SHOEB GOLDBERG

SUNY Polytechnic Institute

Department of Mechanical Engineering Technology

Professor. Jones

Capstone I & II MTC 420, 426

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Introduction

Tightening laces is something that everyone has to do. The purpose of this project is to create an accessible and easy way for anyone, no matter age or disability, to tighten their shoes on their own without having to move. To accomplish this, the construction of a hands-free, mechanical device was necessary. This was designed in a way that resulted in many different iterations in order to accomplish a feasible design. This design utilized a ratchet-lever system that allows the user to crank up the laces hands free, by using the opposite foot to wind up the laces around a spool. The shoe would be loosened by pressing the lever in the opposite direction, thus releasing the locks on the ratchet, and loosening the laces on the foot. In order to accomplish this design, A series of different designs were considered until there was an assembly reached and agreed upon by group members as something that fundamentally works, and was proven through rapid prototyping methods.

We then went on to improve the design in several ways, strengthening certain parts and working through various problems, improving functionality overall. Choosing materials and dimensions for all of these parts, we were able to manufacture and assemble the final design and test it.

Upon testing the design, we were shown how far it has come, and how far it needed to go to be a more functional device. Testing also showed us in real time how forces on our invention would cause it to react. This helped us predict future problems when we made changes to aid these initial problems.

Through doing this we learned what was required to truly create a design from concept to first prototype, which meant figuring out every small detail on how the mechanism functions, and working out the issues we encountered when making and testing it through critical thinking. We also learned a lot about what it means to work in a team, and how ideas can build on each other when brainstorming.

Equipment

There were several tools that we had to use for this project. Since much of this project was conceptual, a lot of the tools used were virtual. To make 3d models, we utilized Solidworks and Fusion 360. These softwares are useful for modeling each individual component, then assembling them together with collision to find how the parts work in conjunction all virtually. These are shown in figure 1 and 2.

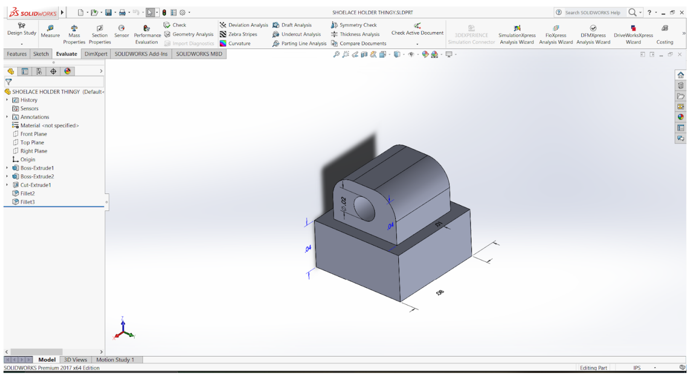


Figure 1.

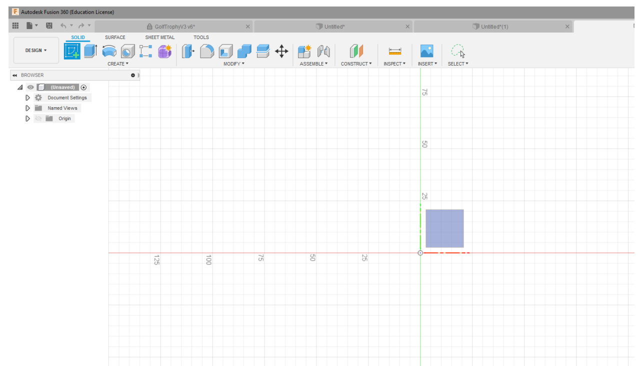


Figure 2.

For some of the physical modeling, we utilized the 3-d printers available to us, the Dremel DigiLab was used to help us to make the parts we modeled and see how they fit in the design. In order to use the printer we had to import our models into the 3d printer’s proprietary software, Dremel Digilab 3D Slicer, shown in *figure 3*. Some 3D printed parts made it into the final design, most notably the housing, to keep the weight as low as possible.

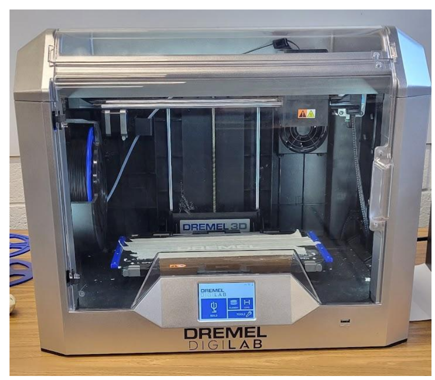


Figure 3.

The printers use PLA plastic which is perfect for prototyping purposes (shown in figure 4), but ideally later on the final parts of our project are to be injection molded with polystyrene plastic. Injection molding is also a far more reliable way of manufacturing parts, as it is faster and more consistent. You don't have to worry about 3-d printers failing the print due to deposition errors.

Figure 4.

In completing the prototype we opted to use Tin Vex Robotics components shown below in order to be able to create a realistic prototype that would be able to withstand the forces that we expect the shoe to be under. (a few of the tin components are shown in fig. 6).

Figure 5.

Before we could begin measuring forces, and creating a prototype we needed a shoe to focus the scope of our testing on. We opted to make a wooden shoe instead of using a real shoe as the rigidity of wooden shoes ment our data would be more consistent, and allow us to get a good starting point (shown in fig. 5). We plan to move on to a real shoe once we are certain our design could work.

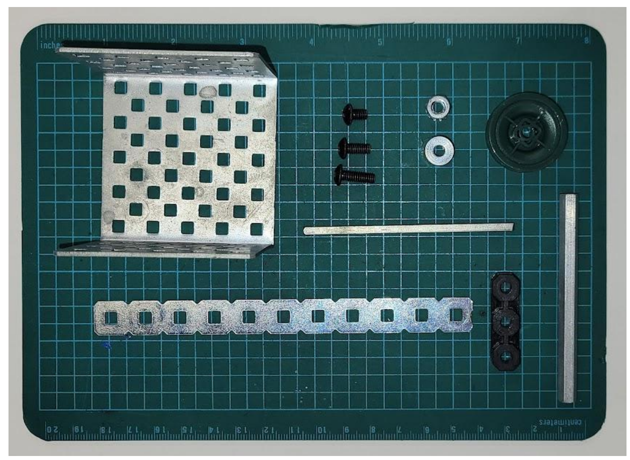


Figure 6.

In terms of force measurement, we used a force pull tester in order to gain a scope of the force needed to tighten the laces adequately and not over-tighten and damage your foot. We used a Vernier Dual-Range Force Sensor (shown in appendix Miscellaneous tools/parts fig 75) which is shown below. This device is a general-purpose device for measuring pushing and pulling forces.

To collect the data we used Logger Pro This was used as it is the recommended software to be used along with the Vernier dual range force tester. Shown in figure 7.

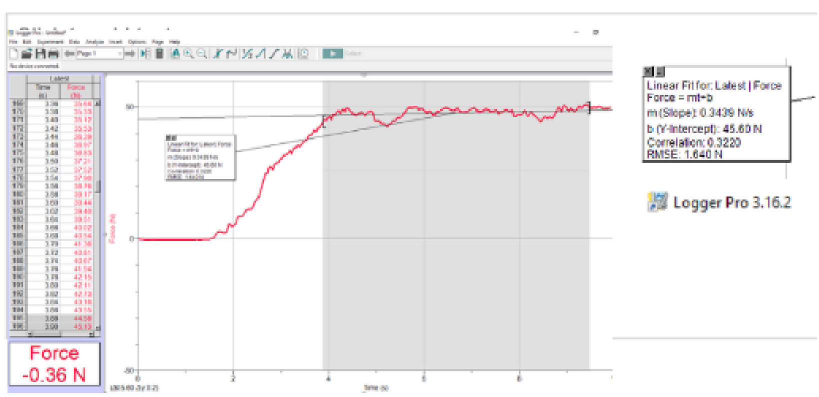


Figure 7.

For research, we utilized google scholar to find scholarly sources on subjects that we needed an in-depth look at for the design.

To manufacture the parts in Capstone II we mostly utilized the waterjet as it was quick to cut out the simple parts that we needed out of aluminum (shown in figure 8). This was especially useful for upgrading the 3-D printed parts that we finalized in the prototype for added strength, as the forces that some parts would need to withstand were very high for such small parts.

Figure 8.

In order to modify some of the parts that we cut out with the waterjet, we used the belt sander and drill press. As we made changes to certain parts, it was faster to modify them with these tools than to re-cut with the waterjet. There were a few tolerance issues we ran into specifically with the main axle where we had to sand it down to make it fit properly, while adding a chamfer to each edge to make it spin better in the housing.

(Additional miscellaneous parts and tools found in the appendixes p.68)

Theory

Units

mm = millimeter, N = newtons, Pa = Pascals

Definining Variables

F = force (N), A = area (m^2), M = moment (N*m or N*mm), d = distance (m)
I = moment of inertia (m^4), c = centroid, σ = stress($\frac{N}{m^2}$), b = base, h = height, N = normal force
L = length, w = width, ε = strain, E = Young's Modulus, t = thickness, P = circular pitch (mm)
N = number of teeth in ratchet wheel, F = factor value, S = safe stress

Known Values

Shoe Size
L = 317.5 mm, h = 101.6 mm, top w = 107.95 mm, bottom w = 76.2 mm
$E_{PLA\ plastic}$ = 4.107 GPa
F = 35, value is due to falling in threshold of 12 to 20 teeth
S = 37 MPa for a safe design

Equations

Area of a rectangle: $A \ = \ b\ x\ h$

Sress: $\sigma \ = \ \frac{Mc}{I}$

Moment of rectangle: $I \ = \ \frac{bh^3}{12}$

Moment: M = F*d

Centriod: c = $\frac{t}{2}$

Circular Pitch: $P \ = \ \sqrt{\frac{F * M}{T * S * N}}$

Strain: $\varepsilon \ = \ \frac{\sigma}{E}$

Procedure

Research-

For this experiment, there were many ways that we can go about winding up the laces. The first thing that we had to do was check how other people tackled a similar issue. The ideas that we came across were mostly electrical approaches, but gave us ideas on how the whole thing was going to be put together. For instance, all applications that we found had some sort of spool that would wind up the laces as the power supply turned it. Now all that was left to do is find out the positioning of the power supply in relation to the spool, and how that it was going to all connect. For the power supply, there was just one major question: should it be electrical or mechanical?

Since our group understood more about mechanical subjects than electrical ones, we decided to go with a mechanical approach. This was not before weighing the pros and cons of the subject in writing shown below in figure 9 &10:

electric	
pros	cons
ties laces faster	heavy
easier to make hands-free	bulky
	needs power supply
	more expensive
	subject to more corrosion

Figure 9.

mechanical	
pros	cons
cheaper	ties slower
safer	harder to make hands free
less complicated based on our experience	

Figure 10.

pros and cons comparison

On top of the cons for the electric approach, to make the components of an electrical shoe fit into such a small volume, a large amount of the sole would have to be cut out. We presumed that with a mechanical approach the shoe in question would be largely un-tampered with. By choosing mechanical we would also avoid the heat transfer, weight, and structural problems, and improve the weight and strength of the overall device. This idea also fits better with the group's educational background.

Theory crafting power supply -

Next was figuring out the general kind of device that we were going to use in order to provide power. The system requirements were simple. We needed to create a power supply that can:

- Provide a 50N (see logger pro graph in fig 70) force to wind up and tighten the laces
- Release tension to loosen the laces

The device will be mounted on the outside, on the heel of the shoes in order to have easiest access to the hands free device. This will also allow the shoe to remain balanced, which will help with comfort and functionality. The device shouldn't be too bulky to mount onto the back of a shoe, nor too heavy to make the shoe cumbersome to wear.

Initial Design -

With these constraints in mind we theory crafted different ways to achieve this. In our theory crafting we came up with initial design that included:

- A turning lace spool such to wind up the laces
- A ratchet and pawl system to drive the spool
- A worm gear to transfer the rotating ratchet to a twisting cylinder

Refer to appendix sec. Additional Free Body Diagrams and design diagrams figs. 79 & 80

Initial lacing system design failure -

We went forward with the above ideas and began designing the specific parts. We continued with dimensioning and prototyping when we discovered key flaws with our initial design:

- Ratchet angle - in order for the ratchet to drive the worm gear, there would need to be an adjustment of the angles present which was not feasible for the geometry and angled nature of the shoe
- We did not account for the gear ratio needed to turn a worm gear. Quick math showed that the amount of teeth needed on the gear connected to the worm gear would create an unreasonable gear ratio for the application. This, combined with other factors of the power transfer system and lace spool being too large led us to reconsider how the shoe is going to be laced up.

The Transfer of the twisting motion from the ratchet lever section all the way to the side of the shoe proved to be a challenge not worth overcoming. Better design ideas were available. The original spool system to wind up the laces was far too bulky, and presented problems with dimensionality and durability when considering outdoor use (see Fig. 11 below). On top of this, the fundamental gear system that we chose to turn the ratchet gear into a twisting motion, ended up being fundamentally non functional for the purpose that it was theorized to work for.

New research -

With our initial failure we decided to take different inspiration from existing mechanical designs. Our design criteria still was the same but we needed to think of a new way to achieve winding the laces in a different way, while eliminating the cylinder spool idea. In our additional research we found several examples of shoes with self lacing designs, but none of them had a way to tighten the laces hands free.

In our research we discovered the Boa Lacing System (shown in Fig. 11). This lacing system uses a *small* spool on the side with a releasable, reversible ratchet to tighten and loosen the laces. It accomplishes all of this while being incredibly compact and durable. We decided that this design would not be too complicated to replicate the fundamentals of this design and include a hands free element through the use of a lever. This discovery was the proof that we needed to follow through with this new lacing design.

Figure 11.

New spool design -

With this new spool design referring to fig 84 we decided that the best way to lace the shoe was also with wire, similarly to the boa system. This allows the spool to be small, as wire has a small diameter and doesn't sacrifice strength, and can be wound up without taking much room. This is built as an ordinary spool, but eliminates the need for the sort of “power transfer” system. The laces no longer wind up from the side of the shoe, the new spool allows all of the control to be consolidated into one body of all the components working in conjunction. The spool would be attached to the ratchet gear, and will turn in a 1 to 1 ratio with it.

Composition and Measurements -

With the idea of how the design would work we now had to begin finalizing all the measurements and tolerances. We also needed to finalize what materials we believed we would use. In total we needed to know:

i. Dimensions of the shoes we would be working on
ii. Type of wire required
iii. Amount of wire
iv. Size of spool
v. Size of lever
vi. Locking mechanism for the wire
vii. How to mount the system to the shoe

Finalizing concepts through prototyping -

The goal of making this prototype (shown in Fig. 25) for the shoe was to prove the functionality of the ratchet and release design through trial and error. Our strategy was to test out several ideas and get closer to the final product with an iterative approach, adjusting details of the main components until we got something that had a foolproof plan to it. The dimensionality of this prototype remained large to make it easy to work with and exchange parts, so we were unable to mount it on the back of the shoe just yet. As we continue to make iterations of this design, it will only become more downsized, sleek, and smoothly-functioning.

Shoe -

Since we were only trying to “ball-park” how this mechanism was going to function in relation to the shoe, we ended up going with a wooden shoe model (shown in Fig. 5) that resembles what the final design would be attached to and function alongside. In the final design, the shoe that we attach the lacing system to will be an athletic or lifestyle shoe of similar dimension. Although, the design will be versatile enough to attach to any type of rigid shoe.
In order to create this, we went to the wood shop and cut out a traced base on a 2 by 4 and stacked two of them on top of each other. We then screwed both of them together and created the general top-down shape and profile shape with a band saw. After filing it down to get a closer shape to what we wanted, we sanded the rough edges off to finish it.

Spool -

We chose a relatively small size as the wire has a small diameter, and would not need a deep groove to feed into. The hole of the spool is square to fit on a square axel, which will allow it to be driven along with the ratchet wheel (fig 12).

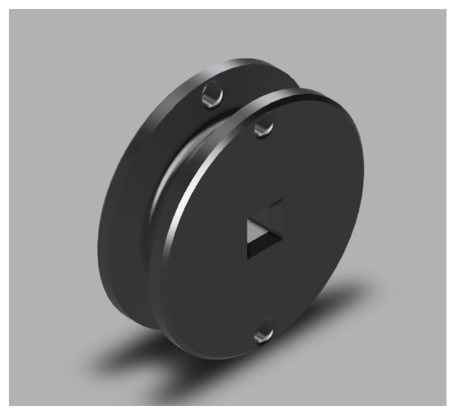


Figure 12.

Handle/Lever -

For the lever, It was assembled with standard Vex tin strips. This was to provide a sturdy frame to attach all of the other components to. The lever is the backbone of the whole design and is rigid. There are two major components attached to it, The ratchet wheel and the drive pawl.

Fishing Cable/Wire vs Synthetic fiber laces -

For the laces we'll be using fishing line or a fine steel wire (fig 50). Both kinds are durable, but the steel wire would be more preferable for the final product, as it is even more durable and resistant to being cut. For the prototype, we simulated laces by using ordinary string, as it serves the same purpose.

Figure 13.

First Locking Mechanism -

This was the most difficult part of the design. Ratchets are used to crank something in one direction typically. There are two points of contact that keep the ratchet in place while it is winding up. The locking pawl and the driving pawl. In order to get it to release, Both of those pawls need to be pulled off of the ratchet gear simultaneously for it to be freed. Once the ratchet wheel is freed, it allows for the laces to unwind due to residual tension forces and loosen the shoe.

There were several ideas that we had to release the pawls. The first attempt was to utilize a clutch system (shown in Fig. 14) to separate the whole spool from the ratchet wheel instead of having them both as one piece. The problem with this design is its very difficult to get the clutch to separate when the lever is on a 90 degree angle to the mechanism. We would have been able to separate the two with a separate button, as we can insert that any place that we want, but it would have made the device much larger in volume, and more complicated than it needed to be. For this reason, we decided to abandon the clutch idea shown in fig. 17, and move onto trying to release the pawls.

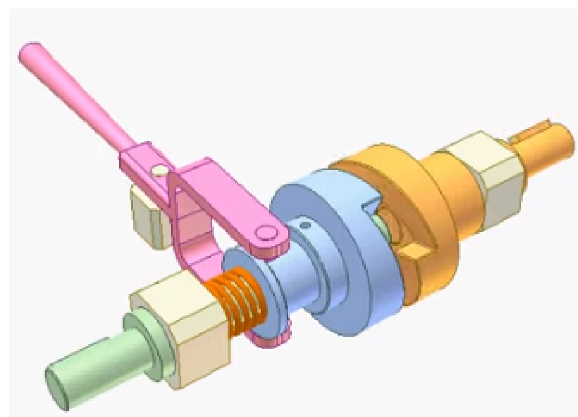


Figure 14.

The design we decided to go with (shown in Fig. 15 and Fig. 16) was two separate systems to release each pawl separately, but simultaneously when the lever is drawn back a certain distance, in the opposite direction that you need to wind it up. For the drive pawl, there was a pillar that simply pushes the drive pawl out of the way when the lever lowers.

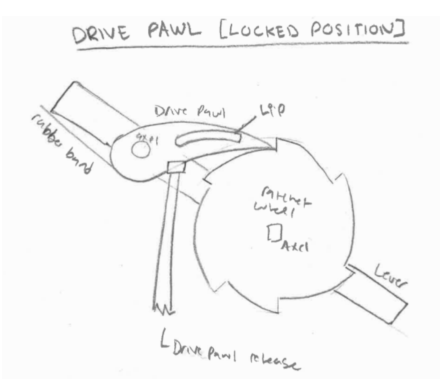


Figure 15.

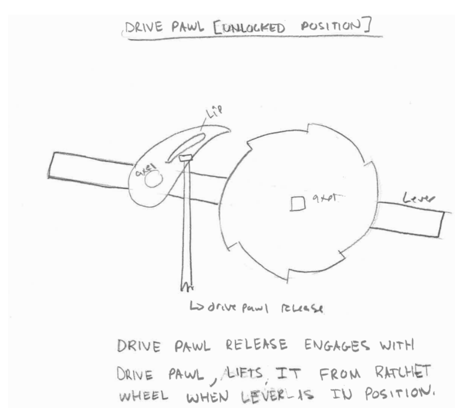


Figure 16.

For the locking pawl, we utilized the bottom part of the lever to create a linkage that can separate the lock pawl from the ratchet wheel. Below is an image of this ratchet and pawl system we created for our design shown in figure 17 & 18.

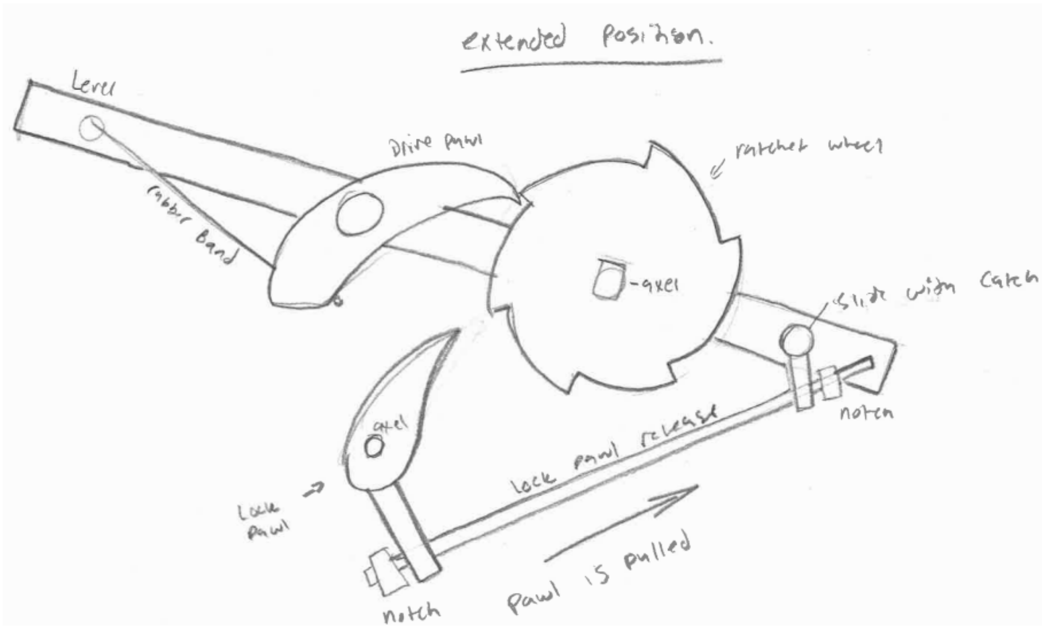


Figure 17.

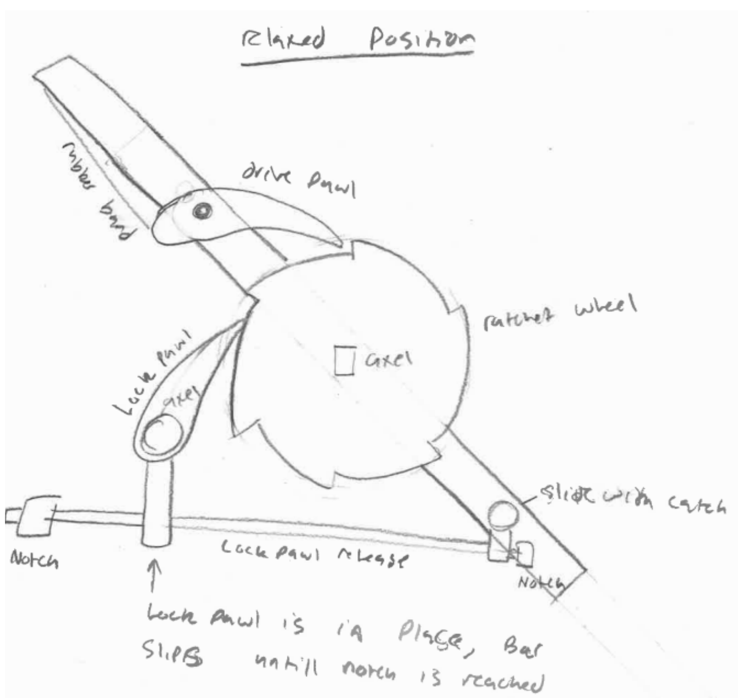


Figure 18.

Wire Eyelet -

The purpose of the wire eyelet is to guide the wire from the spool to the tightening strap (lacing diagram found in appendices Fig. 50). The use of these eyelets should be kept to a minimum, as each extra one will add more friction to the system. To aid this, we made the hole for the wire much larger than the diameter of the wire itself. Theoretically, we would need eyelets strong enough to withstand the constant sawing motion the wire would provide while in use.

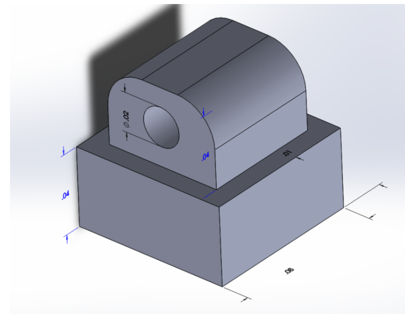


Figure 19.

Ratchet and Pawl System -

For the ratchet and pawl system we had to model several iterations of both the locking and the driving pawl in order to get them to accomplish the function that we need. For the driving pawl, there needs to be tension that keeps it mated with the ratchet wheel when it's supposed to be engaged. This elastic tension also helps it return to the locked position when It no longer needs to be out of the way for loosening the laces. To account for this, the drive pawl has a hole in the back of the pawl that allows for a rubber band or spring to be laced through. This rubber band then attaches further up the lever to an anchor point to keep it under tension (see Fig. 52 to see rubber band example).

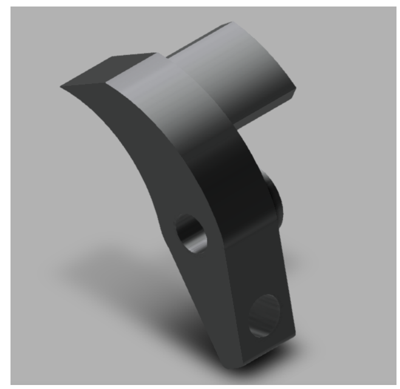


Figure 20.

We also needed to modify the typical pawl so that the driving pawl can be pushed out of the way when needed. To account for this, we simply added a lip to the side of the pawl, so the release has something to push against (shown in Fig 20).

This was later improved upon as seen in the multiview that follows, where the driving pawl and the release pawl look the same but with different release mechanisms. The drive pawl has an eccentric that pushes it out of the way, where the lock pawl has the same groove that pulls it out of the way of the ratchet wheel.

Locking Pawl -

For the lock pawl there were similar modifications that had to be made. In order to have the release attached to this pawl, we needed to add an extension on the bottom of the pawl with a hole in it that the release can grab onto and pull to release it (*found in appendix assorted multiviews of diff. parts fig 54 & 55*). The release activates at the same time as the drive pawl release.


Figure 21.

Slide with catch -

Figure 22.

The lock pawl release attaches to the bottom of the lever with another separate part called the slide with catch. For this part we had to design a piece that would fit into the Vex Constructed lever and hold the lock pawl release, allowing it to slip until it hits the notch to pull the lock pawl. This took a few iterations to get correct, as shown below in fig. 23. The one we finally settled on for the first prototype is shown in fig.22 Fig 24 are the 3D models of the iterations

The hole on the bottom is where it is threaded into the lever, and the hole on the top is where the release feeds through. There were several iterations of this design, similarly to the pawls, until we got a part that was strong and consistent in doing its job. What made this particular part difficult was making it so it can fit within the tightly constrained dimensions.

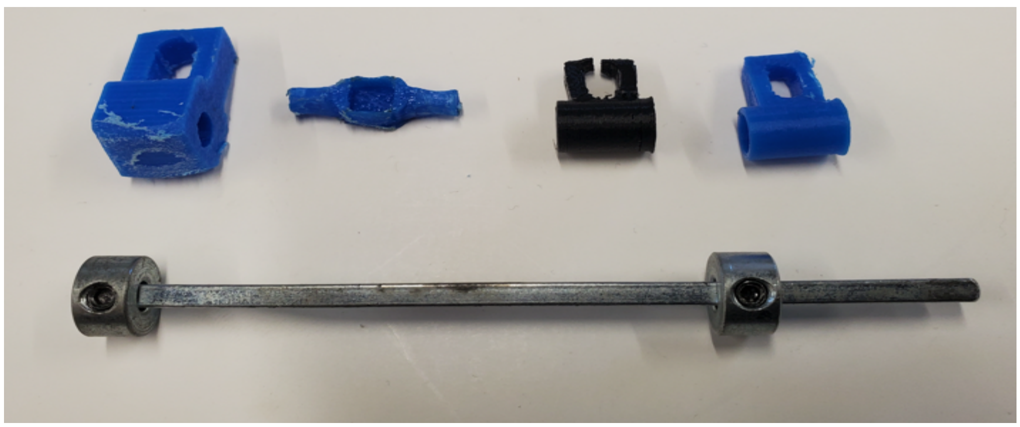


Figure 23.

The rod that you see on the bottom of the slide with a catch is the guide that it attaches to. This pulls on the catch with the notches that attach to the rod. The slide is attached to the bottom of the lever.

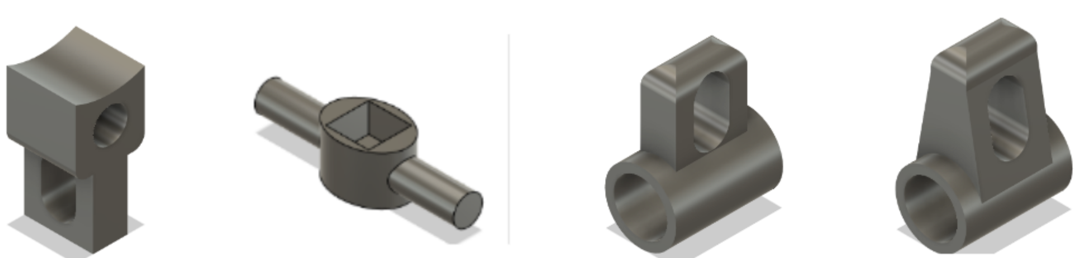


Figure 24.

Ratchet -

For the ratchet we 3D printed (*shown in appendix and Fig.54*) an ordinary ratchet gear that can fit onto the square axel. This part did not provide many problems as it is probably the simplest part in the build that we had to model. The only adjustments that we had to make was widening the square hole that the axel would fit through. In order to do this, we utilized a small square file to stick into the hole and shape it to size.

Housing -

In terms of how the system is going to attach to the shoe, there will be 3d printed housing that allows us to secure the ratchet and lever system directly to the heel of the shoe using screws. The housing itself will be attached to the shoe using epoxy. By the time the design is ready to be attached to the shoe, it will be significantly downsized to be practical size for something you would wear around.

For holding up the spool we came up with two ideas, gluing it directly on to the ratchet and pawl system, or 3d printing the ratchet with the spool directly attached. Both of these in theory would work, but we believe it would be better to glue them together as this would allow us to be able to separately design these components.This was done for our prototype and shown in Fig. 25. For the wire eyelets we are planning to fix them directly onto the shoe itself using the epoxy. We would also put them directly onto the band itself to initiate the tightening motion.

For the lever, the lever will be directly attached to the ratchet and pawl mechanism and power it. This allows us to have a direct connection in driving the spool thus tightening the laces.

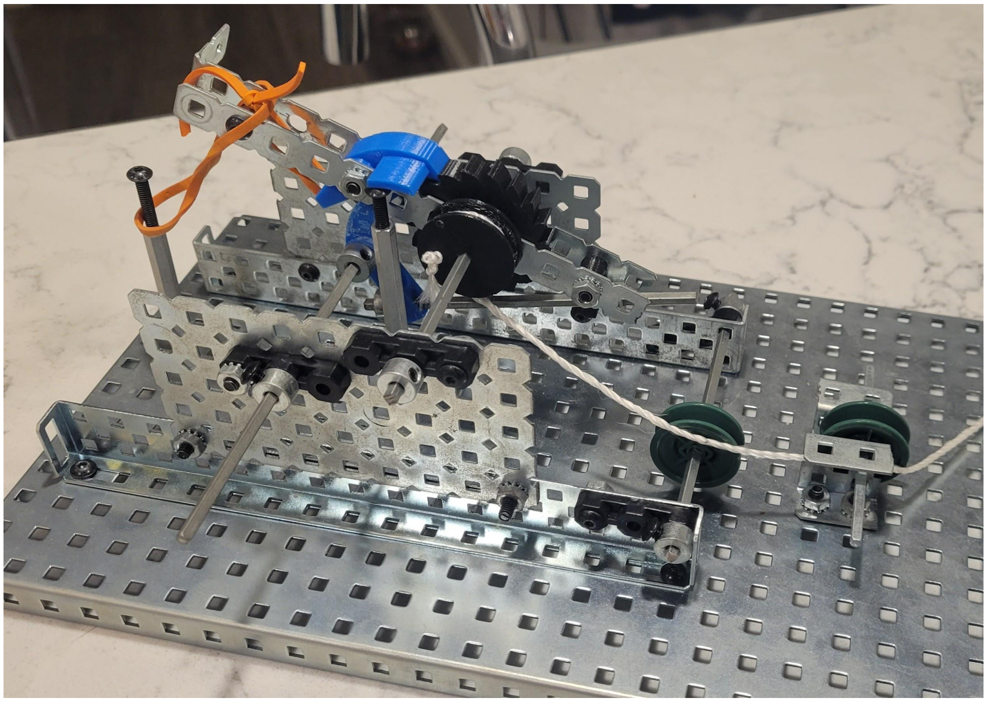


Figure 25.

Future Efforts -

With the design finalized, and a prototype build confirming our design will work, there is now a “gameplan” in building the final version of the lace tying device. In terms of potential roadblock we foresee a few things. Either a problem in 3d printing the parts due to the size of the parts, or a problem attaching the device to the shoe directly might provide a problem.We can test the wire eyelets to see if they will wear down over multiple uses.

After careful consideration, we made further improvements on the original design, and finalized the dimensions in CAD. We decided that the drive pawl would better function with an eccentric pushing it out of the way (shown in Fig. 25). It serves the exact same function as the previous release for the drive pawl and attaches at the axle. On top of this, the drive and locking pawl have been made the exact same, and the release mechanisms have been adjusted to fit their needs. These are the ideas we plan to expand upon as we continue to improve upon the original prototype. The latest dimensional drawings of the adjusted pawls and release mechanisms are found in the appendix. The complete 3-D model assembly and the dimension model assembly is shown down below.

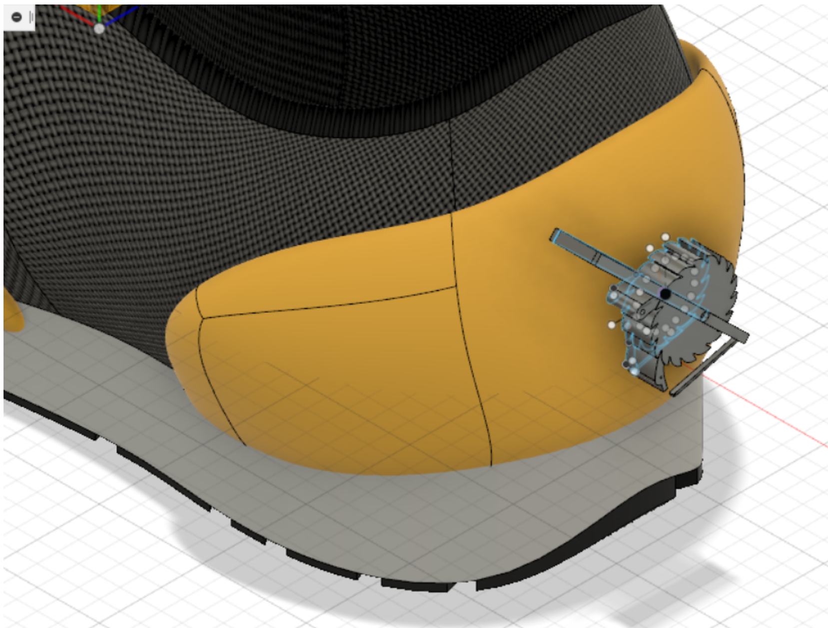


Figure 26.

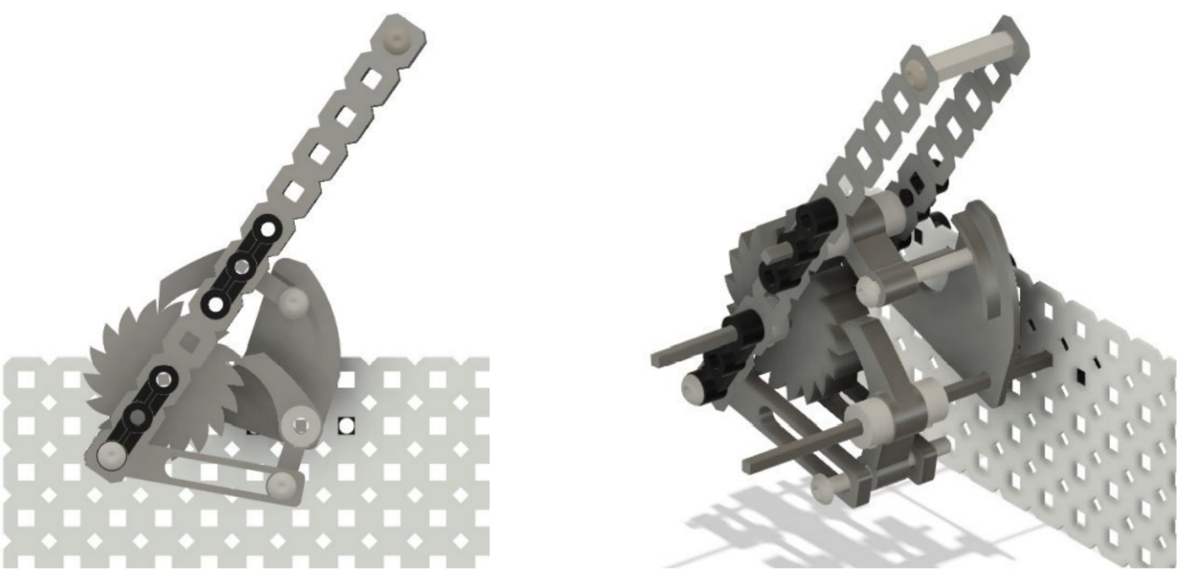


Figure 27.

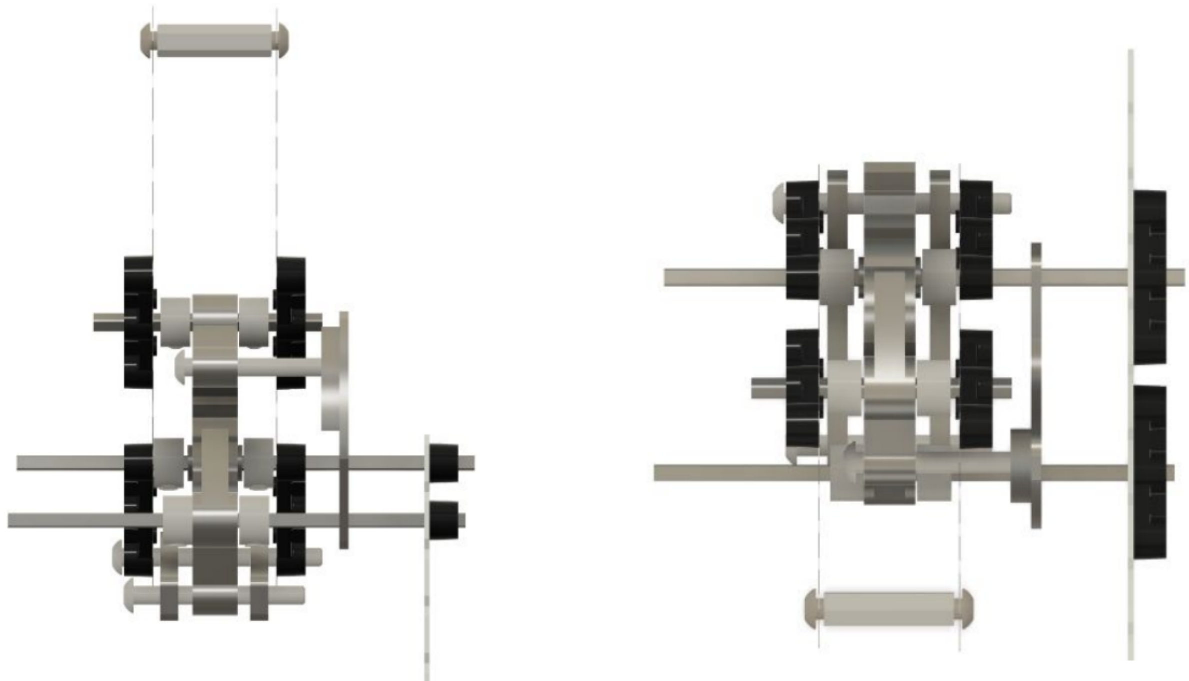


Figure 28.

More details are needed for the final product. The biggest one being the housing that will go around the final design. We have decided that several of the final parts will have to be metal, including the ratchet wheel, lever,axles and the pawls. The forces are lessened in the release functions and those parts will also be protected by a strong housing, likely made out of a hard durable ABS plastic. If it's 3-D printed, it will be 100% filled. Weight is not suspected to be an issue once the mechanism is downsized, so more metal parts will be added if there are malfunctions in the device. Thorough testing, both normal and destructive, will be used to locate points of failure within the design, and the group will adjust the geometry from there.

However, with the dimensionality and other information that we gained from the prototype, we were able to 3-d model an assembly of what the final product will look like. This is accurate to how the final product will look, all that remains is to build and test it to work out all of the issues to create a more perfect device.

Conceptual Modeling Results

The foot was to be the applied force on the crank which would drive the spool to tighten the wire. The free body diagram can be found in fig 83. From the data collected from the force testing it was determined 50 N would suffice in the drive the crank.The crank (lever bar) was made of PLA plastic at the time. The properties were as follows, Young's Modulus of 4.107 GPa and Tensile Strength of 62.701 MPa. To ensure that the crank would not break or deform the calculations made defined that the force was not to be higher than 50 N.

The highest force used was 100 N because it is presumed the person would not be cranking the lever bar with all their might. For the sample calculations can be found in the appendices fig 71. Once the crank was safe, next came the ratchet and pawl system. Below is in the appendices fig 85.

The torque determined that would drive the ratchet was 3952 N*mm. This was used to determine the circular pitch. The theoretical pitch came out to be 4.56 mm. Compared to actual pitch which was 4.5 mm it was deemed safe. Calculations in appendices fig 69 & A.

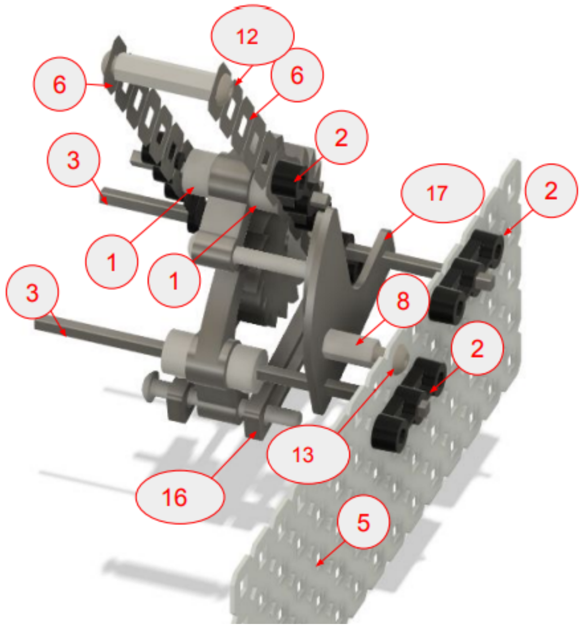
The next part for examination was the spool. The spool was to be made of the same material, PLA plastic. The spool will have an even tension from both sides and the tension determined was 76 N (fig 71). In our measuring we discovered that the tenforce required to tighten the shoe adequately enough was around 48 newtons. To tighten the lace by 25 mm 3 - 4 cranks was determined from the prototype.

To hold the lever together it was determined two extension springs were needed. The length of the larger spring was 75 mm, stretched: 150 mm, and compressed: 55 mm. It was able to withstand the given load. The smaller extension spring was 30 mm and was only needed to balance the driving pawl.

Our prototype was shown to have a weight of about 5lb. This was much heavier than we expected it to be, but we also made it mostly out of aluminum and much larger than what we believe will be on the final version. Taking all different components into consideration, we believe in order to fully build a working version we at the time believed it would require these specific components.

(ADDITIONAL FREE BODY DIAGRAMS FOUND IN APPENDICES)

Capstone 2 Manufacturing



1 - Shaft collar
2 - 0.25 in Bearing
3 - ¼ in square 4 in shaft
5 - 15x5 plate
6 - 0.5 in OC 12 hole bar
8 - 0.5 in standoff
12 - 0.5 in 8/32 screw
13 - 0.25 in 8/32 screw
16 - LWR-SLIDE
17 - Drive release bracket

Figure 29.

Fig 29 shows the prototype that we developed last semester. The design was the same fundamentally, but will contain modifications to make it shoe-ready.

In order to make it shoe ready we first modified it to remove all vex components as shown in fig 30.

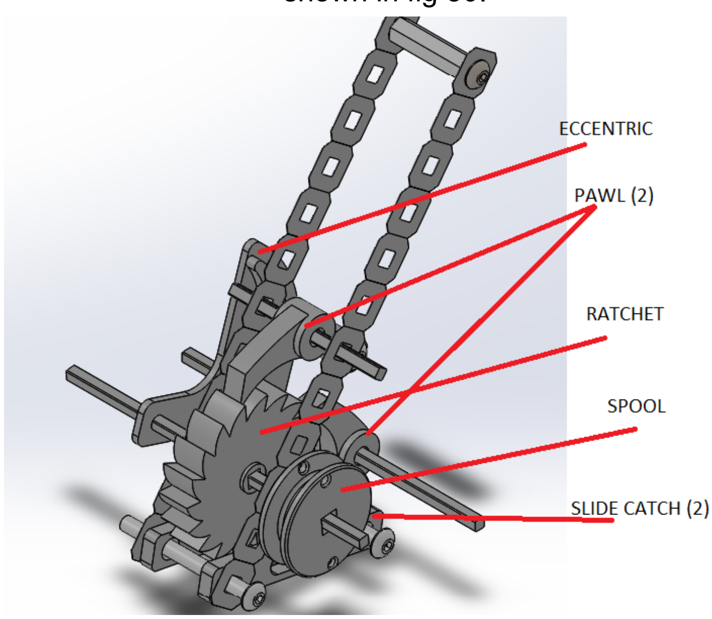


Figure 30.

IMPROVEMENTS:

If you were to compare this to the original prototypes you will see that we eliminated the vex components that mounted the device. With this change we added a few modifications to fully prepare it for manufacturing. This includes:

1. Shortening and Thickening the pedal lever
    a. The plan was to mount the device on the shoe with the pedal lever hanging towards the left, we needed to shorten the pedal lever to ensure it will not be caught on anything while walking, as well as to reduce the moment on the axle it is attached to.
    b. We needed to thicken the pedal lever as the original design has the pedal lever being much too thin to support the forces produced by the foot to crank it up.
2. Creating new housing
    a. The original prototype was mounted only using 3 points of contact (see prototype image) but the new plan was to create a house with 6 points of contact by attaching the axles to the housing on both sides.
    b. Our design resembles a ‘U’ shape, which allowed the design to be sandwiched in between 3-d printed housing.
3. Strengthening of materials
    a. The Original vex prototype was meant to validate that the design worked with all of the interferences between parts and space issues that we had to resolve. Now that those issues were ironed out, there needed to be upgrading in terms of how much force the design can withstand.
    b. The new and improved parts were intended to hold up through the testing phase. We were bound to run into some issues, and redesigning was to take place when needed.

The General flow of how we planned to make and improve our design flaws is shown below in fig 31.

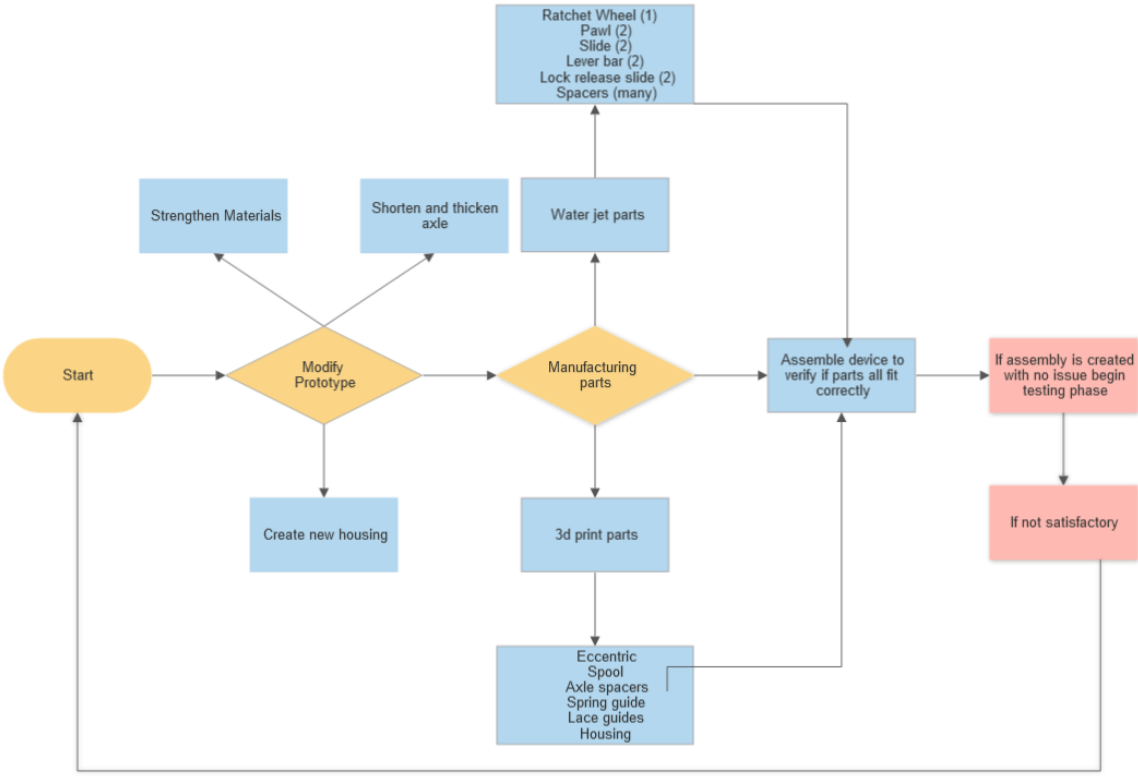


Figure 31.

MANUFACTURING OF PARTS

After the group spoke with John Knight an updated version of the manufacturing plan was done. The plan was to waterjet most of the parts as this was the quickest, and the dimensions of the sheet metal fit well within our design. We planned to create these parts out of aluminum as it was light but presumably strong enough for the application. In total we'd have 6 different parts that needed to be created using a Waterjet. These Include:

1. Ratchet Wheel (1)
2. Pawl (2)
3. Slide (2)
4. Lever bar (2)
5. Lock release slide (2)
6. Spool (3 parts)
7. Spacers (many)

There were many parts that we had to 3-D print, as they did not need to withstand many forces, as they served more miscellaneous functions than structural ones. Those included:

1. Eccentric
2. Spring guide
3. Axle spacers
4. Lace guides
5. Spacers
6. Housing

As for the time estimate for each of these parts, we have concluded that it would take 2 weeks to manufacture the waterjet parts in the worst case scenario upon request, and the same timeframe for the 3-d prints, in case the lab is slow to produce what we need. To minimize time loss, we requested all parts at once and then made any necessary adjustments upon the first assembly.

WATERJET PARTS:

For every single waterjet part, the process was the same. We sent the step file to the lab hand, and they produced the part for us using the waterjet software. Each part would have an uncertainty of around 5 thousandths by the nature of the waterjet deflection through the sheet metal. Luckily, this was not important for most of the parts, and for the parts that attached to the axle, we filed down the aluminum to make it fit the way we need to.

RATCHET WHEEL

The ratchet (shown in fig 32) was cut using a water jet out of quarter inch sheet aluminum stock. This was more than enough strength to hold the spool in place and kept tension in the lace. The hole in the middle slid onto a 1/4in aluminum axle. The Waterjet had a slight deflection when it cut, so we modeled the hole slightly bigger than it needed to be. But during the assembly we did in fact need to file down the hole in the middle to make it fit properly on the axle.

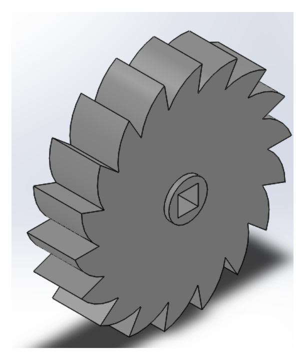


Figure 32.

PAWL

The pawl (shown in fig 33) was cut using a water jet using quarter inch aluminum sheet stock. There was a lip in the model where the hole of the pawl was but this was removed for the ease of manufacturing with the waterjet, as cutting the extra lip would be very hard to do with a CNC machine due to the small scale of the pawl. The lip didn't serve a particularly important purpose other than acting as a spacer.

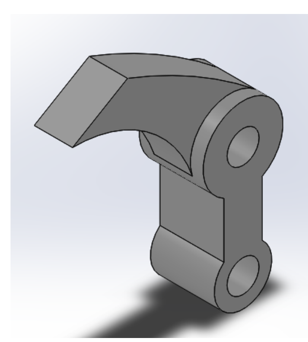


Figure 33.

SLIDE

The slide (shown in fig 34) release was cut out of 8th inch aluminum sheet stock. This part was cut to its exact specifications.

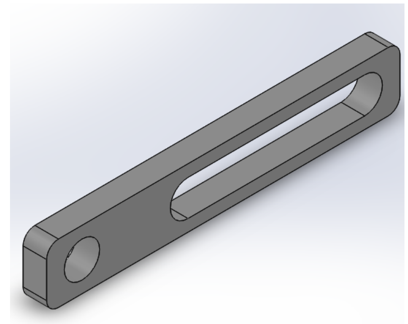


Figure 34.

LEVER BAR

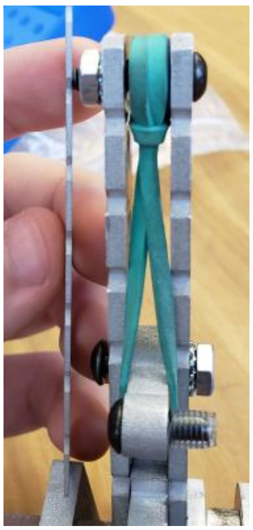


Figure 35.

The lever bar was cut out of 0.13 in aluminum sheet stock. In fig 35 you can see that it was extremely thin.

AXLE

This part was cut to be a .25 in x .25 square in aluminum to add strength and keep it light. But this was not without its challenges. Getting the relatively small axle down to size was a challenge. To do this, we went into the lab and attempted to belt sand the axle down while holding it. That didn't work because it would get far too hot to hold after a few moments of grinding. We decided to hold it with pliers to grind it down evenly and properly, but failed on the first axle. Luckily, we had a second one ready that was waterjetted already. Upon trying again, we were able to successfully grind it down to size.

SPOOL

The spool (shown in fig 36)was split into 3 parts for ease of manufacturing with the water jet as shown in image The holes in the outer section are anchor points for when the laces were attached. The spool would later have to be super glued together in order to make it one solid piece, and have it function without the wire getting off track or in between the crevices of the three parts.

We had to be careful to file down the sharp edges that the waterjet created when cutting each piece out so as to not have the wire get worn down over time. Filing was also required on the inner square hole for all 3 parts to make them fit properly on the thicker axle.

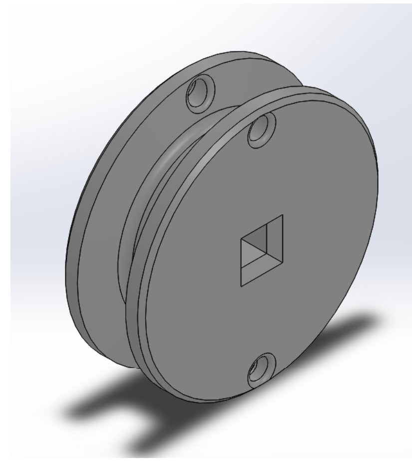


Figure 36.

3-D PRINTED PARTS

The process was the same for manufacturing the 3-D printed parts. We sent them to the lab hand, and they used a slicer software for the Ender 3 Pro and printed out each part. For the 3-D printed parts, the uncertainty was disregarded. Each one of these served a purpose that demanded a very loose tolerance. For example, the purpose of the eccentric was to push the drive pawl out of the way, the dimensions (within reason) did not matter as long as it served this purpose. The average tolerance for the ender 3 pro was +/- 0.5mm, which was well within reason.

ECCENTRIC

The eccentric was 3-D Printed, and is shown in figure 37. This part hardly withstood any forces, and purely existed to move the drive pawl off of the ratchet wheel. With this in mind, it did no't need to be a strong material, and 3-D printing adds the bonus of it being lightweight. The dimensions also did not have to be precise, as the tolerance for this part was very high (¼ in and up in any dimension). It still completed its job even with low precision manufacturing techniques.

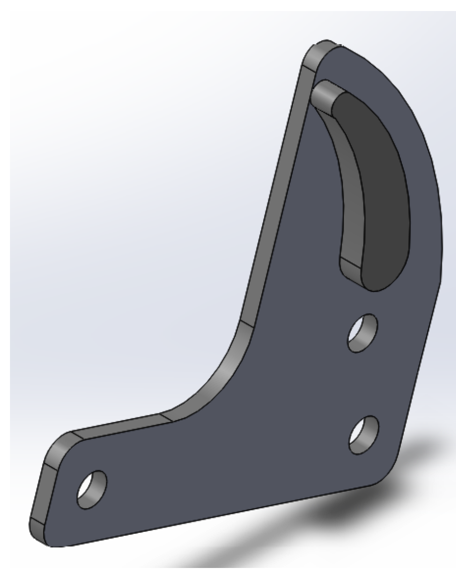


Figure 37.

HOUSING

For the housing shown in fig.38, there are holes for the bolts heads to go into, as well as a third extra supporting bolt on the top to help with the whole device twisting when it is cranked. The new open faced design removed the constraint of a set amount of room to cram all of the parts into, making assembling and disassembling the device much easier (which we had to do several times to add new and improved parts). This ended up saving us a ton of time in the long run. Similarly to the vex components, we printed the new housing with an array of holes to choose from in case we ran into any issues and needed them. This way, instead of having to print the biggest part of our assembly again leading to days of lost time, we can adjust things on the fly. This ended up really helping us later on as well. Finally, The axles in this new design have room to spin without interfering with the housing.

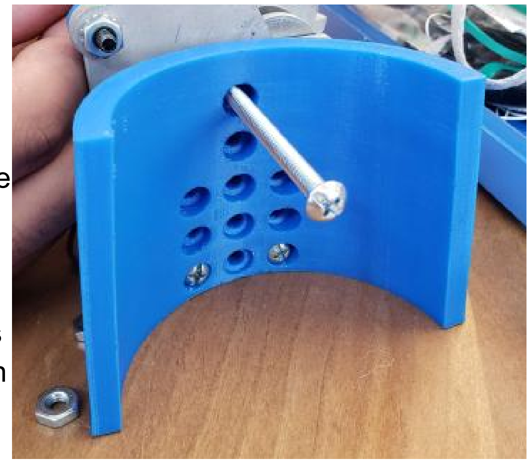


Figure 38.

ADDITIONAL NON MANUFACTURED PARTS

In order to fully assemble the device additional parts were acquired. This included:

SCREWS/WASHERS/BOLTS

- 3 in screw
- 1 in screw
- ¾ in screw
- Axial steel .25
- Axial steel ⅛
- 1.25 Spacers
- 1 ⅛ in
- .25 in
- ⅛ in
- ⅜ in
- Spring
- 2 rubber bands
- Nuts
- Tension spring

Testing

Now that the device was fully built it was finally time for us to begin testing. In order to test, we first determined the points where the forces will be coming from, and see how the device responds and holds up. The testing is broken down into two segments: first, we tested the assembly to withstand the forces from a human foot winding it up. Then, we attached it firmly to the shoe and proceeded with a functionality/endurance test (i.e. using them while running or performing some athletic activity for a long duration of time).

Objects Under Significant Force

Pedal lever

- This part was chosen as the pedal lever would be receiving a lot of force as you kick the pedal lever counter-clockwise. We believe that this could create failure points as the lever transmits a lot of force to several other parts. We started out with a .13 inch sheet aluminum stock, but have thickened up this part and now need to test to see if it will survive the forces we are expecting, where the previous version undoubtedly would have yielded.

Spool

- This part was chosen to justify the design of the assembly surviving the tension forces needed to tighten our shoelaces. We are also unsure of the maximum amount of force that can be pulled without a device and need to ensure that it meets our goal of 50 newtons.

Axles

- These parts were chosen to justify the increase in diameter of the axle that was being driven, and the axle supporting the lock pawl. We aimed to find out if they were strong enough to survive the forces of both holding the entire device up, and the kicking force it will experience while tightening with the pedal lever. previously our axle did not turn properly when it was in equilibrium due to slight deformation. To combat this, we upgraded the thickness of the axle, so it won't deform and will turn properly. We need to test the new axle to see if they would also be able to withstand the expected forces while maintaining functionality.

Testing Methods/Plan

1. **PEDAL LEVER**
    - Attach a weight to the pedal lever and record the force withstood. Test the weight to determine the amount of force that can be applied on the pedal lever and compare with force predicted to be applied via a foot stepping on the pedal lever.
    - Test the upper limits of the pedal lever by applying gradually increasing forces to determine its maximum load capacity until force is equal to the amount predicted to be applied by foot.
    - If no minimal deformation is seen at target loads, the test is considered a success.
2. **SPOOL**
    - Connect a weight to the spool’s wire and test the upper limit of the force that can be pulled by the device.
    - Test the spool's performance under varying tension levels.
3. **AXLE**
    - Mount the device using a newly built thicker axle and check for deformation in the device
    - If no sagging is seen then test upper limits of the axle during the handle testing phase to determine its maximum load capacity.
        - Testing done using weights and seeing how much weight is needed to create deformation in the axle.
        - If deformation is seen adjust design with new axle with either a thicker design or made out of a stronger material
4. **GENERAL FUNCTIONALITY TESTING**
    - Conduct physical tests of the device in actual use, portraying real-life scenarios, to evaluate its overall performance, effectiveness, and reliability.
    - Test the device's performance under different conditions, such as varying shoe sizes, lace types, and tightness preferences, to ensure its versatility and usability.
    - Document all the test results thoroughly, including measurements, observations, and any identified flaws or areas for improvement.

These tests helped us conclude a lot about the pros and cons of our design.

Testing Results

- PEDAL LEVER AND AXLE

The following are the results of the testing carried out on the shoe tying device:

1. 10 lbs: No Deflection in Axle The initial testing with a weight of 10 lbs showed no deflection in the axle, indicating that the device was able to withstand this level of force without any structural issues.
2. 18 lbs: Slide Bar Slides Past Intended Stopping Point At 18 lbs, we encountered an issue where the slide bar we had devised slid past its intended stopping point. This indicated that the slide bar needed additional stopping mechanisms to prevent this issue.
3. Attempted Fix with Two Screws as Stops To address the issue encountered at 18 lbs, we added two screws as stops for the slide bar and reattempted the testing.
4. 18 lbs with Stops: No Deflection in Axle With the screws added as stops, we retested the device at 18 lbs and observed no deflection in the axle, indicating that the slide bar was effectively stopped by the screws and the issue was resolved.
5. 25 lbs with Stops: No Deflection in Axle Further testing at 25 lbs with the stops in place also showed no deflection in the axle, indicating that the device was able to withstand higher forces without any structural deformation.
6. 35 lbs with Stops: No Deflection in Axle, Torsion in Housing At 35 lbs, we observed no deflection in the axle, indicating that the device could still handle the force. However, we noticed torsion in the whole housing, indicating that the device was experiencing twisting due to the moment along the pedal lever, because the weight was offset from the rest of the device.

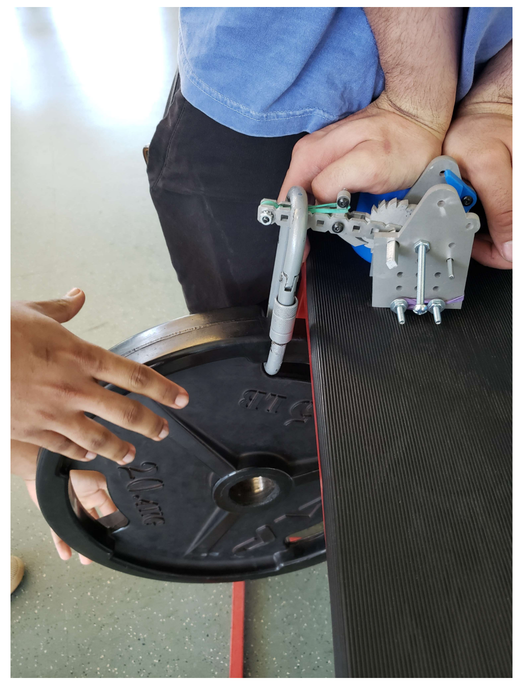


Figure 39.

7. 45 lbs: Large Torsion in Housing, Device Can Be Tightened Testing with a weight of 45 lbs showed significant torsion in the housing. However, we believe that this issue can be mitigated by tightening the device as a whole, indicating that the device can still potentially handle the force with proper adjustments as it was very loose before

<u>Conclusion:</u>

Based on the testing results, it can be concluded that the shoe tying device is capable of withstanding forces up to 45 lbs without any structural failure or deformation. The addition of permanent screws as stops for the slide bar has effectively resolved the issue encountered at 18 lbs. At higher weights, the whole housing would twist due to extreme force as shown below in figure 40

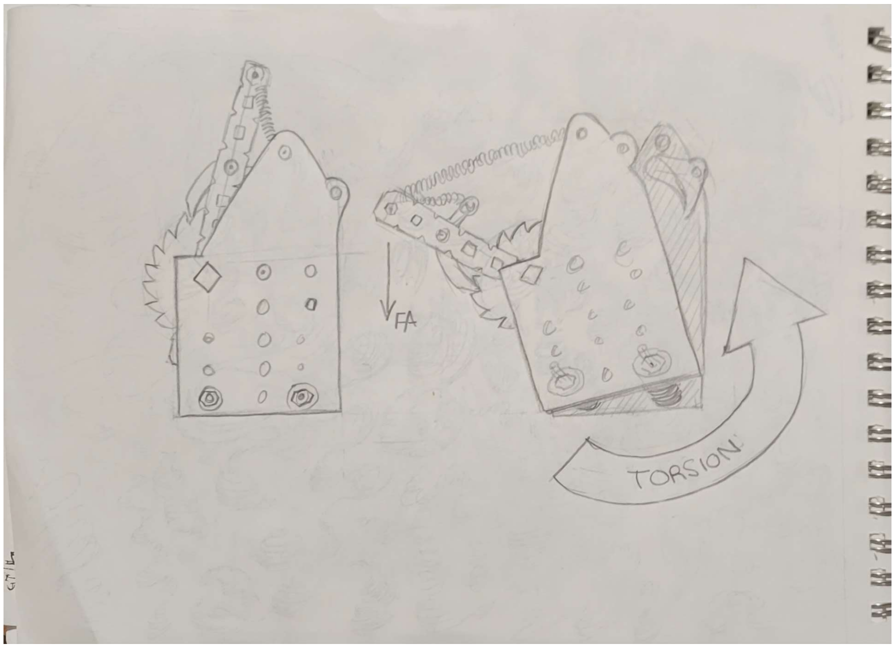


Figure 40.

- SPOOL

Results: The results of our testing are as follows:

Figure 41.

1. At 5 lbs: The device was able to crank up and unwind with no problems. The spool performed well without any signs of torsion or failure.
2. At 10 lbs: The device still performed well, with the spool able to crank up and unwind with relative ease without any noticeable issues.
3. At 13 lbs: We observed some torsion in the body of the shoe tying device. We believe that adding another screw connecting the body of both housing plates could fix this issue and prevent further torsion.
4. At 18 lbs: Torsion in the body of the device was observed on a greater level. This torsion created too much friction in the spool and did not allow the lever to function properly due to the misalignment from the shift of several internal parts.

Conclusion:

Based on our testing results, it is clear that the spool of the shoe tying device is capable of withstanding weights of up to 13 lbs without failing to function. However, torsion in the body of the device was observed and increased at higher weight load leading to failure to function properly.

Recommendations:

1. Add more points of contact between the housing plates to prevent torsion

Functionality Testing Phase

Once the individual parts were fully tested we were now able to begin a functionality test. This involved walking around with the device on for a day, and seeing how the device performed. We tried to make the device encounter anything you may encounter when walking through your average day. This includes walking up and down hills/stairs. We also created an extreme situation for when you may need to sprint in this device. The biggest challenge that the device faced was being exposed to shock and vibration from the small but consistent loads. The added length of the shoe in total with the device sticking out of the back also caused some issues.

Because of the shock and vibrations happening in the device, The hardware that was keeping it together loosened over time. The bolts and nuts started to come undone and Secondary components had to be re-tightened. We attempted to solve this issue by replacing some of the nuts with ones that had higher friction. This worked.
There were also dimensionality issues due to the added total length of the shoe with the device attached to the back. The device was attached to a size 12 shoe, which is already fairly lengthy, and the added length on the back created a tripping hazard in certain situations. Going down stairs was particularly challenging, as the test subject had to turn their foot to the side in order to properly step on each step. Going down hills was another challenge, because if the hill was steep enough, the device would hit the ground before your heel.

The amount of pumps that it takes to wind up the laces from a very loosened state is 16 pumps. This is more than we expected by a decent amount, but it doesn't take long to accomplish due to the smooth cycle the device turned out to have.

The device performed extremely well in keeping the laces tight. There was no loosening for the whole test duration. This was partly because the homing spring that we put on the pedal lever did a great job at keeping the lever in place when it was not in use. Same thing with the locking pawl, where the rubber band provided sufficient tension to keep the ratchet wheel locked down when not in the released mode. Even when sprinting the device remained sturdy, and the laces tight.

The shoe was a great success in terms of comfort. When the shoe is on, and the laces tightened, the shoe feels ALMOST indistinguishable from the normal-laced counterpart. Starting with what went right, attaching the housing to the shoe with bolts was not nearly as uncomfortable as suspected, and created no chafing inside the shoe even after long term use. The bolts were originally supposed to be a temporary way of attaching the housing to the shoe to allow for removal in case we ran into any problems during testing. But as it turns out, they work just as well as a permanent adhesive would have. Below is a picture of 3 three bolts used to attach the housing to the rear of the shoe shown in fig.42.

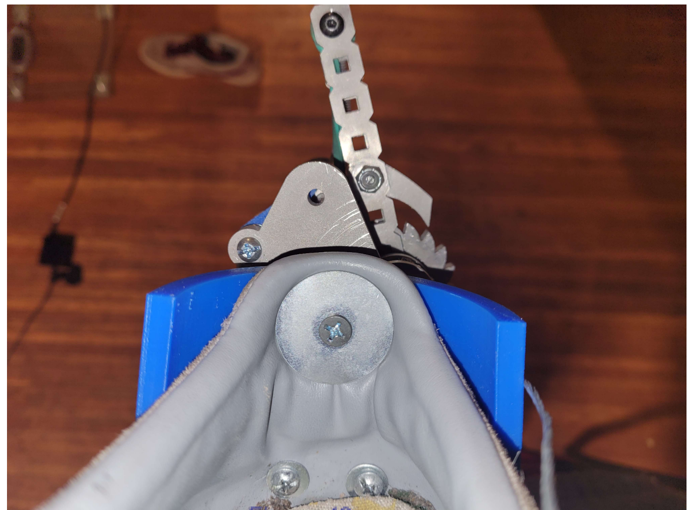


Figure 42.

There are only a few problems that we ran into. The concentrated weight threw off the balance of the shoe and would function better in the center of mass of the shoe if we were to relocate it somehow. Also, despite our best efforts, there were frictional issues that prevented the laces from tightening perfectly evenly.

None of these solved the problem to the degree that we wanted to, but they did help slightly. The problem does tend to resolve itself, for as we moved around in the shoe, the contortion of the soft-bodied shoe helped work the laces into place and even out the distribution of tightness.

The release of the shoe was difficult to get to cooperate after the shoe was tightened around the foot, as the angle of the pulling force of the wire/spool on a diagonal was dragging the axle into an unfavorable position to turn when released. A diagram to visualize this issue is listed below in figure 43 We tried to fix it quickly by adding a guide for the wire on the side of the device, but it did not help much.

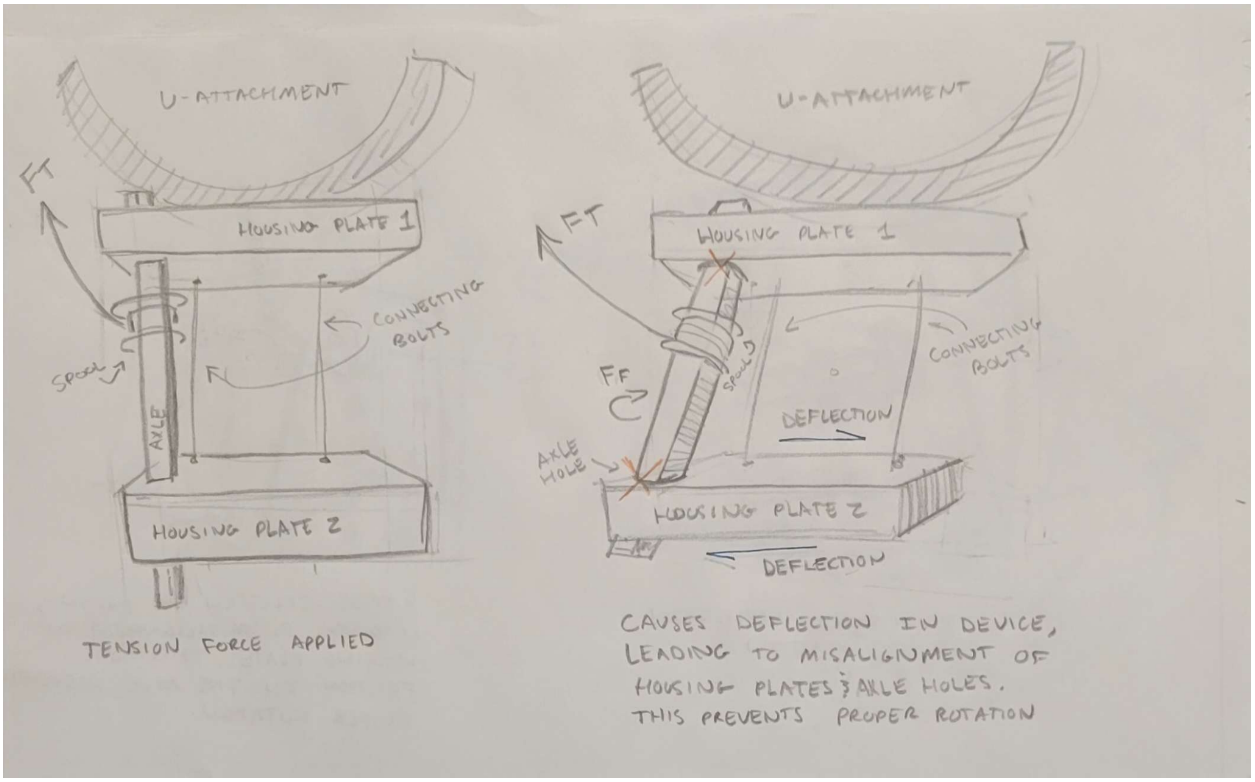


Figure 43.

Conclusion of Testing

Figure 44.

We learned that the device as it stands now is operational within our expected force parameters, but there is always room to improve. Currently our device is bigger and heavier than we expected, but we believe that this isn't the hardest issue to fix. The current weight could be tiring for older users to walk around with all day.

Further downsizing of the housing would also help with interference issues with the environment from functionality testing. Overall, the device performed exceptionally when put up against the forces it was, and no major failures occurred, only areas of poor functionality. The testing helped us understand by witnessing in real time how the bodies reacted to the forces. This knowledge will greatly help us visualize problems in future inventions.

Final Design

After the manufacturing and testing was completed, we assembled all of the parts into the assembly shown below. It was put together by hand and took a few tries to get an even space between all the axles so the housing plates sat correctly. To accomplish this, we created various sized spacers to offset many components where needed. Video of mechanism function The shoe was not cranked with our foot because we didn't have anyone to film at the time. But it works just as well when cranked with the foot.

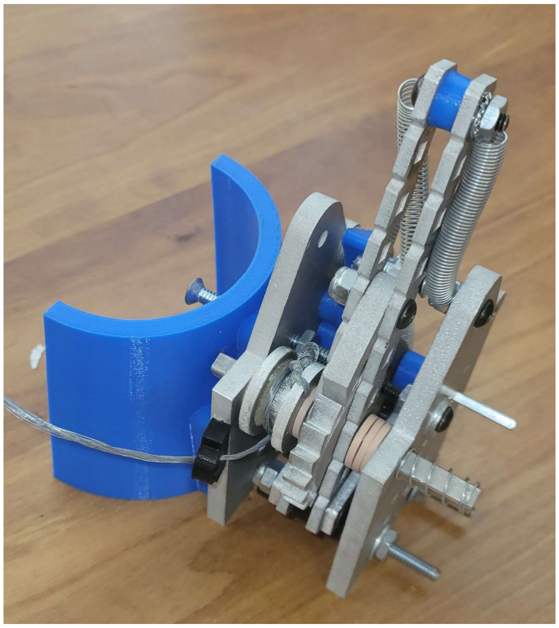


Figure 45.

Teamwork

CAPSTONE 1

Craig - drawings, aesthetic design, testing

- Used shoe to test
- In charge of visualizing design and creating rough drawings.
- Drawings on ideally what the final design would look like.
- Created exploded view
- Developed update power points and final paper with other group members
- Researched release mechanism

Jeremy - research and analysis

- Looked into several gear designs
- Found sources that explained useful mechanisms
- Theorycrafted power transfer from ratchet to spool
- Created first failed design
- Set dates for meetings
-

Ricky - research, assembly, 3-d modeling

- Researched needed formulas
- Stress and force analysis of components
- Solidworks drawings
- 3D printed components
- Added additional information throughout final paper where needed

CAPSTONE 2

Craig - assembly, machining, aesthetic design
- Machined a different parts to suit different needs
- Acquired all hardware to create the device
- Assembled and kept device
- Developed solutions to design flaws with group members

Jeremy - Analysis of assembly, 3d modeling
- Created 3d models for all parts to be machined or 3D printed
- Checked parts to see if matched specifications
- Created manufacturing plan and report'

Ricky - Testing, Scheduling, CAD drawings
- Set dates to meet up to work on device
- Created validation test and report
- Created all CAD drawings
- 3D printed components
- Developed update power points and final paper with other group members

Discussion

In our initial design we learned that we need to put more research into our designs before pushing further in other aspects. We made an incorrect assumption and did not realize until more than halfway through our project. This led to us scrambling to find a new driving mechanism. This was a significant setback and led to us almost being unable to find a new mechanism within our timeframe. Without finding this we would have realized half way through building the final version before failure and be completely unable to fix at all leading to total failure. A combination of this initial failure and guidance from our professor led to us deciding to prototype our new design in order to confirm that it will work. In making this prototype we discovered that our new design would work. The prototype helped us understand every intricate part and detail of the design, and also helped us visualize and prove to the group that our new ratchet design worked. After our initial failure we went head first into designing. The prototype helped us see and understand exactly what were the problems as we did different interactions of designs until we finally found one that would work, and would be able to be changed to a smaller size.

Our results came out to be reasonable because the prototype proves that we can create a working mechanism with the concepts that we tested repeatedly during its development. The ideas that we implemented for the prototype will still have to improve as will later be shown. In terms of forces, the ratchet produces more than enough forces to tighten the shoe. The input force of someone stepping on it is predicted to be significant enough to tighten the shoe, however the device should be able to withstand this force without being damaged or misaligned.

Our resulting prototype was not without its errors. For one, it didn't attach directly to the shoe, the housing was still separate. We found it unreasonable to attach the mechanism to the shoe because it was far too large to be functional. The model shoe was to simulate the pulling of laces over the top until our model was ready to be mounted. In which case, the prototype was successful in verifying the fundamentals of our design.

Despite the problems found, the prototype provided physical proof that our design would work which spurred us to continue pressing onwards in creating the final product. One of the biggest challenges we faced was creating the housing as it took many iterations to create.

What we set out to do in capstone two includes making a final version of our design, and doing testing to find out where failure points are, and adjust the design from there. It was planned that there will be several iterations of the final design, where changes will be made to make the design closer to the final product. The two main goals are to have the final product be consolidated so it's small and light enough to practically fit on the shoe, and durable enough to withstand rough outdoor conditions.

Iterations

Housing:

The shoe support was to be 3d printed. Since it was very thick and durable, this part was able to satisfy the load requirement.The first design of the part that was attached to the back of the shoe is shown in figure 46, followed by the first assembly of the failed housing design.

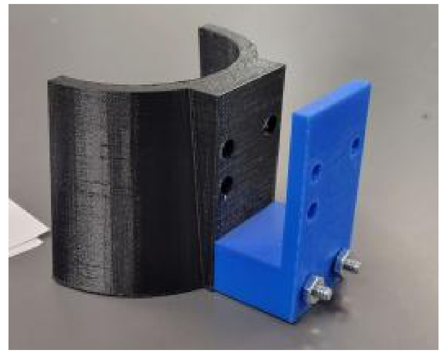


Figure 46.

The first design for the housing was inadequate because It's difficult to assemble and disassemble with the device in such a tight gap between the blue and black pieces. There were no holes for the head of the bolt to sit in, creating a gap in where the black part attaches to the shoe which allowed for the axles to be secured into place properly. This U shape was also not very well supported, and created too much torsion when under load.

To fix all of these problems and more, new housing was developed, which is broken down into three main parts: The “U” shape that attaches to the back of the shoe, and 2 identical housing pilates that the inner workings will be sandwiched between. Just like the last housing, This design will be held together with nuts and bolts.

Housing Plates:

This was 3-D printed because of the weight concern. (shown in fig.47) The tolerance for the 3D printer also falls within our threshold. It turned out it needed to be made out of aluminum due to the deformation caused by the rubber band . Due to the various web of forces on the housing, we were concerned that the fatigue of daily use could deform the housing in other ways. This was a major trade off, because this change of material significantly increased the strength of the *overall* design, but also added significant weight.

Figure 47.

Ratchet Wheel:

The ratchet wheel had to be edited from its existing design as it was also going to be 3d printed. After seeing what happened to the housing plate we decided it would be best to upgrade it to aluminum also.

Slide:

We decided to make this out of aluminum because it was a small part with thin segments and it was suspected a 3-D print would have deformed under fairly minimal load. We also extended it slightly in order to increase the range of motion.

Figure 48.

Pedal Lever:

The pedal lever was first designed to be made with 0.13 in aluminum sheet stock, but we quickly discovered that the product created was too flimsy. Afterwards we had upgraded the thickness to 0.25 inch in order to withstand the forces we believed it would have to withstand. If you look closely, the comparison between the two thicknesses of the handle is shown on the next page in fig.52.

Axle:

The axle was originally ⅛ in in diameter but it was determined it needed to be thicker. The reason was this part was going to have to withstand a lot of forces, both in bending and torsion. We changed it to .25 in x .25 in aluminum to add strength and keep it light. This axle is shown connected to the ratchet wheel in figure 49.

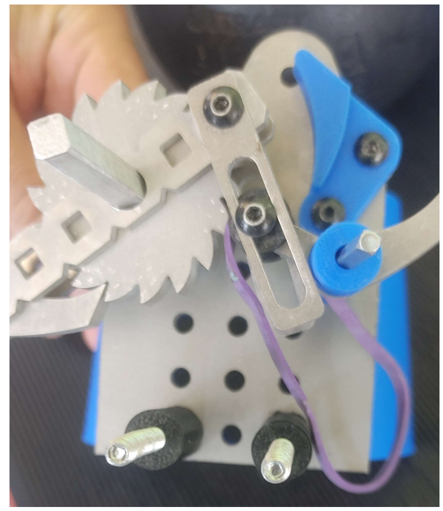


Figure 49.

Resized Parts:

As a result of the axle being resized many parts all had to be resized to accommodate for the new axle. These include:

- Ratchet Wheel (Center hole resized)
- Spool (Remade with larger size)
- Housing Plate (Hole for large axle resized)
- Lever Bar (Hole for large axle resized)

These are all shown in figure 49.

Eccentric:

The original design wasn't the correct shape when it was being assembled. It did not lift the drive pawl due to dimensionality problems. It was also too large to be able to connect it to the housing and have everything else function. Adjustments were made to downsize, and make it interfere correctly. A comparison between these two is shown in the multiview in appendices fig.63

Spool:

The spool was also planned to be 3d printed but we believe that this part would not be able to take the torsional force and would eventually fail/deform under heavy loads. This was changed into aluminum by changing it into 3 separate parts that were later glued together. Multiviews for the updated three parts of the spool are shown in appendices fig 60 & 61.

Lacing System:

We originally went with a traditional lacing system but ran into an issue where the top lace tightens more than the rest of the loops. To combat this, we tried several things:

- Changing the laces to fishing wire and string so the smoother/less bulky laces would slide through the lace holes better. This led to a weaker lace and failure issues.

- Adding hollow rivets in the lace holes to create a smoother surface, and allow the lace to move more freely.

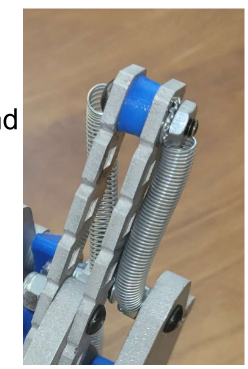
- Several different lacing orientations of how the lace would go through the holes.

Figure 50.

By doing this we eventually found the lacing system shown in figure 50 . This used traditional shoe laces tied to a steel wire. The shoes were laced using an unorthodox lacing system which allowed the force of the tightening to be equally disturbed between the top and bottom.

Return System:

The rubber bands that we used to keep tension in the lock and drive pawl when they aren't released were replaced with tensile springs to make them more durable. The rubber bands kept wearing out and breaking, leading to the unintentional release of the ratchet wheel. A comparison of these two methods is shown in fig. 51 & 52.



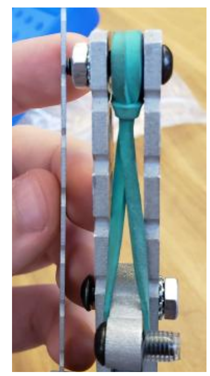


Figure 51 & 52.

Assembly:

The assembly itself went through iterations as problems were found through testing. One such example was the addition to stops in the assembly to prevent the pedal lever from going past its intended range of motion. Screws are shown below in figure 53.

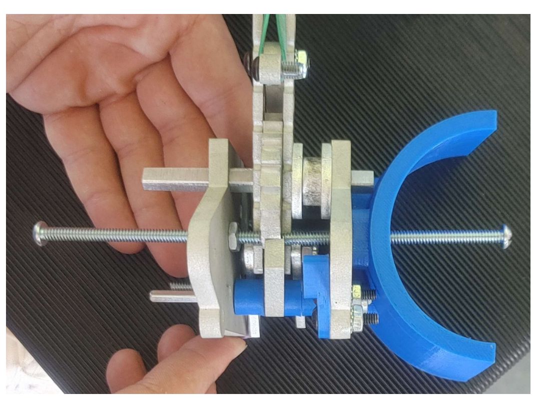


Figure 53.

Reflection

The Good:

The positive aspects of the project were the ability to collaborate on a two-semester long task. It was unique to be able to manage our own time and work together when it was convenient, with only landmark deadlines to meet. These landmark deadlines required a lot of work to meet, but split amongst the group members we were able to accomplish a lot in a timely fashion, especially when we met up to work together, kept each other motivated, and bounced ideas off of each other to help brainstorm and develop different aspects of the project. Each group member was respectful of ideas and was willing to compromise on major decisions.

The overall excitement of the group to see some of our first final parts get manufactured was electric. It was at this point that we knew that we could take it all the way, and reach a point where we could be satisfied. Seeing the project improve in ways that we didn't even anticipate was very rewarding, and challenged us to think outside the box. Each problem that we didn't anticipate made us better at anticipating future problems, and taking preliminary steps to prevent them. The more that we learned, the more we could do. Now that every member of the group is basically an expert at ratchet and pawls, there's no telling where this information can help us down the line.

Documentation and communication skills were essential, where by the end, the team seemed much more comfortable with each other. Nobody was hesitant to share conflicting ideas and disagree. The initial idea of any particular group member often wasn't the perfect solution we were looking for, but led to discussion and further input which helped us make it to the next move. Documenting the project was a beast, but we were able to find out what really goes into communicating a complex idea to fellow students through presentations and report writing.

In terms of general functionality of the device, it did a good job meeting the requirements we set out for. The ones it fell short of were very very close to being made functional. The design effectively created the tension that we needed to keep the shoe tight, and kept them tight. It was also durable enough to be able to survive rough conditions. It held all of the high forces that we anticipated, as well as produced the force that we needed.

The release system functioned well and was consistent with removing the pawls from the ratchet wheel. The lever stayed in its neutral position while it was not in use due to the springs. The housing was able to serve its general purpose.

The device was also easy to mirror, as the housing plates were reversible. This means that even though we only made one device, it can be flipped to the other shoe with ease if we were to make another.

Challenges:

However, with so much freedom comes responsibility. The most challenging part of the semester project was to pace out the work properly and find out what exactly needs to be done, when, and how. For example, in order to create our release mechanism and cranking mechanism it took many trials in order to accurately come up with a design that would meet our design criteria. This is very different in comparison to anything we learned throughout our schooling as usually we are given very set criteria and not given the ability to design something from scratch. Another challenge was pioneering the new format for capstone and figuring out how to conceptually model the project in a communicable way to relay the ideas to classmates that knew nothing about what we were working on. Our greatest challenge resided in neat communication and finding out every small detail of what we need to develop from what hardware to use down to what adhesive keeps everything together, and working out all of the little issues with each detail. If there were anything that was to be changed about the project, it would have to be adding more structure to exactly what we need to provide to make sure the design process is thorough. There was a major point in the project where all group members felt content and thought the communication of the project was adequate, but it ended up the opposite due to our lack of knowledge of what truly makes an effective communication of an idea. Specifically, not knowing a prototype was necessary until it was communicated to the group extremely late.

Upon entering capstone 2, this was also a challenging class in different ways entirely. This class made us realize that jumping from a prototype to finished product was a monumental task, and full of unexpected problems. We were able to collaborate as a team to find out how to solve these various problems as the project kept progressing. This ended up being a continuous cycle of small adjustments. This was fun, as we got to see the project get a little better each time.

Designing around your manufacturing capabilities was also difficult. Many of our parts were simplified and changed in order to make them easy to manufacture, opening our eyes to how much of a difference it makes to the cost and time of manufacturing for a product. Designers have to keep this heavily in mind before they make something, as keeping their design simple is oftentimes better, because this implies less parts, less materials, and less processes before the final assembly.

Tight communication was required with the lab hand, adding a layer of difficulty. We had to strategically time when our parts were going to be ready so we could fix whatever we needed the parts for and continue on.

What we set out to do in capstone two includes making a final version of our design, and doing testing to find out where failure points are, and adjust the design from there. It was planned that there will be several iterations of the final design, where changes will be made to make the design closer to the final product. The two main goals are to have the final product be consolidated so it's small and light enough to practically fit on the shoe, and durable enough to withstand rough outdoor conditions. After accomplishing all of this, there remains only one question left:

What Would We Change?

As expected, and same as the end of capstone 1, we accomplished many goals, but there is still much work that can be done on the device. Every test that we performed highlighted specifically what areas needed the most work. The first one being the main axle, where during the spool and pedal lever test was misaligned, causing excess friction.

Pedal Lever Future Improvements:

further adjustments may be required to address the torsion in the housing observed at higher force levels. The testing also indicated that the device can be further improved by using a clamp to hold it down during testing when the weight exceeds manual holding capacity.

When the lever extended past its intended stopping point, extra housing bolts were added as stops to keep the lever within the intended range of motion. This solved this problem.

Spool testing Future Improvements:

We ran into trouble finding the right type of string/wire to properly hold the load that was expected. At first, we used the original plan, which was a fishing line. Twelve pound test was purchased for initial testing. When that failed to hold a fraction of the goal weight, we upgraded to a string that seemed to be stronger, but still not what we needed. The string also showed sign of wear due to the way it rubbed against the edges of the aluminum parts when functioning, giving us insight into a problem we might run into for long term durability. Finally, we purchased 30lb capacity steel wire, which successfully held the load, and is more resistant to wear that will occur from the friction in the housing and spool. This wire won’t be what laces up the shoe, but rather a lead to connect to the lace, while taking the bulk of the forces and wear from the mechanism. We tried lacing the wire into the lace holes, and it was not malleable enough to tighten properly. The addition of wire guides helped us direct the forces more where we wanted them to, while also keeping the wire in-line with the spool so it wound up correctly without getting in the way of the slide release.

it would help to add additional screws to connect the housing plates of the device to help prevent torsion in the body of the device. This modification is expected to improve the overall performance of the device under heavier weight loads.

Functionality Improvements:

To solve the vibration forces issue from the small forces of walking around with the device, permanent hardware such as rivets would both cut down the size of these components and assure that there is no loosening.

The amount of pumps that it took to wind up the shoe laces.To decrease this number, we would simply have to increase the diameter of the spool.

The best way to fix this in the future would be to implement an unorthodox lacing system, or have the device lace from both sides simultaneously.

If the wire was positioned to pull more perpendicular to the axle, this would have helped the issue. Furthermore, the addition of square-holed bearings into the housing and pedal arm would have undoubtedly monumentally reduced friction and solved this issue.

General improvements:

By switching to a lighter metal we could cut down the weight dramatically. We could also make the parts smaller, but that would require careful consideration, due to the dramatic change in overall strength and force output of the device. The current weight of the device by itself is 0.8 pounds, which is significant if it's dangling off the back of the shoe.

More testing would be needed on the housing itself to be able to optimize its weight, so we could then choose lighter or thinner material. To do this, it would take a better understanding of the torsion forces that made the whole device misalign, and more measures to counteract this. Having a fully enclosed system, or more points of contact between the two housing plates for added rigidity would help this.

To solve the issue of the shoe being unbalanced, we could reposition the device on the shoe entirely, placing it more toward the center of balance and further out of the way. In order to do this, we would need to change how it attaches, and how it laces up. This repositioning won't be needed if the design is lightened and consolidated enough.

To allow the device to release properly when under heavy load, we could have added bearings or bushings into the housing where the main axle sits, as this would reduce friction and have the most critical part be aligned better. This would make the overall functionality of the device smoother as well.

As it currently stands we have a lot of dead space within our device that can be removed by using smaller nuts and bolts, and creating less interference in the arcs of motion. This would also prevent loosening from vibration forces over time. The nuts specifically use a lot of depth, and if replaced by rivets would cut down the size of certain components significantly.

Incorporating springs to hold potential energy *around* the axle to return it to neutral would also help save space.

There needs to be a force limiting element in our design, because with the strength of someone's foot, and with the help of gravity to wind it up as you step down, its possible that you can make the device too tight and possibly cause injury. To accomplish this, we would need to add a force limiter to the ratchet wheel or spool so it wont turn when under a certain torque. Another way to make the device safer would be to enclose the housing to prevent someone from getting their hands stuck in there. This would also help with preventing dirt and grime from interfering with the parts and potentially wearing them out, as well as adding further structural support for the housing.

Conclusion

Over the course of MTC424 our group was able to successfully design a product that not only delivered and met our design criteria, but also learned many important aspects in working in a group. This project was a massive learning experience for all group members. There was discovery in what truly goes into a design, from force calculations, material selection, dimensioning and so on. Even something like our project, which seemed simple on the surface level, was far more complex as the deeper details were delved into. One of the most important aspects that was discovered is the importance of being thorough in research and verifying design decisions are possible and will work.

The general accomplishments of the group was the learning experience of working together on a big project, and figuring out how to divide up the work. Roles were assumed based on strengths, and ability to communicate ideas and criticism improved over the semester. By far the biggest accomplishment of the group was the initial failure and us coming together in designing and assembling a new design and making a working prototype, which took many different ideas, attempts, and research to figure out how it was going to work. Specifically the release mechanism for the ratchet section, as a ratchet is originally designed to only go one direction.

In Capstone II with all the problems we faced in Capstone I we believed that we were ready to tackle any problem that would come our way. We believed that the hard part was designing the device and that building it would be easy, but we learned right away that it would not be as easy as we thought. We had to account for the fact that time constraints would be even tighter now then in the first semester, due to the influx of students all also trying to create their Capstone project. This made it hard to get our parts made on a timely schedule. This led to compromises we had to make such as over engineering certain parts to prevent it from breaking, as our force parameters were so high for such a small device. Failure would be a major setback, as creating new parts would be too time consuming.

This project not only helped us with problem solving skills within our project, but problem solving in general. Anticipating problems was the big one, where material replacements in our design helped save us a lot of time before we manufactured and witnessed the weaker alternatives wear out and break. Understanding how forces will deform a device was another one, where we now know to design structural entities around forces, instead of thinking about them secondarily. This will allow us in the future to prototype at a deeper level.

Material selection was highlighted in this project and is also applicable to so many other situations where weight to strength ratio is an important factor. We realize now that when selecting a material, it's a balance that you have to strike with weight and durability. Learning about the materials that were available to us and weighing the pros and cons of each helped us reach this balance.

Compromises such as this really ended up being the heart of our project and served as an important lesson as to what is to be expected when designing and manufacturing a product. We hit many walls such as 3d printed parts not being as strong as planned, or parts designed in Capstone I that did not end up working. In the end, we were able to improve the design as much as we could, and it ended up exceeding our expectations. This project forced us to use all what we learned in our schooling in order to create a design which was a completely new experience for us, but one that we believe was very important. Using what we learned this semester we believe we have learned most of the tools necessary to succeed in industry once we graduate.

No design is perfect, as engineers are forced to work within physical limits. It's how we deal with these limits and find clever solutions around issues that makes the product closer to what is needed. Our group became far more clever than we were before, as we can understand and pay attention to WHY things are made the way they are. In any product that exists, not a single tiny detail is taken for granted. Everything has a specific purpose and reasoning behind it, and the drive to find these reasons will give us the most ability to grow moving forward.

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Appendices

Assorted multiviews of different parts:

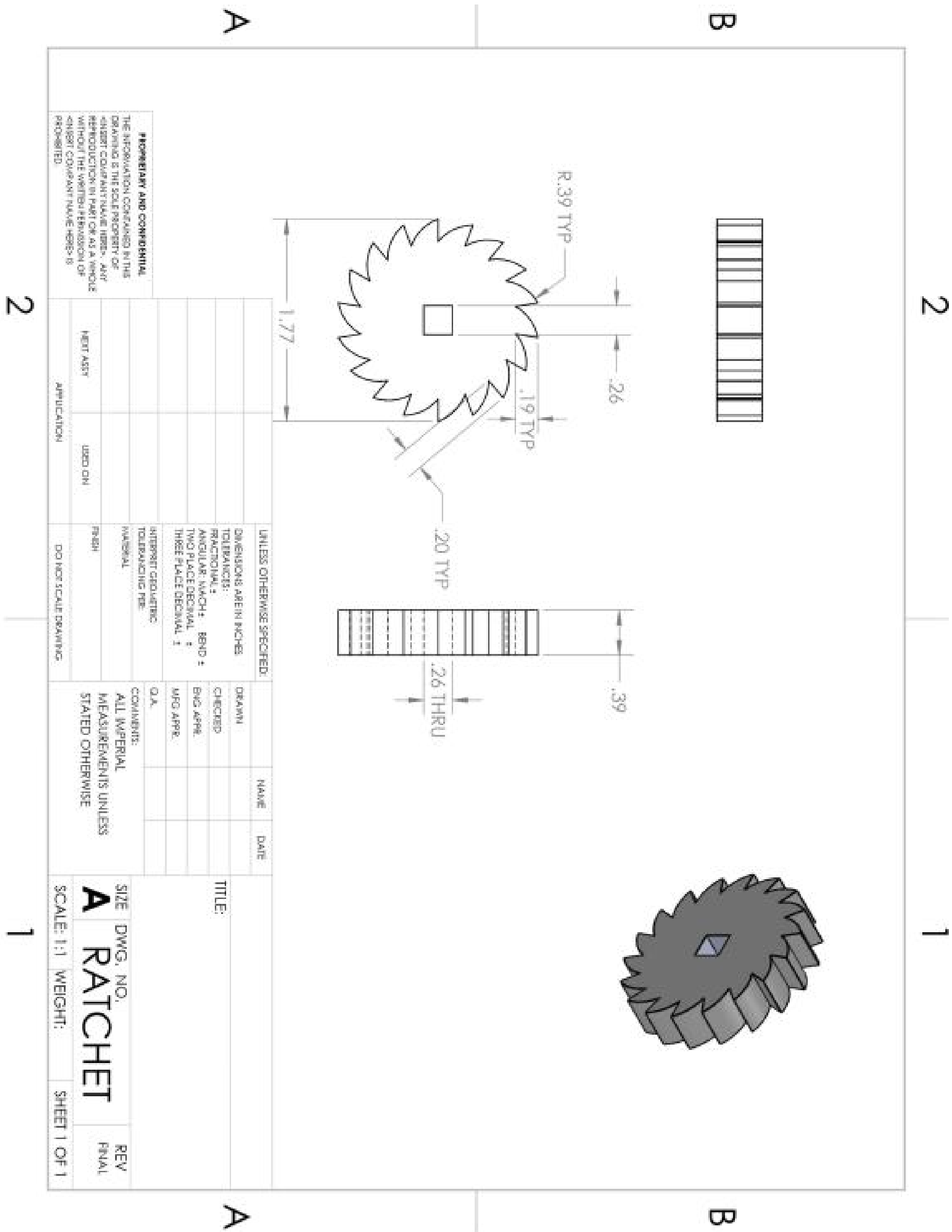

Figure 54.

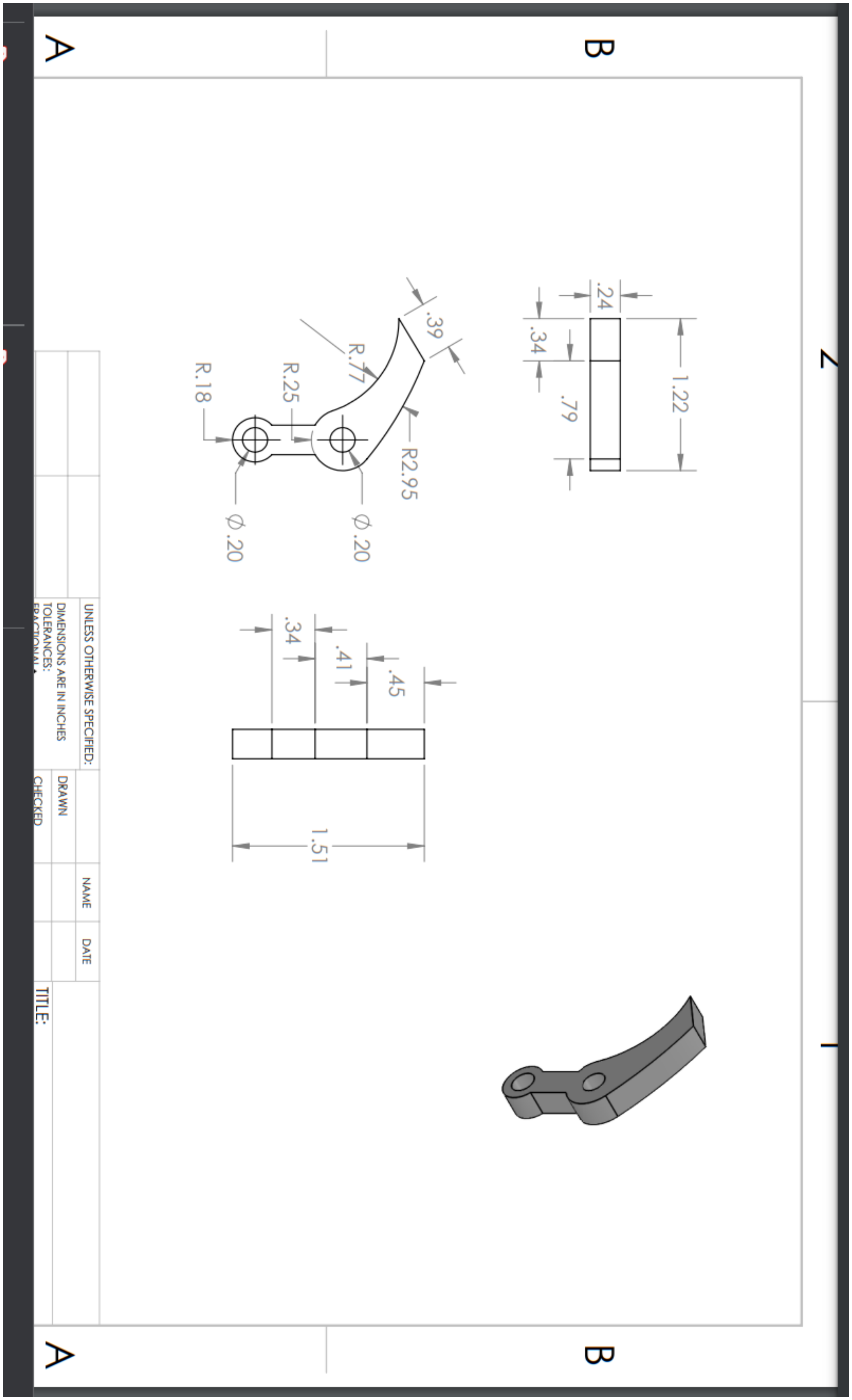

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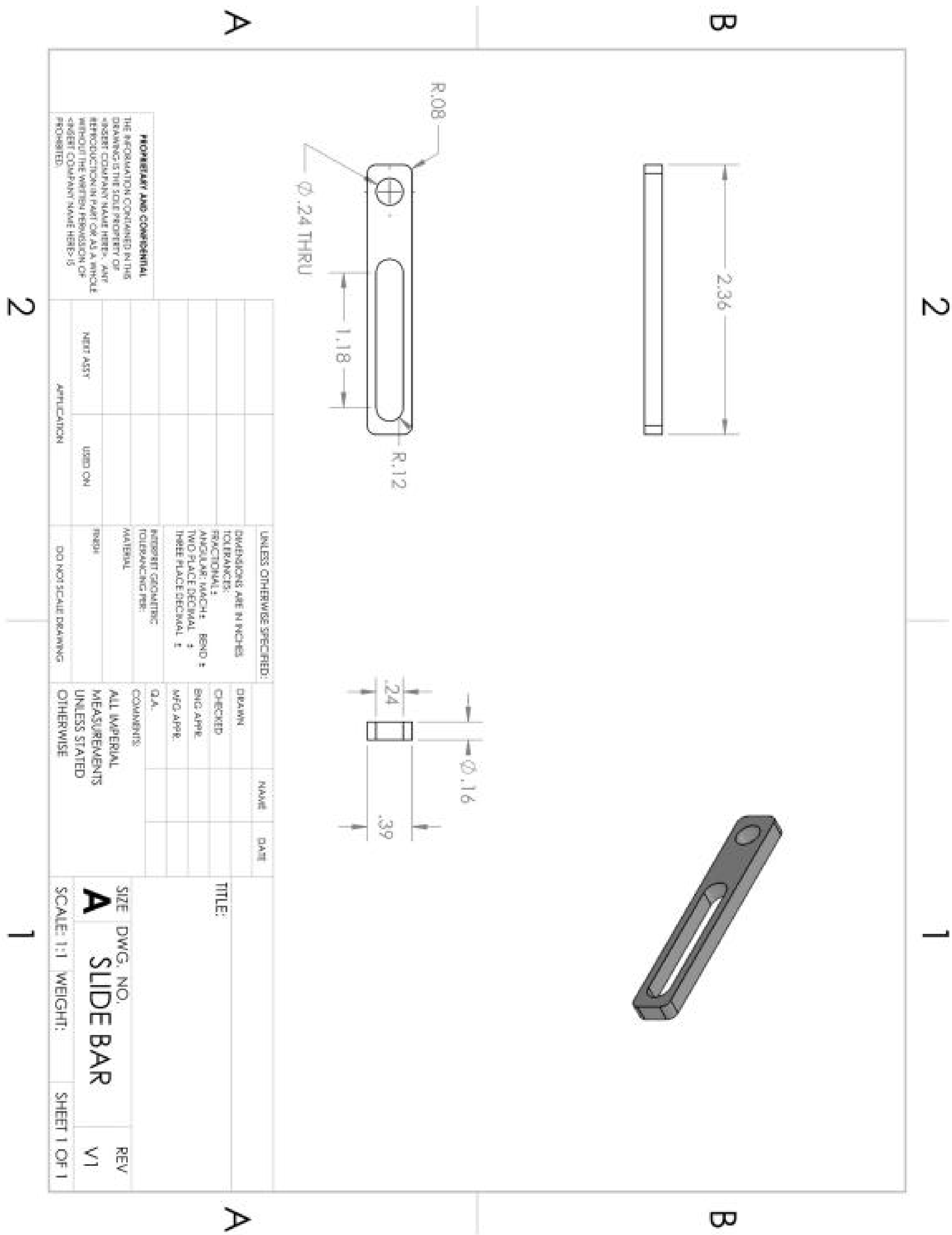
Figure 55.



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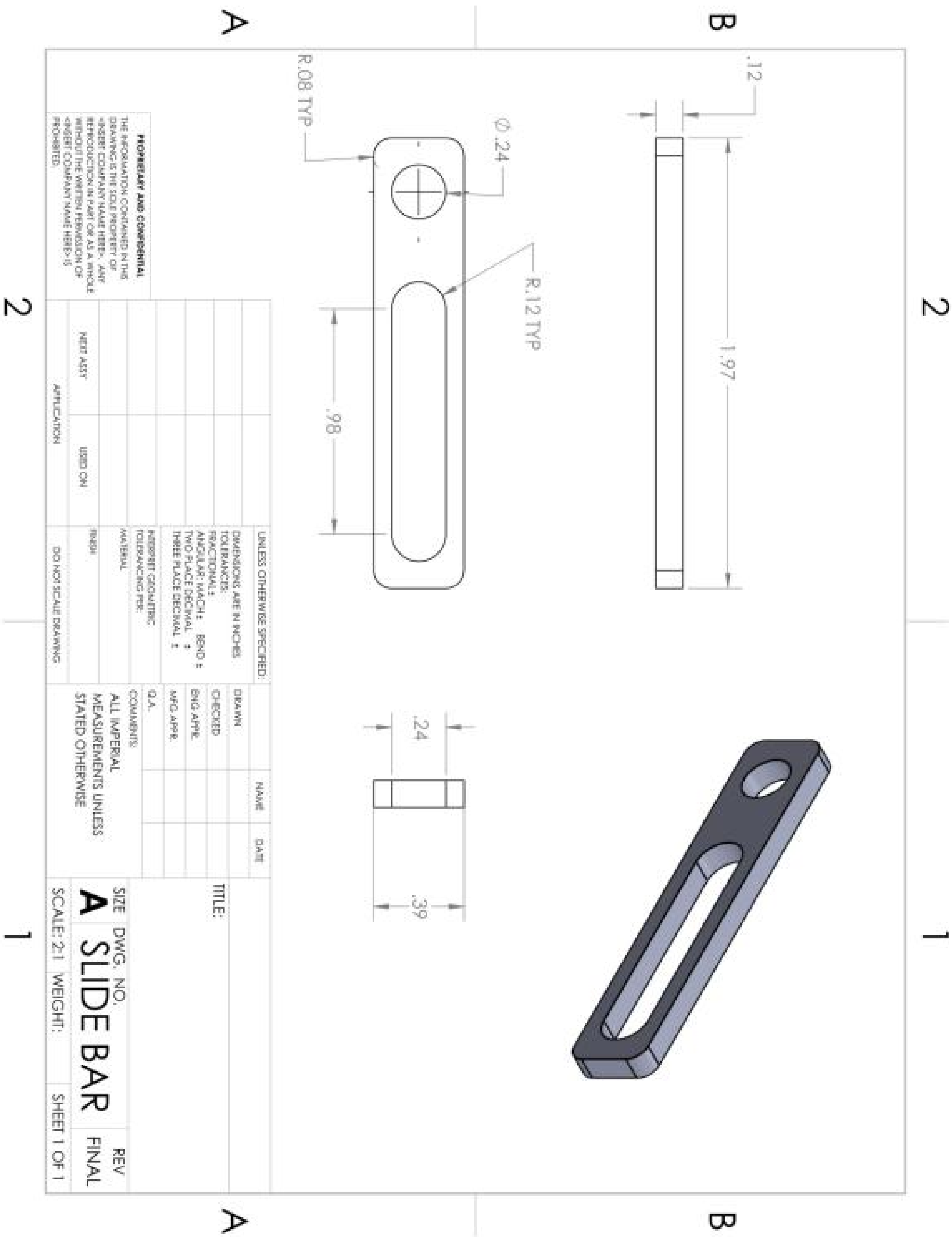
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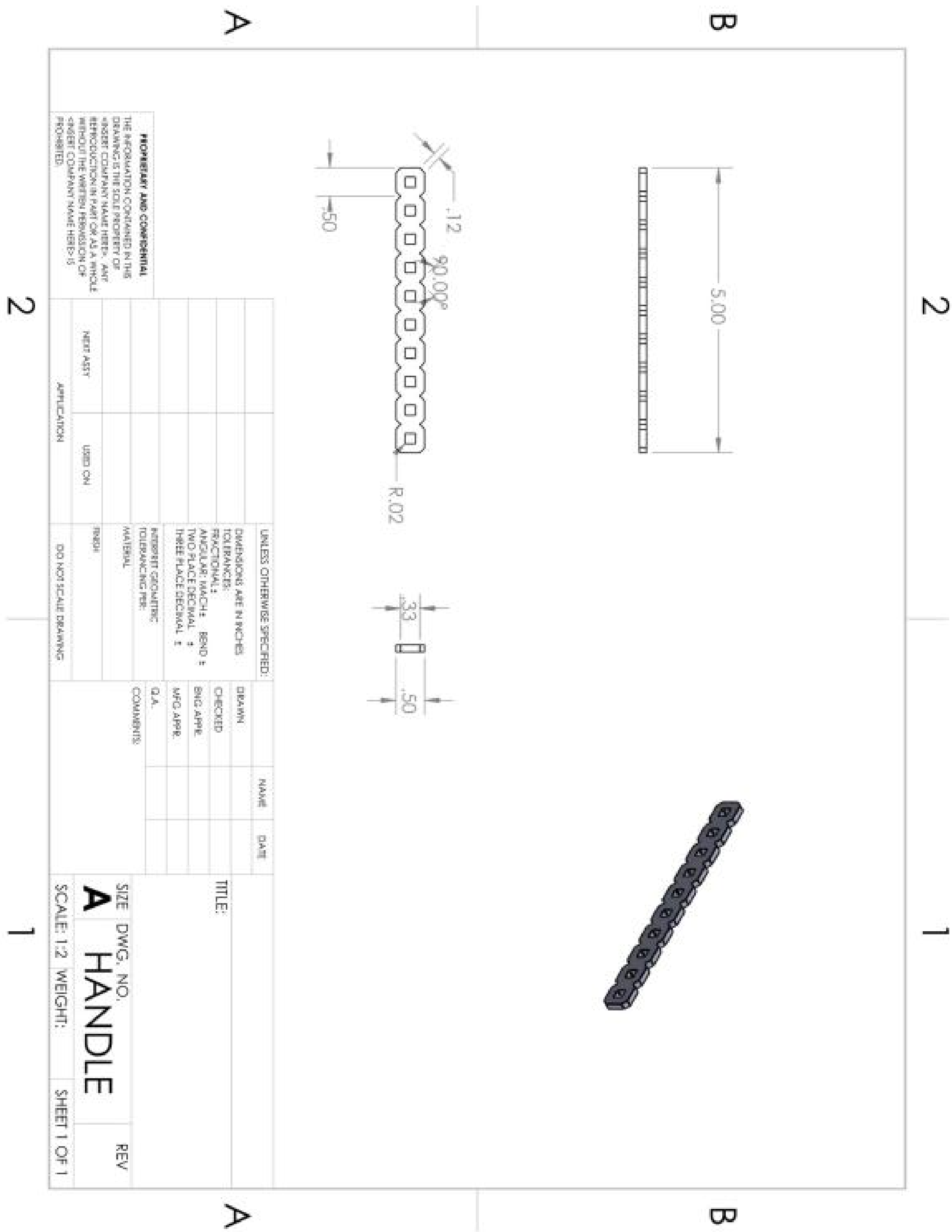

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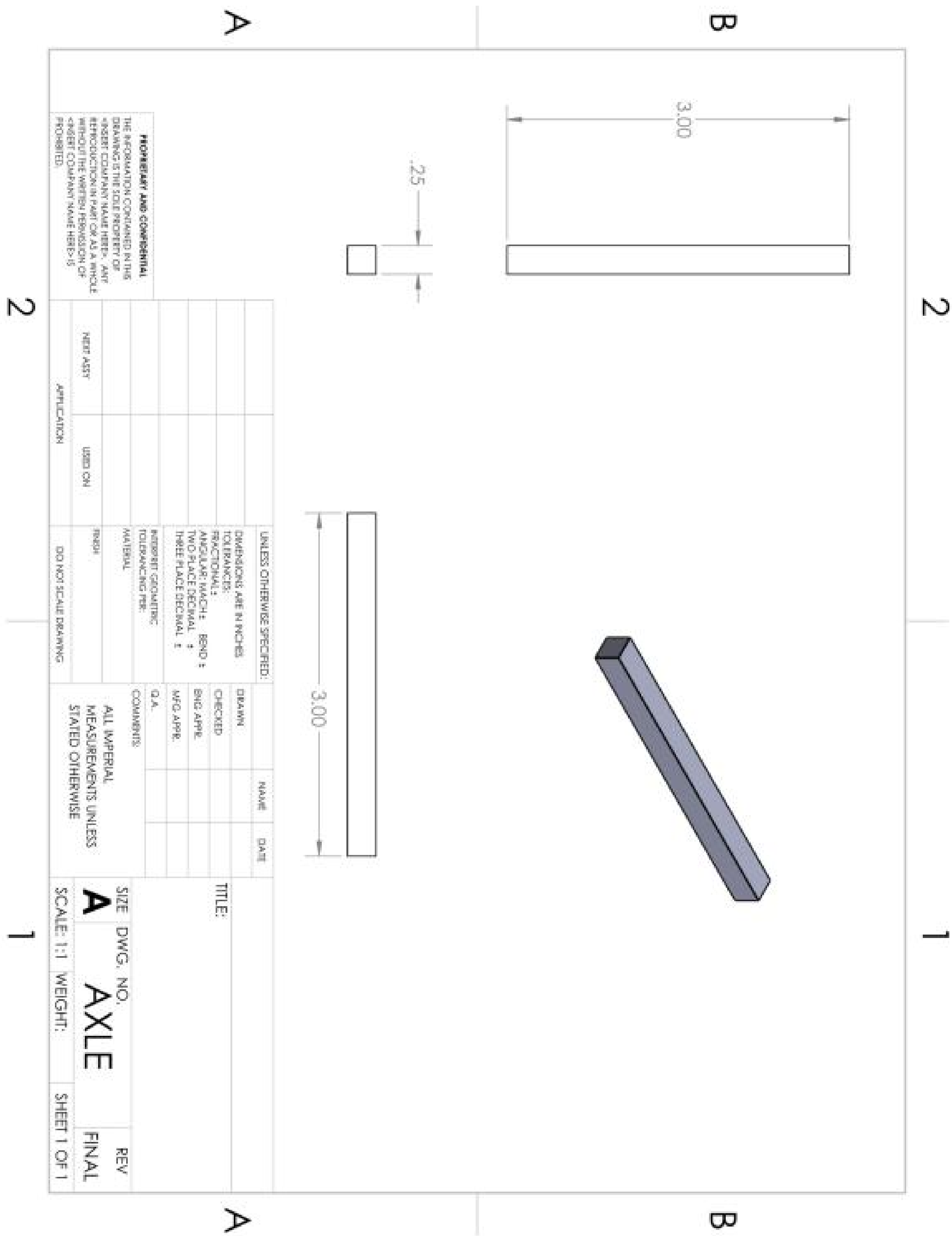
Figure 58.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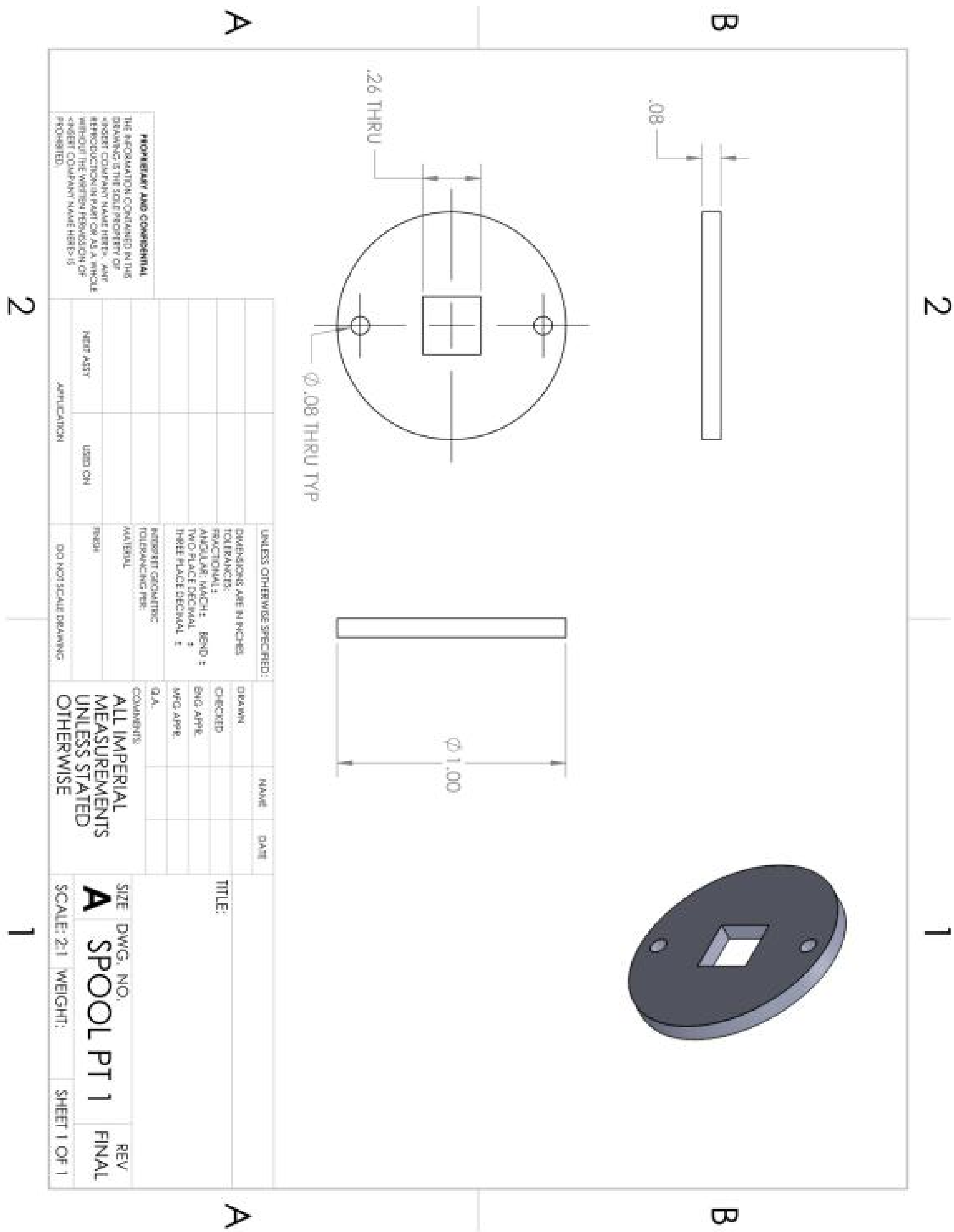
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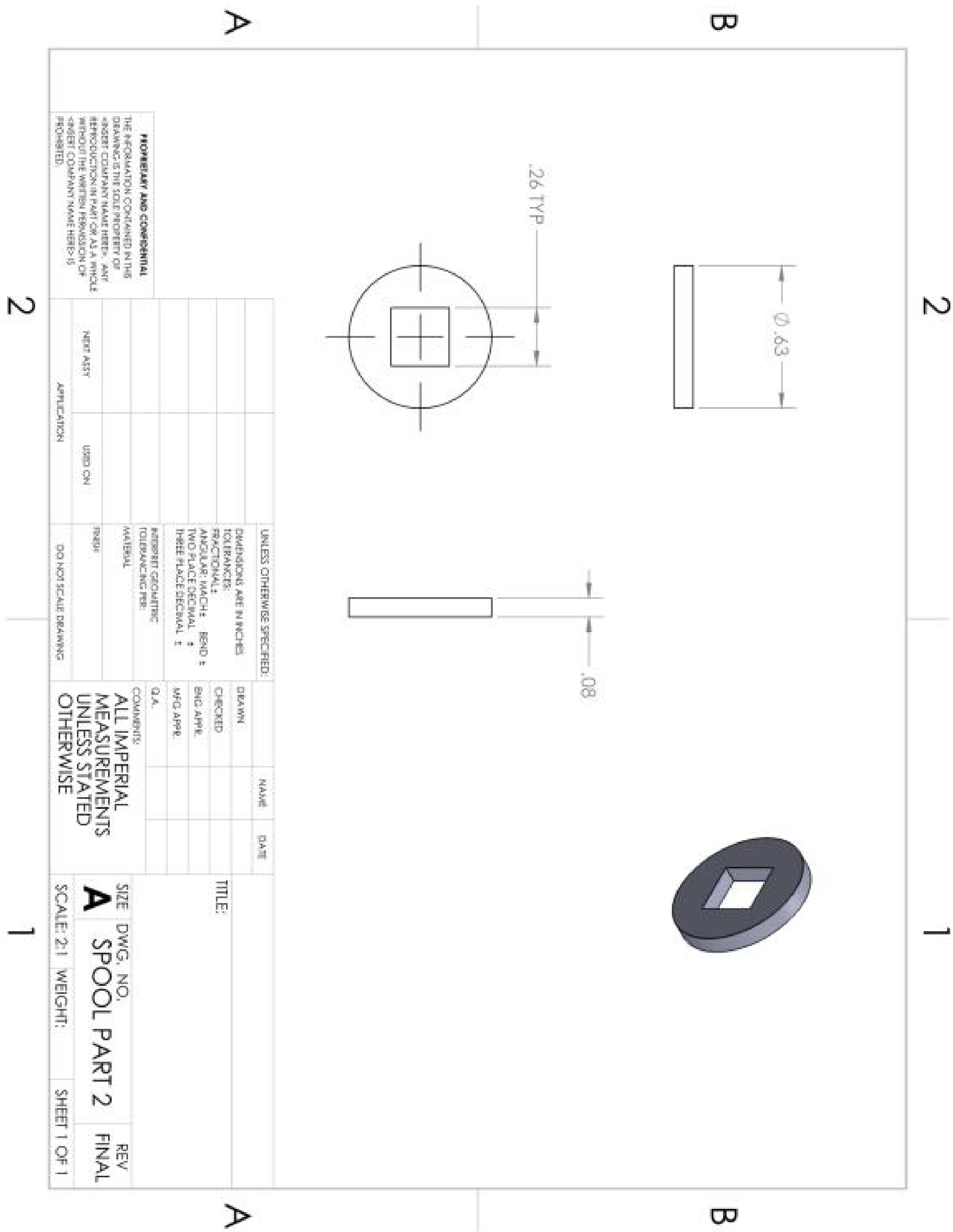
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Figure 61.

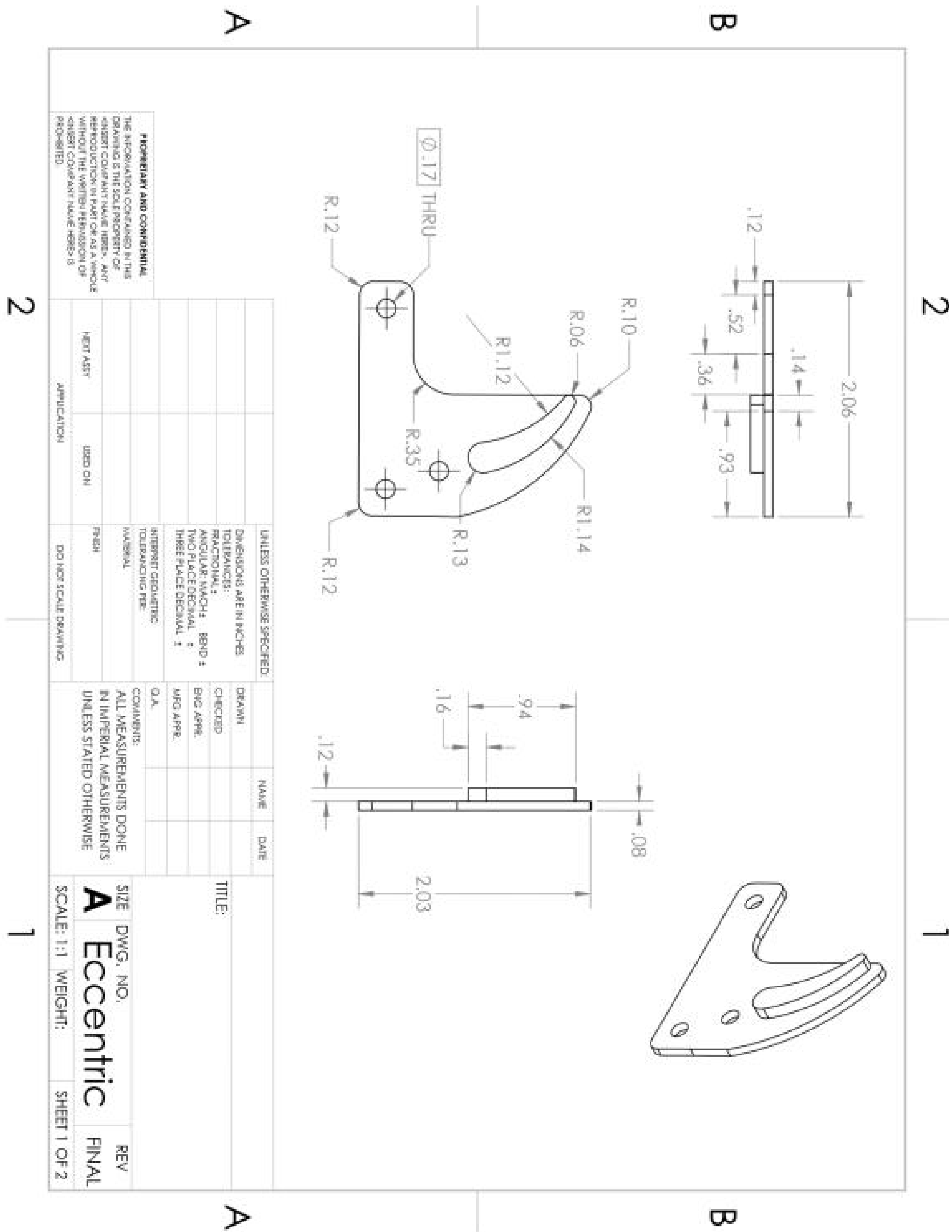
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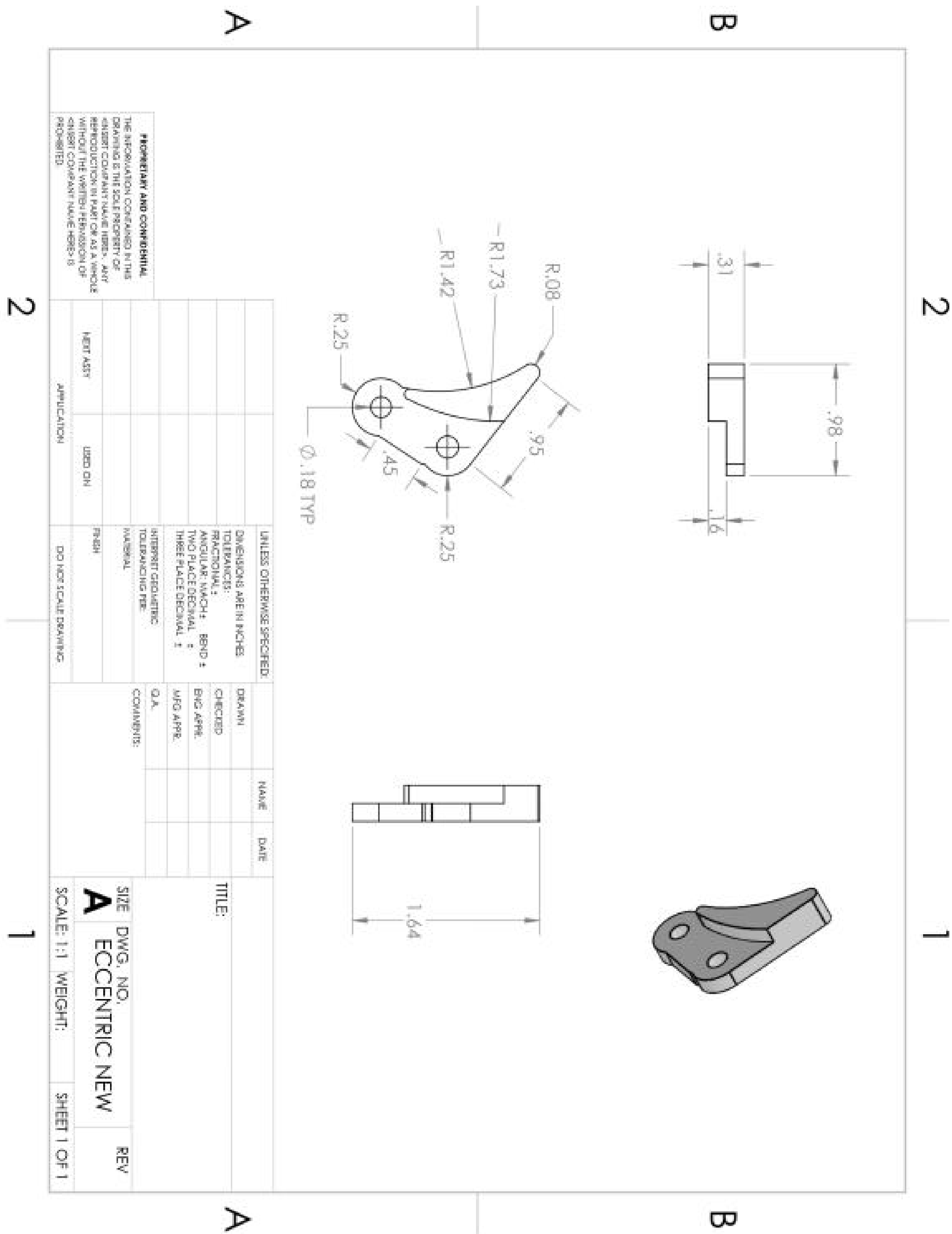
Figure 62.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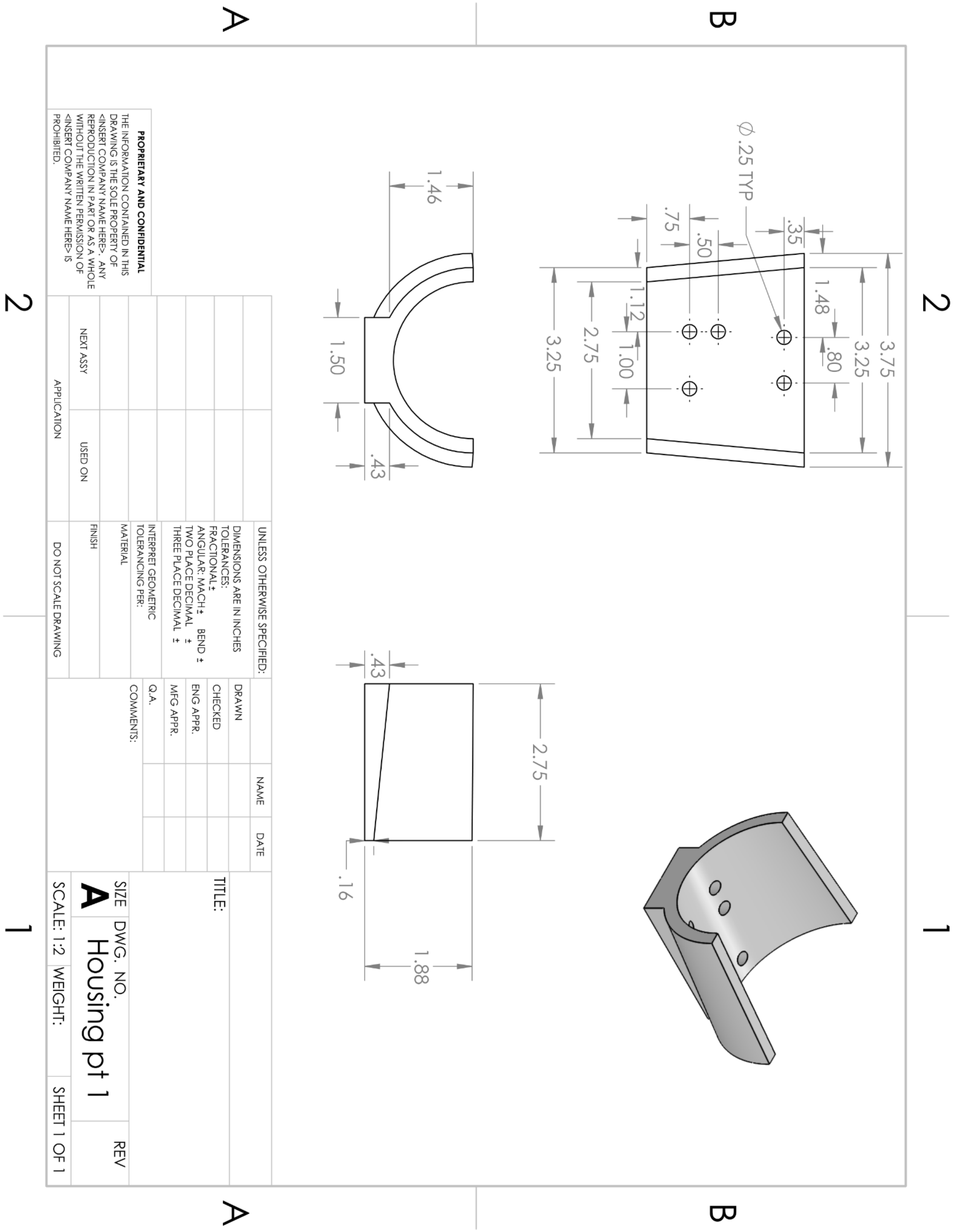

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SHEET 1 OF 1

Figure 64.

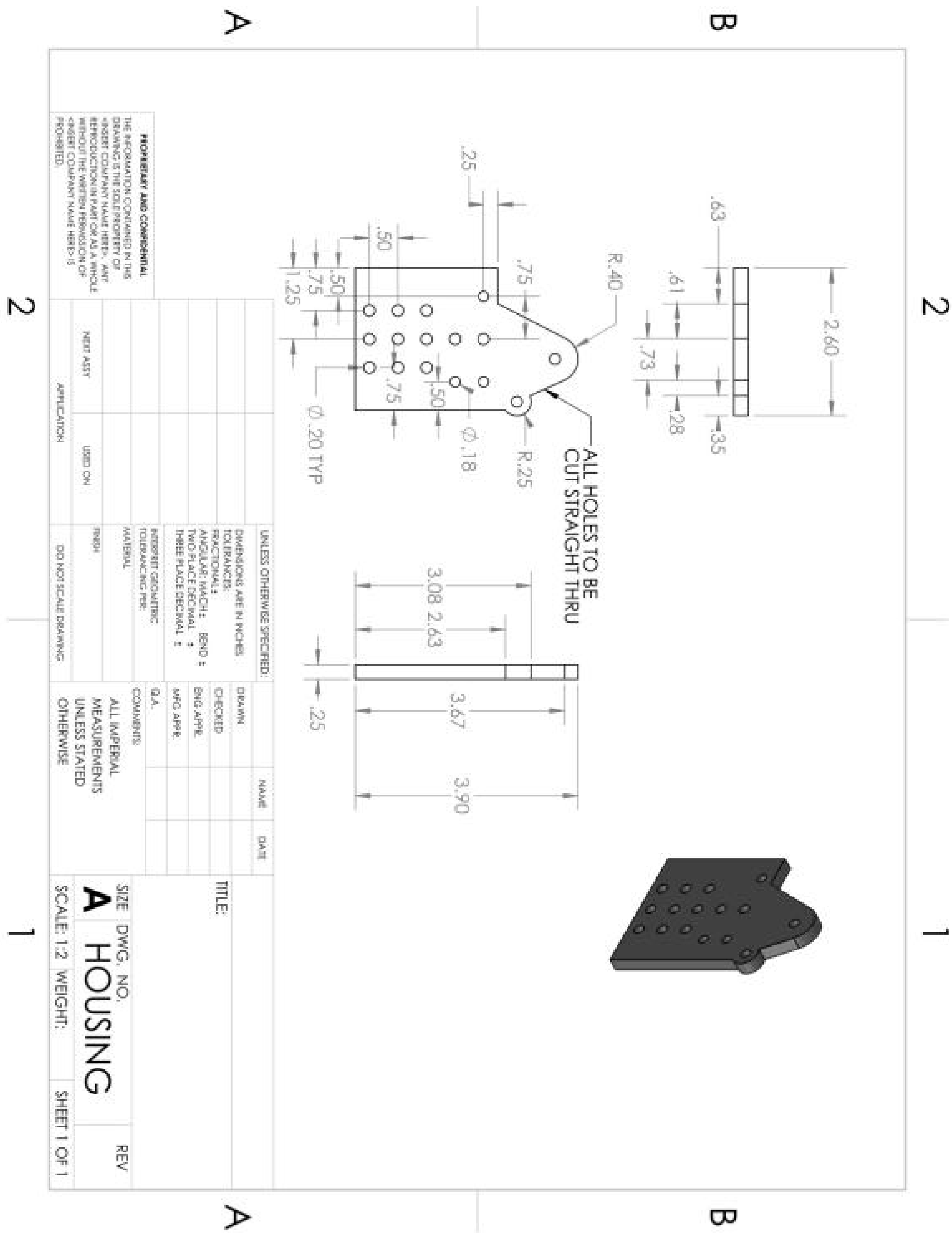

ALL HOLES TO BE
CUT STRAIGHT THRU
R.40
R.25
Ø.18
Ø.20 TYP
2.60
.63
.61
.73
.28
.35
.25
.50
.75
1.25
3.08
2.63
3.67
3.90
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
ALL IMPERIAL MEASUREMENTS UNLESS STATED OTHERWISE
NAME
DATE
TITLE:
SIZE
A
DWG. NO.
HOUSING
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Figure 65.

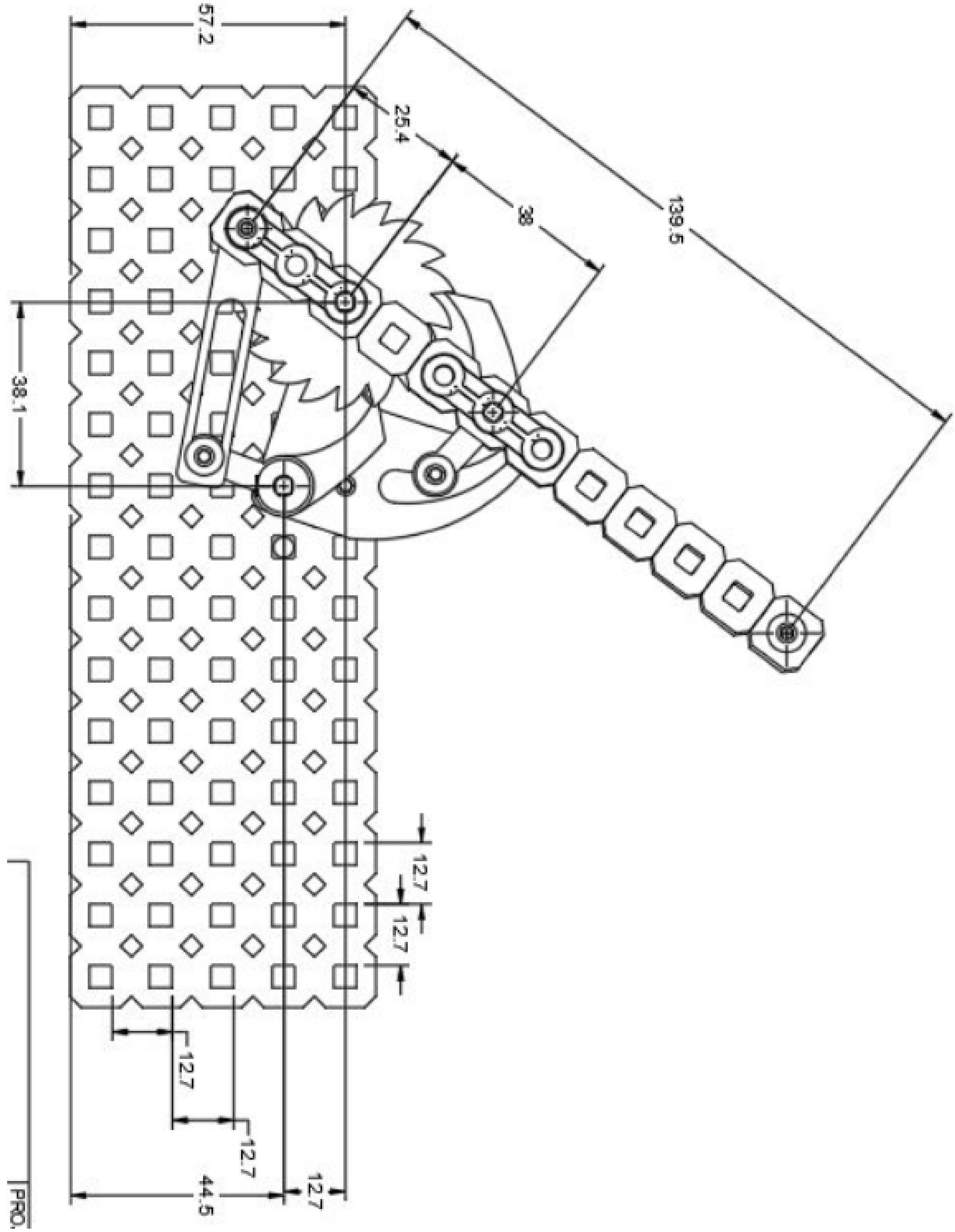


Figure 66.

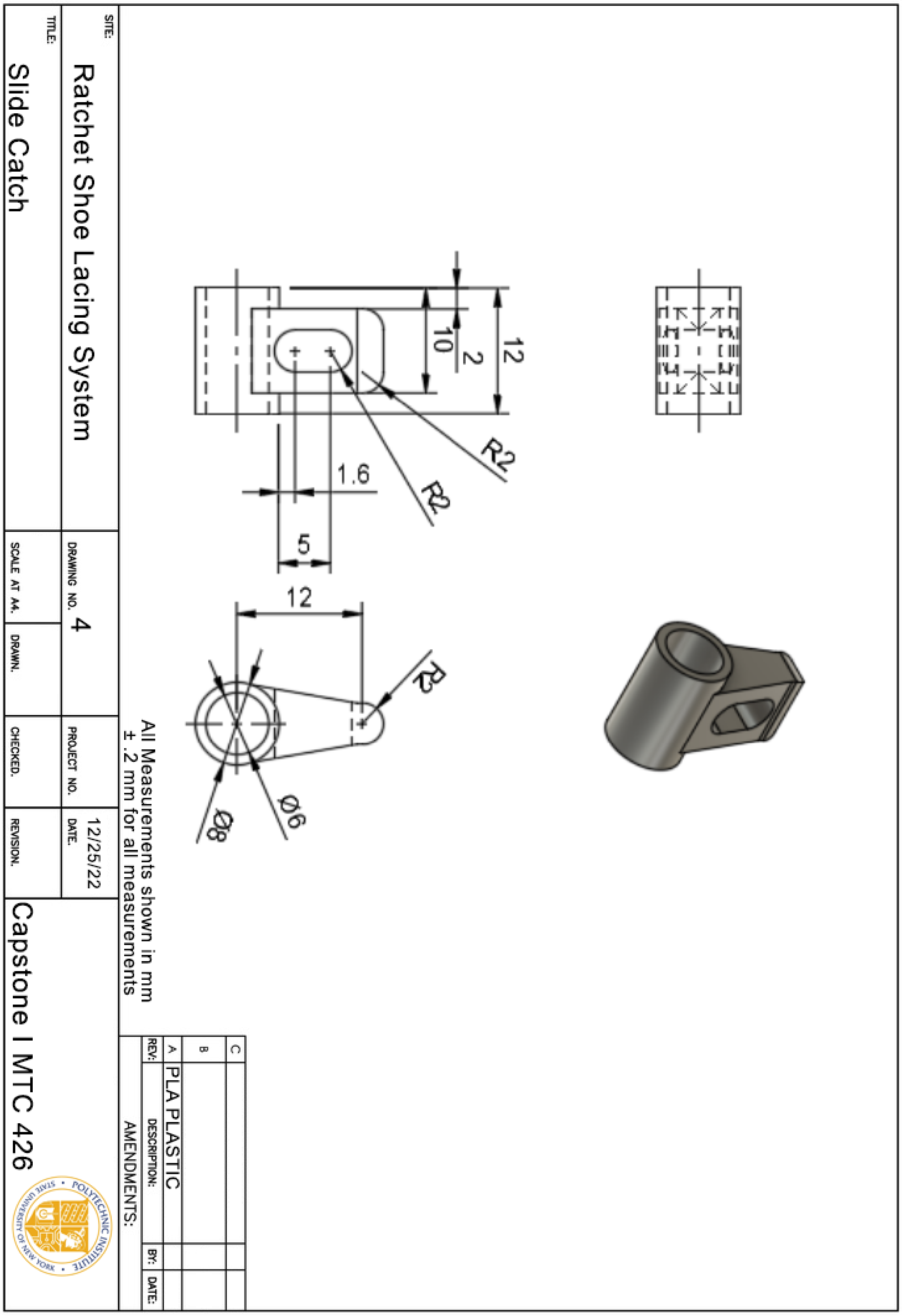

SITE:
Ratchet Shoe Lacing System
TITLE:
Slide Catch
DRAWING NO. 4
SCALE AT A4.
DRAWN.
PROJECT NO.
CHECKED.
DATE.
12/25/22
REVISION.
Capstone I MTC 426
All Measurements shown in mm
± .2 mm for all measurements
REV:
DESCRIPTION:
BY:
DATE:
A
PLA PLASTIC
B
C
AMENDMENTS:
12
2
10
R2
R2
1.6
5
12
R2
Ø6
Ø8

Figure 67.

Calculations & Excel:

Force (N)	A (mm^2)	I (mm^4)	M (N*mm)	Stress (MPa)	Young's Modulus (Pa)	Strain (unitless)
100	650.00	5.42E+03	6.50E+03	6.00E+06	4.11E+09	0.00146
80	650.00	5.42E+03	5.20E+03	4.80E+06	4.11E+09	0.00117
60	650.00	5.42E+03	3.90E+03	3.60E+06	4.11E+09	0.00088
40	650.00	5.42E+03	2.60E+03	2.40E+06	4.11E+09	0.00058
20	650.00	5.42E+03	1.30E+03	1.20E+06	4.11E+09	0.00029
10	650.00	5.42E+03	6.50E+02	6.00E+05	4.11E+09	0.000146
5	650.00	5.42E+03	3.25E+02	3.00E+05	4.11E+09	0.000073

Figure 68.

$$P = \sqrt{\frac{FM}{LSN}} = \sqrt{\frac{35(3952\,N\cdot mm)}{10\,mm(37\,MPa)(18\,teeth)}} = 4.56\,mm$$

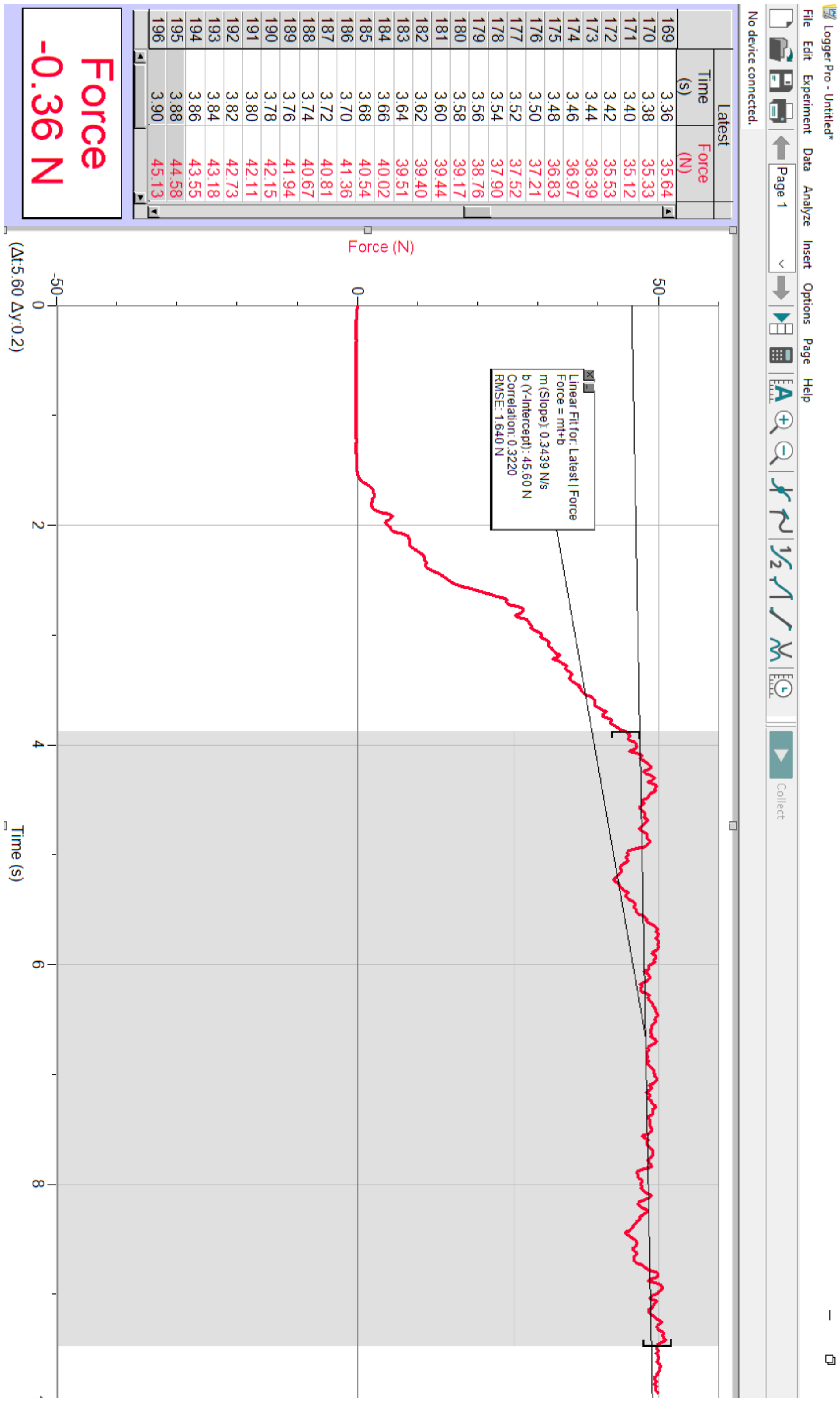
Figure 69.

$$\tau = 0$$

$$(65\,mm\cos 35^\circ)63N - \left(\frac{65\,mm}{2}(\cos 35^\circ)\right)4.4N + F_x \cos 35^\circ = 0$$

$$F_x = 3952\,N\cdot mm = 3.95\,N\cdot m$$

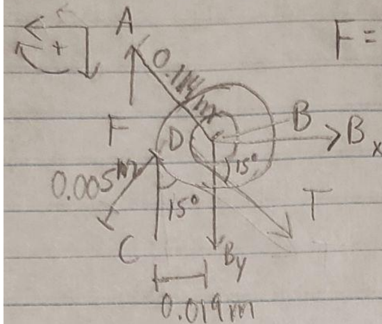
Figure A.



Amount of strain vs amount of force applied

Figure 70.

Crank FBD:



F = 20 N   Moment @ center of radius:

$$\Sigma M_B = 0$$

$$F(D) = T(D)$$

$$20N(0.114\,m) = T(0.03\,m)$$

$$T = 76\ N$$

Moment @ pin of pawl:

$$\Sigma M_C = 0$$

$$76N(0.03\,m) + (20N)0.114\,m = F_{CD}\cos 15°(0.019\,m)$$

$$F_{CD} = 248.5\ N$$

$$\Sigma F_x = 0$$

$$B_x + 76\cos 15° + 90N\cos 90° = 248.5N\cos 15°$$

$$B_x = 166.6\ N$$

$$\Sigma F_y = 0$$

$$C_y = 248.5N\sin 15° + 76N\sin 15° + 90\sin 90°$$

$$C_y = 174.0\ N$$

Net Reaction at B: $B = \sqrt{(174.0)^2 + (166.6)^2}$

$$B = 240.9\ N$$

Figure 71.

Time sheet:

CAPSTONE 1

	Ricky		Craig		Jeremy	
Week	activity	hours	week	hours	week	hours
9/22	Formal Proposal	2	9/22	2	9/22	2
9/29	research	2	9/29	1	9/29	2
10/6	research	4	10/6	2	10/6	3
10/13	conceptual modeling	1	10/13	4	10/13	1
10/20	midway presentation	3	10/20	3	10/20	3
10/27	design adjustment	2	10/27	2	10/27	2
11/3	final presentation	3	11/3	3	11/3	3
11/10	final report/ presentation	2.5	11/10	2.5	11/10	2.5
11/17	final report/ presentation	5	11/17	5	11/17	5
11/22	final report/ presentation	5	11/22	5	11/22	5
12/1	final report/ presentation	5	12/1	5	12/1	5

Figure 72.

Capstone 2

	Ricky		Craig		Jeremy	
Week	activity	hours	week	hours	week	hours
1/16	Brain Storming	2	1/16	2	1/16	2
1/23	Manufacturing Plan	2	1/23	1	1/23	2
1/30	Manufacturing Plan	4	1/30	2	1/30	3
2/6	Manufacturing Plan	1	2/6	4	2/6	1
2/13	Manufacturing Plan	3	2/13	3	2/13	3
2/20	Manufacturing Device	2	2/20	2	2/20	2
2/27	Manufacturing Device	3	2/27	3	2/27	3
3/6	MID PRESENTATION	2.5	3/6	2.5	3/6	2.5
3/13	SPRING BREAK	0	3/13	0	3/13	0
3/20	Validation Test Design	5	3/20	5	3/20	5
3/27	Validation Test Design	5	3/27	5	3/27	5
4/3	Validation Testing	3	4/3	3	4/3	3
4/10	Validation Testing / Presentation	4	4/10	4	4/10	4
4/17	Presentation/Final Report	5	4/17	5	4/17	5
4/24	Final Report	5	4/24	5	4/24	5

Figure 73.

Miscellaneous tools/ parts:

To clean scaffolding off of the 3-d prints and adjust them as needed, we utilized small files, hand tools, and sandpaper. Below is an example of some of the hand tools you would need to replicate this process. We also utilized rubber bands to create tension in both pawls to keep them in position. To alter parts that we manufactured, we used the belt sander and drill press.

Figure 74.

For measuring several dimensions and tolerances of Vex components such as the square axel we later utilize, we used a digital dial caliper.

Figure 75.

Various Vex Robotics components:

In order to make the housing for the prototype, we heavily utilized Vex robotics components. This aided us in being able to change the entire layout of components in short amounts of time.

For research, we utilized google scholar to find scholarly sources on subjects that we needed an in-depth look at for the design. This and SUNY Polytechnic's database was what we utilized

Below is a list of the parts used for the final 3d model.

	RATCHET MECHANISM INITIAL PROTOTYPE BOM Virtual Model		
Part No.	Component	VEX KIT/Custom	QTY
1	276-2010-000 Shaft Collar	VEX	6
2	276-2179-001 0.25 in pitch bearing flat	VEX	6
3	1/4 in square shaft 4 in	VEX	2
4	1/4 in square shaft 2 in	VEX	1
5	275-2023-001 Plate 15x5	VEX	1
6	0.5 in OC bar 12 holes	VEX	2
7	275-1016-001 8-32 1.0 in standoff	VEX	1
8	276-1004-001 8-32 0.5 in standoff	VEX	1
9	276-1011-001 8-32 1.75 in screw	VEX	1
10	276-1010-001 8-32 1.5 in screw	VEX	1
11	276-1009-001 8-32 1.25 in screw	VEX	1
12	276-1004-001 8-32 0.5 in screw	VEX	1
13	276-1002-001 8-32 0.25 in screw	VEX	2
14	RATCHET	Custom	1
15	PAWL	Custom	2
16	LWR_SLIDE	Custom	2
17	DRIVE_RELEASE_Bracket	Custom	1

Figure 76.
List of components used in prototype

Milestone Chart:

Capstone 1

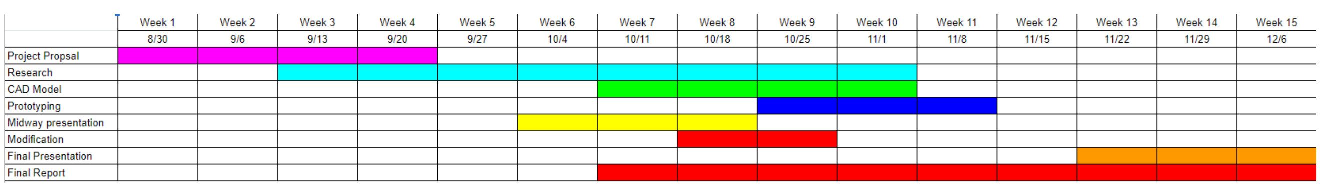


Figure 77.

Capstone 2

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Team 3															
	17 - Jan	24 - Jan	31 - Jan	7 - Feb	14 - Feb	21 - Feb	28 - Feb	7 - Mar	14 - Mar	21 - Mar	28 - Mar	4 - Apr	11 - Apr	18 - Apr	25 - Apr
			Shop Schedule	Manufacturing Process		Manufactured Product	Validation Test Design		Spring Break	Validation Test Report		Presentation	Presentation		Final Report / Teamwork
Deliverables															
1. Shop Scheduale															
2. Manufacturing Process Plan															
3. Prototype Manufacturing Report															
4. Validation Test Design															
5. Validation Test Report															
6. Presentation Slide															
7. Final Report Rewrite															
8. Teamwork Assessment															

Figure 78.

Milestone Chart used throughout semester

Additional free body diagrams and design diagrams:

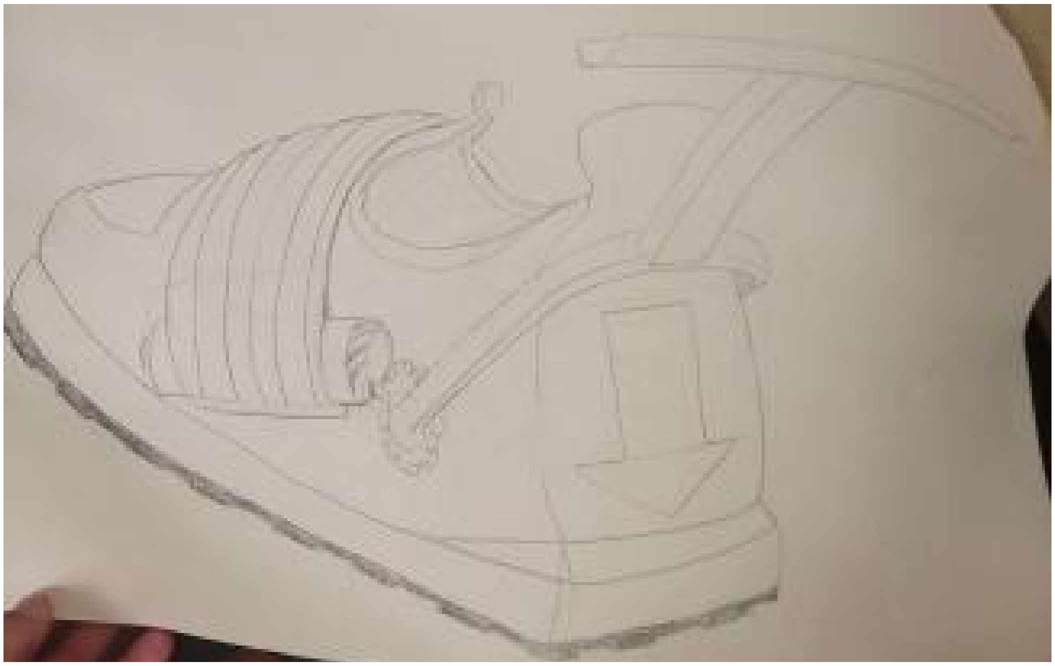


Figure 79.

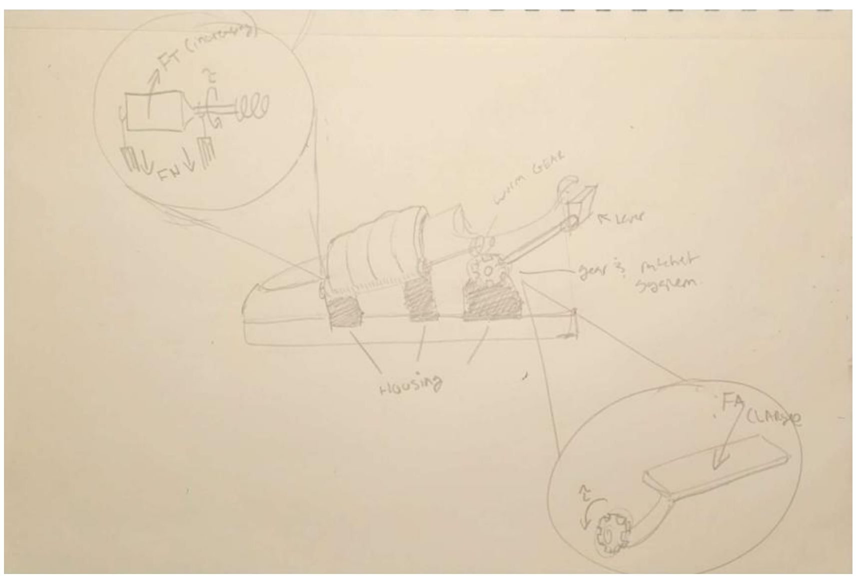
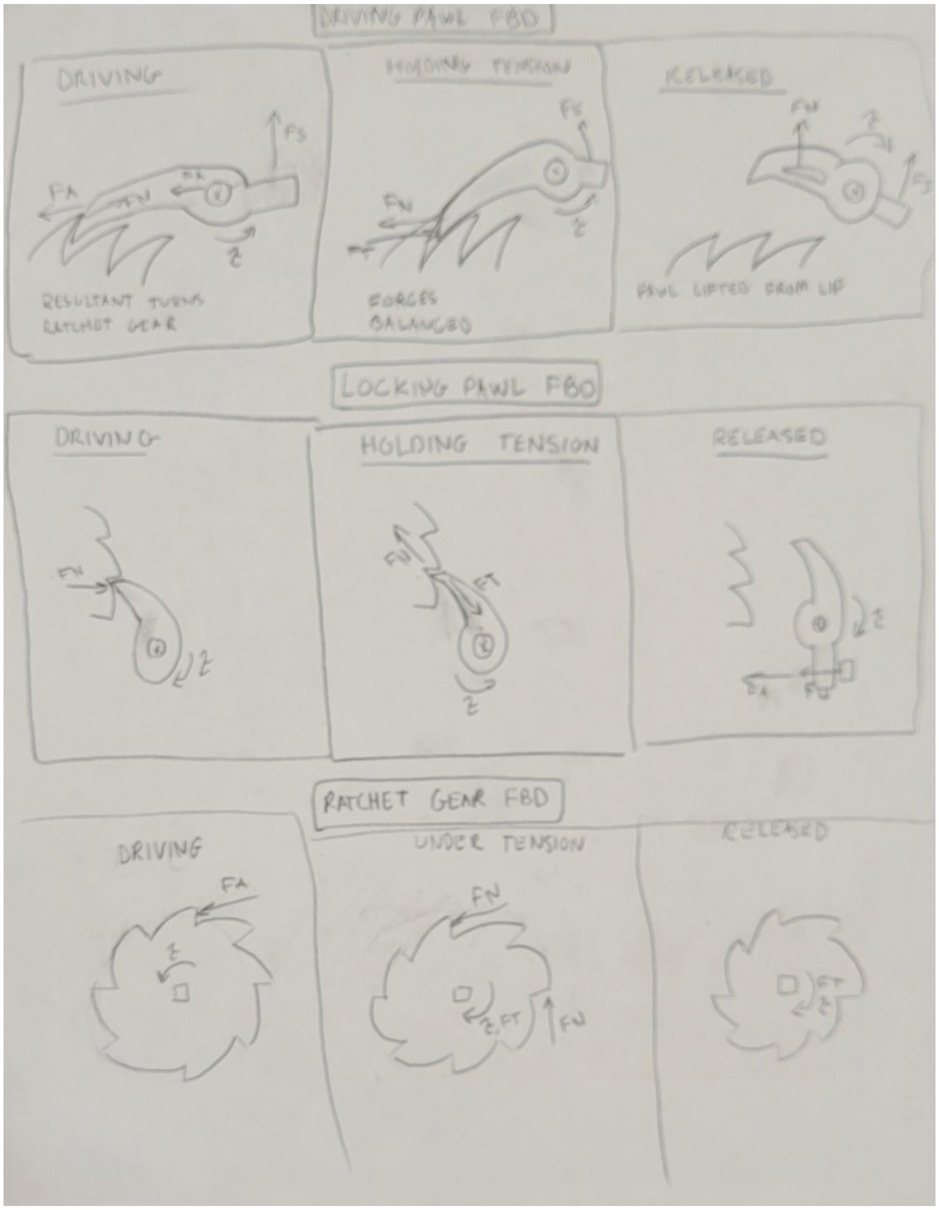


Figure 80.



Free body diagrams different forces in different positions

Figure 81.

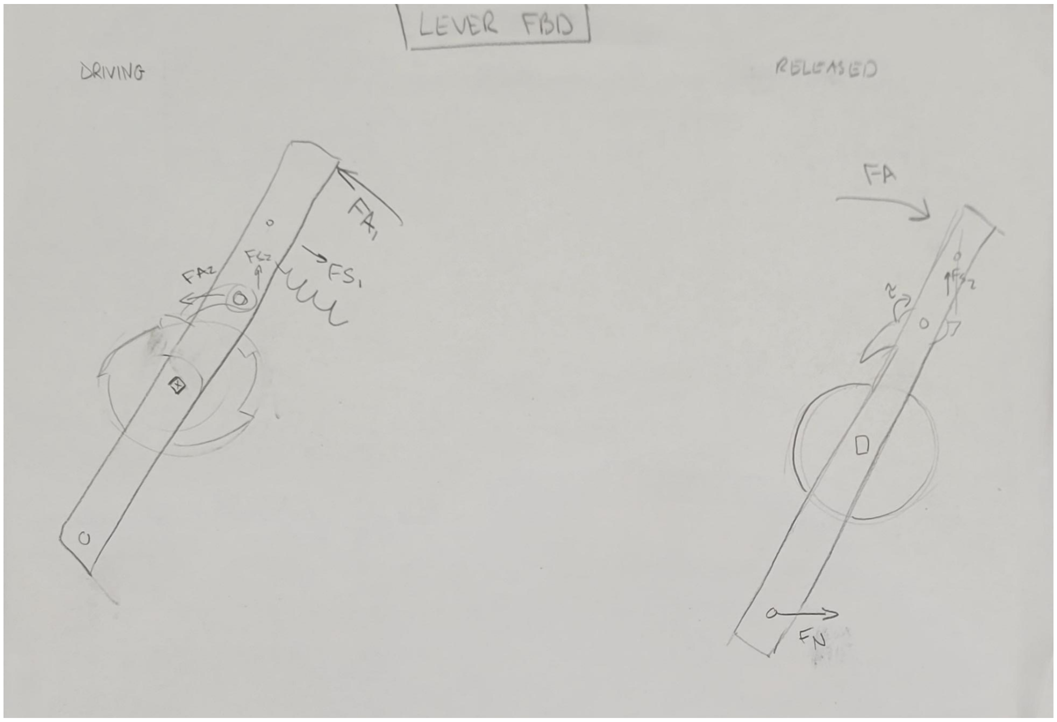


Figure A.
Free body diagrams of forces acting on the lever

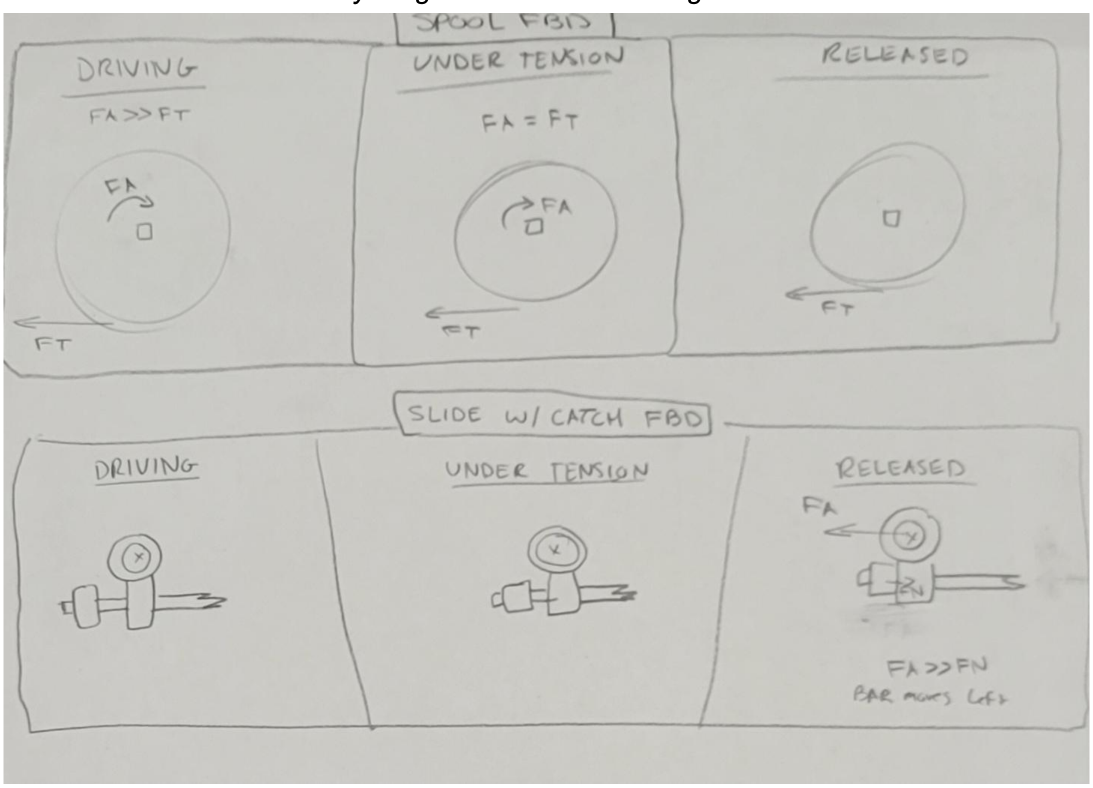
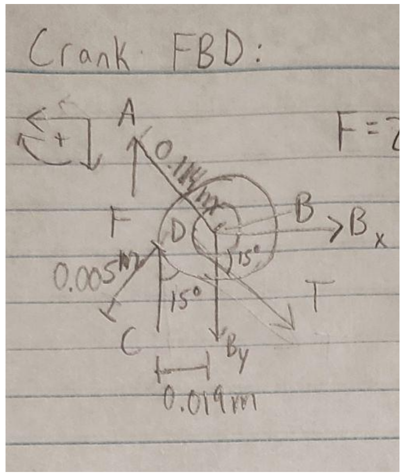


Figure 82.
Free body diagram of forces acting on spool and slide w/ catch



Forces and moments on crank and center pin

Figure 83.

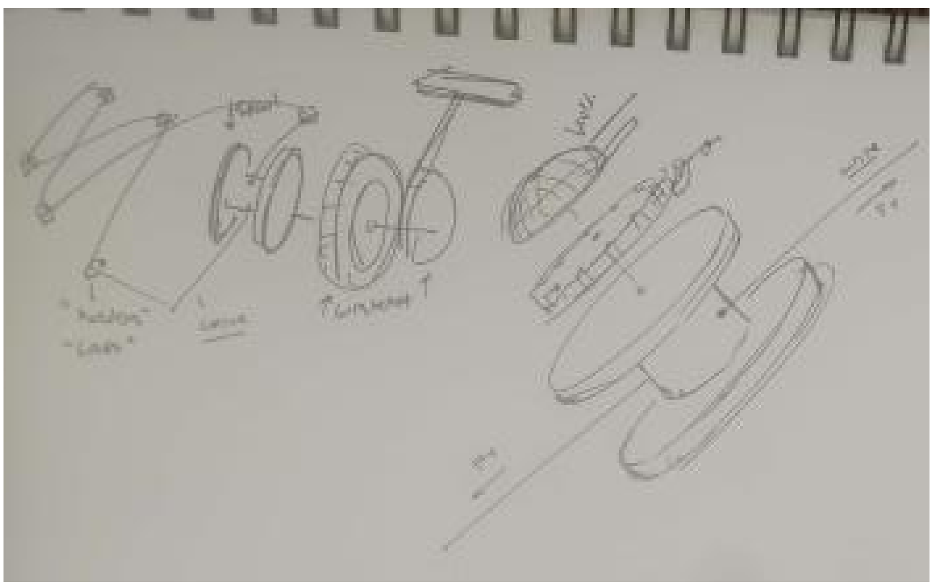


Figure 84.

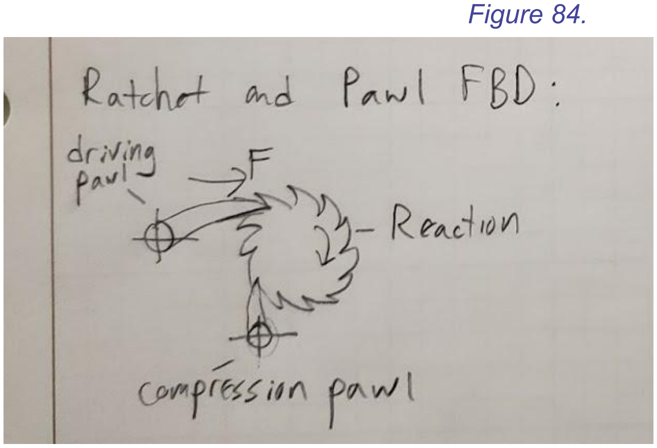
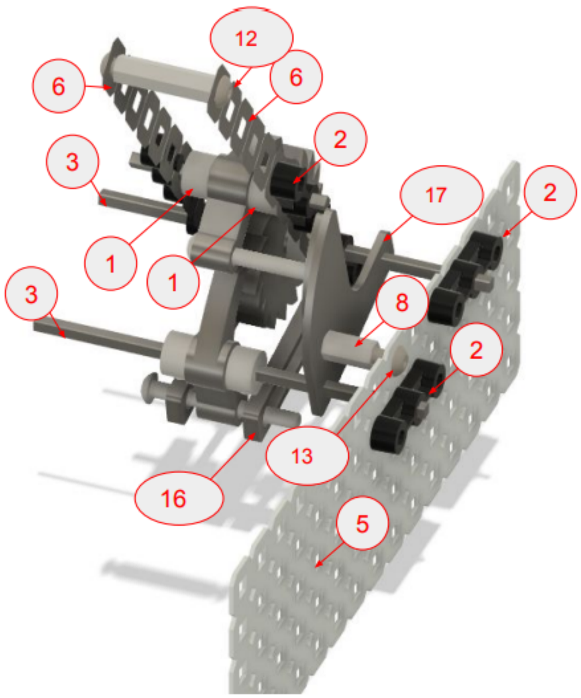


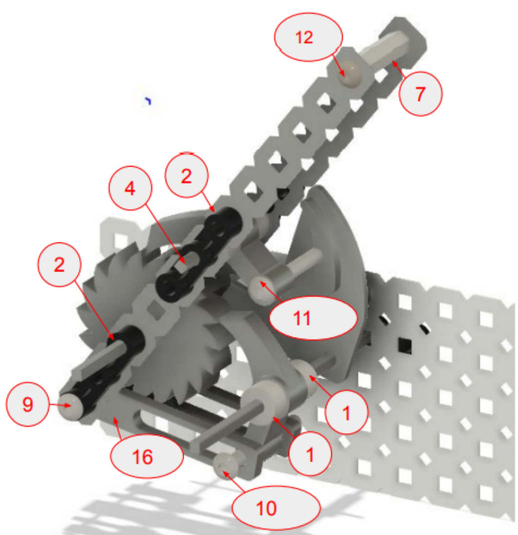
Figure 85.

Diagram labeling all parts on latest prototype:



1 - Shaft collar
2 - 0.25 in Bearing
3 - ¼ in square 4 in shaft
5 - 15x5 plate
6 - 0.5 in OC 12 hole bar
8 - 0.5 in standoff
12 - 0.5 in 8/32 screw
13 - 0.25 in 8/32 screw
16 - LWR-SLIDE
17 - Drive release bracket

Figure 86. *Model with labeled components*

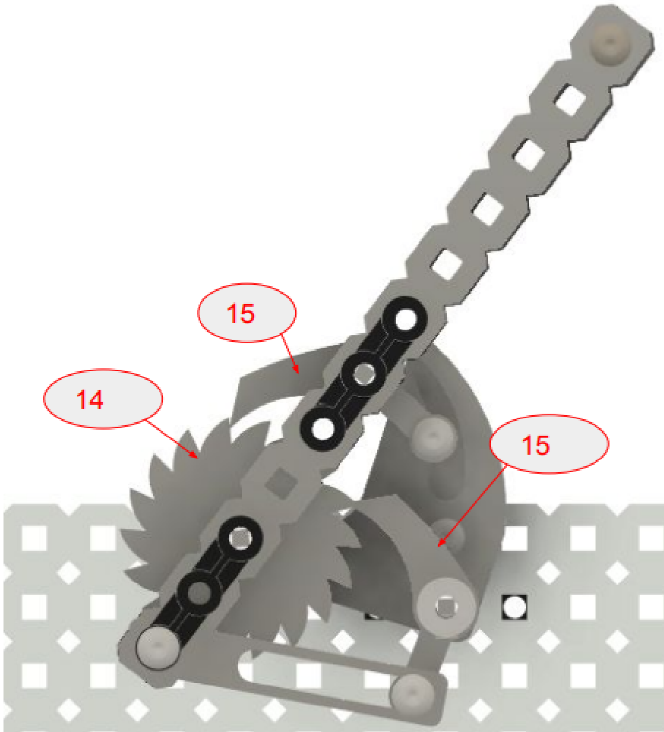


1 - Shaft Collar
2 - 0.25 in bearing
4 - ¼ in square shaft 4 in
7- 1 in standoff
9 - 1.75 in 8/32 screw
10 - 1.5 in 8/32 screw
11 - 1.25 in 8/32 screw
12 - 0.5 in 8/32 screw
16 - LWR-SLIDE

Pt. 1 Model

Figure 87.

with labeled components Pt. 2



14 - Ratchet
15 - Pawl

Figure 88.
Model with labeled components Pt. 3