Final Report: CAD Project
“The Wheel Roller”

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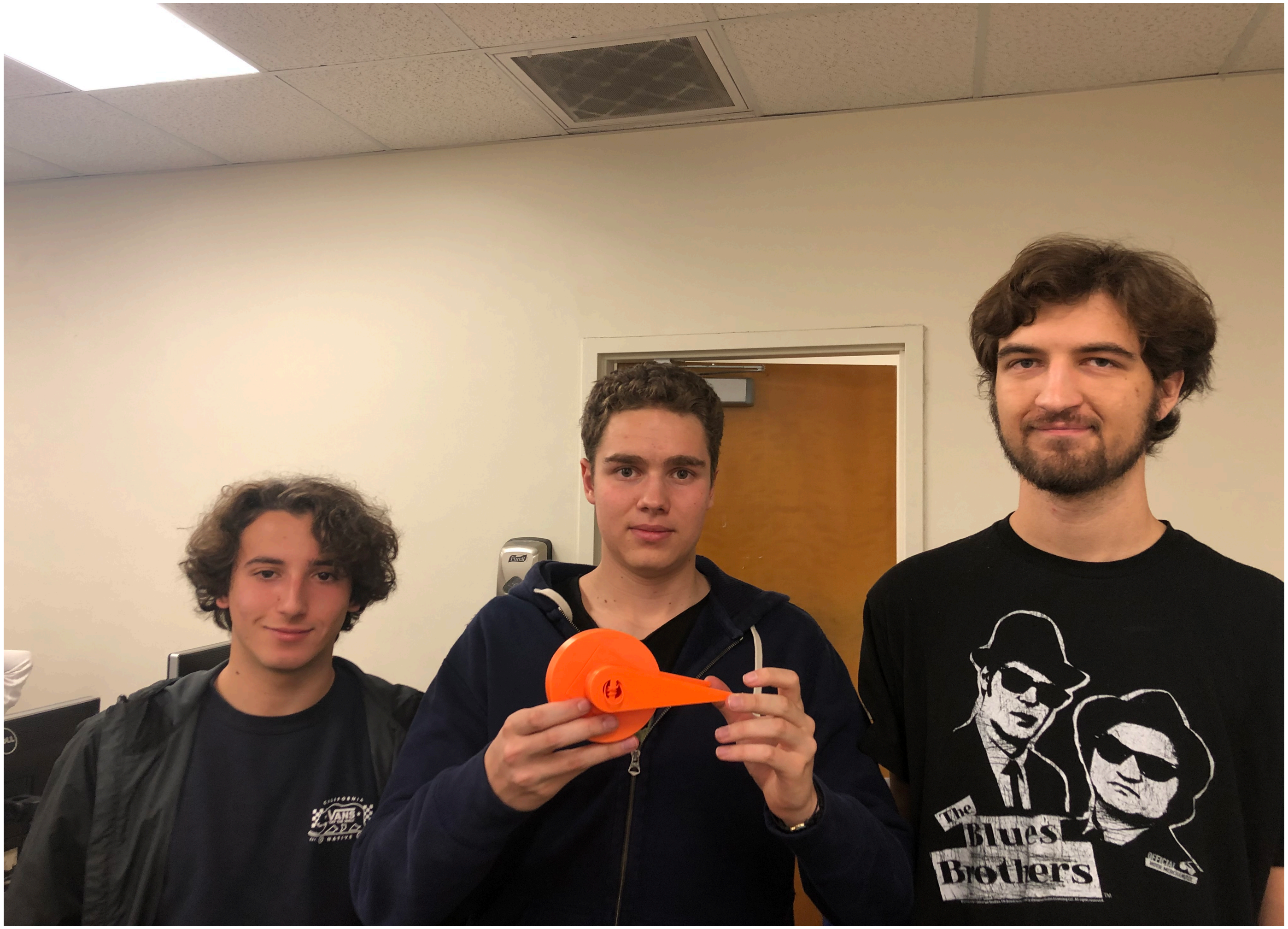

Pictured from left to right: K. Mohseni, M. Mitroshin, and J. Greenwood

Abstract

This report documents in great detail the process of designing and manufacturing a small rubber band powered vehicle. The design of the vehicle was inspired by Bright Lifes' rubber band powered vehicle design showcased in a YouTube video and a LEGO connector peg, but is significantly different from its inspirations. Before proceeding to the design, we outlined our goals, objectives, and were given several design requirements. Three similar design concepts were considered during the design process. The final design was the easiest to dimension, manufacture, and assemble due to simpler geometry of the parts. Moreover, it intended to perform the best.

Solid Modeling was performed for second and final design concepts, and parts drawings as well as an assembly drawing were produced from the final design concept. Solid modelling of the design was challenging because we wanted some of the parts to have an interference fit in assembly in order to remain still during the vehicle's motion while others had to spin without having too much friction with the neighboring part. As we did not want to use glue, extra accuracy was required in the design of all the details. Fabrication was tedious for several reasons. Primarily, it took over 11 hours for a single 3D printer to produce all the 7 parts. Secondary, as we used 10% infill for Pegs and Holes and 15% infill for the other parts, Pegs and Holes had to be printed separately. In the final version of the design, the "Wheel Roller" is an assembly of 7 parts. The parts for a single vehicle were produced by a 3D printer in about eleven hours.

For the final design, the assembly worked as intended, as the imprecisions in the manufacturing were insignificant. The device is propelled by four rubber bands by wrapping and twisting two rubber bands on each side of the Band Restraint and through each Hole and Peg. After winding the rubber bands via spinning one peg clockwise and the other one counterclockwise, we increase elastic potential energy of the rubber bands which is the converted into kinetic energy of the vehicle as it moves forward. For the vehicle to move in a straight line, equal amount of twists should be made on each side.

In the pre-competition tests the vehicle was able to move about 5 meters. Perhaps, reducing friction between the Pegs and Holes would allow the device to move further. Overall, we consider our product a success because it fulfilled our goals and objectives. Therefore, we believe our product can be used as a template or inspiration for other rubber band powered devices.

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1. Introduction and General Background

Although, small rubber band powered vehicles are mostly used as toys and nowadays are being substituted by toy vehicles powered by electric motors, there is still demand for these vehicles among those who cannot afford a motor-powered device and amateurs who seek to build their own small vehicles with materials at hand. However, the small rubber band powered vehicles made by amateurs mostly use “trial and error” method, so often their parts do not fit as desired or the devices do not work at all. Therefore, the UCLA Mechanical and Aerospace Engineering 94 class of Fall 2019 was tasked with designing and producing a working concept of a device that is powered entirely by rubber band(s) and is capable of travelling on a flat surface. To avoid the issues described above, we based our designs on calculations of the elastic potential energy stored by the rubber bands and consequently the force provided by the rubber bands. Furthermore, we utilized CAD software SolidWorks to design and dimension the parts of our vehicle. In an effort to address other current product shortcomings, such as rusting, inability to relaunch the vehicle right after finishes the ride, and small wheels getting worn out after several trials, and to fulfill the aforementioned need, we have designed a device that is made entirely of plastic, has a single big wheel, and is capable of being relaunched.

Our design process started with researching the existing designs of rubber band powered vehicles based on which we produced a hand sketch of a concept we intended to realize. After that we created a CAD model of our design and received approval for the concept from the Professor. After finalizing the design for the single parts, we created an assembly correcting any uncounted flaws in the design of the parts. Then, we estimated the spring constant of the rubber band(s) we were going to use, and the force that the rubber band(s) would exert on different parts of the car. Based on these calculations we eliminated the flaws in our design which perhaps would have been spotted only during the tests. The final version of our device was going to be made of Acrylonitrile butadiene styrene (ABS) or Polyactic acid (PLA) plastic and manufactured using a 3D Printer.

The device was built in accordance with several key design requirements, and ultimately will be pitted against competing designs. We are confident that our design will prove to be the most effective rubber band powered vehicle on the entire UCLA campus.

2. Design Goals and Objectives

The design goals and objectives for this project are outlined below:

The device must:

(1) Move under its own power on flat surface without falling apart using a maximum of 4 rubber bands

(2) Be Manufacturable on a 3D printer with the optional aid of adhesive

(3) Be easy to reset to a starting state

(4) Be self-contained with maximum dimensions of the device being 0.10 x 0.10 x 0.20 m^3

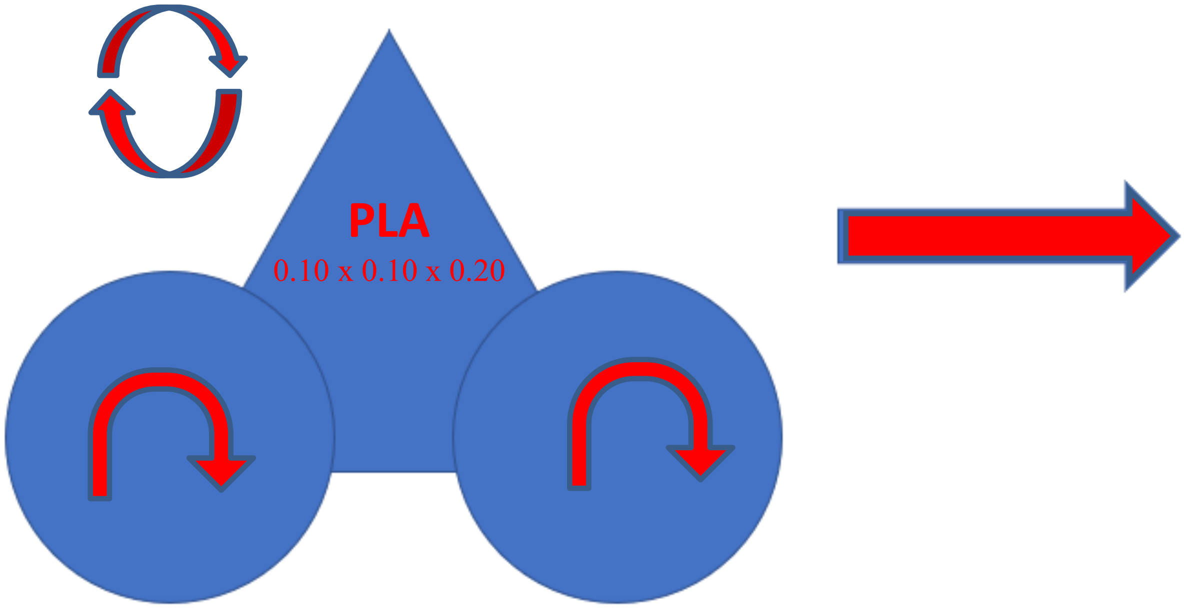

Figure 1: Demonstration of goals. The device must move under its own power

3. Prior Work (State-of-the-art) or Scientific History

There are many different ways to power a car with rubber bands. The most popular ones include twisting the rubber bands and tensioning the rubber bands to rotate either the wheels or propeller connected to a car. For this design, inspiration was drawn from two sources. The first is from a YouTube video by Bright Lifes, as pictured in Figure 1. The idea is to use the rotational torsion of the rubber band instead of linear stretching. A slightly different approach was be taken to this concept, requiring a rotating joint. The inspiration for this joint was drawn from the LEGO connector peg.

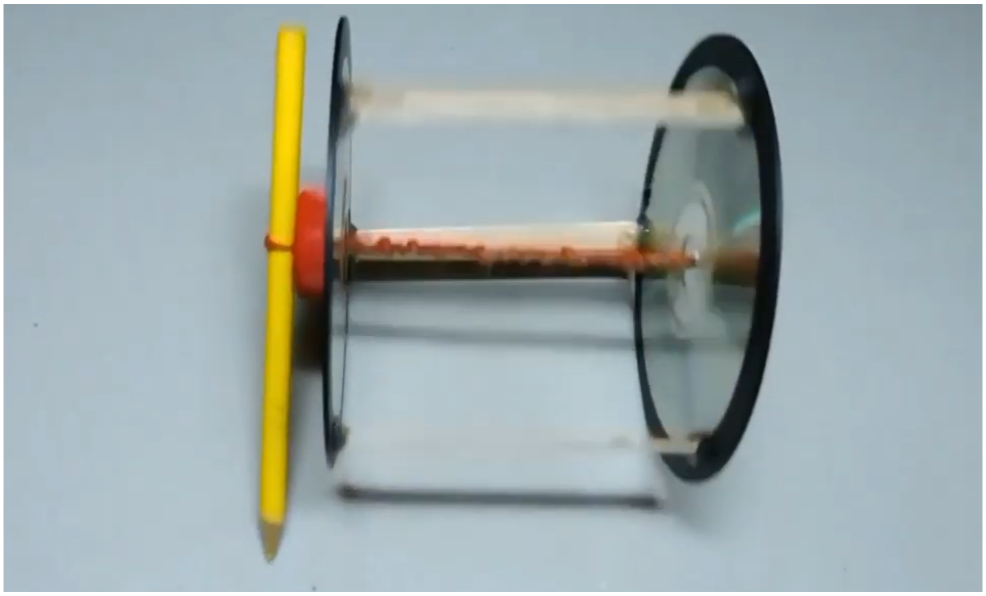

Figure 2: Rubber band powered car manufactured by Bright Lifes on YouTube [1]

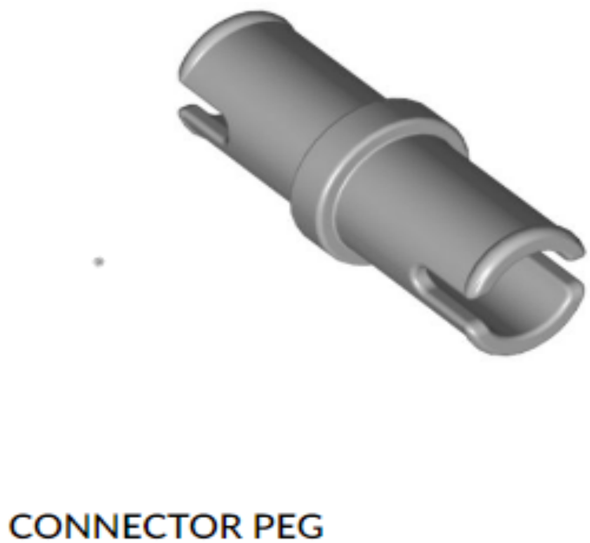

Figure 3: The LEGO connector peg which inspired our design [2]

We decided to implement a different approach to the torsion concept by using a single wheel and multiple “legs” to ensure straighter motion.

4. Concept Development

4.1. First Design Concept

The initial design was based upon 6 parts. The first part is a 10 cm diameter wheel with a whole through the center. This whole has three notches. The next part is a band restrain. This part holds the rubber bands in the middle of the wheel. Two rubber bands are connected to either end. This piece is connected to the wheel using the insert. This part attaches the wheel to the band restraint. The other end of the rubber bands is connected to the legs. These are parts with the peg piece modeled after the LEGO peg. These pegs are inserted into the hole part. These parts have a circular lip for the peg to be inserted into and have the negative profile of the hole in the wheel so they can be inserted snugly. Additionally, there is a connector bar to balance the force created by both legs.

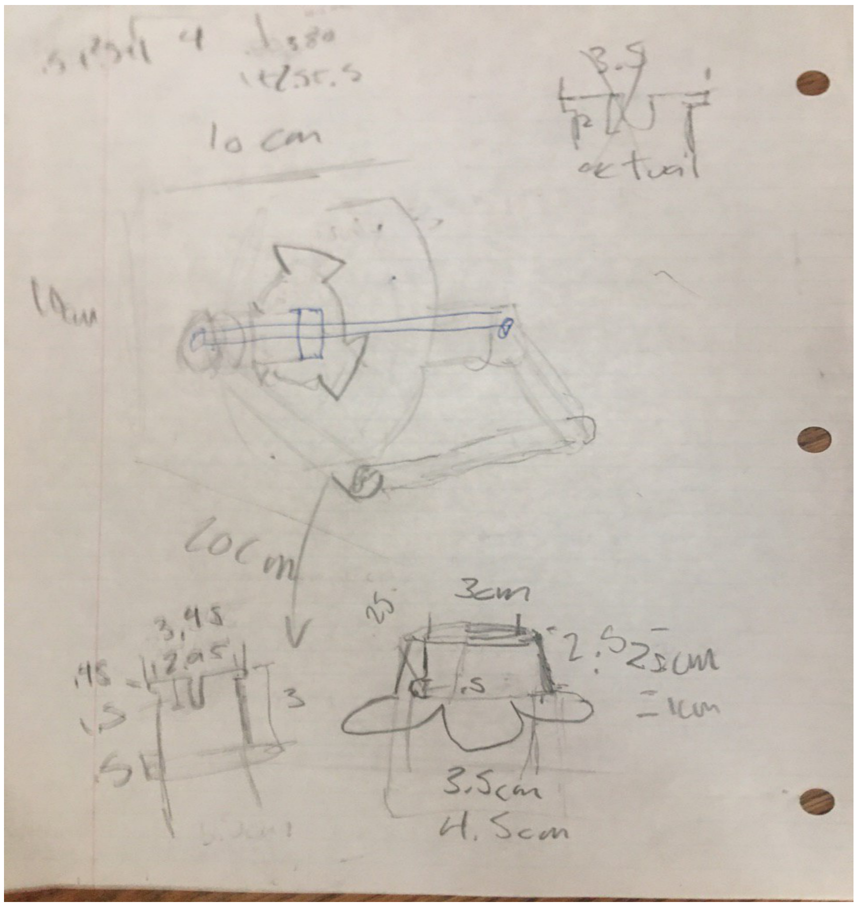

Figure 4: Schematic of the initial design

4.2 Second Design Concept

In this first revision, the concept was created in SolidWorks. The connector bar was omitted, but the slots in each leg were left in case one was necessary. However, through testing, it was determined that one would not be necessary. The initial three petal design was replaced with a five petal one. The thought was that this would be more secure.

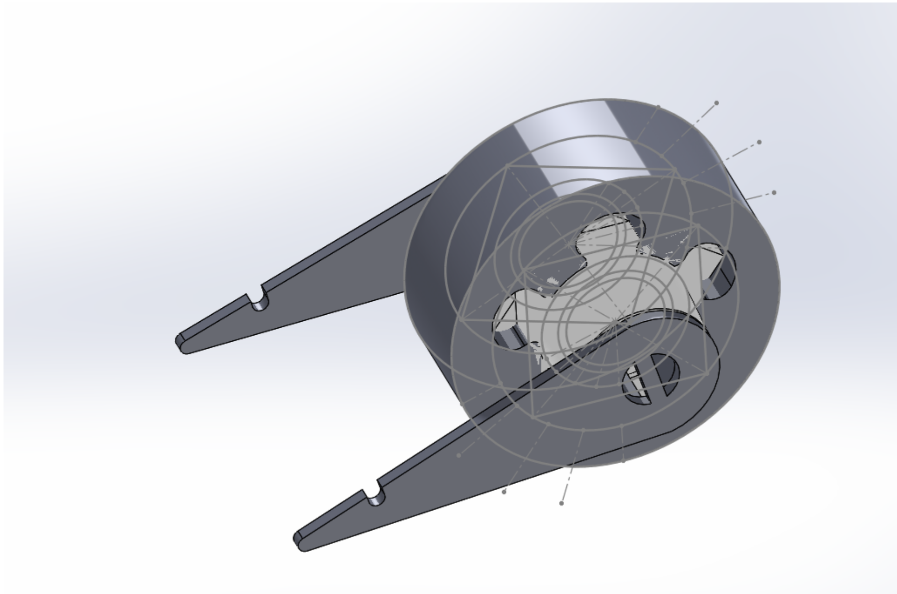

Figure 5: First SOLIDWORKS model assembly

4.3 Final Design Choice

For our final revision, the slots for the connector bars were completely removed as seen in Figure 6. Additionally, the design for the wheel hole was again changed, this time to a square. This made manufacturing much easier and lowered the print time. Through testing, it was determined that the device would perform more effectively if the diameter of the hole and the peg parts was smaller. For this revision, it was shrunk on both parts.

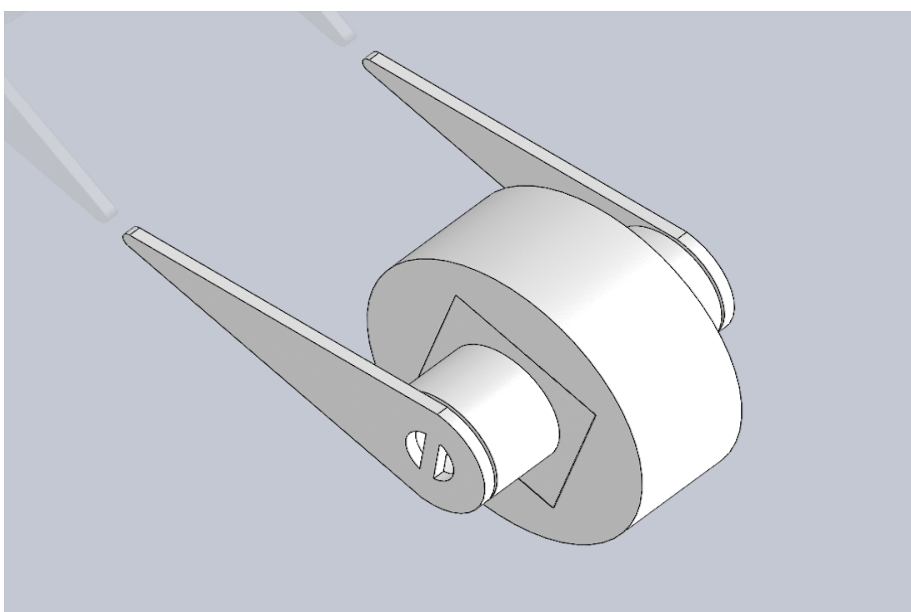

Figure 6: Assembly of the final SolidWorks design

5. Theoretical Calculations

In order to determine the total mass of our cutting device, we had to find the density of PLA plastic. The density is 1.24 g/cm³. All parts were made of PLA plastic. Using SolidWorks the total mass of the device was estimated to be 0.0497015 kg.

The mass was estimated first by measuring its weight and then compared with the mass calculated by using the "mass properties" feature of SolidWorks. The mass estimations for the complex parts in our design can be found below in Table 1.

Table 1: Mass of Each Part

Part	Mass (kg)
Wheel	.0307455
Peg 1	.001815
Peg 2	.001815
Hole 1	.003433
Hole 2	.003433
Insert	.0082575
Band Restraint	.0002025

6. Design Specifications

The device is made of 7 parts. In this section we outline the design specifications of each part and of the final product.

6.1 Final Design Description

The 7 parts that make up our vehicle are the Wheel, the Insert, the Band Restraint, the two Pegs, and the two Holes. The overall dimensions of the vehicle are given in Table 1.

Table 2: Device Dimensions

Parameter	Value
Length	.168 m

Height	.100 m
Width	.098 m
Weight	3.590132 N

The Solid Model of the final assembled device and a caption of the device's interior can be seen below. Black arrows show the direction which the Pegs are twister, the wheel spins, and the device moves. Each part's functions and design are described in detail in the next section. The device is propelled by four rubber bands by wrapping and twisting two rubber bands on each side of the Band Restraint and through each Hole and Peg.

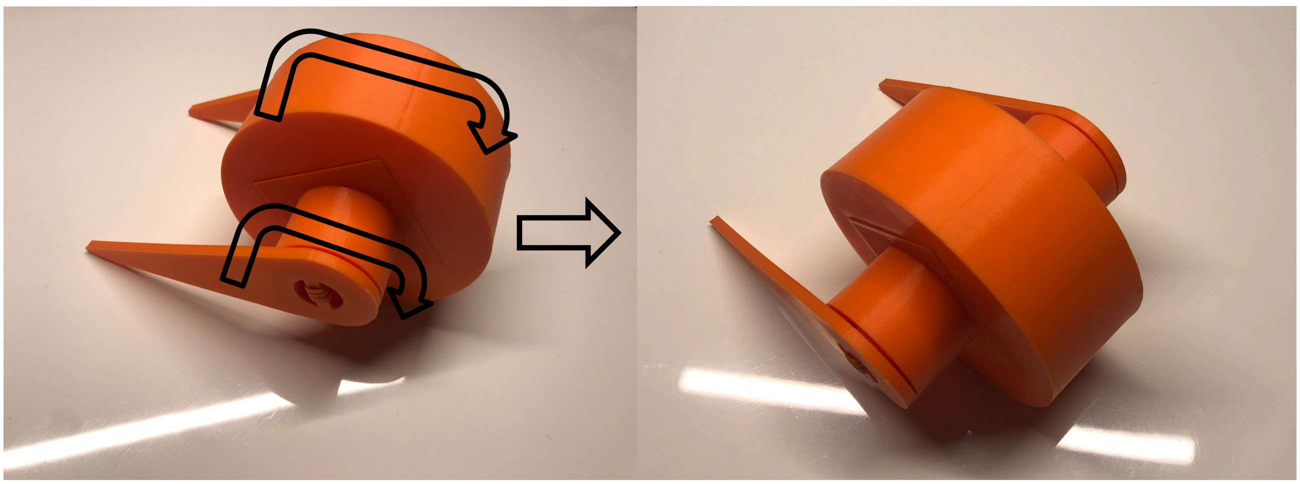

Figure 7: Solid model of the final assembled device "The Wheel Roller".

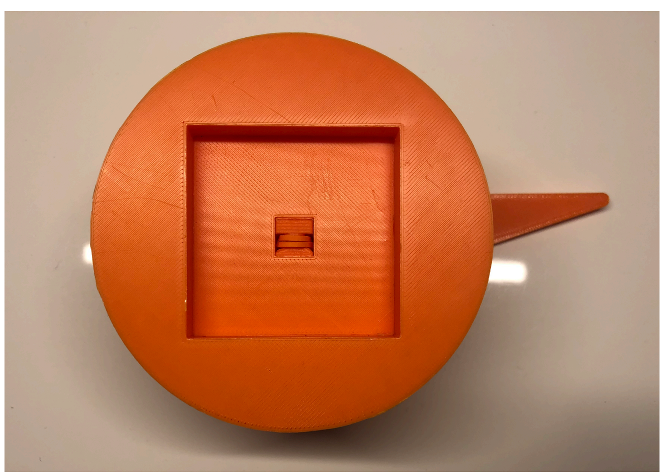

Figure 8: Showcase of the interior of the solid model of the final assembled device "The Wheel Roller"

From the Figures above it can be observed how the rubber bands are attached to the Pegs and Band Restraint. To wind the rubber bands the user has to simply twist one peg clockwise and the other peg counterclockwise.

The exploded view gives a better understanding of the part's design and powering of the device, because parts of details/whole details as well as the rubber bands are hidden inside the device. The exploded view of the device's assembly is seen below and the full-size assembly drawing is available in Appendix B.

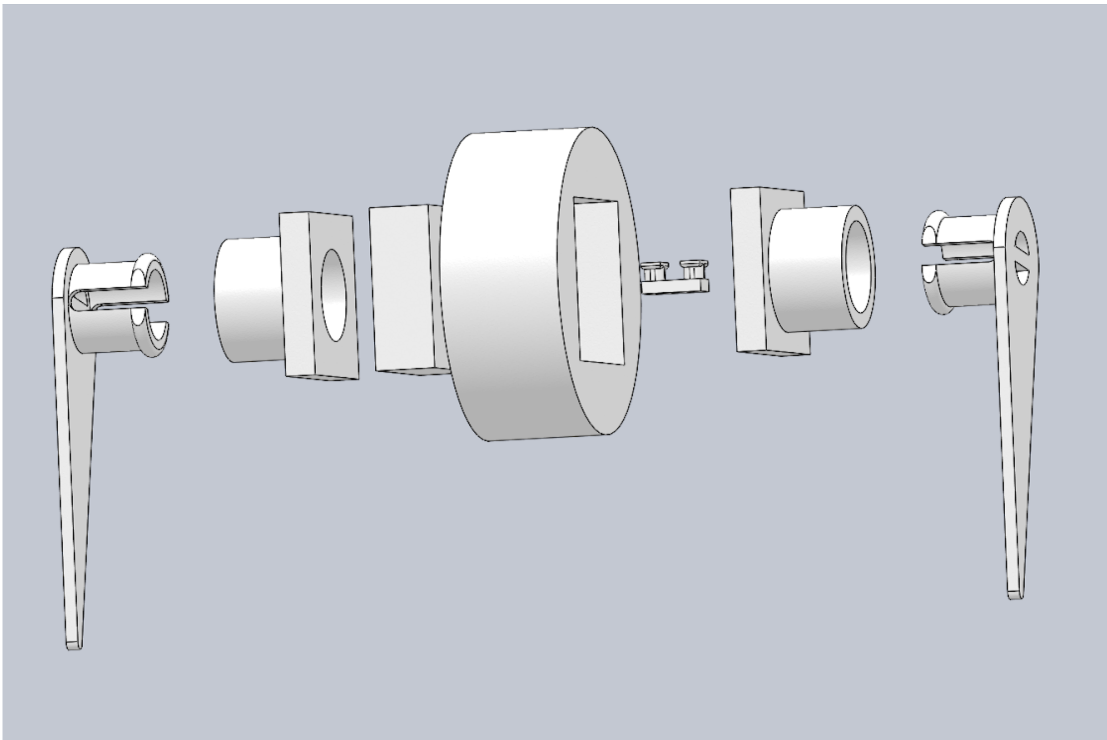

Figure 9: Exploded view of the device's assembly

6.2 Device Parts Design

Wheel

The Wheel is located in the center of the vehicle and is the only part meant to come in contact with the ground. The force generated by the rubber bands is meant to be output onto the Wheel. The infill on this part is 0.15 as it's meant to be heavy enough to keep moving forward by having a high moment of inertia.

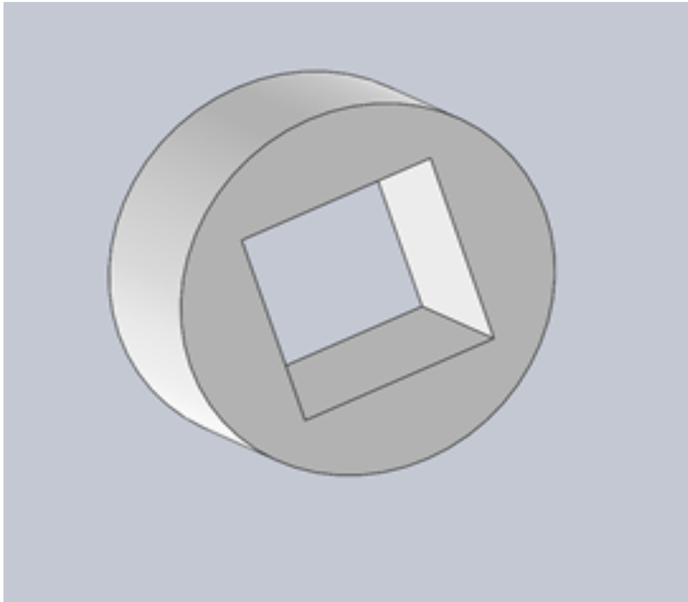

Figure 10: Wheel component of the final design

Insert

The Insert is designed to fit securely inside the square hole of the Wheel and secure the band restraint to which the rubber bands are attached. The simplest possible geometry was chosen for this part and hole to facilitate manufacturing and assembly. The size of the hole was chosen to have interference fit with the band restraint.

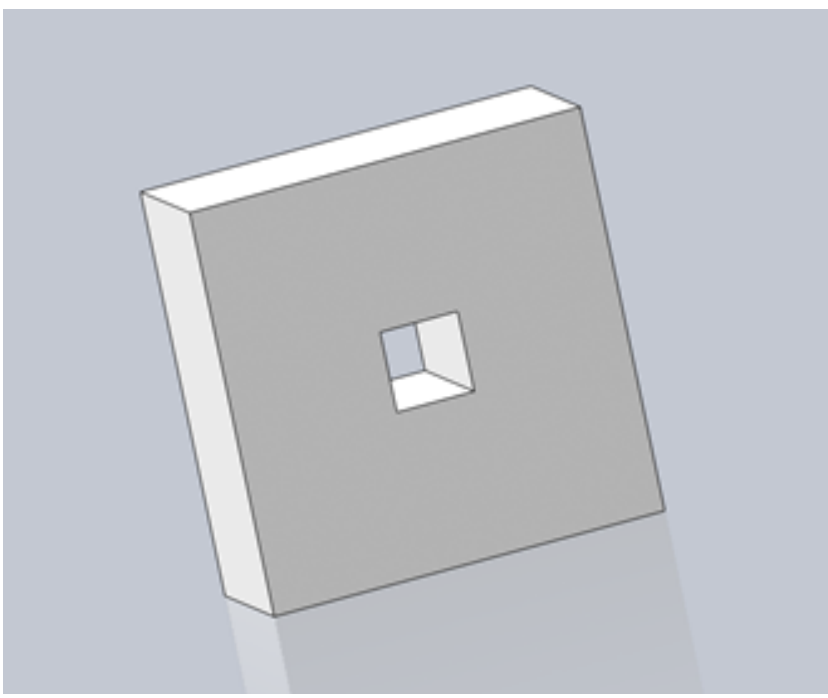

Figure 11: Insert component of the final design

Band Restraint

The Band Restraint is what all four rubber bands are meant to be attached to (two from each side), and is placed inside the hole of the Insert. Therefore, the unwinding of the rubber bands causes it to spin in one direction, which in turn causes the Insert and Wheel to spin in the same direction. All the power is transferred from the rubber bands to the Wheel through the Band Restraint. It's the smallest part in the entire vehicle and weighs the least but experiences the most force. The fillets were used for this part to make sure the rubber bands attached to it are not cut while unwinding. Higher infill (15%) was chosen for this part to make sure it doesn't break due to normal force from unwinding rubber bands.

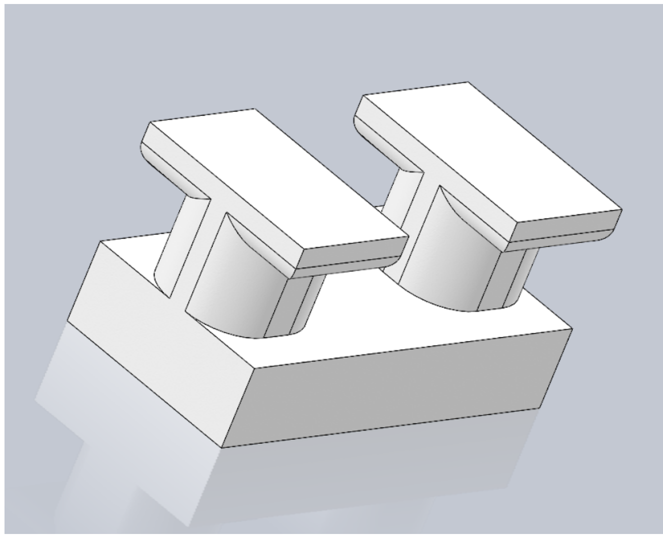

Figure 12: Band Restraint component of the final design

Pegs

There are two Pegs, one attached to each Hole on either side of the Wheel. The Pegs are meant to fit securely inside the Holes while not having too much friction to the point where they aren't able to spin. Ideally, the rubber bands on each side would unwind in the same direction to cause the Pegs to spin in the same direction and propel the Wheel either forward or backward. It is one of the parts most likely to fail due to too much friction, preventing the vehicle from moving. It's not meant to weigh too much and is very thin. The other ends of the rubber bands are meant to attach through and around the two semicircular holes on the outside of the Pegs. This way the whole vehicle is attached as one system.

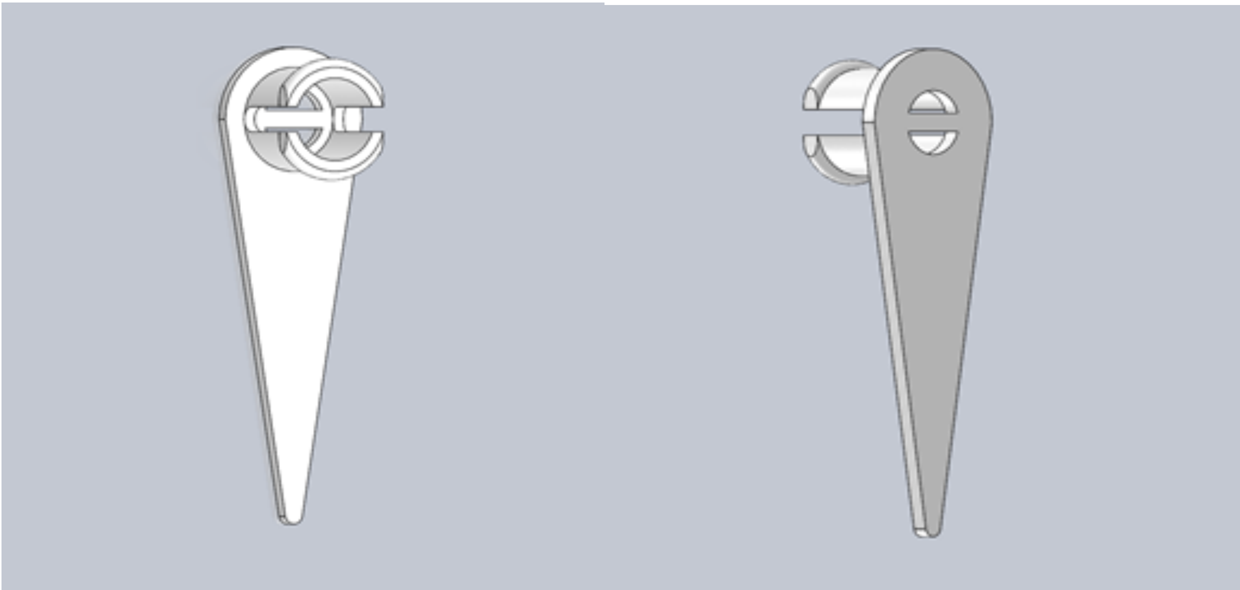

Figure 13: Peg component of the final design

Holes

The Holes are designed for the square side to fit into the edge of each side of the Wheel and the circular side to protrude out the sides of the Wheel and carry the two Pegs. This part is not meant to have a lot of friction with the Peg, but should tightly fit inside the Wheel not to fall out of the Wheel during the vehicle's motion due to normal force from the twisted rubber bands.

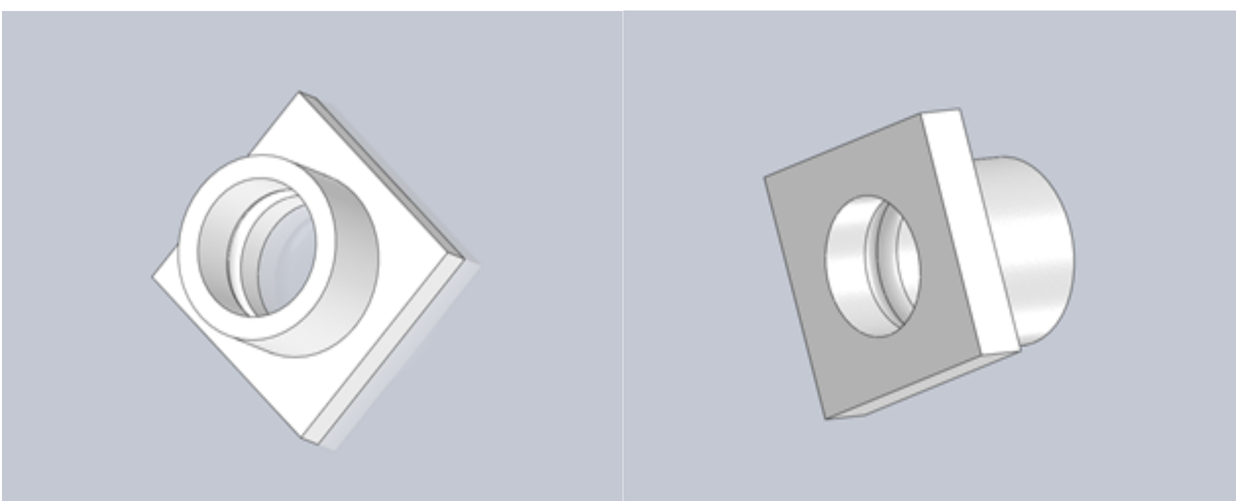

Figure 14: Hole components of the final design

Detailed engineering drawings of the pats described above can be found in Appendix A.

6.3 Powering the Device

The device is propelled by four rubber bands by wrapping and twisting two rubber bands on each side of the Band Restraint and through each Hole and Peg. After winding the rubber bands via spinning one peg clockwise and the other one counterclockwise, we increase elastic potential energy of the rubber bands which is the converted into kinetic energy of the vehicle as it moves forward. For the vehicle to move in a straight line, equal amount of twists should be made on each side. Figures 6 shows how the rubber bands are attached and twisted through the wheel for each side.

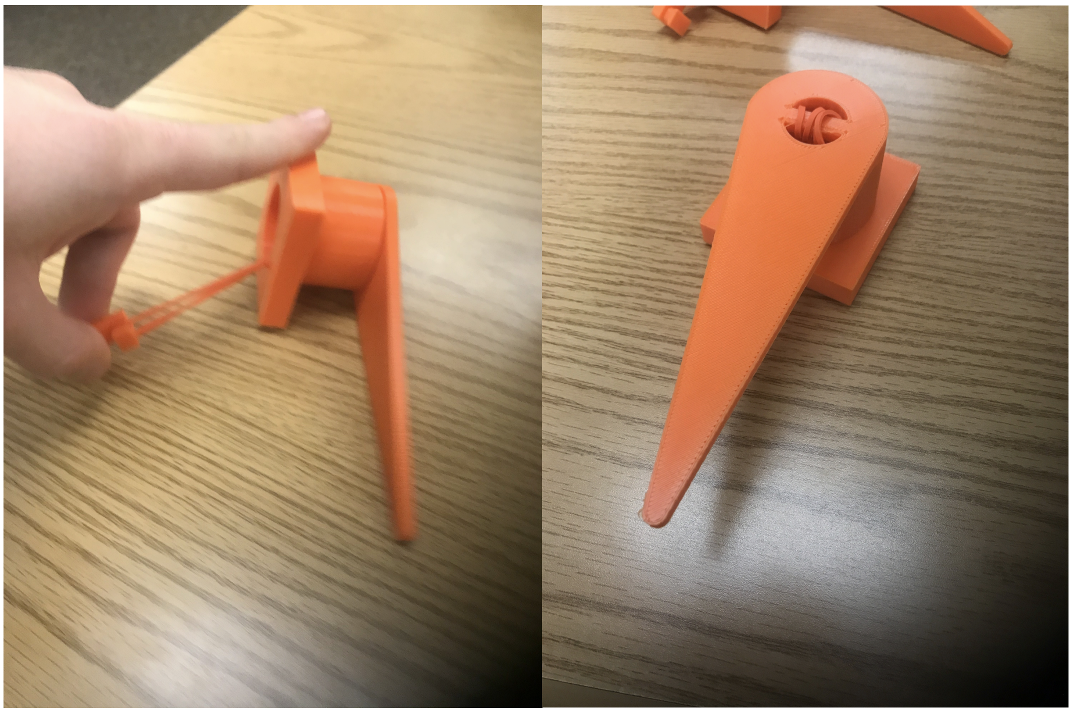

Figure 15: Showcase of how the rubber bands are attached and twisted through the wheel for each side

7. Manufacturing and Fabrication

All the parts were 3D printed on the UCLA Makerspace's 3D printers using PLA filament. The wheel, band restraint, and insert have a 15% infill with a gyroidal infill pattern. Both peg and hole parts have a 10% infill and use a concentric infill pattern. To assemble the device, the pegs are fit into the hole by forcing the two flanges together and forcefully inserting into the holes until they pop into place. Next two rubber bands tied to each peg. The rubber bands from one of the pegs are attached to the band restraint. Then the band restrain is threaded through the insert and the insert and the hole assembly are inserted into the wheel. The rubber bands from the other peg are connected to the band restraint and then that hole is also inserted into the wheel. The pegs are turned to wind and tension the rubber bands.

8. Conclusions

As a result of various design iterations, the completed rubber band propelled device, the “Wheel Roller” is an assembly of 7 parts. All the parts were initially sketched on paper by us inspired by several YouTube videos. Three different design concepts were considered during the design process. The device had the same dimensions and was powered identically in these design concepts, but the fitting of the parts in these concepts was different due to different geometry of the hole on wheel and consequently the two identical band restraint details. The following design was chosen, because it was easier to dimension, manufacture, and assemble due to simpler geometry of the parts. More complicated geometry was unnecessary for the device to achieve the goals.

Solid Modeling was performed for second and final design concepts, and parts drawings as well as an assembly drawing was produced from the final design concept. Solid modelling of the design was challenging because we wanted some of the parts to have an interference fit in assembly in order to remain still during the vehicle’s motion while others had to spin without having too much friction with the neighboring part. As we did not want to use glue, extra accuracy was required in the design of all the details. Fabrication was tedious for several reasons. Primarily, it took over 11 hours for a single 3D printer to produce all the 7 parts. Secondary, as we used 10% infill for Pegs and Holes and 15% infill for the other parts, Pegs and Holes had to be printed separately.

Performance was tested for both design concepts. It was challenging to run the tests for the initial design of the “Wheel Roller” because the holes had a clearance rather than interference fit with the wheel. Gluing the parts was not an option because we won’t have been able to take out the rubber bands then if the design did not work. Therefore, the geometry of the was simplified in the final design concept. For the final design, the assembly worked as intended, as the imprecisions in the manufacturing were insignificant. However, another difficulty encountered in testing the device’s performance was that we had to figure which way to twist the peg on each side for the rubber bands to unwind in the same direction for the device to move. After several trials we figured out that one peg had to be twisted clockwise and the other one counterclockwise.

In the pre-competition tests the vehicle was able to move about 5 meters which perhaps is not its maximum distance as the rubber bands could have been twisted more, but we did not want them to get worn out.

We learned several lessons from designing and manufacturing this device. Primarily, we understood that the simplest possible geometry should be used for the details to facilitate both manufacturing and assembly. Furthermore, using the same infill for all the parts will eliminate the need for 2 separate printing jobs. Finally, we figured out that it is better to run the tests with the same rubber bands as would be used in competition to make sure the vehicle performs as intended. If we were to further develop the current design, we would concentrate on reducing friction between the Pegs and Holes. Perhaps, designing the holes and pegs in such a way that it would be possible to disassemble would allow periodic introduction of lubricants to reduce friction between these parts. Overall, we consider our product a success because it fulfilled our goals and objectives.

9. References

[1] https://www.youtube.com/watch?v=9WUGJRkxgoY, accessed 10/02/2019

[2] https://www.lego.com/en-us/page/static/pick-a-brick?query=peg&page=1, accessed 10/05/2019

10. Appendix

A. Parts Drawings:

In this appendix we post the engineering drawings of all the parts of the "Wheel Roller" device .

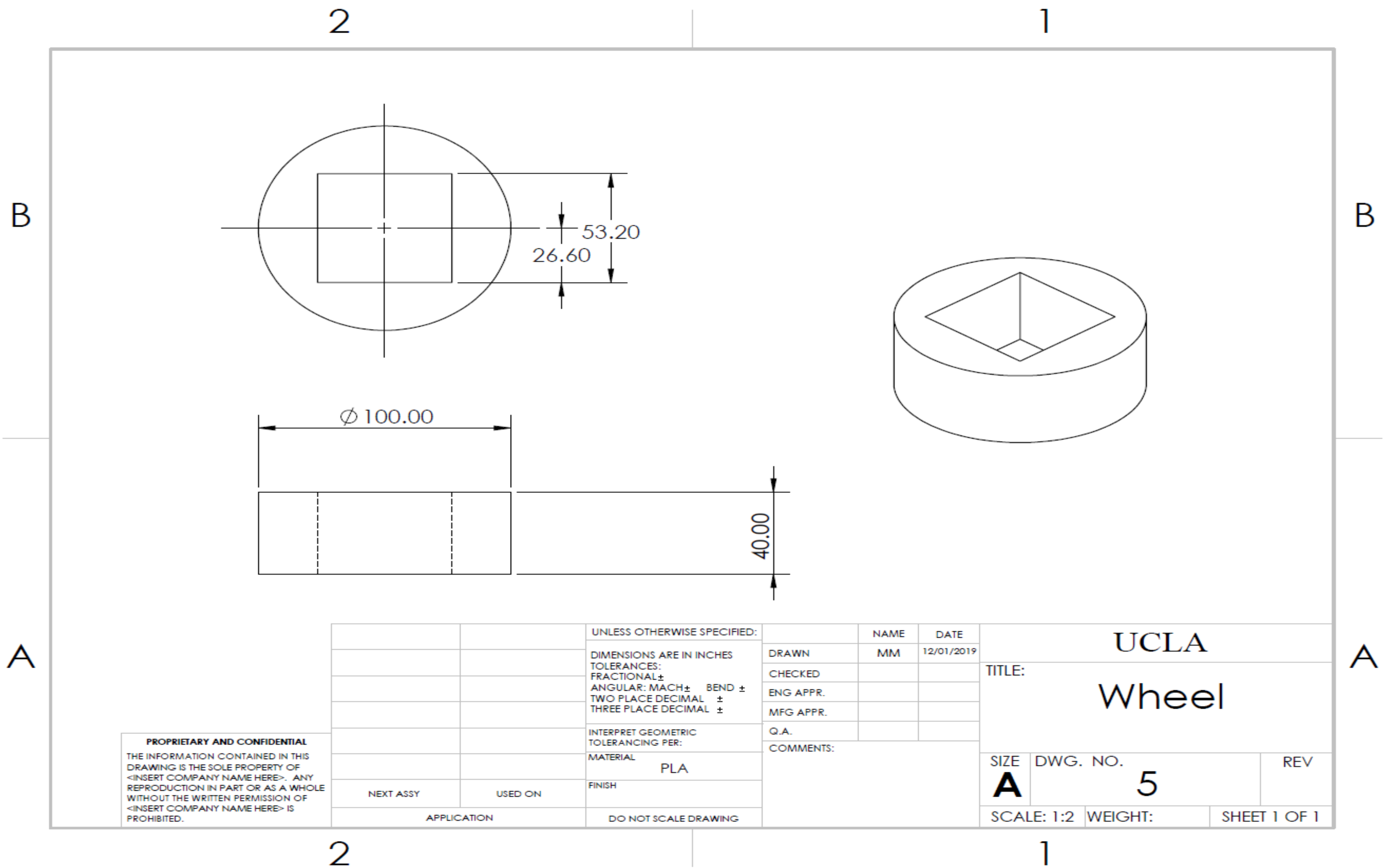

Figure 16: Drawing of the Wheel Component

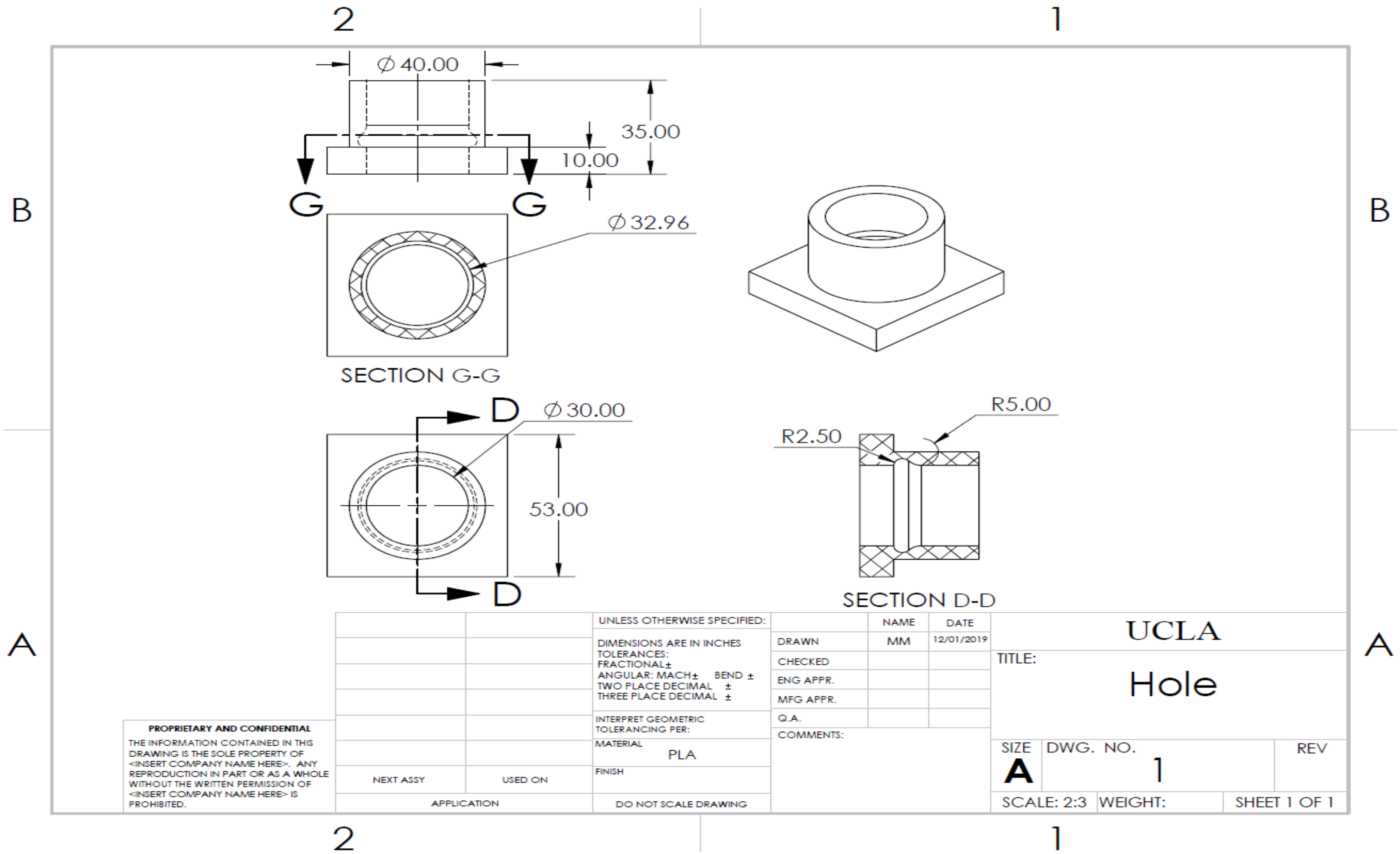

Figure 17: Drawing of the Hole component

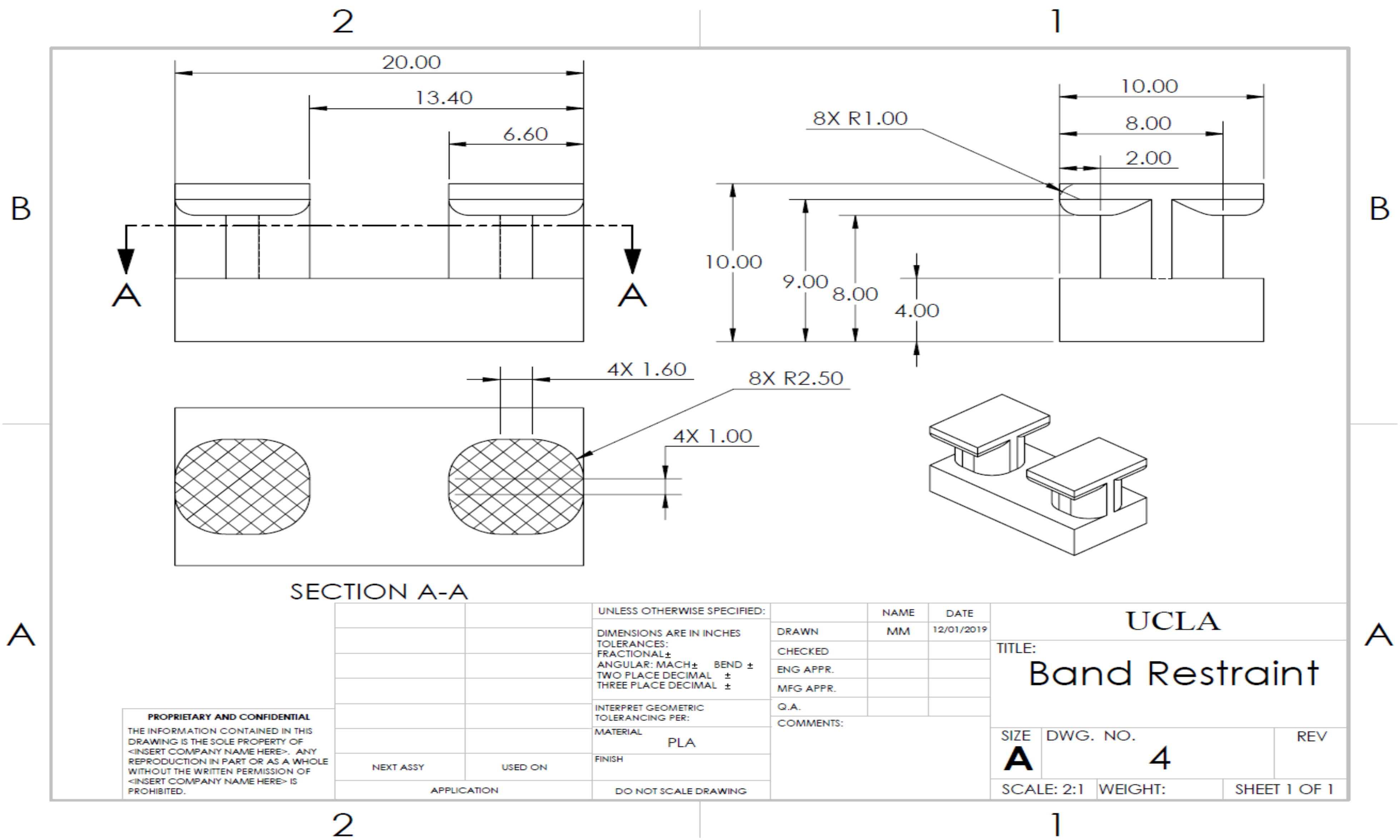

Figure 18: Drawing of the Band Restraint Component

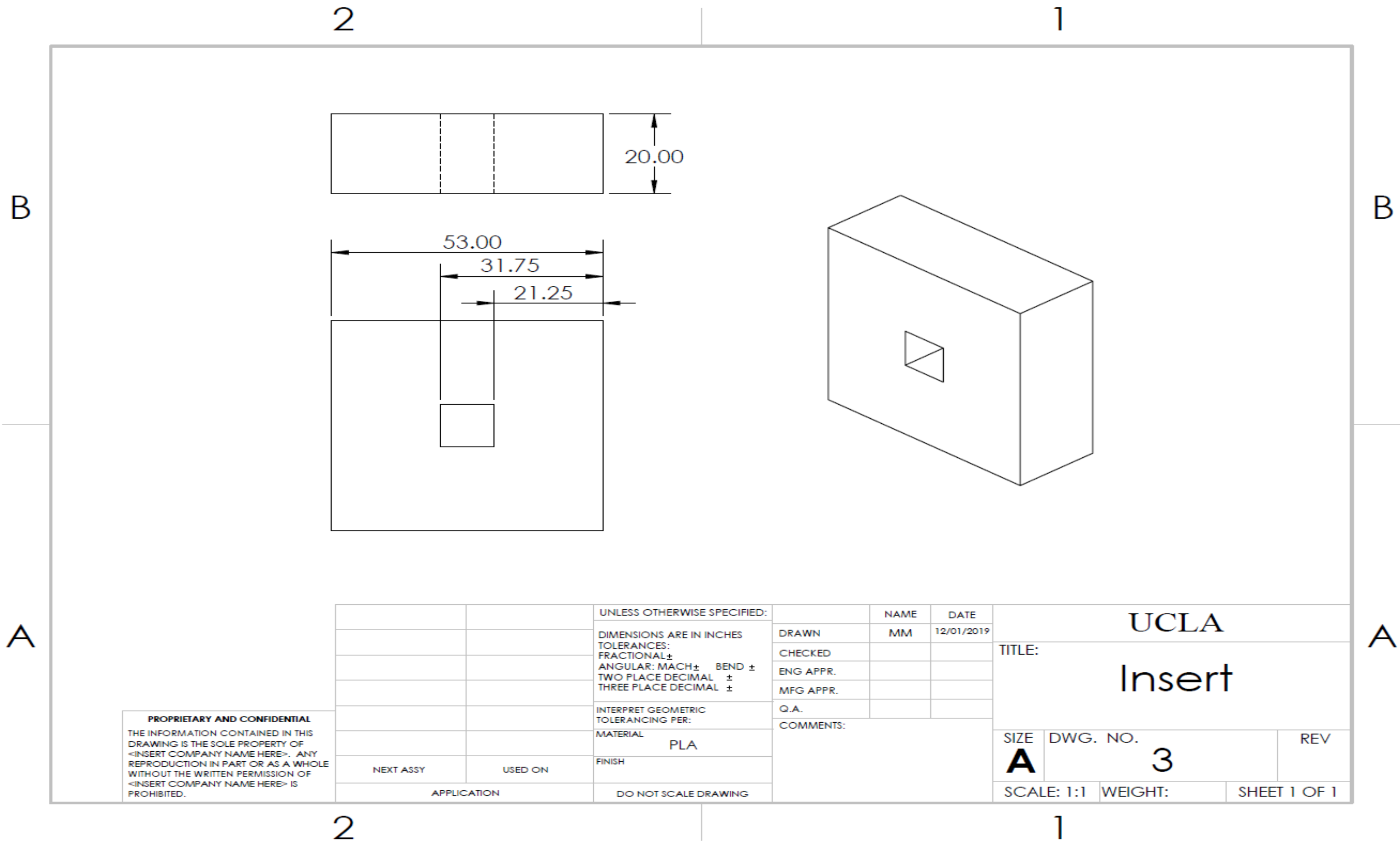

Figure 19: Drawing of The Insert component

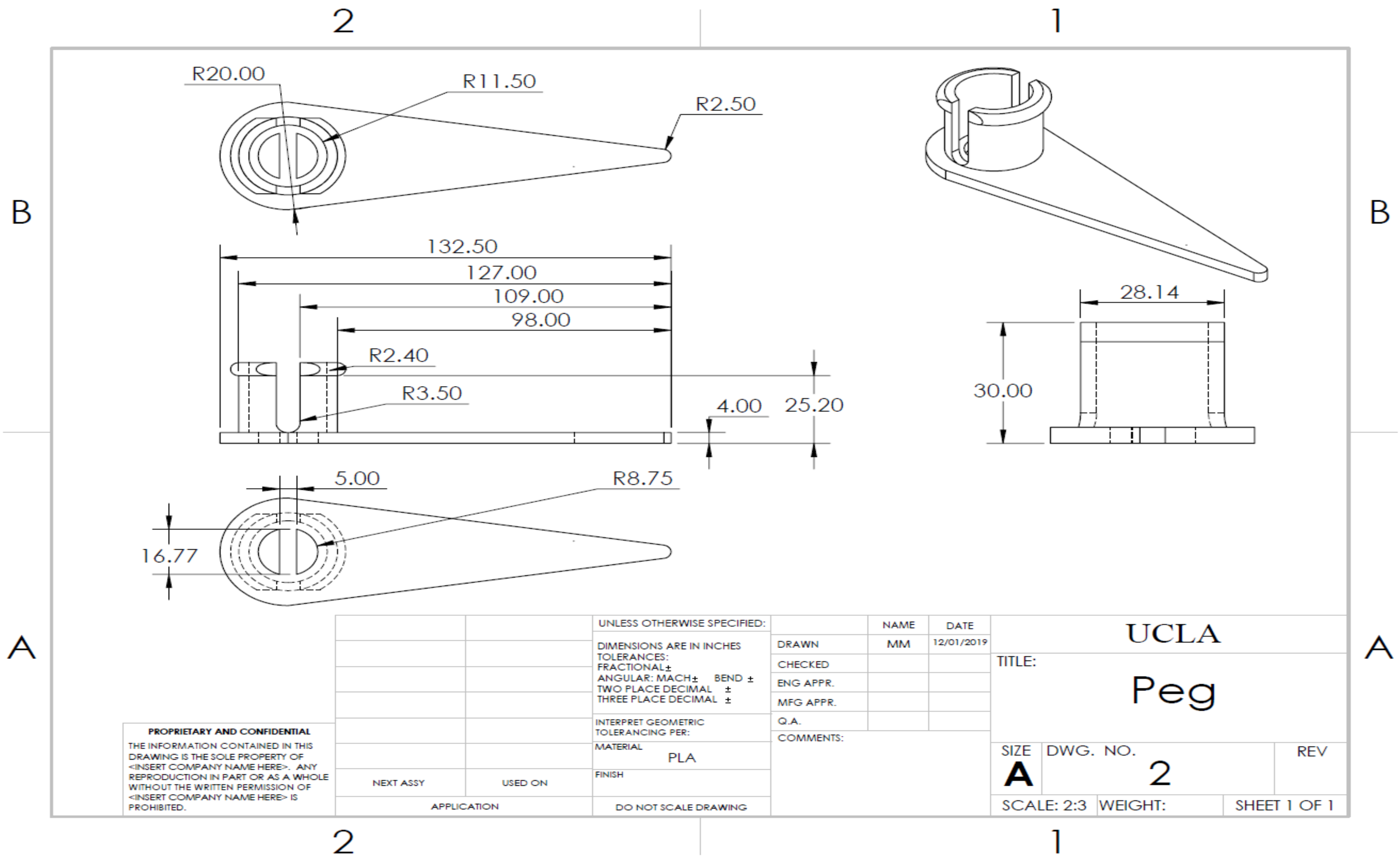

Figure 20: Drawing of the Peg component

B. ASSEMBLY Drawing:

In this appendix we post the assembly drawings of the “Wheel Roller” device .

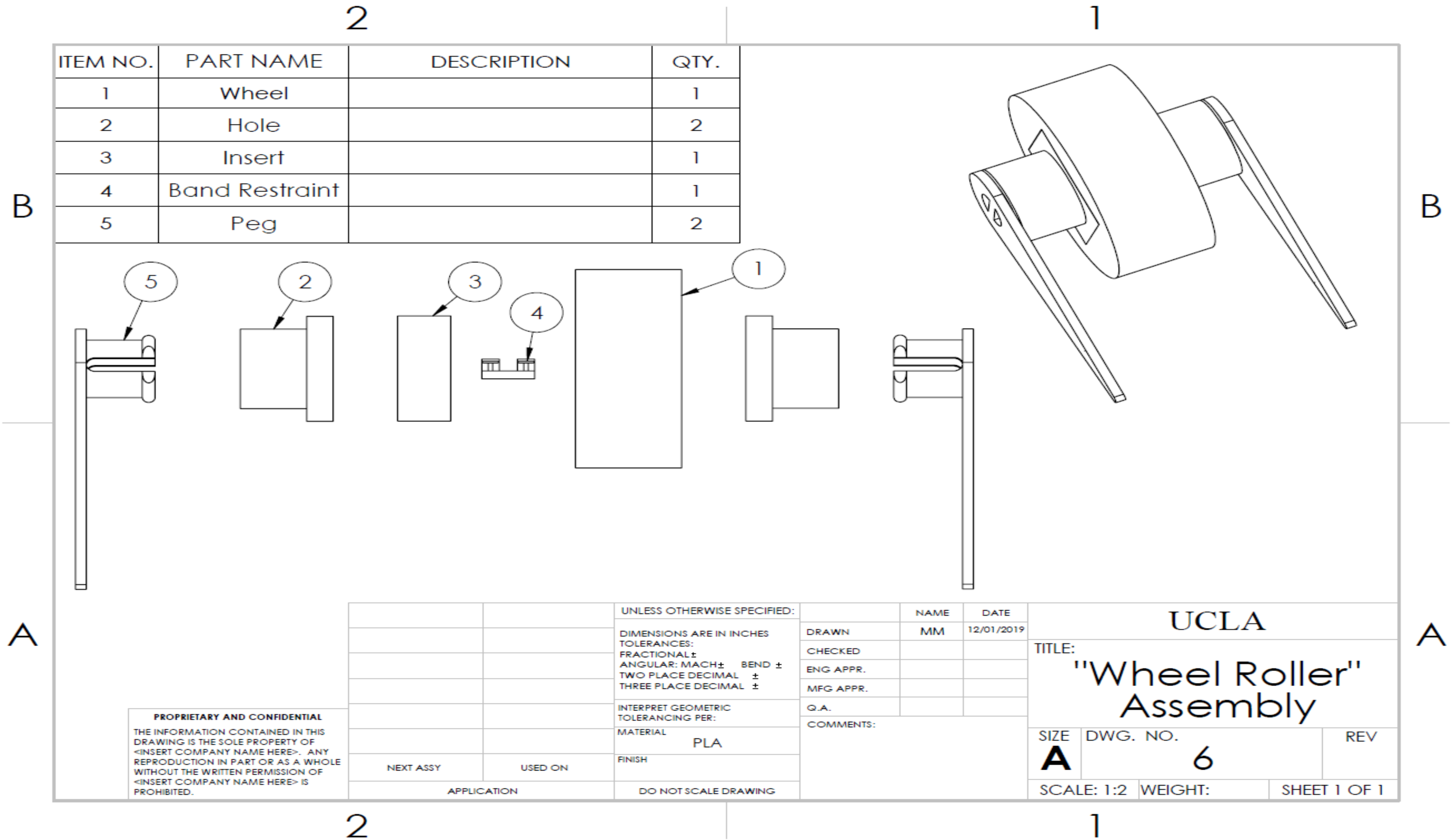

Figure 21: Assembly Drawing of the Final Design of the "Wheel Roller" device