rate in climbing the actual ramp, usually because the alignment of the wheels can be askew after its shifting travel across the track. If it does climb, the car drops down from a flip lever and onto its grill, in a vertical upright position (figure 5). In this position, the toy car does not recover by flipping back to its original driving position.

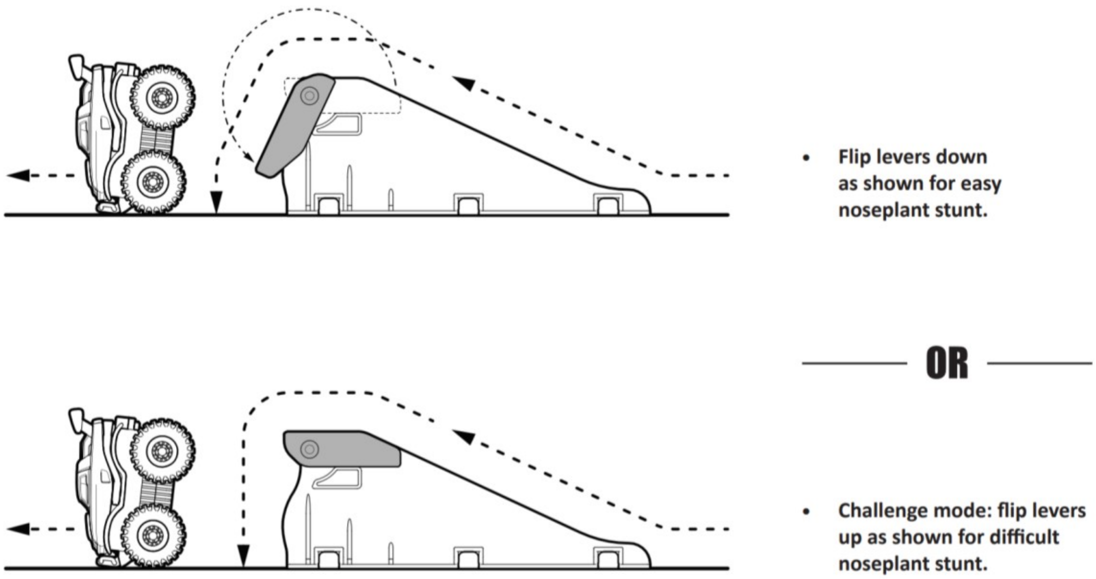


Figure 5. Monster ramp stunt, the first obstacle the toy car encounters

Tidal Wave Stunt

The second obstacle that the toy car has to overcome is the tidal wave stunt. Again, the wheels don't always align exactly with the rails of the obstacle course, even in with the guide track in place, and the progress through the track stops (figure 6). If the toy car manages up the tidal waves, the design and geometry of the wheels prevents it from flipping through the wave's curved patterns (figure 6). Weight is also an issue as the toy car can flip, then slide into the very bottom of the wave, and remain hinged.

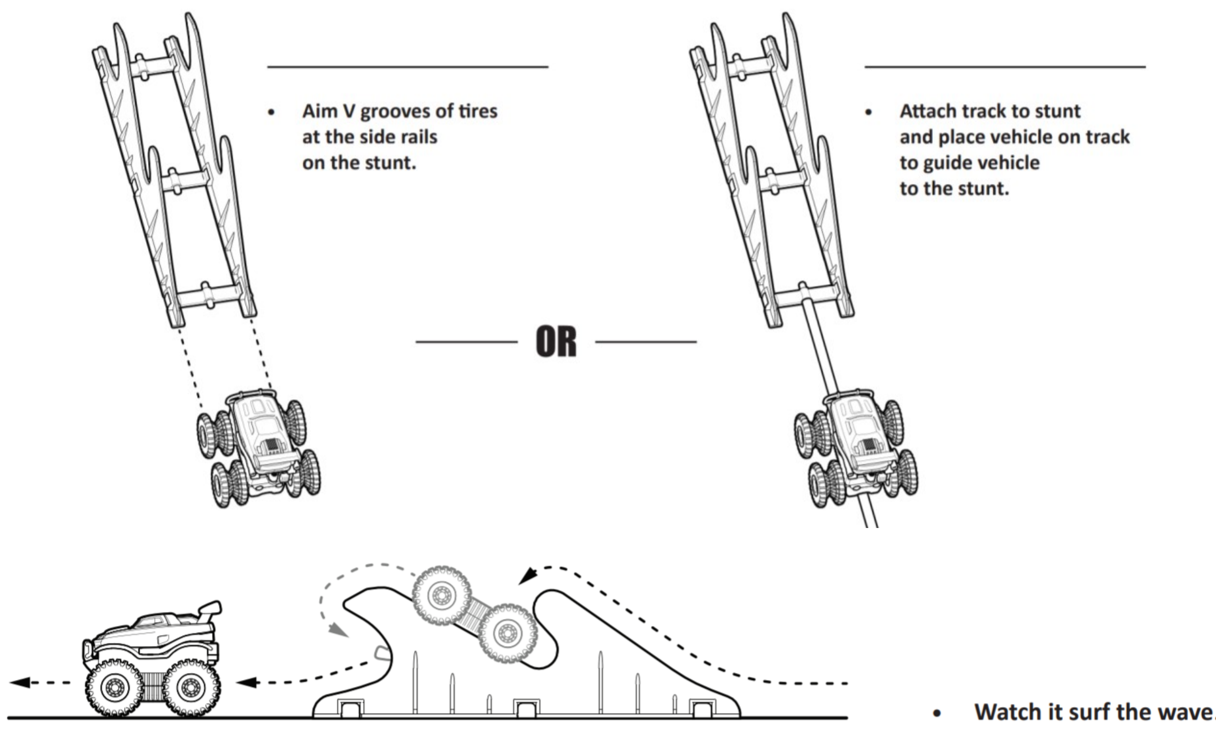


Figure 6. Tidal Wave obstacle course.

Rumble Road/Cliffhanger Stunt

Again the track guide is not always accurate in aligning the truck into the next obstacle. Additionally, much like the monster ramp obstacle, the car does not fully recover when it noseplants from the top level (figure 7). If the toy car travels through the lower level of the obstacle, the serrated geometry of the wheels to not perfect mesh with the track itself and can cause for some impediments in its movement.

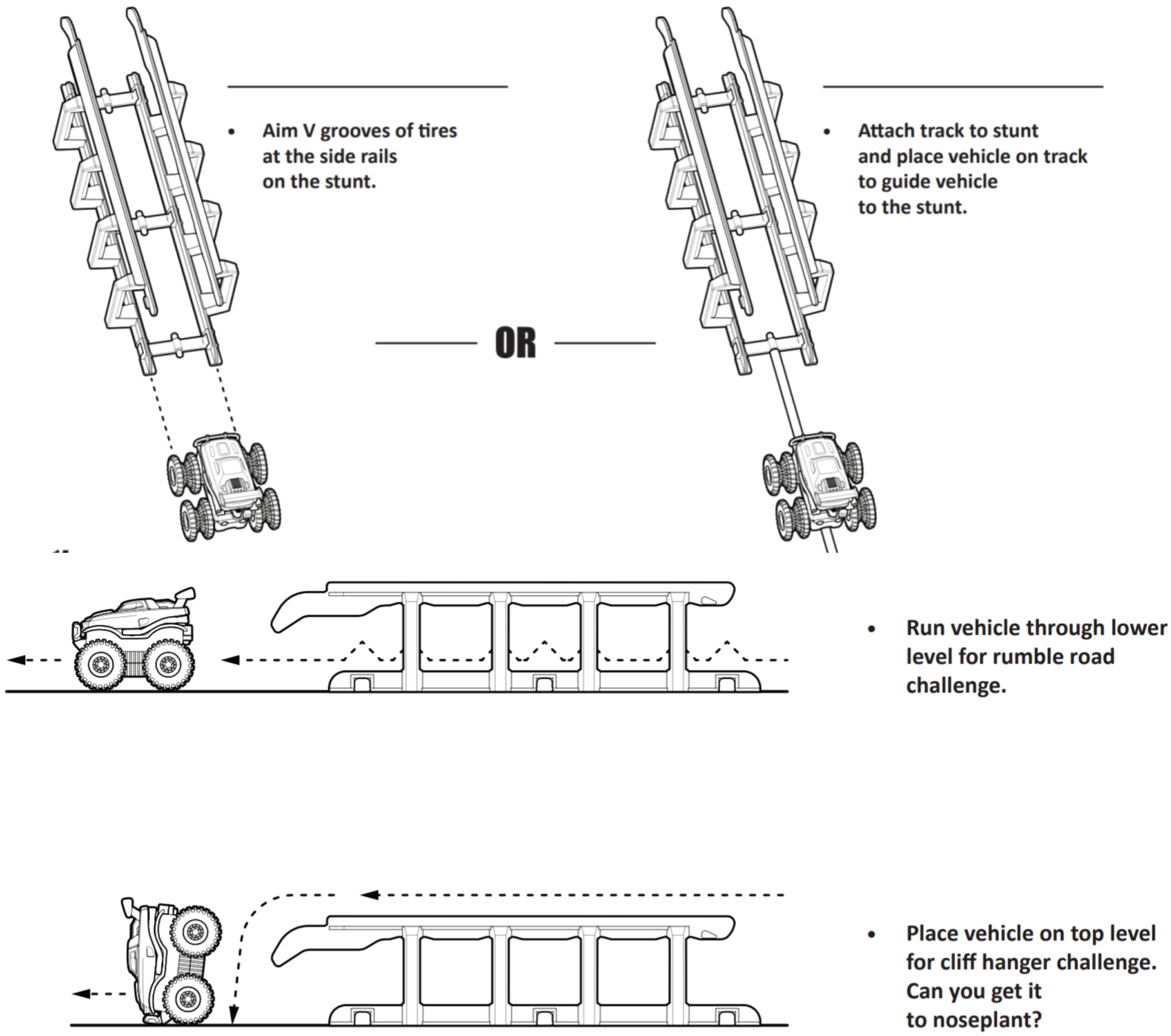


Figure 7. Rumble Road/Cliffhanger Obstacle

Double Stunt Super Challenge

This is an alternate obstacle that can be created with an attachment that connects the monster ramp to the cliffhanger obstacle in the previous section, to give access to the top level of the track (figure 8). The obstacles would be connected by a “stint-to-stunt connector”. All of the previous issues mentioned with each individual obstacle still exist when the obstacle courses are connected. However, instead of landing nose-first, the toy car lands on the back end, but struggles to recover to its original position at times.

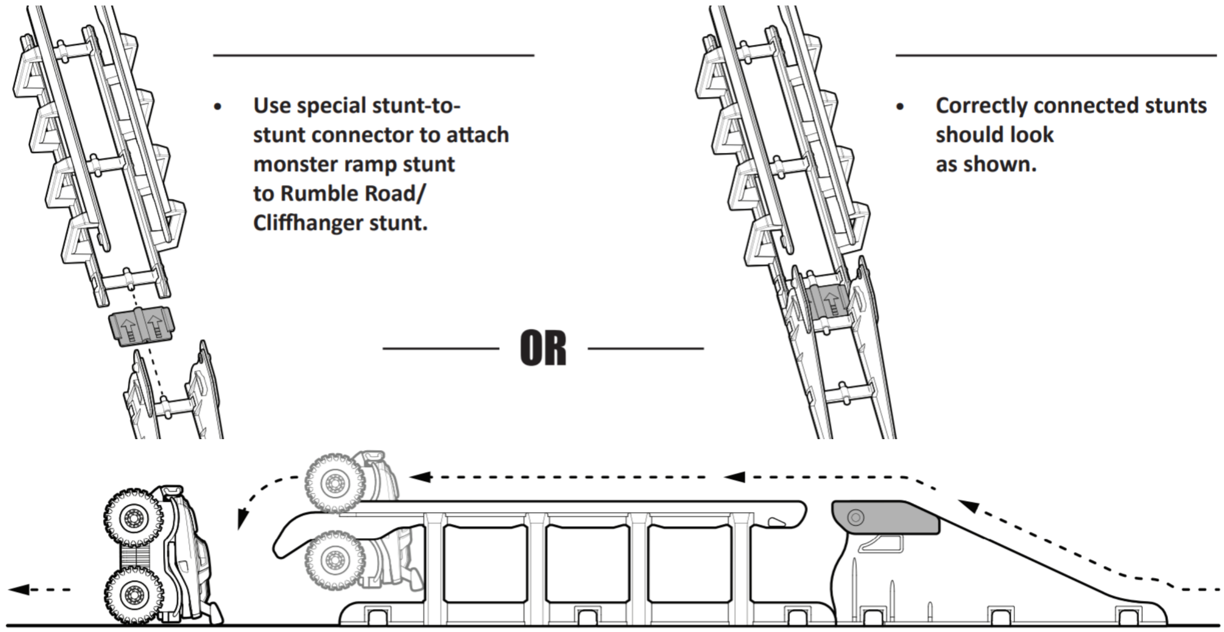


Figure 8. Double Stunt Super Challenge

Aerial Stunt

The very last stunt perhaps the lowest success rate in completion, the zip-line feature of this product (figure 9), assuming the toy car makes it to this point of the obstacle course. The center of mass of the object itself is not perfectly center, as various objects are not mirrored on both sides, such as the singular button switch on the right back-side of the battery unit. Other parts that could skew the center of mass would be the differences in the front and rear wheel assemblies, as well as the placement of the motor within the power transmission assembly. Because of these oversights, the toy car does not stay in perfect balance when scaling across the two zip lines, as it favors one side and falls off the zip-line.

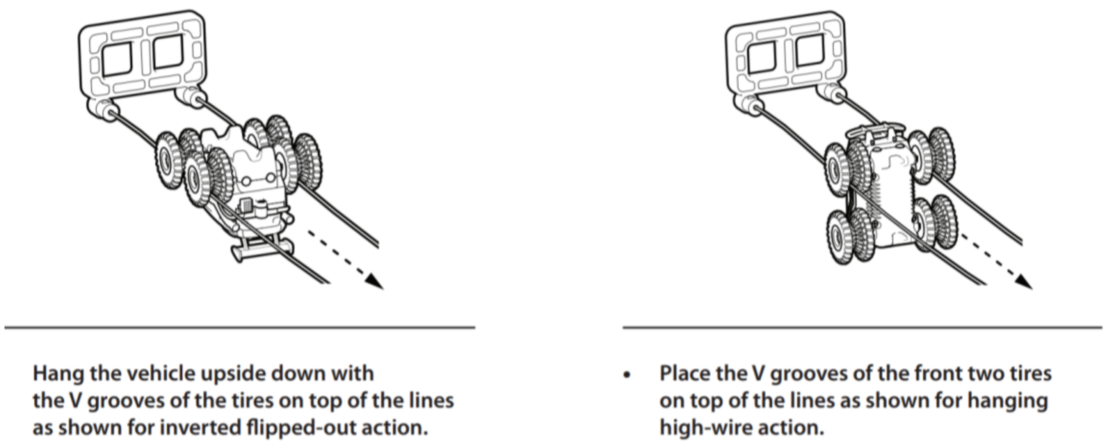


Figure 9: Aerial Stunt Obstacle

V. BLACK BOX DIAGRAM

The first step in our reverse engineering project was to analyze the product in terms of inputs and outputs. This was done by first creating a black box diagram (seen in Figure 10). The operation of the car is started by a sliding square toggle that switches the car from off to on, which converts energy from three AAA batteries to power a motor, that translates into rotational movement of the wheels through a shaft and worm gear. Noise and vibration and also heat is produced as outputs, but are negligible for the purposes of this project, as other areas of improvement hold priority . The user then placed the toy car at the start of the obstacle to complete the track. Observing these inputs and outputs revealed some initial areas of improvement that the car could benefit from. With the inputs, the battery unit seemed to have some complications, both through observation and customer review through Amazon, with entry and ease of use. With the outputs, the rotational translation to the wheels could not survive the entirety of the course. Two initial dysfunctional areas of this diagram encouraged us to explore more.

Figure 10. Black Box Diagram of Trix Trux Monster Truck

Before the physical dissection of the toy car, the subassemblies were first determined, being: Battery Power Unit, Power Transmission, Front Wheel, Rear Wheel, and Power Source, and Body. This allowed the team to better understand the different subsystems in which it had to model. For example, the interior cover of the body encloses the power transmission (drivetrain), which could have been misunderstood as the same subsystem, as the exterior cover hides both the interior and drivetrain subassemblies. The physical dissection of the toy car followed the black box diagram, with the use of simple tools, screwdrivers, and by hand (figure 11).

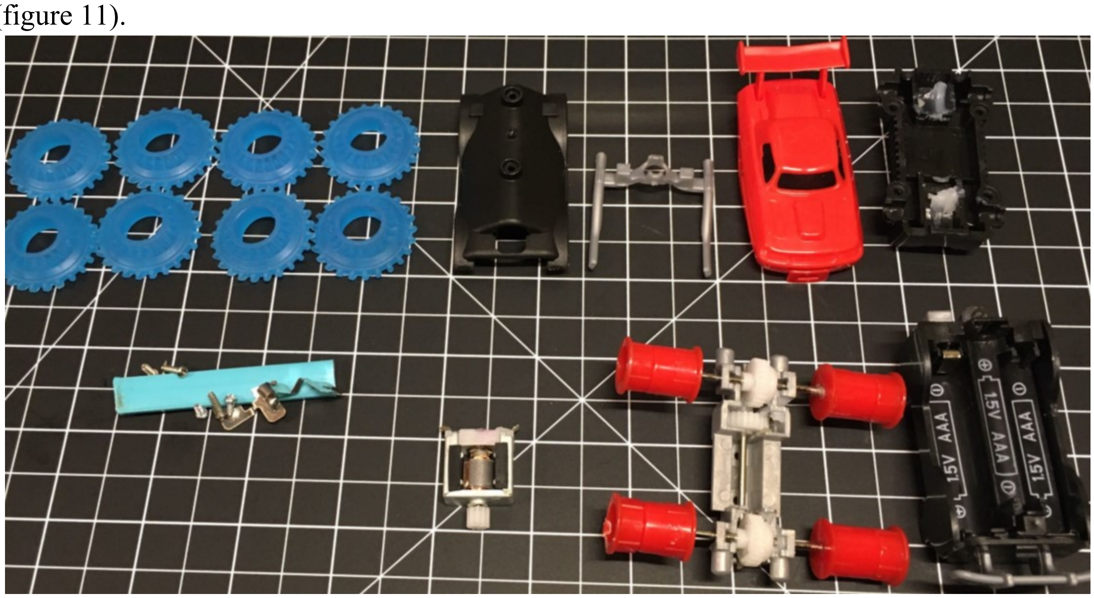


Figure 11. Initial disassembly of the toy car.

VI. GLASS BOX DIAGRAM AND SUBASSEMBLIES

After disassembly, a glass box diagram was created to examine the electrical and mechanical interactions developing within the subassemblies (figure 12). The Glass Box Diagram discloses the details not previously displayed in the Black Box Diagram, listing the following components: the switch, the motor, the gear train, the shaft, the gear train, and the wheels. These components form the basis of the following subassemblies: Battery Power Unit, Power, Power Transmission, Front Wheel, Rear Wheel, and Exterior Body. Each subassembly will be examined further for interfacing, function, and electrical use.

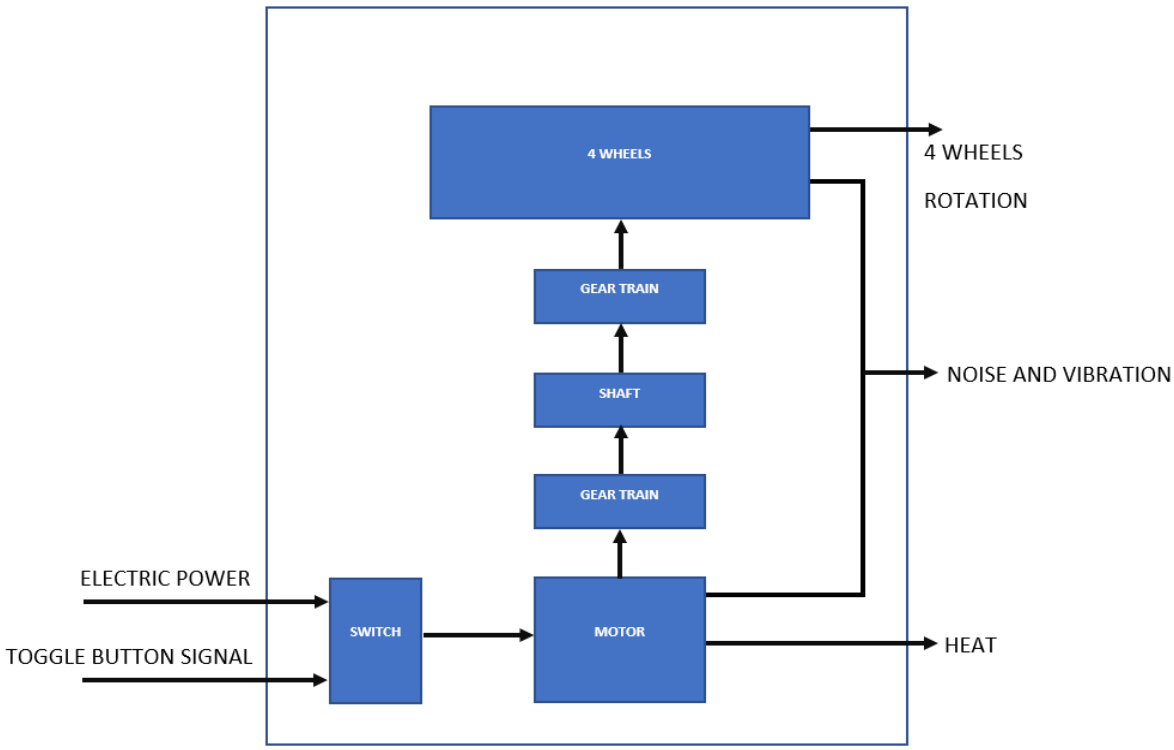


Figure 12. Glass Box Diagram of Toy Car

Boulder Pack Unit Assembly

The Battery Case (figure 13) for this part holds three AAA batteries in alternating direction (INPUT). The toggle switch is attached to the back side of the battery pack, slotting into the battery pack and up against a metal tab that is facing the negative battery terminal. Upon sliding the square switch from left to right (as seen in last orientation in figure 14), the button presses the tab against the battery, making the electrical circuit complete (INPUT), powering the motor with an 8-tooth gear attached to the end of the motor, producing heat, noise, and vibration with its rotation (OUTPUT). The Battery Case is then closed by a Battery Cover (figure 13, right), the two are secured together by phillips-head screw (as seen in the first orientation in figure 14). This current assembly with a fastener and the additional step of having to snap the top shield onto the battery pack unit is quite cumbersome for something as simple as placing batteries into a device, which customer reviews have voiced. As mentioned, the boulder pack unit interfaces with the top shield and bottom cover, both later detailed in the exterior body assembly section.

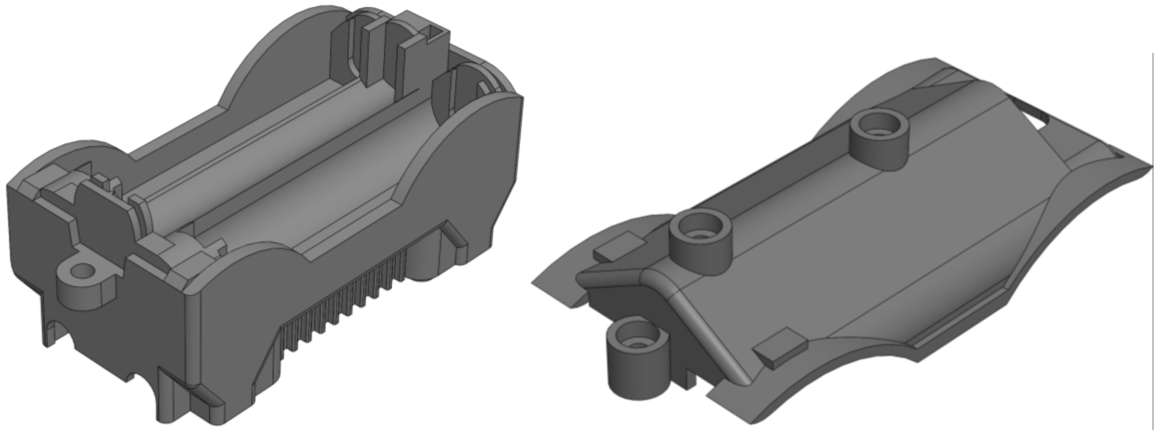


Figure 13. CAD of Battery Case (Part 1030, Left) and Battery Cover (3033, Right)

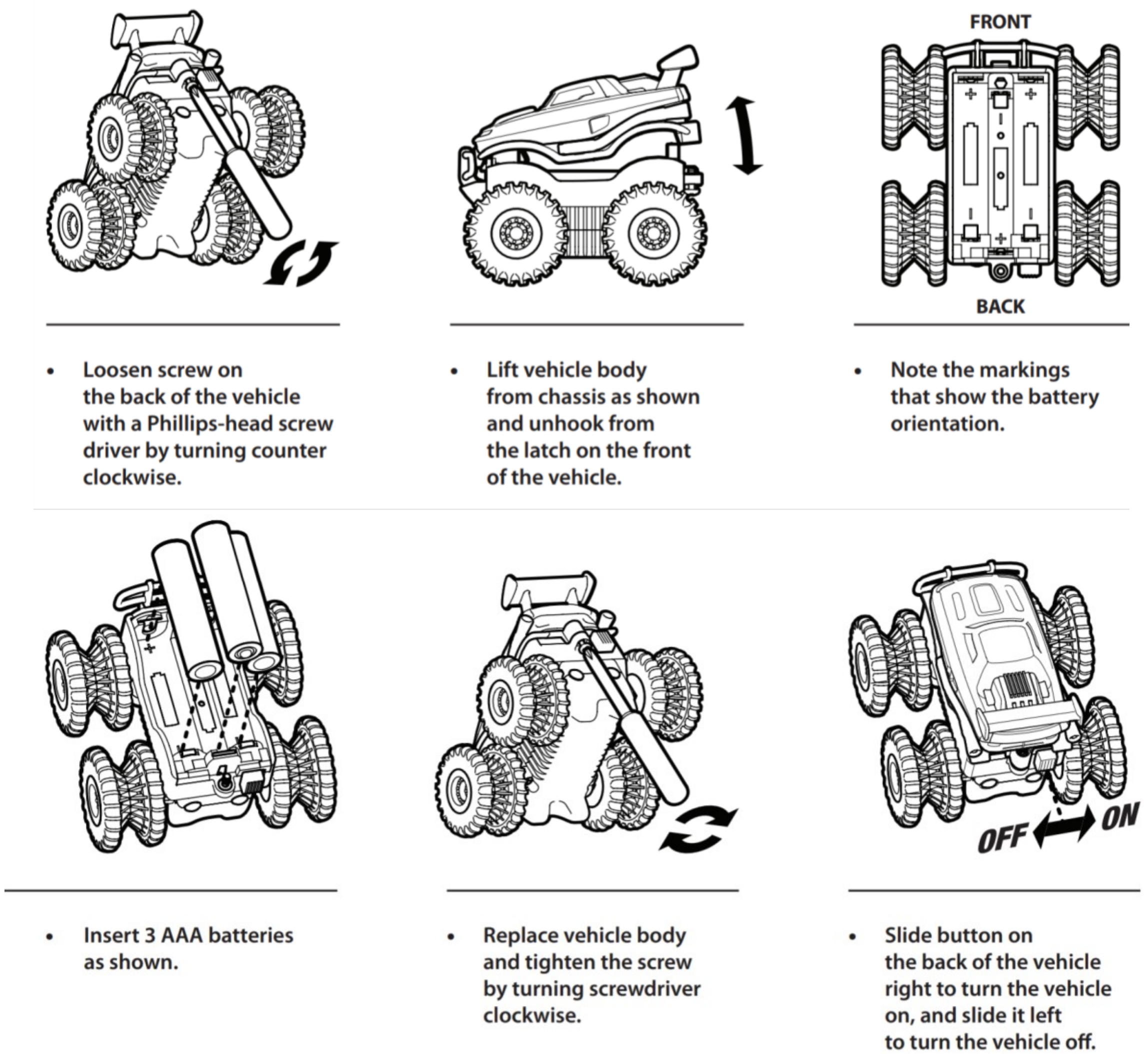


Figure 14. Battery Installation and Vehicle Operation Instructions

Power Assembly

The power comes from a 3V DC Motor, motor wiring, stator pads, geared brush, plastic cap, and a 10-tooth gear. As previously stated, electricity from three AAA batteries are activated upon toggling the switch from off to on (INPUT), which directly transmits energy to the motor through bent tabs of the compartment that the motor sits in, producing noise, heat, and rotation of the motor geared brush (OUTPUT). The motor wiring is tightly enclosed around the motor itself and rotates smoothly around two stator pads. All of these components are held tightly compact within an aluminum alloy steel compartment with bent tabs to keep the stator pads in place (figure 15). The compartment also secures a plastic cap that holds the end of the geared brush with bent tabs.The other end of the motor has an attached 10-tooth gear that interfaces with the Drivetrain Body and Main Spur Gear, both in the following Power Transmission assembly section.

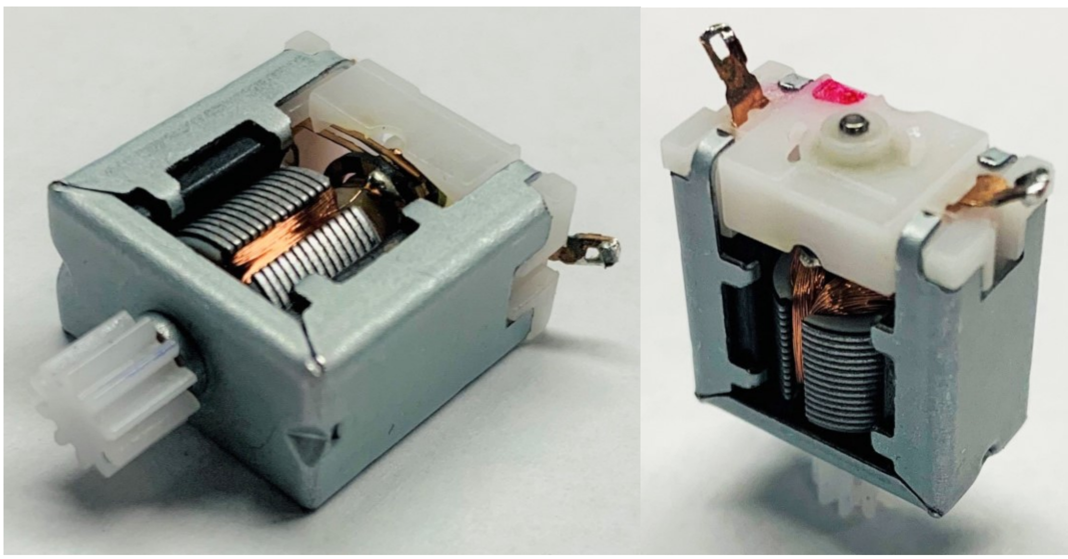


Figure 15. Power Source Assembly, power is connected to the tabs seen on the left

Power Transmission Assembly

The transmission includes the Drivetrain Body, Main Spur Gear, Worm Gear, and Main Drive Shaft. The 10-tooth gear attached to the motor, from the aforementioned power assembly, meshes to the 24-tooth Main Spur Gear, producing translational power to the Main Drive Shaft (OUTPUT).. This main spur gear fits inside the largest horizontal shelled section (seen in figure 16) as the power assembly self-aligns itself within the slot of the Drivetrain Body (seen in figure 17). At the end of the Main Drive Shaft, there is a worm gear that will initiate the rotational movement (OUTPUT) as it meshes with the Rear and Front Axle Gears, later detailed in the following subassembly sections. The interfacing between the four mentioned assemblies - Power Assembly, Power Transmission Assembly, Rear/Front Wheel Assembly can be visualized better in figure 17.

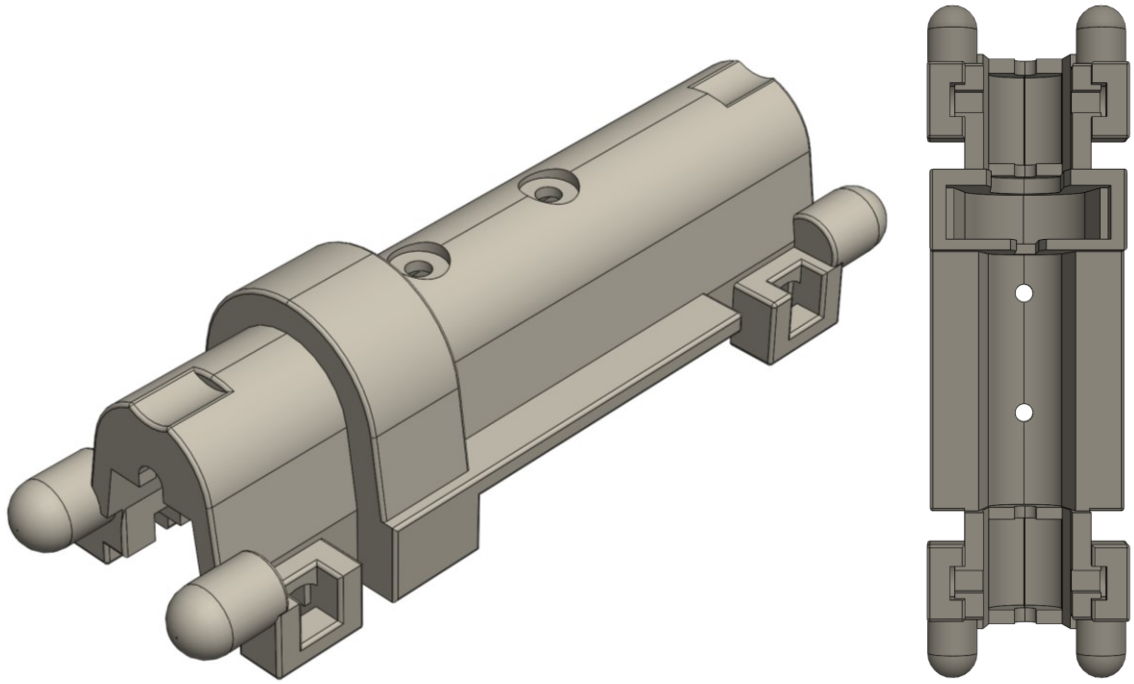


Figure 16. CAD of the Drivetrain Body, Bottom view is shown on the right, which houses both the gears and all the drive shafts

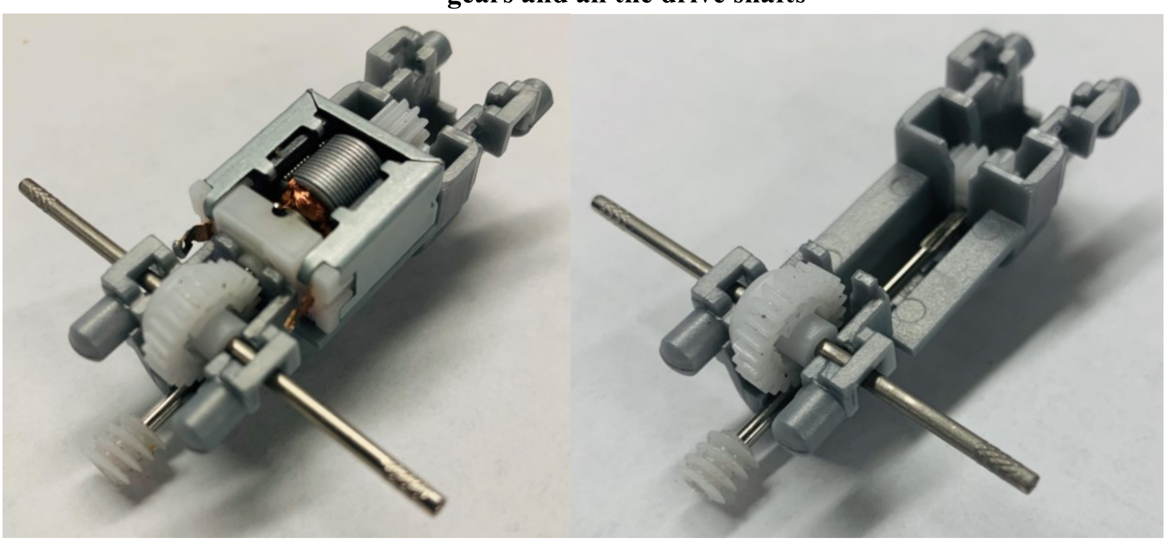


Figure 17. Actual Power Transmission Assembly with Rear Wheel Axle and Axle Gear attached, Worm Gear is pushed out for visualization (it should sit beneath the Axle Gear). Power assembly translates power (left) to this system.

Rear and Front Wheel Assembly

The Rear Wheel Assembly is comprised of the Rear Wheel Axle, the Locking Gear, the Wheel Axle Gear, the Wheel Hub, and the Tires. After the Worm Gear from the Power Transmission meshes with the Rear and Front Wheel Axle Gears, the Rear and Front Wheel Axles rotate (OUTPUT), producing the rotational movement in the Wheel Hub and Tires. The Locking Gear secures the Wheel Axle Gears to the middle spline feature of the Wheel Axles. At the end of the Wheel Axles, there is a cross pattern that prevents slipping when the axle is pushed into the Wheel Hub, in which the tires snap into fit over the wheel hub lip, as the tire material is quite flexible.

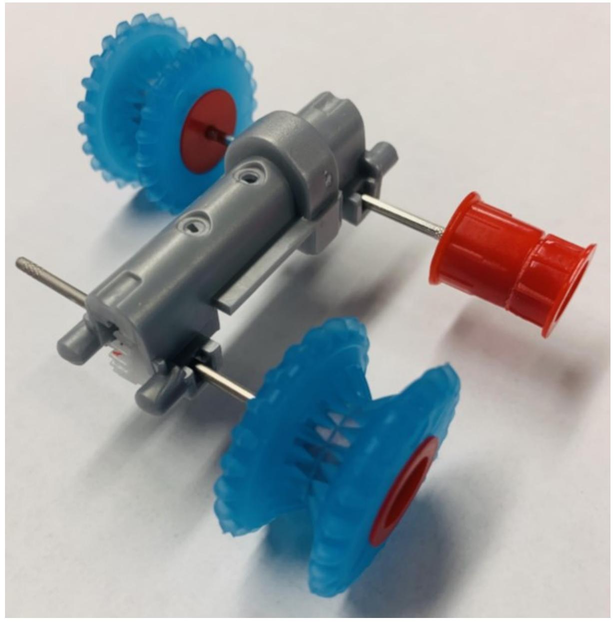


Figure 18. Rear and Front Wheel Assembly (partial assembly to help describe the individual components)

Exterior Body Assembly

The final subassembly is the Exterior Body Assembly, which is broken down into the Rear Spoiler, Bottom Car Body, Top Shield, and Silencer. The function of these components is merely to provide aesthetics to help market the product, as it conceals the internal assemblies and components mentioned above. It also provides a slight amount of structure, as the batteries cannot dislodge and slipping is reduced in the axles within the drive train interfaces.

VII. FISHBONE DIAGRAM

The following Fishbone Diagram separates the toy car into subassemblies, and further down into individual components, as previously described in the subsections of the glass diagram analysis above. All of these subassemblies (angled lines) and their respective components (horizontal fish bones) form the Trix Trux Toy Car (the head of the fish). The diagram serves as a visual representation of all the parts that make-up our product (figure 19).

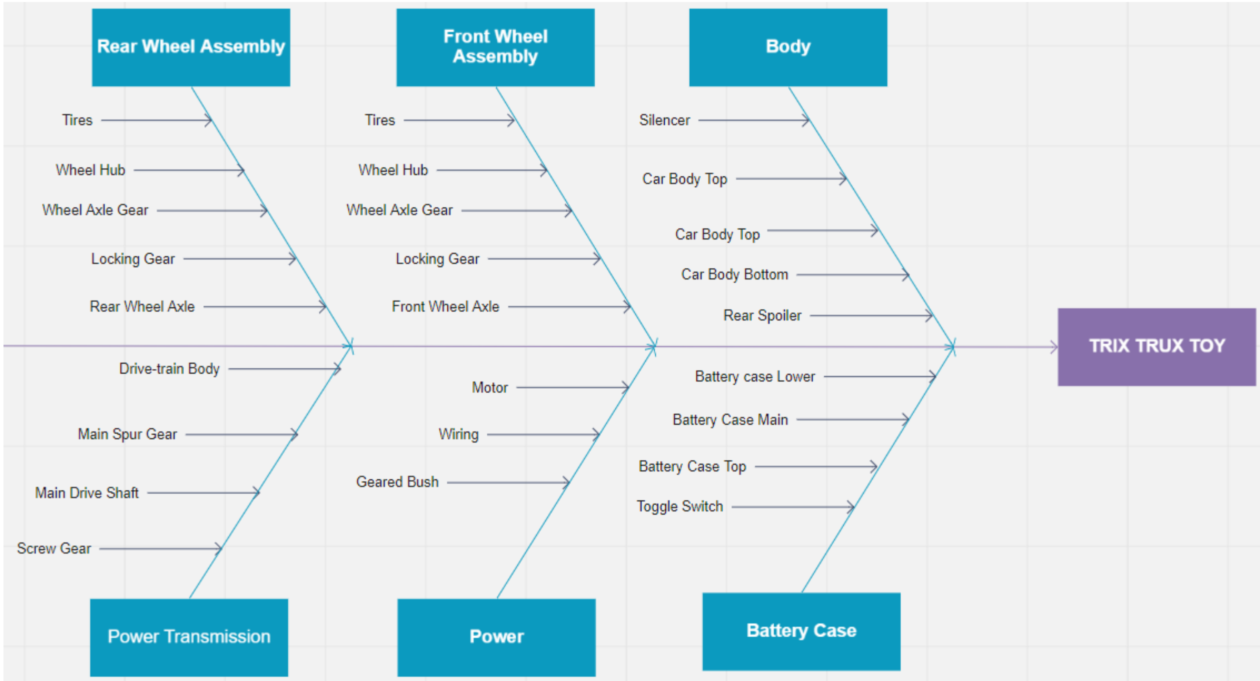


Figure 19. Fishbone Diagram

VIII. PATENT SEARCH

To have better insight on the evolution of our product through the years, a patent search was conducted. Our product Trix Trux monster car is exclusively designed and produced by Tristar Products Inc. which does not have a patent registered for the design. The product registered under the serial number 87526652 in US Federal Trademark Registration on July 13, 2017 had the patent information sent to US patents but the status is still pending. But here are some of the patents that were referenced by the company to reach to their unique design.

5131880, July 21, 1992

The overall design of the monster truck was referenced from a 1992 patent from Nesbit and Mark. The design gave reference to the bigger wheels and the centre of gravity calculation of the monster truck. Figure no. 20 provides a view of the 1992 model of a monster truck.

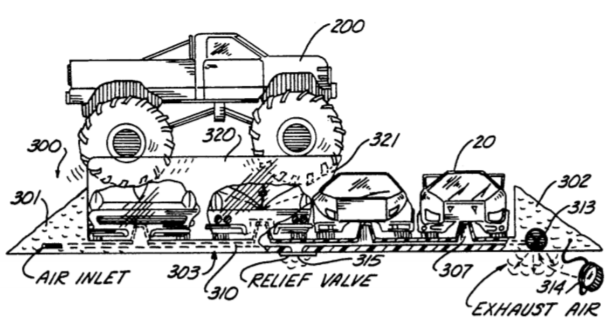


Figure 20. Sketches of 1992 design of monster car

7749047, July 6, 2010

The Trix Trux is marketed to travel through challenging tracks. Reference to the toy car of such a function was taken from the 2010 US patent of Dunham and Steve. Isometric view of the design is shown in figure no. 21.

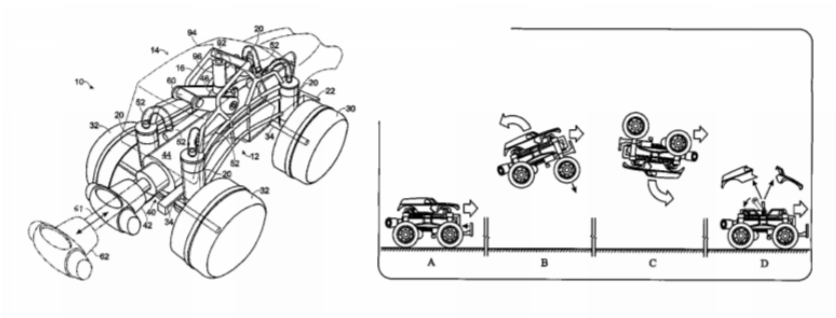


Figure 21. Isometric view of 2010 patent by Dunham and Steve

D769152, October 18, 2016

The body of the toy car references the 2016 patent invented by Perini and Filipo. Although the engineering performed with aerodynamics in the design has least role to play in the Trix Trux product, the stylized design of the body added to the aesthetics of the toy and made it attractive enough to customers among the other competitive products. The spoiler of the car in patent was primarily researched to increase the stability of the vehicle, but the spoiler in Trix Trux was effectively used to perform a tricky wheelie stunt. Isometric view of the patented design is shown in figure no. 22.

Figure 22. Isometric view of 2016 patent by Perini and Filipo

By studying patents over the years, we observed that, most of the reference designs of Trix Trux had focussed on functionality of components and overall aesthetics which can shoot up the assembly and manufacturing cost of the product. Our project of reverse engineering on Trix Trux monster car was primarily focussed on reducing the overall cost of production and maintaining optimum functionality of the product.

IX. PARTS AND COMPONENTS

Part VII: Glass Box Diagram and Subassemblies detailed all of the components of each subassembly, how each assembly interfaced each other in terms of inputs and outputs, and provided visuals of these details (figures 13-18). Additionally, the fishbone diagram (figure 23) provides another visual skeleton of the entire product. This section will detail any information not mentioned in previous, in regards to parts, components, and their respective interfaces, for a more comprehensive overview. To do this, we separate the product into two subsystems to look at them more in-depth: the gear train system and the structural system. Although information on the gears and structural components were detailed in the aforementioned sections of this report, this will divide the product into all of the parts producing movement from all the parts that aren't, to better understand and document the interfacing involved.

Gear Train Subsystem

The gear train system will consist of the the Switch 3V DC Motor, Motor Shaft, the Wheel Shaft, Main Drive Worm Gear, Main Drive Spur Gear,, Locking Gear, Wheel Axle Gear, Wheel Hub, and Wheel Tire (figure 23).

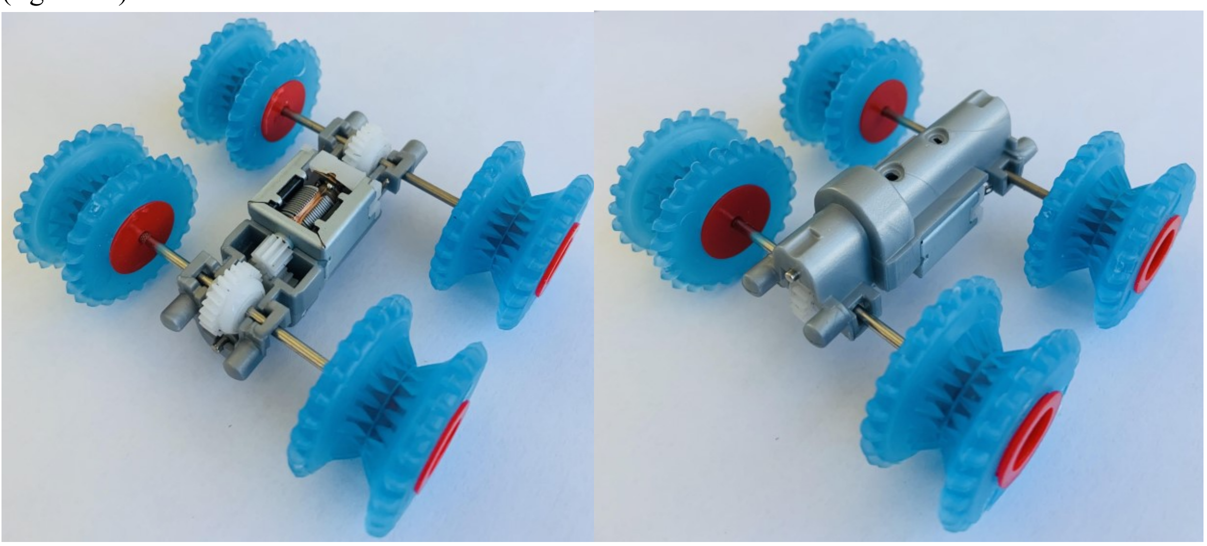


Figure 23. Gear Train Subsystem underside (Left), top-side (Right)

The following describes the gear system by a step process:

1. The 3V DC Motor is powered by the 3 AAA batteries, upon toggling on the Switch
2. The 10-tooth gear attached at the end of the motor geared brush rotates
3. The 10-tooth gear meshes with the 24 tooth Main Drive Spur Gear
4. The Main Drive Spur Gear rotates the Motor Shaft
5. The Motor Shaft rotates the Main Drive Worm Gears at each end of the shaft
6. The Main Drive Worm Gears meshes with the Wheel Axle Gears
7. The Wheel Axle Gears are secured onto the Wheel Shafts by the Locking Gears
8. The Wheel Axle Gears rotate the Wheel Shafts
9. The Wheel Shaft applies a torque and rotates the Wheel Hubs and Wheel Tires.

Structural Subsystem

The structural system consists of all the components that do not produce movement, but provide structure and aesthetic to the components of the Gear Train System, made up of the Battery Case, Top Cover, Front Guard, Car Silencer, Drivetrain Body, Spoiler, Bottom Cover, and Top Shield (Figure 24).

Figure 24. Structural Subsystem assembled (Left), disassembled (Right)

Each component is listed and their purpose stated.

1. The bottom-end of the Battery Case houses the Gear Train System
2. The Bottom Cover covers the Battery Case
3. The Top Cover covers the top-end of the of the Battery Case
4. The Front Guard, Silencer, Spoiler, and Top Shield are all for aesthetic purposes
5. The Wheel Tire and Wheel Hub

The following section, Design and Disassembly Documentation, will provide better visuals for each component, and in particular, the Gear Train Subsystem, as the disassembly follows the gear and shaft interfaces.

X. DESIGN AND DISASSEMBLY DOCUMENTATION

Preliminary Bill of Materials (BOM)

A list of all individual parts was made as the product was disassembled. For each part, a description was written down, the quantity (QTY) of that specific part was noted, the type of material was assumed if not obvious, and on-the-shelf (OTS) items were marked down. The material was determined through observation, benchmarking commercial materials, testing, and material analysis. In total, the product comprised of 18 individual parts, not including the fasteners. The information is more easily viewable by an initial bill of materials table below (table 2). This table, specifically the item numbers, will be referred to later in the disassembling documentation to follow.

Bill of Material				
Product: Trix Trux Monster Car				Date:01/23/20
Assembly: Original Design Assembly				

Item #	Part #	Qty	Name	Material
1	1011	1	Main Drive Spur Gear	POM
2	1025	1	Top Cover	ABS
3	1030	1	Battery Case	ABS
4	1055	1	Switch	ABS
5	1066	1	Front Guard	ABS
6	2001	1	Motor Shaft	304 SS
7	2002	2	Wheel Axle Shaft	304 SS
8	2063	1	Car Silencer	ABS
9	2184	2	Main Drive Worm Gear	POM
10	2222	1	3V DC Motor	Various
11	2888	1	Drivetrain Body	ABS
12	3000	1	Spoiler	ABS
13	3003	8	Wheel Tire	Rubber
14	3030	4	Wheel Hub	ABS
15	3033	1	Bottom Cover	ABS
16	3303	1	Top Shield	ABS
17	3333	2	Locking Gear	POM
18	3366	2	Wheel Axle Gear	POM
19	3380	2	Number 1 Size, 3/16" Long Screw	18-8 SS
20	3381	1	2-56 Thread, 5/16" Long Screw	Steel Black Oxide
21	3382	4	Number 1 Size, 5/16" Long Screw	18-8 SS

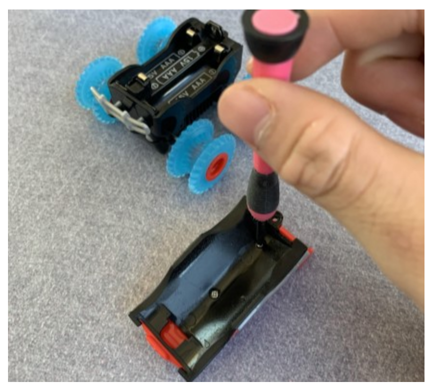
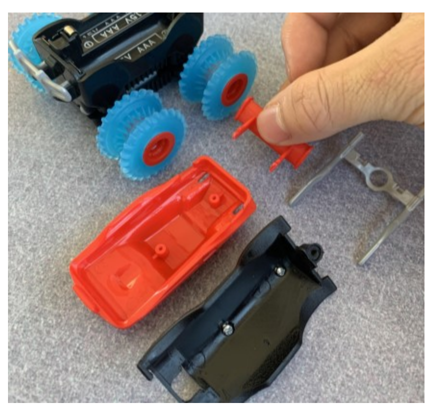
Team member: Athish Ram Das	Prepared by: Athish Ram Das
Team member: Ruhan Yang	Checked by: Will Tse
Team member: Will Tse	Approved by:

Table 2. Preliminary Bill of Materials done during disassembly

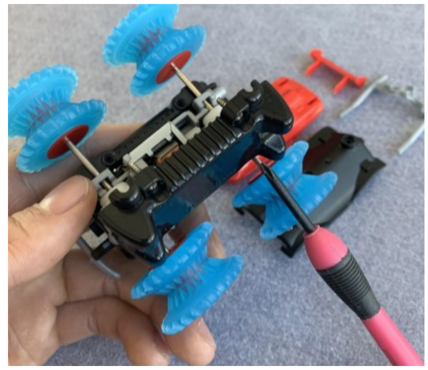
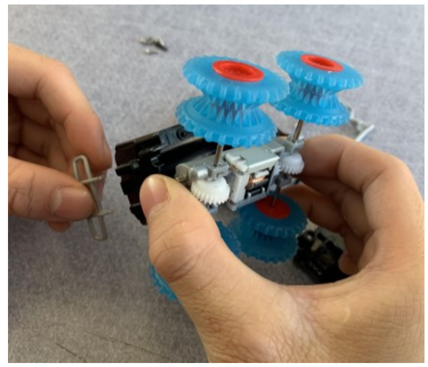
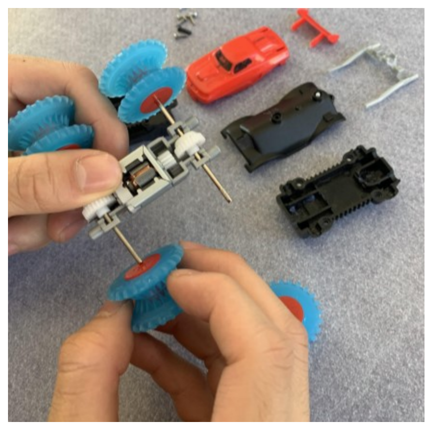
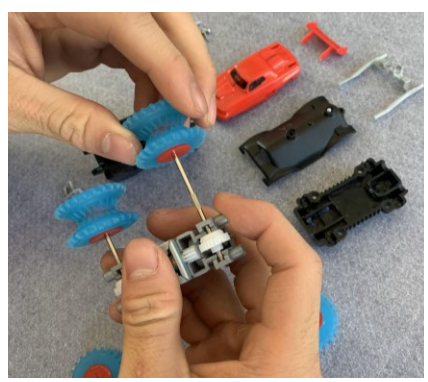
Documentation of Disassembly

At the basis of reverse engineering, the most information about product assembly is revealed through the disassembly of the product. The team documented each step chronologically as the toy car was dismantled, which disclosed initial areas where improvement could be made in terms of assembly time and cost. The documentation of these steps is better visualized by the table below (table 3).

Table 3. Documentation of Disassembly

Step #	Procedure	Item #	Reference Image
1	Remove (1x) 2-56 Thread, 5/16” Long Screw (Item 20) located on Battery Case (Item 3) with a phillips head screwdriver	3, 20	
2	Separate the snap-fit Top Shield (Item 16) from the Battery Case (Item 3)	3, 16	
3	Flip Top Shield (Item 16) Over and Remove (2x) Number 1 Size, 3/16” Long Screw (Item 19) attaching the Top Cover (Item 2) to the Top Shield (Item 16) with a Phillips head screwdriver	2,16,19	
4	Separate snap-fit Spoiler (Item 12) from Top Shield (Item 16) and shape-fit Car Silencer (Item 8) from Top Cover (Item 2)	2,8,12,16	

| Step # | Procedure | Item # | Reference Image |

Step #	Procedure	Item #	Reference Image
5	Remove (4x) Number 1 Size, 5/16" Long Screw (Item 21) attaching the Bottom Cover (Item 15) to the Battery Case (Item 3)	3,15,21	
6	Separate snap-fit Switch (Item 4) snap-fit Front Guard (Item 5), and Drivetrain Body (Item 11) from Battery Case (Item 3)	3,4,5,11	
7	(2x) Separate press-fit Wheel Hub (Item 14) from Wheel Shaft (Item 7) and remove (4x) Wheel Tires (Item 13) from Wheel Hub (Item 14)	7,13,14	
8	(2x) separate Wheel Shaft (Item 7) from Wheel Axle Gear (Item 18) and from the Locking Gear (Item 17)	7.,17,18	

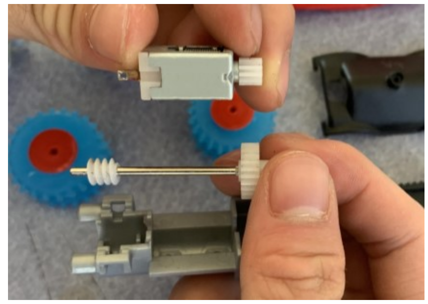
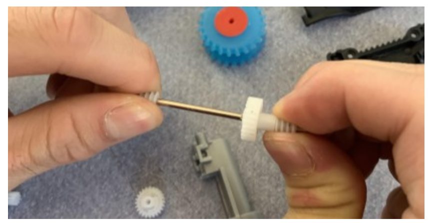
9	Repeat Step 7 using a hammer	7, 13, 14	
10	Separate shape-fit 3V DC Motor (Item 9) and shape-fit Motor Shaft (Item 6) from Drivetrain Body (Item 10)	6,9,10	
11	(2x) Separate press-fit Main Drive Worm Gear (Item 9) and (1x) Main Drive Spur Gear (Item 1) from Motor Shaft (Item 6)	1,6,9	

Table 3. Chronological steps of disassembly

The toy car was disassembled by a hammer and phillips screwdriver, with 11 unique steps (Figure 25).

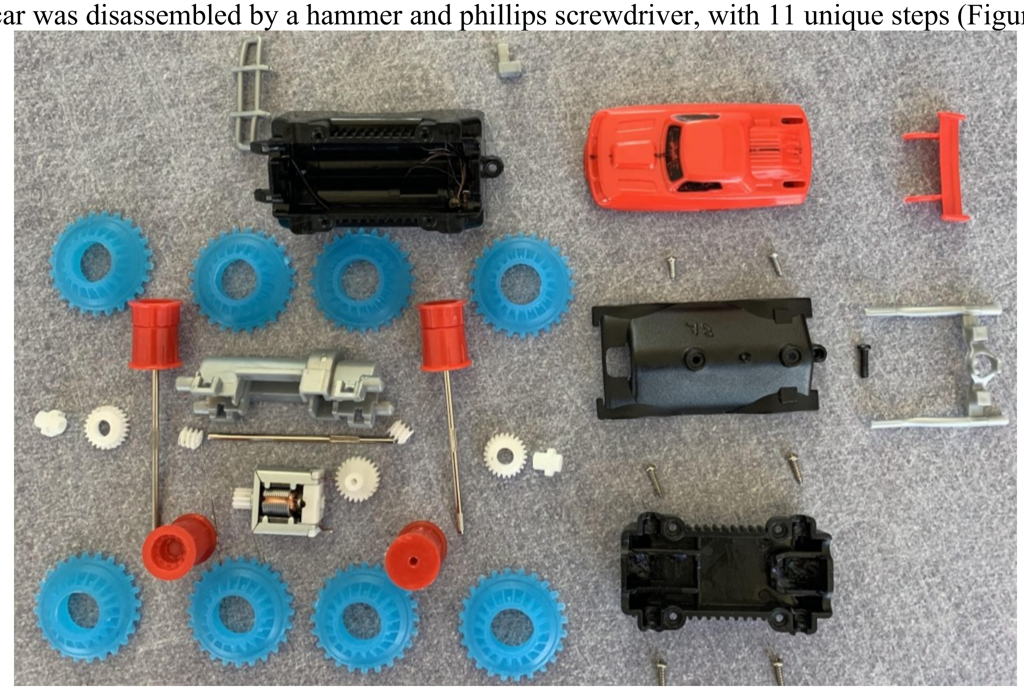


Figure 25. Full disassembly of toy car

System Function

The remodeled toy truck applied DFMA principles. From the consumer standpoint, the body curvature and the same ergonomic shape and size remained. The total weight did not change a significant amount, and in turn, has the same general feel. The reduction of fasteners through the changes by combining parts allowed for easier access to the battery case and an improved assembly time rate, so it will improve user-friendliness of accessing the battery with a snap fit as opposed to using a screwdriver. As this product is targeted for children, they do not have to ask their parents to access the battery for them. The Toy car is further analyzed into the Gear Train Subsystem and Structural Subsystem

Gear Train Subsystem
The Gear Train Subsystem includes the Switch 3V DC Motor, Motor Shaft, the Wheel Shaft(2x), Main Drive Worm Gear(2x), Main Drive Spur Gear, Locking Gear(2x), Wheel Axle Gear(2x), Wheel Hub(4x), and Wheel Tire(8x). The functionality of the gear train has remained fairly the same. The only change iterated was the combining of the wheel tires and wheel hub, so instead of half wheel tires, there are four full wheels. This will make for smoother assembly and disassembly

Structural Subsystem
The Structural Subsystem consists of the Battery Case, Top Cover, Front Guard, Car Silencer, Drivetrain Body, Spoiler, Bottom Cover, and Top Shield. The functionality of these components have changed. The Top CoverCar Silencer, Spoiler, and Top Shield have all been combined into one piece as well as the Battery Case and the Front Guard, so they are not separated by different snap fits and screwed together with fasteners. This allows for better a better assembly, eliminating multiple steps in the process. Additionally, functionality has been improved because the user would have to unscrew the Battery Case and remove a snap-fit in order to access the battery compartment to place new batteries in. This has been improved to snap fit.

Final Bill of Materials with Design Changes

After implementing the design changes, later detailed in this report, the bill of materials below represents all the individual parts of the remodeled product (Table 4). A number of items were either removed, modified, or reduced, and are further specifically detailed:

- Top Shield(formerly item 16)
- Front Guard (formerly item 5)
- Car Silencer (formerly item 8)
- Spoiler (formerly item 12)
- 2-56 Thread, 5/16" Long Screw (formerly item 20)
- Number 1 Size, 3/16" Long Screw (formerly item 19)
- Wheel Hub (formerly item 14)

Bill of Material				
Product: Trix Trux Monster Car			Date:03/01/20	
Assembly: Remodelled Design Assembly				
Item #	**Part #**	**Qty**	**Name**	**Material**
1	1011	1	Main Drive Spur Gear	POM
2	1030	1	Battery Case	ABS
3	1055	1	Switch	ABS
4	2001	1	Motor Shaft	304 SS
5	2002	2	Wheel Shaft	304 SS
6	2184	2	Main Drive Screw Gear	POM
7	2222	1	Motor	Various
8	2888	1	Drivetrain Body	ABS
9	3003	4	Wheel Tire	Silicone Rubber
10	3033	1	Bottom Cover	ABS
11	1025	1	Top Cover	ABS
12	3333	2	Locking Gear	POM
13	3366	2	Wheel Axle Gear	POM
14	3382	4	Number 1 Size, 5/16" Long Screw	18-8 SS
Team member: Athish Ram Das			Prepared by: Will Tse	
Team member: Ruhan Yang			Checked by:	
Team member: Will Tse			Approved by:	

Table 4. Bill of Materials after design changes have been implemented

XI. DESIGN FOR ASSEMBLY (DFA) ANALYSIS

Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name	Number of Parts (N_p)	Number of Interfaces (N_i)	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
3366	WHEEL AXLE GEAR	2	2	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
3333	LOCKING GEAR	2	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
3303	TOP SHIELD	1	6	0	1	L	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0
3033	BOTTOM COVER	1	8	1	0	L	1	1	0	0	0	0	0	1	0	0	0	1	0	1	0
3030	WHEEL HUB	4	3	0	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0
3003	WHEEL TIRE	8	2	1	0	L	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
3000	SPOILER	1	1	0	0	L	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0
2888	DRIVETRAIN BODY	1	6	0	0	L	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0
2222	MOTOR	1	3	1	0	M	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
2184	MAIN DRIVE SCREW GEAR	2	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
2063	CAR SILENCER	1	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	WHEEL SHAFT	2	4	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
2001	MOTOR SHAFT	1	4	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
1066	FRONT GUARD	1	1	0	0	L	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1055	SWITCH	1	1	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1030	BATTERY CASE	1	5	1	0	L	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0
1025	TOP COVER	1	5	0	1	L	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1011	MAIN DRIVE SPUR GEAR	1	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
3380	Number 1 Size, 3/16" Long Screw	2	3	1	0	L	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3381	2-56 Thread, 5/16" Long Screw	1	3	1	0	L	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0
3382	Number 1 Size, 5/16" Long Screw	4	3	1	0	L	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
	Totals	39	68	14	2	0	17	4	4	1	1	0	4	5	8	0	8	4	4	10	7
	Design for Assembly Metrics	**51.49757276**		**35.9%**	**Pract. Effy.→**		**43.6%**	**0.57**		**0.14**			**1.21**				**2.36**				
	Targets			**60.0%**																	

Table 5. Initial DFA Analysis

XII. DESIGN CHANGES

The first change we made combining all the upper parts, the top shield, the spoiler, and the top cover, into one top part. We removed the silencer since it doesn't have any function with it (Figure 26).

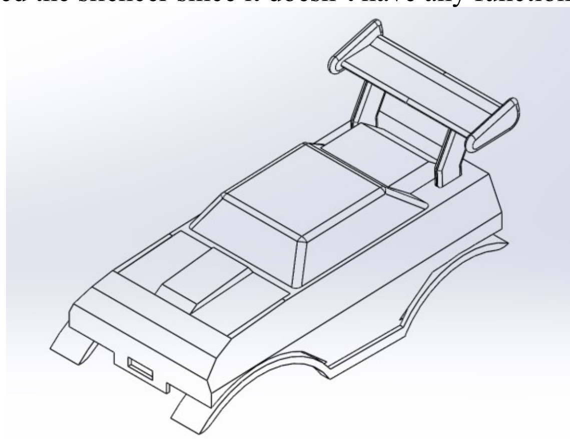


Figure 26. New Top Shield

Then we combined the front guard with the battery case, and also changed the angle between them. With the new design, the car now won't be flipped over from the front (figure 27).

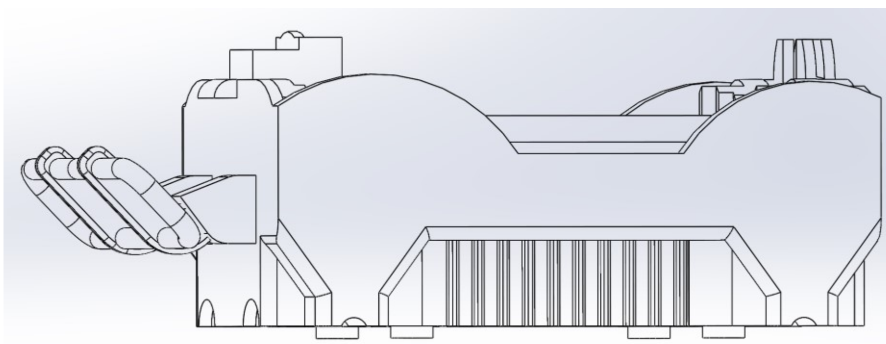


Figure 27. New Battery Case

For the interface between the top shield and the battery case, it was initially using a screw on the back to fix them together. We changed that into a snap fit, shows as below (figure 28):

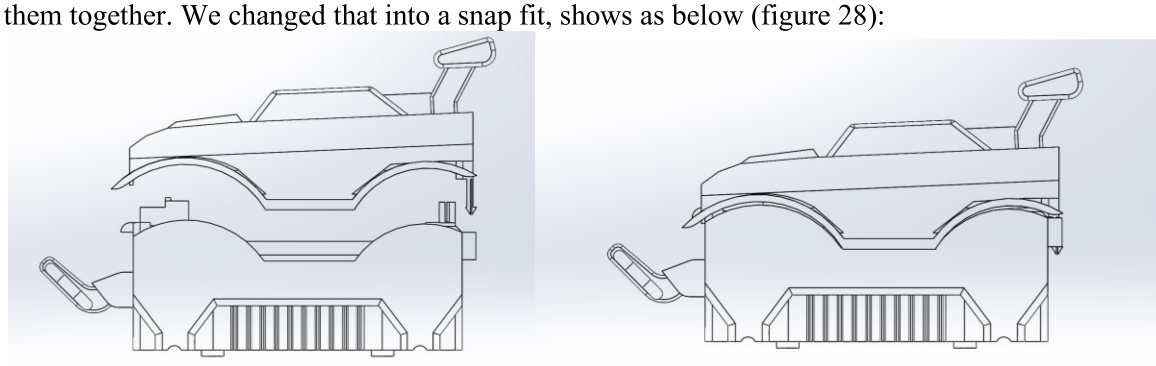


Figure 28. New Interface Between the Top Shield and the Battery Case

We also combined the wheel tire and hub together into one part (figure 29). This will increase our efficacy a lot, since it reduced ⅔ parts while keeping the same function.

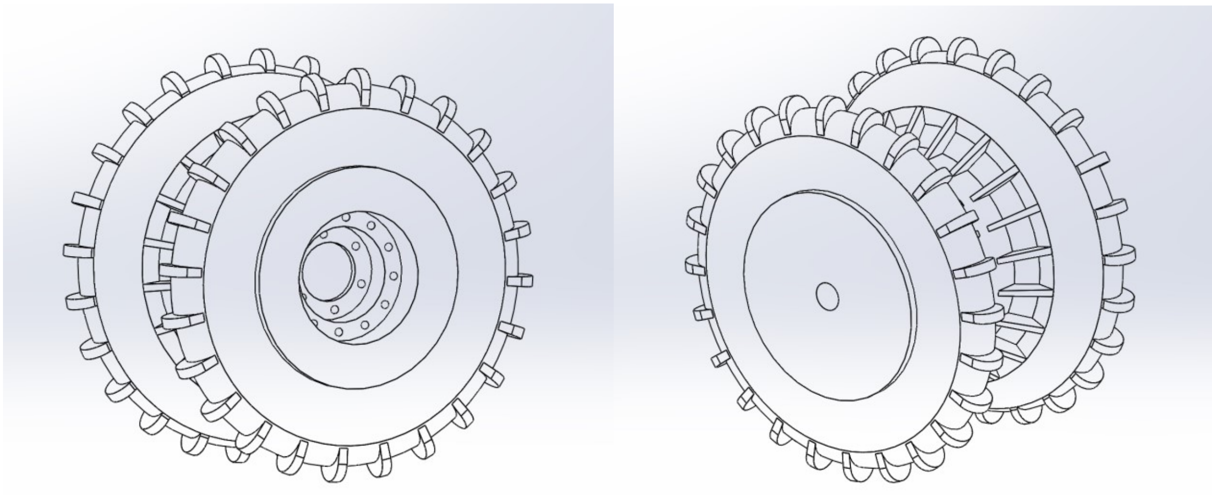


Figure 29. New Wheel Tire

XIII. FINAL DFA ANALYSIS

After we completed the redesign, there were some significant changes in our DFA analysis (Table 6). The total number of parts reduced from 39 to 24, and the number of interferences reduced from 68 to 49. All the parts now are minimized.

Part		DFA Complexity		Functional Analysis / Redesign Opportunity				Error Proofing		Handling			Insertion				Secondary Operations				
Part Number	Part Name	Number of Parts (N_p)	Number of Interfaces (N_i)	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
3366	WHEEL AXLE GEAR	2	2	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
3333	LOCKING GEAR	2	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
3303	TOP SHIELD	1	3	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3033	BOTTOM COVER	1	8	1	0	L	1	1	0	0	0	0	0	1	0	0	0	1	0	1	0
3003	WHEEL TIRE	4	1	1	0	L	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2888	DRIVETRAIN BODY	1	6	1	0	L	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0
2222	MOTOR	1	3	1	0	M	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
2184	MAIN DRIVE SCREW GEAR	2	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
2002	WHEEL SHAFT	2	4	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
2001	MOTOR SHAFT	1	4	1	0	L	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1
1055	SWITCH	1	1	1	0	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1030	BATTERY CASE	1	8	1	0	L	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0
1011	MAIN DRIVE SPUR GEAR	1	2	1	0	L	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1
3382	Number 1 Size, 5/16" Long	4	3	1	0	L	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
	Totals	24	49	14	0	0	14	3	0	1	0	0	3	3	7	0	7	2	1	10	7
	Design for Assembly Metrics	**34.2928564**		**58.3%**	←Theor. Effy. Pract. Effy.→		**58.3%**	**0.21**		**0.07**			**0.93**				**1.93**				
	Targets			**60.0%**																	

Table 6. Final DFA Analysis

XIV. MATERIAL ANALYSIS

One of the major concerns during the operation of the Toy car was that it sticks onto the plastic tubing of the track track due to higher friction between the track and the underside bottom cover of the car. We observed that the lower ratings that the product got in amazon.com was majorly due to this concern of the customers.

The two major concerns we had to redesign this mechanism was that the bottom cover has to slide with the track for it to follow the path and at the same time, it has to produce the least friction with the track. We conducted a material analysis to solve this issue.

Material analysis helps to decide the best material that we have to use for a particular component based on the manufacturers constraints. Figure no. 30 shows the various steps that are followed by the material analysis.

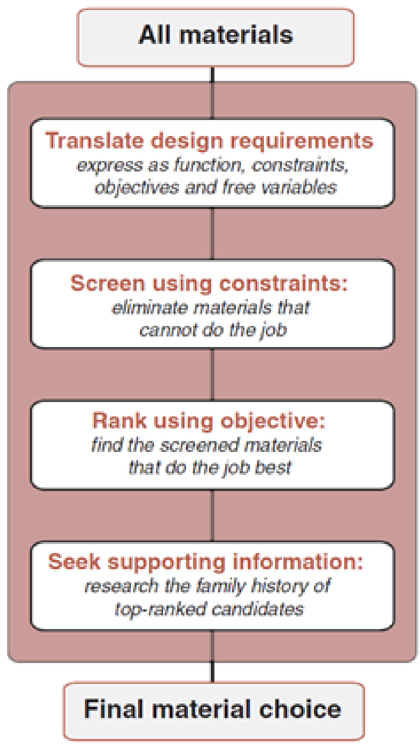


Figure 30. Steps of material analysis

Bottom Cover

1. **Translate design requirements**

Constraints

- Must be smooth and low friction material
- Must have enough stiffness
- Must be lightweight to reduce load on the motor
- Low cost
- Must be wear resistant to maintain its functionality

2. **Screen using constraints**

One of the methods of screening the material is screening by material performance index. Material indices for various loading conditions are given in Table no. 7

Design Objective: Minimum Weight for Different Shapes and Loadings	**To Maximize Strength**	**To Maximize Stiffness**
Bar in tension: load, stiffness, length are fixed; section area is variable	σ_f/ρ	E/ρ
Torsion bar: torque, stiffness, length are fixed; section area is variable	$\sigma_f^{2/3}/\rho$	$G^{1/2}/\rho$
Beam in bending: loaded with external forces or self-weight; stiffness, length fixed; section area free	$\sigma_f^{2/3}/\rho$	$E^{1/2}/\rho$
Plate in bending: loaded by external forces or self-weight; stiffness, length, width fixed; thickness free	$\sigma_f^{1/2}/\rho$	$E^{1/3}/\rho$
Cylindrical vessel with internal pressure: elastic distortion, pressure, and radius fixed; wall thickness free	σ_f/ρ	E/ρ
Other design objectives, as stated below		
Thermal insulation: minimize heat flux at steady state; thickness given	$1/k$	
Thermal insulation: minimum temperature after specified time; thickness given	$C_p\rho/k$	
Minimize thermal distortion	k/α	
Maximize thermal shock resistance	$\sigma_f/E\alpha$	

α_f = failure strength (yield or fracture stress as appropriate to problem); E = Young's modulus; G = shear modulus; ρ = density; C_p = specific heat capacity; α = thermal expansion coefficient; k = thermal conductivity.

Table 7. Material performance indices under various loading

From figure 31 we can see that the component under consideration is under the loading condition of a beam in bending.

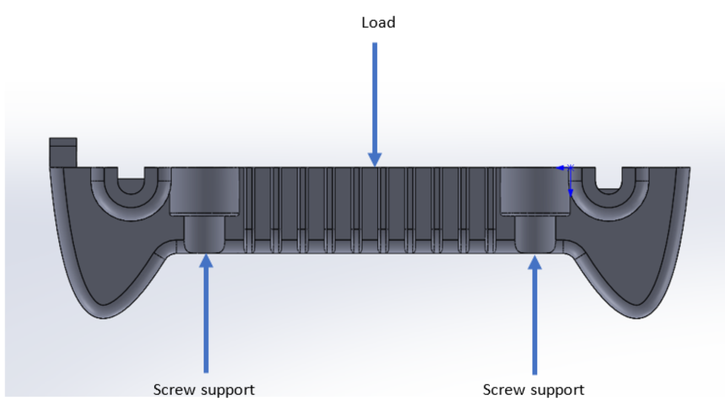


Figure 31. loading condition of bottom cover

So for stiffness, Material performance index,

$$M=(\sqrt{E})/\rho$$

Using Ashby Chart in Figure no. 32, we can deduce that forms, soft metals and other flexible material can be eliminated as they have a low performance index. Rubber and other elastomers can also be eliminated as they have less stiffness. High density alloys can also be eliminated to reduce the load on the 3V DC motor

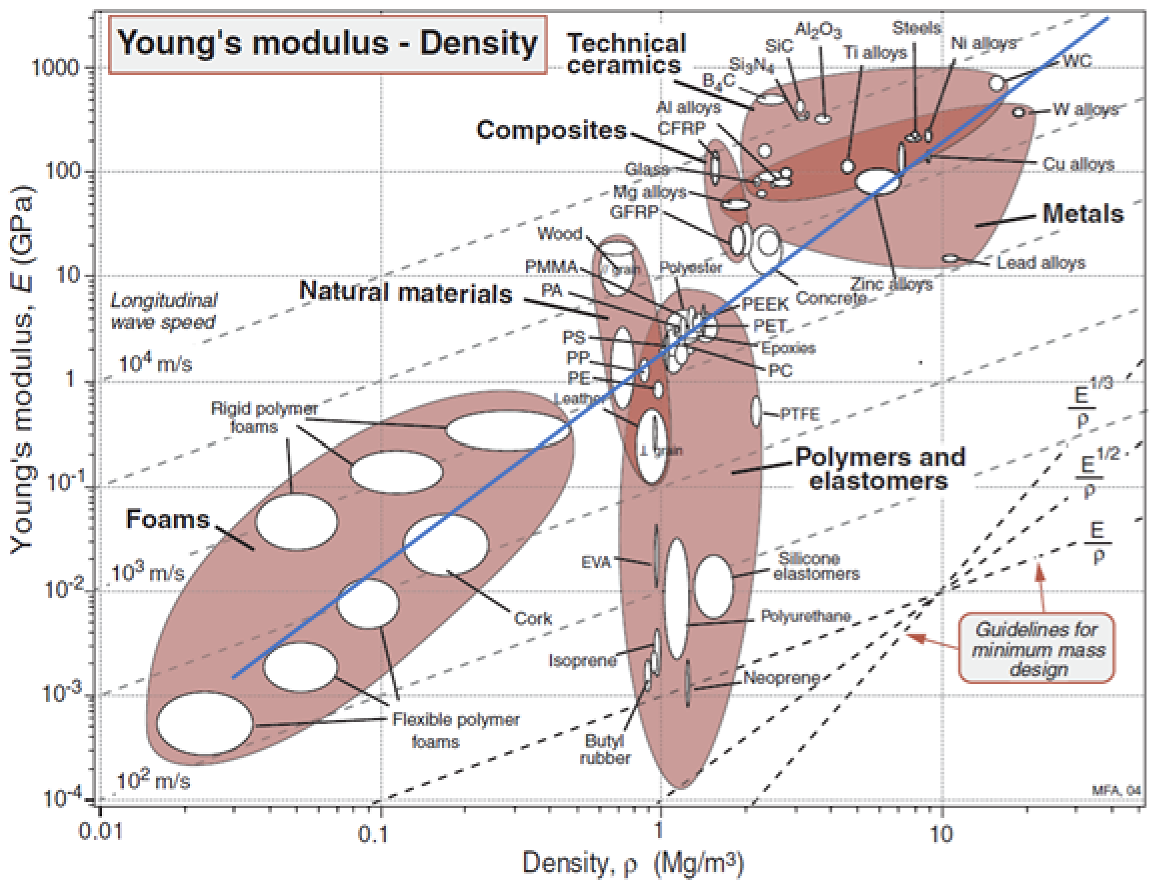


Figure 32. Ashby's chart

Ashby's chart leaves us with material choices such as,

- CFRP
- PVC
- ABS
- Polyoxymethylene (POM)
- Steel

3. **Rank using objectives**

Based on Ashby's chart performance index, materials can be ranked as below,

1. Steel
2. CFRP
3. POM
4. ABS
5. PVC

4. **Seek supporting info**

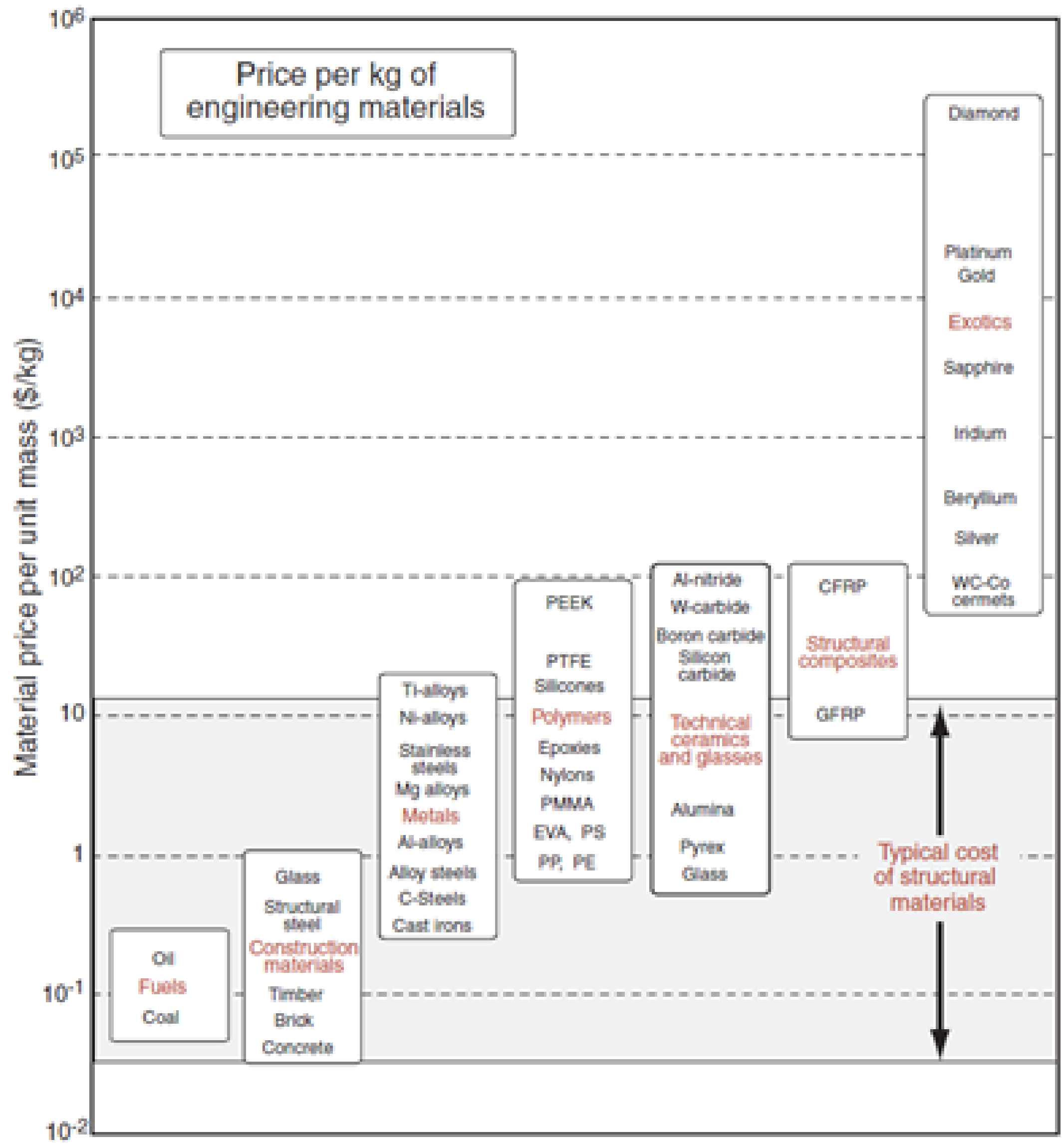


Figure 33. Price per kg of Engineering materials

From figure 34 we can see that the cost of CFRP is high and can be eliminated to reduce the overall cost of the product. PVC has less strength compared to other plastics.ABS has higher friction value than POM. POM gains an advantage over steel as it is lightweight and smooth.

5. **Material Selected: Polyoxymethylene (POM)**

To find the possibility of finding a better material to use for tires, we did material analysis on it.

Tire

From figure 35, we can see that the material loading condition is material under compression

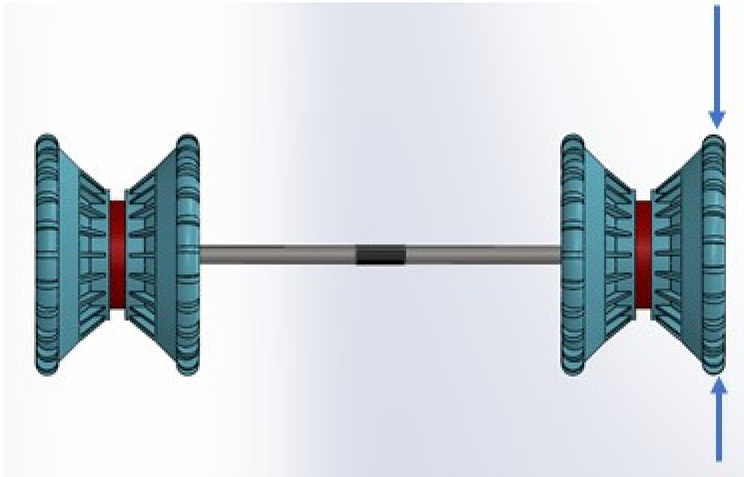


Figure 34. Loading condition of tire

1. **Translate design requirements**

Constraints

- Must have high friction to grip on to the track
- Must be wear resistant
- Must be strong enough to take the load of the whole assembly
- Ability to cast onto complex shapes

2. **Screen using constraints**

Based on the constraints, metals can be eliminated as they have less friction values. Certain plastic material can also be used to make tyres but the specific functional requirement of Trix-Trux monster truck cannot be met with material with lower friction. Elastomers and certain natural materials like leather have high friction and can be shortlisted. But leather with its high wear makes it less competent in the list and can be eliminated.

Choices are:

- Silicone elastomer
- Polyurethane
- Natural rubber

3. **Rank using objective**

Materials can be ranked according to friction it provides as below,

1. Natural Rubber
2. Silicone elastomer
3. Polyurethane

4. **Seek supporting info**

Materials can be ranked according to friction it provides as below,

1. Natural Rubber
2. Silicone elastomer
3. Polyurethane

Silicone elastomer can be easily moulded to any shape through injection moulding and can be used to manufacture complex geometries. This is an advantage of Silicone elastomer over other shortlisted materials.

5. **Material Selected: Silicone elastomer**

Main drive spur gear

As the cost per unit of POM was higher than other comparable materials, we decided to see for an opportunity to replace the components made of POM in our design. As seen in figure 36, we can see that the loading condition of the spur gear is cantilever under loading

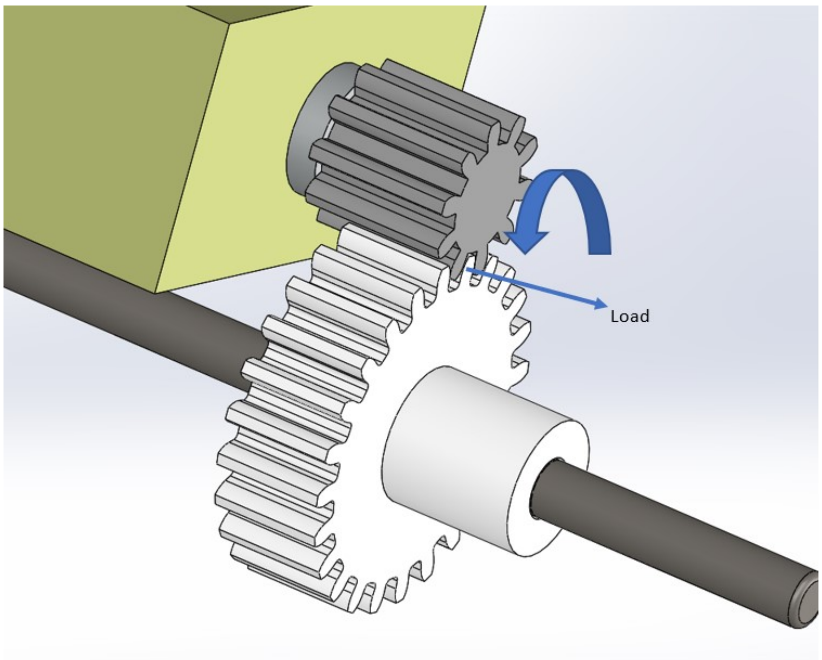


Figure 35. Loading condition of main drive spur gear

1. **Translate design requirements**

Constraints

- Must have stiffness to take load from the pinion gear
- Must not wear easily
- Low cost
- Can Easily slide without much friction

2. **Screen using constraints**

The component is in the form “Cantilever in bending”

So, for stiffness, Material performance index;

$$M = (\sqrt{E})/\rho$$

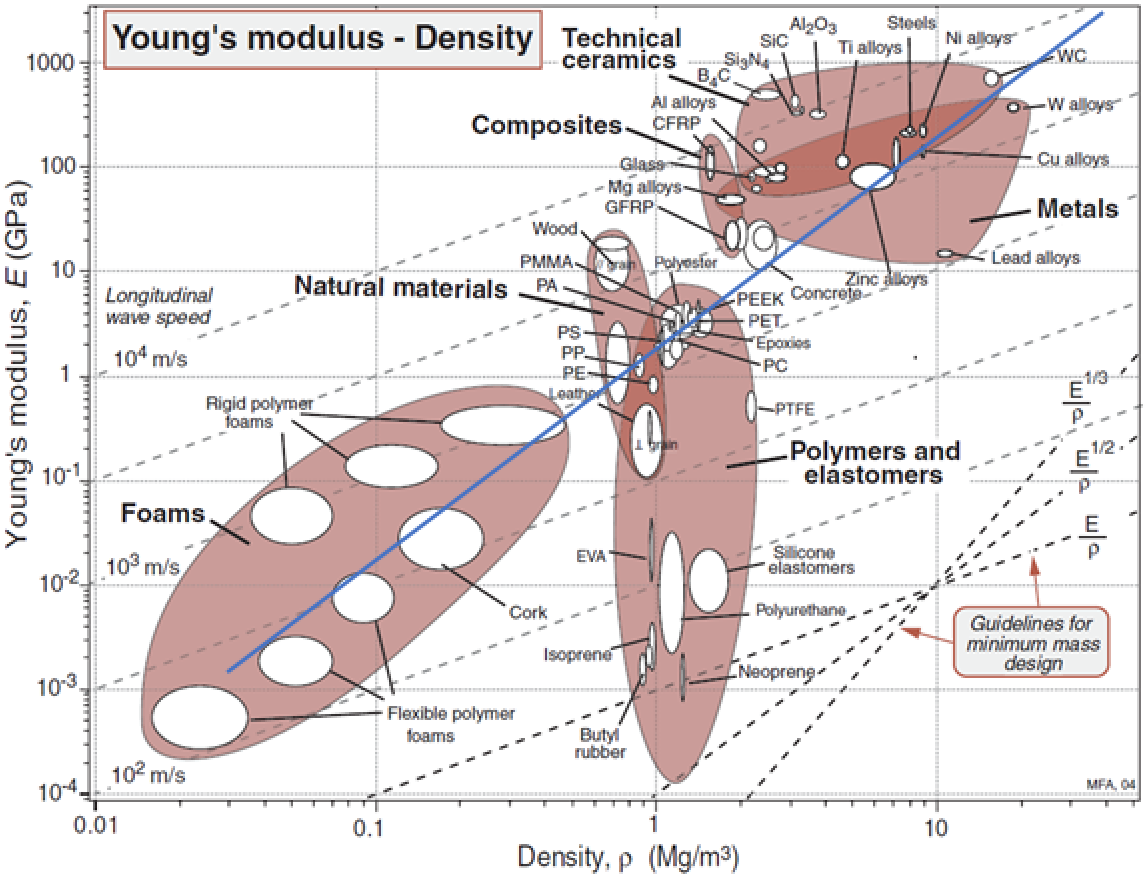


Figure 36. Ashby's Chart

Using Ashby Chart (figure 37), we can deduce that elastomers don't have the required material performance index to sustain the stiffness of the material under loading. Soft metals also can be eliminated using the same method. Various form materials have to be eliminated as they have less strength and low wear resistance.

From Ashby's chart, various materials like wood also show to be having great material performance index. But wood will have high friction which counter effects the functionality of the gear. Ashby chart gives the possibilities of the materials given below,

- Cast Iron
- Steel
- ABS
- PVC
- POM

3. Rank using objectives

Materials can be ranked as below according to the material performance index from Ashby's chart.

1. POM

2. Cast Iron
3. ABS
4. PVC
5. Steel

4. Seek supporting info

Cast iron and stainless-steel need additional lubrication to avoid friction between the gears. Whereas, POM is smooth and has a very slow rate of wear even when lubrication is not used. This is the advantage of POM over other polymers such as PVC and ABS as well.

5. Material Selected: POM

XV. PROCESS SELECTION

Most of the plastic components in the product have a very complex geometry. The tire which is made of silicone rubber is also quite complex in its shape. To select a process for the manufacture of all plastic components in the product, we decided to analyse the most complex component in the design and based on that we can standardise the manufacturing and invest in the equipment to be used.

For process selection analysis, we selected part 38. 1030 - Battery case lower part

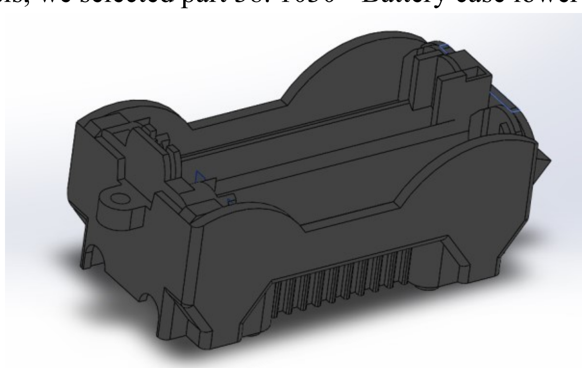


Figure 37. Isometric view of Battery case lower part

The spatial complexity of the part is high. To find out possible processes of manufacturing, we referenced the part complexity table (Table no. 8)

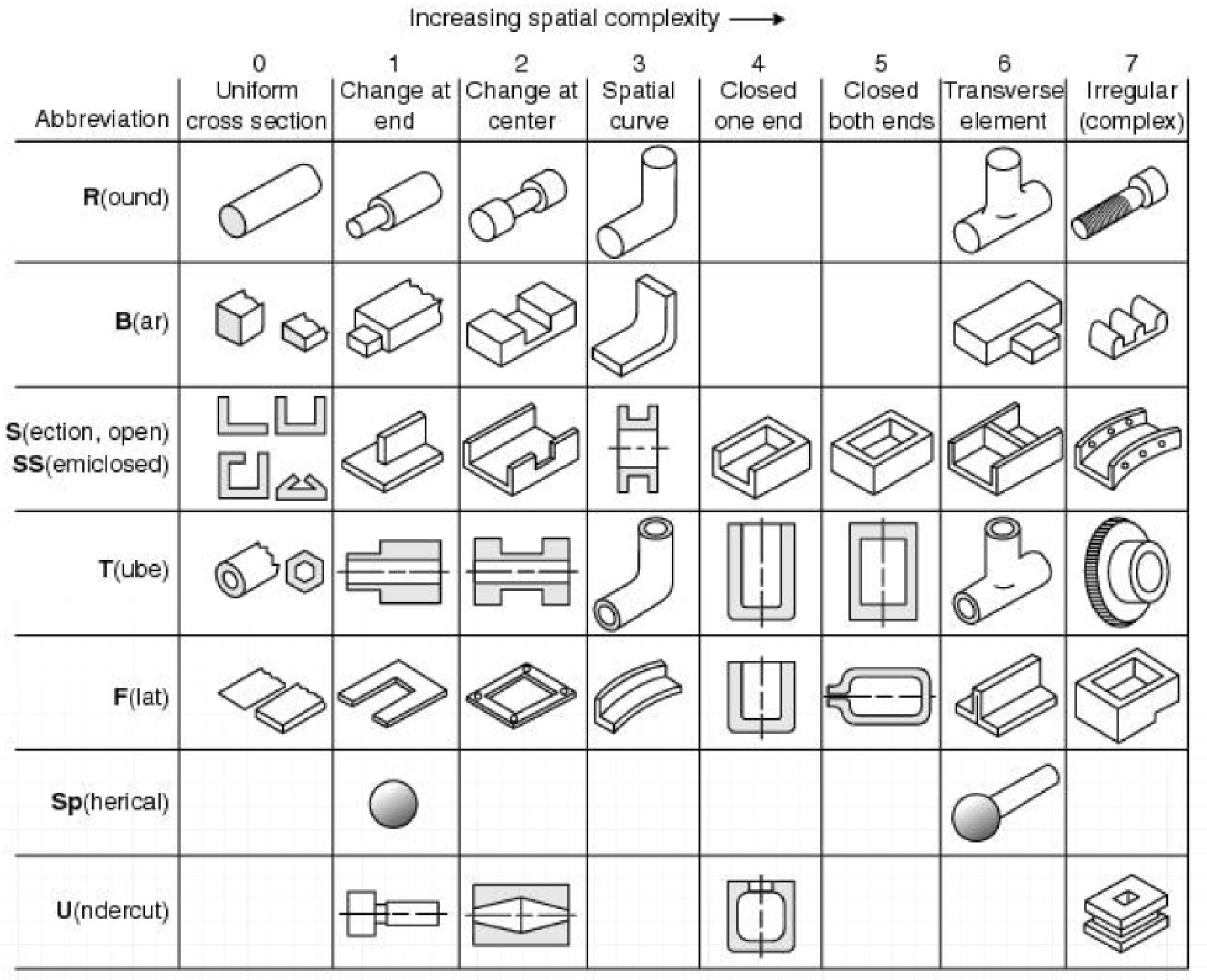


Table 8. Part complexity table

From the table we can find out that the battery case would fall into the category U7. Now the possible processes to manufacture U7 geometries were found out from Table no. 8.

Ability of Manufacturing Processes to Produce Shapes

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

Table 9. Ability of manufacturing processes to produce shapes

From the table it was found out that the possible processes included

- Sand casting
- Plaster casting
- Investment casting
- Injection molding
- Compression molding
- Cold press and sinter
- Hot isostatic pressing
- Powder injection molding
- PM forging
- Milling

Out of these processes, initial screening was conducted to eliminate non feasible choice of processes. Table 10 describes this process of screening

Process	ABS (Thermoplastic) Yes or No	Reject?	Reason for elimination
Sand casting	N		
Plaster casting	N		
Investment casting	N		
Injection molding	Y		
Compression molding	Y		
Cold press and sinter	Y	R	High material Cost
Hot isostatic pressing	Y	R	High material cost
Powder injection molding	N		
PM forging	Y	R	Not economical in higher batch sizes
Milling	N		

Table 10. Initial Screening of candidate processes

From the initial screening, we are left out with two processes to manufacture battery case in large volume. Injection molding and compression molding.

For further screening, the section thickness of the battery case was determined and was found to be 0.635 mm.

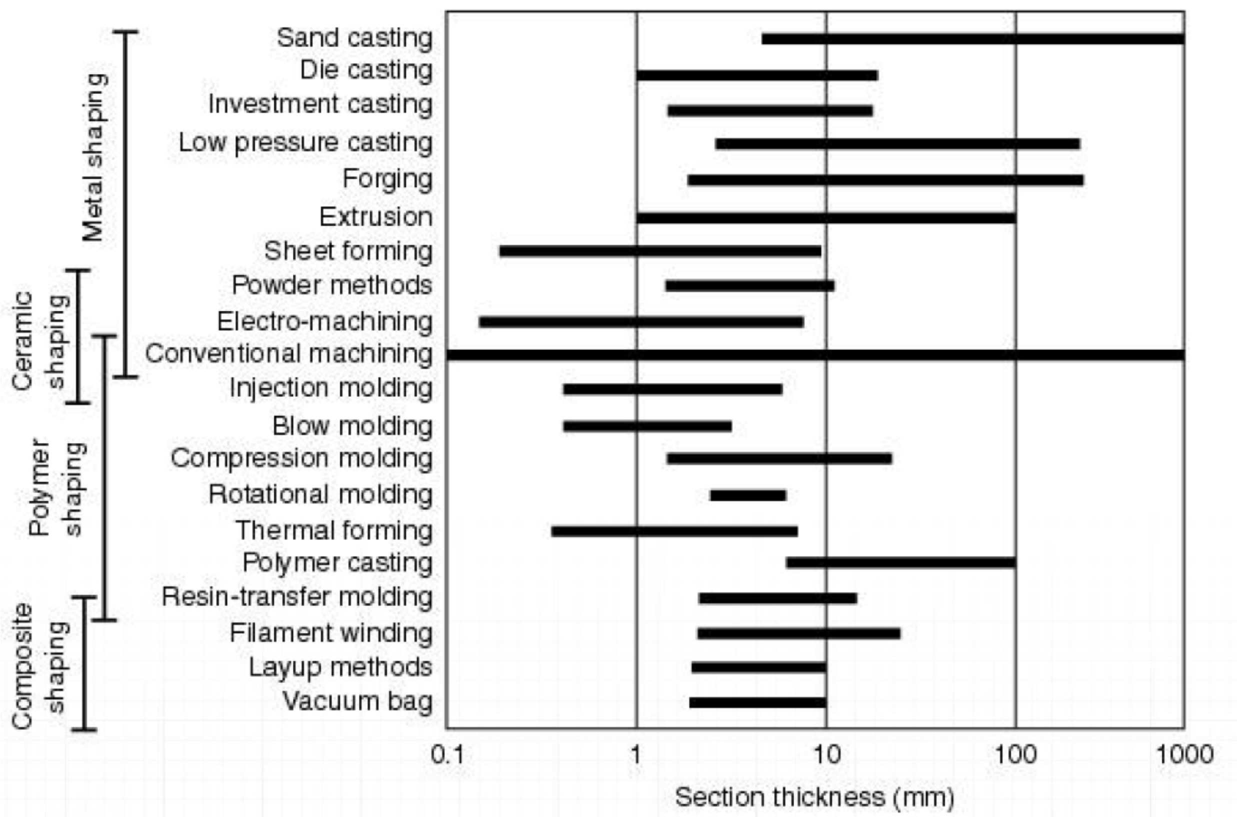


Figure 38. Process capability with section thickness

From figure 39, it can be seen that compression molding is not suitable for parts with section thickness less than 1mm. So compression molding can also be eliminated. So the process selected for manufacturing the battery case is injection molding

Process Selected: Injection molding

XVI. COST ANALYSIS

Cost analysis of each component was done to substantiate and review the design changes that were made to the original design of the product. This helped us in constraining the project to make the most sensible changes in design which otherwise can go to any extent of designer's creativity.

In the report, cost analysis of components before and after redesigning was performed to compare and quantify the benefits we achieved after the changes were made.

For comparing and error proofing the analysis, various methods of cost estimation were used.

A. OME Estimate

OME cost estimation was used to roughly calculate the manufacturing and selling cost of each component. The OME estimate works on the thumb rule of 1:3:9. That is, if the material cost of a component is 'x', then

Manufacturing cost = 3*x

Price = 9*x

The material weight of non OTS components were determined from the CAD files of each component and was put for estimate. Table 11 shows the OME estimate that was done on the components.

Part No.	Part Description	Material	Mass (lb)	Material Rate ($/lb)	Material Cost ($)	Mfg Cost	Price	Qty	Total Price
1011	Main Drive Spur Gear	POM	0.001	2.3	0.0023	0.0069	0.0207	1	0.0207
1025	Top Cover	ABS	0.01	1.5	0.015	0.045	0.135	1	0.135
1030	Battery Case	ABS	0.03	1.5	0.045	0.135	0.405	1	0.405
1055	Switch	ABS	0.0005	1.5	0.00075	0.00225	0.00675	1	0.00675
1066	Front Guard	ABS	0.001	1.5	0.0015	0.0045	0.0135	1	0.0135
2001	Motor Shaft	304 SS	0.003	1.72	0.00516	0.01548	0.04644	1	0.04644
2002	Wheel Shaft	304 SS	0.003	1.72	0.00516	0.01548	0.04644	2	0.09288
2063	Car Silencer	ABS	0.001	1.5	0.0015	0.0045	0.0135	1	0.0135
2184	Main Drive Worm Gear	POM	0.0002	2.3	0.00046	0.00138	0.00414	2	0.00828
2888	Drivetrain Body	ABS	0.01	1.5	0.015	0.045	0.135	1	0.135
3000	Spoiler	ABS	0.001	1.5	0.0015	0.0045	0.0135	1	0.0135
3003	Wheel Tire	Rubber	0.02	1.6	0.032	0.096	0.288	8	2.304
3030	Wheel Hub	ABS	0.01	1.5	0.015	0.045	0.135	4	0.54
3033	Bottom Cover	ABS	0.02	1.5	0.03	0.09	0.27	1	0.27
3303	Top Shield	ABS	0.025	1.5	0.0375	0.1125	0.3375	1	0.3375
3333	Locking Gear	POM	0.0003	2.3	0.00069	0.00207	0.00621	2	0.01242
3366	Wheel Axle Gear	POM	0.0007	2.3	0.00161	0.00483	0.01449	2	0.02898
							Total Cost		4.38345

Table 11. OME Estimate of original design parts

From the analysis, the cost of manufacturing all the non-OTS components was calculated to be **$4.383.**

We have OTS components such as screws and motor. The cost of these components were determined from a bulk order quotation from “fastener superstore” and “pavaykamall”. The total unit cost calculation is given below.

Unit cost of 0.025” screws = $0.066
Number of screws in design = 7
Total cost of screws = 0.462
Cost of motor = $1.2
Total unit cost of Trix Trux Car before redesign = $6.045

OME estimates were done again after incorporating the design changes. Estimates are shown in Table 11.

B. Cost to manufacture method

Unlike the OME estimate, the cost to manufacture method takes into consideration the minor details in manufacturing facility and so is much comprehensive. For the cost analysis we did on our product, we had the following assumptions

- 2 number of injection molding equipment and molds used for all ABS plastic components
- 2 number of injection molding equipment and molds used for all POM plastic components
- 2 number of rubber molding equipment and molds used for rubber components
- 500000 number of parts to be manufactured
- 1 operator per equipment
- 50 weeks per year operation
- 18 hours of machine operation per day in 3 shifts
- In case of components which are same in design but appears multiple times in a unit of the product, parts to be manufactured will be multiplied to the number of repeats it has in the design

Cost to manufacture method considers the following variables in its estimates,

1. Material Cost

The material cost of a component can be calculated using the following formula,

$$C_M = \frac{m c_m}{1 - f}$$

Where C_M = Material cost
m = Mass of the component
c_m = Unit cost of the material
f = Fraction of element that is scrap

The material cost of various plastics used in components of our design was procured from the website plasticsinsight.com and the metal prices of various metals used was procured from agmetalminer.com

2. Labour cost

Labour cost determines the price added on to the unit cost of the component due to the labour wages in production. Labor cost can be calculated by the formula,

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

Where C_L = Unit cost of labor
c_w = Labor cost ($/h)
n' = Production rate

3. Tooling Cost

Tooling cost determines the fraction of price that contributes to the overall price of the product due to the expense in tools used during its manufacture. Tooling cost can be determined by,

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

Where	C_T	= unit cost of tooling
	c_t	= Tooling cost($/set)
	k	= Sets of tooling required
	n	= Total production run (units)

4. **Equipment cost**

The unit cost of equipment used in production of the component can be found out by the formula,

$$C_E = \left(\frac{1}{n'}\right)\left(\frac{c_e\, n_e}{L t_{wo}}\right) q$$

Where	C_E	= unit cost of capital equipment
	c_e	= Capital cost, ce ($)
	n_e	= Number of equipment used
	t_{wo}	= Capital write-off time(yrs)
	L	= Load fraction (Fraction)
	q	= Load sharing fraction

5. **Overhead cost**

The cost contributor to the unit cost of the component due to the overhead expenses of the facility can be calculated by,

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

C_{OH}	= unit cost of factory overhead
c_{oh}	= Factory overhead ($/h)

6. **Total Cost**

Total cost of a component can be estimated by,

Total unit cost = $C_M+C_L+C_T+C_E+C_{OH}$

Based on the formulas, all non-OTS components of the original design were put to cost to manufacture analysis. Table 12 provides the details.

	Material cost				Labor cost			Tooling cost					Equipment cost					Overhead cost		Total cost
Equation	$C_M = \frac{m c_m}{1-f}$				$C_L = \frac{c_w}{n'}$			$C_T = \frac{c_t k}{n}$					$C_E = \left(\frac{1}{n'}\right)\left(\frac{c_e n_e}{L t_{wo}}\right) q$					$C_{OH} = \frac{c_{oh}}{n'}$		
Cost element	c_m	f	m (lb)	C_M	c_w ($/h)	n', (units/h)	C_L	c_t ($/set)	n (units)	n_t (units)	k	C_T	c_e ($)	t_{wo} (yrs)	L	q	C_E	c_{OH} ($/h)	C_{OH}	Total unit cost = $C_M+C_L+C_T+C_E+C_{OH}$
Part - 1011 Main Drive Spur gear	2.3	0.05	0.0015	**0.004**	15	20000	**0.001**	10000	500000	250000	4	**0.08**	500000	5	1	0.2	**0.00032**	15	**0.001**	**0.085**
Part - 1030 Battery Case	1.5	0.05	0.03	**0.047**	15	1500	**0.010**	20000	500000	250000	4	**0.16**	500000	5	1	0.2	**0.004**	15	**0.010**	**0.232**
Part - 1025 Top Cover	1.5	0.05	0.01	**0.016**	15	3000	**0.005**	18000	500000	250000	4	**0.144**	500000	5	1	0.2	**0.002**	15	**0.005**	**0.172**
Part - 1055 Switch	1.5	0.05	0.0005	**0.001**	15	25000	**0.001**	10000	500000	250000	4	**0.08**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.082**
Part- 1066 Front Guard	1.5	0.05	0.001	**0.002**	15	22000	**0.001**	10000	500000	250000	4	**0.08**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.083**
Part - 2063 Car Silencer	1.5	0.05	0.001	**0.002**	15	22000	**0.001**	12000	500000	250000	4	**0.096**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.099**
Part - 2184 Main Drive Worm Gear	2.3	0.05	0.0002	**0.0005**	15	25000	**0.001**	11000	1000000	250000	8	**0.088**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.090**
Part - 2002 Wheel Shaft	1.7	0.1	0.003	**0.006**	15	5000	**0.003**	10000	1000000	500000	2	**0.02**	100000	5	1	1	**0.001**	10	**0.002**	**0.031**
Part - 3000 Rear Spoiler	1.5	0.05	0.001	**0.0016**	15	18000	**0.001**	13000	500000	250000	4	**0.104**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.108**
Part - 3033 Bottom Cover	1.5	0.05	0.02	**0.0316**	15	3000	**0.005**	18000	500000	250000	4	**0.144**	500000	5	1	0.2	**0.002**	15	**0.005**	**0.188**
Part - 3303 Top shield	1.5	0.05	0.025	**0.0395**	15	2500	**0.006**	20000	500000	250000	4	**0.16**	500000	5	1	0.2	**0.003**	15	**0.006**	**0.214**
Part - 3333 Locking Gear	2.3	0.05	0.0003	**0.0007**	15	30000	**0.001**	10000	1000000	250000	8	**0.08**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.082**
Part - 3366 Wheel Axle Gear	2.3	0.05	0.0007	**0.0017**	15	20000	**0.001**	11000	1000000	250000	8	**0.088**	500000	5	1	0.2	**0.000**	15	**0.001**	**0.091**
Part - 2001 Motor Shaft	1.7	0.1	0.003	**0.006**	15	5000	**0.003**	10000	500000	500000	1	**0.02**	100000	5	1	1	**0.001**	10	**0.002**	**0.031**
Part - 2888 Drivetrain Body	1.5	0.05	0.01	**0.016**	15	2300	**0.007**	15000	500000	250000	4	**0.12**	500000	5	1	0.2	**0.003**	15	**0.007**	**0.152**
Part - 3003 Wheel Tire	1.6	0.01	0.02	**0.032**	15	5000	**0.003**	12000	4000000	250000	32	**0.096**	70000	7	1	0.3	**0.000**	17	**0.003**	**0.135**
Part - 3030 Wheel Hub	1.5	0.05	0.01	**0.016**	15	4000	**0.004**	10000	2000000	300000	13	**0.065**	500000	5	1	0.2	**0.002**	15	**0.004**	**0.090**
																			Total Cost	**1.965**

Table 12. Cost to manufacture analysis of original design

The cost of non OTS components was found out from the analysis to be **$1.965**

Custom partnet

From the custompartnet online cost estimator service, the total unit cost of product was estimated to be $2.17

Break-even Analysis

To get the selling price of the manufactured components, a break-even analysis has to be done. Break-even analysis provides the margin in which the selling price of a certain component has to be set in order to achieve profit within the business goals of a company.

In order to do break-even analysis, it was assumed that the business goal of the company is to achieve profit after production of 5000 units of the manufactured component.

The break-even point of a product is given by the equation,

$$Q_B = \frac{f}{P-v}$$

Where		
	Q_B	= Break Even Point
	f	= fixed cost ($)
	P	= Sales price ($/unit)
	V	= Variable cost ($/unit)

In the current problem, we have to find out the sales price for 10000 units of material production. It can be found from the above equation,

Sales price $$P = \frac{f}{Q_B} + v$$

Break even analysis of the manufactured components before redesigning is shown in Table 13.

	G&A Expense	Factory Expenses	Sales & OH	Depreciation	Total Fixed Cost, f ($)	Labor cost	Material cost	Total Variable cost per unit, v ($/Unit)	Break even target, Q_B (Units)	Selling price, P ($/unit)
1011 - Main Drive Spur gear	600	400	500	2400	3900	0.01	0.004	0.014	10000	0.404
1030 - Battery Case	600	400	500	2400	3900	0.01	0.047	0.057	10000	0.447
1025 - Top Cover	600	400	500	2400	3900	0.005	0.016	0.021	10000	0.411
1055 - Switch	600	400	500	2400	3900	0.001	0.001	0.002	10000	0.392
1066 - Front Guard	600	400	500	2400	3900	0.001	0.002	0.003	10000	0.393
2063 - Car Silencer	600	400	500	2400	3900	0.001	0.002	0.003	10000	0.393
2184 - Main Drive Worm Gear	600	400	500	2400	3900	0.001	0.0005	0.0015	20000	0.1965
2002 - Wheel Shaft	400	300	500	2400	3600	0.003	0.006	0.009	20000	0.189
3000 - Rear Spoiler	600	400	500	2400	3900	0.001	0.0016	0.0026	10000	0.3926

	G&A Expense	Factory Expenses	Sales & OH	Depreciation	Total Fixed Cost, f ($)	Labor cost	Material cost	Total Variable cost per unit, v ($/Unit)	Break even target, Q_B (Units)	Selling price, P ($/unit)

3033 - Bottom Cover	600	400	500	2400	3900	0.005	0.0316	0.0366	10000	0.4266
3303 - Top shield	600	400	500	2400	3900	0.006	0.0395	0.0455	10000	0.4355
3333 - Locking Gear	600	400	500	2400	3900	0.001	0.0007	0.0017	20000	0.1967
3366 - Wheel Axle Gear	600	400	500	2400	3900	0.001	0.0017	0.0027	20000	0.1977
2001 - Motor Shaft	400	300	500	2000	3200	0.003	0.006	0.009	10000	0.329
2888 - Drivetrain Body	600	400	500	2400	3900	0.007	0.016	0.023	10000	0.413
3003 - Wheel Tire	700	500	500	2600	4300	0.003	0.032	0.035	40000	0.08875
3030 - Wheel Hub	600	400	500	2400	3900	0.004	0.016	0.02	40000	0.1175
									Total Selling Price	5.42285

Table 13. Break Even analysis of manufactured components before redesign

In the Breakeven estimation done above, parts that have more than one quantity in a single unit were dealt with increasing the breakeven point proportionally.

From the estimation we found out that the selling cost of the manufactured product can be set to an amount of $5.423 per unit in-order to break even at 10000 units of the product.

After Redesign

After redesigning the product, we conducted cost analysis on the new set of components, similar to what were conducted on original design.

A. OME Estimate

Table 14. shows the OME estimate of the redesigned components

Part No.	Part Description	Material	Mass (lb)	Material Rate ($/lb)	Material Cost ($)	Mfg Cost	Price	Qty	Total Price
1011	Main Drive Spur Gear	POM	0.001	2.3	0.0023	0.0069	0.0207	1	0.0207
1025	Top Cover	ABS	0.037	1.5	0.0555	0.1665	0.4995	1	0.4995

1030	Battery Case	ABS	0.03	1.5	0.045	0.135	0.405	1	0.405
1055	Switch	ABS	0.0005	1.5	0.00075	0.00225	0.00675	1	0.00675
2001	Motor Shaft	304 SS	0.003	1.72	0.00516	0.01548	0.04644	1	0.04644
2002	Wheel Shaft	304 SS	0.003	1.72	0.00516	0.01548	0.04644	2	0.09288
2184	Main Drive Screw Gear	POM	0.0002	2.3	0.00046	0.00138	0.00414	2	0.00828
2888	Drivetrain Body	ABS	0.01	1.5	0.015	0.045	0.135	1	0.135
3003	Wheel Tire	Rubber	0.02	1.6	0.032	0.096	0.288	8	2.304
3030	Wheel Hub	ABS	0.01	1.5	0.015	0.045	0.135	4	0.54
3033	Bottom Cover	POM	0.02	2.3	0.03	0.09	0.27	1	0.35
3333	Locking Gear	POM	0.0003	2.3	0.00069	0.00207	0.00621	2	0.01242
3366	Wheel Axle Gear	POM	0.0007	2.3	0.00161	0.00483	0.01449	2	0.02898
								Total Cost	4.36995

Table 14. OME estimate of redesigned components

From the analysis, the cost of manufacturing all the non-OTS components was calculated to be $4.370. OME analysis did not portray much edge to the design changes that we have made as the total cost before design change was $4.383. This is because the design changes made did not reduce the mass of any material used in the product. The redesign was focussed on bringing down the complexity of assembly and manufacture and also rectifying some functional requirements. These changes did not reduce the mass of material and OME estimate completely depends on the mass of material used.

B. Cost of Manufacture method

	Material cost				Labor cost			Tooling cost					Equipment cost					Overhead cost		Total cost
Cost element	C_m	f	m (lb)	C_M	c_w (\$/h)	n', (units/h)	C_L	c_t (\$/set)	n (units)	n_t (units)	k	C_T	c_e (\$)	t_{wo} (yrs)	L	q	C_E	c_{OH} (\$/h)	C_{OH}	Total unit cost = C_M+C_L+C_T+C_E+C_{OH}
Part - 1011 Main Drive Spur gear	2.3	0.05	0.0015	0.004	15	20000	0.001	10000	500000	250000	4	0.08	500000	5	1	0.2	0.00032	15	0.001	0.085
Part - 1030 Battery Case	1.5	0.05	0.03	0.047	15	1500	0.010	20000	500000	250000	4	0.16	500000	5	1	0.2	0.004	15	0.010	0.232
Part - 1025 Top Cover	1.5	0.05	0.037	0.058	15	3000	0.005	18000	500000	250000	4	0.144	500000	5	1	0.2	0.002	15	0.005	0.215
Part - 1055 Switch	1.5	0.05	0.0005	0.001	15	25000	0.001	10000	500000	250000	4	0.08	500000	5	1	0.2	0.000	15	0.001	0.082
Part - 2184 Main Drive Worm Gear	2.3	0.05	0.0002	0.0005	15	25000	0.001	11000	1000000	250000	8	0.088	500000	5	1	0.2	0.000	15	0.001	0.090
Part - 2002 Wheel Shaft	1.7	0.1	0.003	0.006	15	5000	0.003	10000	1000000	500000	2	0.02	100000	5	1	1	0.001	10	0.002	0.031
Part - 3033 Bottom Cover	2.3	0.05	0.02	0.0484	15	3000	0.005	18000	500000	250000	4	0.144	500000	5	1	0.2	0.002	15	0.005	0.205
Part - 3333 Locking Gear	2.3	0.05	0.0003	0.0007	15	30000	0.001	10000	1000000	250000	8	0.08	500000	5	1	0.2	0.000	15	0.001	0.082
Part - 3366 Wheel Axle Gear	2.3	0.05	0.0007	0.0017	15	20000	0.001	11000	1000000	250000	8	0.088	500000	5	1	0.2	0.000	15	0.001	0.091
Part - 2001 Motor Shaft	1.7	0.1	0.003	0.006	15	5000	0.003	10000	500000	500000	1	0.02	100000	5	1	1	0.001	10	0.002	0.031
Part - 2888 Drivetrain Body	1.5	0.05	0.01	0.016	15	2300	0.007	15000	500000	250000	4	0.12	500000	5	1	0.2	0.003	15	0.007	0.152
Part - 3003 Wheel Tire	1.6	0.01	0.02	0.032	15	5000	0.003	12000	2000000	250000	16	0.096	70000	7	1	0.3	0.000	17	0.003	0.135
Part - 3030 Wheel Hub	1.5	0.05	0.01	0.016	15	4000	0.004	10000	2000000	300000	13	0.065	500000	5	1	0.2	0.002	15	0.004	0.090
																		Total Cost		1.521

Table 15. Cost to manufacture estimate of redesigned parts

Custom partnet
From the custompartnet online cost estimator service, the total unit cost of product after redesign was estimated to be $1.65

Break-even Analysis
Break even analysis was conducted on redesigned parts to estimate the selling price. Details of the estimate is shown in Table 16.

	G&A Expenses	Factory Expenses	Sales & OH	Depreciation	Total Fixed Cost per	Labor cost	Material cost	Total Variable cost per unit, v (\$/Unit)	Break-even target, Q_B (Units)	Selling price P(\$/unit)

					month, f ($)					
1011 - Main Drive Spur gear	600	400	500	2400	3900	0.01	0.004	0.014	10000	0.404
1030 - Battery Case	600	400	500	2400	3900	0.01	0.047	0.057	10000	0.447
1025 - Top Cover	600	400	500	2400	3900	0.005	0.037	0.042	10000	0.432
1055 - Switch	600	400	500	2400	3900	0.001	0.001	0.002	10000	0.392
2184 - Main Drive Worm Gear	600	400	500	2400	3900	0.001	0.0005	0.0015	20000	0.1965
2002 - Wheel Shaft	400	300	500	2400	3600	0.003	0.006	0.009	20000	0.189
3033- Bottom Cover	600	400	500	2400	3900	0.005	0.0484	0.0534	10000	0.4434
3333 - Locking Gear	600	400	500	2400	3900	0.001	0.0007	0.0017	20000	0.1967
3366 - Wheel Axle Gear	600	400	500	2400	3900	0.001	0.0017	0.0027	20000	0.1977
2001 - Motor Shaft	400	300	500	2000	3200	0.003	0.006	0.009	10000	0.329
2888 - Drivetrain Body	600	400	500	2400	3900	0.007	0.016	0.023	10000	0.413
3003 - Wheel Tire	700	500	500	2600	4300	0.003	0.064	0.067	40000	0.1745
3030 - Wheel Hub	600	400	500	2400	3900	0.004	0.016	0.02	40000	0.1175
									Total Selling Price	3.9323

Table 16. Breakeven analysis of Redesigned parts

From breakeven analysis, we found out that the selling price of manufactured parts reduced to $3.923. The price comparison before and after the design change is shown in table 17 below.

	Estimation technique	Original Design	Redesigned
Manufacturing cost	OME	$1.46	$1.46
	Cost to manufacture	$1.965	$1.52

	Custompartnet	\$2.17	\$1.65
Selling price	OME	\$4.383	\$4.37
	Break Even analysis	\$5.422	\$3.932

Table 17. Cost comparison of original and redesigned parts

We can see that the OME estimate of original and redesigned components did not vary substantially. This is because the redesign focussed on reducing the number of interfaces between the components and performed CAD changes to the parts that did not reduce the material required for that part. As OME estimate completely depends on the mass of material used, the reduced interfaces and DFA advantages were not reflected in the estimate.

Whereas, the cost estimation done through breakeven analysis shows significant change which justifies the DFA techniques that were used in the design changes.

We can see that the redesigned model saves a significant cost in its manufacture. This would help the manufacturer produce and sell goods at a lower rate and the increased functionality would bring higher popularity of the product among customers.

XVII. HUMAN FACTORS, SAFETY, AND ETHICAL CONSIDERATIONS

With the remodeled product, the human factors, safety, and ethical considerations must be reviewed to maintain the prior status of the product. It must be safe for consumers, the assembly of it is safe and ethical, and no ethical violations occur in the numbers behind the calculations, results, and analyses within this report. The team has made sure that all of these considerations have been met, as no design changes have classified the product as harmful to the consumer, namely children. If anything, the changes have improved the safety of the product by eliminating the snap fit of the Spoiler and Guard, which are small pieces that can be ingested. By combining the Guard with the Battery Case and the Spoiler with the Top Shield and Top Cover as one piece, the pieces would be too large for a child to swallow. In terms of assembly, no unethical assembly processes or means have been changed to produce the remodeled product, and all numbers from cost, material, manufacturing, and DFA analyses have been disclosed trufully.

XVIII. CONCLUSIONS

A great deal of engineering experience resulted from reverse engineering the TRIX TRUX Monster Truck and the process of reverse engineering itself. The objective was to understand the assembly processes behind the product, analyze areas where design could be improved, and implement them to improve the product in regards to manufacturing, assembly, and marketability. In this process, a number of specific engineering practices were used including: black box, glass box, and fishbone diagrams, patent search, documentation of disassembly, as well as DFA, Material, Manufacturing, and Cost analyses.

Both manufacturability and assembly of the TRIX TRUX Monster Truck was improved. These improved processes both decrease the production cost, while possibly increasing the production rate. The design changes responsible for these improvements included: snap fit features to eliminate the use of fasteners and combining individual parts to eliminate the number of components.

The part count total decreased from 21 to 14 with these design changes. One design change combined the Top Shield, Top Cover, and Spoiler into one component. Another combined the Battery Case with the Front Guard. Another combined the Wheel Hub, and Wheel Tire halves into one component. The last change was a snap-fit change that eliminated the fastener that accessed the battery case. All of these changes help significantly reduce the manufacturing cost, by 25 percent.

The project was similar to the Reverse Engineering Project seen in Manufacturing and Design in the Undergraduate Program at the University of Colorado Boulder, but implemented more advanced engineering practices such as the fishbone, glass box, and black box diagrams, as well as the Manufacturing, Material, DFA, and Cost analyses. In addition, design changes were asked as opposed to the undergraduate class. The project itself was new to two out of the three students on the team, as two are international students. Overall, the team gained real-world engineering experience, project managing, and valuable CAD experience not available in previous.

XIX. REFERENCES

[1] Dan Rifell

[2] CustomPartNet v 1.3.4. 2020

[3] Tristar Products

[4] amazon.com

[5] fastenersuperstore.com

[6] pavaykamall.com

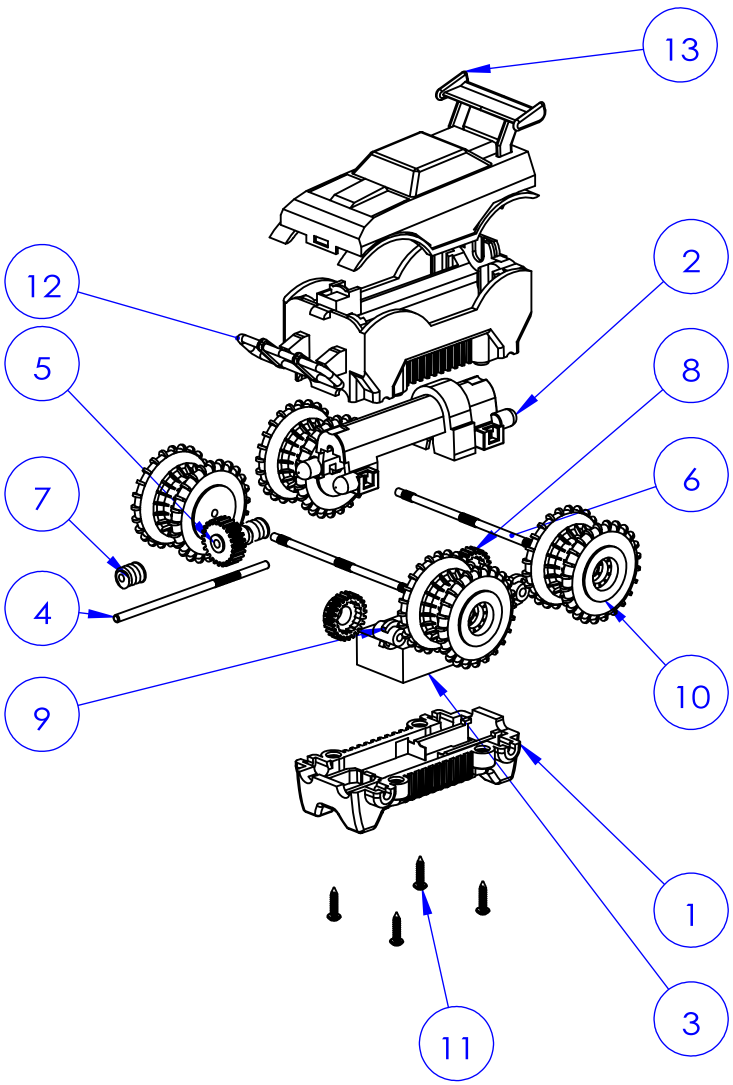
[7] polyplastics-global.com

[8] agmetalminer.com

XX. APPENDIX

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/3/5

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3033	BOTTOM COVER	1
2	2888	DRIVENTRAIN BODY	1
3	2222	MOTOR	1
4	2001	MOTOR SHAFT	1
5	1011	MAIN DRIVE SPUR GEAR	1
6	2002	WHEEL SHAFT	2
7	2184	MAIN DRIVE SCREW GEAR	2
8	3366	WHEEL AXLE GEAR	2
9	3333	LOCKING GEAR	2
10	3033	WHEEL TIRE	4
11	3382	NO.1 SIZE, 5/16" LONG SCREW	4
12	1030	BATTERY CASE	1
13	3330	TOP SHIELD	1



UNIVERSITY OF COLORADO

1111 ENGINEERING DRIVE
BOULDER, CO 80309-0427

DESCRIPTION
ASSEMBLY

PN	REV		SHEET
6666	A		1 of 1

REV.	DESCRIPTION	DATE
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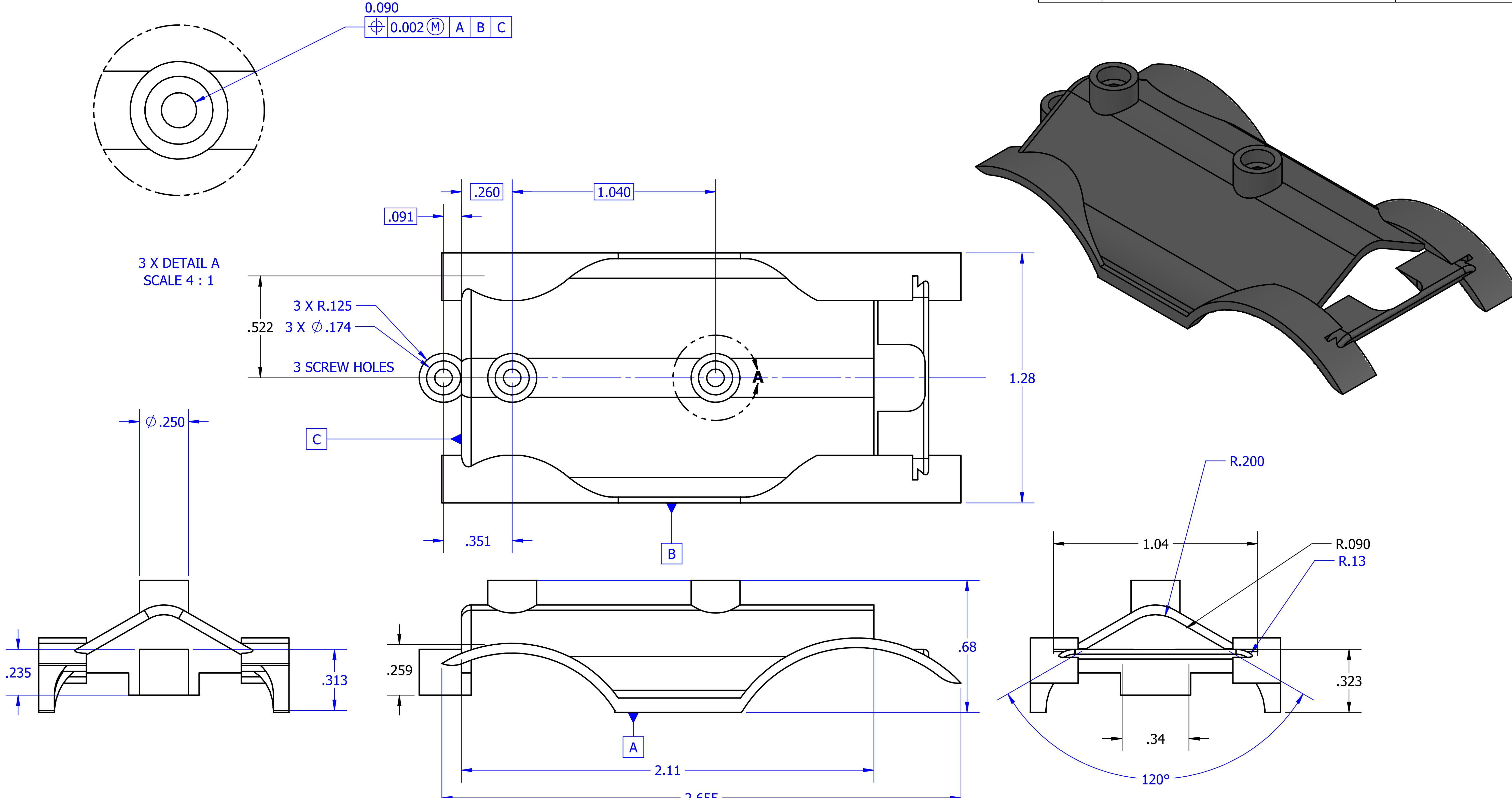

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UNITS: INCHES		
MATERIAL PVC Rigid		DESCRIPTION CAR BODY LOWER
FINISH NONE		PN 1025 · REV A · SHEET 1 of 2

REV.	DESCRIPTION	DATE
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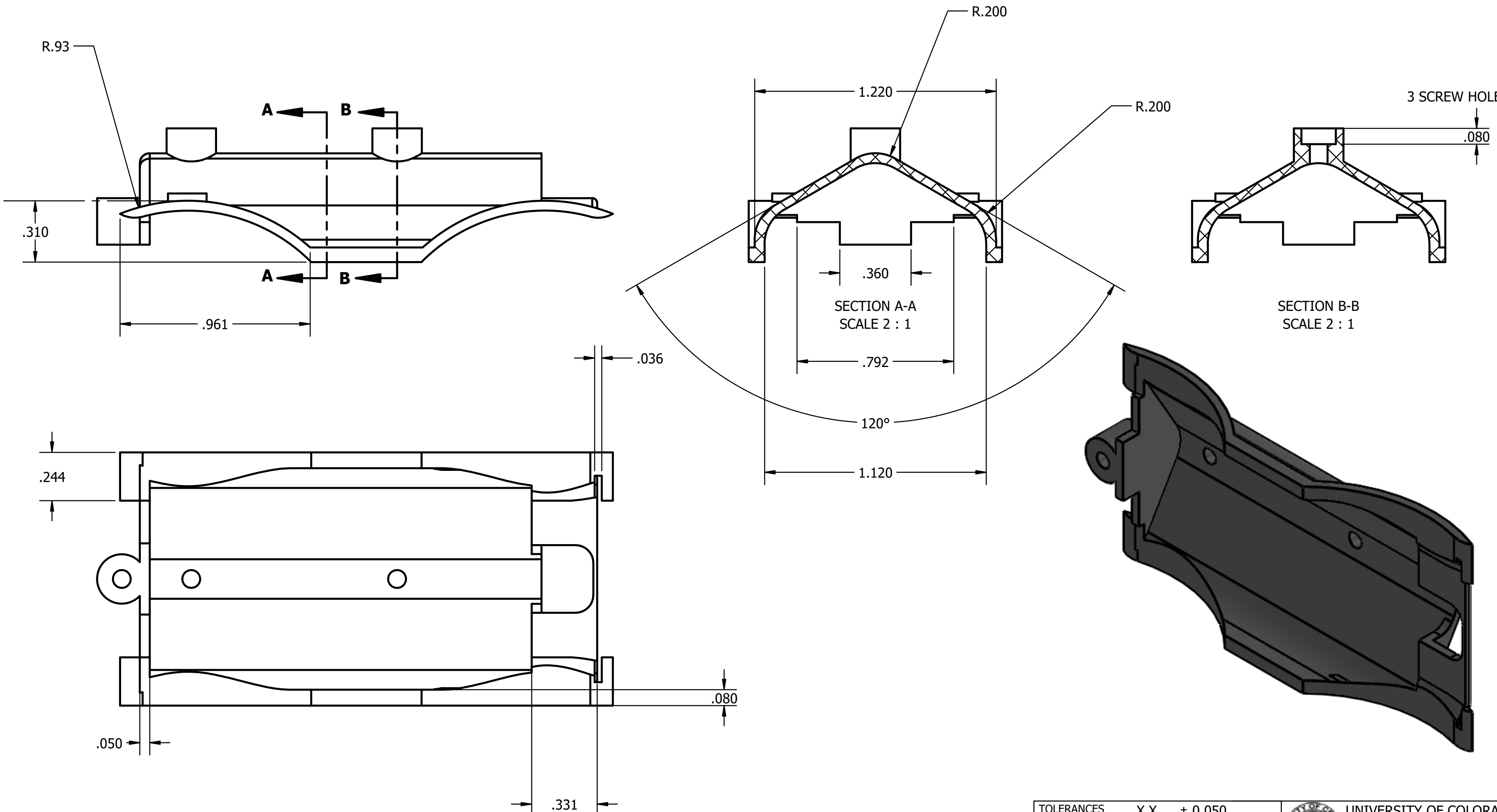

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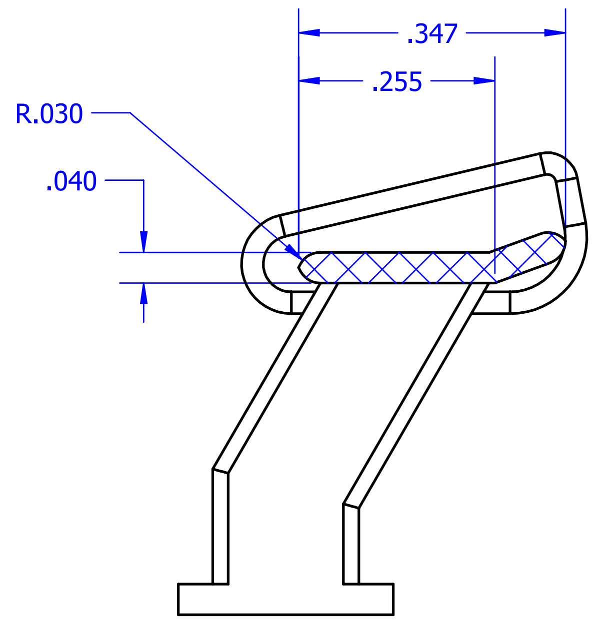
UNITS: INCHES		
MATERIAL: PVC Rigid		DESCRIPTION: CAR BODY LOWER
FINISH: NONE		PN: 1025 / REV: A / SHEET: 1 of 1

PROPRIETARY AND CONFIDENTIAL

REV.	DESCRIPTION	DATE
A (A)	INITIAL RELEASE	2/5/2020



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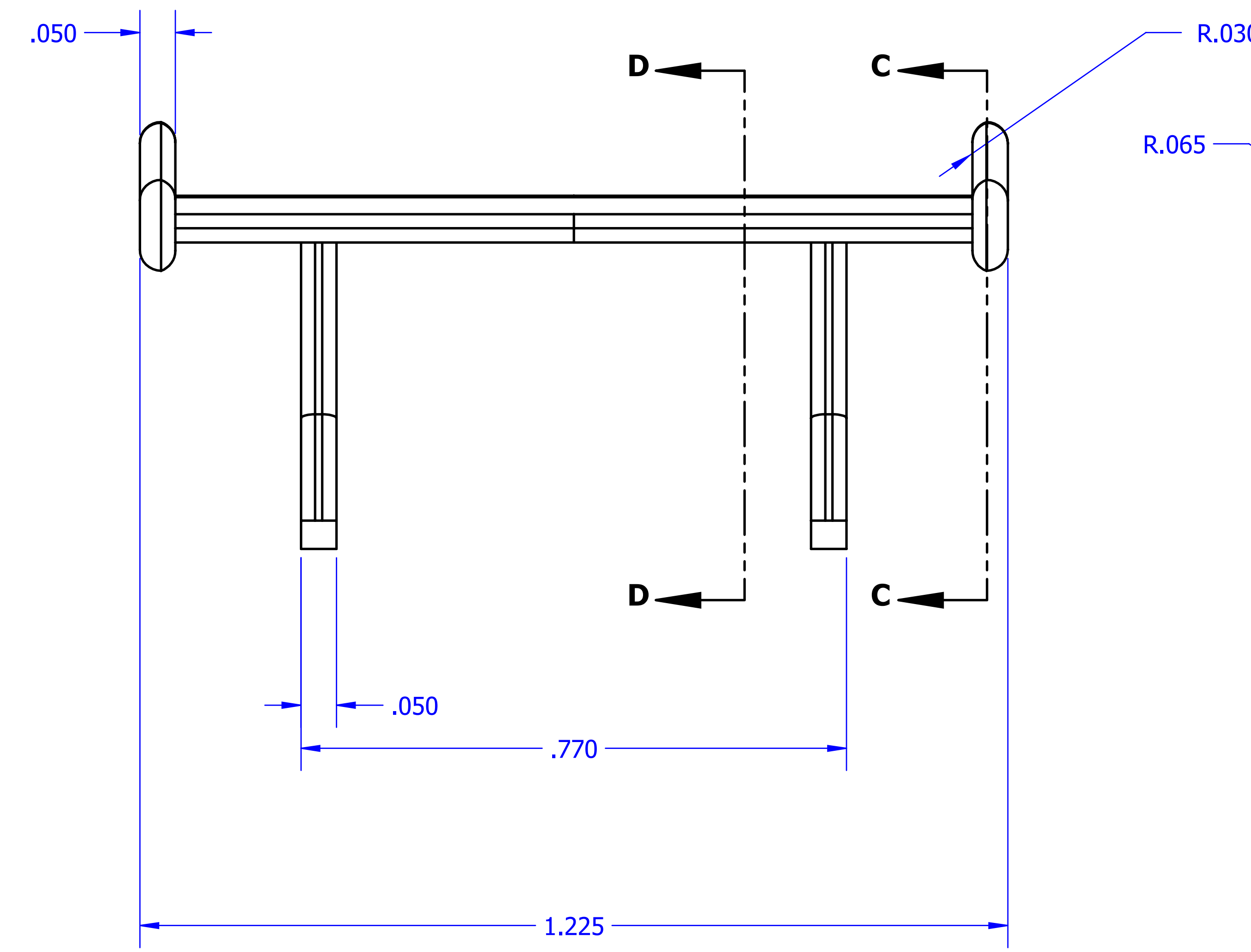

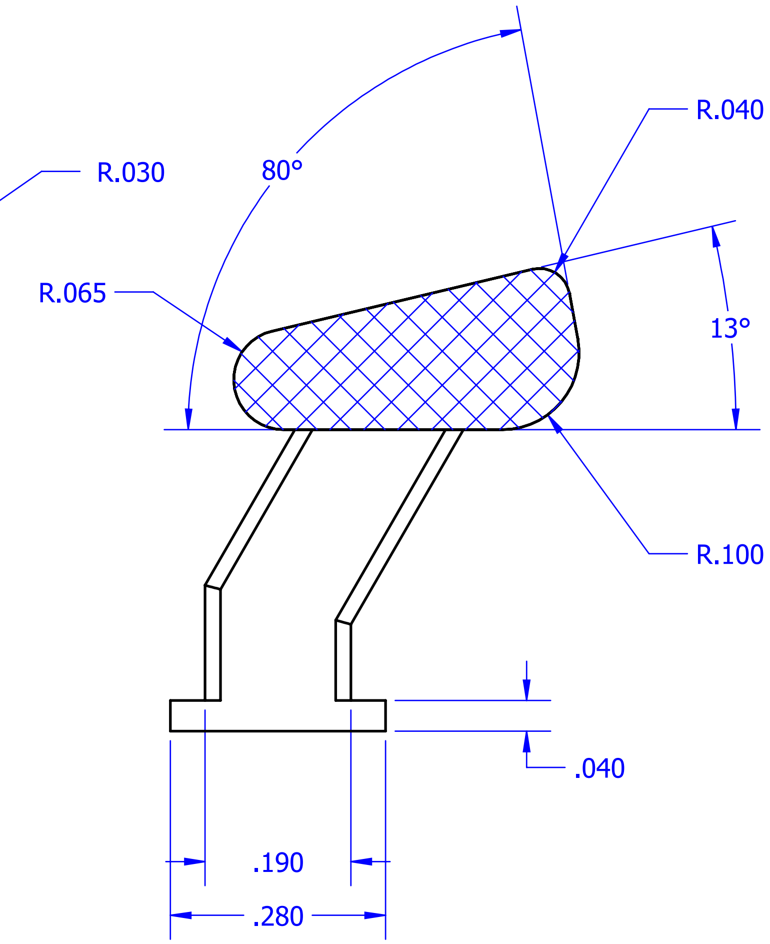

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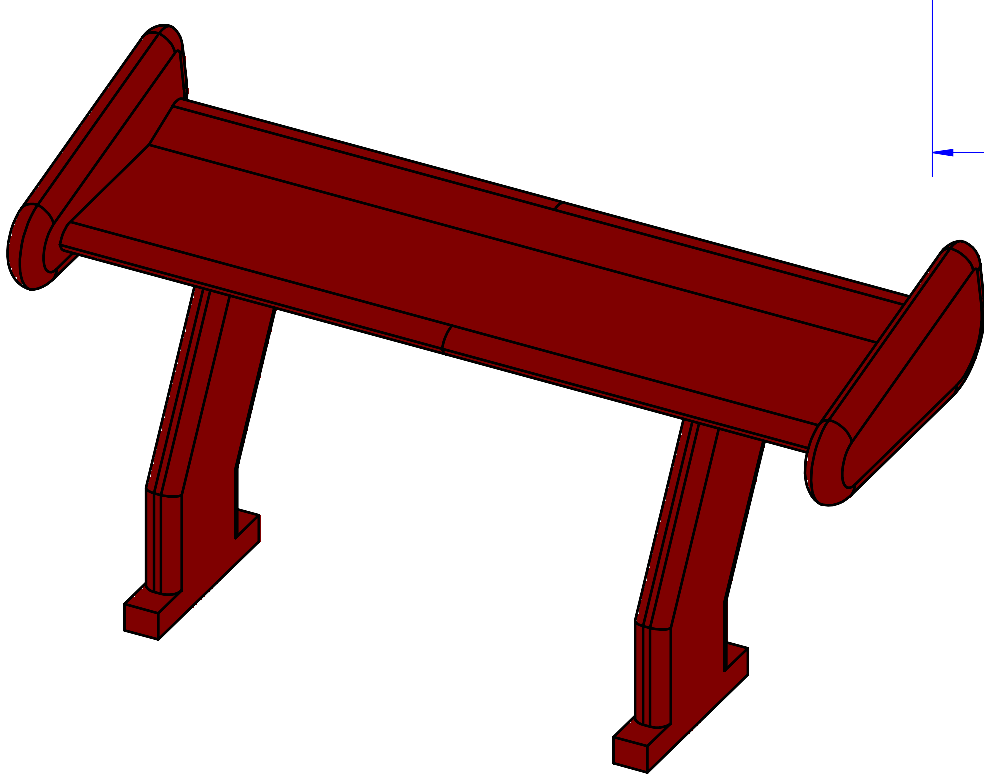

TOLERANCES UNLESS NOTED: X.X ± 0.050, X.XX ± 0.010, X.XXX ± 0.005, X.X° ± 1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS	DESCRIPTION Spoiler	
FINISH NONE	PN 3000 REV A	SHEET 1 of 1

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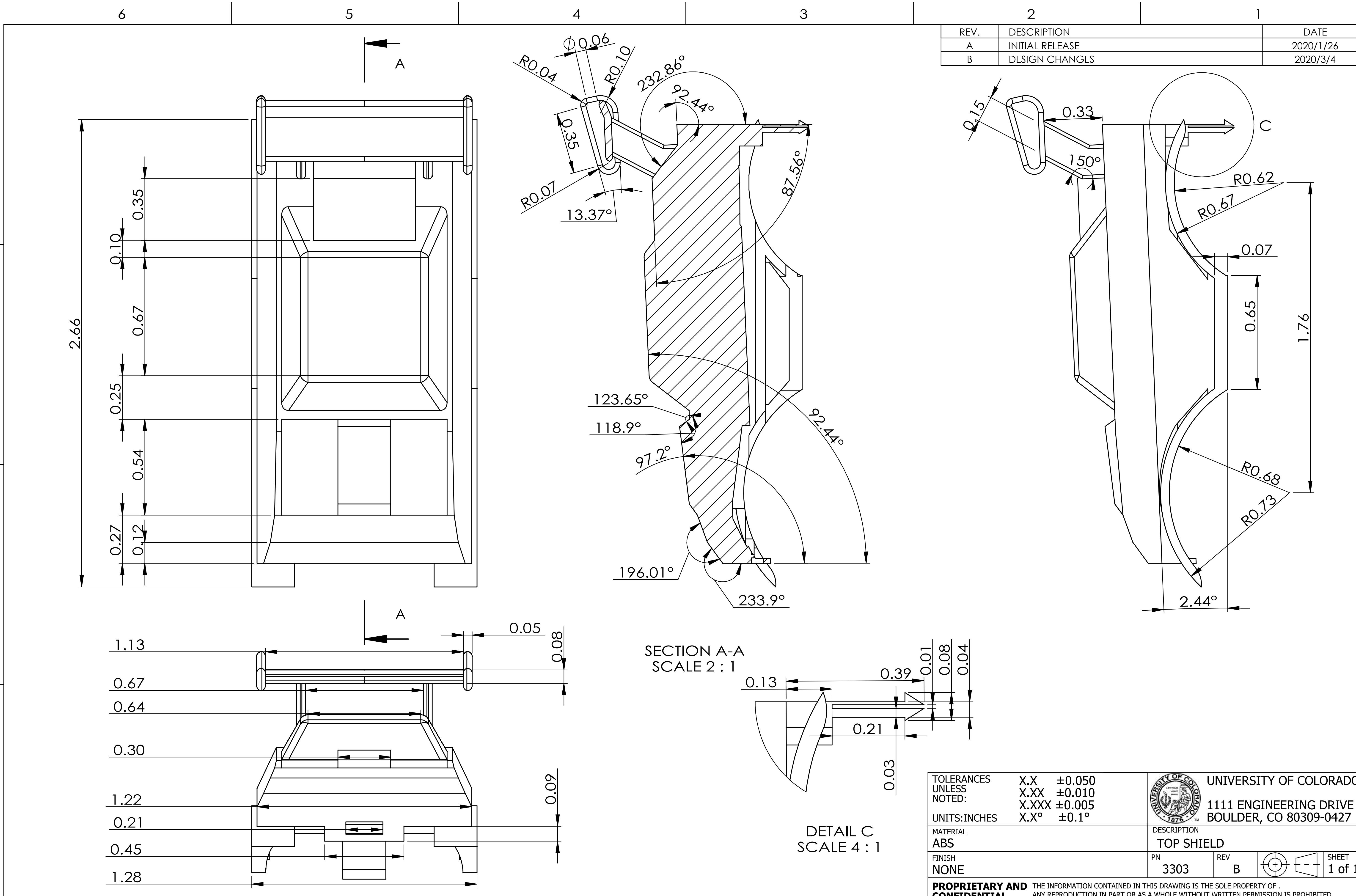
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/26
B	DESIGN CHANGES	2020/3/4



TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±0.1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL ABS		DESCRIPTION TOP SHIELD	
FINISH NONE		PN 3303	REV B · SHEET 1 of 1

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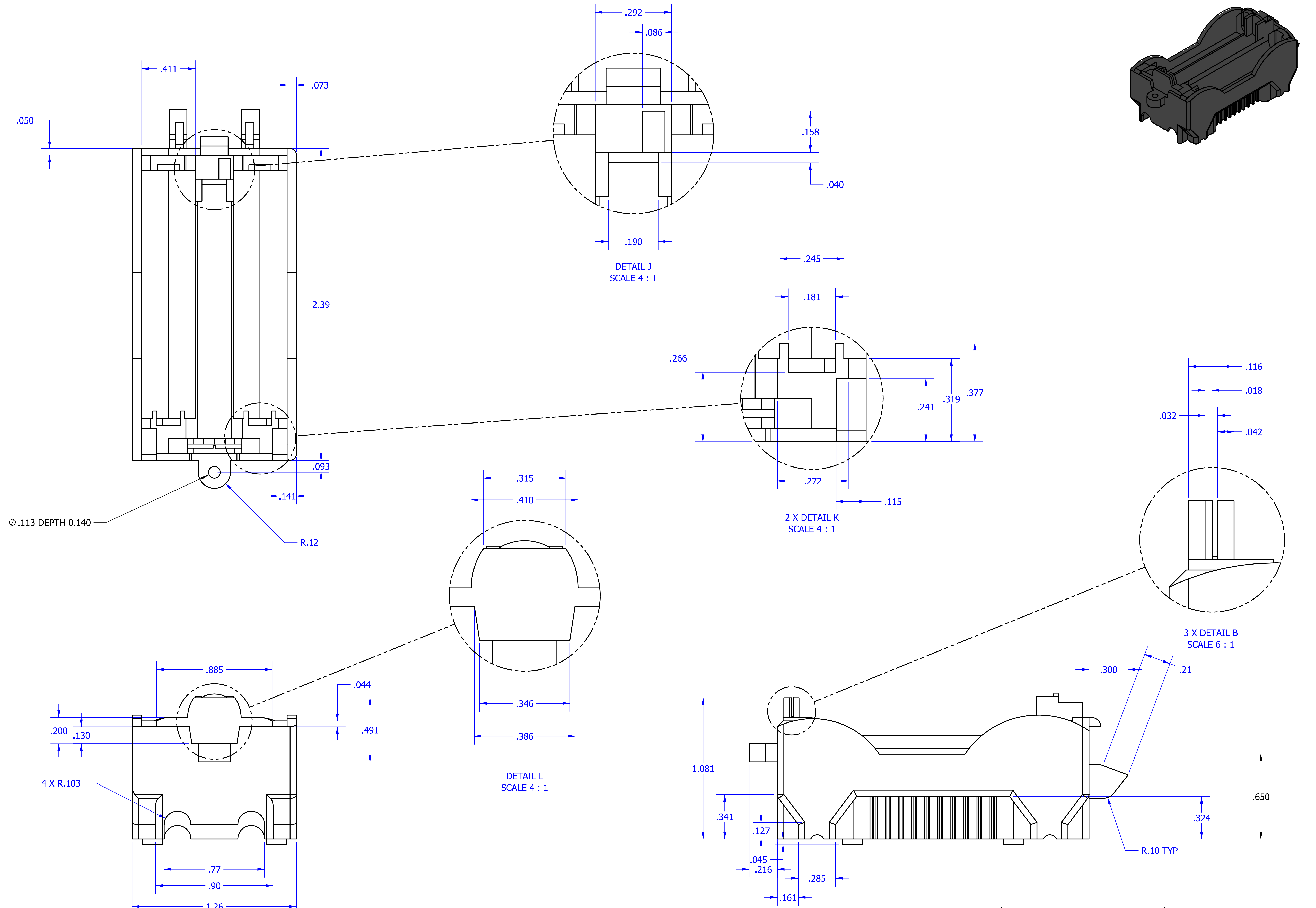
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	02-02-2020
B	DRAWING WITH GD&T	06-02-2020



TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.02, X.XXX ± 0.005, X.X° ± 1°	UNITS: INCHES	UNIVERSITY OF COLORADO, 1111 ENGINEERING DRIVE, BOULDER, CO 80309-0427
MATERIAL: PVC Rigid		DESCRIPTION: BATTERY CASE BOTTOM COVER
FINISH: NONE		PN: 1030 / REV: B / SHEET: 1 of 2

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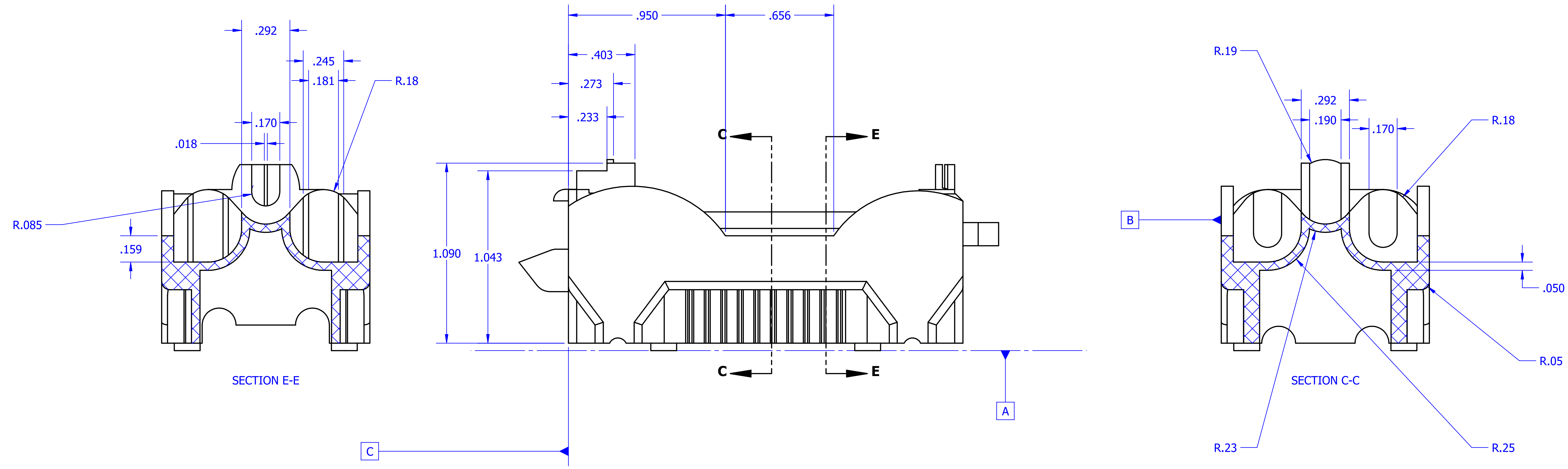
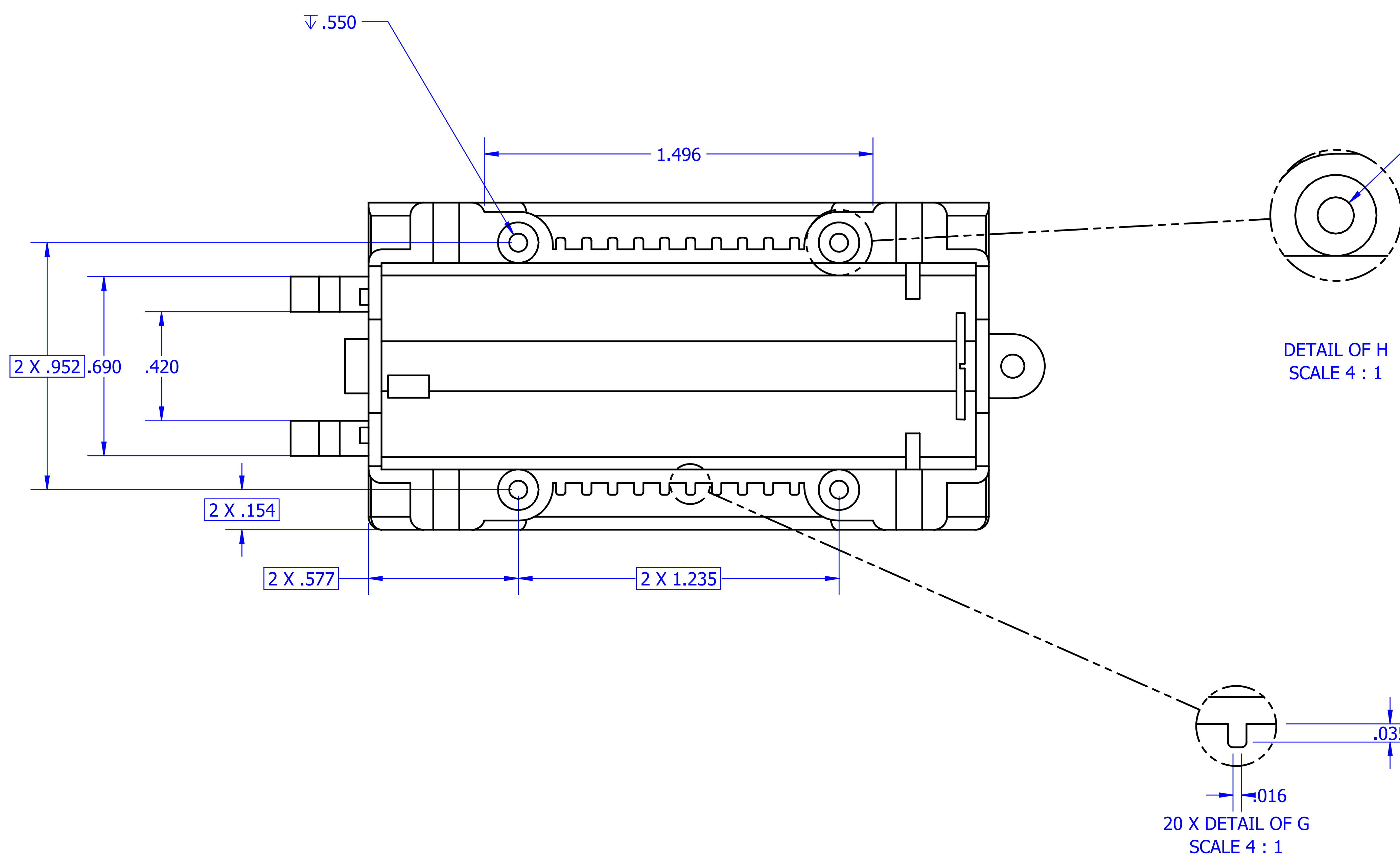




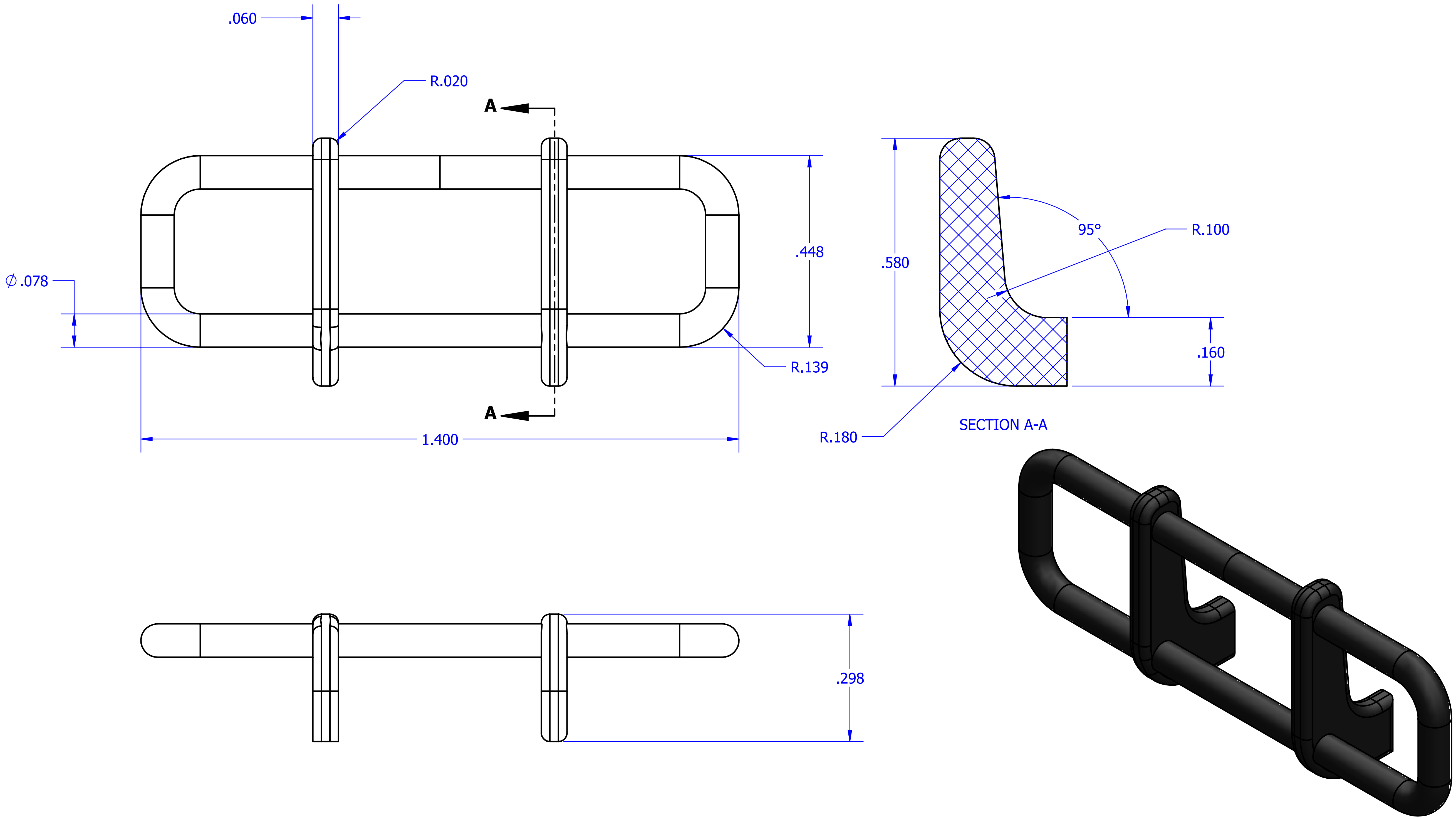
IF THE MATERIAL IS MADE WITH A HOLE DIAMETER LESS THAN THE MAXIMUM MATERIAL CONDITION, THEN A BONUS TOLERANCE IS PERMISSIBLE, THE VALUE OF WHICH IN THIS CASE IS
MMC - DIAMETER OF THE HOLE = BONUS TOLERANCE

EXAMPLE:
IF DIAMETER OF HOLE = .073
LMC = .075
BONUS TOLERANCE = .075 - .073 = .002 INCHES
THEREFORE TOTAL TOLERANCE = POSITIONAL TOLERANCE + BONUS TOLERANCE

TOTAL TOLERANCE = .002 + .002 = .004

TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.1 X.XX ± 0.02 X.XXX ± 0.005 X.X° ± 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL: PVC Rigid		DESCRIPTION: BATTERY CASE BOTTOM COVER
FINISH: NONE		PN: 1030 — REV: B — SHEET: 2 of 2

REV.	DESCRIPTION	DATE
A (A)	INITIAL RELEASE	2/3/2020



TOLERANCES UNLESS NOTED:	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ± 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL ABS		DESCRIPTION Front Guard
FINISH NONE		PN 1066 · REV A · SHEET 1 of 1

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REV.	DESCRIPTION	DATE
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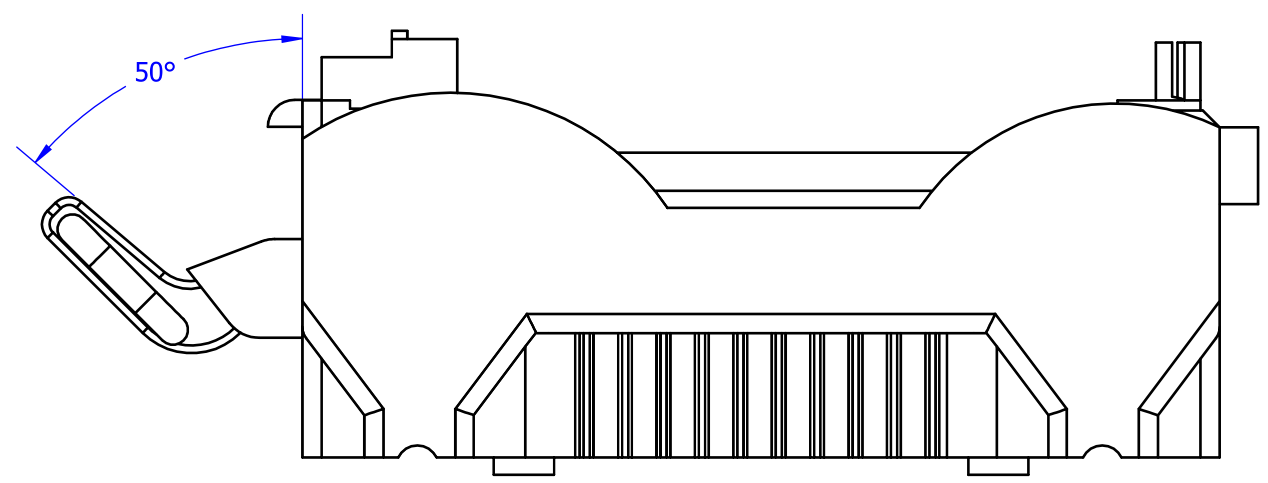
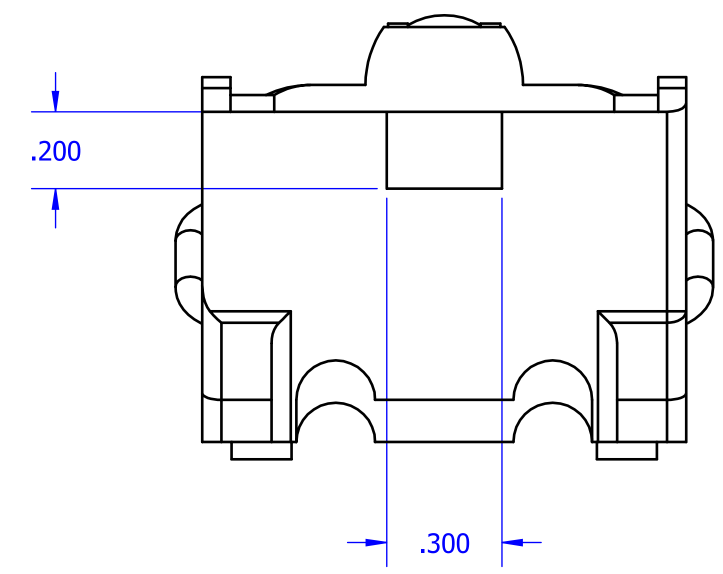
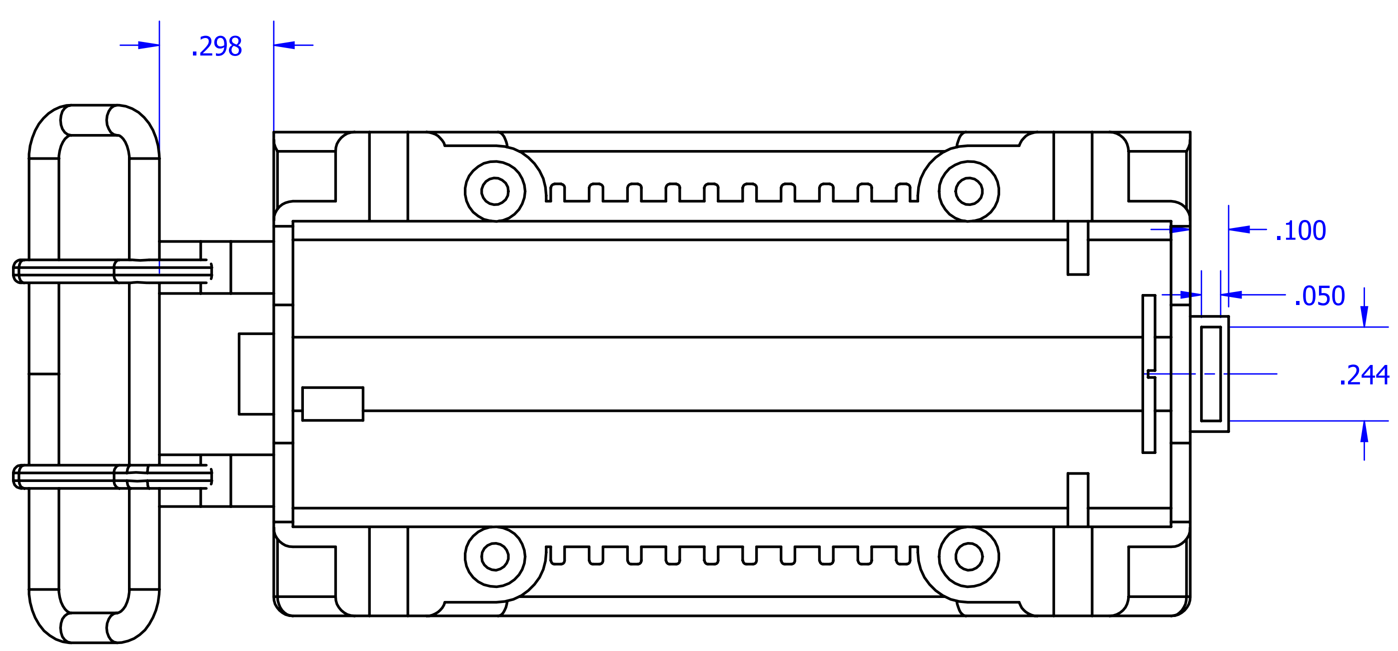
B	DESIGN CHANGES	05-03-2020







FOR OTHER DIMENSIONS, REFERENCE TO THE RWV A OF 1030 AND 1066.

TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.02, X.XXX ± 0.005, X.X° ± 1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL PVC Rigid	DESCRIPTION BATTERY CASE	
FINISH NONE	PN 1030 REV B	SHEET 1 of 1

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REV.	DESCRIPTION	DATE
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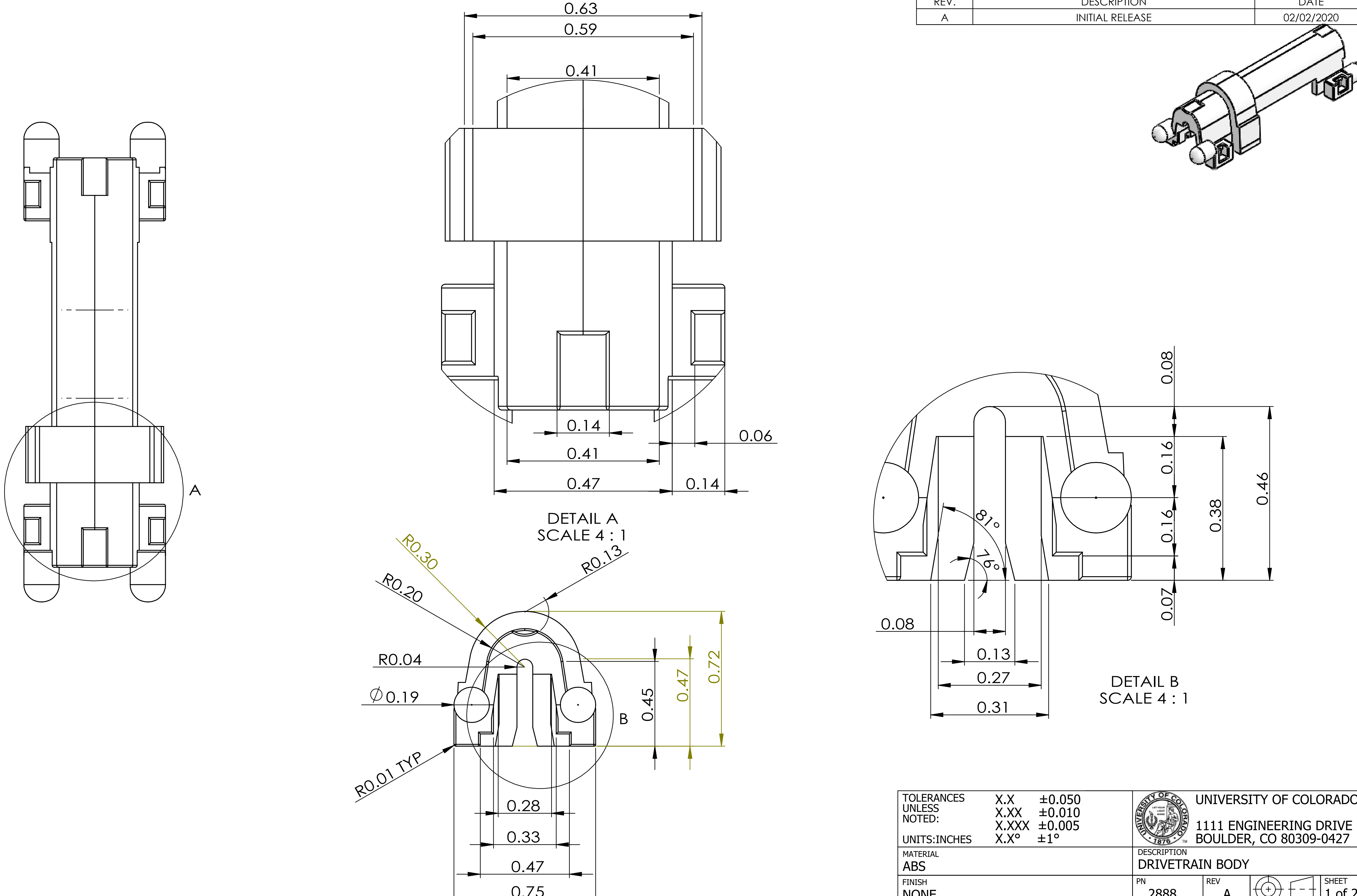
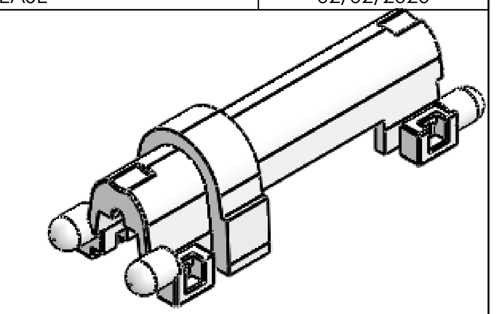
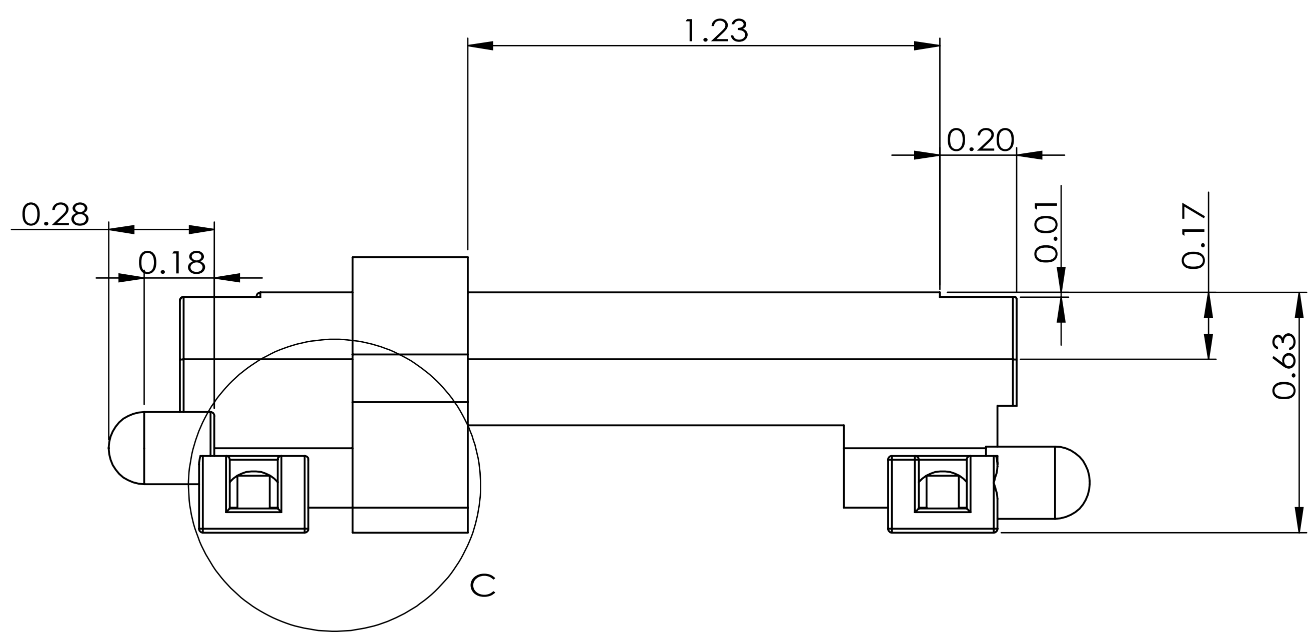
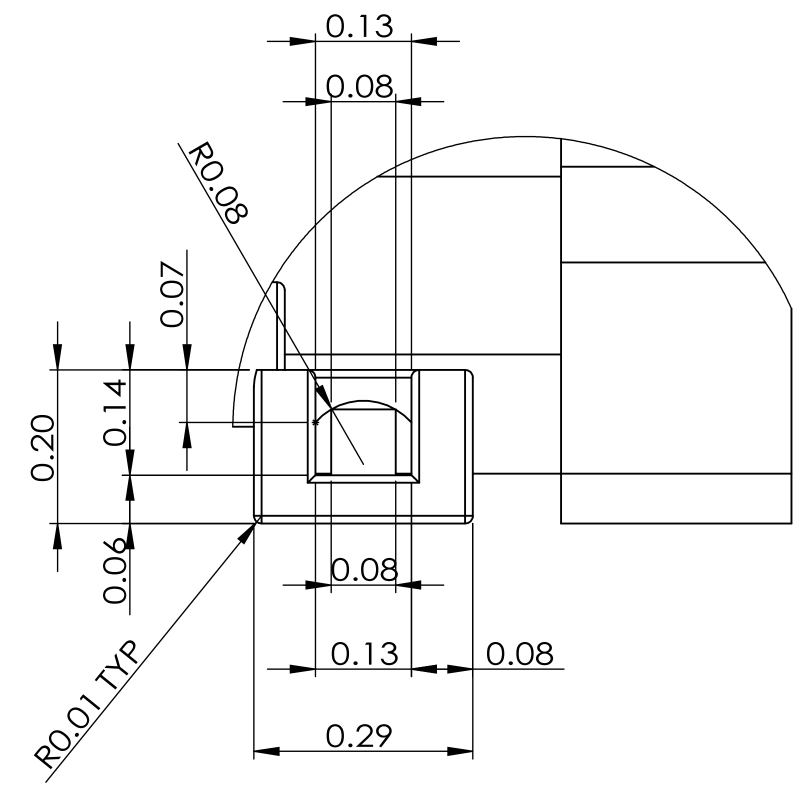


TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS:INCHES		
MATERIAL ABS		DESCRIPTION DRIVETRAIN BODY
FINISH NONE		PN 2888 · REV A · SHEET 1 of 2

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	02/02/2020







DETAIL C
SCALE 4 : 1

TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
MATERIAL ABS		DESCRIPTION DRIVETRAIN BODY		
FINISH NONE		PN 2888	REV A	SHEET 2 of 2

REV.	DESCRIPTION	DATE
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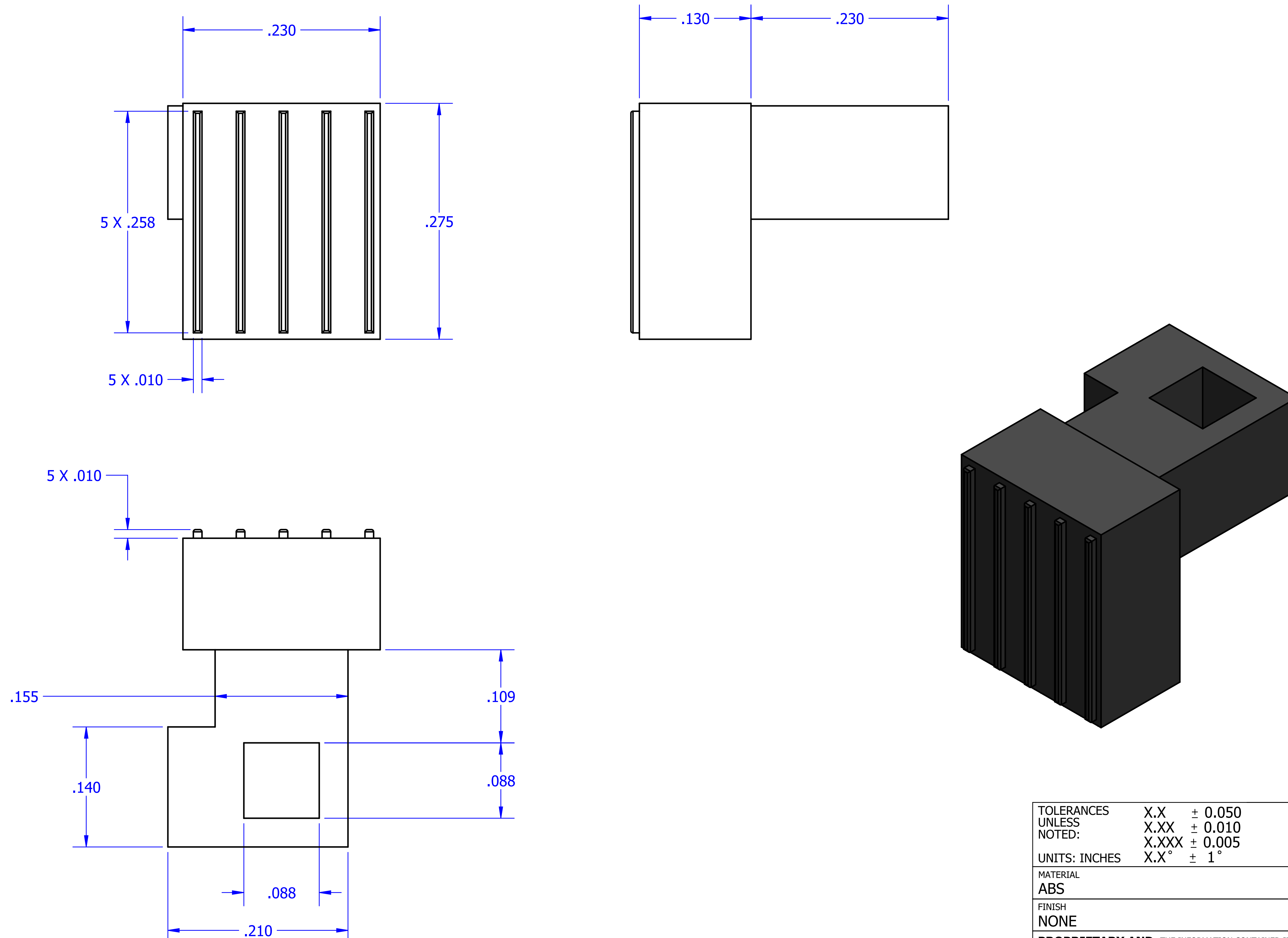
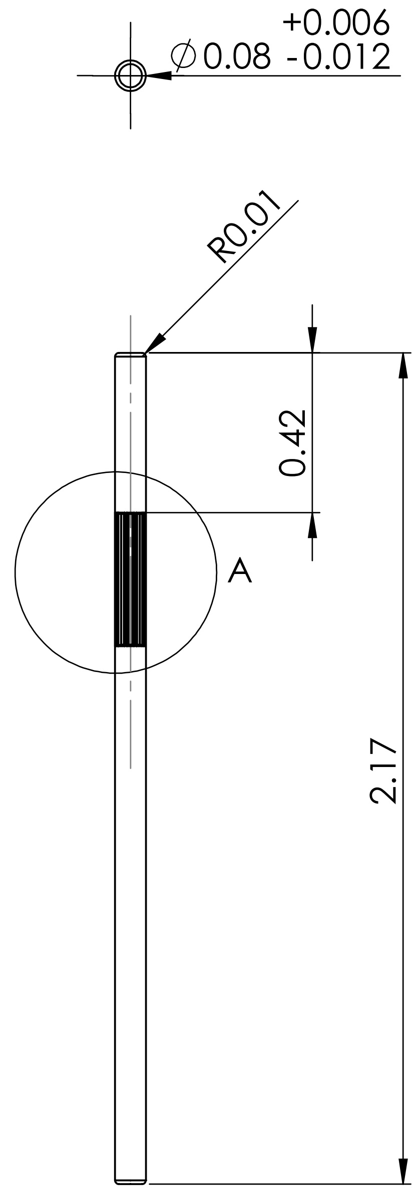
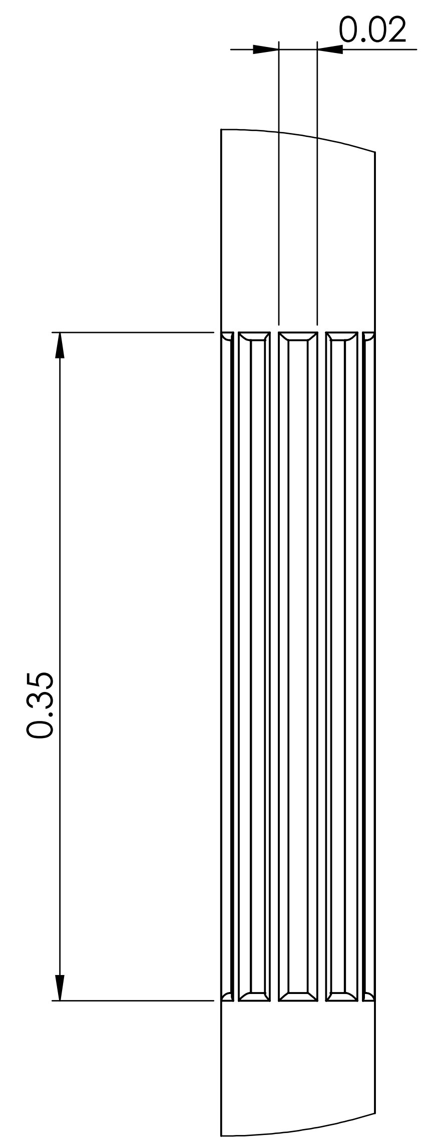


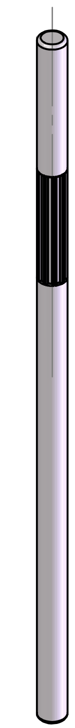
TOLERANCES UNLESS NOTED:	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ± 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS: INCHES		
MATERIAL ABS		DESCRIPTION SWITCH
FINISH NONE		PN 1055 · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/29





DETAIL A
SCALE 10 : 1



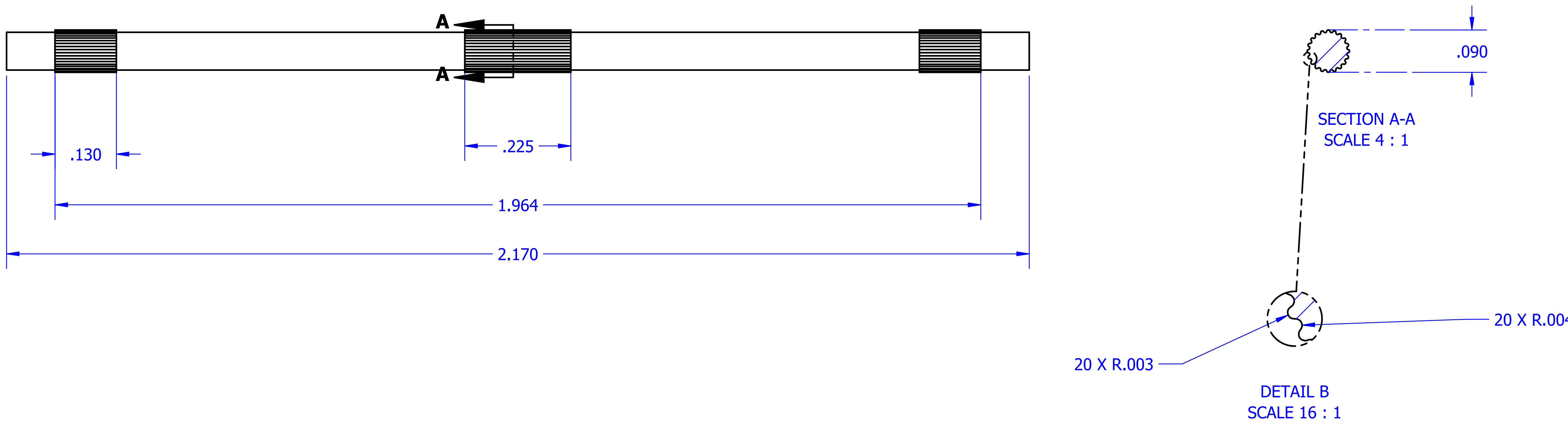
NOTE:

1. SPLINE PATTERN ON SHAFT HAS A FILLET ON EDGES OF 0.004" TYP BUT THIS TOLERANCE DOES NOT HAVE TO BE MET. THIS FILLET WILL OCCUR NATURALLY WHEN MACHINING THE PATTERN

2. TOLERANCE DIMENSION FOR SHAFT SHOWN TO DEMONSTRATE UNDERSTANDING OF RC 6 FIT OF A 0-0.12" NOMINAL SIZE RANGE FOR A SHAFT, IN REALITY IT DOES NOT NEED THIS TOLERANCE DIMENSION

TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
MATERIAL 304 STEEL		DESCRIPTION MOTOR SHAFT			
FINISH NONE		PN 2001	REV A		SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/6/2020



TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ± 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL AISI 304		DESCRIPTION WHEEL SHAFT
FINISH NONE		PN 2002 · REV A · SHEET 1 of 1

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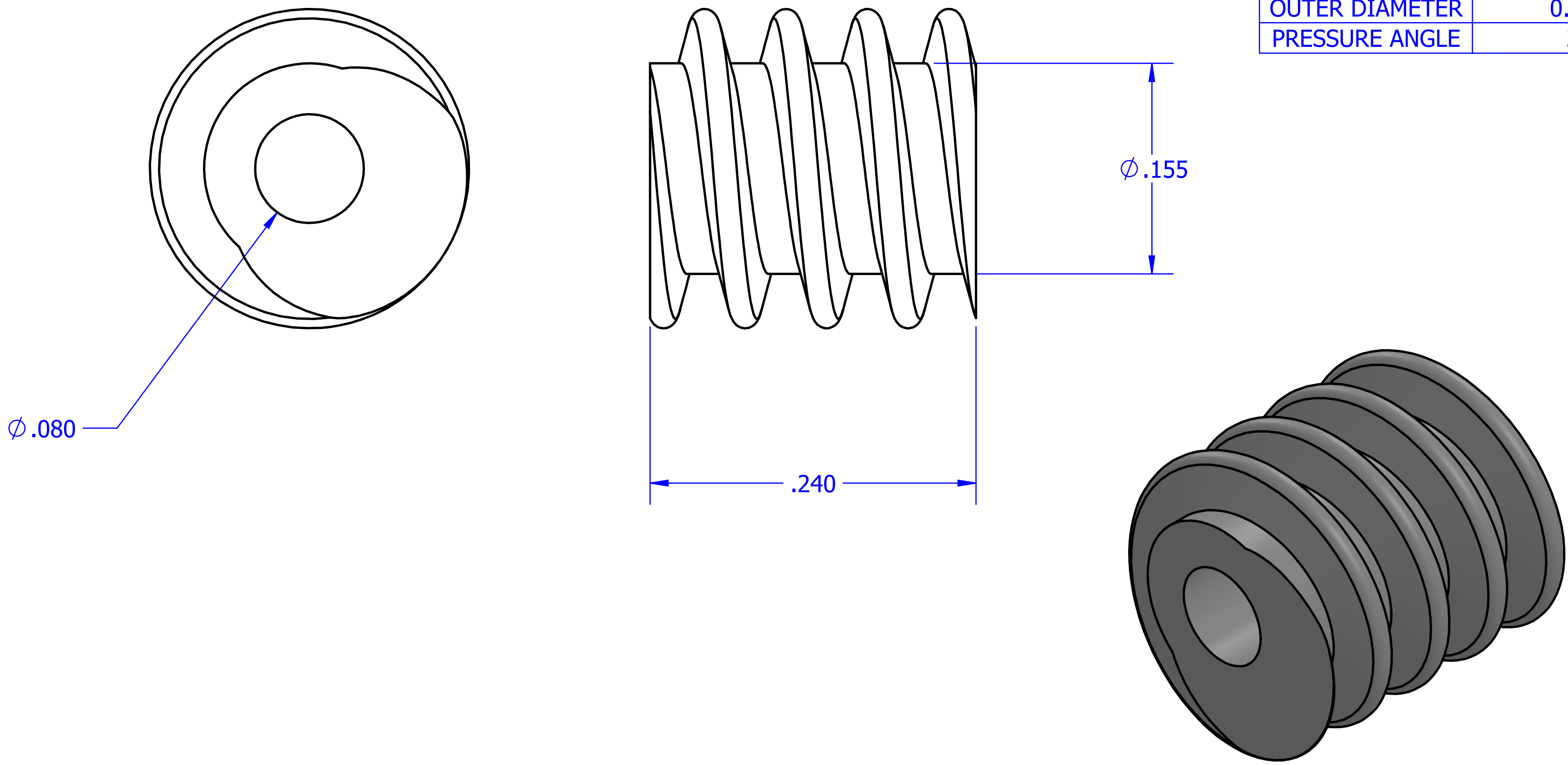
REV.	DESCRIPTION	DATE
A (A)	INITIAL RELEASE	2/5/2020

WORM GEAR SPECIFICATIONS	
CIRCULAR PITCH	0.06
PITCH CIRCLE DIAMETER	0.204
OUTER DIAMETER	0.235
PRESSURE ANGLE	20



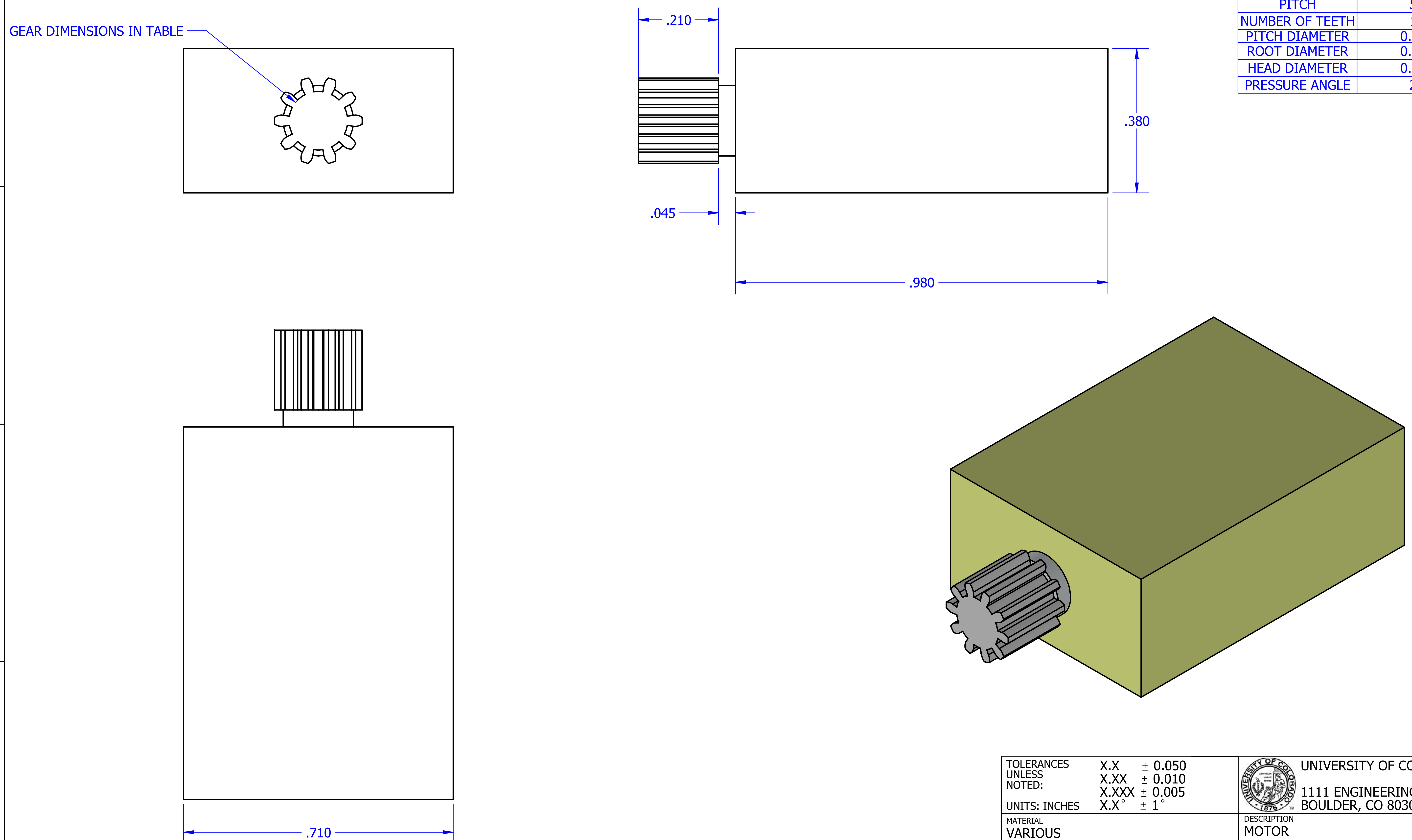
TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	
UNITS: INCHES		
MATERIAL POM Acetal Copolymer		
FINISH NONE		

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

DESCRIPTION			
Worm Gear			
PN 2184	REV A		SHEET 1 of 1

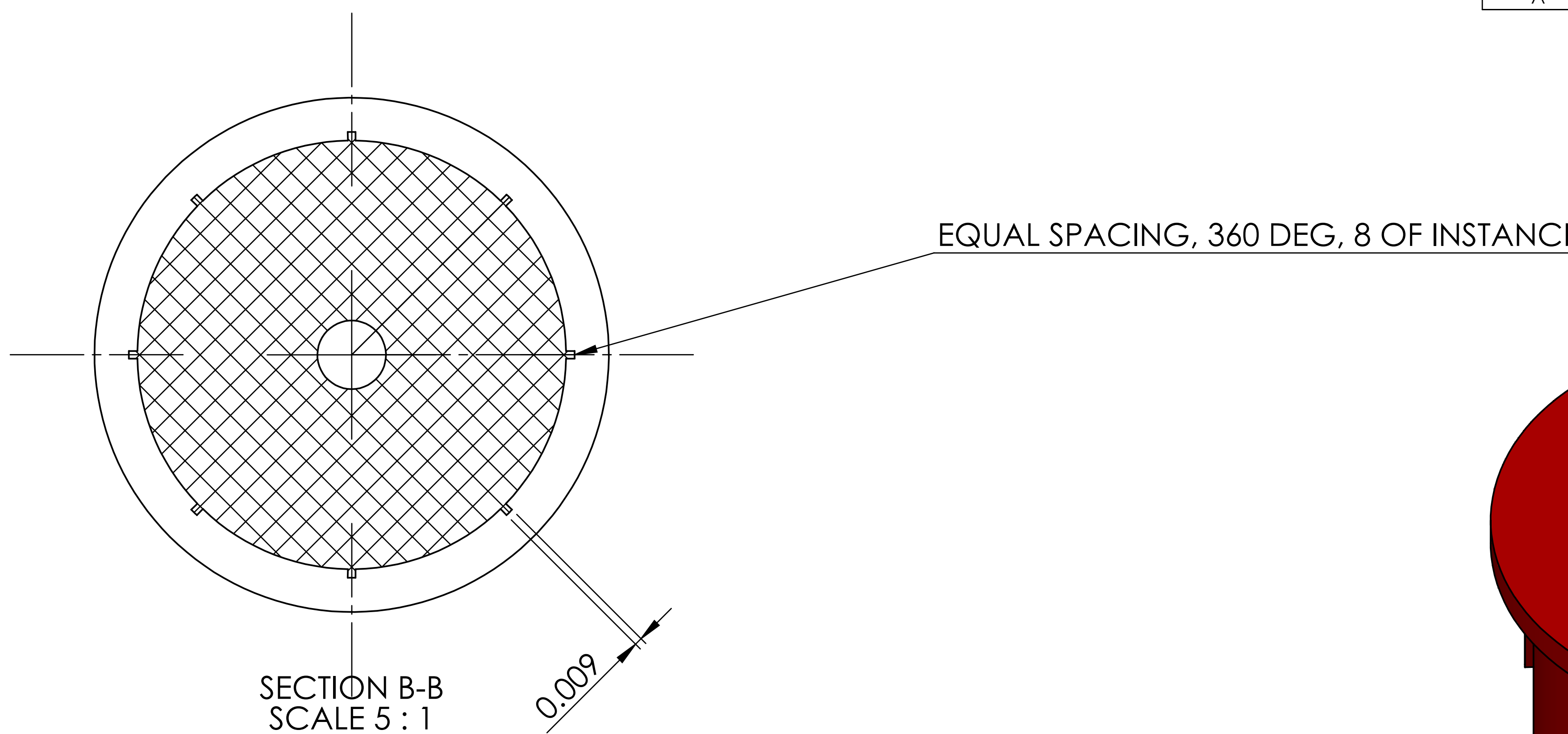
REV.	DESCRIPTION	DATE
A (A)	INITIAL RELEASE	2/5/2020

GEAR SPECIFICATIONS	
PITCH	52
NUMBER OF TEETH	10
PITCH DIAMETER	0.192
ROOT DIAMETER	0.144
HEAD DIAMETER	0.231
PRESSURE ANGLE	20

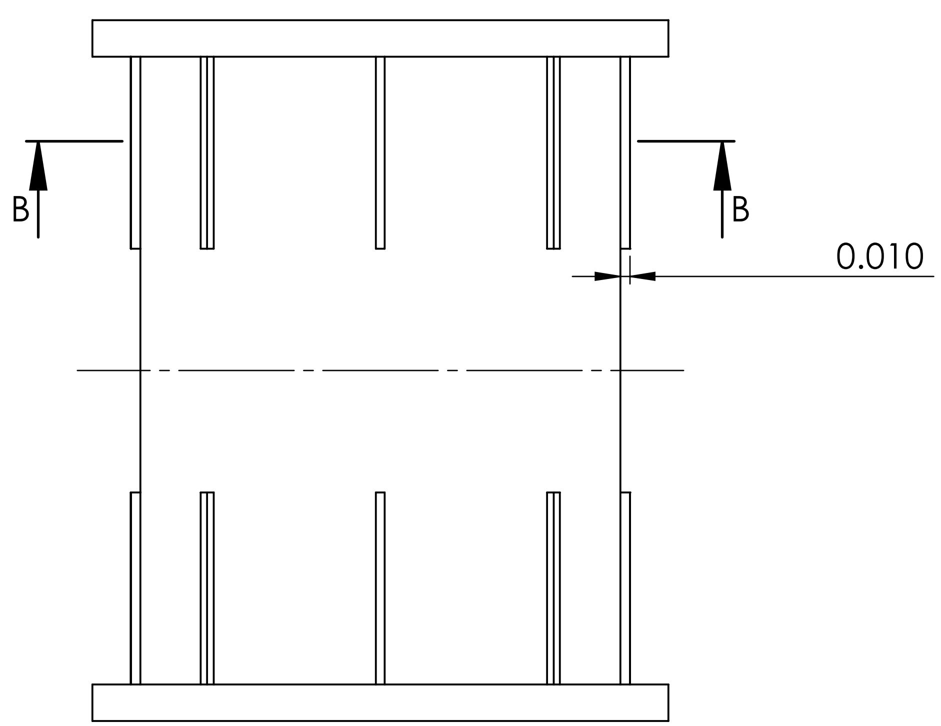


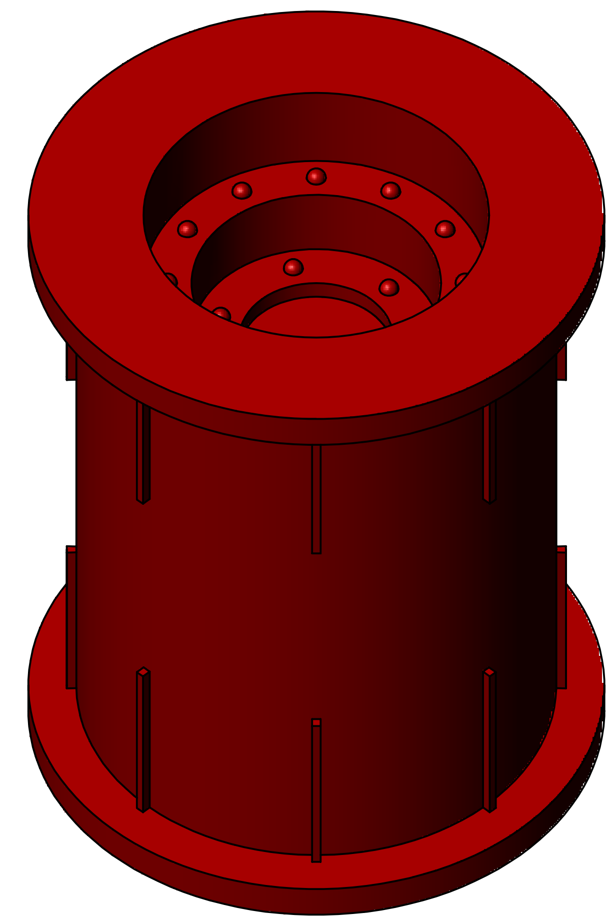
TOLERANCES UNLESS NOTED:	X.X ± 0.050	UNIVERSITY OF COLORADO
	X.XX ± 0.010	1111 ENGINEERING DRIVE
	X.XXX ± 0.005	BOULDER, CO 80309-0427
UNITS: INCHES	X.X° ± 1°	
MATERIAL: VARIOUS		DESCRIPTION: MOTOR
FINISH: NONE		PN: 2222 · REV: A · SHEET: 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/26



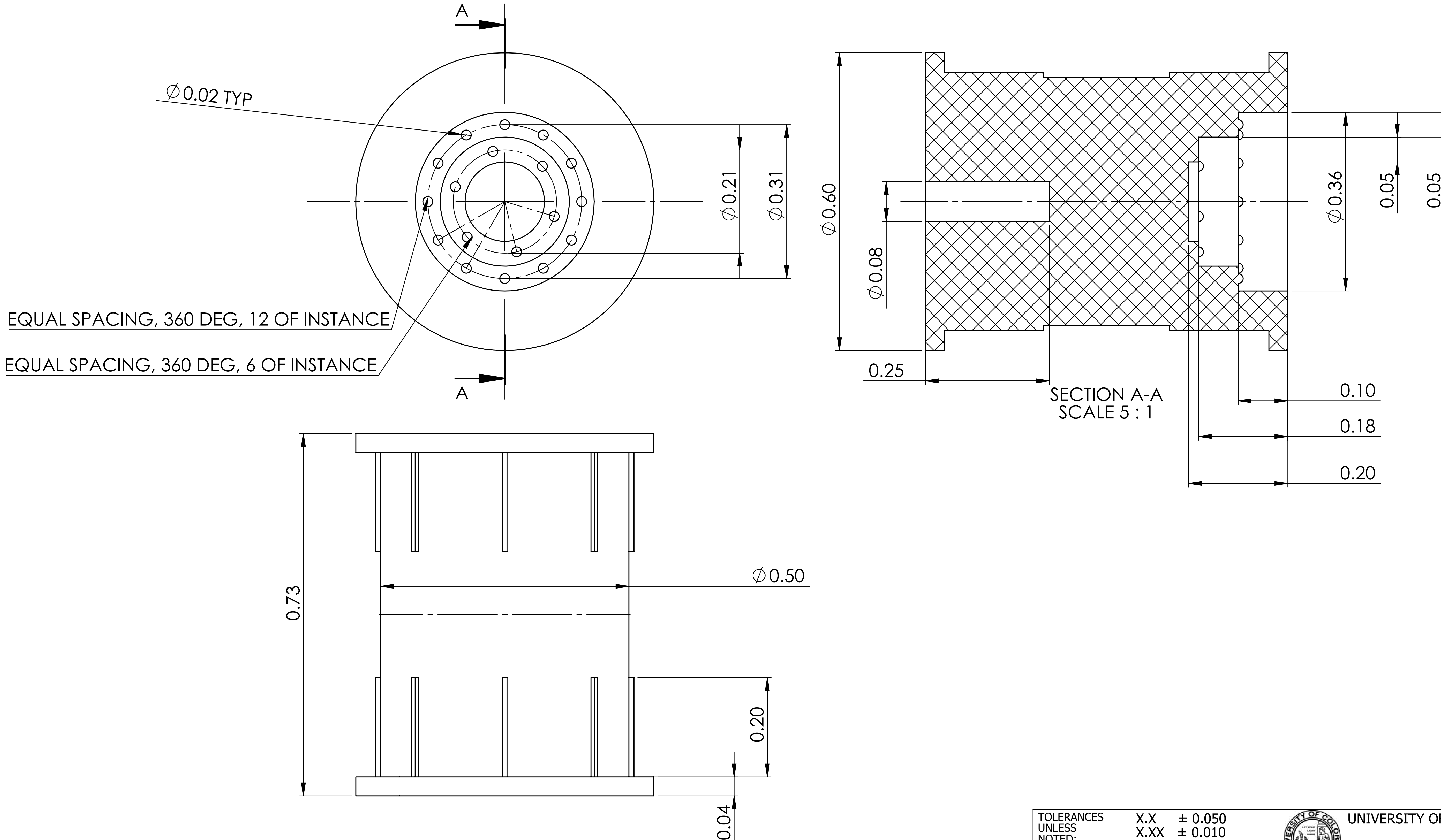
SECTION B-B
SCALE 5 : 1





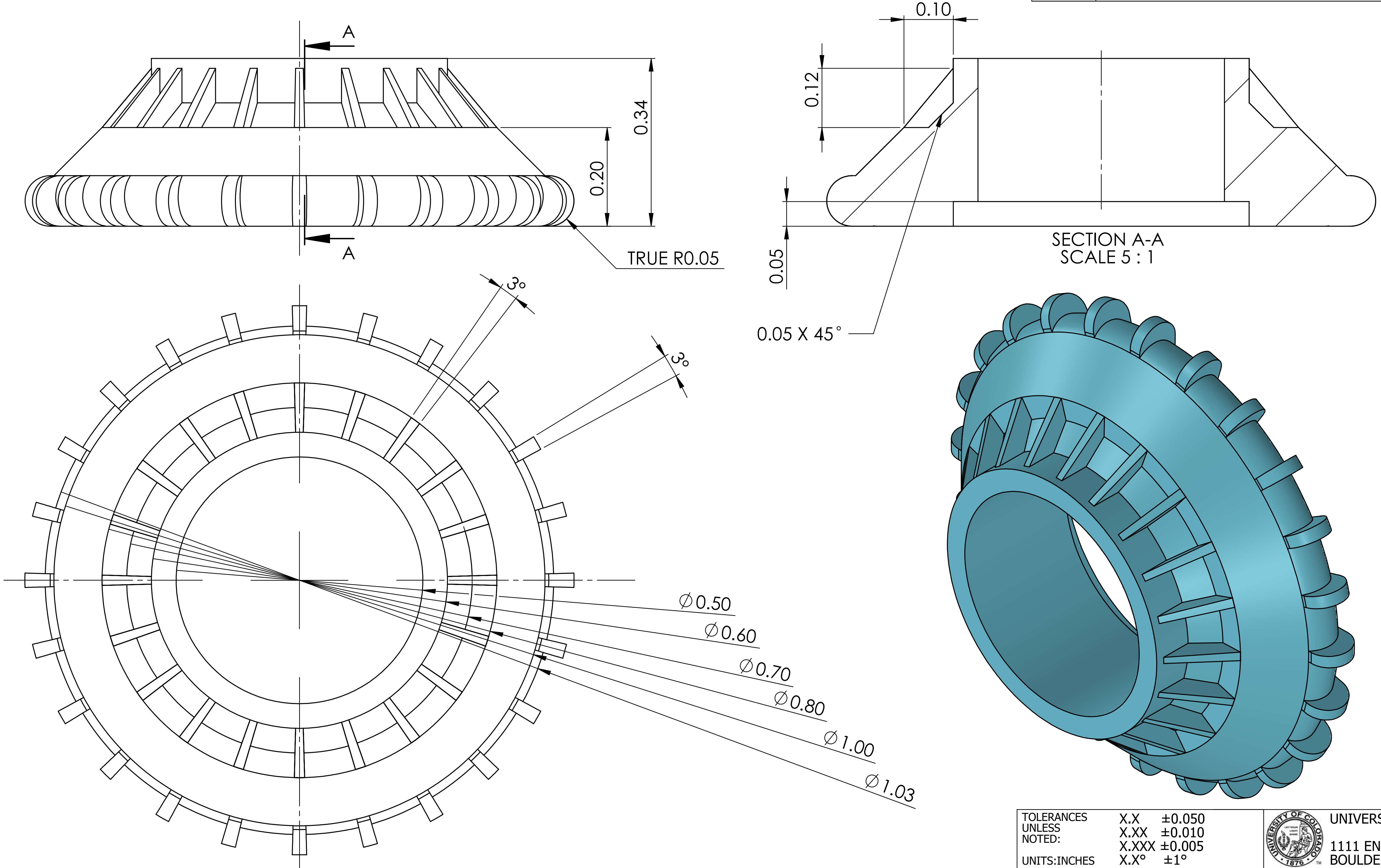
TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427			
MATERIAL ABS		DESCRIPTION WHEEL HUB			
FINISH NONE		PN 3030	REV A		SHEET 2 of 2

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/26



TOLERANCES UNLESS NOTED:	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
UNITS:INCHES		
MATERIAL ABS		DESCRIPTION WHEEL HUB
FINISH NONE		PN 3030 | REV A | SHEET 1 of 2

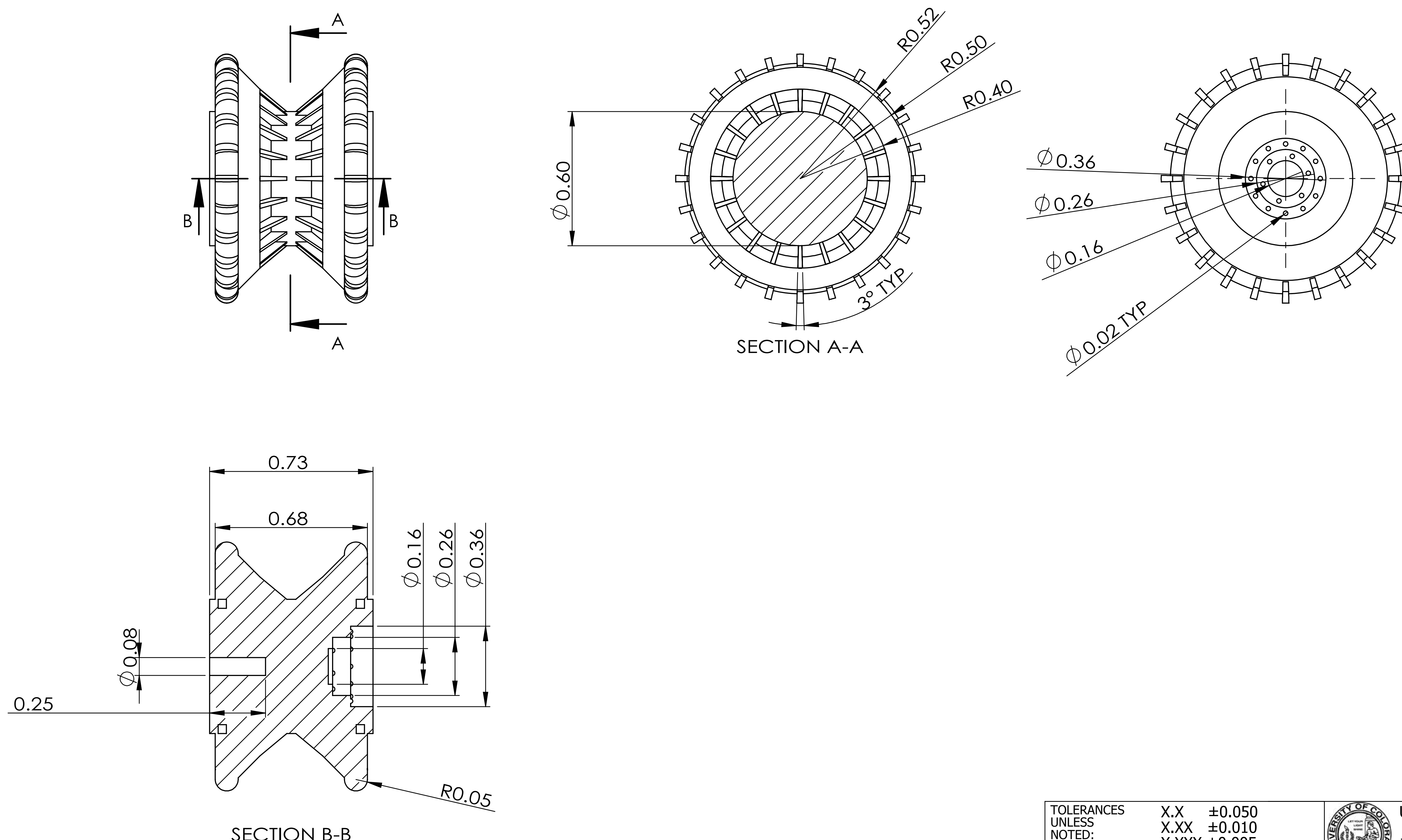
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/26



NOTE:
1. TRIANGULAR RIB FEATURE IS EQUALLY SPACED, 24 INSTANCES
2. CIRCULAR RIB FEATURE IS EQUALLY SPACED, 24 INSTANCES

TOLERANCES UNLESS NOTED:	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427		
UNITS:INCHES				
MATERIAL RUBBER		DESCRIPTION WHEEL TIRE		
FINISH NONE		PN 3003	REV A	SHEET 1 of 1

REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2020/1/26
B	DESIGN CHANGES	2020/3/4



TOLERANCES UNLESS NOTED: UNITS:INCHES	X.X ±0.050 X.XX ±0.010 X.XXX ±0.005 X.X° ±1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL RUBBER		DESCRIPTION TIRE	
FINISH NONE		PN 3003	REV B · SHEET 1 of 1

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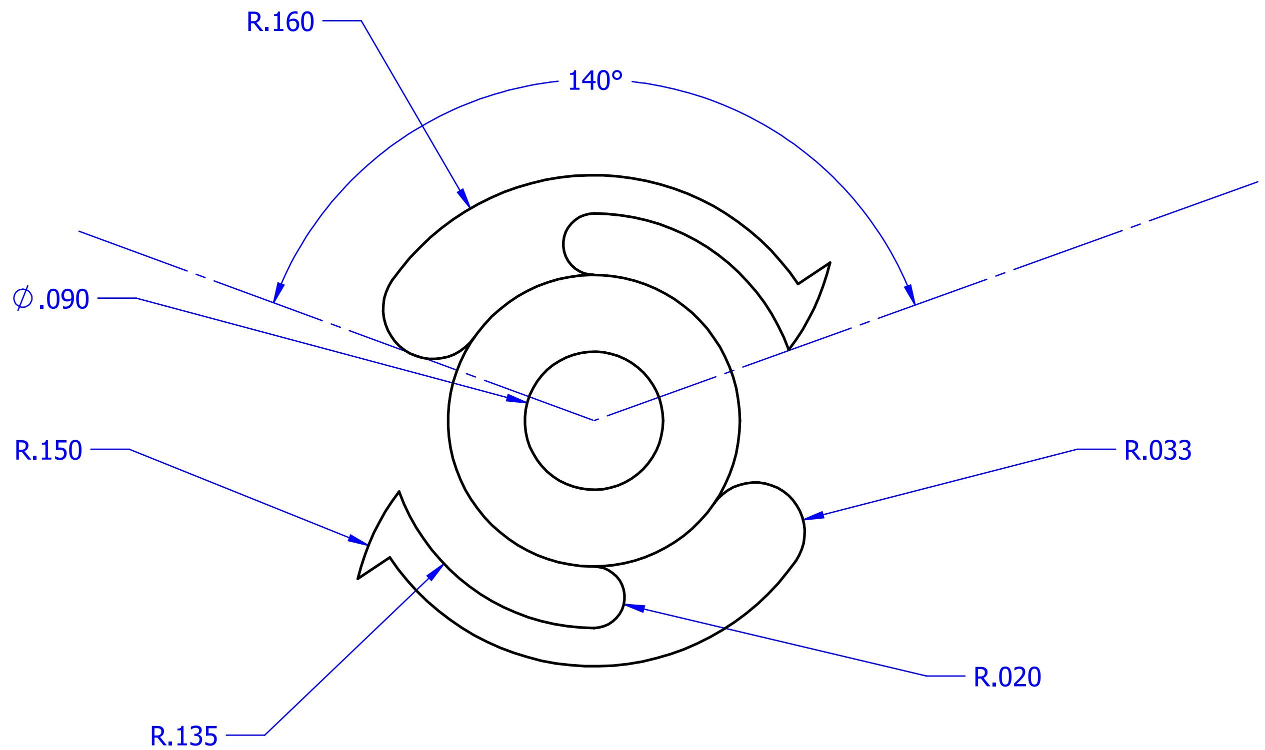
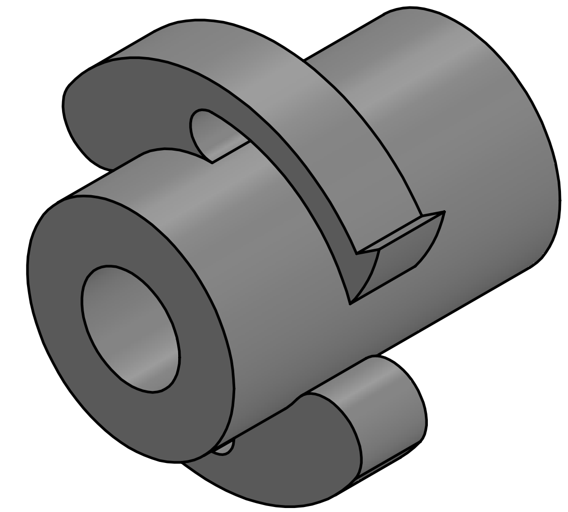
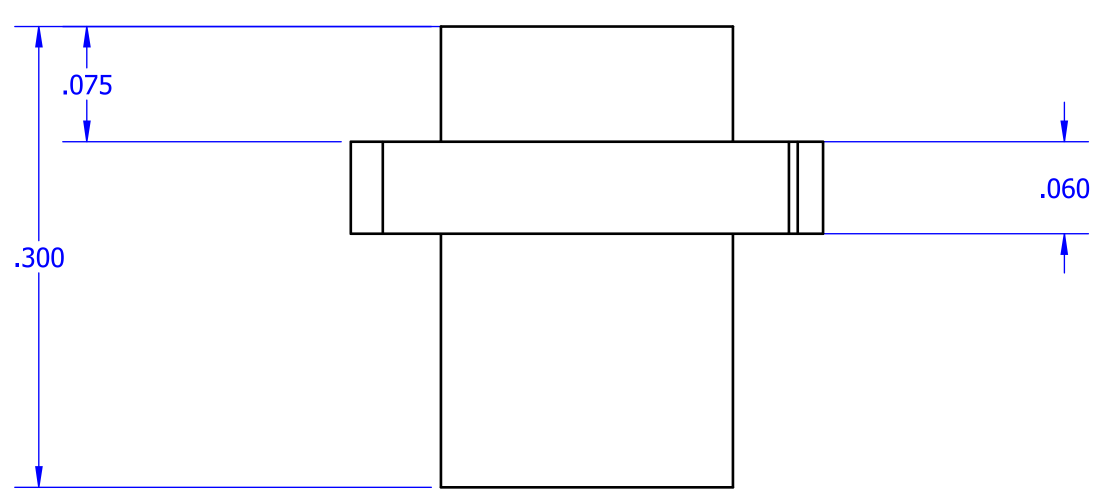
REV.	DESCRIPTION	DATE
A	INITIAL RELEASE	2/4/2020



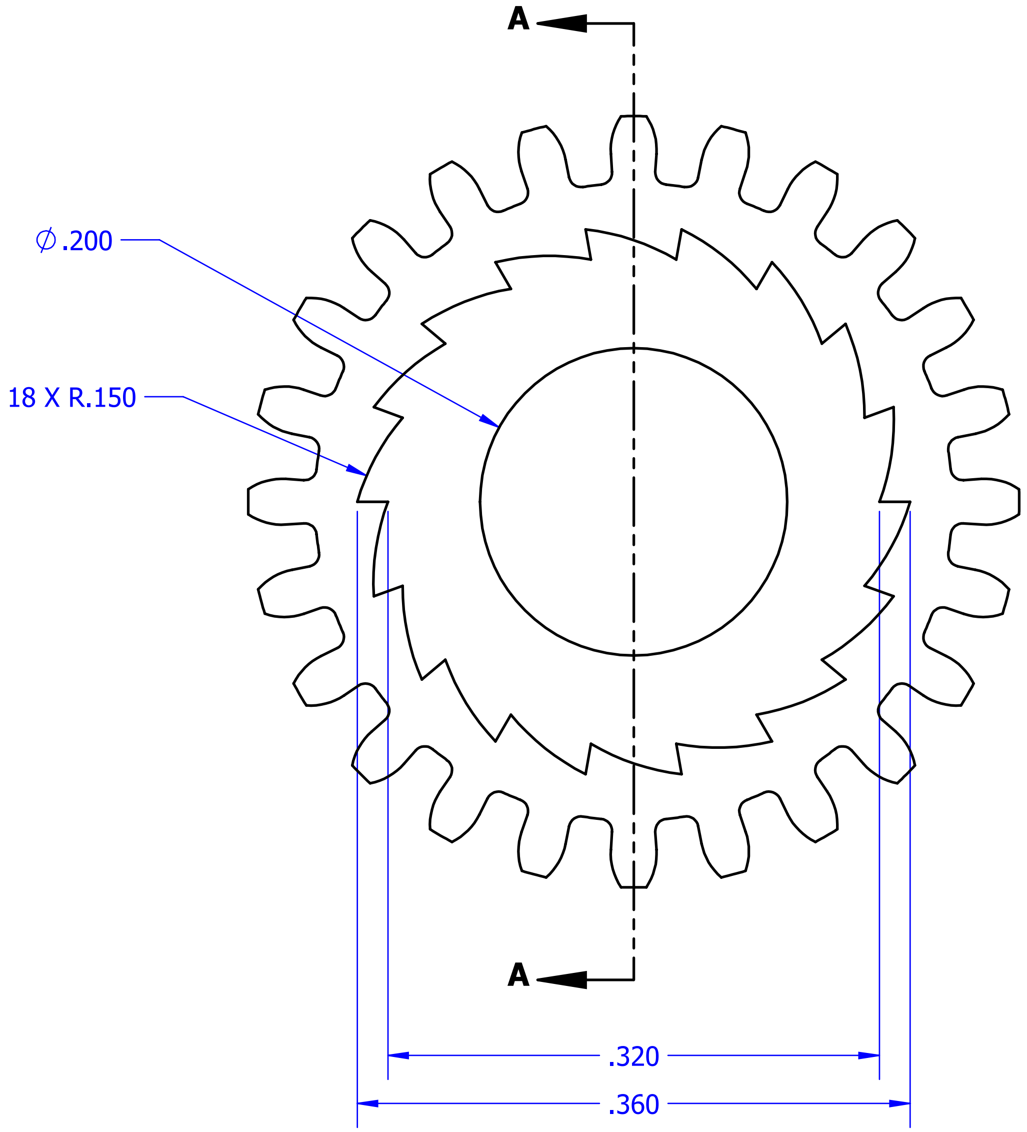


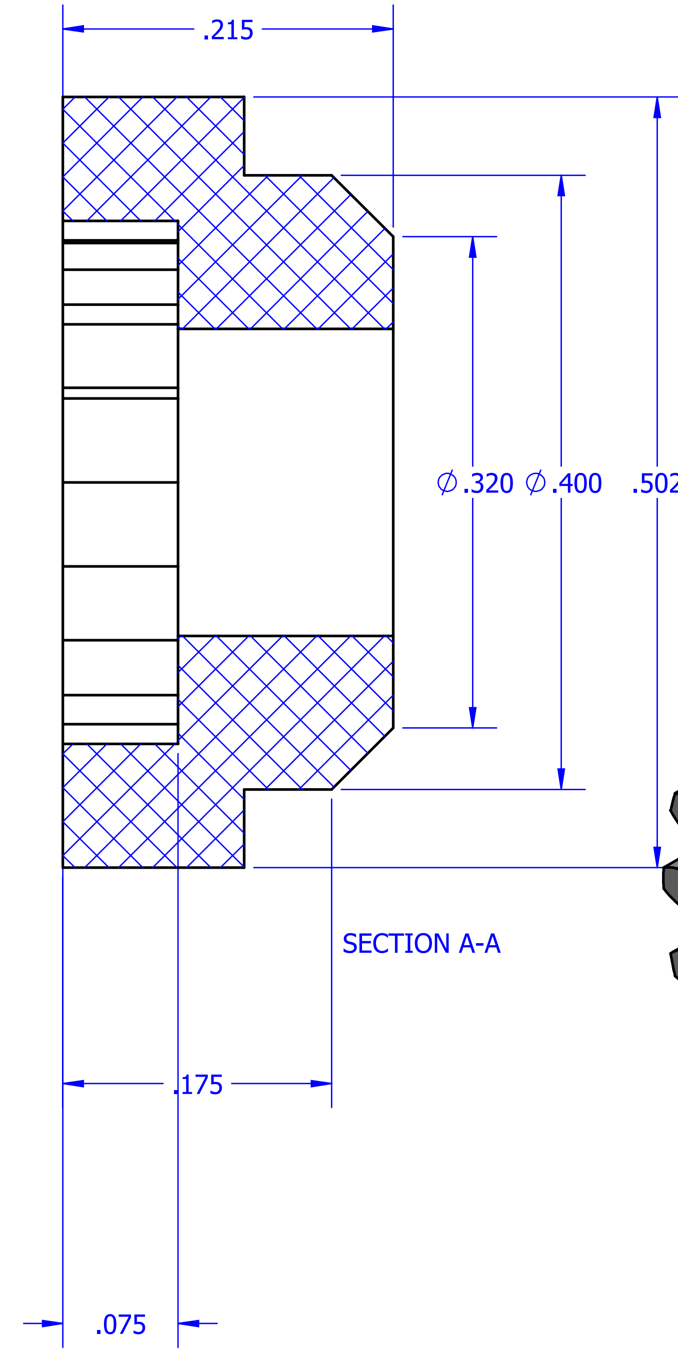


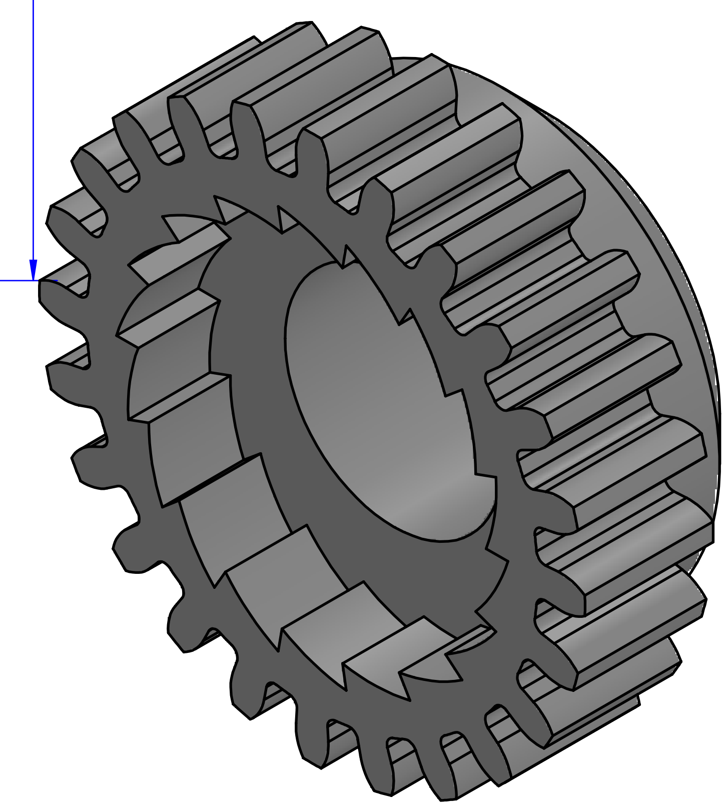
TOLERANCES UNLESS NOTED: UNITS: INCHES	X.X ± 0.050 X.XX ± 0.010 X.XXX ± 0.005 X.X° ± 1°	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427
MATERIAL POM Acetal Copolymer		DESCRIPTION LOCKING GEAR
FINISH NONE		PN 3333 · REV A · SHEET 1 of 1

REV.	DESCRIPTION	DATE
A (A)	INITIAL RELEASE	2/3/2020

GEAR SPECIFICATIONS	
PITCH	52
NUMBER OF TEETH	24
PITCH DIAMETER	0.462
ROOT DIAMETER	0.413
HEAD DIAMETER	0.500
PRESSURE ANGLE	20







TOLERANCES UNLESS NOTED: X.X ± 0.050, X.XX ± 0.010, X.XXX ± 0.005, X.X° ± 1° UNITS: INCHES	UNIVERSITY OF COLORADO 1111 ENGINEERING DRIVE BOULDER, CO 80309-0427	
MATERIAL: POM Acetal Copolymer	DESCRIPTION: MAIN DRIVE SPUR GEAR	
FINISH: NONE	PN: 3366 REV: A	SHEET: 1 of 1