Final Report
Product Development

"Car Powered by Rubberbands, SolidWorks, Sweat, and Tears[1]"

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[1]Of Lux Lab Workers

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1 Abstract

Computer-aided design has the ability to turn an idea into something more. In the class MAE 94, we are going to learn how to use CAD and apply it to a real project. This project will be to make a 3D-printed rubber-band powered car, completely from scratch. With the assistance of SolidWorks, the car will be designed, optimized, and then manufactured.

2 Lists

2.1 List of Figures

2.2 List of Tables

2.3 List of Symbols

Symbol	Description	Unit (SI)
F	Force	N
k	Spring Constant	$\frac{\text{N}}{\text{m}}$
a	Acceleration	$\frac{\text{m}}{\text{s}^2}$
L	Length of Car	m
H	Height of Car	m
W	Width of Car	m
U	Potential Energy	J
r	Radius	m
x	Length	m
$\vec{p}$	Momentum	$\text{N} \cdot \text{s}$
$\vec{v}$	Velocity	$\frac{\text{m}}{\text{s}}$
m	Mass	kg

3 Introduction

The Fall 2018 UCLA Mechanical and Aerospace (MAE) 94 class was tasked with constructing a rubber-band powered device. This project was meant to encompass all the processes that we learn in the class into a tangible application.

The class revolves around computer-aided design, and the program of our choosing was SolidWorks, a powerful parametric modeling software capable of making models, assemblies, and even simulations.

Before we were allowed to dive straight into CAD, we had to learn to appreciate it by seeing what people had to do by hand in the old days, starting from da Vinci's engineering drawings. We spent a few weeks learning about the standard practices and procedures associated with today's engineering drawings.

After learning the nicks and nacks of SolidWorks, we learned about additive manufacturing and how to optimize parts for 3D printing.

From the 5^{th} week onwards, we had most of the tools we needed to start planning out the vehicle. We then did tests with the rubber bands to find its spring constant and related forces.

With a better idea of what forces our cars will be experiencing, we learned how to use Finite Element Analysis to optimize the geometry and components of the vehicle.

Along with a quick but important tangent on sustainability, we spent the final couple weeks flushing out a design, and then bombarded LuxLab to have them 3D print our parts for assembly. During the last day of class, we put our design to the test.

4 Design Requirements

For this class, there are design requirements for the vehicle that limit the size and allowable materials.

These are the design requirements: [1]

1. Must traverse a flat distance of 2 feet
2. Constructed entirely out of ABS or PLA
3. Max dimensions are $.1 \times .1 \times .2\text{m}^3$
4. Only source of power are rubber bands, which can be manipulated in any way
5. Maximum of 4 rubber bands
6. No separate external features or supports
7. Entire device, including rubber bands, have to be transported
8. No auxiliary parts like pins, fasteners, clamps, screws
9. All adhesives except for tapes allowed
10. Cosmetic features allowed
11. All parts must be fabricated using UCLA Lux Lab

5 Prior Work

While I was researching rubber-band powered cars, I found quite a couple vehicles on YouTube [2][3] that were all propeller powered. I found these designs to be pretty enticing because it reminds me of airplanes.

On the lecture slides [1], there were a few examples of cars that were powered using a windup method. This works by using the rubber bands to wind up an axle and allowing the resulting unraveling to propel the vehicle. While extremely practical, I found these designs uninteresting.

In lecture, we also looked at examples of vehicles from the previous years competitions. Some memorable vehicles included a car that had the ability to go backwards and a wheel.

6 Concept Development

6.1 Concept 1

The first concept aims to use a pair of rubber-band powered propellers to move the vehicle. It will feature four wheels, with the back wheels being placed at a wider distance from each other for added support. Additionally, the vehicle intends to have a sleek aerodynamic design to increase its mileage as well as a unicorn horn to maximize the distance traveled by making the vehicle longer.

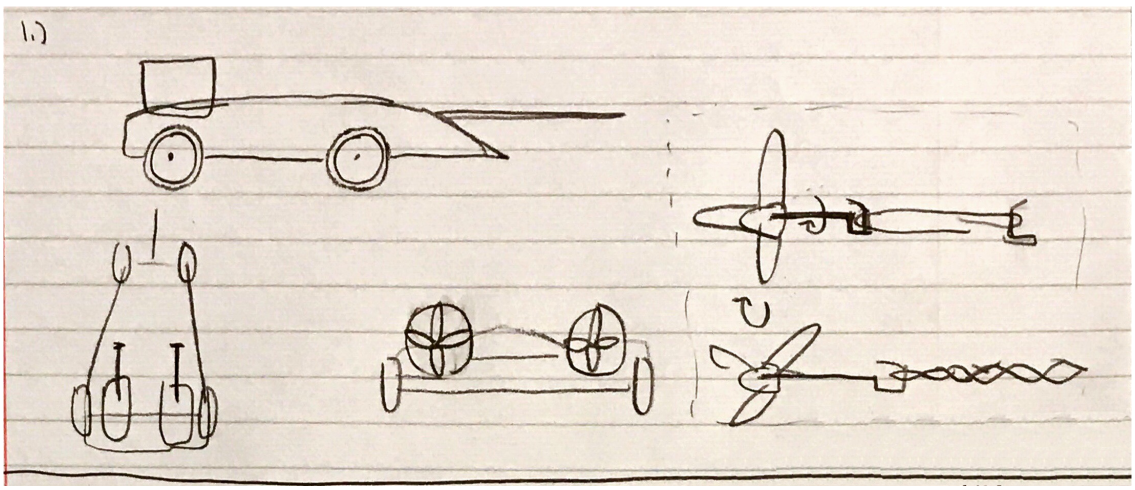


Figure 1: The vehicle will be propelled by a pair of propellers, each with its own hook to allow for the twisting motion of a rubber band. Additional features included rubber-band covered wheels and casings for the proeller

6.2 Concept 2

This second design will be using a slingshot mechanism. A slot will be placed in the car to allow one or more rubber bands to go through. Internal wheels will increase the compactness of the vehicle, which is important because it would improve its speed and stability. The design rationale of this vehicle is “K.I.S.S,” which stands for “Keep It Simple, Stupid.”

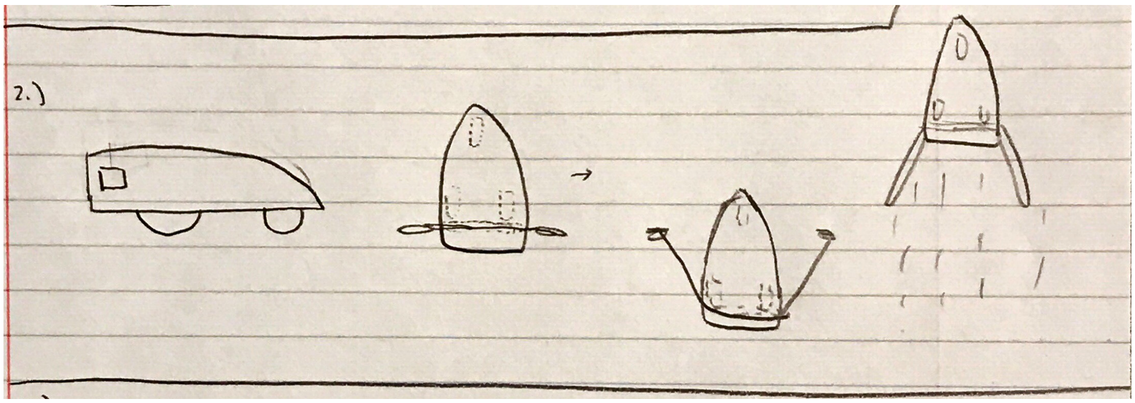


Figure 2: The Concept 2 vehicle will use rubber bands to propel itself almost like an arrow. It would be made from very few pieces.

6.3 Concept 3

he third design concept is basically a big wheel with little stabilizer wheels to keep it going forwards and to prevent it from tipping. It is powered by the coiling of rubber bands, and the unwinding of these coils should propel the vehicle.

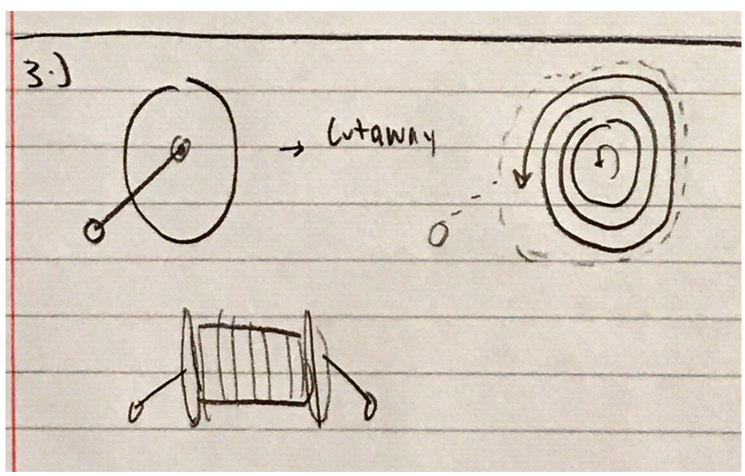


Figure 3: This design is the most similar to a windup car mechanically, but the least similar to a car in every other aspect.

6.4 Chosen Concept

First, I want to eliminate the third concept because I didn't like it once it left my mind and stared back at me on the page. Choosing between the first two concepts was hard, but ultimately, I used a random number generator and now I want to develop the first concept. It looks like the most fun vehicle to create and is a tried and tested design as can be seen by the various YouTube videos[2]. Some feature that I plan on implementing on my vehicle, such as rubber band hooks, will give me the opportunity to use FEA analysis to see if things will break. Furthermore, the second design's major drawback is that it might get slowed down by dangling rubber bands. In a perfect world, I would make everything, but for the sake of this class, I will be opting to use the first design concept.

7 "Final" Design

7.1 Final Design Description

Right from the get-go, a device not too far off from Figure 1 was designed.

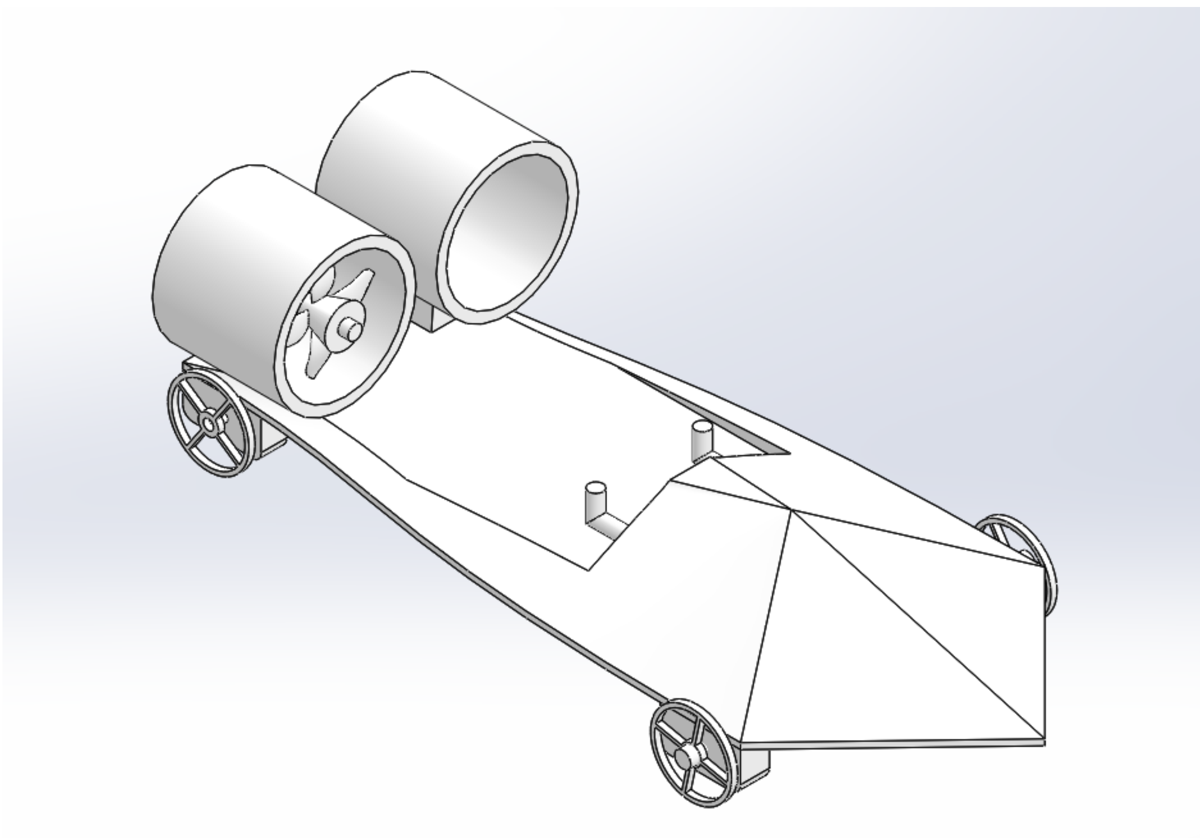


Figure 4: The overall shape changed a bit from Figure 1 and the unicorn horn was removed. The chassis had a cool diamond peak drawing inspiration off of the F-117 Stealth Fighter. It looked almost like a hovercraft. Another change that was made from the original drawing was that the wheels were made as small as possible to decrease weight and friction. Drawing from similar observations, the idea to wrap rubber bands around the wheels was also disregarded.

After some discussions with the Professor in his office hours, I learned that this design was

[2]See citations above, [2] and [3]

faulty because it doesn't attempt to minimize mass and it will also probably collapse in on itself like a sideways taco if rubber bands were connecting the hooks and propellers.

The next stage in the design's evolution is to address these issues.

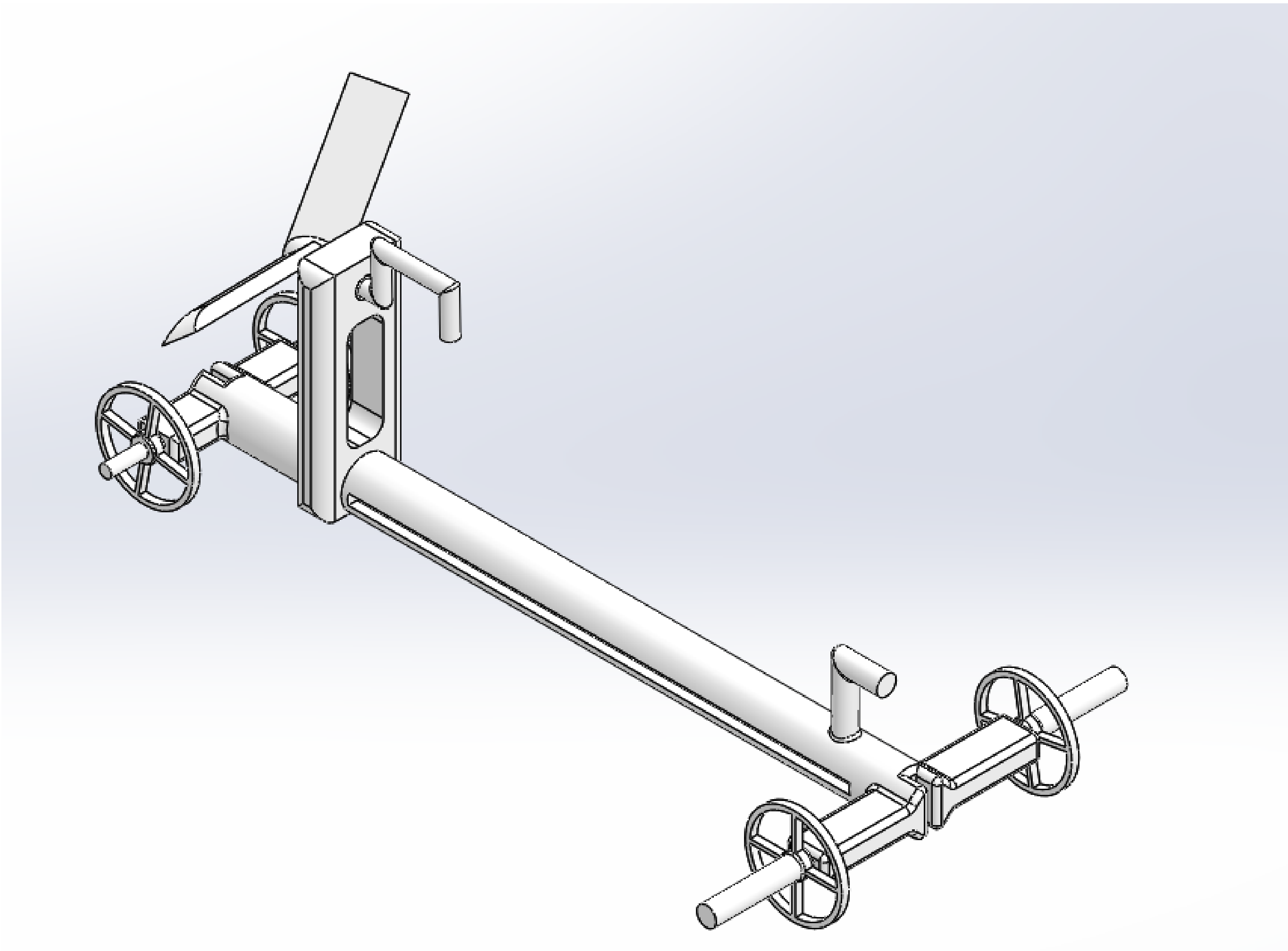


Figure 5: This design was more minimalist and decreased weight by 78%. The new frame was also designed to support the forces that when the rubber band will be attached to the propeller. Due to the nature of the design, one large propeller is used instead of two small propellers.

Below is a table detailing the specs of the car.

Parameter	Value
L (along x-axis)	162 mm
H (along y-axis	72 mm
W (along z-axis)	85 mm
m	19.99 grams
Material	PLA

Table 1: Table showing the dimensions of the vehicle

7.2 Device Parts Design

This vehicle can be broken down into 8 parts.[3]

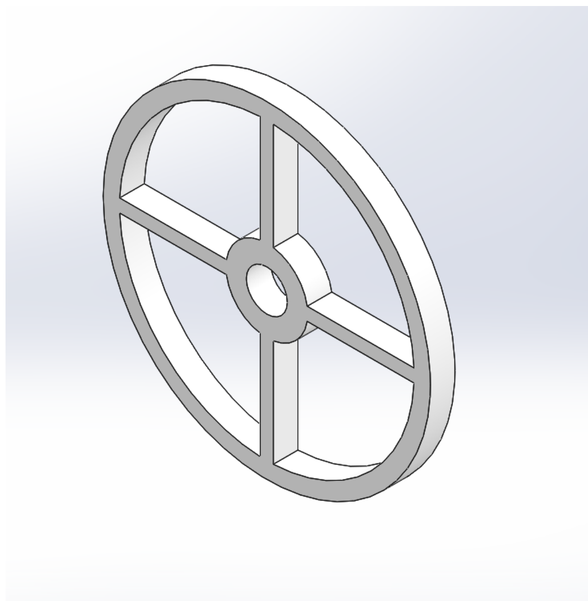


Figure 6: Wheel optimized to reduce as much mass as possible.

[3]Engineering drawings *not* included in Appendix

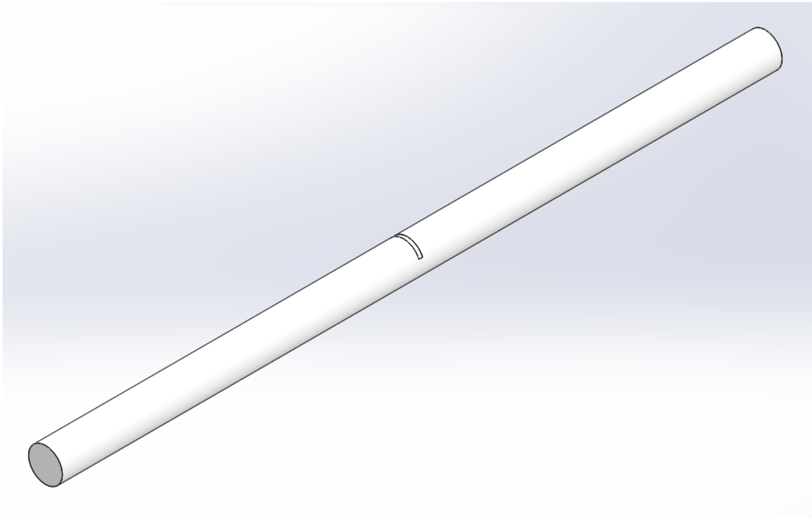


Figure 7: Axle, length varied for front/rear wheels. A little notch was placed in the center to assist with centering.

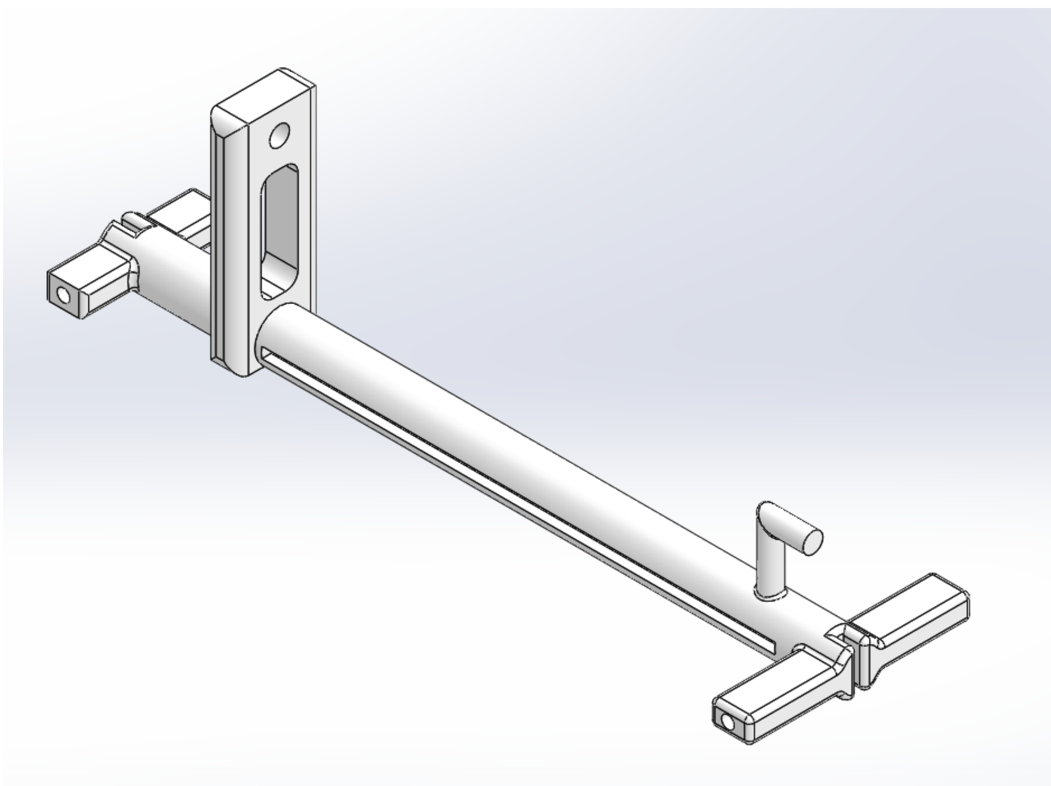


Figure 8: Chassis of the vehicle, a single puece that includes mounts for both the rubber band and propeller. Features include many fillets and slits at the front and rear to assist with centering axles.

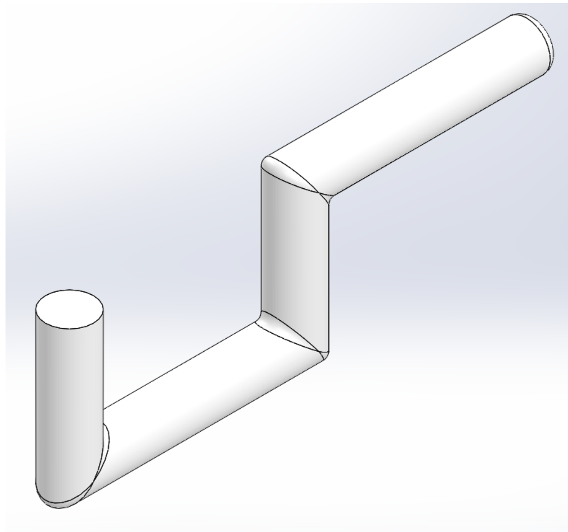


Figure 9: Hook for the propeller. One of side sticks into the propeller and the other attaches to the rubber band

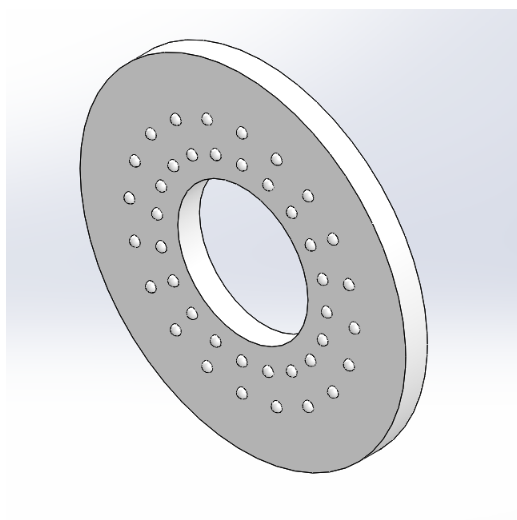


Figure 10: Washer that goes between propeller and propeller mount to reduce friction

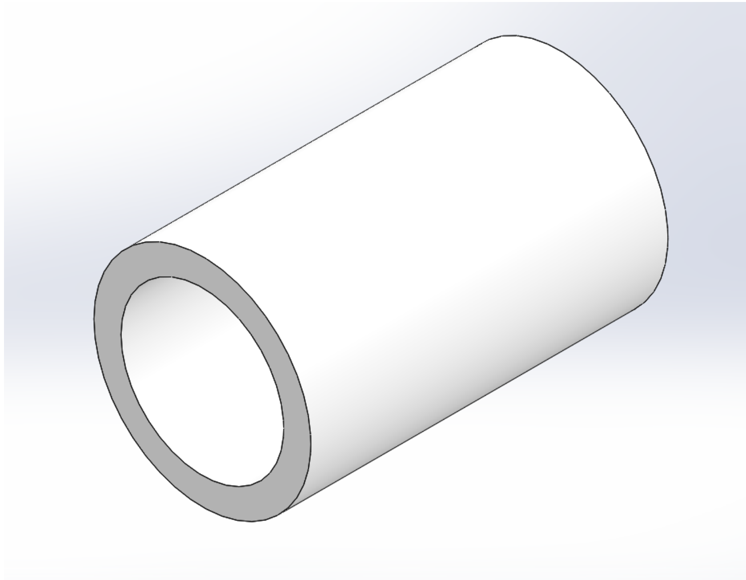


Figure 11: Busing that goes around the hook and into the propeller mount to reduce friction

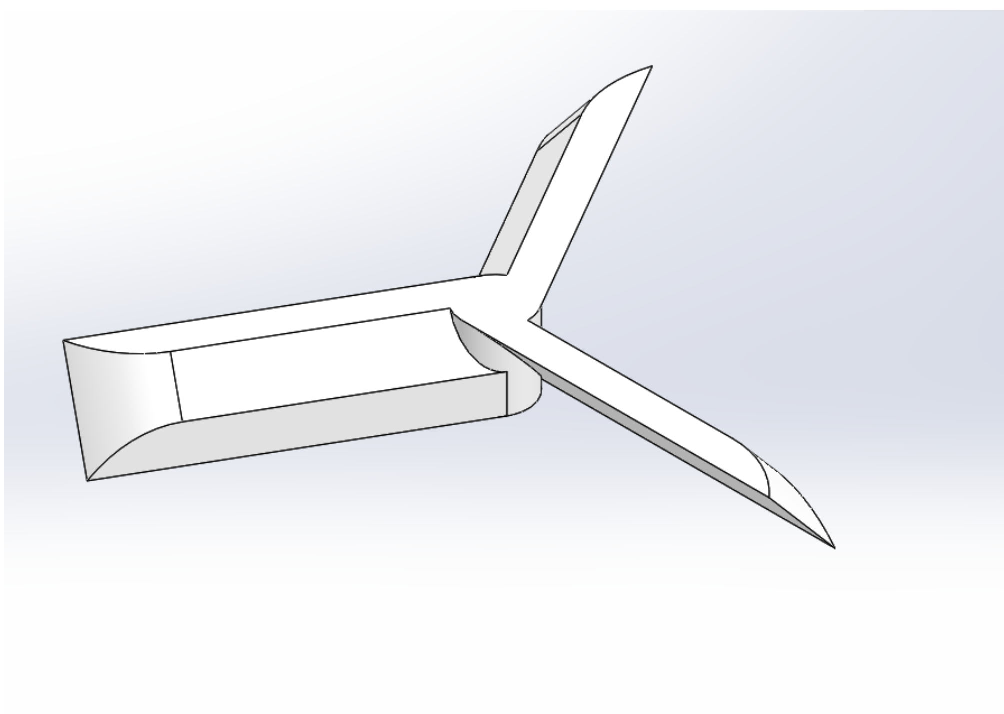


Figure 12: Propeller was designed with flat edges to improve the ease of manufacturing

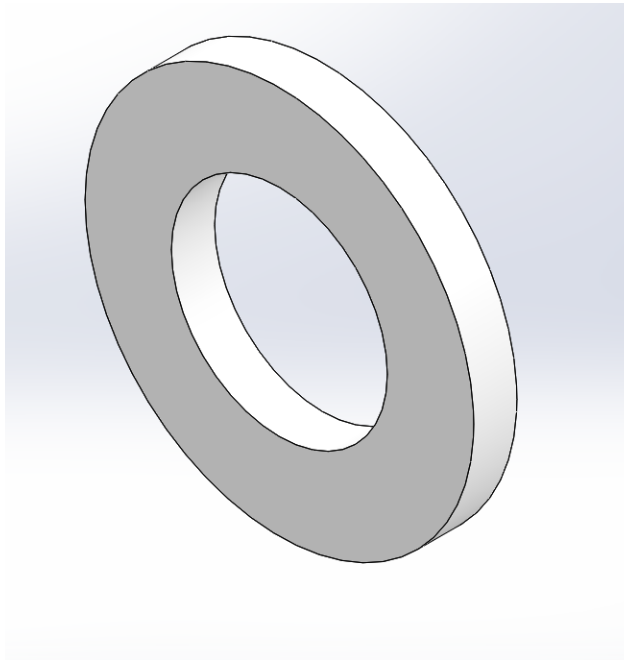


Figure 13: Washers that reduce friction caused by wheel and chassis

7.3 Powering Method

This device is powered by using rubber bands in series to fasten the propeller to the hook on the chassis. The propeller will the rotate and twist the rubber band. Upon release, the rubber band should untwist and the propeller should rotate in the direction opposite of its earlier rotation. This should produce a thrust that will cause the vehicle to move forwards.

8 Calculation and Analysis

8.1 Mass Properties

The entire vehicle is made is made of PLA and weighs roughly 20 grams. This weight was calculated using the mass properties feature in SolidWorks, which uses the volume of the assembly and the density of ABS, a plastic that has similar mass properties to PLA.

Below is a table showing the weight of each component:

Part	**m (grams)**	**Quantity**	**m_{total} (grams)**
Wheel	.15	4	.58
Long Axle	1.09	1	1.09
Short Axle	.25	1	.25
Chassis	16.32	1	16.32
Hook	.33	1	.33
Propeller Washer	.02	1	.02
Bushing	.04	1	.04
Propeller	1.32	1	1.32
Axle Washer	.01	8	.04

Table 2: Weight of each individual component. Note that most of the weight contribution comes from the chassis. Of course, this is also only an estimation and doesn't account for infill percentage nor sanding or other alterations.

Since the majority of the weight contribution comes from the chassis, the center of mass will by very close to the center of the axis, with a slight bias towards the edge with the propeller.

8.2 Spring Constant

To measure the spring constant of the rubber band, I used the legs of a chair to hold the rubber band in place while I incrementally added water to two water bottles that are weighing down the rubber band. Each water bottle had labels marking every 8 ounces up to 24 ounces.

Figure 14: This picture shows the method used to measure k, the spring constant of the rubber band. I used calipers to make accurate measurements.

Water Level (fl oz)	Mass (kg)	Force (N)	Total Length (m)	Displacement (m)	Comments
0	0	0	0.09127	0	2 Empty Bottles
8	0.24	2.352	0.10846	0.01629	
16	0.48	4.704	0.12868	0.03651	
24	0.72	7.056	0.15916	0.06699	1 full bottle and 1 empty bottle
32	0.96	9.408	0.18677	0.0946	
40	1.2	11.76	0.24778	0.15561	
48	1.44	14.112	0.32021	0.22804	2 full 24 oz bottles

Table 3: Table showing the measurements acquired to measure the spring constant. Measurements were originally taken in mm but scaled to m for ease of calculation. The water level is based off of marking on the bottles. The mass was calculated using the density of water. The force was calculated using the mass multiplied by the acceleration due to gravity. The total length is the length of the rubber band, and the displacement is how far removed the measured length is from the reference position, which is with two empty bottles in this case.

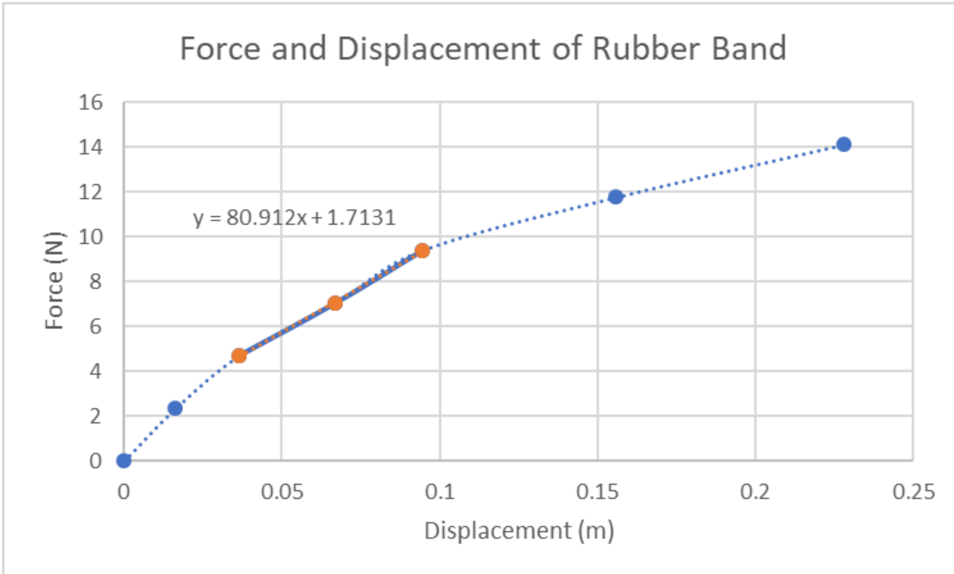


Figure 15: The data from above was plotted to make a graph with the axes being Force and Displacement. From here, a region was selected (with the criteria being "the straightest" to calculate the spring constant; this region underwent a linear regression and the slope, and our estimated spring constant, is $80.912\frac{\text{N}}{\text{m}}$

8.3 Finite Element Analysis

Equipped with a CAD model and some values for forces, we proceeded to do a finite element analysis.

The first simulation that I want to do was a Computational Fluid Dynamics one to find the thrust produced by the propeller. This will help my know how much propulsion the car can receive. The only unknown parameter in this simulation is the RPM at which the propeller spins. A ball park estimate is 75 rpm, since rubber bands are not that capable.

The simulations are pretty basic and due to the limitations of my skills and perhaps even SolidWorks itself, some physical elements such as friction between the propeller and its hook cannot be properly simulated.

To perform the simulation, the SolidWorks Flow Simulation Add-in was used. Essentially, we had the propeller rotate at 75 RPM and saw the force that was exerted.

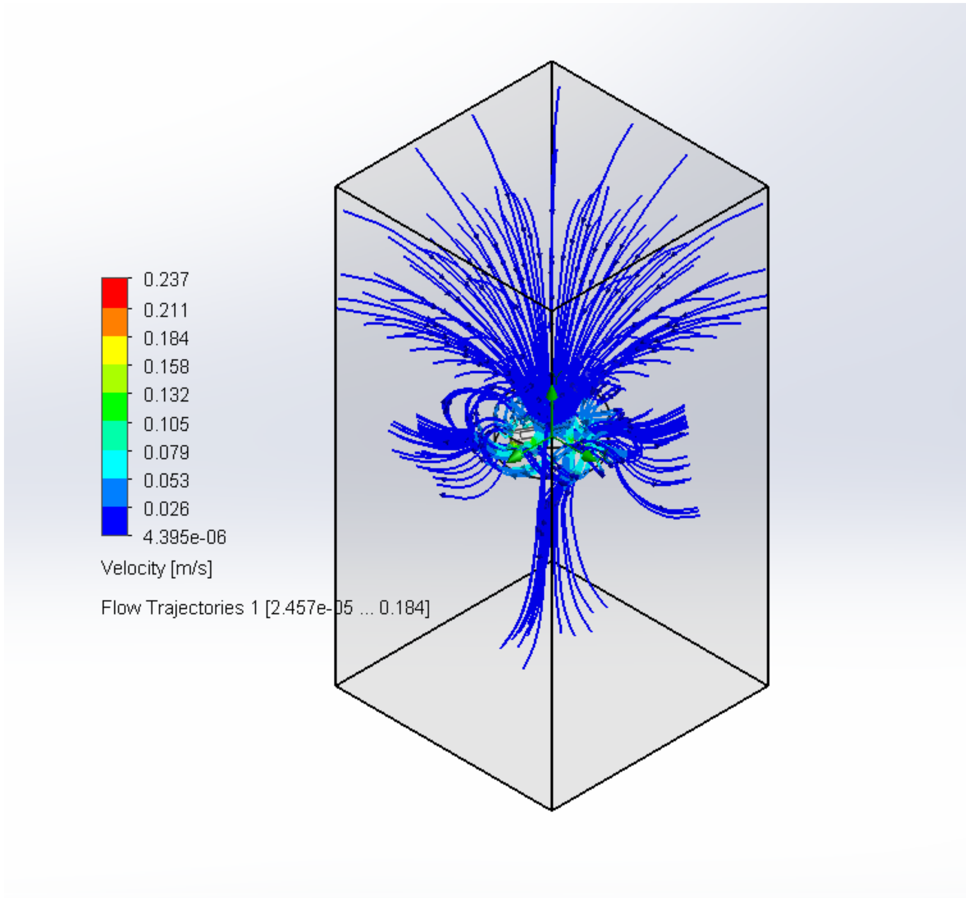


Figure 16: Flow trajectories of propeller as it rotates.

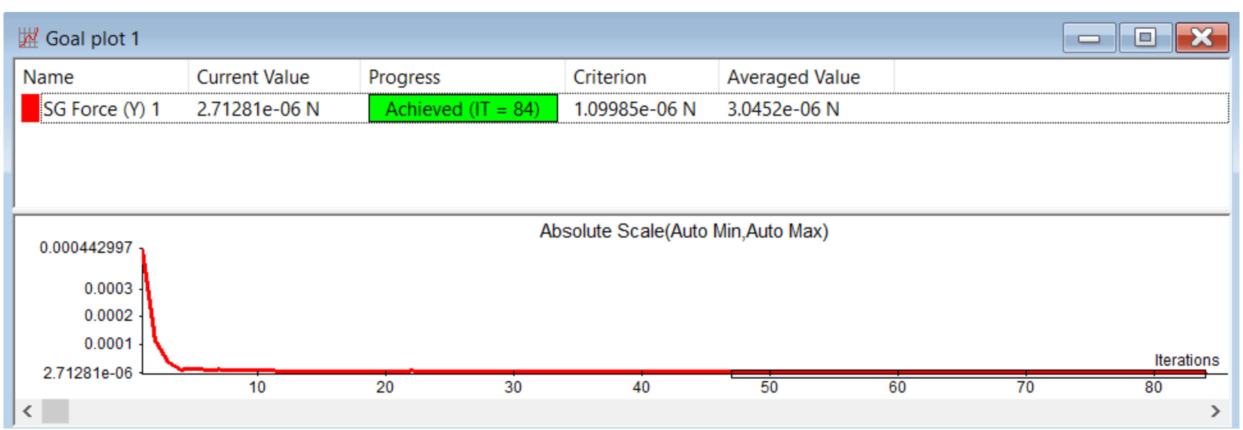


Figure 17: The CFD concluded that the average force generated by the propeller is about 3 micro-newtons. This is enough to accelerate a 20 gram object at .15 millimeters per second per second.

These results are giving me a lot of doubts about the propeller mechanism.

The next finite element analysis was done on the propeller hook. I wanted to make sure that it could withstand the forces exerted on it by the rubber band. The applied force that I am using is $k\Delta x$, where k is the spring constant (See Figure 15) and Δx is .512 meters, which was obtained from a combination of the circumference of the rubber band and the number of twists. After multiplying by a safety factor of 2.5, the force ended up being 25.88 N.

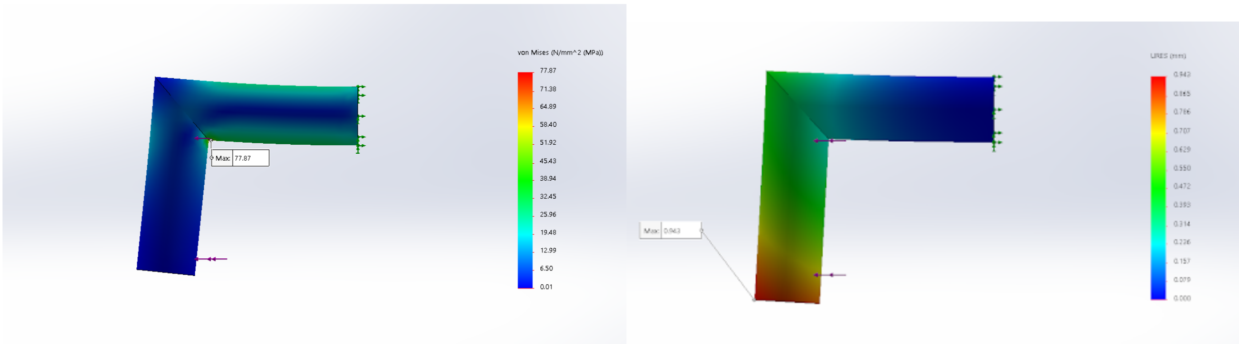


Figure 18: This image shows the von Mises stress and displacement of the original hook. Most of the stress is concentrated in the corner (90° angle) of the hook. At this region, the stress experienced is equal to 77.87 MPa. The maximum displacement occurs on the part that is being pulled, which is .9 mm.

The ultimate tensile strength of 3D printed PLA is about 10MPa, so I need to make configurations to reduce the stress of the hook.

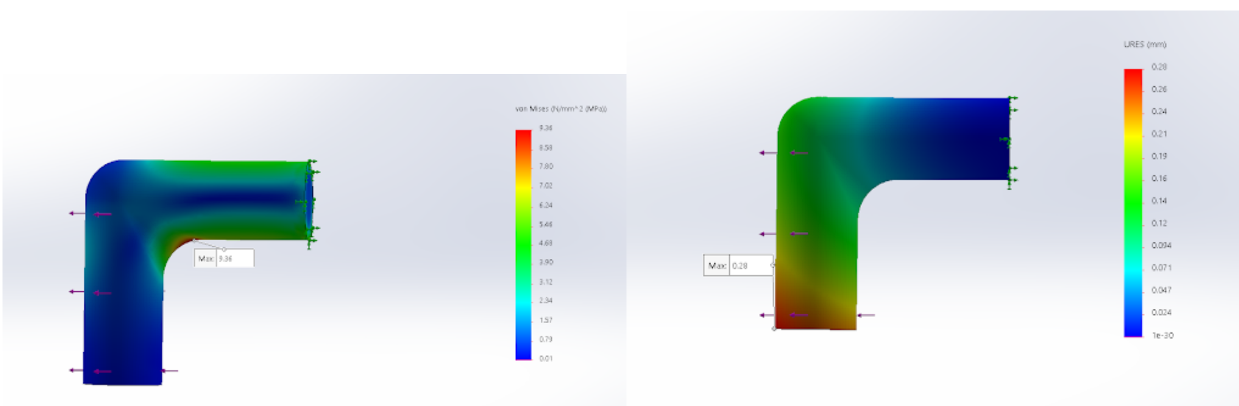


Figure 19: To reduce the amount of stress, I added fillets to round out the edges and thickened the hook's cross section. The stress was reduced to 9.36 MPa and the displacement to .028 mm, but at the cost of size and wight.

This configuration will have a butterfly effect on the rest of the vehicle. This is because changing the diameter of the propeller means that the mount, washer, bearing, and the propeller itself will need to be changed accordingly. Changing the frame will then change the entire chassis, and so forth.

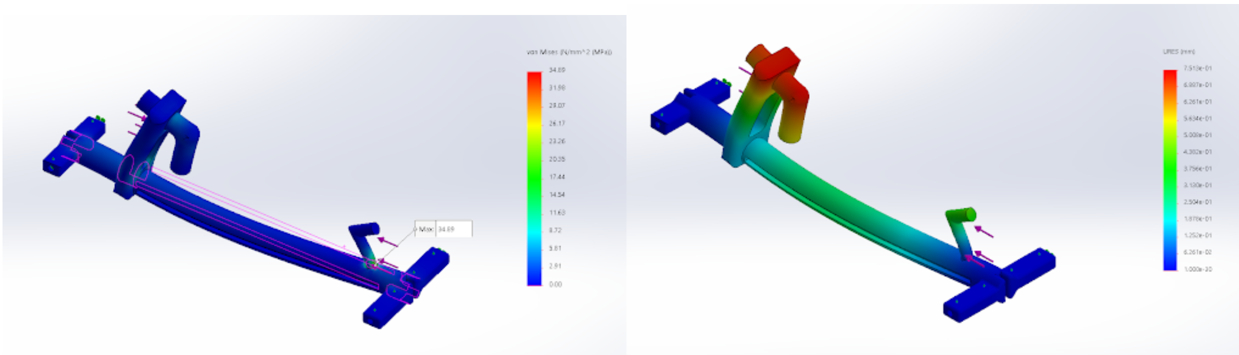


Figure 20: FEA on the chassis, showing the displacement and stress. For this analysis, the axles were fixed while forces were exerted on the hooks. The small hook on the chassis experiences more stress than the 10 MPa limit, and the force exerted by the rubber bands would still cause the car to fold in on itself like a sideways taco.

Fixing these complications will drastically increase the weight of the vehicle, which is something that I can not afford to do if I want my car to move. At this point, I had effectively given up on rubber-band powered propellers. The evolution of this design has halted here, it became extinct.

9 *Real* Final Design

A this point I decided to change my design up to make a vehicle similar to the one shown in Figure 2

9.1 Final Design Description

Initially, the entire car was going to be 3D-printed.

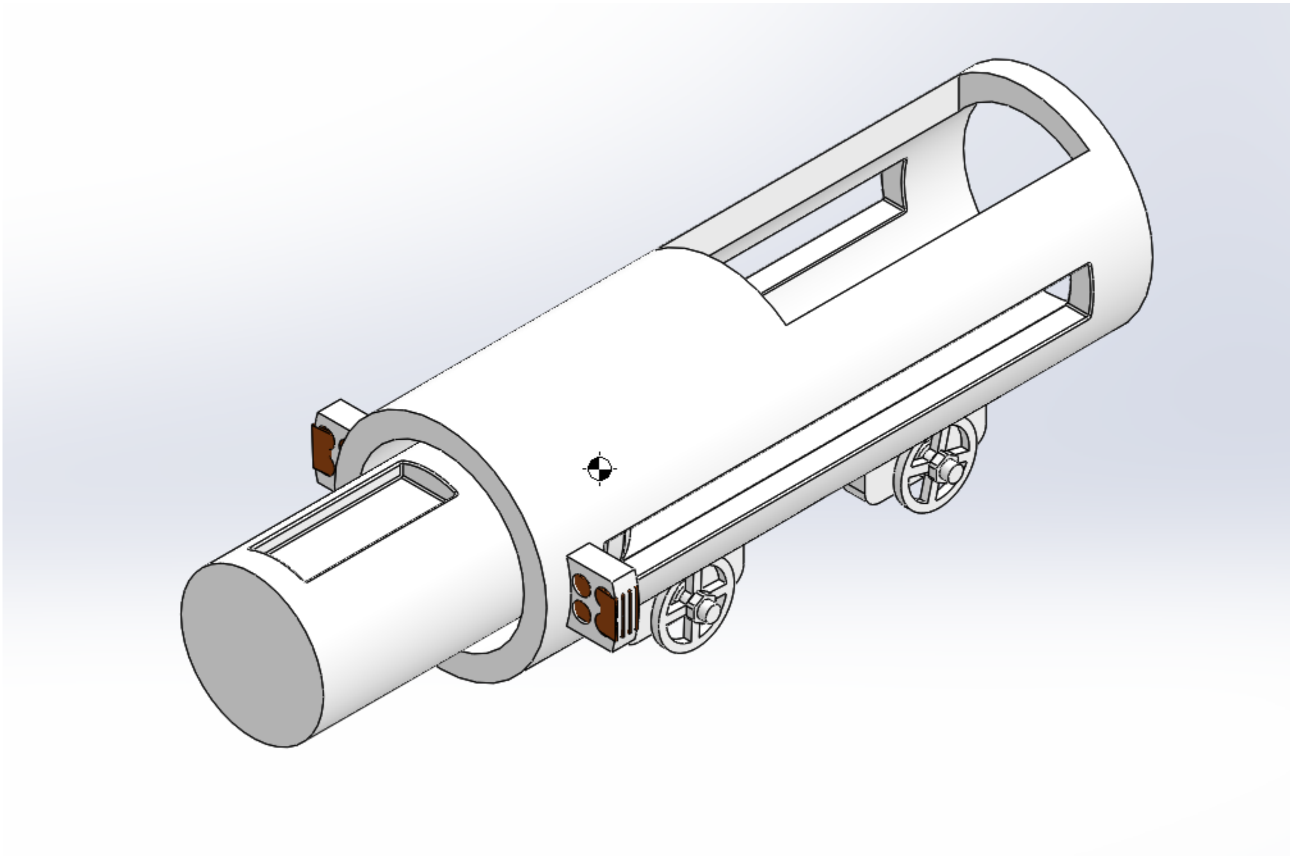


Figure 21: Isometric view of the car's redesign. It had a ram that could be loaded into the vehicle and released to provide force through Newton's Third Law of Motion. There were many holes to allow the rubber bands to travel, to improve accessibility, and to reduce the weight of the vehicle.

However, due to the lack of time, the design was optimized for manufacturability. The most major changes that were made was that the majority of the vehicle will now be made of acrylic instead of PLA.

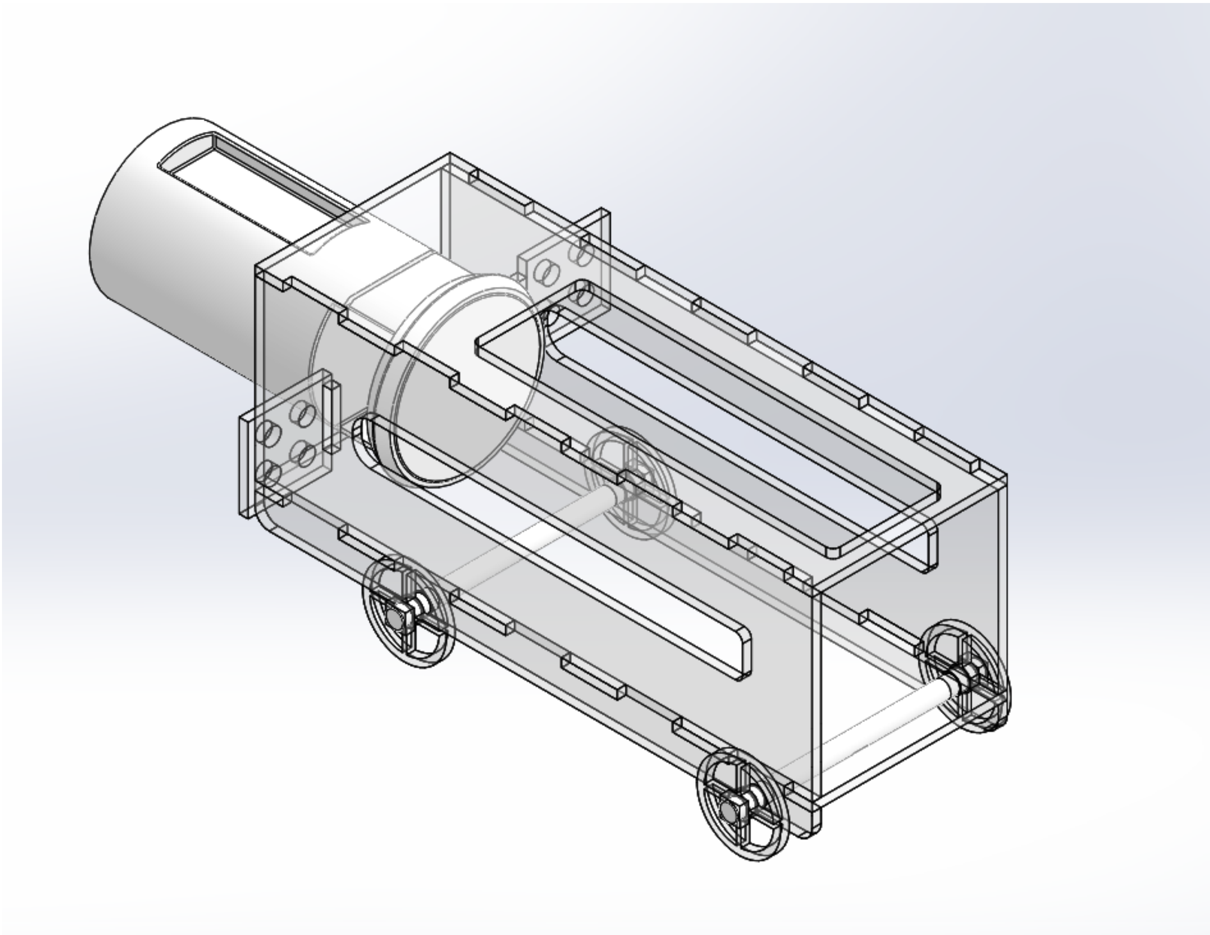


Figure 22: Isometric view of the final vehicle. The major modification is that acrylic sheets were used instead of PLA because laser cutting is many times faster than 3D printing. This meant that instead of being a cylindrical, the vehicle is now quadrilateral.

9.2 Device Parts Design

This vehicle can be broken down to 9 unique parts. Detailed drawings of each part can be found in Section 15, the Appendix.

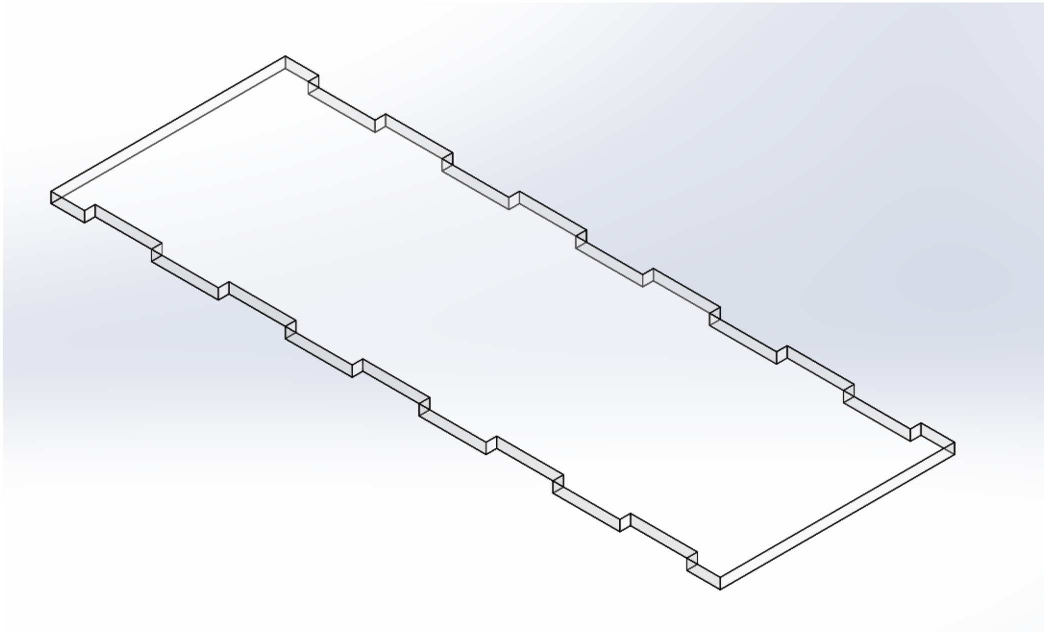


Figure 23: Bottom acrylic plate of the car.

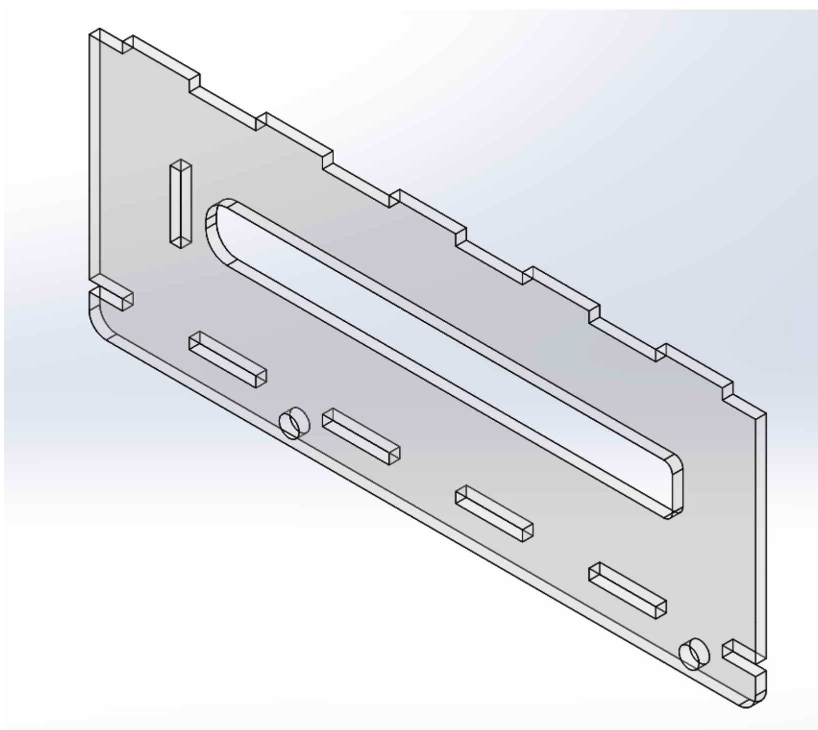


Figure 24: Side plates, which feature holes for the axles, band holders, and other plates.

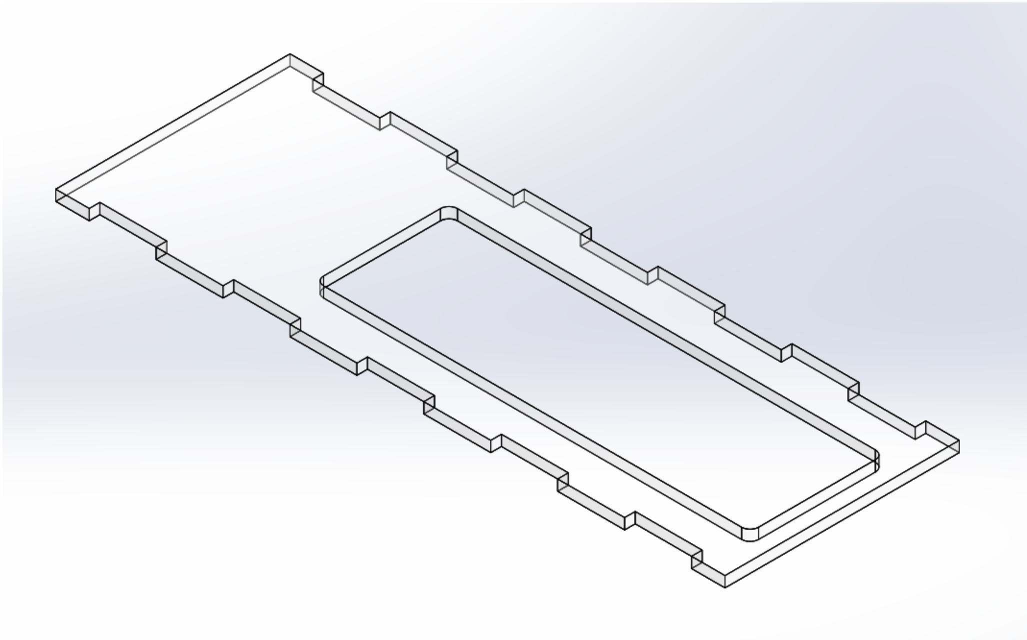


Figure 25: Top acrylic plate, includes a hole so that the ram can be reached from above.

The walls that form the chassis of the car have been carefully designed to fit together like a 3D puzzle piece.

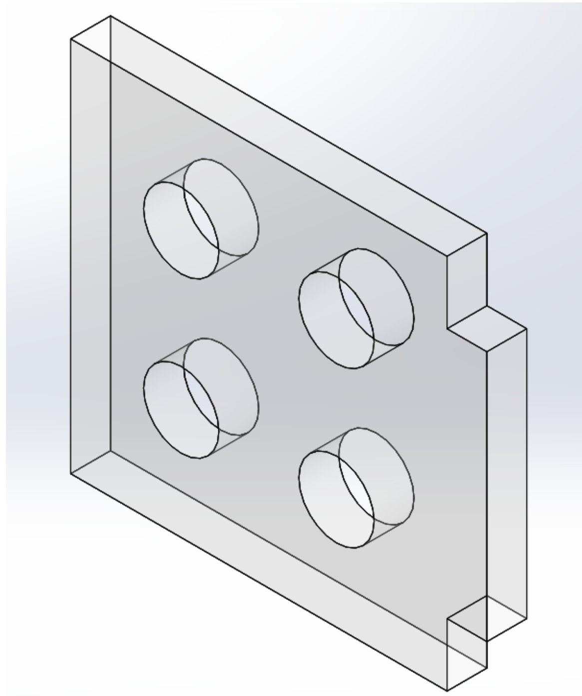


Figure 26: A piece of acrylic with hole cutouts for rubber bands. My inspiration for this idea came after I was playing with a rubber band and my jacket zipper.

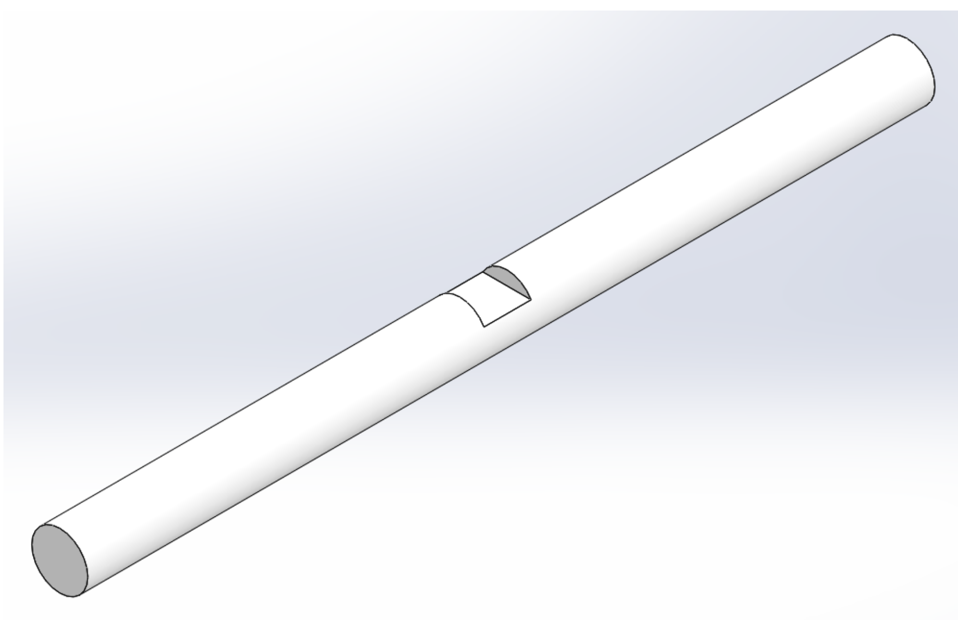


Figure 27: Differs from the axle of the old design slightly; the diameter and length were changed.

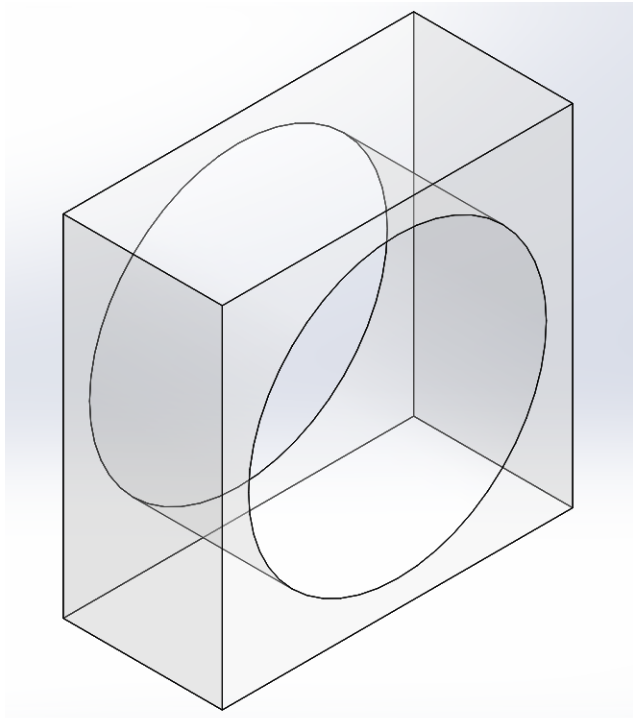


Figure 28: A nut that is supposed to go on the outside of the washer.

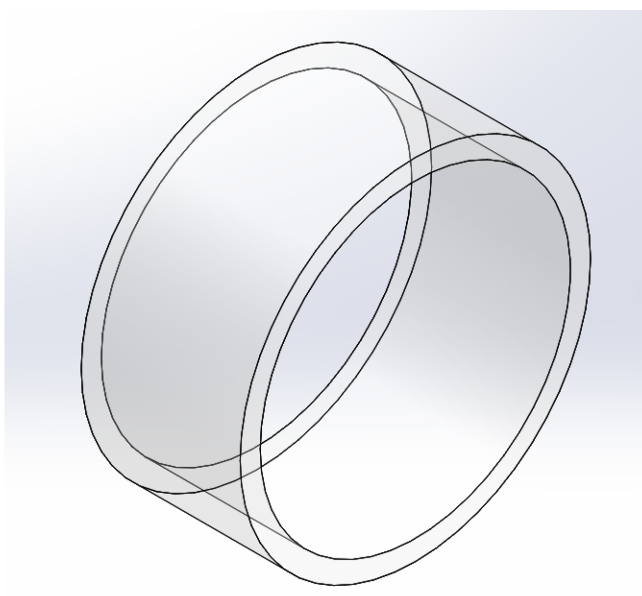


Figure 29: Washers that go between the wheel and sidewalls. It will be made of very thin acrylic.

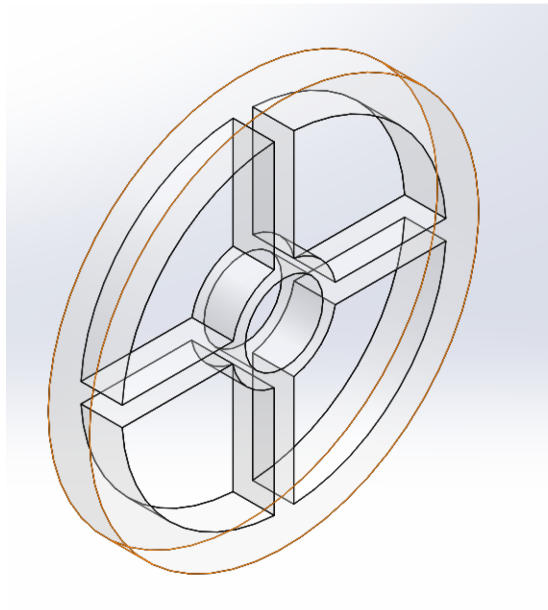


Figure 30: Redesigned wheel is similar to previous wheel, just with different dimensions

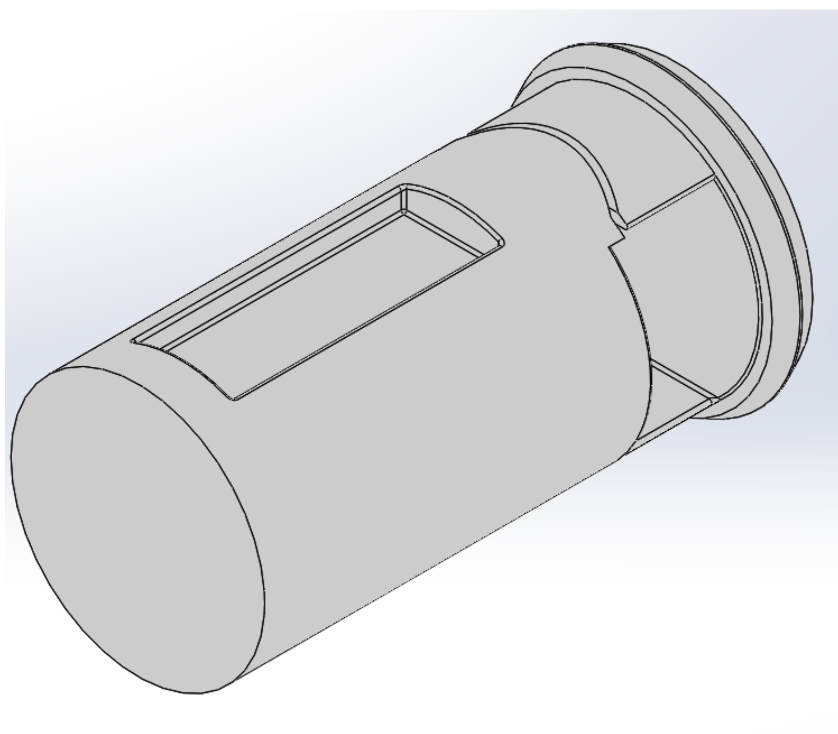


Figure 31: The ”engine” of the vehicle. Has a big hole for the rubber bands to go through and fits inside of the box created by the four walls.

9.3 Powering Method

This device will be powered similar to a pen being pushed down against a table and springing up, or like a rocket ejecting its mass (burning its fuel) to propel itself, except that it is "illegal" in this case because the one of the design requirements states that nothing should be left behind.

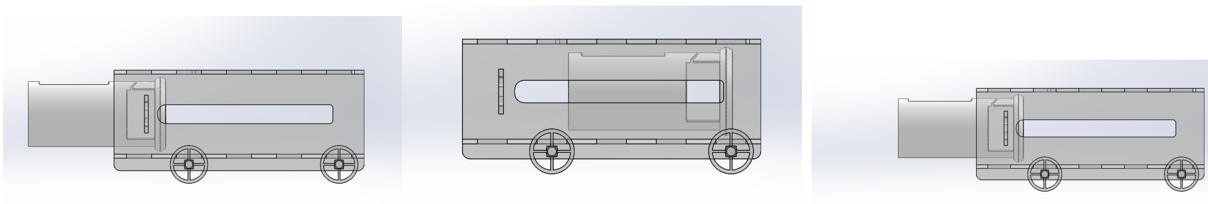


Figure 32: A rough image of how the movement is generated from the car. Not included in this schematic are the rubber bands or force vectors.

9.4 Analysis

9.4.1 Mass Properties

The entire vehicle weighs 378.06 grams, which is a bit more than 12× heavier than the propeller car.

Part	m **(grams)**	**Quantity**	m_{total} **(grams)**
Bottom Plate	50.92	1	50.92
Side Plate	50.12	2	100.23
Top Plate	31.13	1	31.13
Band Holder	3.24	2	6.48
Axle	2.53	2	5.05
Nut	0.08	4	.32
Washer	0.03	4	.13
Wheel	1.10	4	4.41
Ram	179.38	1	179.38

Table 4: Weight of each individual component. Note that most of the weight contribution comes from the ram. As the ram moves within the car, the center of mass also shifts.

9.4.2 Finite Element Analysis

Admittedly, I did not do any FEA when designing this vehicle. This is because I ran into two issues. The first issue is that I didn't know how to properly simulate glue, and I didn't even know what glue I was going to use until the final week. Second, I had limited time and prioritized getting files to the Lux Lab.

There should be a way to model this system using the $\vec{p} = m\vec{v}$ and the conservation of momentum.

10 Product Fabrication

For the vehicle, most of the parts were fabricated with laser-cut acrylic, with only the axles and ram being 3D printed.

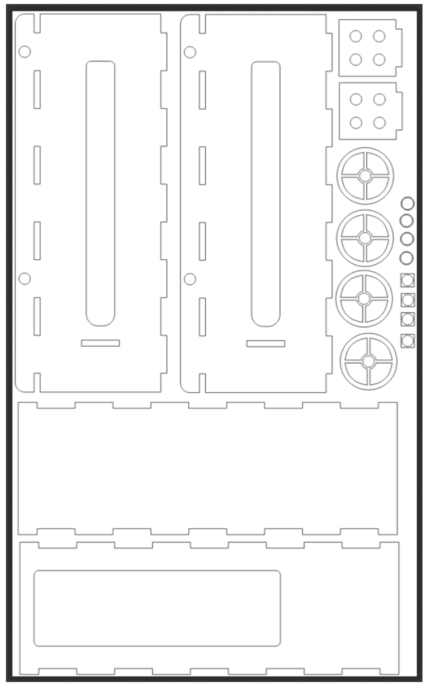


Figure 33: A scaled down version of the file that I sent to the Lux Lab to cut out. One minor issue was that .dxf files were not properly scaling. To fix this issue, I saved the file as a .pdf and then converted it to a .ai. This works because Adobe sort of owns both of them.

Figure 34: Acrylic Cutouts being removed from the sheet provided by Lux Lab. There were many small pieces, and devices like pens and tweezers were helpful.

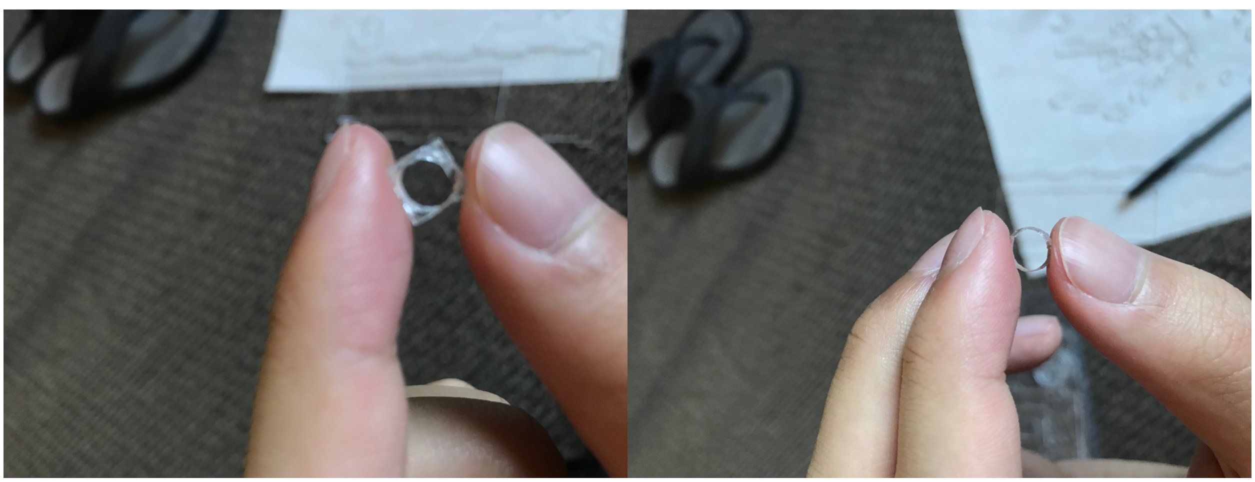


Figure 35: Some of the smallest and most challenging pieces to work with were the nuts and washers. They made me realize why small children with their small fingers are the often sought out for sweatshops (mostly way back in the day, but probably is still happening today.)

Figure 36: The 3D printed parts of the assembly were the ram and axles.

Figure 37: Sanding the axles to make them fit in the holes that were laser cut. The 1mm tolerance that I gave was not enough. My sanding technique was to start with 80 grit and work until the axle goes through the hole, then switch to 120 grit, and finally 180 grit.

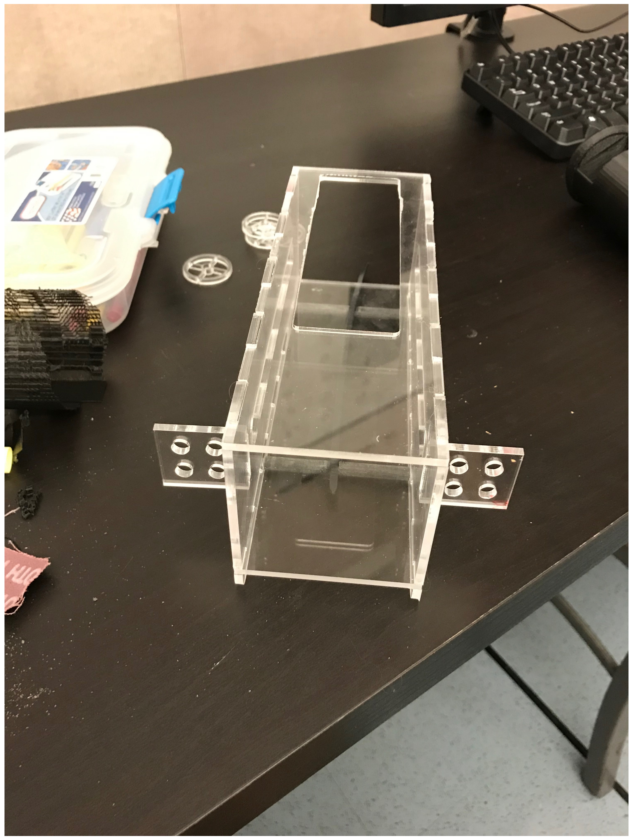


Figure 38: Partially assembled chassis. The rubber band holders were attached to the side walls using Scigrip 16, a glue specially made for acrylics that works by bonding acrylic to itself, creating an acrylic-like material that connects the acrylic, all while releasing flamable carcinogenic fumes.

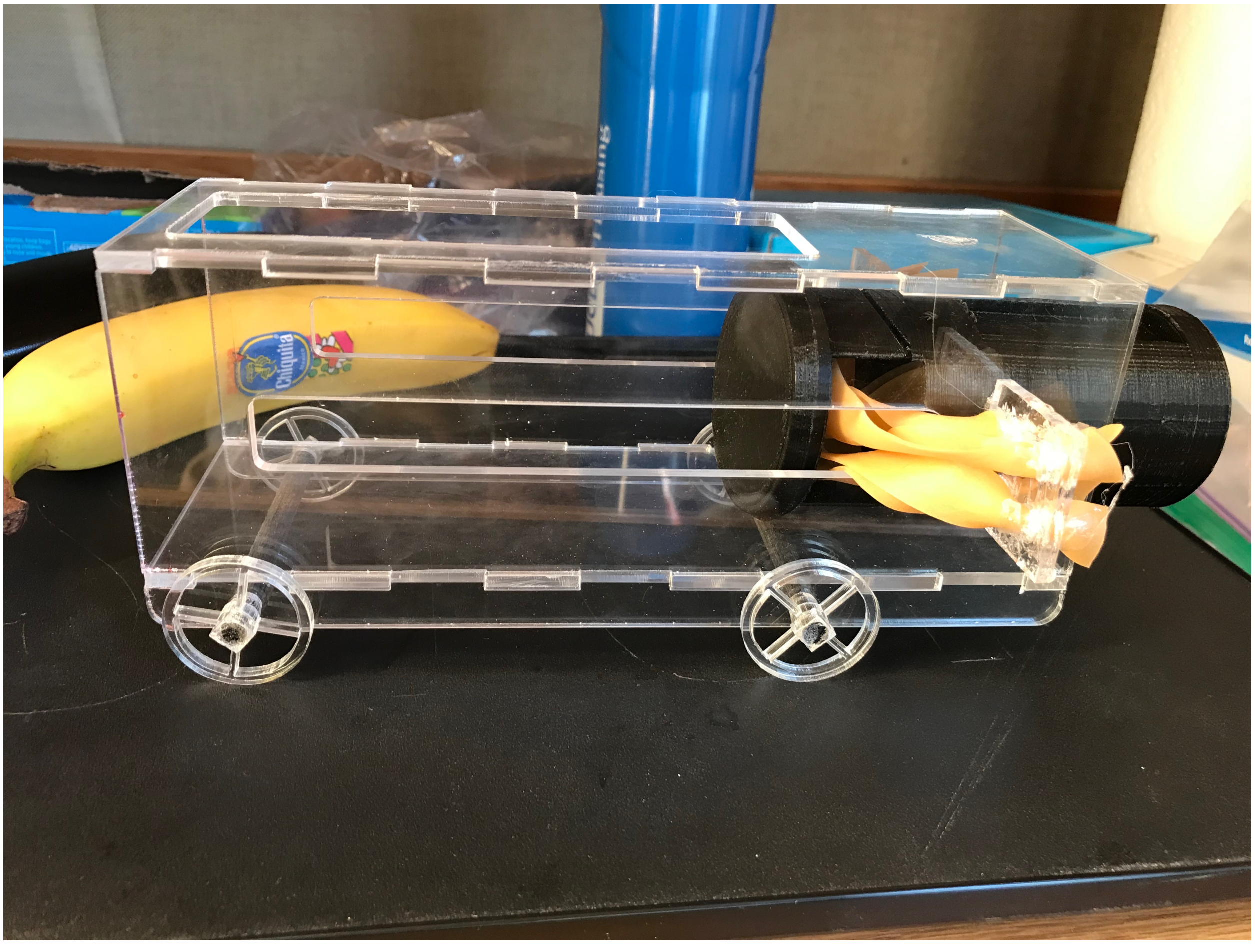


Figure 39: The fully finished car with a banana for scale.

11 Product Testing and Evaluation

Thankfully the vehicle managed to pass 2 feet.

Trial	Distance Traveled (ft)	Comments
1	1	Was very cautious
2	6	n/a
3	2	Tried to full power, ended up skidding to the side

Table 5: The vehicle's performance after 3 trials. This is exponentially greater than what a propeller design would've done.

12 Design Requirement Fulfillment

The following table reviews the design requirements to see if they were met.

#	Description	Met?
1	Traverse 2 feet	Yes
2	Constructed out of entirely ABS or PLA	No - Used plenty of acrylic
3	Max dimensions are .1 × .1 × .2 m^3	Yes
4	Powered only by rubber bands	Yes
5	Maximum of 4 Rubber Bands	Yes
6	No separate external fixtures or supports	Yes - unless you include my hand
7	No parts left behind	Yes
8	No auxiliary parts	Yes
9	Adhesives, but no tape	Yes
10	Cosmetics allowed	N/A
11	All parts made using Lux Lab	Yes

Table 6: Table descibing if the design requirements were fulfilled.

13 Conclusions

I am happy with my experience in this course and the performance of the vehicle. I liked that it was non-traditional, but I would've enjoyed it more if it was more effective. I think that future design changes should be made to improve the security of the rubber-band holders, like maybe a pair of plates on each side instead of two. I could've also made the ram piece have a larger infill.

It's a shame that propellers are a novelty with these design conditions, hopefully one day somebody is able to succeed in a high-performing propeller vehicle. In my wildest dreams, someone will be able to power their car by burning the rubber bands. That would be a sight.

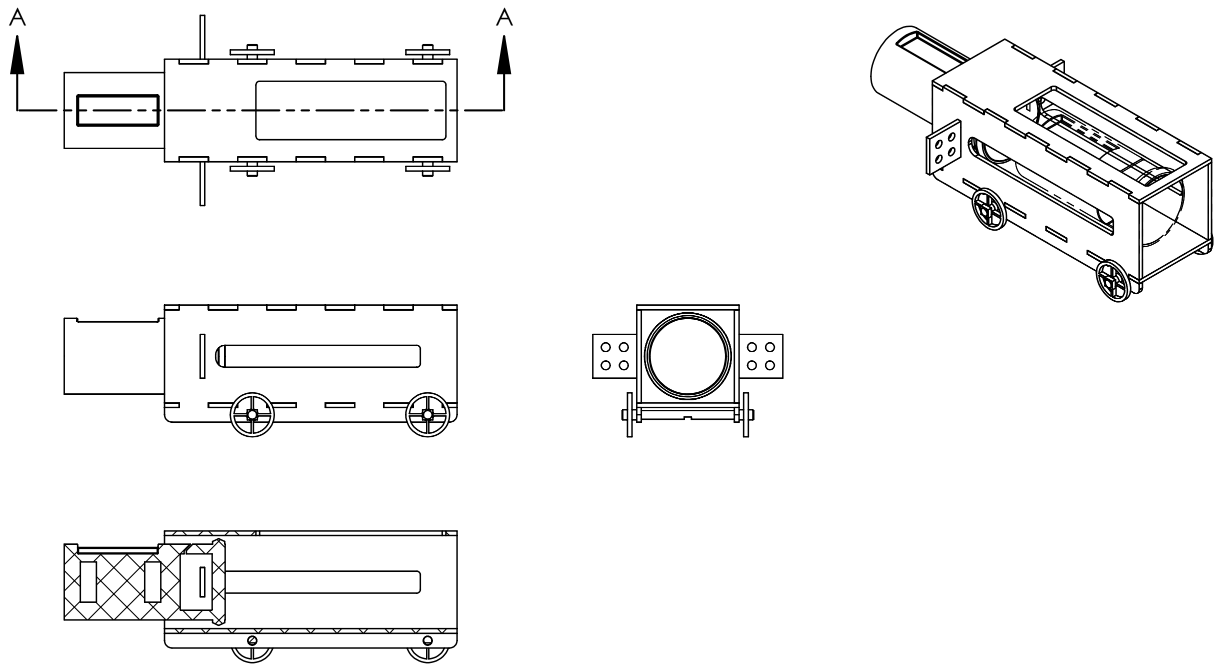
14 References

[1] Shaefer, Robert S. "Lecture 1 : Introduction to Computer Aided Design. Mech. & Aerospace Engr. Dept., University of California Los Angeles (UCLA), Los Angeles, CA Oct. 1st, 2018" Lecture posted on UCLA MAE Dept. CCLE website.

[2] LXG Design. "How to Make a Rubber Band Powered Car - Air Car." YouTube, YouTube, 22 June 2015, www.youtube.com/watch?v=YSqj1c8fBns.

[3] JoshBuilds. "Propeller Driven Rubber Band Car." YouTube, YouTube, 16 Mar. 2016, www.youtube.com/watch?v=jxrjayTzZkY.

15 Appendix



SECTION A-A

2 1 B A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
PLA, Acrylic

FINISH

NEXT ASSY | USED ON
APPLICATION | DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	W.T.	11/28/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

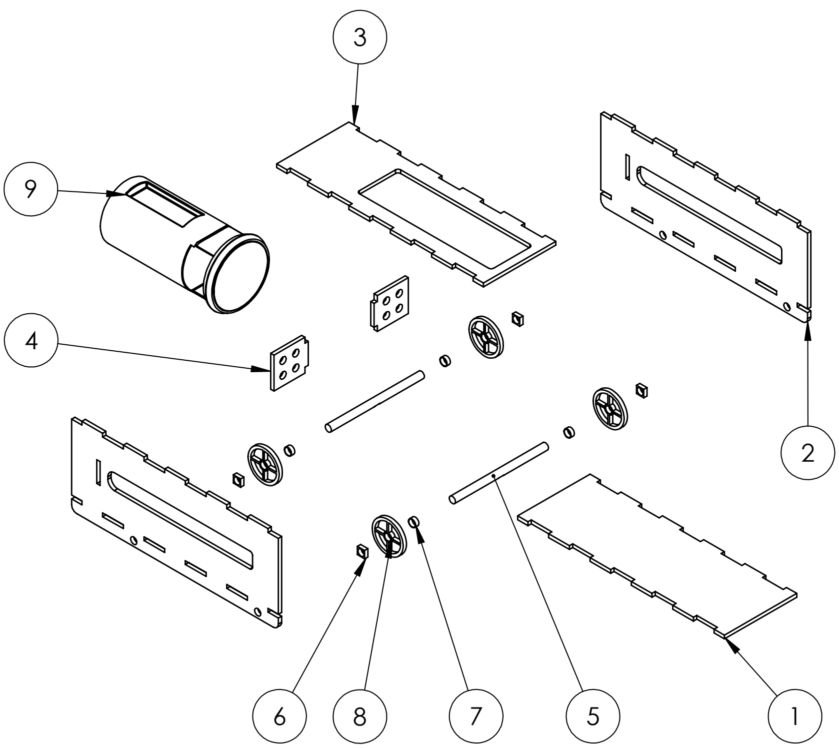
MAE94 - UCLA

TITLE:
3-View and Isometric View

SIZE A | DWG. NO. 1-1 | REV

SCALE: 1:4 | WEIGHT: .83 LBS | SHEET 1 OF 12

2 1



ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	Bottom Plate	Acrylic	1
2	Side Plate	Acrylic	2
3	Top Plate	Acrylic	1
4	Band Holder	Acrylic	2
5	Axle	PLA - 100% Infill	2
6	Nut	Acrylic	4
7	Washer	Acrylic	4
8	Wheel	Acrylic	4
9	Ram	PLA - 40% Infill	1
N/A	Rubber Band	Provided	4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
PLA, Acrylic

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

	NAME	DATE
DRAWN	W.T.	11/28/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
NOT SHOWN: Rubber Band, QTY = 4

MAE94 - UCLA

TITLE:

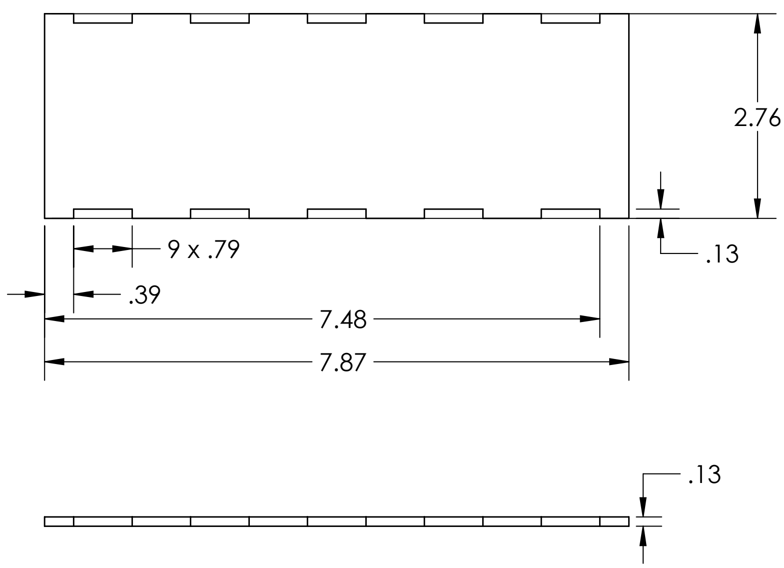
Exploded View and BOM

SIZE **A** | DWG. NO. 1-2 | REV

SCALE: 1:4 | WEIGHT: .83 LBS | SHEET 2 OF 12

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	11/28/18
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Acrylic	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

MAE 94 - UCLA

TITLE:

Bottom Plate

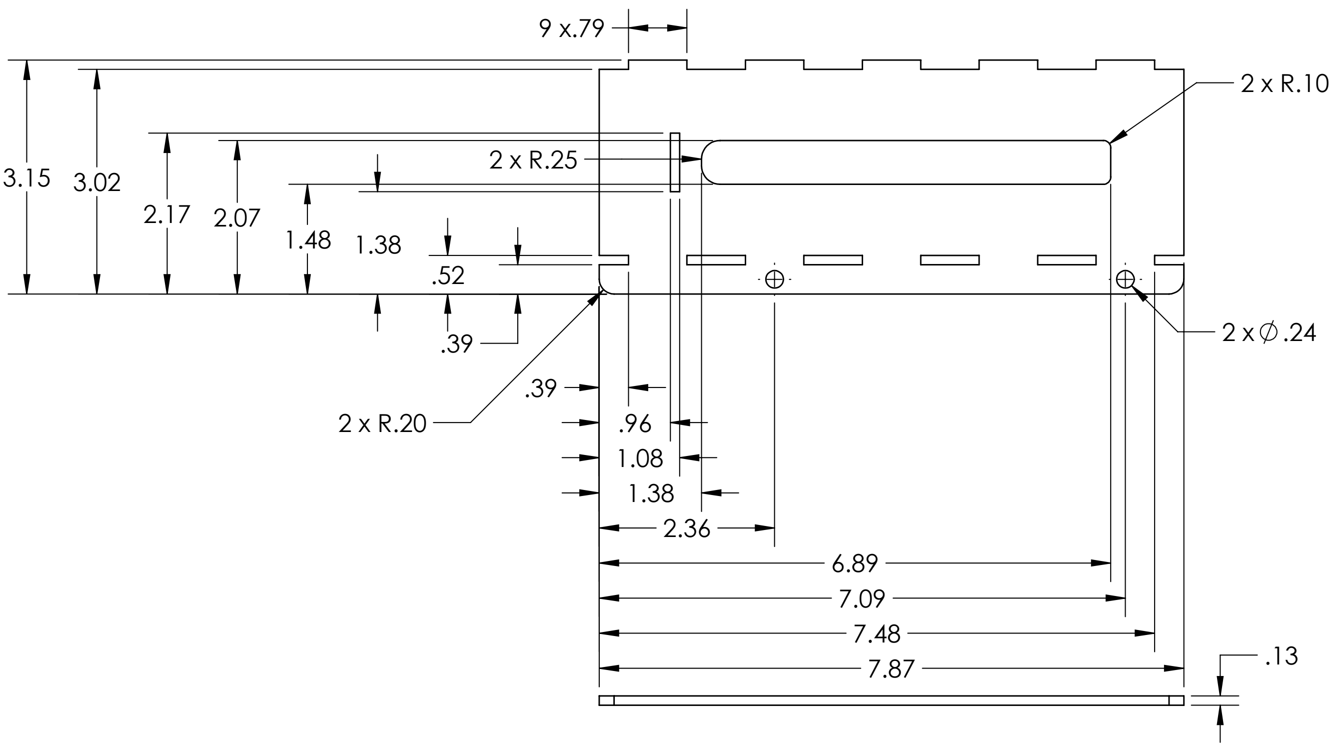
SIZE A | DWG. NO. 2-1 | REV

SCALE: 1:2 | WEIGHT: .11 LBS | SHEET 3 OF 12

2 1

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL Acrylic
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	W.T.	12/06/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

MAE 94 - UCLA

TITLE:

Side wall

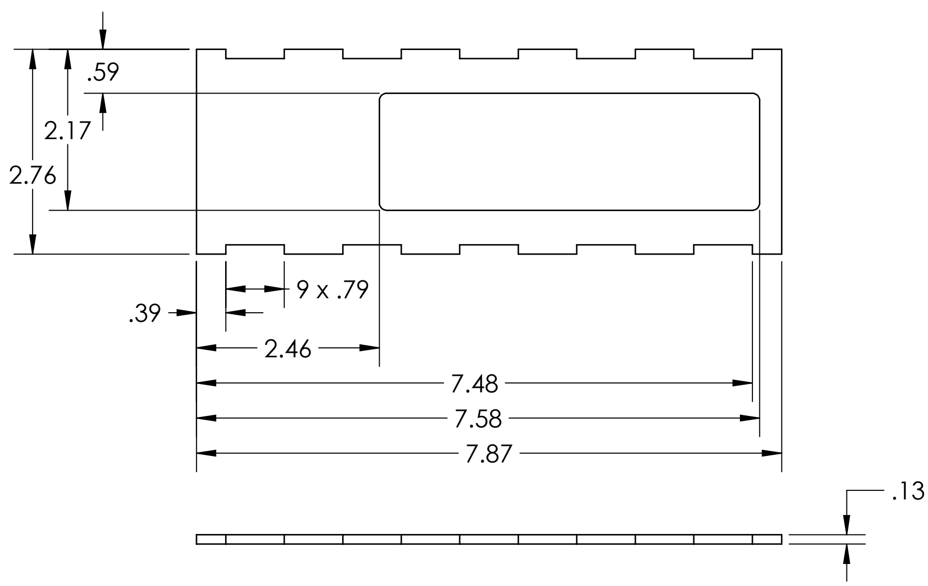
SIZE	DWG. NO.	REV
A	3-1	

SCALE: 1:2 | WEIGHT: .11 LBS | SHEET 4 OF 12

2 1

2 1

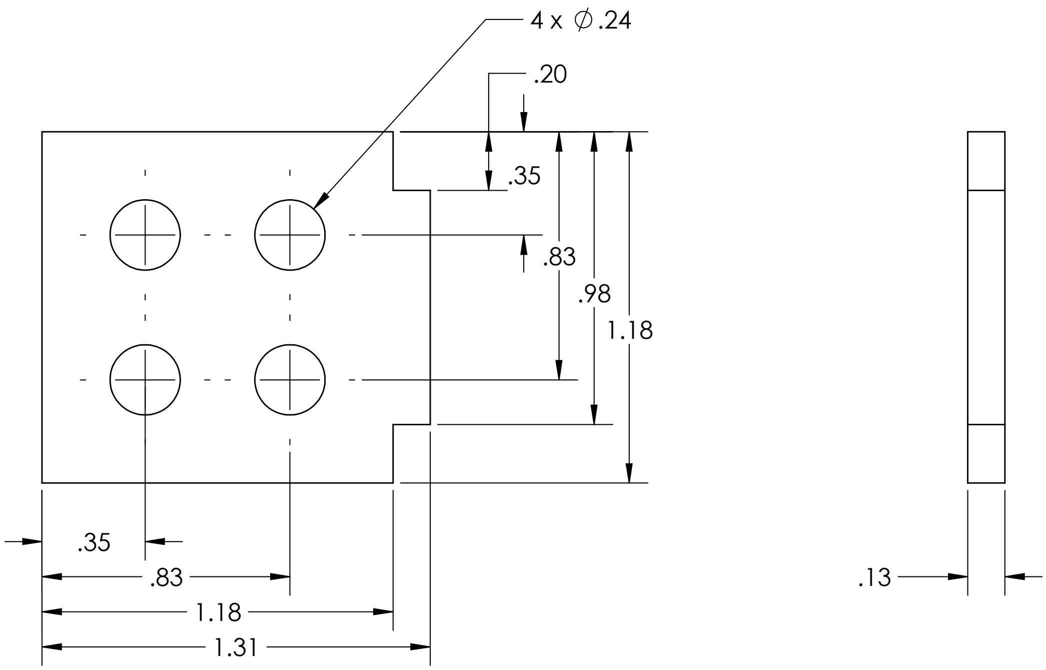
B B



A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAE 94 - UCLA
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	12/06/18	TITLE: Top Plate
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Acrylic	COMMENTS:			SIZE A / DWG. NO. 4-1 / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 / WEIGHT: 0.07 LBS / SHEET 5 OF 12

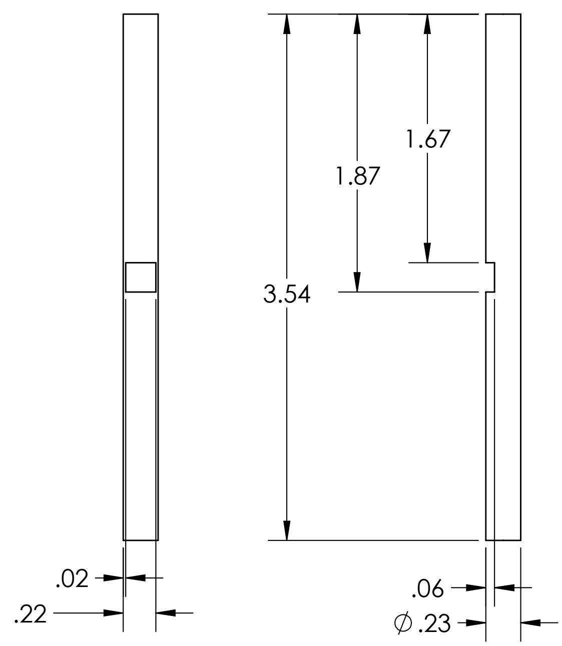
2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAE 94 - UCLA	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	12/06/18	TITLE:	
	CHECKED			Band Holders	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Acrylic	COMMENTS:			SIZE A	DWG. NO. 5-1	REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 2:1	WEIGHT: 0.01 LBS	SHEET 6 OF 12

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
PLA - 100% Infill

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	W.T.	12/06/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY	USED ON
APPLICATION	

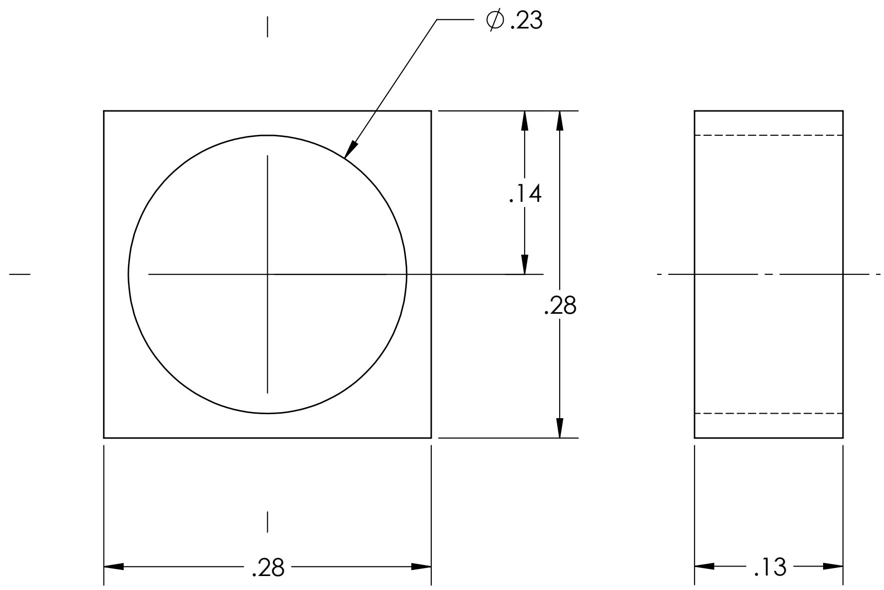
MAE 94 - UCLA

TITLE:

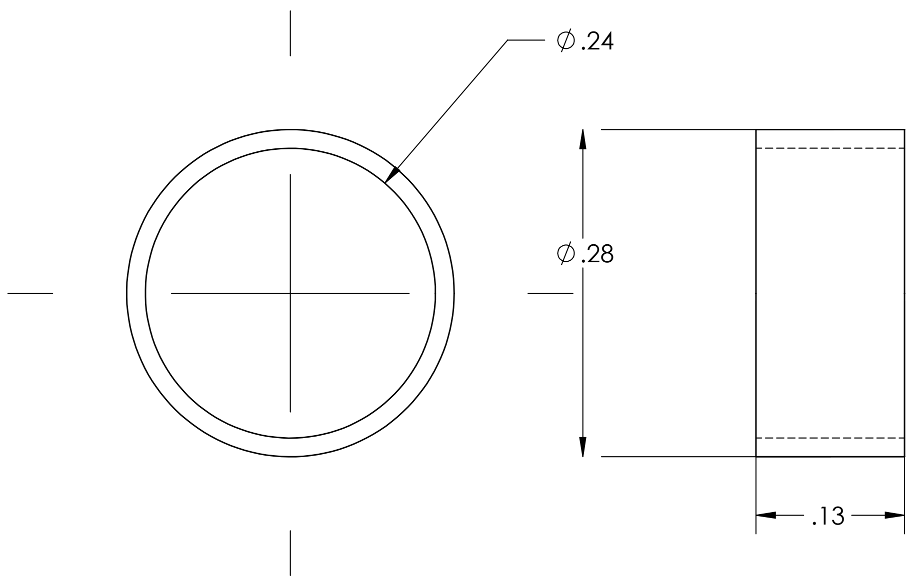
Axle

SIZE **A** | DWG. NO. 6-1 | REV

SCALE: 1:1 | WEIGHT: 0.01 LBS | SHEET 7 OF 12



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAE 94 - UCLA
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	12/06/18	TITLE: Nut
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Acrylic	COMMENTS:			SIZE A · DWG. NO. 7-1 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 8:1 · WEIGHT: .00002 LBS · SHEET 8 OF 12



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Acrylic
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	W.T.	12/06/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

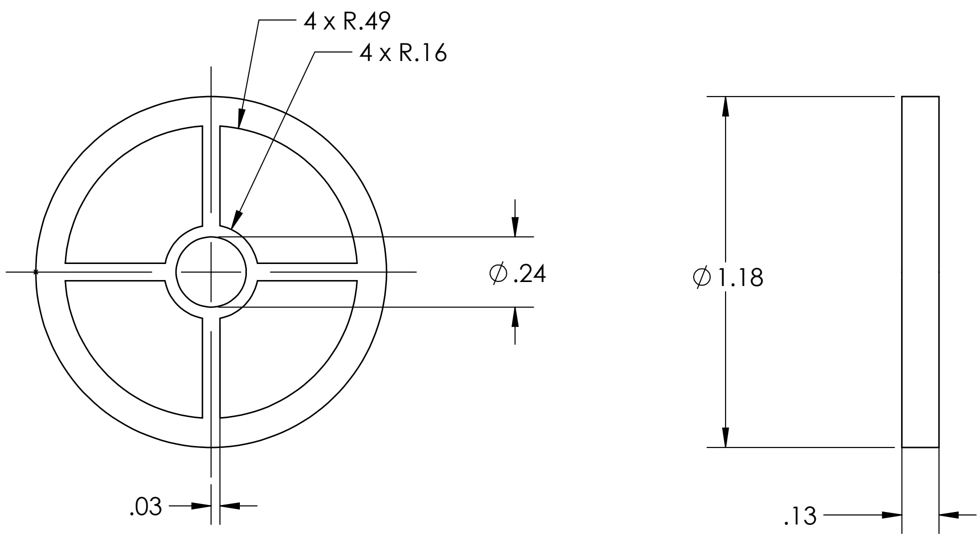
NEXT ASSY	USED ON
APPLICATION	

MAE 94 - UCLA

TITLE: Washer

SIZE A | DWG. NO. 8-1 | REV

SCALE: 8:1 | WEIGHT: .00007 LBS | SHEET 9 OF 12



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Acrylic

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	W.T.	12/06/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

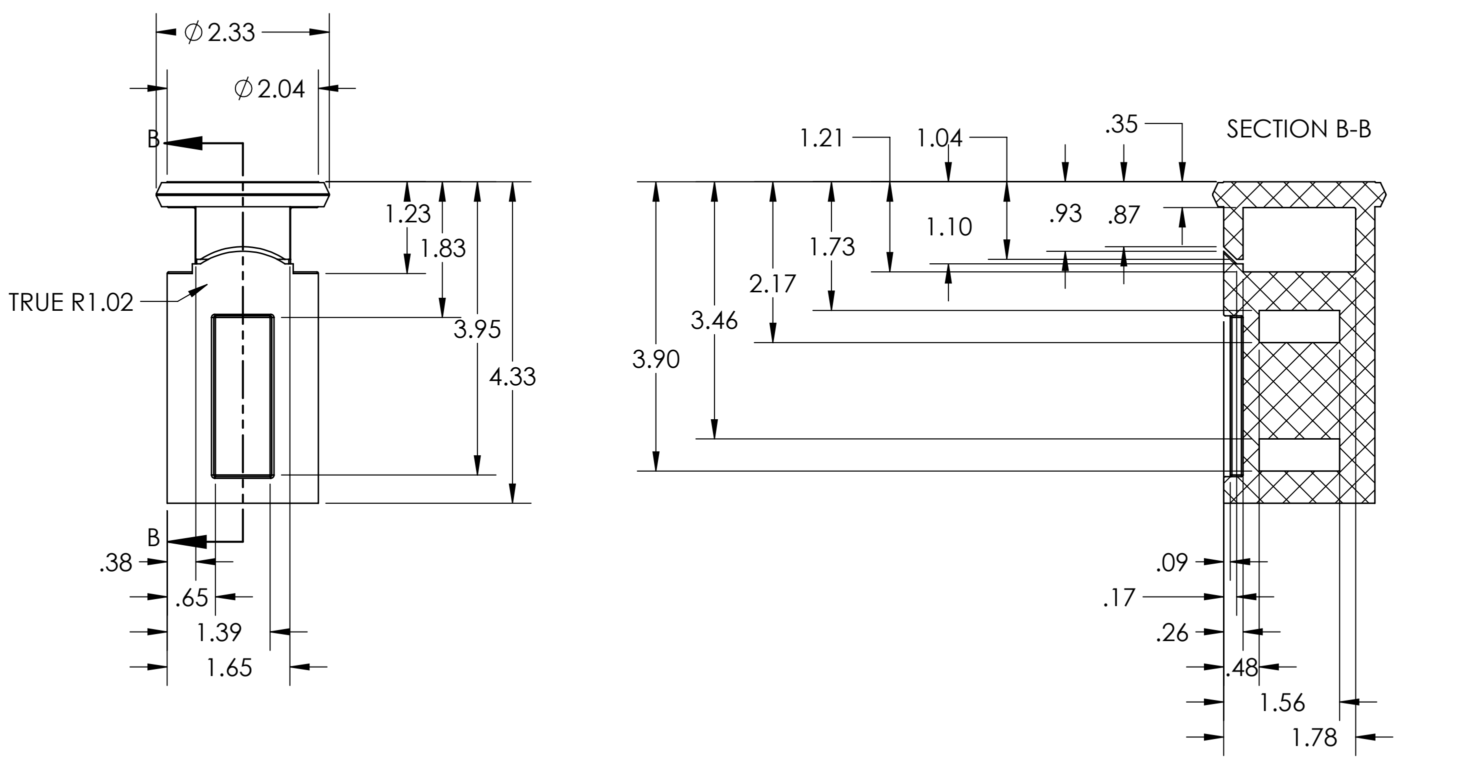
MAE 94 - UCLA

TITLE:

Wheel

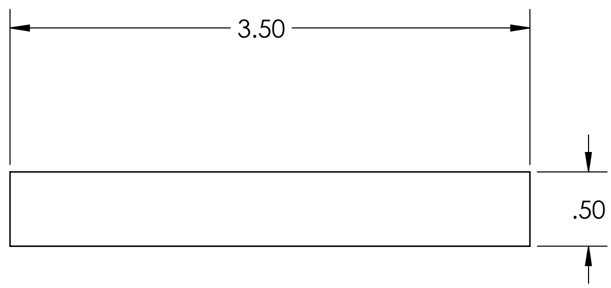
SIZE **A** DWG. NO. 9-1 REV

SCALE: 2:1 WEIGHT: .002 LBS SHEET 10 OF 12



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAE 94 - UCLA	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	12/06/18	TITLE:	
	CHECKED			Ram	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL PLA - 40% Infill	COMMENTS: ALL FILLETS .05 IN			SIZE A	DWG. NO. 10-1 · REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: .40 LBS	SHEET 11 OF 12

NEXT ASSY	USED ON
APPLICATION	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAE 94 - UCLA	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	W.T.	12/06/18	TITLE: Rubber Band	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Rubber	COMMENTS: SIZE 84 RUBBER BAND			SIZE A	DWG. NO. 11-1 REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: .004 lbs	SHEET 12 OF 12

NEXT ASSY	USED ON
APPLICATION	