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Name	Student ID	Signature*
Jordan Vanriel	xxxx53867	
Abdul Shahnawaz	xxxx99837	
Denish Suthaharan	xxxx63419	
Aston Wright	xxxx72204	
Sina Sartipzadeh Amirghasemi	xxxx01049	

(Note: remove the first 4 digits from your student ID)

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Abstract

Our group was given a task of building a car with these materials: 8 inch by 10 inch sheet of acrylic, a 12 inch dowel, 24 inch of string, 12 nuts and bolts, 2 paper clips and 6 rubber bands. The car had to be made in such a way that it can go through these challenges, travel 4 meters in 15 seconds while being relatively straight and be able to go up hill. For those challenges we had to make our car with some requirements such as the car having enough power/endurance, the car must be fast, and the car must be strong enough to hold its weight and the force applied on it by the rubber band. We made the front wheels of the car smaller than the rear wheels because we believe that give more power to the whole system, we added gears to the car because that make the power more constant rather instant, and we added rubber bands to the back wheels for more traction to the track. By doing these things to the car we were able to obtain a car that passes all our requirements and our testings.

Table of Contents

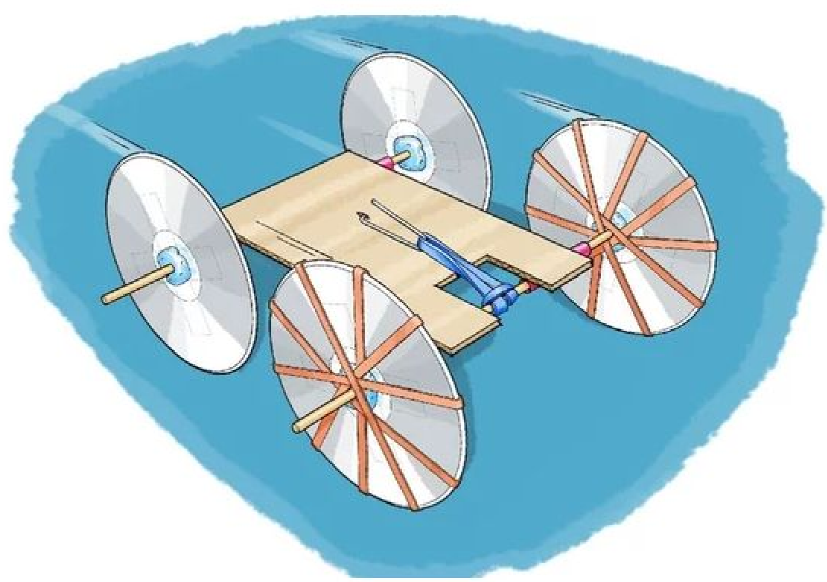
Introduction

Design Brief

In manufacturing the process behind designing a device or part is often more important that brashly manufacturing an unthought out device. This is due to many constraints put on manufacturers when developing a device. Likewise, in this project we are tasked to make a rubber band device. This design has a wide range of possibilities yet due to the restraints and rules on the design we must manufacture something that fits within them.

To fit these requirements we must design a device that can **travel uphill, travel a far distance, and be fast.**

Reference Design



[1]**Figure 1.0: Rubber Band car**

When doing research on devices that were powered by rubber bands, we had to keep in mind all the rules for the competition. This led our group to think about cars. A car would be able to drive uphill, go far distances as well as be fast. Thus, our group discovered a design for a rubber band car. Due to its 4 wheels, it would naturally have a straight path of travel as well as its rubber band propulsion, it would be able to perform the distance and speed competitions fine. As well, due to the added grip on the wheels from the rubber bands, it would also have a better uphill capability.

Discussion of Design

Product Requirements

1) Device must have endurance
    a) Must travel 4 meters
    b) Must not crash into guide walls
        i) Must stay within a 5ft width raceway
2) Device must travel through different terrains
    a) Must travel uphill
3) Device must be fast
    a) Must cross 4 meters of track in 15 seconds
    b) Must not be too heavy
4) Device cannot have any module parts
5) Device must be easily manufacturable
    a) Based on Material Constraints
    b) Laser Cutter Capabilities

Material Constraints

1) 8x10in by 1/8in thick acrylic
2) 12 #4-40 x 1/2in long screws and nuts
3) 6 rubber bands
4) 2 paper clips
5) 1/4in diameter wooden dowel 12in in length
6) 24inch of string

System Identification Matrix

The following table identifies what requirements will fall under our various systems. This will help the design process for our embodiments.

Table 1: System Identification Matrix

Functional Requirement	Structure	Propulsion	Wheels	Startup
Travel far distances		x	x	
Travel across different terrains	x		x	
Move quickly		x		x
No module parts	x	x	x	x
Easily	x	x	x	x

Manufacturable				

Morphological Chart

In the below chart we listed out embodiments for each of our sub systems

Table 2: Morphological Chart

Systems	Embodiments				
Frame (5)	Triangular Piece	Straight Bar	H-Bar	No Frame	Rectangular
Propulsion (4)	Elastic and gear	Elastic	Elastic and Flywheel	Fan	
Wheels (4)	Free Wheel	Power System wheel	Gear Wheel	Cylindrical wheels	
Startup (4)	Hold and release	Pull Back and release	Wind up	String Wind up	

320 possible designs.

Inconsistent Embodiments

Based on that rigorous evaluation, we decided to eliminate certain embodiments or combinations of embodiments which either do not fit with our requirements and/or do not fall within our material capabilities. Below we have provided explanations for each one of the embodiments and pairs of embodiments which have been removed.

- We removed the ‘No Frame’ embodiment due to it not following one of our constraints, being that the device must not crash into guide walls. Due to not having a frame we assume that the direction the device moves would not be as accurately straight as possible.
- We removed the ‘Hold and Release’ embodiment due to the requirement of a downhill surface which is not part of the competition guidelines
- We removed cylindrical wheels and straight bar due to the possibility of a fracture of the bar due to the weight of the wheels.
- We removed cylindrical wheels and fan due to not enough thrust being applied to push the weight of the wheels forward.
- We removed ‘Straight bar’ embodiment due to it being so fragile and not reliable enough to follow a straight path on its own.
- We removed ‘Fan’ and ‘Gear wheel’ due to lack of thrust being produced by the rubber band.
- We removed ‘No frame’ and Gear wheel’ because these two will not work together.

Table 2.2: Inconsistent Embodiment Chart

		Frame					Propulsion				Wheels				Startup			
	Embodiements	triangle	Straight Bar	H-Bar	No Frame	Rectangular	Elastic and gear	Elastic	Elastic and Fly Wheel	Fan	Free Wheel	Power System wheel	Gear Wheel	Cylindrical wheels	Hold and release	Pull Back and release	Wind up	String Wind up
Frame	triangle	-	x	x	x	x									x			
	straight bar	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	H bar	-	-	-	x	x									x			
	no frame	-	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x
	Rectangular	-	-	-	-	-									x			
Propulsion	elastic and gear	-	-	-	-	-	-	x	x	x	x			x	x			
	elastic	-	-	-	-	-	-	-	x	x	x		x		x			
	elastic and fly wheel	-	-	-	-	-	-	-	-	x	x				x			
	Fan	-	-	-	-	-	-	-	-	-		x	x	x	x			
Wheels	Free Wheel	-	-	-	-	-	-	-	-	-	-	x	x	x	x			
	Power system wheel	-	-	-	-	-	-	-	-	-	-	-	x	x	x			
	gear wheel	-	-	-	-	-	-	-	-	-	-	-	-	x	x			
	cylindrical wheel	-	-	-	-	-	-	-	-	-	-	-	-	-	x			
Startup	Hold and release	-	-	-	-	-	-	-	-	-	-	-	-	-		x	x	x
	pull back release	-	-	-	-	-	-	-	-	-	-	-	-	-			x	x
	wind up	-	-	-	-	-	-	-	-	-	-	-	-	-				x
	string wind up	-	-	-	-	-	-	-	-	-	-	-	-	-				

Design Evaluation

Based on the embodiments left after removing much of them through the inconsistent embodiment phase, we can brute force choose concepts that we like. So the following concepts are the final 5 concepts chosen to develop a final design. By creating concept sketches for each of these designs we can better picture what our final design will be.

Concept 1

Embodiments

- Elastic
- Triangle
- Power System Wheel
- Wind up

Product Requirement

1. Device must have endurance

Explanation: This design for the car will have less endurance because the elastic powering the back wheels directly, which causes for wheel spin therefore resulting into power loss.

2. Device must travel through different terrains

Explanation: This device will be able to travel through most of the terrains that will be tested however the uphill terrain will be difficult because of power loss at the start.

3. Device must be fast

Explanation: This device will be fast because of the power being directly attached to the back wheels.

4. Device cannot have any module parts

Explanation: The device does not require any other parts.

5. Device must be easily manufacturable

Explanation: It will be harder to manufacture this device because of the shape its in.

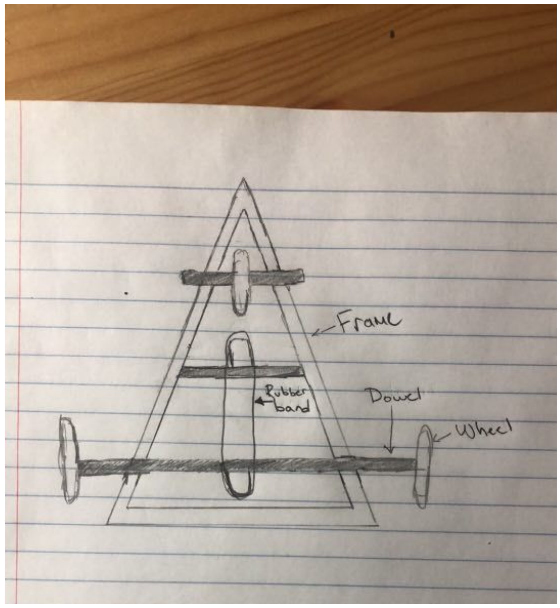


Figure 2.0: Concept 1 Car

Concept 2

Embodiments

- Rectangular
- Elastic
- Free Wheel
- Wind up

Product Requirement

1. Device must have endurance

Explanation: The device has endurance due to the elastic power system which would be able to provide the required distance.

2. Device must travel through different terrains

Explanation: This device may have trouble traversing uphill due to the small diameter of the wheels

3. Device must be fast

Explanation: Device will meet this requirement because due to the smaller wheels it will have a greater acceleration

4. Device cannot have any module parts

Explanation: Device does not require any additional parts

5. Device must be easily manufacturable

Explanation: Device uses basic geometry and components like rectangles, circles and rubber bands. Also all materials given to us.

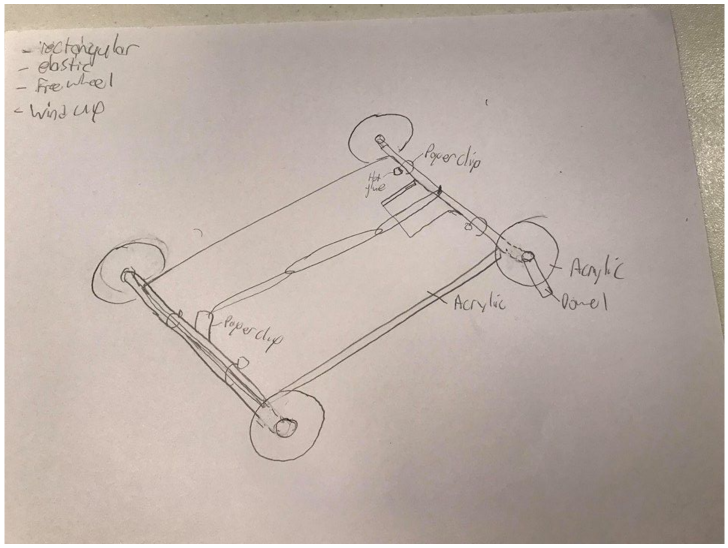


Figure 2.1: Concept 2 car

Concept 3

Embodiments

- H-bar
- Elastic Gear
- Gear Wheel
- Pull back and release
- Calculated Breaking

Product Requirement

1. Device must have endurance

Explanation: The gear system will provide the consistent power needed for endurance

2. Device must travel through different terrains

Explanation: The car may struggle to travel uphill due to the small wheels, but the gear system may compensate for it

3. Device must be fast

Explanation: The gear system may inhibit the maximum speed of the car

4. Device cannot have any module parts

Explanation: Device cannot have any module parts

5. Device must be easily manufacturable

Explanation: The frame and wheels are easily manufacturable, but the gears may prove difficult

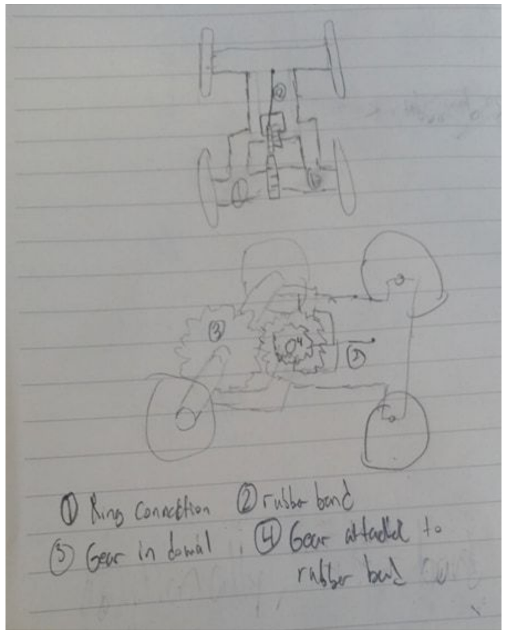


Figure 2.2: Concept 3 car

Concept 4

<u>Embodiments</u>

- H-bar
- Fan
- Freewheel
- Pull back release

<u>Product Requirement</u>

1. Device must have endurance
   The large gear will bring good strength while going uphill.
2. Device must travel through different terrains
   Large wheels allow for good ground clearance. Tight holds for the wheels make for a steady and straight ride.
3. Device must be fast
   The strength to go uphill will reduce the ability of the car for speed. However the geared wheels will provide superior traction.
4. Device cannot have any module parts
   Non of the device parts can be detached
5. Device must be easily manufacturable
   Glue is and screws are used for attachment. Order of operation does matter.

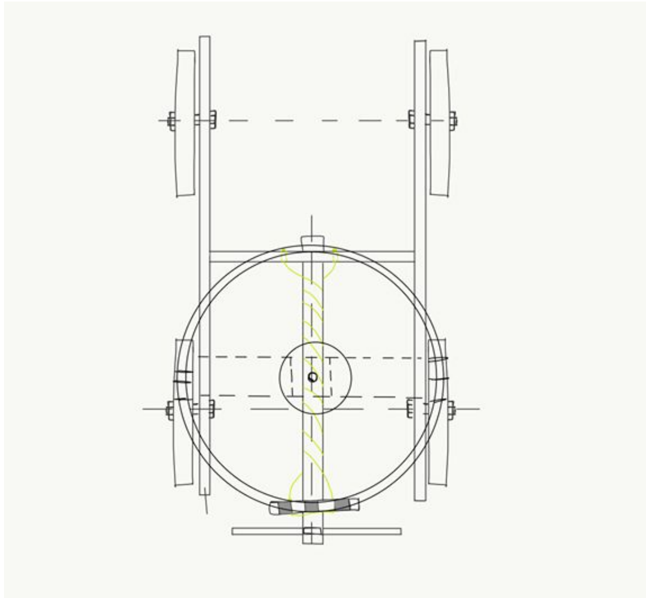


Figure 2.3: Concept 4 car

Concept 5

Embodiments

- Triangular frame
- Elastic
- Wind up
- Free wheel

Product Requirement

1. Device must have endurance

Explanation: This device will has considerably less endurance since the power will be directly transferred to the rear wheels without any gear system.

2. Device must travel through different terrains

Explanation: It will be difficult for this device to go up on an incline for an extended period of time, as there is a considerable loss of power when the device is initially launched

3. Device must be fast

Explanation: This device will be fast since the power from the stretched elastic bands will be directly transferred to the rear two wheels.

4. Device cannot have any module parts

Explanation: This device does not require any additional parts.

5. Device must be easily manufacturable

Explanation: It will be harder to manufacture this design to the nature of the triangular frame.

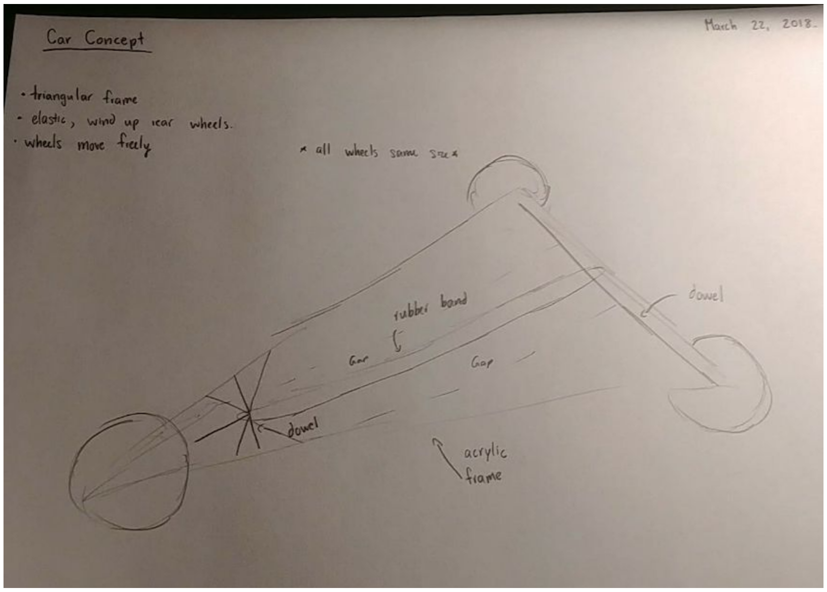


Figure 2.4: Concept 5 car

Pairwise Comparison

The following figure compares each product requirement and determines which one is more important for our design.

Table 3: Pairwise Comparison

		Endurance A	Versatility B	Speed C	Manufacturability D	Not Module E
Endurance	A	-	AB	A	AD	A
Versatility	B	-	-	B	D	E
Speed	C	-	-	-	D	C
Manufacturability	D	-	-	-	-	D
Not Module	E	-	-	-	-	-

RESULTS (ranked)	Percentage
Endurance	33.33%
Versatility	16.66%
Speed	8.33%
Manufacturability	33.33%
Not Module	8.33%

- We determined the ability to go uphill and the devices endurance to be equally as important due to those both being important parts of the competition
- We determined endurance to be more important than speed due to our team thinking that if the device could go far, we could adjust for speed later
- We determined endurance and manufacturability to be equally as important because the ability to manufacture the device is a major restriction to the device we can design

- We determined endurance to be more important that the not having module parts because endurance is more important for the competition
- We determined uphill to be more important than speed due to more design changes need to made to make the device travel uphill
- We determined manufacturability to be more important than versatility because we are restricted by the constraints on manufacturing and materials
- We determined not module to be more important than versatility because if we want to make our device more versatile we cannot add any module parts to it
- We determined manufacturability to be more important that speed because building the device for speed still needs to fall under our constraints
- We determined speed to be more important than not being module because speed can be easily manipulated without module parts
- We determined manufacturability to be more important than not being module because having module parts would decrease our success in the competition

Weighted Design Matrix

The following figure rates the concepts 1-5 and compares each product characteristic to our reference design. Determining which concept is the best compared to our reference design will help narrow our choices of final design.

Table 4: Weighted Design Matrix

		CONCEPTS											
		REFERENCE DESIGN		CONCEPT 1		CONCEPT 2		CONCEPT 3		CONCEPT 4		CONCEPT 5	
Criteria	Wgt	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Endurance	0.3333	0	0	0	0	0	0	2	0.6666	2	0.6666	0	0
Versatility	0.1666	0	0	-2	-0.3332	-1	-0.1666	-1	-0.1666	1	0.1666	-1	-0.1666
Speed	0.0833	0	0	2	0.1666	2	0.1666	1	0.0833	1	0.0833	2	0.1666
Manufacturability	0.3333	0	0	1	0.3333	1	0.3333	0	0	-1	-0.3333	1	0.3333
Not Module	0.0833	0	0	0	0	0	0	1	0.0833		0	0	0
TOTAL					0.1667		0.3333		0.6666		0.5832		0.3333
RANK					D		C		A		B		C
CONTINUE?					No		No		Yes		Yes		No

After careful evaluation of our concepts it was determined that concepts 3 and 4 are the top concepts which will be implemented into our final design.

Engineering Calculations

Elasticity and Force

One of the key reasons of our cars success or failure will be from the amount of force applied from our elastic band to create motion of the car. Based on how far we stretch the elastic band the amount of force it can exert can be calculated using the following equation

$F = k\Delta x$ **Equation 1**

F is the force applied to elastic material(N), k is the spring constant (N/m) and Δx is the change in length of the elastic material. But to determine the force, we must determine the spring constant from various experiments with our elastic band, as well as the change in length from the original diameter.

Experiment 1: To determine k we hung various masses from the rubber band and measuring the length after the apparent stretch of the rubber band. And by manipulating Equation 1 we can determine the various k values as seen below.

$$F = mg \Rightarrow k = \frac{mg}{\Delta x}$$ **Equation 2**

The following figure shows an example of some of the weights used to determine the k-value.

Figure 3: hanging water bottles off of rubber band

Based on 4 different masses the following calculations were gathered in this table.

Table 5: Values found by texting elasticity of rubber band

Mass Type	Mass (kg)	Δx (m) (stretched -0.0635)	k (N/m)
Casio fx-991MS	0.130	0.0333375	38.211
Samsung Galaxy S5	0.155	0.0381	39.909
1 Water bottle	.500	0.0762	64.37
2 water bottles	1.00	0.1778	55.174

These calculations provided a lot of different outcomes for k so we decided to graph the change in length by the force from each mass due to gravity (9.81m/ s^2).

Table 6: Force calculation

Δx (m) (stretched -0.0635)	Mass (kg)	Force (N) = (m x 9.81m/ s^2)
0.0333375	0.130	1.2753
0.0381	0.155	1.52055
0.0762	.500	4.905
0.1778	1.00	9.81

Due to Equation 1, if Force and change in length are plotted on a graph the slope of the line of best fit will be the final k value.

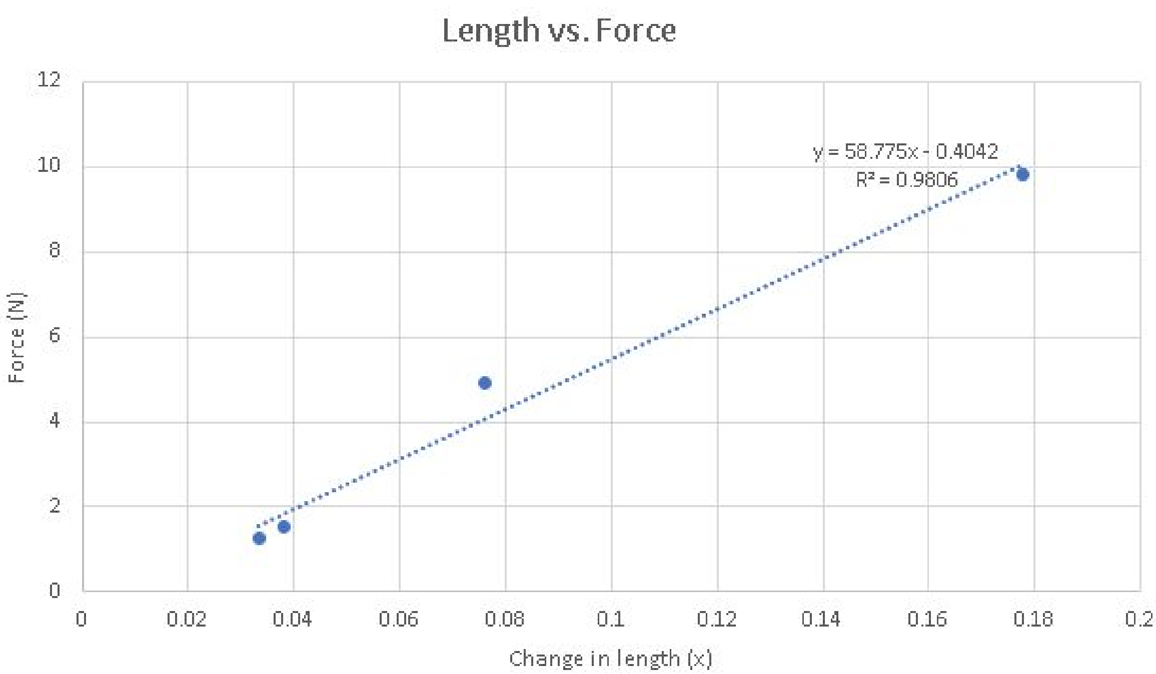


Figure 4: Graph showing the amount of force created as the rubber band is stretched

Based on this graph the spring constant value k is 58.775 N/m.

Using this spring constant we can determine the amount of force exerted on the rubber band depending on how far it is stretched. This calculation will help us determine the amount of force outputted on the rubber band based on the number of times the rubber band is wound up.

$$F = k\Delta x \textbf{ Equation 1}$$

$$F = 58.78N/m * (((\# \textit{ of rotations} * \textit{circumference of dowel}) + \textit{length from front to gear}) - 0.0635m)$$

Table 7: The following table provides the force from given rotations.

# of Rotations	Δx (m) (stretched -0.0635)	Force (N)
2.5	0.10055	5.91
3.0	0.1105	6.495
3.5	0.12045	7.08
4.0	0.1304	7.665

Based on experiments we determined that 3 rotations are enough to produce the amount of distance and power needed to travel 5 meters. Also, 3.5 rotations caused too much of a force within the band which caused some malfunctions of our car.

Friction Forces

Naturally, our group understood that careful consideration of friction forces had to be acknowledged during the designing of the car. Friction is dependent on the surface that are in contact with each other, meaning that we researched the static friction coefficients of various combinations of the material (rubber on rubber, rubber on dry concrete). We did not measure the effects of kinetic friction as our physical prototype model all performed well when the car was successfully put into motion. As a result, we focused on ensuring that there was enough friction to transfer power from the wheels to the "ground" but not too much that the car would be slowed down.

In our initial prototype, we had all four wheels made from acrylic, meaning the acrylic would be in contact with concrete and then rubber coating respectively during the competition. Since the power transfer from the rubber band solely occurs to the rear wheels, we quickly found out during our prototype testing that the back wheels would spin too fast, wasting the energy of the elastic bands. As a result, we decided to cover the back wheels with rubber bands, effectively increasing the friction force present at the back wheels. This ensured that the wheels had enough "grip" with the ground to successfully transfer energy. The methodical calculations we did proving this are as follows:

- Mass of car = 0.16lbs = 0.07257478kg
- g = 9.81m/s^2

Assuming all wheels are made from acrylic:

Static coefficient for acrylic on concrete = 0.20

$$F_s = \mu_s F_N$$
$$F_s = \mu_s(m * +g)$$
$$F_s = 0.20(0.07257478kg * 9.81m/s^2)$$
$$F_s = 0.1423917184N$$

Assuming all wheels are made from rubber:
Static coefficient rubber on concrete: 0.85

$$F_s = \mu_s F_N$$
$$F_s = \mu_s(m * +g)$$
$$F_s = 0.85(0.07257478kg * 9.81m/s^2)$$
$$F_s = 0.605164803N$$

The static friction force is considerably higher when the acrylic wheels have a rubber band surrounding when compared to the acrylic wheels without rubber band surrounding. This explains why our group observed better results with the back wheels having a rubber band surrounding, since the power was transferred better between the wheels and the "ground".

Calculations of Torque and Power

As found above the force due to tension of the elastic spring is 6.495 N when turned 3.0 times. This force is tangent to the dowel and can be used to find angular velocity and power and torque at the dowel.

R=0.43 in is the radius of the gear. And m is the mass of the car which is 0.086 kg .x = 0.1105. G is torque and P is power.k = 58.78N/m

Torque $G = \frac{0.5 * I * w^2}{\theta}$
Power $P = G * w$
Energy balance $\frac{1}{2} * k * x^2 = \frac{1}{2} * I * w^2$
Moment of inertia $\frac{3}{2} * m * R^2 = I = 0.0000153$
Angular velocity $w = \sqrt{\frac{2 * k * x^2}{3 * m * R^2}}$
w= 21.64 rad/s P= 0.00411 N.m/s G= 0.00019 N.m

It should be noted that do to friction and the large wheels we will have power loss at the wheel. However the friction and gearing is used to slow down the power transfer and get a longer range. The number of turns used for the elastic band cannot be changed because the structure is not strong enough to take on more tension. There for this value of power cannot be optimized any more without major changes to design.

Ergonomics

In this case, ergonomics relates to how the user (wind-up person) interacts with the car. It must be safe and simple for the user to windup the car, while being able to replicate this action successfully. Moreover, it is ideal if the car can be transported easily, with the least amount of physical and mental stress to the user as possible.

Safety

To wind our car up, we first place one end of the rubber band over the dowel piece and the other end over the bent paperclip. This is safe as the rubber band is not in a stretched position. To wind up the car, the user will roll the two rear wheels back. To ensure that this does not hurt the hands, we surrounded the rear wheels with rubber bands. Moreover, turning the rear wheels back to wind up the car ensures that the user will not have to touch the rubber in its stretched position.

Simplicity

To make the wind up process simple, we documented how much the rubber should stretch by relating it to the total rotations of the rear wheels. From our experimental testing, we observed that three rotations of the rear wheels gave us the best results. To ensure that the user can easily count three rotations, we put a marker line at the wheel so the user can look at that in conjunction with the dowel piece to gauge the rotation number.

Transportability

The car is very light due to the nature of the material, and the car takes up a small amount of space, 4.55 in^3. There are designated holding areas on the car, which are the two parallel rectangular frame pieces on opposite lengths of the car. This allows the car to be carried with 1 hand if so desired.

Final Design

Based on our weighted design matrix concepts 3 and 4 are the ones we will use to base our final design off of. The design consists of a rectangular frame. Holes in the front and the back of each side allow for front and rear dowels to be inserted. The large wheels are attach to the end of the rear dowel, while small wheels are attached to the front dowel. One rubber band is attached to rear dowel, and the car is pulled back in order to stretch the rubber band. On release, the car propels forward.

Prototype 1

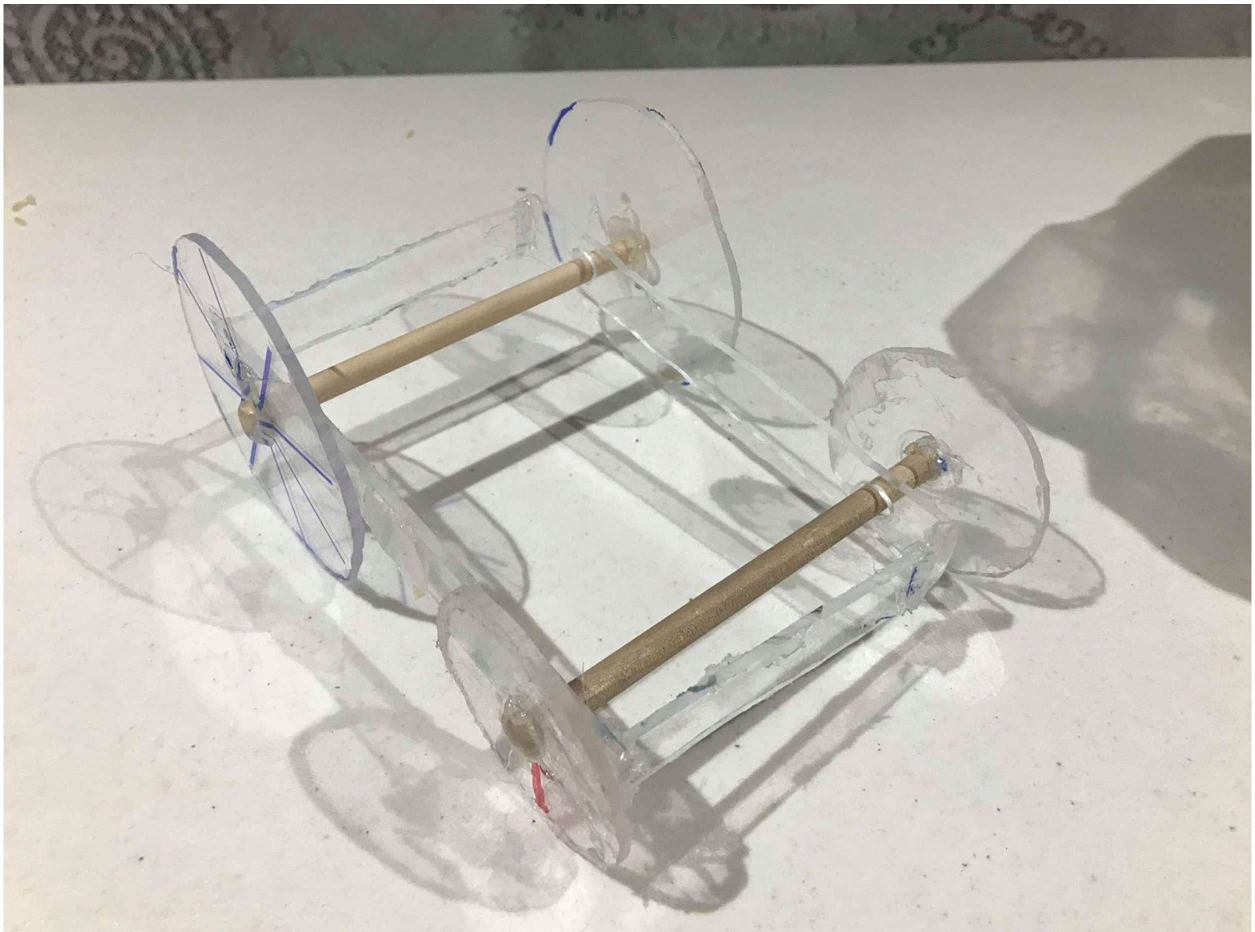


Figure 5: Prototype

Materials used:

Given:
- None

Purchased:
- Glue
- Dowel
- Acrylic parts
- Rubber bands

Embodiments
- Rectangular base
- Elastic

- Hold and release
- Calculated distance

Implemented solutions:
- None

Issues with Design:
- The wheels would spin out instead of driving the car forward.
    - Solution: Wrapping rubber band around the rear powered wheels provides the necessary traction needed to prevent the wheels from spin out.

- Instead of the car going forward, it would flip around then proceed to drive in reverse.
    - Solution: Adding weight to the front of the car stops it from flipping over.

- When released, the car would veer to the right.
    - Solution: This was a result the asymmetry of the prototype, which was caused by the poor manufacturing of the car parts. The high precision of the laser cutter will eliminate this error.

Prototype 2

Materials used:

Given:
- Acrylic parts
- Rubber bands
- Bolts

Purchased:
- Glue
- Dowel

Embodiments:
- Rectangular base
- Elastic
- Hold and release
- Calculated distance

Implemented solutions:
- Wheel wrapped with rubber bands
- Weighted front bumper
- Cleanly cut parts

Issues with Design:
- Finding the optimal number of winds required to propel the car past the necessary distance

- Solution: Introducing a gear system provides a source of resistance that reduces the spike in power to the wheels

Final Design

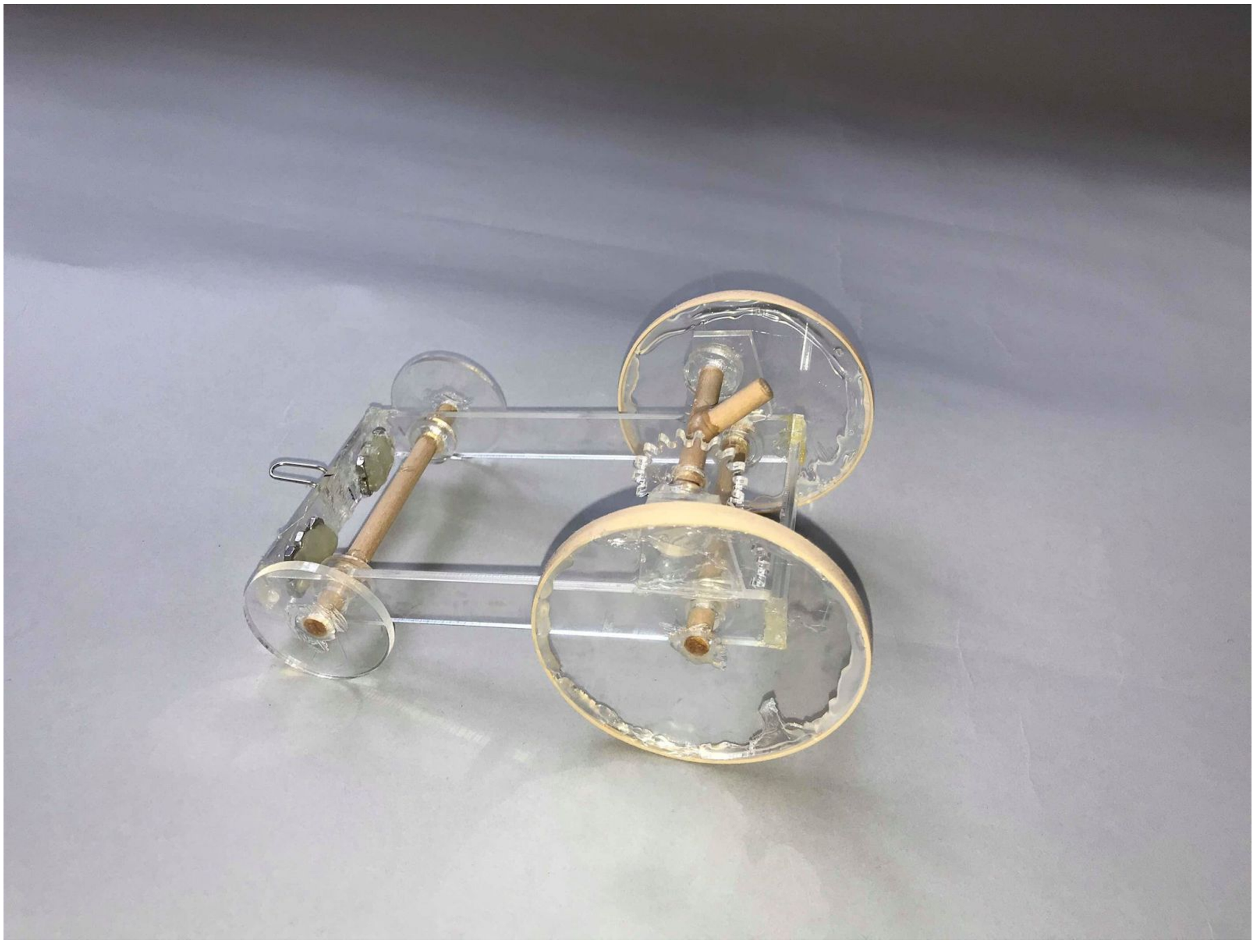


Figure 6: Final Design

Materials used:

Given:

- Acrylic parts
- Rubber bands
- Bolts
- Dowel
- Paper clip

Purchased:

- Glue

Embodiments:

- Rectangular base
- Elastic and gear

- Hold and release
- Calculated distance

Implemented solutions:
- Rear wheels wrapped with rubber bands
- Weighted front bumper
- Cleanly cut parts
- Gear system

Conclusion

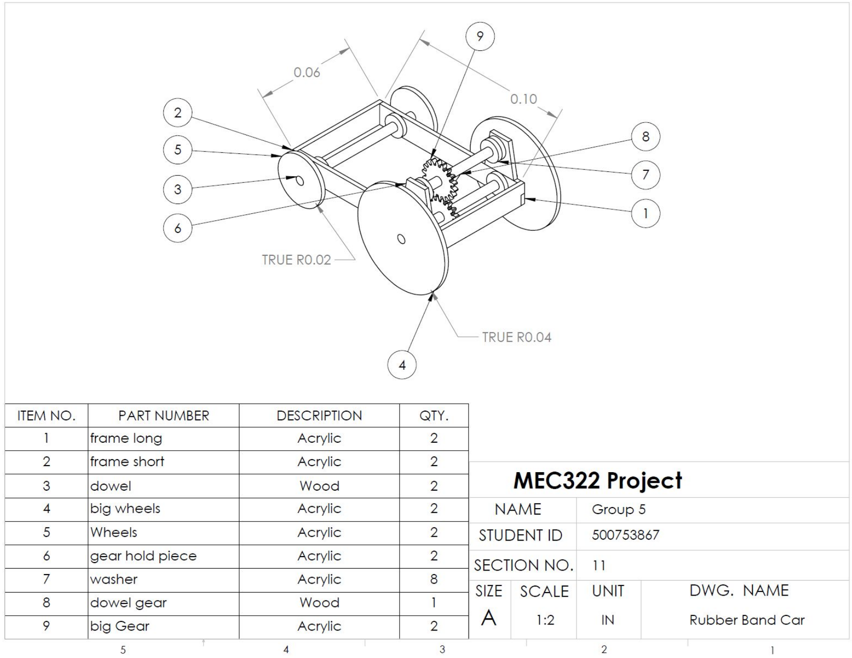
In conclusion we were able to produce a car that fits the requirements of the materials and the requirements of the race, however we do not know if our car will be able to go up the ramp because we do not have anything similar to the situation but we do believe the front bumper might hit the ramp. Also we did not use all of the materials required such as some of the cut acrylic parts, rubber bands and the screws.

Recommendations

If more time was given to build this car we could have made many changes. We would made the front wheels a bit larger because we believe the bumper might hit the ramp therefore slowing the car or preventing the car to go even go up the ramp. Another thing we can add to the new car will be more gears, by having more gears it makes the power of the elastic band last longer which results into a better distance and makes the car travel uphill more efficiently

Final CAD drawing

Now that we have the final design, the following figures are our final solidworks drawings.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	frame long	Acrylic	2
2	frame short	Acrylic	2
3	dowel	Wood	2
4	big wheels	Acrylic	2
5	Wheels	Acrylic	2
6	gear hold piece	Acrylic	2
7	washer	Acrylic	8
8	dowel gear	Wood	1
9	big Gear	Acrylic	2

Figure 7: Assembly Drawing

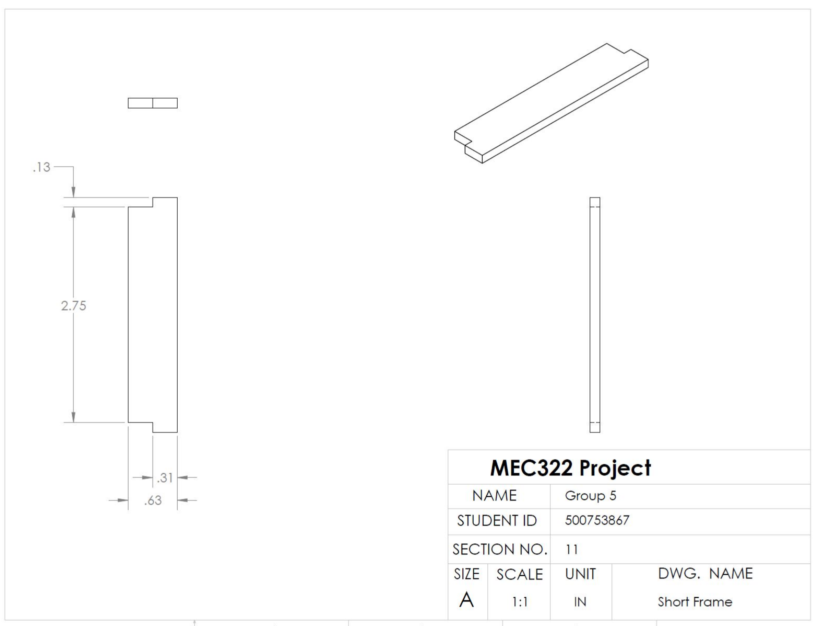


Figure 8: Short Frame

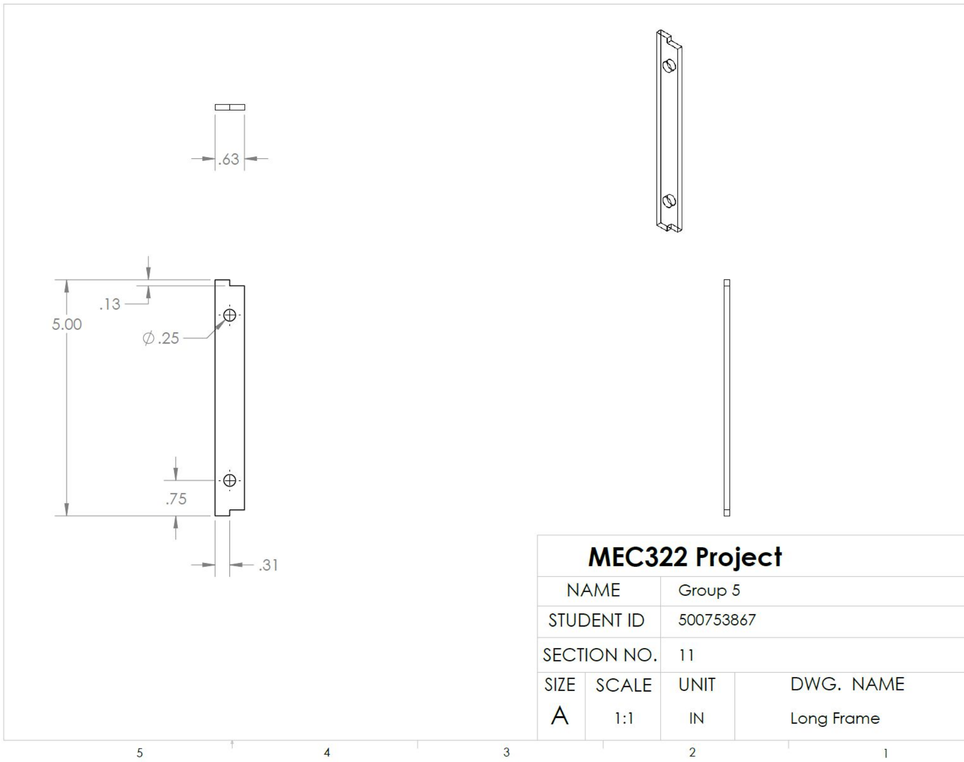


Figure 9: Assembly Drawing

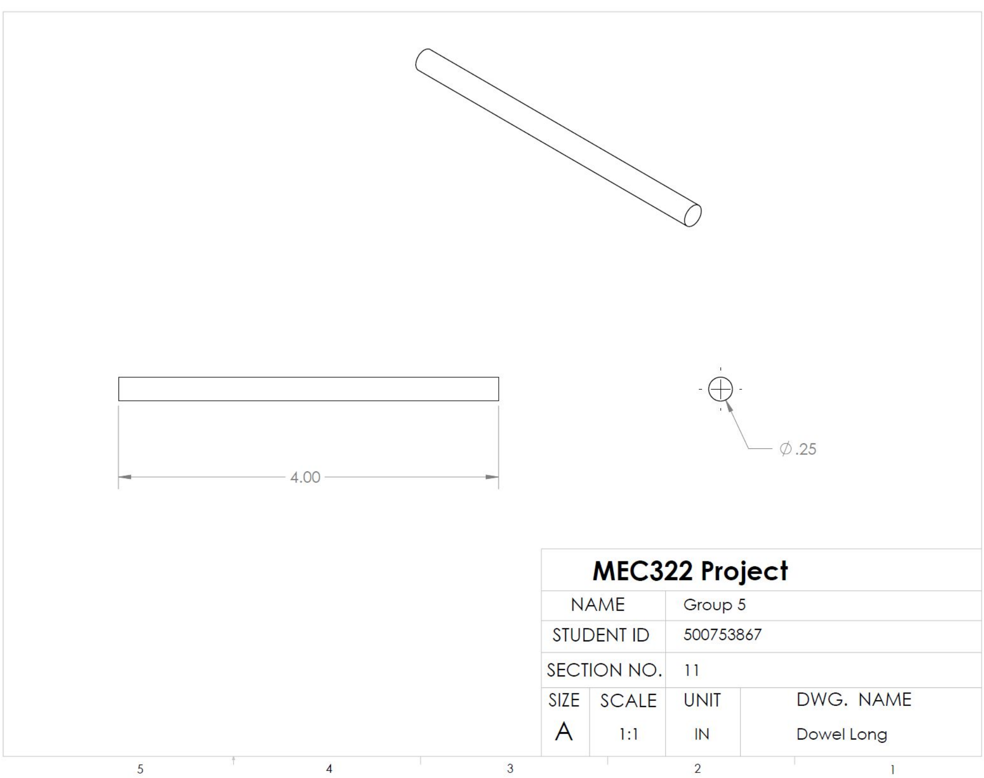


Figure 10: Long Dowel

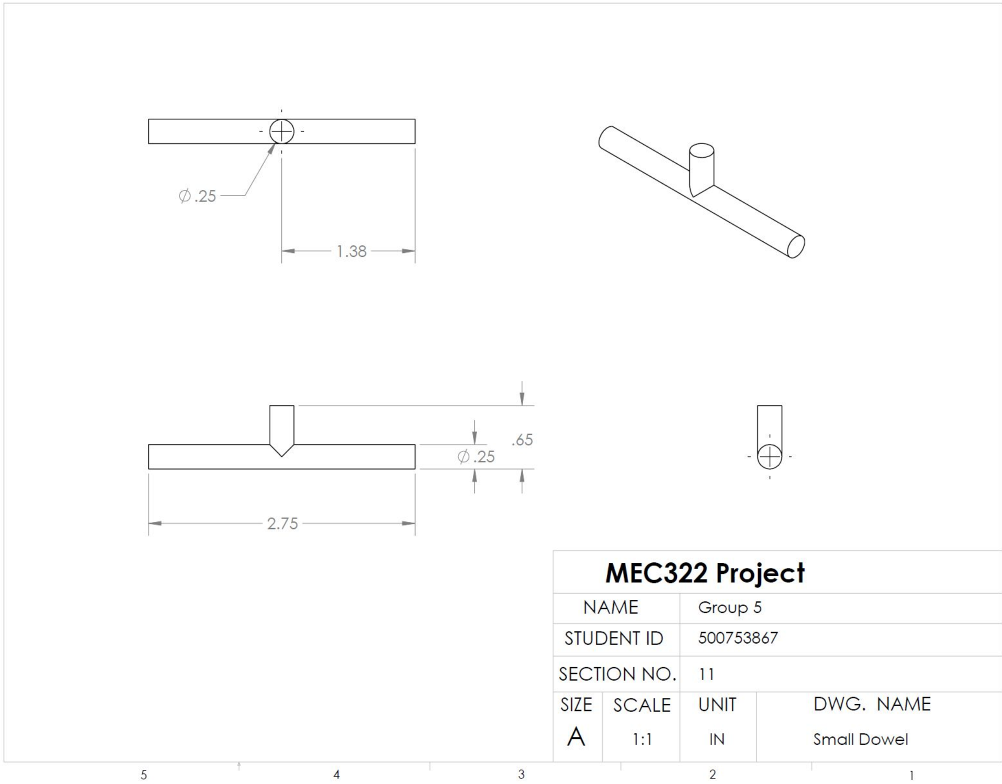


Figure 11: Small Dowel

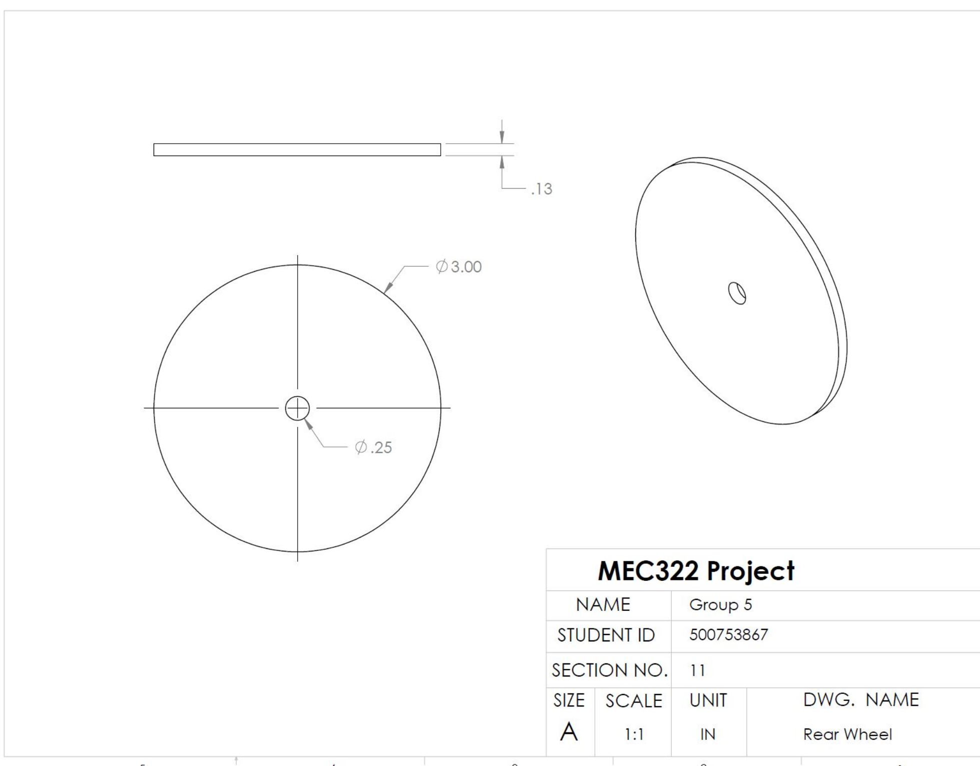


Figure 12: Rear wheel

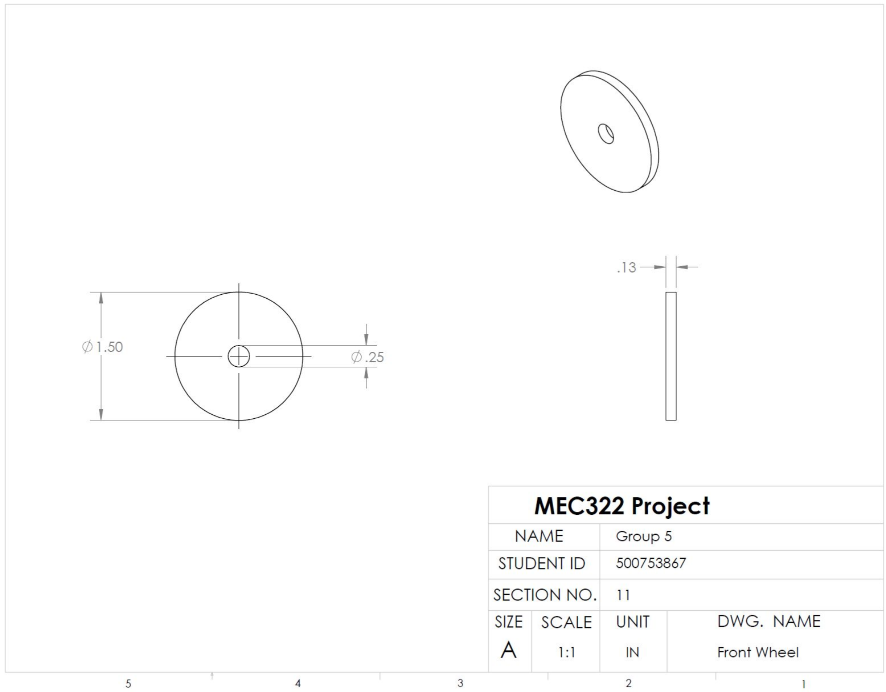


Figure 13: Front Wheels

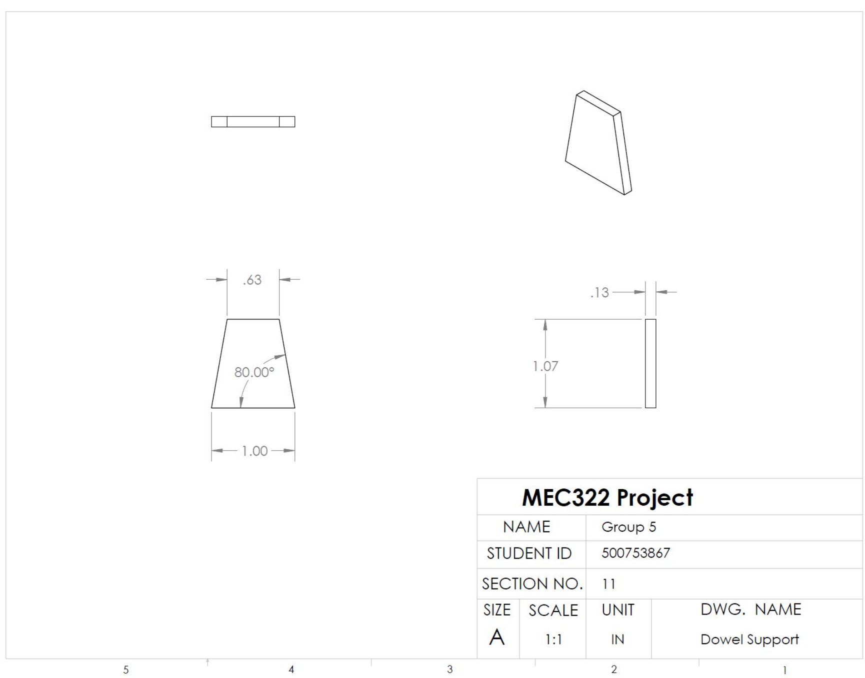


Figure 14: Dowel Support

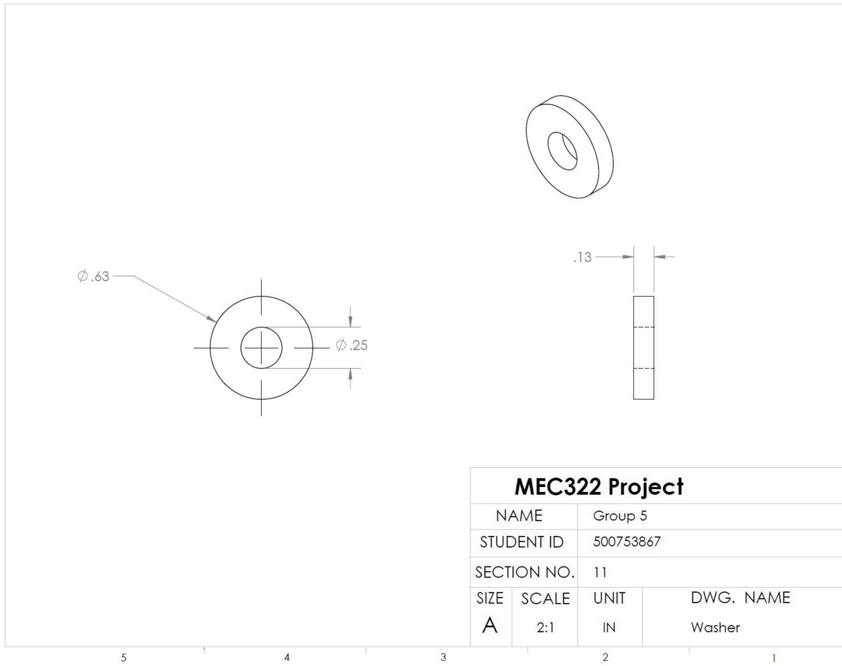


Figure 15: Washer

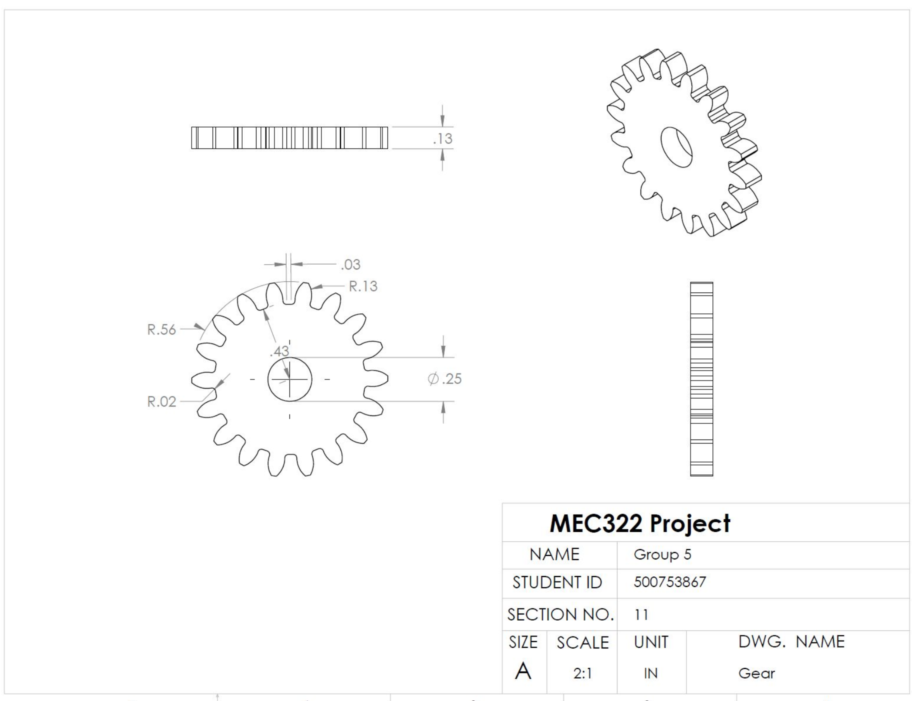


Figure 16: Gear

References

[1] Finio, B. (2018, January 11). Build a Rubber Band–Powered Car. Retrieved April 06, 2018 from https://www.scientificamerican.com/article/build-a-rubber-band-powered-car/
[2] Katz R. , Semat H. (1958), physics, rotational motion. University of nebraska - Lincoln.