ME 250 DESIGN AND MANUFACTURING I
Winter 2019

BOTIANA

Team #21
ME 250 Section #2

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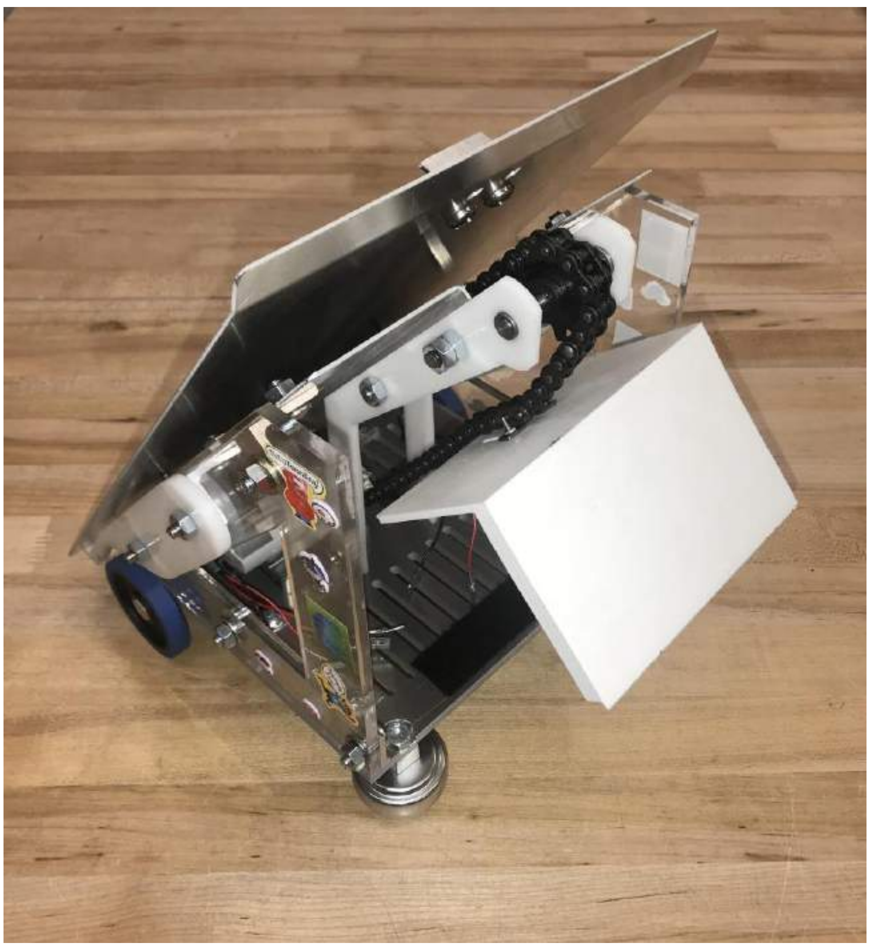


Edited by Jonah Shifrin

Table of Contents

1. ABSTRACT

In this report, we discuss our squad strategy, design process, and the steps we took to decide on the best final design of our Remotely Manipulated Vehicle, RMV. Our RMV was tasked with scoring cubes in the high goal, and we assigned it the specific functional requirements that it must be able to traverse the small gravel pit in 45 seconds, maneuver through the maze and turn around 90° corners with a maximum turning radius of 11" and must be able to pick up a volume of $14.5in^3$ and raise the cubes 11" to score them in the high goal. We also determined plans for how we were to test these functional requirements. We also explain our analysis of our dimensions and gear ratios chosen for our final design.

We then move into discussing the manufacturing process as well as the complete list of our parts we manufactured to completely assemble our RMV. We cover any issues that we faced during manufacturing and changes that our design underwent due to change in materials, as well as if other processes would have been more fit for our part.

Overall, in the competition, Squad 20 placed 3rd and scored 55 points. In this report, we analyze what worked in our strategy, what failed, and how our strategy could have been improved.

2. INTRODUCTION

The goal of the Game of Zones is for each squad of 4 RMV's score the most points possible, according to the predefined game rules, in a 5-minute period. Squads are broken down into 4 teams, with each team building a unique RMV to achieve the specific tasks designated to them from the squad based on the squad strategy. Points can be scored by depositing colored cubes into either of two goals. The high goal offers a greater point multiplier than the low goal. Bonus Points are also awarded for successfully lowering a drawbridge, moving a heavy block, and/or traversing the seesaw.

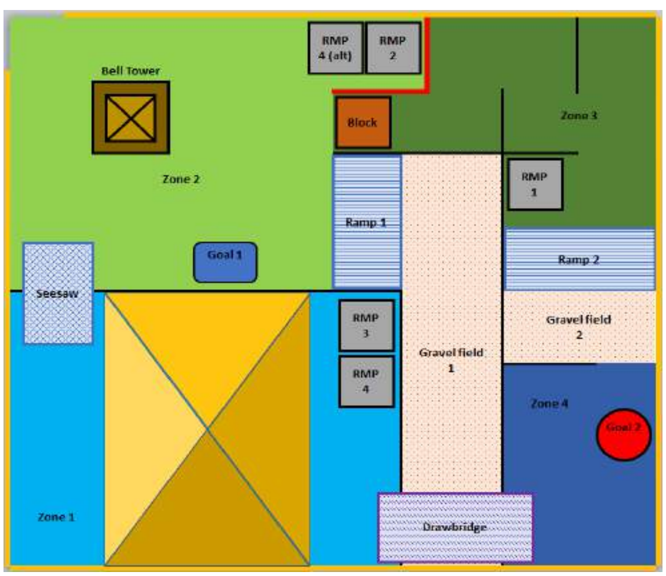


Figure 1. This figure shows the playing field as outlined in the course specifications.

The playing platform is split into 4 zones, each with different challenges to overcome as seen in Figure 2. Squads must utilize the unique designs of their RMV's to successfully score the most points and win the Game of Zones.

3. RMV DESIGN

The primary obstacle of this project is to make design decisions based on both self-defined and given physical and mechanical design restraints. Beginning from the squad strategy functional requirements for our RMV and means of quantitatively testing each; followed by designing mechanical subsystems, constructing a rough prototype, physics-based design analysis, and a fully articulate CAD model assembly.

3.1. Strategy and RMV Strategy

The squad strategy prioritizes the yellow blocks and placing as many cubes as possible into the high goal. The yellow cubes will be taken by RMV 3 from Zone 1 to Zone 4, after the drawbridge is lowered by RMV 4. RMV 2 will take the cubes from Zone 2 and place them over the low wall into Zone 3. The cubes will be taken by RMV 1 and scored into the high goal.

Our RMV, RMV 1, will focus on moving the four green blocks into Zone 4, and then navigating the maze to reach the blocks dropped over the low wall into Zone 3 by RMV 2. Getting the blocks over the gravel pit is essential to this, as is cooperation between RMV 1, RMV 2, and RMV 4, which each have their own stage of block movement. The advantage of having RMV 1 score is that there is less work for RMV 4 and gives RMV 2 more options in placing red cubes over the wall.

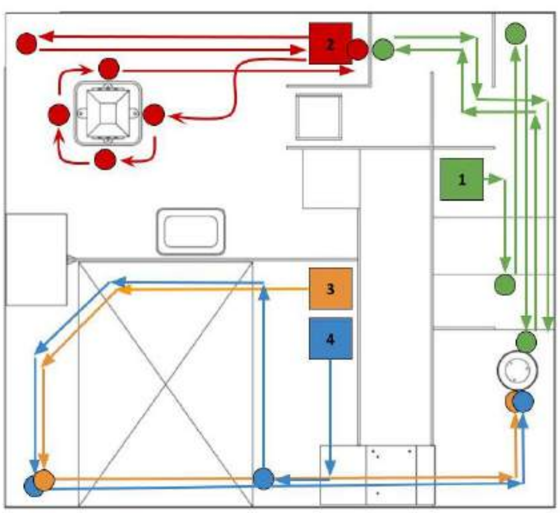


Figure 2. This figure shows the team 20 whole team strategy broken down into the movements of each of the 4 team RMVs.

Team 21's RMV will start by laying the ramp down across the gravel pit so that we have a path from the ramp on the table to the elevated surface. We will then pick up the four green blocks from the corner of Zone 3 and transport them back to the elevated surface and score them in the high goal. Once we have accomplished that, we will go through the maze, pick the blocks that RMV 2 is dropping over the wall, transport them back to the elevated surface and score them in the high goal. We will continue to repeat this process until the time is up or all the designated cubes are deposited in the high goal. The movement path of RMV 1 is displayed in Figure 4 on the following page.

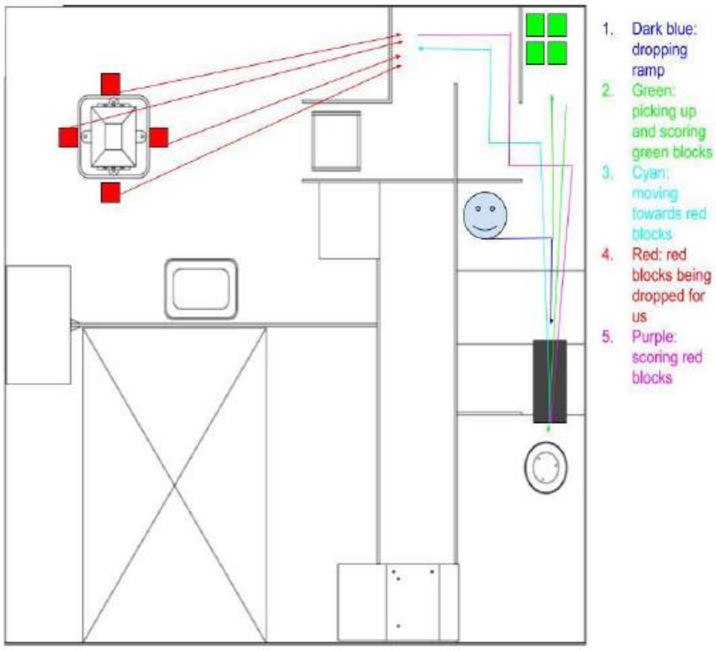


Figure 3. Team 21 individual strategy color coded by operation objective objectives described in legend to the right.

3.2. Functional Requirements and Test Plans

Our three most important functional requirements for our RMV are that it must be able to traverse the small gravel pit in 45 seconds, it must be able to maneuver through the maze and turn around 90° corners with a maximum turning radius of 11", and it must be able to pick up a volume of $14.5in^3$ and raise the cubes 11" to score them in the high goal. We chose the functional requirements because the provide a reasonable efficiency of scoring and movement for our RMV. To test the first functional requirement, we will drive the RMV over our ramp across the gravel pit and record the time. We will need the RMV steering subsystem with cube lift subsystem to make sure that all expected moments are accounted for, 4 cubes, the ramp and gravel pit from the zones, and a stopwatch. We will record how long it takes to cross the gravel pit carrying the cubes.

For the second functional requirement, making 90 degree turns, we will drive the RMV through the maze and record data on its turning. To do this, we will need the RMV steering subsystem, a model of or the actual maze, and length measuring devices. We will record the turning radius and base dimensions. Testing the third functional requirement, picking up 4 cubes and depositing them into the high basket, we will drive the RMV and pick up for cubes, ensuring that the RMV can lift all 4 in one trip, and that the RMV can deposit these into the high goal. This will require 4 cubes, functioning lift and driving subsystems, and a model of or the actual high goal basket. The number of blocks successfully loaded will be recorded, as will whether they are deposited into the targeted basket.

3.3. Design Concepts and Subsystems

The first attempt at achieving the functional requirements set by our team strategy resulted in 3 design concepts which were compared using a pew chart.

Design Concept 1

In our first design, a metal ramp is initially attached to the back of the RMV and held in the upright position using a hook and latch. We would then drop the metal ramp so that it lies across the gravel from the end of the ramp on the table to the elevated surface, therefore meeting functional requirement 1. The RMV has a square base with two wheels in the front, each controlled by a motor, and two dummy wheels in the back. Having a motor controlling each of the wheels allows for one to go forward while the other is in reverse, therefore giving the RMV the ability to make tighter turns and fulfill functional requirement 2. Also, there is a metal ramp attached to the frame with a scoop at the end that allows the RMV to pick up cubes and then flip the ramp up and drop the cubes over the top of the RMV, therefore giving the RMV the ability to execute functional requirement 3.

Design Concept 2

Design concept 2 has a triangular vertical frame as well as a triangular base. It has two wheels, each controlled by its own motor, with a "dummy wheel" located in the back. These independently powered wheels allow one to be put in reverse while the other can be powered forward, allowing the RMV to make tight turns and therefore meeting functional requirement 2. The conveyor belt has a scoop that is attached to it that allows the RMV to pick up cubes which then the conveyor belt brings up to then drop over the top of the RMV, which fulfills functional requirement 3. In front of the conveyor belt there is a lip that allows a metal ramp to sit when the scoop is in a position at the top of the conveyor belt. We plan to place this ramp across the gravel field by having the conveyor belt move the scoop down, which will cause the metal ramp to fall forward. This will meet functional requirement 1.

Design Concept 3

Design concept 3 has a triangular vertical frame attached to a square platform. On each side of the platform there are three wheels with treads spanning across them. These treads were put in place to allow the RMV to cross the gravel field, therefore fulfilling functional requirement 1. Since there is a set of wheels on each side, we can have one set go forward while we put the other set in reverse to allow the RMV to make tight turns, which gives us the ability to execute functional requirement 2. Attached to the top bar of the frame is a lever arm that has a scoop at the end that gives us the ability to scoop up blocks and score them into the high goal, which meets the standards for functional requirement 3.

The three described design concepts are compared In Table 1 on the following page.

Table 1. This Table is a pew chart used to select between the three designs described above. The intention is to identify the optimal choice of the three.

Requirement	Weight	Design Concept 1	Design Concept 2	Design Concept 3
Deliver blocks across pit	6	Drop ramp/plate using a hook and a latch. 0	Drop ramp/plate using scoop on the conveyor belt. +1	Using treads to transverse the gravel pit. -1
Maneuverability	5	Two independently powered wheels in the front and two dummy wheels in the back (zero-point turning). 0	Two independently powered wheels in the front and one dummy wheel in the back (zero-point turning). 0	Two independently powered treads. -1
Pick up/Drop blocks	6	Rotating scoop attached to hinge on top of RMV. 0	Scoop picks up blocks, conveyor belt brings scoop to top to drop blocks over the top of the RMV. +1	A scoop that splits down the middle. -1
Ability to score	6	Scoop doubles as a chute to score with. 0	Scoop can drop blocks over the top of the RMV. -1	Extendable arms with scoop that splits down the middle. +1
Manufacturability	4	0	-1	-1
Creativity	3	0	+1	0
Total	N/A	0	+5	-15

Picking up and dropping blocks, delivering them across the pit, and the RMV's ability to score have the highest weights as these are most important to us as a team. Scoring blocks is the biggest requirement for our RMV to achieve. If the RMV cannot deliver the blocks to the elevated surface and then score, we will not be able to earn any points and our RMV will have failed its purpose. Maneuverability is also high on our requirements as ease of movement will allow our RMV to move faster and therefore score the blocks quicker. We also felt that manufacturability was important for our team, because if the RMV is too difficult to manufacture, we may not be able to complete our design and fail our squad. We want to make sure that we can keep in mind our lack of manufacturing practice in the event parts need to be remade due to errors in machining.

Creativity was one of our lower priorities, as our focus for our RMV was its ability to complete the task. As a team, we decided that we would rather our RMV efficiently execute a given task by simple design that allowed for changes along the way, while it may not be the most creative.

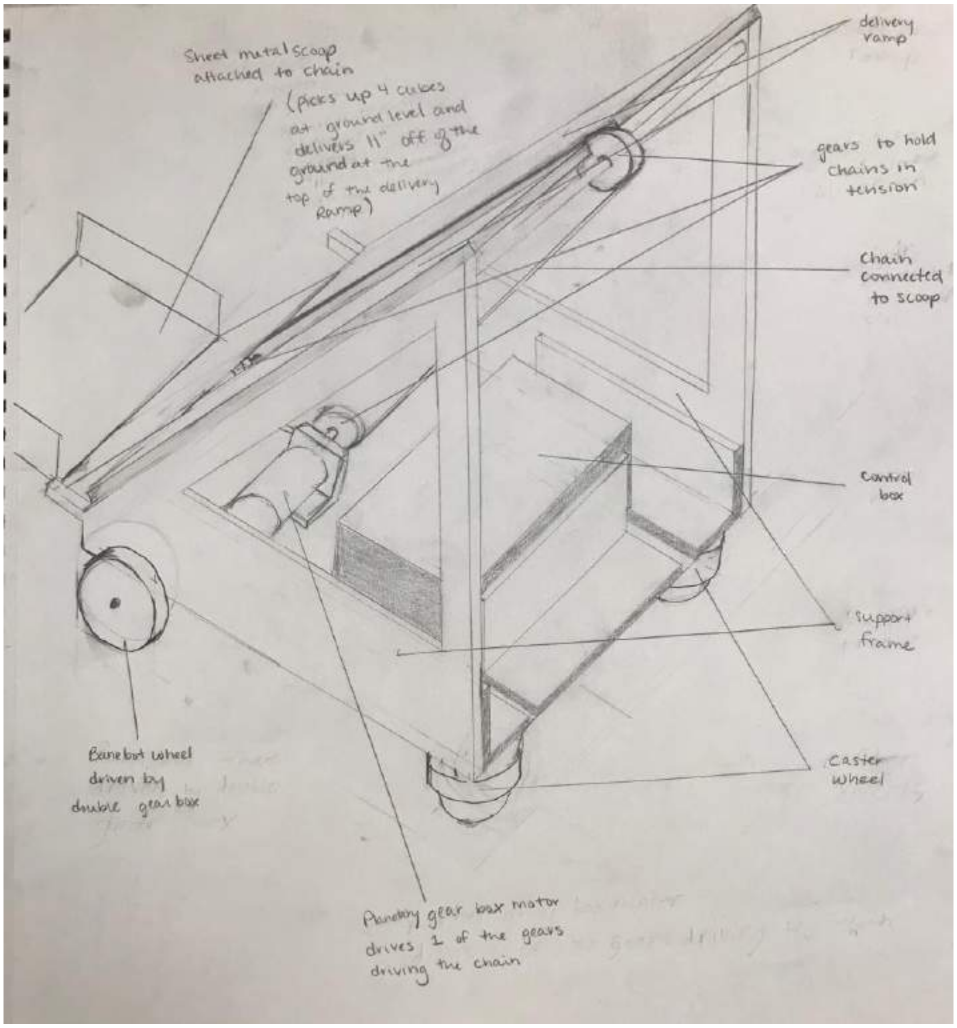


Figure 5: Final Design Concept of team 21 RMV with label call outs. Hand drawn in isometric perspective; not to scale.

Our RMV will start by laying the ramp down across the gravel pit. We will line the front of the RMV up with the gap of the elevated surface between the two walls and drop the ramp so that we now have a path from the ramp on the table to the elevated surface. We will then move over to pick up the four blocks from the corner of our zone by putting our scoop under the blocks and pressing them into the wall so that they are pushed fully onto the scoop. Then we will tilt the scoop slightly upwards in order to ensure that the cubes do not fall out while we are transporting them back up to the top of the elevated surface. Once back on the surface, we will line the back of our RMV up with the high goal, and then lift the scoop using our chain lift system so that the cubes fall over the top of the RMV and back into the high goal. Once we have accomplished that, we will move through the maze to the short wall by Zone 2 where RMV 2 will be dropping red cubes over the wall. We will make the tight turns in the maze by having one wheel go forward while we put the other in reverse. This will allow us to have a tight turning radius to move through the maze efficiently. We will gather up these cubes four at a time in the same way that we picked up the first set of cubes. We will move back through the maze and up onto the elevated surface, where we will put these red cubes in the high basket the same way we deposited the first set of cubes. We will continue to repeat this process until time is up or all the designated cubes are deposited in the high goal.

For our final design, we chose a mixture of Design 1 and 2. We used mostly elements of Design 2 but chose to use a square base with two caster wheels, rather than a triangle base with one caster wheel. This is because the square base adds stability to the RMV and more space for motors and other components. We selected dropping a ramp over the gravel pit because this provides an easy and fast way to traverse the gravel pit, in comparison to repeatedly trekking through the gravel and climbing the 1-inch ledge into zone 4. It also allows us to focus our maneuverability on just going through the maze, rather than both the maze and gravel pit. We are using two independently powered wheels in order to use a "zero-point" turning based system; this should allow us to make the 90 degree turns in the maze easily, and our small base should prevent corners from getting stuck on the walls. Although the scoop-arm concept is known to work and likely easier to manufacture, we selected using a chain and sprocket system as opposed to a lever-arm scoop because the chain would require less torque than the arm, which would be fully extended and heavier. A chain and sprocket scoop also seemed more creative than the fairly common arm scoop, while also providing us an easy way to drop our ramp over the gravel and on to Zone 4.

2 Main Subsystems:

Driving

The steering subsystem is composed of our two front wheels, each controlled by their own motor, and the two caster wheels in the back. The two front wheels function independently from one another which allows us to put one wheel in reverse while having the other move forward. This gives the RMV the ability to make tight turns and traverse the maze, therefore fulfilling our first and second functional requirements which state that our RMV must be able to maneuver through the maze, turn around corners, and cross the gravel pit.

Lift

The lift subsystem is composed of a scoop and a pulley system that is controlled by a motor. The RMV picks up the cubes by pushing them against the wall and onto the scoop. The scoop then can be raised up the side of the frame of the RMV and over the top so that the cubes can then be scored into the high goal, and this same action can be used to drop the disposable ramp over the gravel pit. This subsystem allows us to achieve our third functional requirement which states that our RMV must be able to pick up cubes and score them into the high goal, as well as cross the gravel pit.

3.4. Mockup

Our mockup was primarily used to resolve which base shape would best navigate the maze, how tall our A-frame should be to successfully score the cubes, the height of the scoop required to reach the ground based on the radius of the chosen driving wheels, and how we would be able to assemble our final RMV. The first three points were most important for finalizing our design geometries; however, the last issue was more focused on our ability to easily and logically put our final design together.

Through making a prototype we were able to figure out solutions to these issues. The primary disadvantage of prototyping was that in order to prototype efficiently we had to use alternative materials such as foam, cardboard, and hot glue in lieu of aluminum, acrylic, and screws. So while prototyping was very useful in the geometry aspect of the base and frames, it did not completely prepare us for other issues we would face during manufacturing.

In constructing this mockup we were able to specifically determine the shape of our RMVs footprint, a relatively square 7.5"x7.8". We were also able to realize that the primary driving motor for our scooping mechanism would best fit as a third inner sprocket.

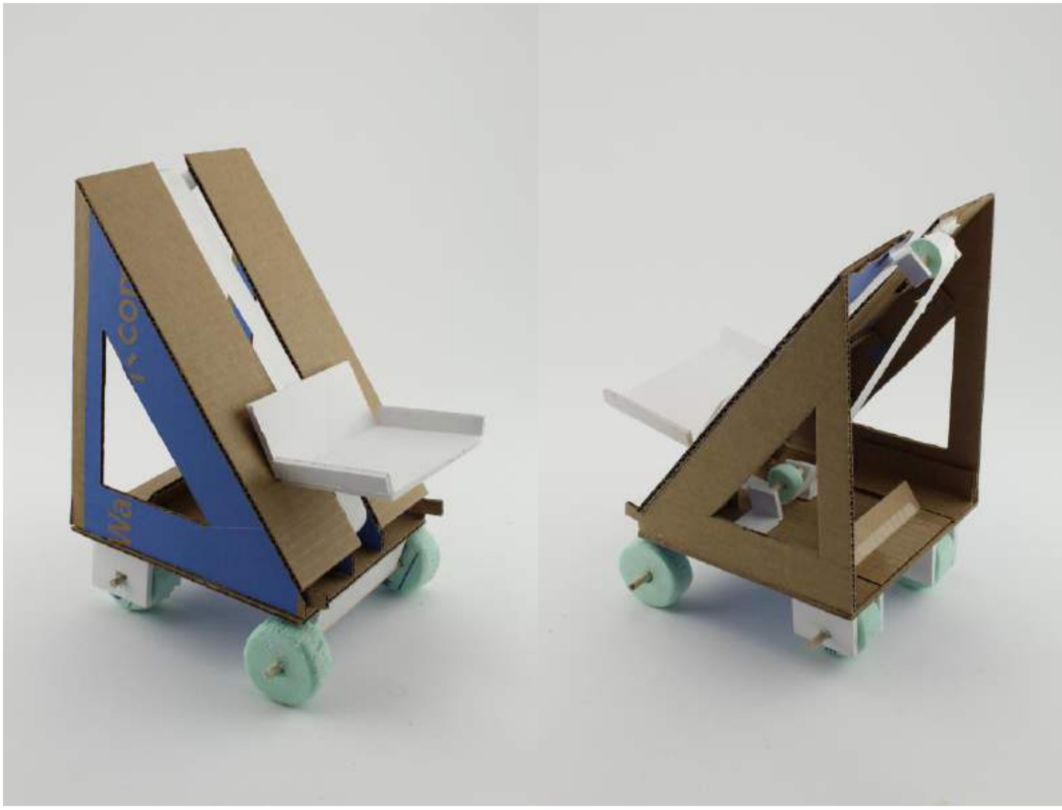


Figure 6: (left) Picture of mockup front; (right) Picture of mockup back.

3.5. Analysis

Lift subsystem

To determine the necessary gear ratio to operate our lift system, we needed to find the torque required with an applied safety factor. We did this using Equation 1 below.

$$T_{safety} = m * g \cdot R \cdot SF \qquad \text{(Eqn. 1)}$$

where T_{safety} was the torque required to lift the scoop and cubes with an applied safety factor *SF*, *mg* was the weight of all lifted components, and *R* was the radius of the sprocket. By applying a safety factor to the required torque, we determined the necessary gear ratio to successfully operate.
Using this safety torque, we then solved the equation.

$$T_R = 0.2\gamma T_{stall} \qquad \text{(Eqn. 2)}$$

where γ was the efficiency of the planetary gearbox and T_{Stall} had been scaled for the input voltage of 6V for the planetary motor. We then found the required gear ratio, *M* by using equation 3 below.

$$M = \frac{Tsafety}{TR} \qquad \text{(Eqn. 3)}$$

Plugging in the total weight of the lift system, 3.072 oz, the driving sprocket radius of 1.331in, and a safety factor of 2 we found that T_{safety} is 8.178 oz-in. If the gearbox efficiency ranged between 30% and 5% for the planetary gearbox depending on the gear ratio, we took $\gamma = 17.5\%$ to estimate our efficiency, and T_{stall} to be 2.4 oz-in which yielded a T_R of 0.084 oz-in. Solving for our gear ratio, we found *M* to be 97.35, so the 100:1 gear ratio was required.

Driving subsystem

Similar to the previous calculations to find the torque for the lift system, we too needed the driving torque for our RMV.

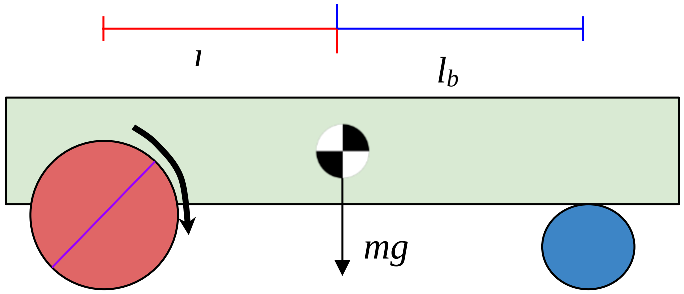


Figure 7. This figure shows a free body diagram used to model the mechanics of RMV 21's propulsions system.

$$\boldsymbol{T} = (\boldsymbol{\mu} \cdot \boldsymbol{mg} \cdot \boldsymbol{l_b} \cdot \boldsymbol{R})/(\boldsymbol{l_a} + \boldsymbol{l_b} - \boldsymbol{\mu} \cdot \boldsymbol{R}) \quad \text{(Eqn. 4)}$$

Where μ was the friction between the driving wheels and the table, *mg* was the total weight of the RMV, l_a was the distance between the center of gravity and the driving wheel, l_b was the distance between the center of gravity and the caster wheel, and *R* was the radius of the driving wheel.

We know that the required torque for the driving system is really going to be half of the total mass of the RMV since we are using 2 metal motors, but when we applied a safety factor of 2, the total torque simply came out to be *T*.

We assumed that the coefficient of friction between the rubber wheels and the game table ranged between 0.5-0.8, and for our calculations we used a coefficient of friction of about 0.65. The weight of our RMV from the CAD was 4.86 lbs, l_a was 2.72 in, l_b was 3.58 in, and the radius of our Banebot wheels was 1.1875 in. Solving for *T* we found we required a driving torque of 38.66 oz-in and using equations 2 and 3 again we found *M* to be 3.067.We determined the speed our RMV was going to move by using Equation 5 below.

$$\omega_s = \frac{2\omega_{no\ load}}{M} \quad \text{(Eqn. 5)}$$

where ω_s was the speed of the motor at a given gear ratio and $\omega_{no\ load}$ is the no load speed of the metal motor Based on the specifications for the metal motor we know $\omega_{no\ load}$ is 97 rpm. Once we find ω_s to be 63.25 rpm, and solving for $T_v = \gamma M \cdot T_s$, we can find the speed of the RMV using Equation 6 below. The final calculation resulted in a linear speed of 50.59 in/min.

$$speed = \frac{\omega_s}{T_v} \cdot (T_v - T) \quad \text{(Eqn. 6)}$$

3.6. Final Design and CAD Model

Our final RMV design is centered around an acrylic a-frame that has a cut-out both for light weighting and ease of assembly. This A-frame is attached to the base by ¼-20 bolts run through ⅛ in L-brackets on the bottom of the frame. On the top of each A-frame are 3 small L brackets which secure a sheet metal support ramp. The left end of this photo shows a support leg which is meant to hold the disposable ramp that allows our RMV to cross Gravel Pit 2 before it is dropped. Also, on the left is the banebot wheel we have press fit onto a shaft. Each banebot wheel is connected to their respective metal gear motors. The RMV is then leveled by two non-driven, solid steel caster wheels on the right-hand side of the picture spaced out from the base by a ½ square aluminum block. Figure 8 below shows a side view rendering of the final 3D assembly.

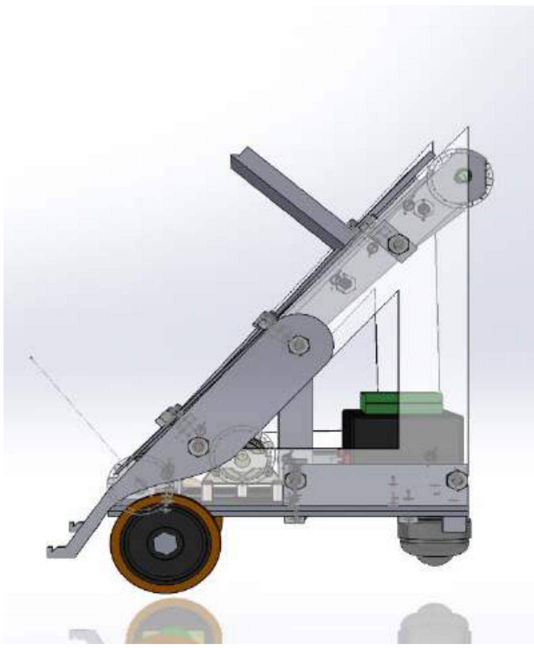


Figure 8. This figure shows the final CAD in side view of the team 21 RMV.

In our Most Critical Subsystem, the lift system, our scoop is attached to a .35 chain and lifted with 3D printed sprockets. The left bottom sprocket ensures that the scoop is able to collect cubes on the ground, while the right upper sprocket ensures the cubes can be delivered 10.5" above the ground. Each of these sprockets is suspended by a Delrin frame connected by L-brackets screwed to the baseplate. The upper sprocket's frame is supported at the top through a bolted connection to the support ramp. The addition of supports to the top corner of the support ramp were made for two reasons. First, to add stability to the support ramps, and second, to enable the sprocket shaft to slip into a press fit bushing that would not have been well supported by sheet metal alone. We have also modified the design to utilize the support ramp as a means of preventing damage to the sprockets should the scoop begin to tilt while operating. This means that the scoop is no longer expected to ride on the support ramp but rather slightly above it.
The chain and sprocket system is to be driven by a third tensioning sprocket attached to the planetary motor, which is elevated by cylindrical washers. The purpose of these supports is to allow the sprocket to turn without interference from the baseplate.

After beginning to machine our parts we ran into a few issues of human error that required us to modify our final CAD and make adjustments. For example, in manufacturing our base plate, we realized four of our ¼-20 holes had been drilled into slip fit instead of thread fit, which required us to make countersinks in order to ensure nuts could be placed on the bolts without interfering with other components. Because of this, we removed material from the larger L-brackets. In the end, this actually made our assembly easier and allowed us to successfully secure the L-bracket and caster wheels.

Another issue we ran into happened only a few days before the competition. In practicing with our RMV to lower the disposable ramp, the two acrylic legs of the A-frame snapped off. This required us to redesign some easily attachable and more durable legs. The following isometric screen captures are of our RMV before adding the new Delrin legs instead of our acrylic frame. The new legs also include a concave cutout, as opposed to the previous convex cut, to help further the ramps security as it drives.

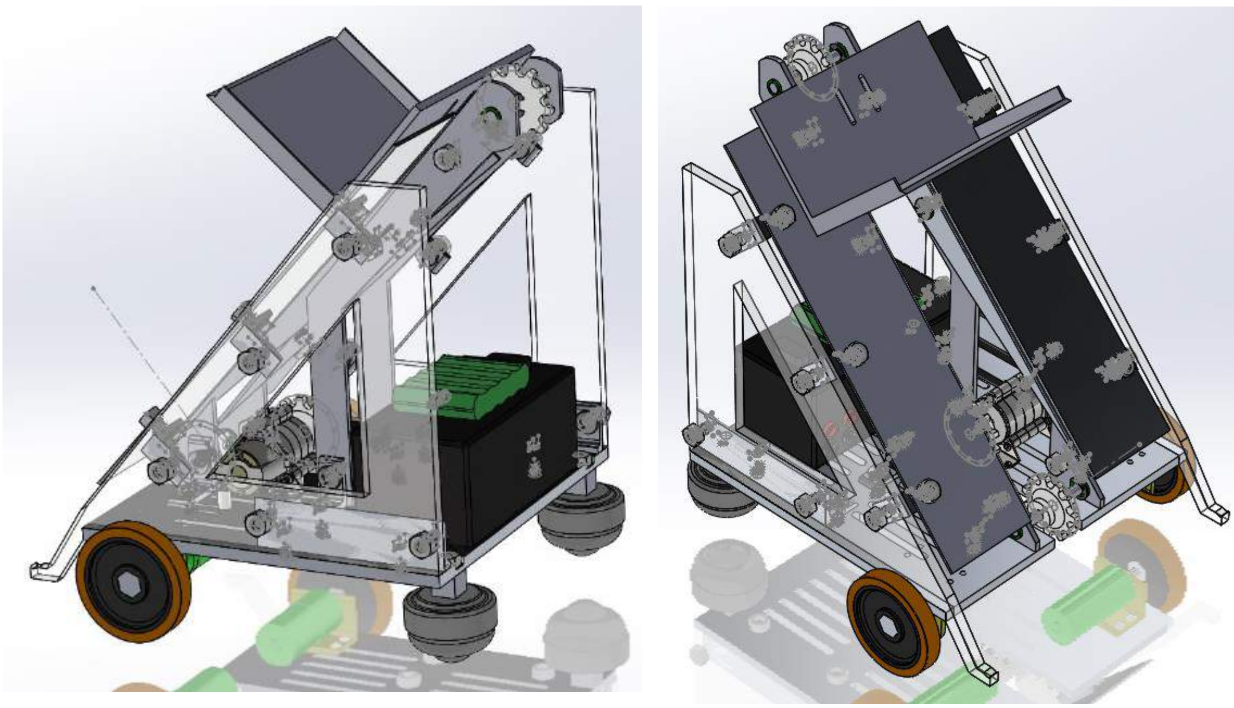


Figure 9. This figure demonstrates perspective views of the final RMV 21 CAD assembly.

4. RMV MANUFACTURING

RMV manufacturing was done based on engineering drawings and manufacturing plans generated from the Solid Works assembly and parts.

4.1. Bill of Materials

The manufactured parts are listed in Table 2, spanning pages 13 through 16, below.

Table 2. This table shows the full bill of materials to construct RPV 21 including number title supplier notes and contributors.

Part No.	Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Contributors		
								Design/ CAD	*Drawing /Plan*	*Machin-ing*
1	4" L bracket A	Aluminum 90 degree Angle stock 1/8"	4"	Kit	1	---	Used the 90° angle stock because these are 90° L-brackets	Jonah	Kelsey/ Jonah	Kelsey
2	4" L bracket B	Aluminum 90 degree Angle stock 1/8"	4"	kit	1	---	Used the 90° angle stock because these are 90° L-brackets	Jonah	Jonah	Rachel
3	1/2" L bracket	Aluminum 90 degree Angle stock 1/8"	1/2"	Kit	8	---	Used the 90° angle stock because these are 90° L-brackets	Jonah/ Kelsey	Jonah	Luca
4	MS6 Base	Aluminum plate, 1/4" thick	7.8"x7.8"	Kit	1	---	Used waterjet Provided the strongest base for the least mass	Rachel	Kelsey/ Rachel/ Aidan	Jonah
5	caster wheel	---	---	Kit	2	---	traded with team 23	---	---	---
6	Sheet Ramp	Aluminum sheet, 1/16"	11.54"x4.15	Kit	2	---	Used waterjet Lightweight, easy to bend, capable of supporting chain tension	Luca	Kelsey	Jonah

7	Inner frame	Delrin 1/8"	1.5"x2.17"	kit	2	---	Used laser cutter Lightweight, large supply, can press fit bushings into	Luca/ Kelsey	Kelsey	Kelsey
8	Planetary Washer	Ultra machinable 1/4" diameter steel rod	1.6"	kit	4	---	Easy to machine, already correct OD	Luca	Kelsey/ Aidan	Rachel
9	New Frame	Acrylic	9.34"x10.4"	Kit	2	---	Used laser cutter Strong in compression, easy to manufacture	Aidan/ Jonah	Kelsey	Luca
10	#35 Sprocket for Lift	PLA plastic	1.331" pitch diameter	3D printer	3	---	3D printed Easy to make, easily replaceable	Luca	Luca	Aidan
11	.35 chain tab	Aluminum	---	McMaster	2	$4.00		---	---	---
12	Eclips	---	---	kit	6	---		---	---	---
13	spring pin	---	---	kit	3	---		---	---	---
14	Lift Shaft Top	ultra machinable steel 1/4" steel rod	.15"Dx1/4"	kit	1	---	Easy to machine	Rachel	Kelsey/ Aidan	Jonah
15	Lift Shaft Bottom	ultra machinable steel 1/4" steel rod	1.75"	kit	1	---	Easy to machine	Luca	Kelsey/ Rachel	Aidan
16	Bushing	---	---	kit	4	---		---	---	---
17	.35 chain	Aluminum	25"	McMaster	1	$8.13		---	---	---
18	1/4-20 Phillips head 3/8"	steel	.25"Dx3/8"	kit/crib	16	---		Jonah	---	---
19	1/4-20 Phillips head 1/2"	steel	.25"Dx1/2"	kit/crib	18	---		Luca	---	---
20	4-40 screw	---		McMaster	16	$8.12		---	---	---

21	1/4-20 Phillips head 1/4"	steel	.25"Dx1/4"	kit/crib	2	---		Rachel	---	---
22	1/4-20 nut	steel	.3"x1/2"hex	kit/crib	34	---		Jonah	---	---
23	Cut Scoop	PLA plastic	---	3D printer	1	---	3D Printed Lightweight, easy to make changes to, strong enough for lifting cubes	Luca/Kelsey	Kelsey	Jonah
24	Planetary Motor	---	---	kit	1	---	100:1 gear ratio	---	----	---
25	Top Support	Delrin 1/8"	4.67"x8.80"	kit	2	---	Somewhat flexible, strong enough to provide support	Jonah	Kelsey	Jonah
26	Motor Bracket	Aluminum 90 degree Angle stock 1/8"	1.5"	kit	2	---	Used the 90° angle stock because these are 90°	Jonah	Kelsey	Rachel
27	BaneBots wheels	---	---	Kit	2	---		---	---	---
28	Front Wheel Spacer	Aluminum 1/2" square stock	0.5"x0.5"x.44"	kit	2	---	Large enough to get bolt through, won't compress	Jonah	Kelsey	Rachel
29	control box	---	---	Kit	1	---		---	---	---
30	Metal Motor	---	---	Kit	2	---	traded in double gearbox	---	---	---
31	set screw	---	---	crib	4	---		---	---	---
32	Hex drive shaft	Multipurpose 6061 Aluminum Bar, 1/2" Hex Size, 2'	.84"	crib	2	---	Long Banebot wheels have hex holes	Luca	Aidan	Rachel
33	4-40 nut	---	---	McMaster	4	$2.36		---	---	---

34	Add and Connect Link for ANSI #35 single strand roller chain	Aluminum	---	McMaster	2	$3.56		---	---	---
35	disposable ramp	Aluminum sheet, 1/16"	13"x9"	kit	1	---	used waterjet Lightweight, can support RMV, bendable	Aidan	Kelsey	Luca
36	disposable ramp supports	Aluminum sheet, 1/16"	1.25"x.73"x.77"	Kit	2	---	used waterjet Bendable	Aidan	Rachel	Luca
37	disposable ramp support legs	Delrin 1/8"	8.19"x1.58"	Kit	4	---	Laser-cut Strong enough to support disposable ramp	Rachel	Rachel	Luca

4.2. Manufacturing Process

We were able to waterjet and laser-cut many of our RMV components, such as the acrylic frame and ¼" aluminum baseplate. This drastically reduced the time spent machining these pieces. Most of our machining time was spent milling tapped, reamed, and counterbored holes. We also lathed planetary support washers, along with wheel shafts. For the most part we were able to waterjet and laser-cut the outlines and clearance holes for our parts. This saved us a lot of time that would otherwise have been spent machining, allowing us to fix any errors that arose during assembly and testing. Most of the RMV is assembled using nuts, bolts, and washers. The axles that the sprockets are mounted on are clearance fitted into bushings to allow rotation.

We also 3D printed some critical components of our RMV, which included our sprockets and our scoop. We ran into difficulty due to our dependence on the CAD and some miscommunication between teams within our squad. The 3D printed parts also were weaker than we anticipated, and we had to adjust our design multiple times to account for this. There was also difficulty with the acrylic frame due to the fragility of the leg extensions. We remedied this by laser-cutting delrin legs of the same outline and bolting these to the frame.

5. RMV TESTING

After manufacturing and assembling the final RMV design the RMV was tested on its design objectives before being run in the final timed and scored competition. While not preforming as expected, the design decisions made enabled a successful secondary mode of point scoring.

5.1. Preliminary Test

We performed a preliminary test on each of the subsystems to make sure that they were functioning properly. First, we tested the drive system of our RMV. We found that our RMV could move very fast and could make very tight, accurate turns. The only issue we had was that the set screws continued to come loose. We applied Loctite to the set screws to make them more secure. This seemed to resolve the issue for a short time, but we ended up having to use the Loctite twice again before the competition as the drive shafts kept coming loose from the metal motor shafts. We know that in the future, we would make sure to use spring pins instead of set screws to connect the drive shafts to the metal motor shafts.

When testing the cube lifting subsystem, we identified that there was enough torque being supplied by the motor to lift just the chain and the scoop, but it could not lift the scoop if it were carrying more than one cube. We realized that there was a large amount of friction each of the shafts and the bushings that they were turning in. We also realized that in our initial calculations for the required gear ratio of the planetary motor, we did not take into consideration the weight of the chain, which would increase the torque needed from the planetary to move the chain and sprocket. To resolve these issues, we sanded down the ends of each of the shafts so that they would rotate more smoothly in the bushings. Additionally, we added a gear to the planetary motor, and therefore increasing the gear ratio from 25:1 to 100:1. Just to ensure the efficiency of the system, we filed down the teeth of each of the sprockets to make them narrower so that they would fit into the slots of the chain properly. After making these changes, the planetary motor was able to move the chain and scoop with four blocks on it seamlessly.

Next, we tested dropping the disposable ramp. This worked very well the first few times that we attempted it, but once we increased the gear ratio, the force on the legs of the acrylic frame that held the ramp up ended up being too much for the legs to handle and they snapped off of the A-Frame. To address this issue, we designed a new leg that could be bolted to the side of the frame, which we then laser cut four of these out of the Delrin sheet and bolted two of them to each side. In doing this, the ramp was much more stable when our RMV was driving around. Because Delrin is a little more flexible than acrylic, it could handle the scoop pushing down with more force on the disposable ramp. Additionally, because the new leg piece attaches to the side of the frame, in the event the legs broke again, it would be much easier to replace if it were to have broken again.

5.2. Competition Results

The Game of Zones competition went well for our squad. We were not able to follow our squad strategy perfectly, but every team was able to score at least a few points and contribute to the overall success of the squad. RMV 2 in our squad was able to score all the cubes in their zone into the low goal, RMV 4 was able to pull down the drawbridge, RMV 3 was able to score three yellow blocks into the high goal basket, and our RMV was able to push the block fully out of its original position.

Our RMV was unable to complete our intended tasks because we accidentally hit a wall while moving into position to drop the disposable ramp, so the ramped slipped off the legs before we had a chance to drop it properly into position. We then attempted to flip the ramp over with our scoop, but due to overuse of the scoop earlier in the week for testing, as well as the fact that we had never tried to lift our ramp before, our sprocket failed. Because the fill for our sprockets were 30% honeycomb fill, the exertion of competition finally caused the spring pin to break through the wall of the 3D sprocket and wear a path all the way through. This caused our shaft to spin but the sprocket would no longer move, which meant that our scoop would no longer lift. We then proceeded to weave through the maze and push the block out of position. This was not an intended task of our RMV, but we wanted to be able to contribute at least a few points to our squad's overall score.

We believe that we could have improved our RMV and overall squad performance by having a little more practice driving our RMV and scrimmaging before we had the actual competition. We think this could have helped us avoid running into the wall. This could also have helped us troubleshoot during the competition. If we would have practiced more before the competition, we would have most likely run into the same problems at some point, and then would have discovered the best ways to handle these problems during the competition.

6. SUMMARY & NEXT STEPS

We started off the project with an idea of the tasks that our RMV needed to complete and we then proceeded to brainstorm ways to complete each of these tasks. From the beginning, we had a pretty clear idea of what we wanted our RMV to look like and what functions we wanted it to have. As we got into designing and manufacturing our RMV, we ran into some issues, which was expected, and some problems were easier to fix than others.

Over the course of the semester, we found that our RMV had many strengths but also many weaknesses. We believe our strongest subsystem is the driving subsystem. This subsystem worked almost exactly as we wanted it to from the beginning. Before we started manufacturing, we shifted from a double gearbox controlling the wheels to two metal motors, each controlling one wheel. This decision positively impacted the quality of our driving as it increased the speed of our RMV significantly. The one downfall of our drive system was that the set screws that connected the wheel shafts to the drive shafts kept coming loose even after we used Loctite to secure them to each other. Looking back, we believe that knowing what we know now, we would have not even considered the double gear box for this subsystem in the first place and we would have used spring pins instead of set screws to secure the metal motor shafts to the wheel shafts.

Our weakest subsystem was the cube lifting subsystem. We ran into many problems with this subsystem, mostly due to a lack of knowledge of how to incorporate the weight of the chain into our initial calculations. These problems were relatively easy to resolve once they were identified, mostly due to the fact that it was a fairly simple process for us to disassemble and reassemble our RMV. Additionally, the 3D-printed sprockets were not very reliable in their function within the subsystem. With the size of the scoop, it was also quite difficult to pick up four cubes at a time if they shifted out of place at all on the table. Looking back on it, we feel that we should have purchased the sprockets instead of 3D- printing them, made our scoop wider, made our disposable ramp wider, and done a little more research on how the chain factors in to the calculation for the desired gear ratio for the planetary motor.

If we were to scale our production to mass produce our RMV, we would choose to extrude our base as well as our caster wheel supports and planetary supports. The constant thickness of these parts would make them ideal candidates to be extruded. The only holes that require specific tolerances for the base plate could be machined after the extrusion to achieve the tapped holes required for the caster wheels. These changes would save time and money in mass production but would not at all be suitable for producing a single RMV. It would be an expensive process to make one base plate, two wheel supports, and only four planetary supports, so machining them and water jetting the base plate is a better option for small scale production.

An idea we have for a project in this class is a relay race/obstacle course idea where there are four different sections of an obstacle course and each RMV in the squad must be able to traverse one section of the obstacle course. There will be a maximum time limit of 2 minutes for an RMV to complete their section of the obstacle course, and whichever squad completes the entire obstacle course in the shortest amount of time wins.

7. ACKNOWLEDGEMENTS & REFERENCES

We would like to thank all the ME 250 instructors, the GSIs, all of the shop staff with special thanks to Mike Umbriac and Dan Cooper; our graduate supervisor: David Mark; Charlie, Toby, and Jon for their patience and wisdom in the shop; as well as the rest of Squad 20.

[1] Ramsdale, Robert. *Coefficient of Friction Reference Table* **-** *Engineer's Handbook*, www.engineershandbook.com/Tables/frictioncoefficients.htm.

[2] Provided course material for MECHENG 250 at university of Michigan School of Engineering

APPENDICES

A. Preliminary design concept SKETCHES

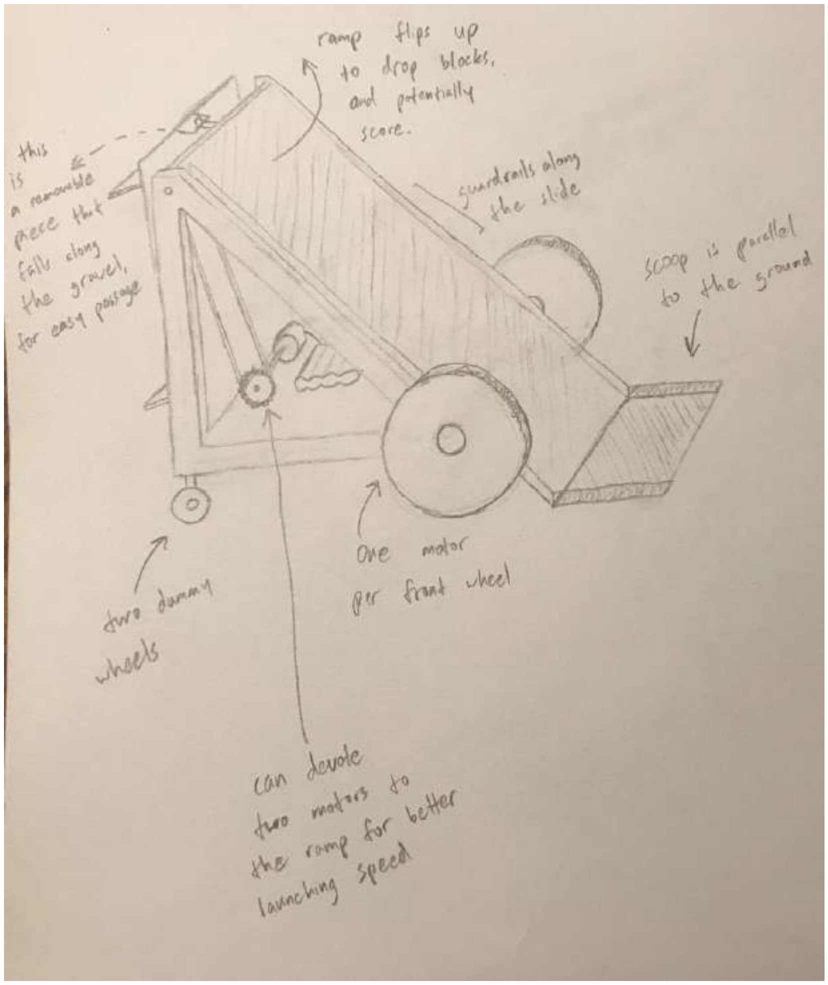


Figure A.1. This concept used a long rotating scoop to pick up cubes, a droppable ramp, and two independently powered motors, in addition to two "dummy" wheels. This is like our final design.

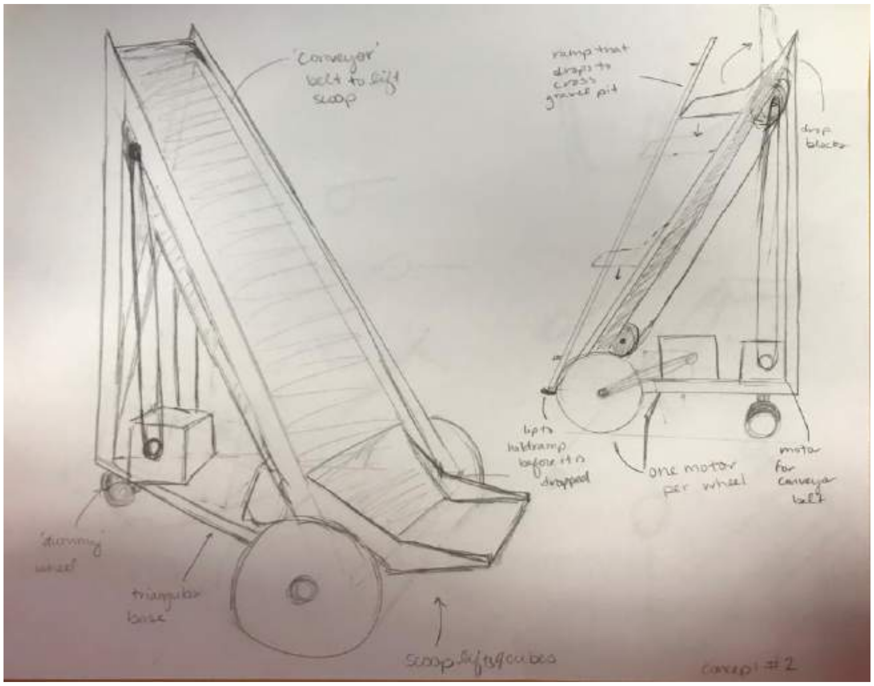


Figure A.2. This concept used a scoop attached to a conveyor belt to lift the cubes up, and the scoop would rotate at the top of the belt, dumping cubes into the basket. It had two independently powered wheels and one "dummy" wheel.

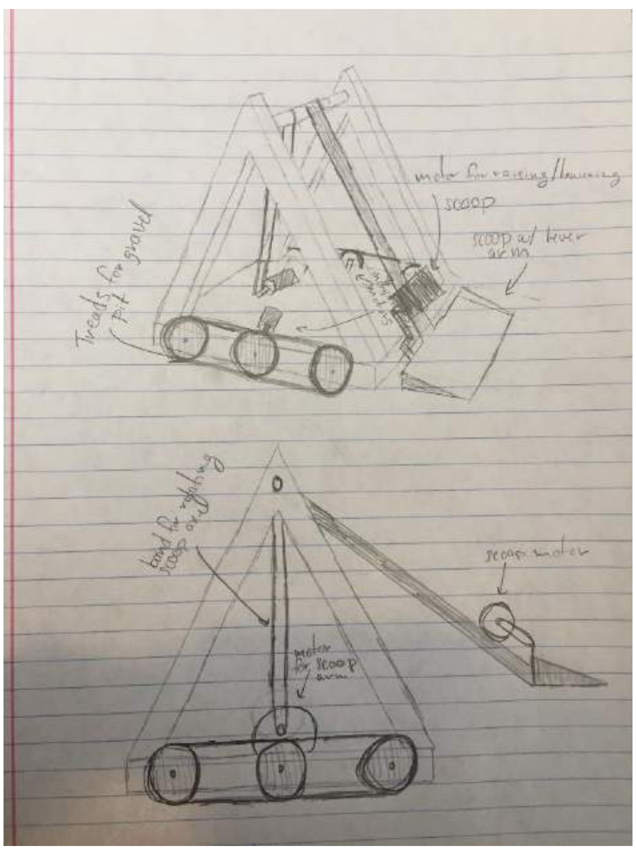


Figure A. 3. This concept used treads to traverse the gravel pit. It employed a scoop arm to pick up cubes, with a motor attached to provide more control over the scoop bed.

B. PURCHASED AND TRADED ITEMS

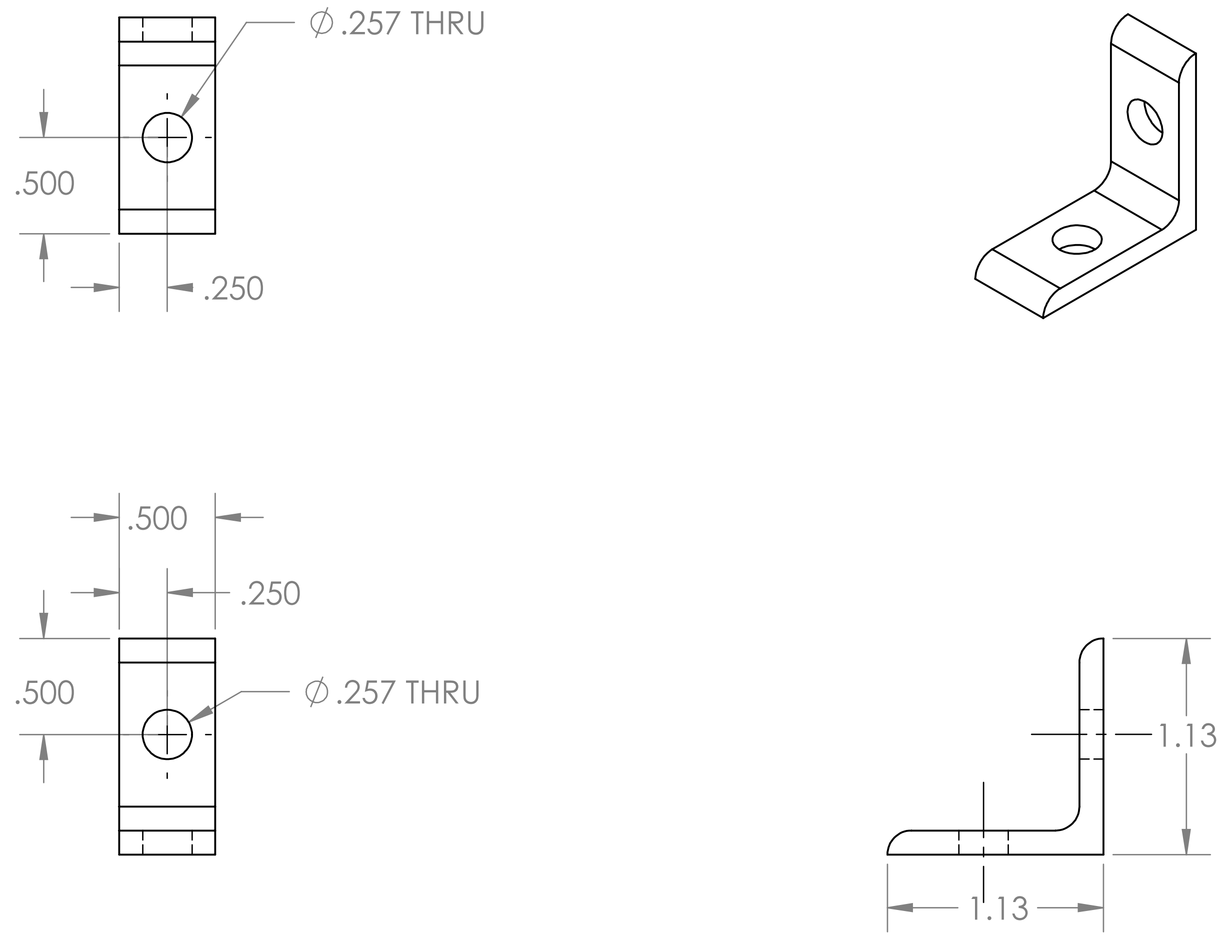
Table B.1: Purchased Parts

Supplier	Part name/number	Dimensions	Total quantity	Price	Description
McMaster	.35 chain/17	25”	1	$8.13	Chain for lift system
McMaster	4-40 screw/20	---	40	$8.12	Screws for the washers planetary gearbox sits on
McMaster	4-40 nut/33	---	4	$2.36	Nuts for the washers planetary gearbox sits on
McMaster	Add and Connect Link for ANSI #35 single strand roller chain/34	---	2	$3.56	Chain connection for lift system
McMaster	.35 chain tab/11	---	2	$4.00	Connection for scoop to chain for lift system
Total				$26.18	

Table B.2: Traded Parts

Trade-in part	Trade-out part(s)	From	Positive Trade Deficits	Description
Steel threaded rod, 1/4"-20	Caster wheel	Crib	$0.26	Wheel to allow smaller turning radius and ease of maneuvering
Ball bearings (2)	Acrylic sheet	Crib	$1.95	A-frame leg broke early in manufacturing, so we needed to laser cut the part

Appendix C: Engineering Drawings



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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum 90 Degree Angle Stock - 1"x1", 1/8" thick	COMMENTS: Quantity: 8			SIZE A — DWG. NO. — REV
NEXT ASSY	USED ON	FINISH Burr Free				
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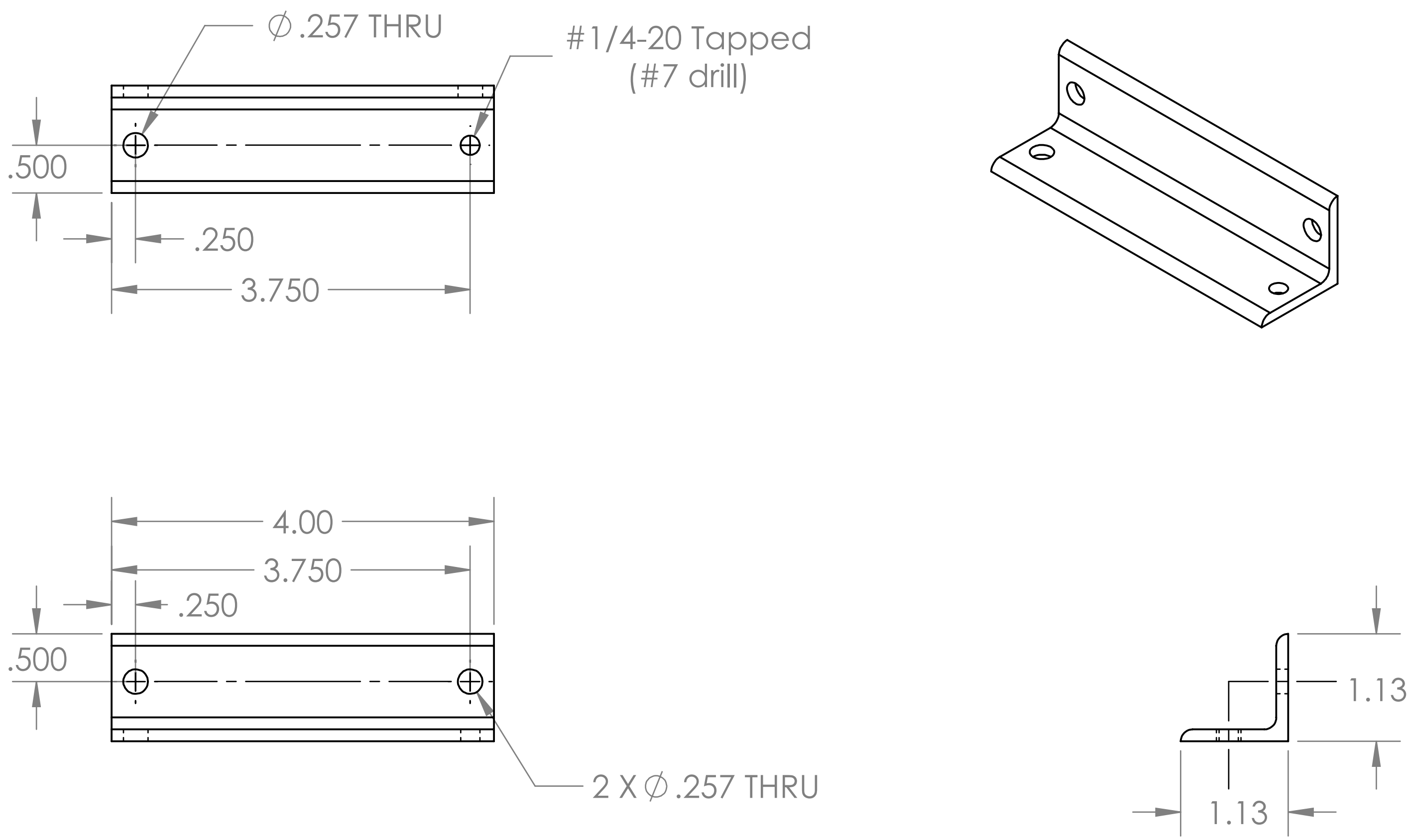

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum 90 Degree Angle Stock - 1"x1", 1/8" thick

FINISH
Burr Free

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DRAWN	K. Philipps	3/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

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TITLE:

Team 21 Part #1

SIZE A | DWG. NO. | REV

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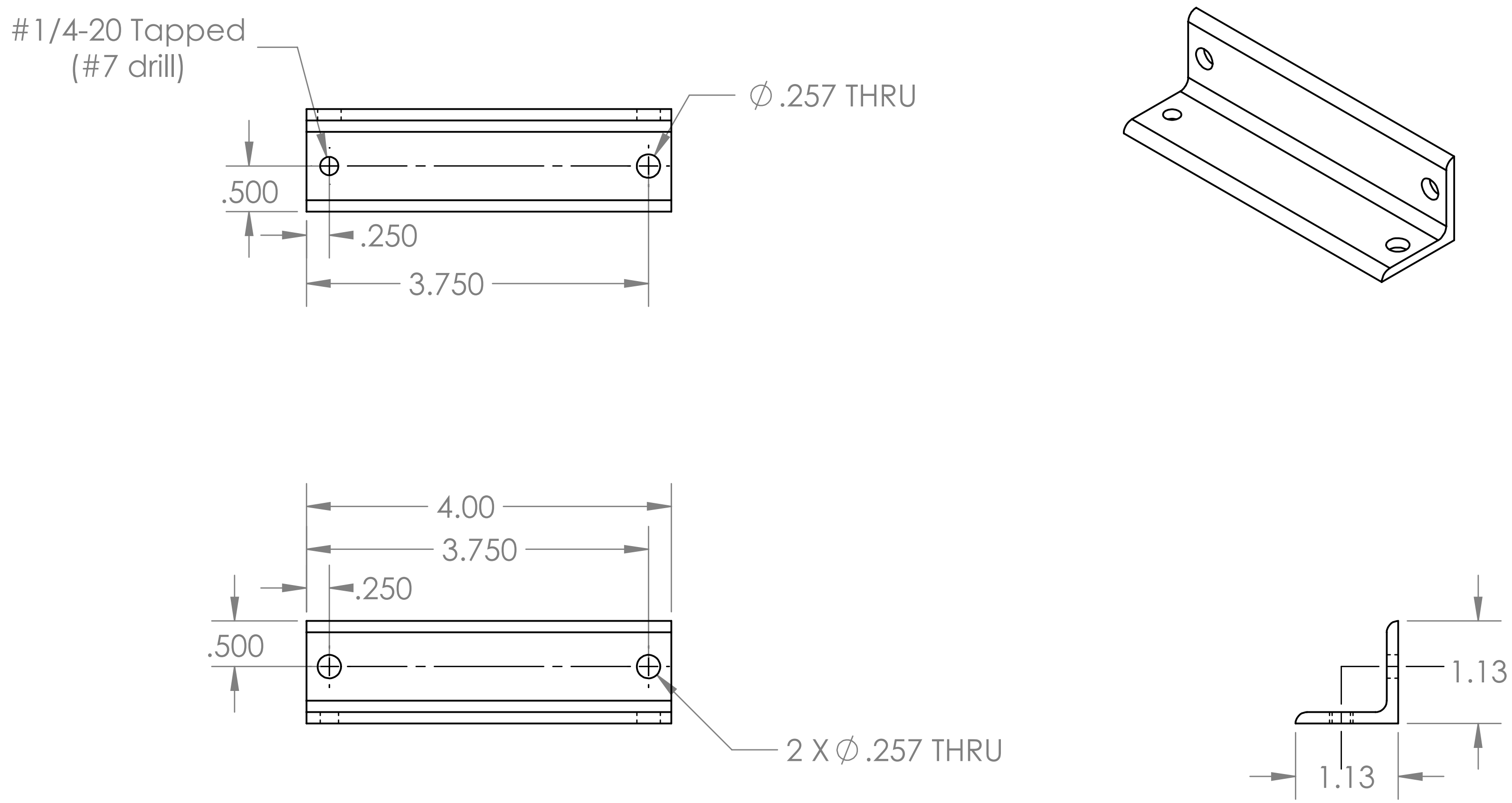

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APPLICATION		

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum 90 Degree Angle Stock - 1"x1", 1/8" thick

FINISH
Burr Free

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DRAWN	K. Philipps	3/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Quantity: 1

TITLE:

Team 21 Part #2

SIZE	DWG. NO.	REV
A		

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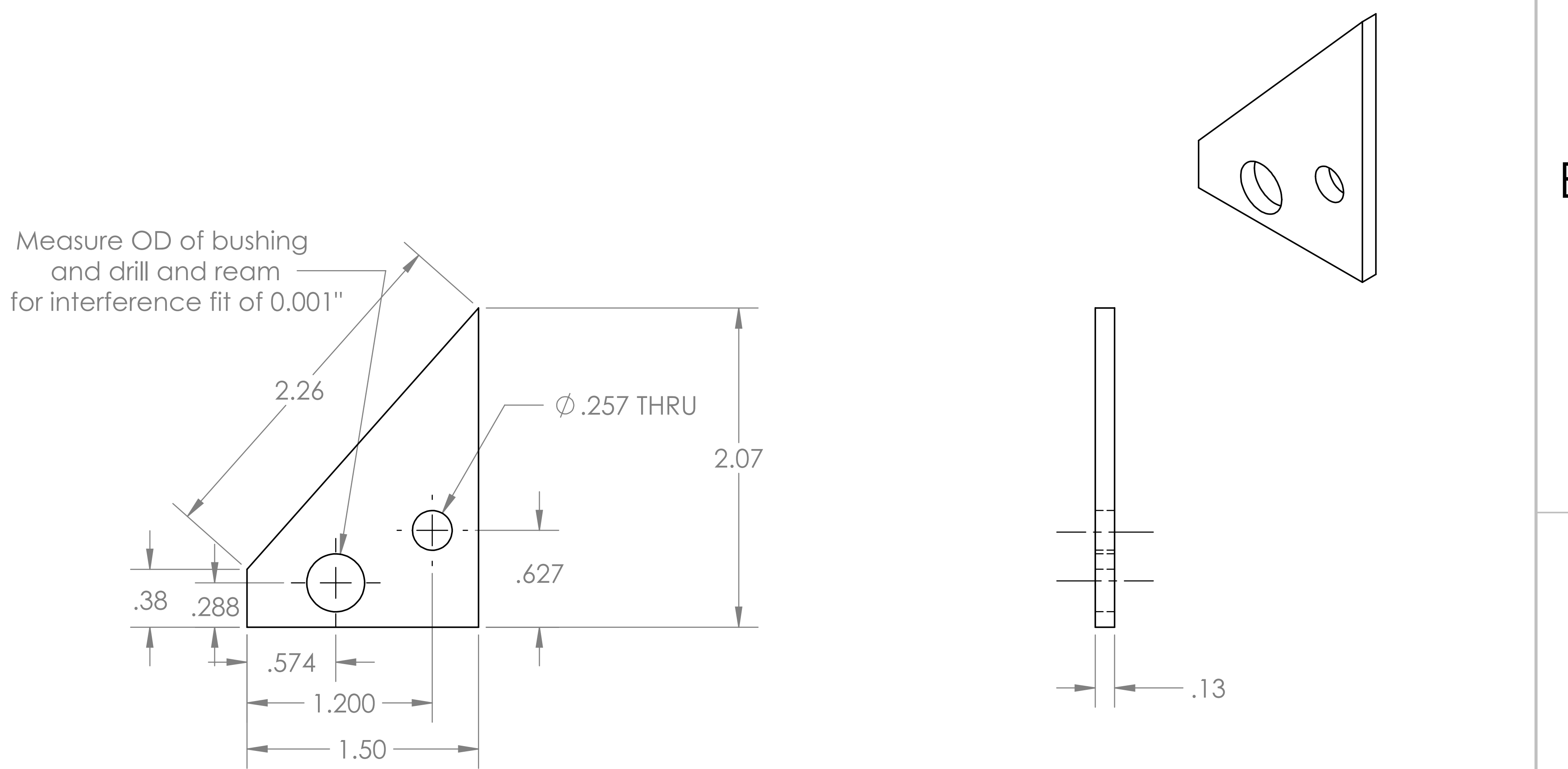

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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 1/8" Delrin plate	COMMENTS: Quantity: 2			SIZE A · DWG. NO. · REV
NEXT ASSY	USED ON	FINISH Burr Free				
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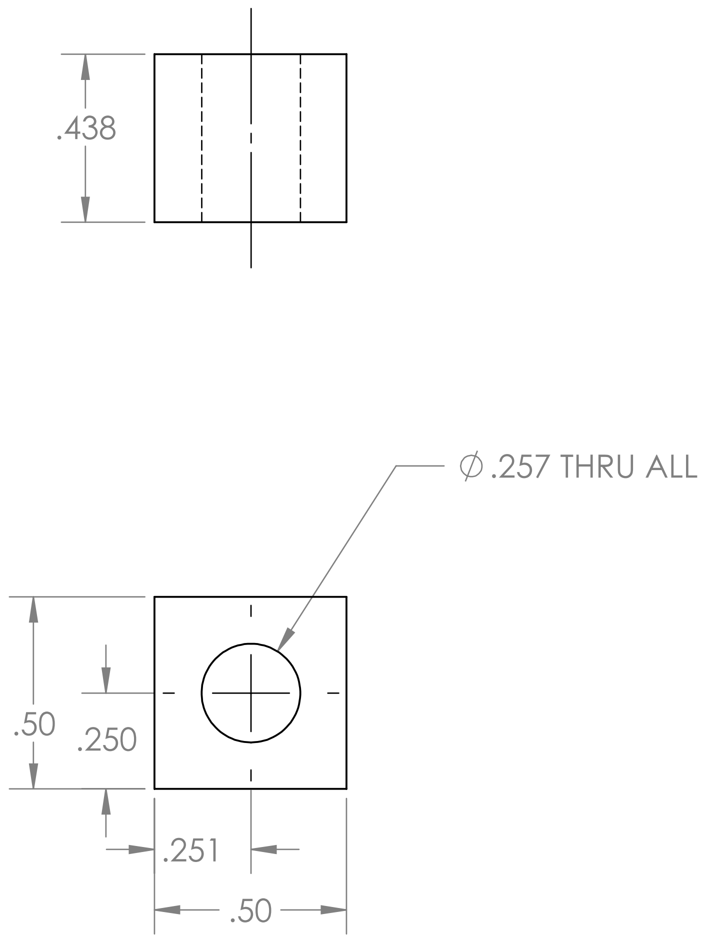

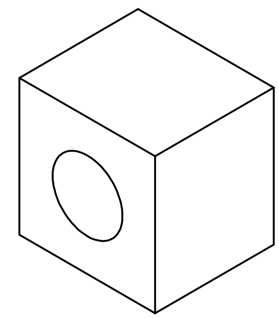

PROPRIETARY AND CONFIDENTIAL

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Aluminum .5" square stock

FINISH Debur

DO NOT SCALE DRAWING

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DRAWN	Aidan V.	3/27/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Quantity: 2

TITLE:

Team 21
Part #29
Front wheel spacer

SIZE	DWG. NO.	REV
A		

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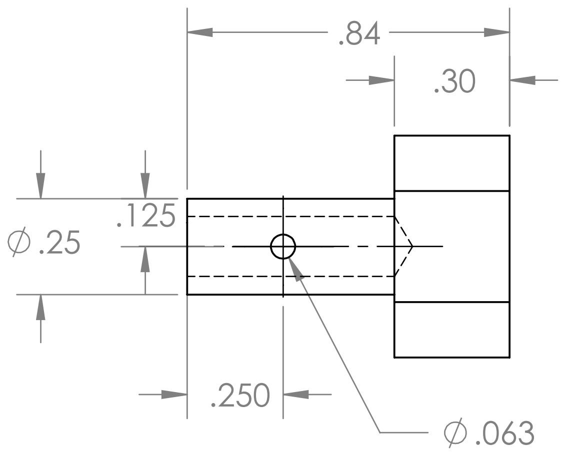

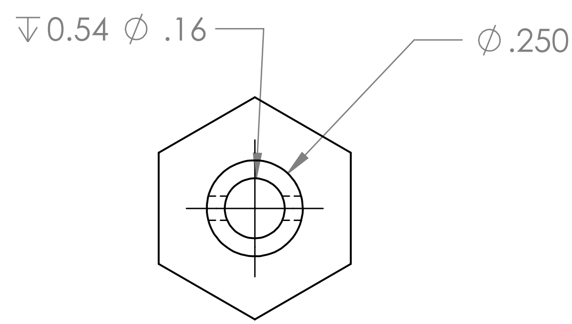

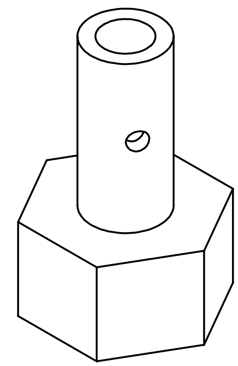

	NAME	DATE	
DRAWN	L. Geralds	3/26/19	
CHECKED			
ENG APPR.			
MFG APPR.			
Q.A.			

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Multipurpose 6061 Aluminum Bar, 1/2" Hex Size, 2' Long

FINISH
Burr Free

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NEXT ASSY | USED ON
APPLICATION

COMMENTS:

Quantity: 2

TITLE:
team 21
part #33
hex drive shaft short

SIZE A | DWG. NO. | REV

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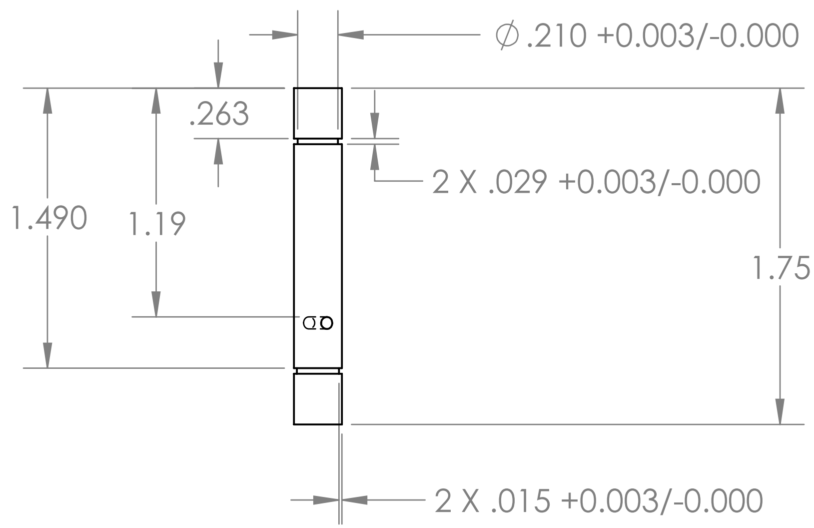

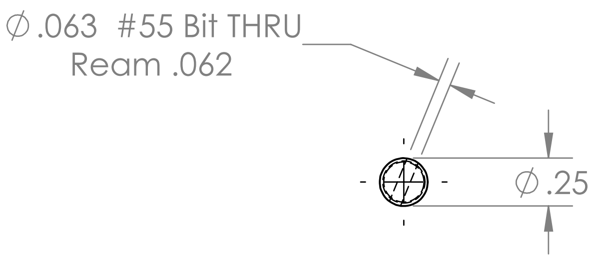

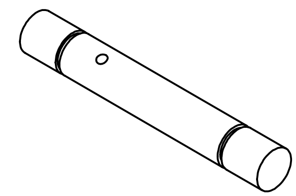

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	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Tight-Tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" Diameter, 1ft long	COMMENTS: Quantity: 1			SIZE A · DWG. NO. · REV
FINISH Burr Free				
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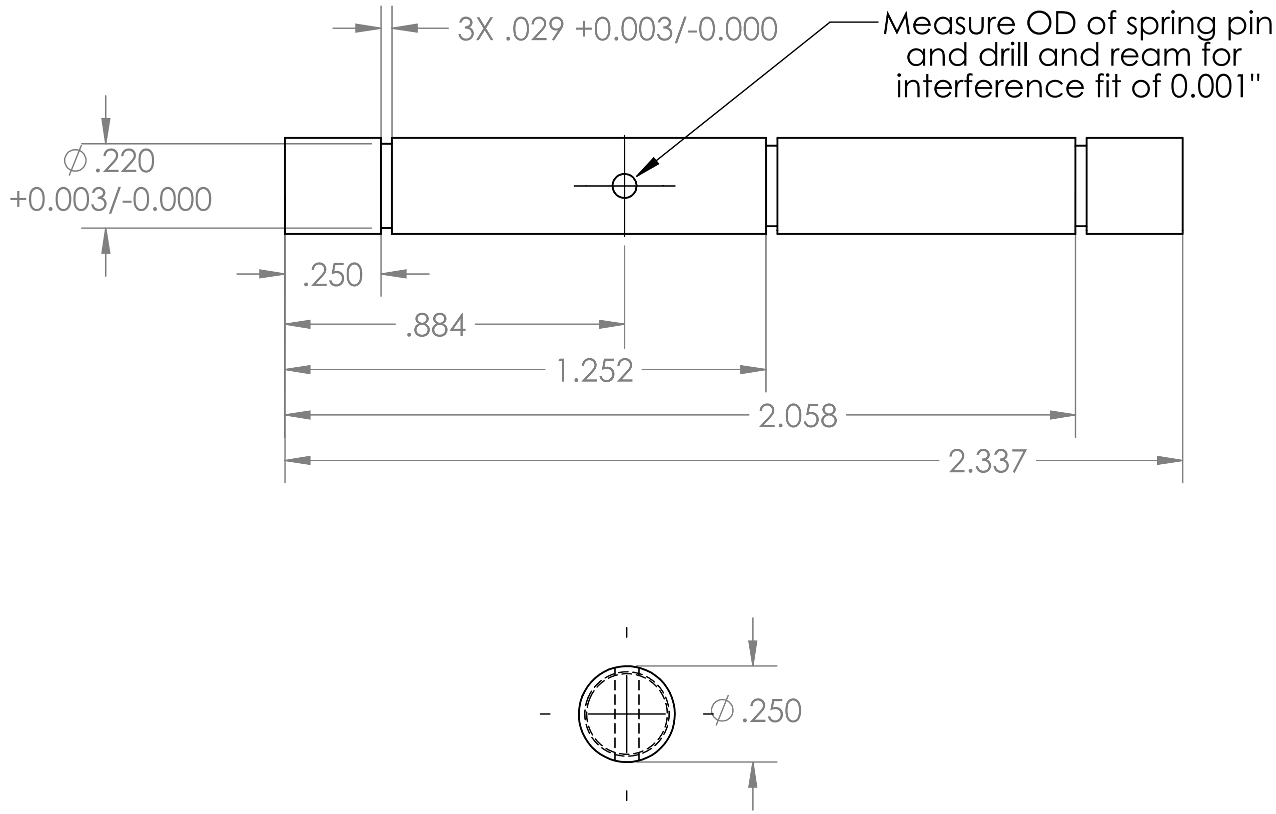

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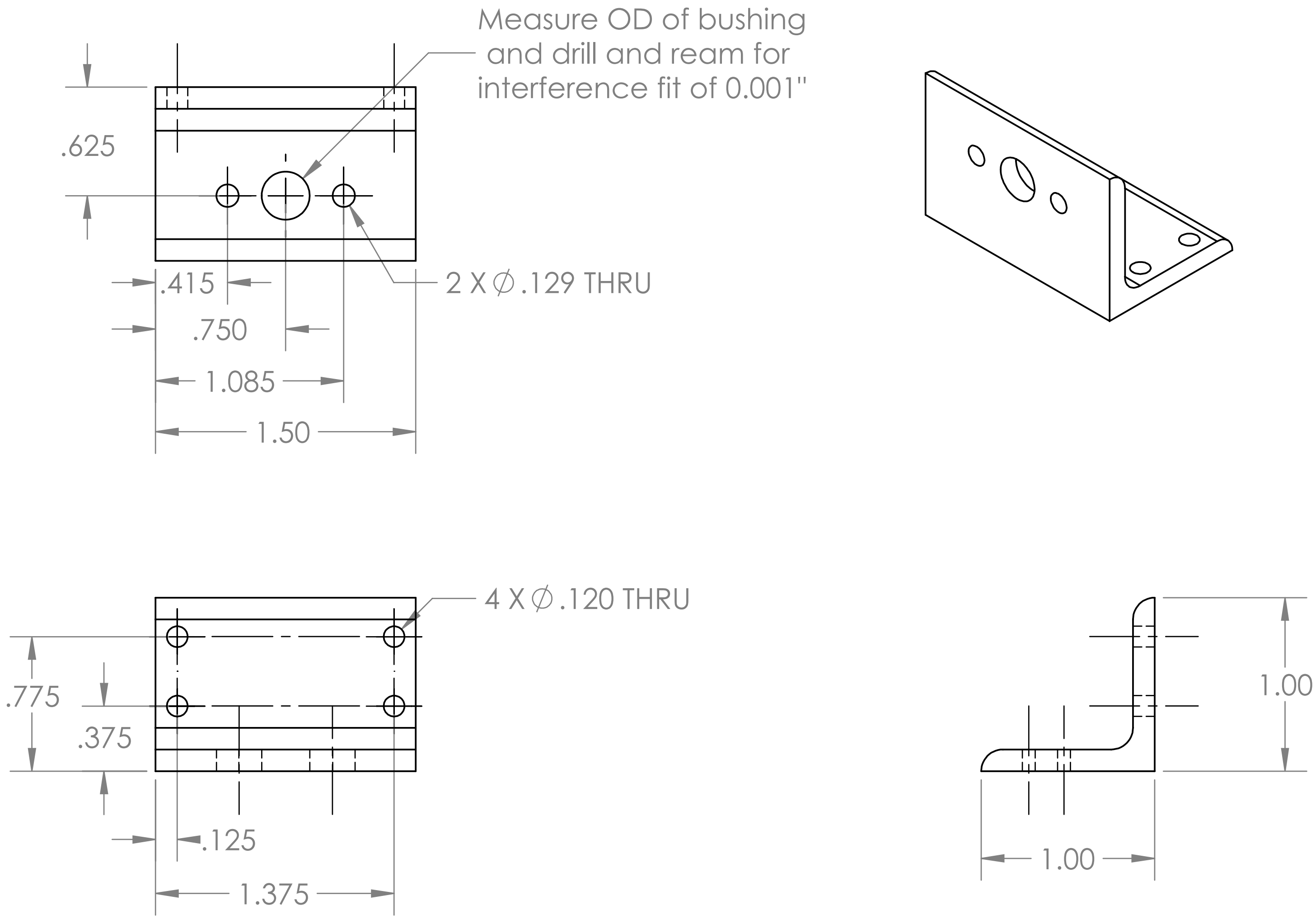
MATERIAL Tight-tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" diameter, 1ft long		
FINISH burr free	NEXT ASSY	USED ON
DO NOT SCALE DRAWING	APPLICATION	

	NAME	DATE
DRAWN	R Martin	3/25/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: Team 21 Part #15 Lift Shaft Bottom

SIZE	DWG. NO.	REV
A		

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum 90 degree Angle stock 1/8"

FINISH
Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	K. Philipps	3/25/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

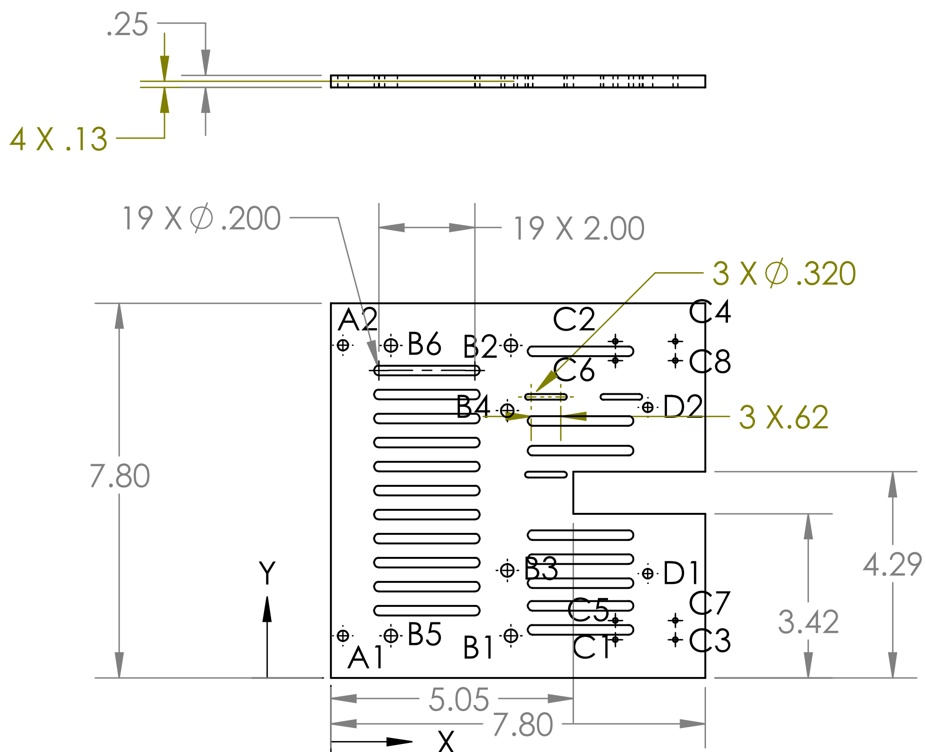
Quanitity: 2

TITLE: Team 21 Part #26 Motor Bracket

SIZE A | DWG. NO. | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



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A2	.250	6.925	#1/4-20 tapped
B1	3.750	.875	∅ .266 THRU ALL
B2	3.750	6.920	∅ .266 THRU ALL
B3	3.675	2.238	∅ .266 THRU ALL
B4	3.675	5.562	∅ .266 THRU ALL
B5	1.250	.875	∅ .266 THRU ALL
B6	1.250	6.920	∅ .266 THRU ALL
C1	5.926	.795	M3 tapped
C2	5.926	7.005	M3 tapped
C3	7.176	.795	M3 tapped
C4	7.176	7.005	M3 tapped
C5	5.926	1.195	M3 tapped
C6	5.926	6.605	M3 tapped
C7	7.176	1.195	M3 tapped
C8	7.176	6.605	M3 tapped
D1	6.601	2.169	#1/4-20 tapped
D2	6.601	5.631	#1/4-20 tapped

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/4" Aluminum Sheet

FINISH
Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Aidan V.	3/13/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Quantity: 1

NEXT ASSY | USED ON

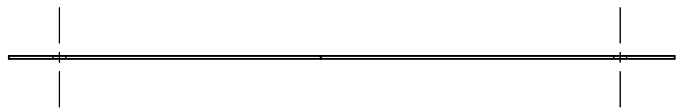
APPLICATION

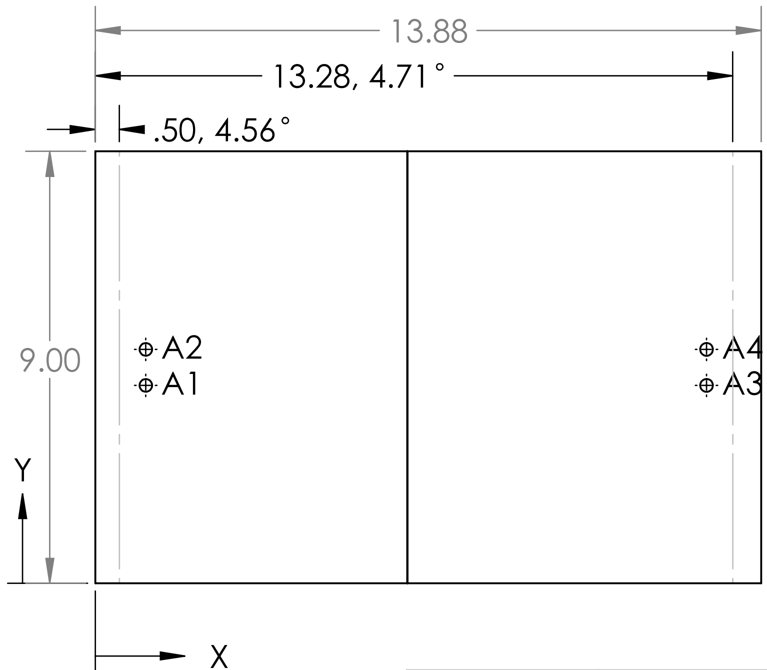
TITLE:

Team 21 Part #4 MS6 Base

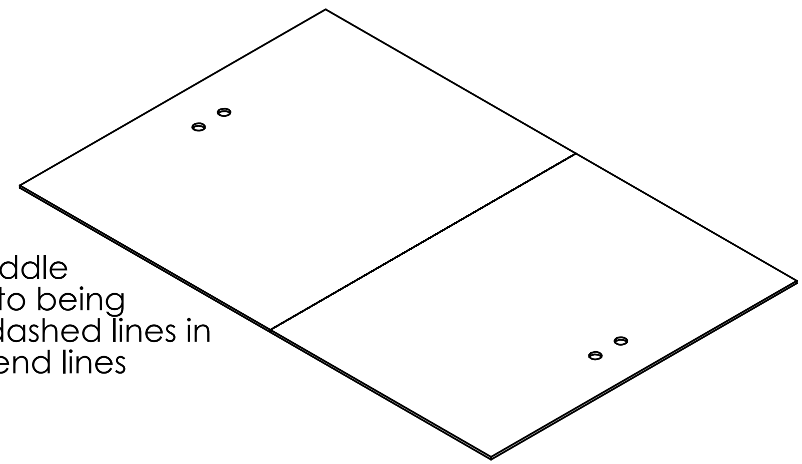
SIZE A | DWG. NO. | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1





Note: Line in middle of ramp is due to being an assembly; dashed lines in top view are bend lines



TAG	X LOC	Y LOC	SIZE
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A2	1.052	4.875	∅ .266 THRU ALL
A3	12.735	4.125	∅ .266 THRU ALL
A4	12.735	4.875	∅ .266 THRU ALL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/16" Aluminum Plate

FINISH
Deburr

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Aidan V.	3/26/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

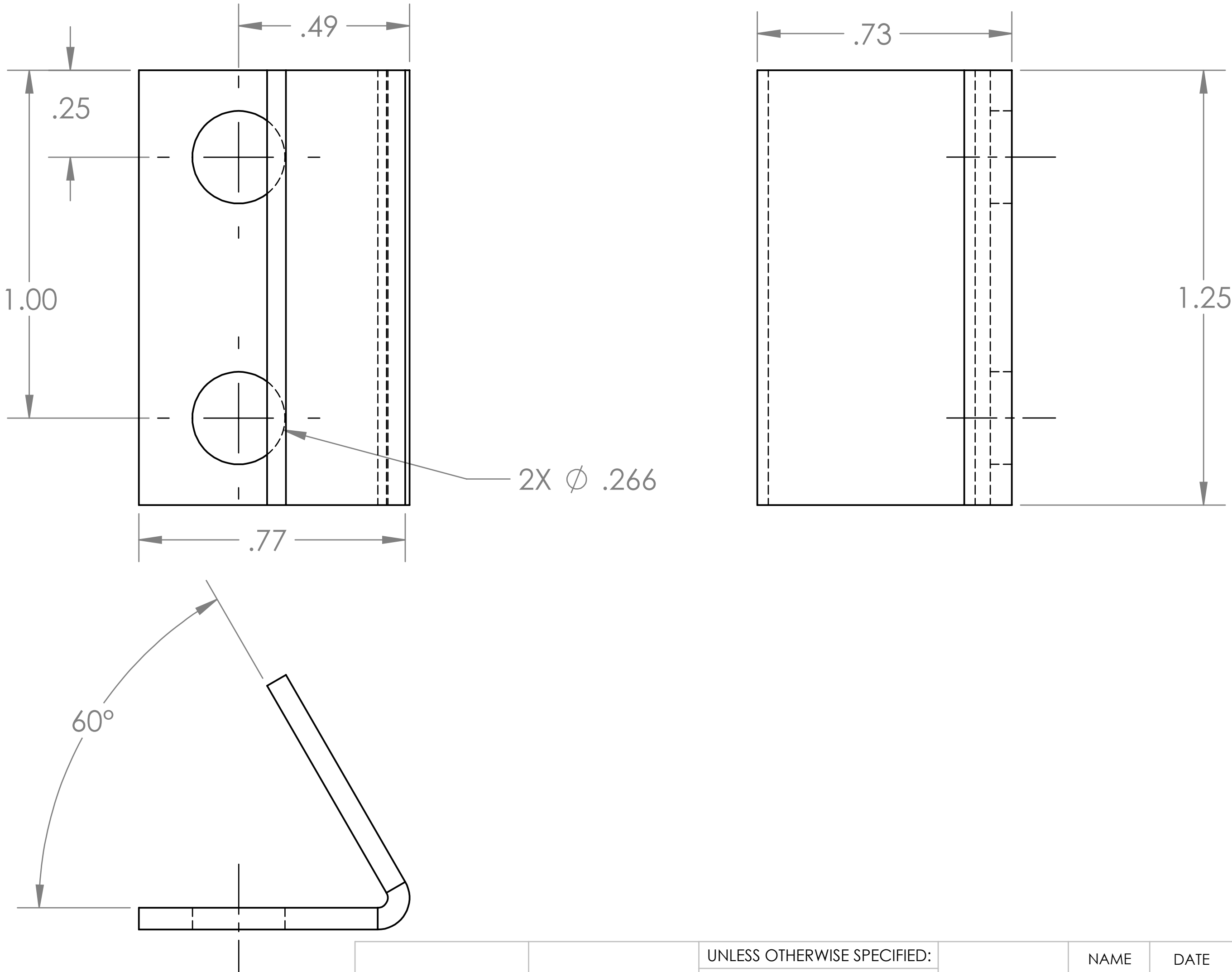
Quantity: 1
Waterjet

TITLE:

Team 21 part 36 Disposable ramp

SIZE A | DWG. NO. | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



	NAME	DATE	
DRAWN	R Martin	3/25/19	
CHECKED			TITLE: Team 21 Part #37 Disposable Ramp Support
ENG APPR.			
MFG APPR.			
Q.A.			
COMMENTS:			

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum plate, 1/6"

FINISH
Burr Free

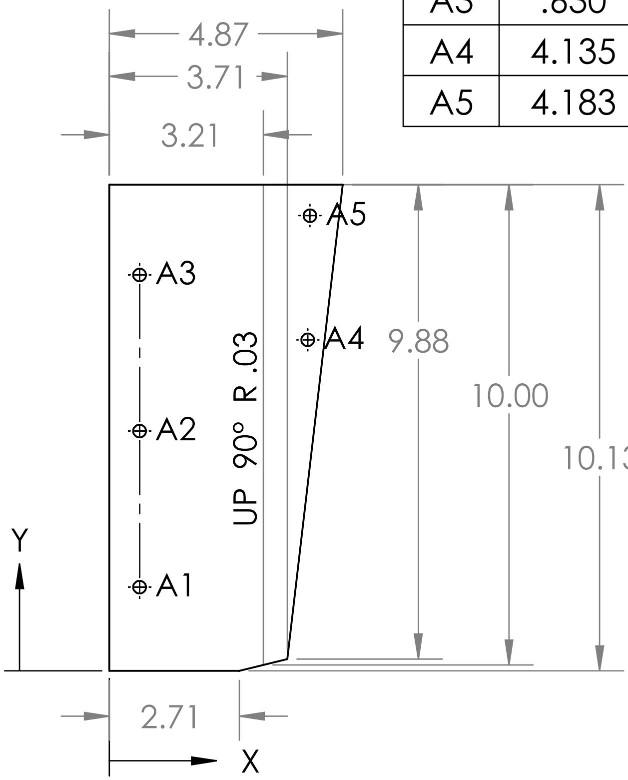
DO NOT SCALE DRAWING

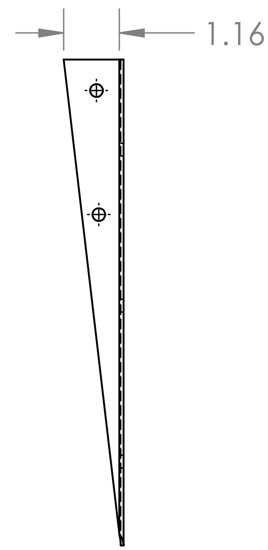
NEXT ASSY	USED ON
APPLICATION	

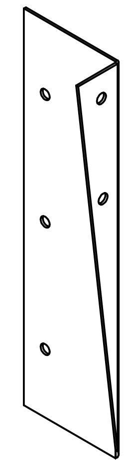
SIZE	DWG. NO.	REV
A		

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

TAG	X LOC	Y LOC	SIZE
A1	.630	1.745	∅ .266 THRU ALL
A2	.630	4.995	∅ .266 THRU ALL
A3	.630	8.245	∅ .266 THRU ALL
A4	4.135	6.894	∅ .266 THRU ALL
A5	4.183	9.478	∅ .266 THRU ALL







NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/16" Aluminum Sheet Metal

Finish
Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	K. Philipps	3/20/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

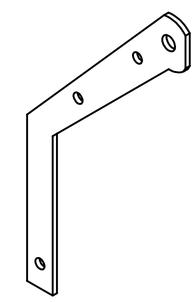
Quantity: 2

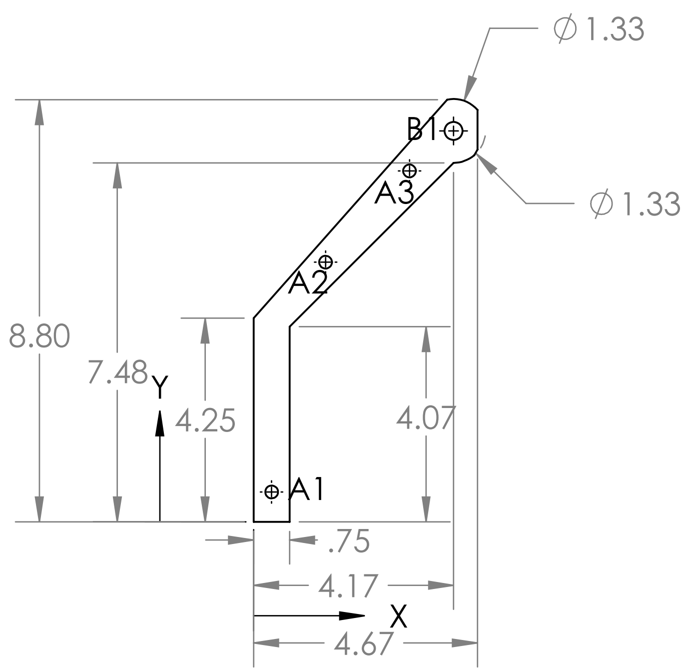
TITLE: Team 21 Part #6 Sheet Ramp

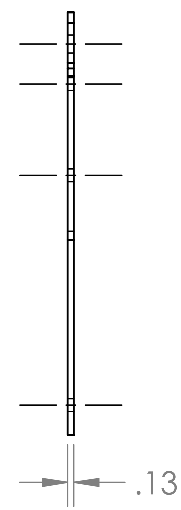
SIZE	DWG. NO.	REV
A		

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

TAG	X LOC	Y LOC	SIZE
A1	.375	.625	∅ .266 THRU ALL
A2	1.500	5.412	∅ .266 THRU ALL
A3	3.250	7.313	∅ .266 THRU ALL
B1	4.168	8.147	Measure OD of bushing and drill and ream for interference fit of 0.001"







NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/8" Delrin

FINISH
Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	K. Philipps	3/25/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Quantity: 2

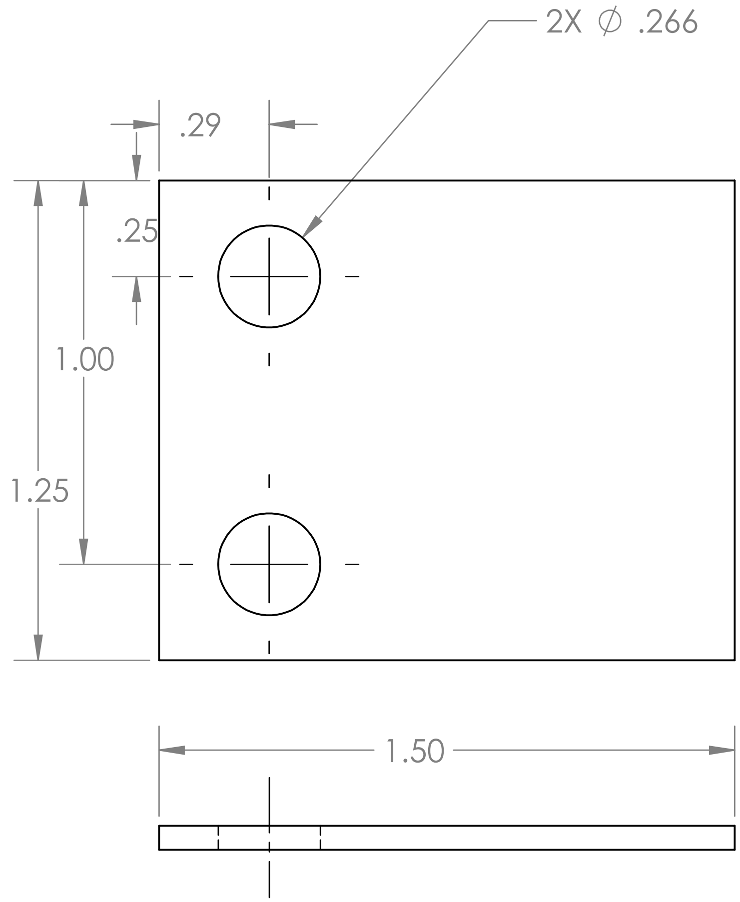
TITLE:
Team 21 Part #25 Top Support

SIZE	DWG. NO.	REV
A		

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum plate, 1/16"

FINISH
Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R Martin	3/25/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

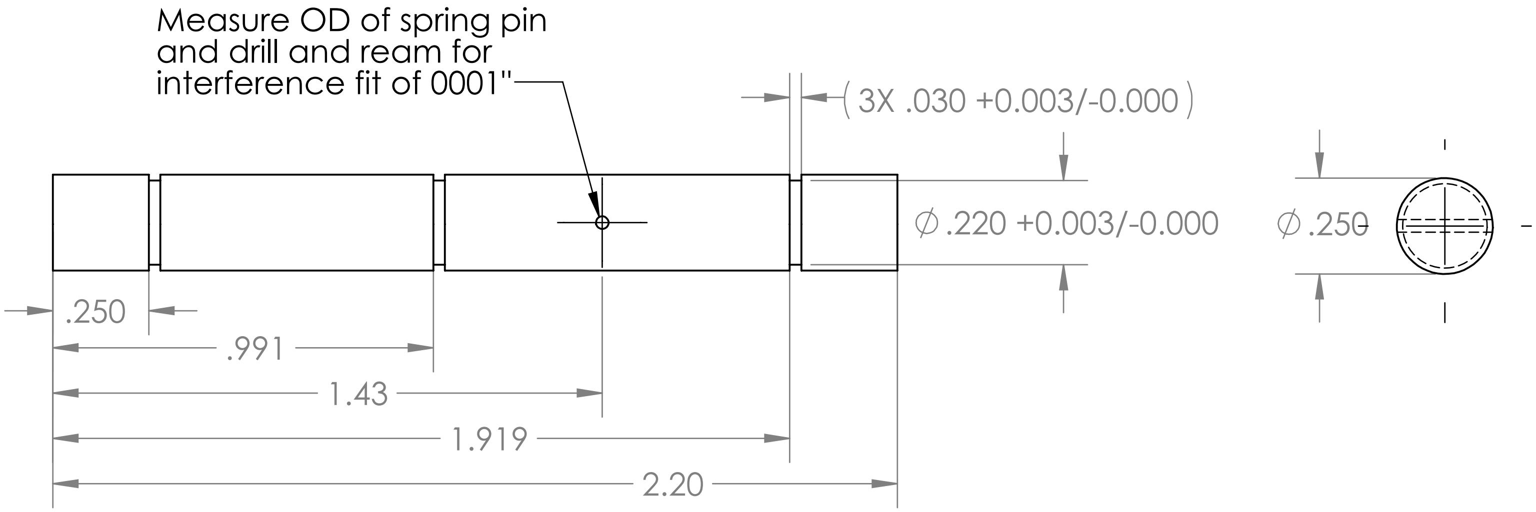
COMMENTS:

TITLE: Team 21 Part #37 Disposable Ramp Support

SIZE	DWG. NO.	REV
A		

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

2 1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL Tight Tolerance 12L14 Carbon Steel Rod Ultra-Machinable, 1/4" diameter, 1ft long
NEXT ASSY	USED ON	FINISH Burr Free
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R Martin	3/25/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

Team 21
Part #14
Lift Shaft Top

SIZE	DWG. NO.	REV
A		
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1