ME250 DESIGN AND MANUFACTURING I
Fall 2016

Michigan Ninja Relay Competition

Team 104

ME 250 Section 10, Team 104

Team Members

Nafisa Newaz
Devin Stevens
David Van Dyke
Sarah Wang
Mitch Williams

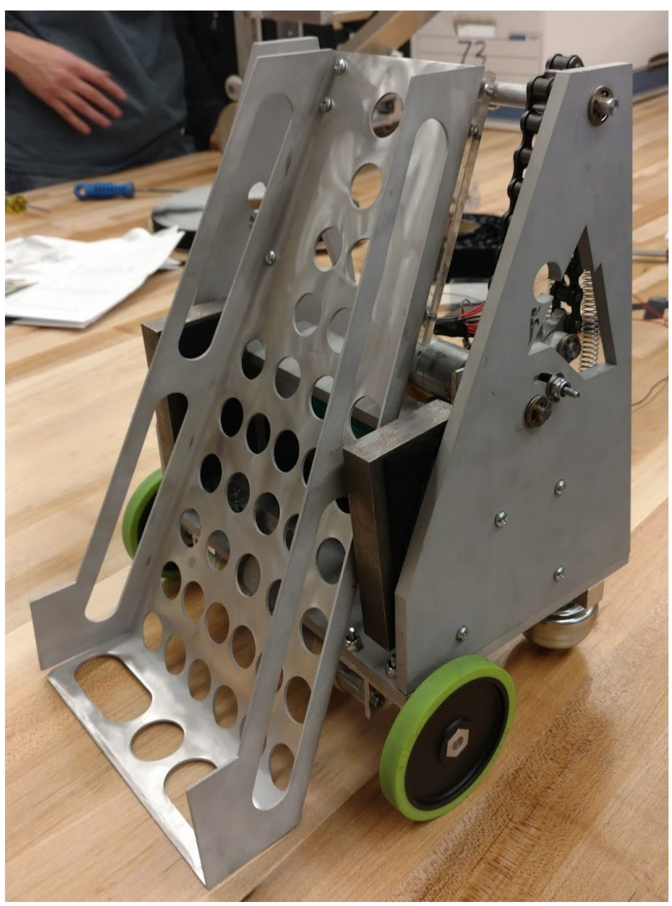

Figure 1: Final robot machine player (RMP)

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1. ABSTRACT

Team 104 has designed and manufactured a robotic machine player (RMP) to compete in the Michigan Ninja Relay challenge. Our RMP, codename *Sisyphus*, competes in zone 4 of the challenge. Our strategy is to push the large cubes that block *Sisyphus* in the starting point out of the way, push the remaining blocks out of the way ,catch cubes from zone 3, carry them to the goal, and drop them in. We prioritize cubes coming in from zone 3 and will only attempt to move the cubes in zone 4, our zone, if there is surplus time.

The three functional requirements we have created for our RMP are to pick up at least three cubes at a time, move the blocks, and drop all of the cubes into the goal at once. Other specific requirements are that it must initially fit in a volume no larger than 10" x 10" x 12", use the provided power/control box and the wireless controller, attach the provided control box to the RMP with velcro, have less than four axes of motion, and not pose a risk of injury to others. *Sisyphus* has met all of these requirements.

The two major subsystems of *Sisyphus* are the tray system and the wheel drive system. The tray is a bent piece of sheet metal capable of picking up three cubes at once and dropping all of these cubes into the goal at once by rotating about an axis at the top of the RMP, causing all of the cubes to slide down into the goal. This tray is powered by one motor at a 99:1 gear ratio. Torque is transferred from the motor to the tray through a chain and sprocket. In order to power the drivetrain of the RMP, *Sisyphus* has two front wheels each independently powered by a separate motor at a 99:1 gear ratio. The rear wheels are two ball-casters for agile mobility.

We designed *Sisyphus* using Solidworks and manufactured it in the x50 machine shop. A majority of the RMP, including the entire frame and sprockets, was created using the water jet. Small features, such as press fit holes for bearings, key ways for sprockets, and angle brackets to connect the frame and motors were made on a manual mill. Axles with e-clip grooves were manufactured on a manual lathe.

Sisyphus did not do well in initial testing. We were unable to push the largest block or lift the tray. After modifying the RMP by adding two extension springs to add more torque to lift the tray and adding counterweights to the front, *Sisyphus* was able to fulfill our functional requirements. According to our calculations, our tray motor is unable to lift the tray and at least 3 cubes, but after testing, we found that if we lower the tray in order to pick up momentum, we were able to lift the tray and cubes. Our pusher calculations indicate that our motors provide enough torque to push the blocks, but we added counter weights in order to increase the friction between the wheels and the field.

Sisyphus performed very well in final testing. At competition, *Sisyphus* managed to drop eight cubes into the goal and was a part of the winning squad. No technical issues occurred during the competition and *Sisyphus* completed every task with ease.

For future models and mass production of *Sisyphus* some parts would need to change. The frame can be simplified to reduce machining time and an extra motor should be added to increase torque provided to the tray. This report details the creation, calculations, design, manufacturing process, bill of materials, test results, recommendations for future models, and engineering drawings for our RMP.,

2. INTRODUCTION

The Michigan Ninja Relay Competition is a five-minute game that includes a team of four or five students to collaborate within a squad of 4 teams to design and build a remote-controlled machine (aka RMP) to overcome the obstacles presented in each assigned zone. There are four zones: in Zone 1, the RMP must cross over a 6 inch pyramid to collect its six cubes and transport them to Zone 2; the RMP in Zone 2 needs to either cross a ball pit or take a narrow path along the edge of the table border to collect its five cubes along with Zone 1 cubes then transfer them to Zone 3; in Zone 3, the RMP is required to maneuver through a maze that consists of a shorter, more narrow path or a longer, wider path to collect whatever cubes coming in from Zone 2 and its own cubes to transfer to Zone 4; and finally, the RMP in Zone 4 must move the blocks that initially barricade the RMP, the Goal, and the zone border to create a path that allows the RMP to collect the cubes coming in from Zone 3 and cubes from its own zone to drop them into the Goal. The objective of the game is to score as many points as possible by passing the cubes from each zone or cubes from previous zones onto the next zone, while the fourth and final zone needs to drop as many cubes into the Goal basket.

3. PROTOTYPE DESIGN

3.1. Strategy and Zone Strategy

For the Michigan Ninja Relay Game, our squad strategy is to pass the cubes over the borders instead of through the holes. In addition to that, our squad strategy includes each adjacent zone collaboratively transporting the cubes from one zone to the other. Thus, RMP1 will go for the zone 1 cubes and then come back to the zone 1/zone 2 border to meet with RMP2. During that time, RMP2 will go into the ball pit to pick up their own cubes first and drop them over the border to zone 3. Depending on how long RMP1 and RMP2 will take, RMP3 will position the zone 3 cubes near the two paths then wait at the border between zone 2 and zone 3. If RMP2 is able to quickly head to the border to drop the zone 2 cubes into zone 3, RMP3 will go to pick up the zone 2 cubes and take one of the paths to meet with RMP4. Meanwhile, RMP4 will try to move the blocks away from its path and clear the paths to its own cubes, to the border, and to the Goal. That way, RMP4 can make many trips to pick up the cubes from RMP3 and drop them into the Goal throughout the game. This interaction will be repeated until time is up.

The advantages to this squad strategy include:

1. Time efficiency: We chose to pass the cubes over the wall between zones rather than through the holes so we can quickly transfer more cubes between zones.
2. Maximize points: we prioritize cubes from the previous zone in order to maximize points earned.

Our RMP has been assigned to Zone 4. After careful consideration of what is needed from our zone for a successful squad strategy, our team came up with a final zone strategy to prioritize the cubes coming from

Zone 3 and to pick up three cubes at a time. Cubes coming from Zone 3 will be prioritized because they have a higher scoring potential. RMP4 will pick up three cubes at a time but have the ability to pick up more. By picking up three cubes at a time, we reduce the risk of dropping cubes along the way. Since the RMP4 will be capable of holding more than three, it can pick up as many cubes as possible if time is running low. In addition, RMP4 will begin by pushing the blocks out of the way in order to clear a path for itself. It will then clear a path from the drop-off location between Zone 3 and 4 to the Goal because the priority is receiving the cubes coming from Zone 3 and transferring them into the Goal. By clearing that path first, it will make transporting the cubes through the zone to the Goal more time efficient. Finally, RMP4 will deliver the cubes into the Goal all at once, allowing more time to transport more cubes to the Goal.

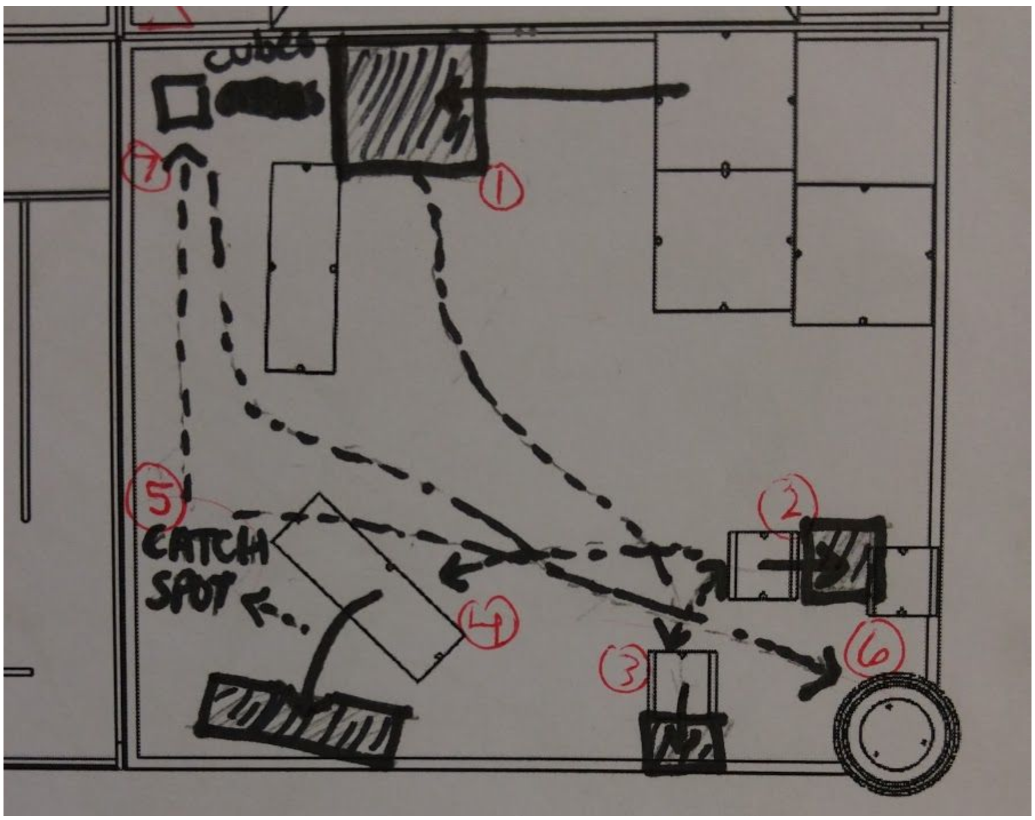


Figure 2: Sketch of Zone 4 Strategy

3.2. Functional Requirements, Specifications, and Target Values

To successfully output our zone strategy for the Michigan Ninja Relay Race, we considered three major functional requirements, a quantifiable performance specification for each functional requirement, and target values for those specifications that our RMP must achieve.

The three functional requirements, specifications, and target values are:

1. Functional Requirement: Pick up three cubes at a time
   Specification: The weight the arm can lift
   Target values: Lift a minimum of three cubes (45 grams)
2. Functional Requirement: Move the Blocks
   Specification: The minimum force the RMP can push
   Target values: The minimum force the RMP can push is 22.2N (with a safety factor of 2)
3. Functional Requirement: Drop all cubes into the Goal at once
   Specification: Height and width of the tray
   Target values: The RMP should be at least 6.75 inches wide (with a safety factor of 1.5) and at least 6 inches long (safety factor of 2) designed to carry 6 cubes (75 grams) (safety factor of 2)

The reason we chose the first functional requirement of picking up at least three cubes at a time instead of a greater number of cubes is that picking up only three cubes at a time as it is less likely to fail whereas there is a higher chance of cubes falling out during transportation or missing the Goal with more cubes than three. The second functional requirement of moving the blocks to clear a path between the goal and the zone border allows the RMP to get rid of its major obstacle in the beginning, thus having more room to freely maneuver itself throughout the zone. Once the blocks are out of the way, the RMP would have more time to only focus on transporting the cubes and dropping them into the Goal. And finally, the third functional requirement of dropping all the cubes into the Goal at once was chosen based on the fact that it is more time efficient, allowing us more time to retrieve more cubes after each drop.

For the first specification, the target weight the RMP will be able to lift is 45 grams, the weight of three cubes. The decision on this value was made based on the fact that the RMP should be able to pick up all of the cubes in our zone at once, which is three cubes, Our second specification and its target values include being able to push with a minimum force of 22.2 N, since the heaviest block slips with a minimum force of 11.1 N and we used a safety factor of 2. The last specification requires the height and width of the tray to be at least 6.75 inches wide (with a safety factor of 1.5) and at least 6 inches long (safety factor of 2) because we are accounting for carrying at most 6 blocks. This width allows us to pick up at least three cubes at once and its length ensures we can carry six cubes.

3.3. Design Concepts and Subsystems

Before choosing our final design, we created preliminary designs and considered the advantages and disadvantages of each one, recognizing the possible tradeoffs of the different design concepts.

The Design Concept 1 employs a wide tray that is positioned over the top of the machine. This tray would be collapsed down to under the 10 inch limit when it rotates to be square with the ground and pick up cubes. As the tray rotates backwards, it will extend to be able to reach the Goal and deposit the cubes. The RMP will push the blocks away with the side opposite the tray that picks up the cubes.

In Design Concept 2, the RMP has a tray in the front that cubes will be pushed onto. The tray is then elevated from the ground vertically along the arm to a height of 11 inches, the height of the goal. It will then drop the cubes by rotating the tray so the cubes slide into the goal. The tray will then move downward, until it touches the ground, so it can pick up more cubes. The RMP will push away blocks with its body on the side opposite of the tray. And finally, Design Concept 3 indicates the RMP will use a shovel type tray to pick up the cubes, similar to a bulldozer. It will then lift the cubes up, back over the RMP, and drop them into the goal. The RMP will push the blocks away with its bulldozer inspired tray.

Table 1: Pugh Chart of Design Concepts

Requirement	Weight	Concept 1: Extendable tray that lowers to be square to the ground	Concept 2: Elevator tray that extends vertically to reach the height of the goal	Concept 3: Bulldozer style tray to pick up cubes and carry them to the goal
Pick up at least three cubes	3	0	0	-1
Push away blocks	5	0	0	+1
Drop Cubes into the goal	4	0	+1	-1
Catch cubes from Zone 3	2	0	0	-1
Cube Retention	3	0	-1	+1
Manufacturability	3	0	+2	+1
Total		0	7	2

The Pugh chart made us consider every aspect of each design. We learned that Concept 2 would be the easiest to manufacture while Concept 1 is the hardest to manufacture. We learned that though Concept 1 would excel at pushing blocks and cube retention, the design is not suited for picking up many blocks at a time, accurately dropping cubes into the goal, or catching cubes from zone 3. Concept 2's strong point is its ability to drop cubes into the goal accurately, but it may not be able to steadily carry cubes in its tray across the zone. We also learned Concept 3 would surpass the other designs in picking up many cubes at a time and would be mediocre at pushing away blocks, dropping cubes into the goal, and catching cubes from zone 3.

Our final design was chosen based on combinations of our preliminary design concepts and the factors from the Pugh Chart. It combines the tray of Concept 1 and the bulldozer pushing style of the tray from Concept 3. Our new design is composed of a triangular body with a tray that combines features from Concept 1 and Concept 2, but instead, starts in the vertical position and swings past the horizontal position to dump cubes into the goal. In the vertical position, the tray has front walls that push the blocks similar to the bulldozer tray in Concept 3.

The final sketch , shown in Figure 3 below, demonstrates that the back or front of the RMP can be used to push the blocks. Moreover, the sketch indicates that the tray is long enough to carry and catch more that 6 cubes, but will pick up 3 cubes at a time based on the width of the bottom of the tray. The back end of our RMP has a cutout to fit around the Goal basket to ensure accurate delivery of the cubes into the goal.

The major subsystems of our RMP include the tray system and the driving system. The tray meets the functional requirement of picking up three cubes and dropping the cubes into the Goal, and the drivetrain meets the functional requirement of pushing the blocks. The tray is a long piece of sheet metal that pivots around the top of the RMP. It is used to pick up the cubes from the ground and lift them up to the same height as the Goal. The tray power system is the subsystem that the tray is attached to, which powers the tray axle to pivot and allows the RMP to drop cubes into the Goal.

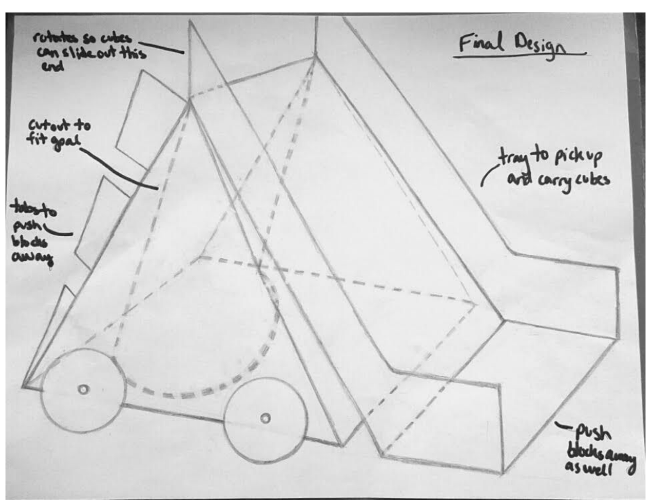


Figure 3: Final Design Concept of our RMP

3.4. Mockup

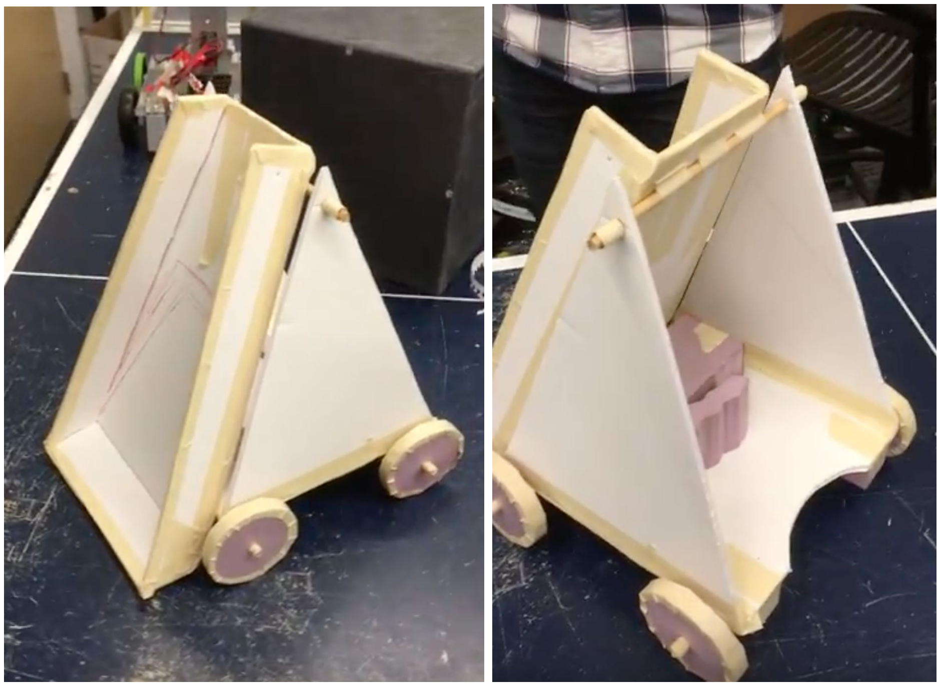


Figure 4: (left) Front view of mockup; (right) Back view of mockup

The first subsystem our prototype mock up models is our tray system. We wanted to design a tray that was able to scoop at least 3 cubes off the ground and then lift and drop them into the goal that is 11 inches tall. We were uncertain about how wide we wanted to make the tray at the bottom, and what minimum height we wanted in order for the cubes to slide down the lifted tray and into the goal safely. We constructed our prototype tray with a dimension of 8 inches at the bottom in order to safely fit three cubes side by side. We knew we wanted our RMP overall height to be 11.5 inches in order to be above the goal, so then, we found that we needed our tray to be 12.75 inches long in order to reach the ground and when attached to its axle at the top of the RMP. When testing, we found that our tray dimensions were well fit for its tasks as it could fit 3 cubes in at the bottom and lift and drop cubes into the 11 inches tall goal. However, to reduce the weight of the tray, we found a width of 8 inches is more than we need, so we reduced the width to 6.75 inches.

Our second subsystem prototype mock up models our drive system. We designed our RMP to have a cutout in the back of the base that fits around our goal so that we could get closer to the goal to further ensure our cubes fall into the goal when dropped. We were uncertain about the dimensions needed for this cutout and we were also uncertain about if we could fit a motor in the back for a possible rear wheel drive. To decide the dimensions of the cutout, we measured the dimensions of our goal and decided to make the curved cut out 2 inches from either side and 1 inch deep. After making this cut out, we set our prototype around the goal and found the end of our tray where the cubes would be deposited was able to slide further into the middle of the opening of the goal, ensuring all our cubes will fall into the goal when dropped. Next, we found that with this cutout, we would not be able to fit a motor in the back in order to build a rear wheel drive system, so the mock up also helped us decide to make our RMP a front wheel drive.

The advantage of creating a physical model is that we are able to better visualize the design of our RMP and test its design components. For example, building a physical model for our tray and drive system, we were able to decide the dimensions of our tray, the dimensions of our cutout in the base, and whether we could fit a rear wheel drive system by respectively, placing cubes into our tray to see if they would fit, fitting our cutout around the goal to ensure it would increase how close our RMP could get to the goal, and placing a motor around the base cutout to see where we could fit the motor. The disadvantage of creating a physical model is that although we are able to test our design's physical dimensions, the physical model does not help us test the functionality of our RMP, such as if our motors will be able to lift our rather large tray or if we can push the blocks away with our front wheel drive.

3.5. Analysis

TRAY CALCULATION

The required driving torque of the motor with a safety factor of 1 is about 0.677 Nm, but the metal gearmotor with the chain and sprocket system with an assumed efficiency of 20% and a gear ratio of 1 (all the sprockets are the same size) can only provide about .226 Nm. The gearmotor with the chain and sprocket are not able to lift the tray and our target number of three cubes; we need an additional about .45 Nm of torque. Thus, to provide more torque, we added extension springs that extend from the chain to the floor base of our RMP. From our calculations, we found that we require 5 of the 3" extension springs provided in our project kit in order to supply the required torque. In our calculations of the torque provided by the springs, we assumed the springs provide a perfectly perpendicular direction to the axle of the tray. After testing, we found that adding two springs is sufficient. With only two springs, the tray does not lift well in small increments as it requires momentum in order to move past the horizontal (parallel to the ground) position, but this momentum is easily obtained by lowering the tray slightly and bringing it back up. We chose not to use all 5 extension springs, because with five springs, we found our tray moved too fast which would risk us losing cubes from flinging the tray too fast and we found it harder to lower the tray as the five springs provide a torque in the opposing direction when lowering the tray.

$safety\ factor = f_s = 1$
$length\ of\ tray = L = 12.75\ in = 0.32385\ m$
$center\ of\ mass\ of\ tray\ from\ tray\ axle\ end = 9.47\ in = 0.240538 m$
$distance\ axle\ end\ tray\ to\ COM\ of\ cubes = 12.75 in - 0.75 in = 12 in = 0.3048 m$
$mass\ of\ each\ cube = m_{cube} = 15\ g = 0.015\ kg$
$mass\ of\ tray = m_{tray} = 0.49\ lbs = 0.23\ kg$
$target\ number\ of\ cubes\ to\ lift = n = 3$
$efficiency\ of\ chain\ and\ sprocket\ system = \gamma = 0.20$

$T_D = f_s F r$

$T_D = 1.0(m_{tray} * g * d \ + \ L * m_{cube} * g * n)$

$T_D = 1.0((0.23 * 9.81 * 0.240538) + (0.3048 * 0.015 * 9.81 * n)$

$T_D = .5427258894 + .04485132 * 3$

$.6772798 \leq \gamma(1.13)$

$.6772798\ Nm \leq .226\ Nm$

$.6772798\ Nm \leq .226\ Nm + F_{spring}$

$F_{spring} \geq .4512798\ Nm$

$initial\ length = L_i = 3\ in$

$final\ length = L_f = 8\ in$

$Force\ applied = F\ = (2.5)\ lbs = 11.12N$

$F\ = F_i + kx$

$F_i = F - kx = 11.12N - (2.047N/in)(8in - 3in) = 0.885N$

$initial\ length = L_i = 8.5\ in$

$final\ length = L_f = 7.0\ in$

$F_{spring} = F_i + kx = .885\ N + (2.047\ N/in)(|7.0\ in - 8.5\ in|) = 3.96N$

$spring\ torque\ arm = 1.0in$

$T_{spring} = Fr = 3.96N(1.0in) = 3.96Nin$

$number\ of\ springs = n = 2$

$total\ torque\ supplied\ by\ 2\ springs = T_{spring} * n = 3.96Nin * 2 = .201168\ Nm$

$total\ torque\ supplied\ by\ 4\ springs = T_{spring} * n = 3.96Nin * 4 = .402336\ Nm$

$total\ torque\ supplied\ by\ 5\ springs = T_{spring} * n = 3.96Nin * 5 = .50292\ Nm$

$required\ torque\ is\ provided\ with\ 5\ additional\ springs:$

$.6772798\ Nm \leq .226\ Nm\ +\ .50292\ Nm$

$.6772798\ Nm\ \leq .72892\ Nm$

TIP OR SLIP CALCULATIONS

In this section, we measured the minimum force required for a block to slip with a scale and calculated the height at which the block would tip when pushed at with the minimum force measured earlier. When calculating the height where the block would slip when pushed, we calculated it with the minimum force required for it to slip and with a safety factor of two to account for the insensitive scale used and possible human error when measuring the minimum force required for the block to slip. We found that the cube block would slip with a force applied of 11.1 newtons and would tip when pushed with this force at a height 14.5 inches, the tall block would slip with a minimum force of 4.0 newtons and would tip at a height of 14.4 inches when pushed with this force, and the block laying down would slip with a minimum force of 3.34 newtons. We did not perform the tip calculation for the laying down block, because since it lays so low to the ground, we can safely assume we will never tip this block.

CUBE BLOCK

Slip Calculation:

$F \geq 11.1N$ (measured with scale)

Tip Calculation:

$W = 14.5lbs * \frac{4.45N}{lbs} = 64.3\ N$

$\Sigma F_y = 0 \Rightarrow N = W = 64.3\ N$

$tip\ M < 0 :\ W(d/2) - F(d') < 0$

$(64.3N)(5in) - Fd' < 0$

Tips when pushed at distance d' from bottom: $d' > \frac{322N*in}{F}$

If we push with minimum slip force with a safety factor of 2:

$F = 22.2N$

$Will\ slip\ when\ pushing\ at\ distance\ d' > 14.5\ inches$

TALL BLOCK

Slip Calculation:

$F \geq 4.0N$ (measured with scale)

Tip Calculation:

$W = 11.50lb * \frac{4.45N}{lbs} = 51.18N$

$\Sigma F_y = 0 \Rightarrow N = W = 51.18N$

$F = 0.750lbs * \frac{4.45N}{lbs} = 3.34N$

$tip\ M < 0 :\ W(d/2) - F(d') < 0$

$(51.18N)(2.25in) - Fd' < 0$

Tips when pushed at distance d' from bottom: $d' > \frac{115.2\ N*in}{F}$

If we push with minimum slip force with safety factor 2:

$F = 8.0N$

$Will\ slip\ when\ pushing\ at\ distance\ d' > 14.4\ inches$

LAYING DOWN BLOCK

Slip Calculation:

$F \geq 3.34N$ (measured with scale)

PUSHER CALCULATION

We want our RMP to be able to push our heaviest block at its minimum force required to slip. Our heaviest blocks are the cube blocks that require a minimum force of 11.1 newtons to push but we used a safety factor of 2 in order to account to for the insensitivity of the scale we used to measure and for possible human error when measuring. We found that our wheels required a torque of .8103 Nm and our metal gear motor, with a gear ratio of 1, is able to provide a torque of 1.13 Nm.

Metal Gearmotor

$T_s = 1.13\ Nm \quad n_0 = 100\ rpm$

$V_1 = 6\ V \quad V_2 = 6\ V$

$f_s = 2 \quad F_{total} = 11.1\ N$

$r = 0.0365125\ m$

$T_{D_{total}} = f_s * F * r \rightarrow 2 * 11.1 * 0.0365125 = .8103\ Nm$

$N_{o2} = \frac{V_2}{V_1} * N_{o1} \rightarrow \frac{6}{6} * 100 = 100\ rpm$

$T_{s2} = \frac{V_2}{V_1} * T_{s1} \rightarrow \frac{6}{6} * 1.13 = 1.13\ Nm$

$M_r = T_D / T_r = .226/(.226) = 1$

$T_D \leq \gamma M T_s \rightarrow .8103 \leq 1 * 1.13 \rightarrow .8103 \leq 1.13$

3.6. Final Design and CAD Model

Figure 5: CAD Model of the final design

The final design for *Sisyphus* is shown in Figure 5 above.

The tray is used to pick up the cubes and drop them into the goal. The RMP pushes the cubes up against the wall with the tray, pushing the cubes into the tray. The tray then rotates about the top axis and drops the cubes into the goal. The tray is made of 1/16” thick aluminum and has many holes cut into it to reduce weight. It is also tapered inward to help make the cubes fall into the goal. On the back of the tray, are two small pieces of ¼” acrylic. These help distribute the torque from the axle so that all of the force is not on the two bolts that connect the axle to the tray. An exploded view of the tray assembly is in Figure 6 below.

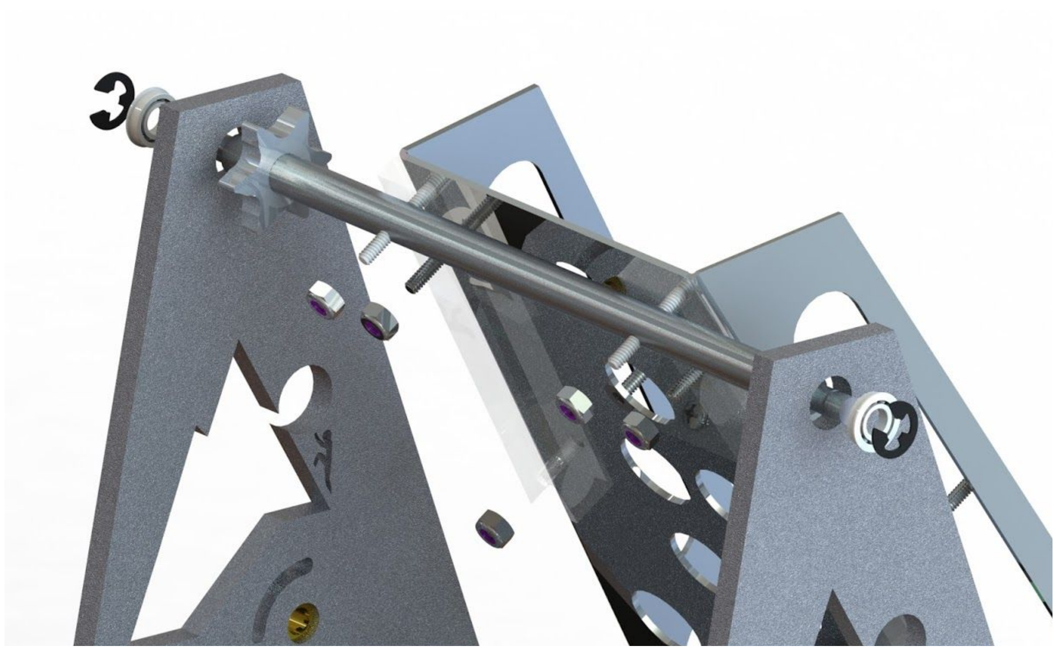


Figure 6: CAD model of how the tray attaches to the axle

This tray is different from the final design sketch as the sketch does not have any holes in it. The sketch was made before any calculations were done and it was discovered that the tray was too heavy for the motor to lift.

The frame of the RMP is entirely made up of ¼" thick Aluminum plates cut on the waterjet. Aluminum was chosen over other available materials such as acrylic or delrin because it is heavier. It is ideal for *Sisyphus* to be heavy because we wanted to ensure that there is a lot of friction on the wheels so they do not lose traction. The frame walls were designed to be at a height just over the height of the goal, so that the tray could easily drop the cubes into it. The frame walls can be seen in Figure 7 below.

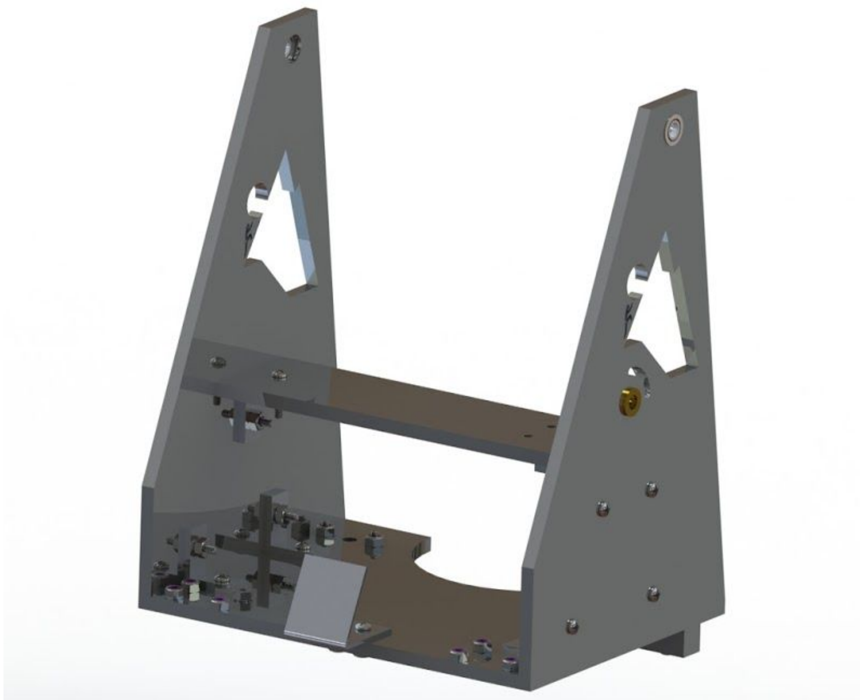


Figure 7: Frame of the RMP

The frame base has a circular cutout in it, as can be seen in Figure 8 below. This cutout allows the goal to be positioned right up against the trays axis of rotation, ensuring that the cubes are dropped directly into it. Each frame piece is connected with angled aluminum brackets with a bolt in each face.

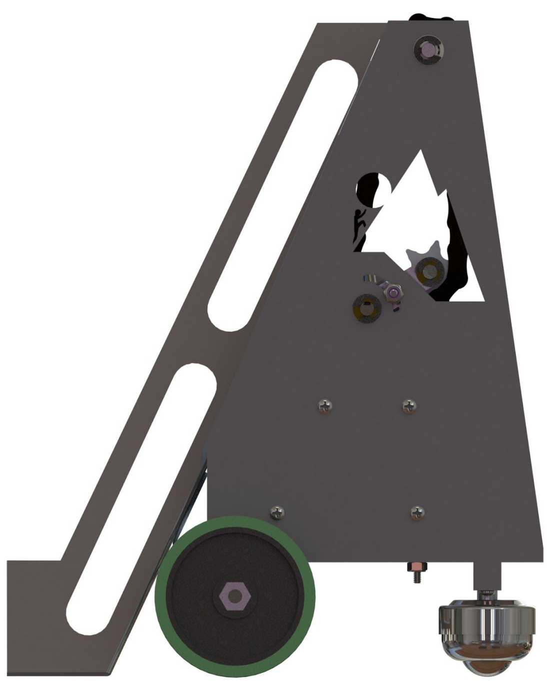


Figure 8: Side of the RMP

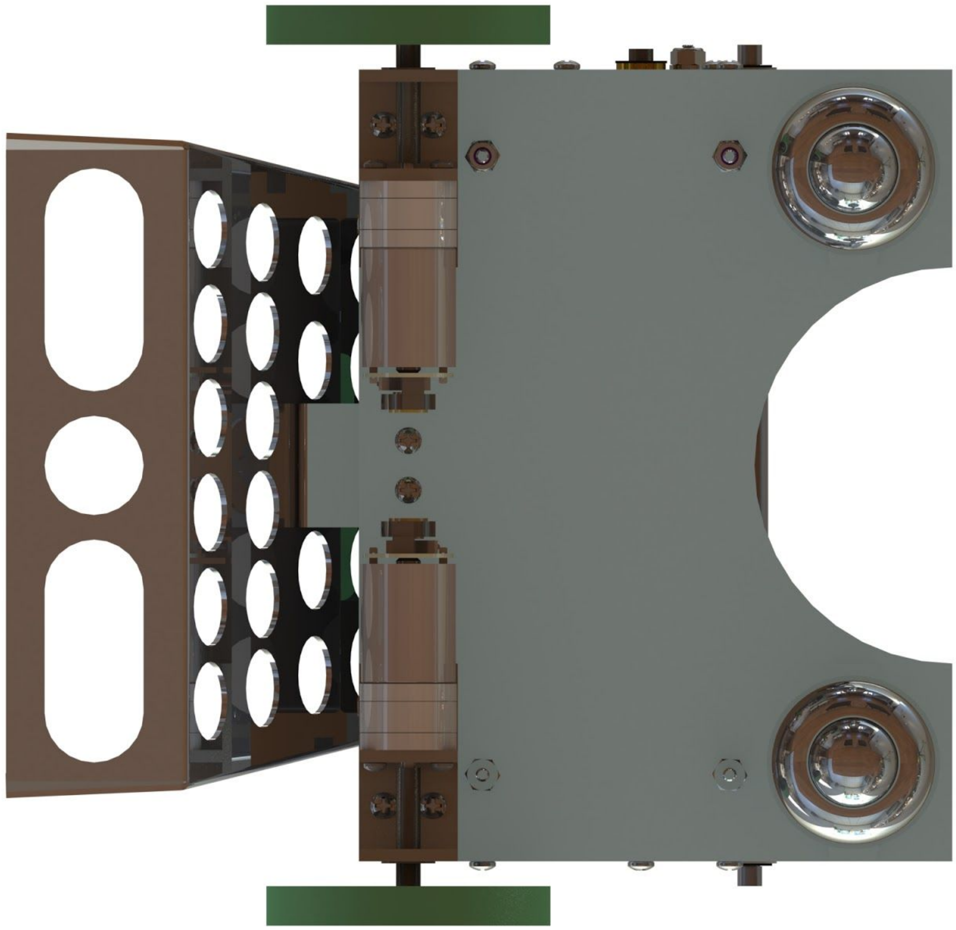


Figure 9: Bottom of the RMP

The drive train can be seen in Figure 9 above. *Sisyphus* has two independently powered front wheels driven by Pololu metal gearmotors at a 99:1 gear ratio. These two wheels are what drive the RMP and the fact that they are independently controlled allows us to steer it. The rear wheels are two metal ball casters. These were chosen as it gives the RMP a very high turning radius. The metal gearmotors are connected to angled aluminum brackets with M3 screws. The aluminum brackets are then screwed into the base. The wheel axles are ¼" steel and are connected to the wheel with a hex piece pressed into the wheel, and a spring pin. There is a hole on the opposite side of the axle which the motor axle goes into and is secured with a 4-40 set screw. This axle is press fit into a ¼" bearing pressed into an angled aluminum bracket that is bolted to the base. An exploded view of this assembly can be seen in Figure 10 below.

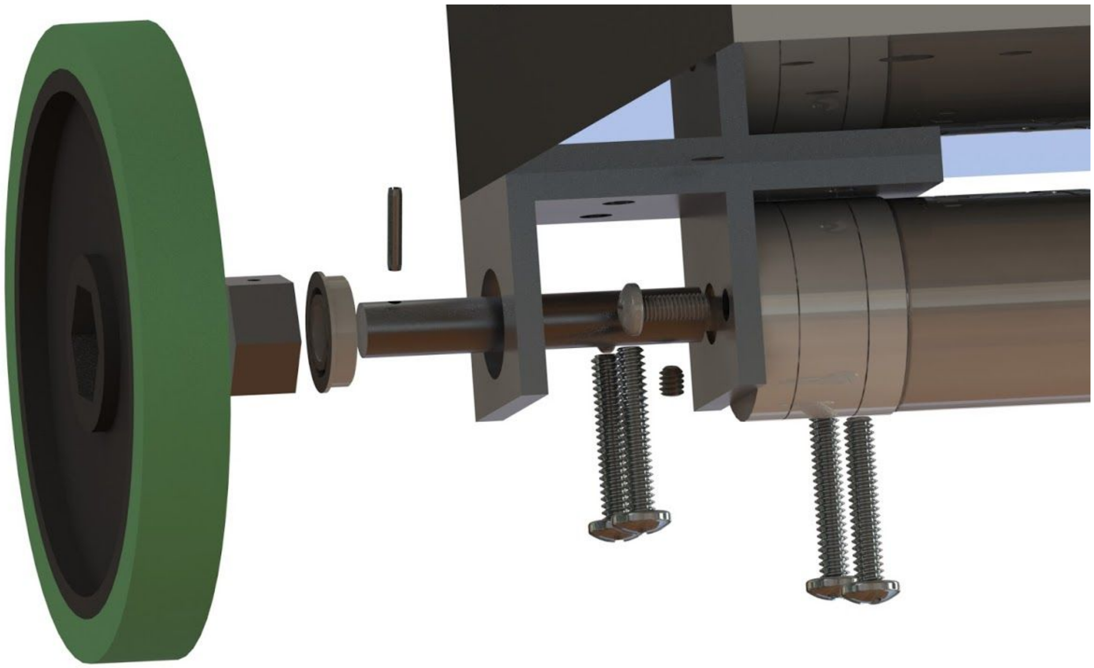


Figure 10: Exploded view of the front wheel assembly

The ball casters are mounted to the base with one 1-4/20 tapped hole each. A tapped square spacer is bolted to the base to ensure that the ball caster has full thread engagement. The mounting system can be seen in Figure 11 below.

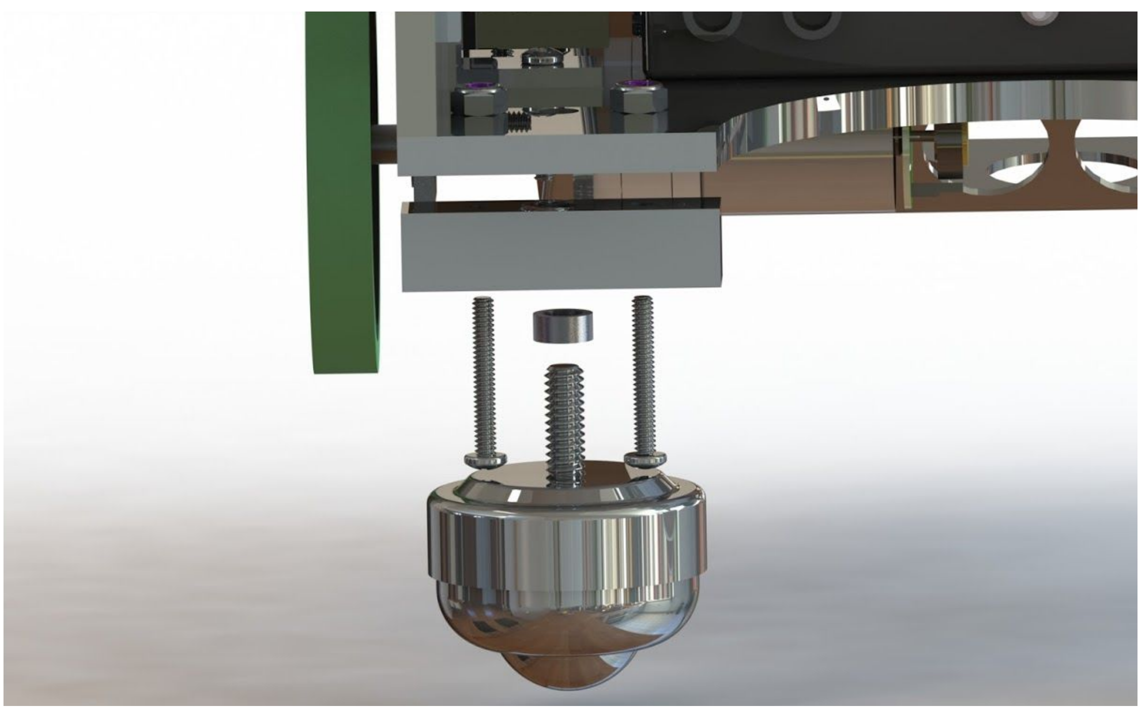


Figure 11: Exploded view of the front wheel assembly

The initial design used four wheels, instead of having the two wheels and two ball casters. We opted to switch to the ball casters for the rear wheels because having normal wheels in the back would make it very difficult to turn and navigate around the blocks.

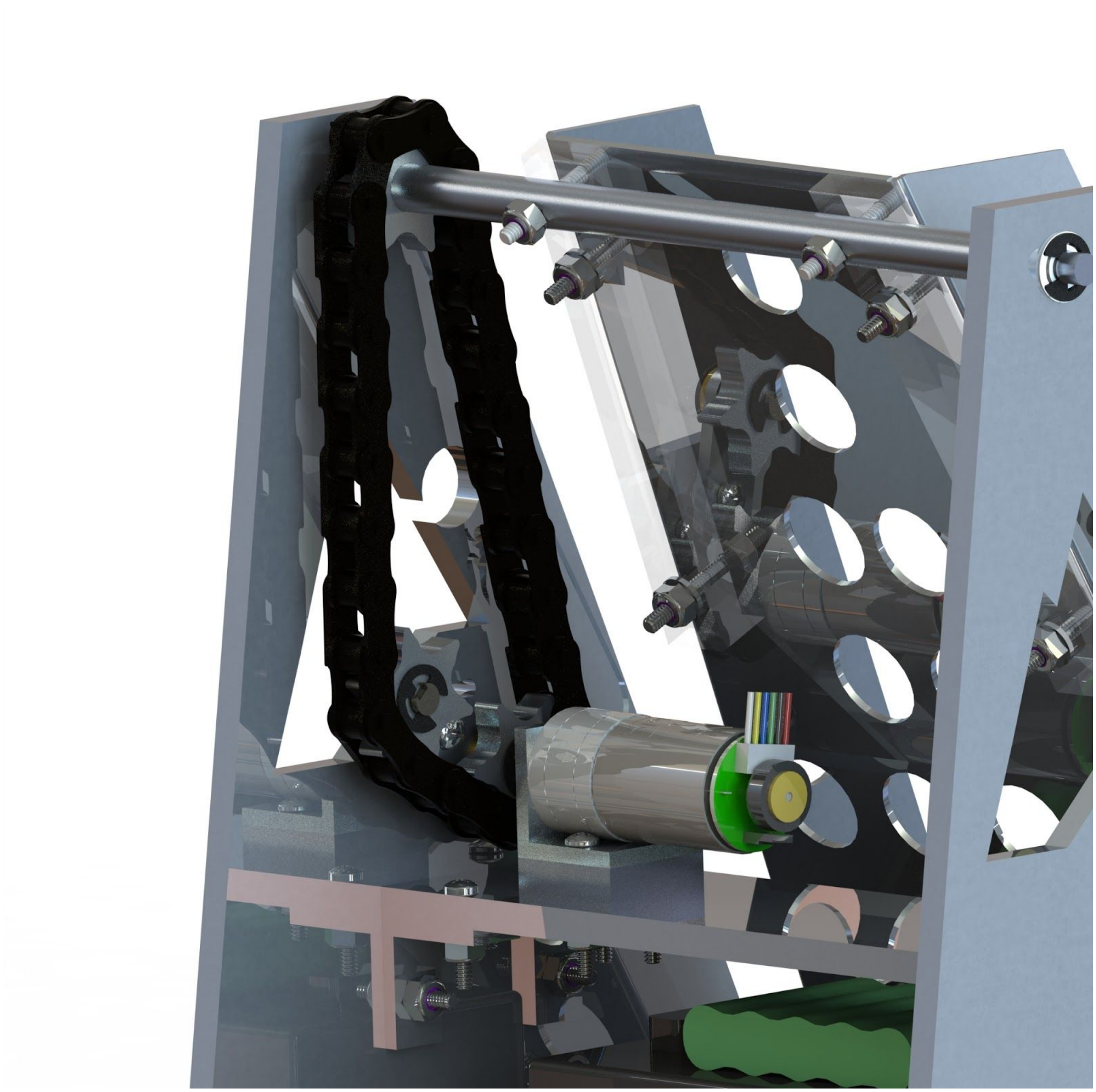


Figure 12: Tray power system

Figure 12 above depicts the power system for the tray system. The tray is powered by one Pololu metal gearmotors at a 99:1 gear ratio. The torque is transferred from the gear motor to the tray with a chain and sprocket. The chain was purchased from McMaster Carr and the sprockets were made from ¼" aluminum and cut on the water jet. Each of the sprockets has six teeth, creating a 1:1 gear ratio from the motor to the tray. The chain also has a tensioner, which ensures the chain does not have any slack during operation. The tensioner is held down by a bolt that is connected to the wall of the RMP, and is then tightened down with a nut. An exploded view of the entire subassembly is in Figure 13 below.

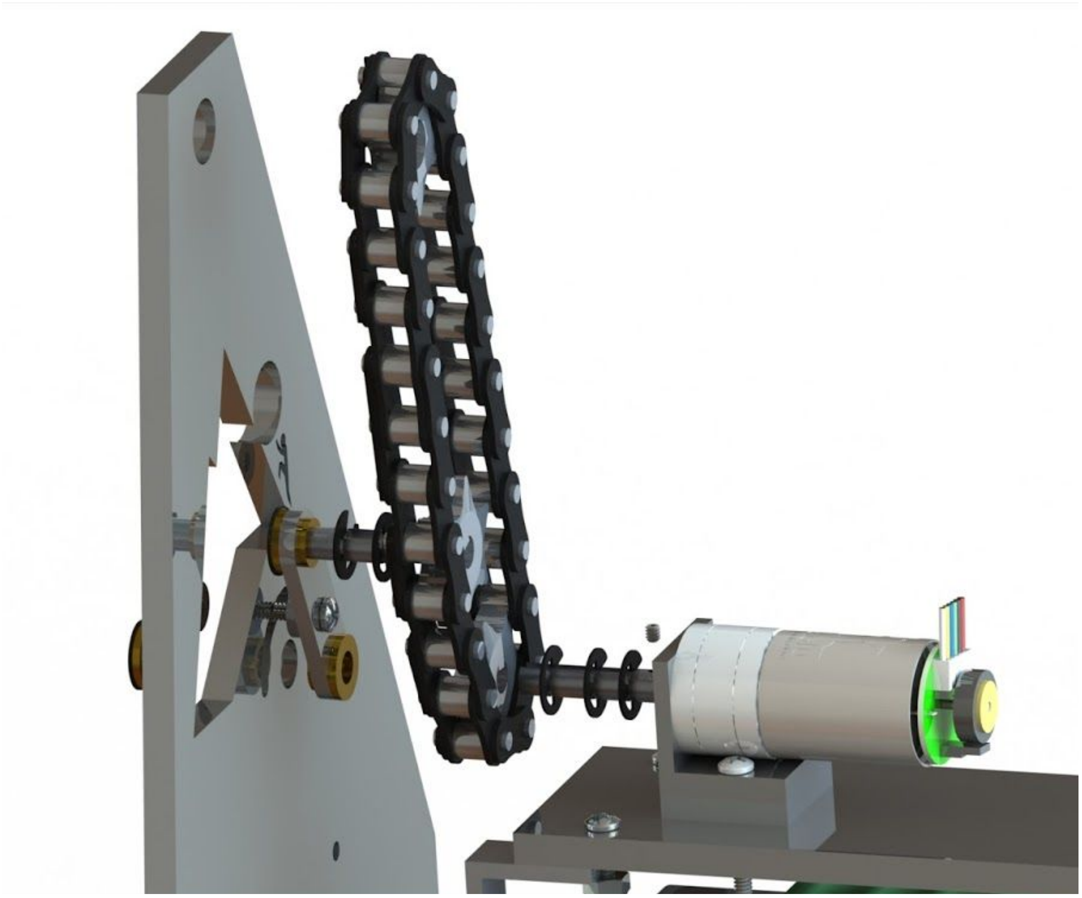


Figure 13: Exploded Tray power system

The gearmotor is mounted to the frame in a very similar way to the ones that power the wheels. It is connected to an angled piece of aluminum with two M3 screws and the bracket is bolted to the base, An axle is than connected to the gearmotor with a set screw. This axle has a 1/8" wide 1/16" deep key slot for the sprocket to slide into. The axle, with the sprocket and tensioner attached, is supported by a bushing in the left wall. E-clips are used to ensure the parts stay an appropriate distance from each other. The tensioner body is a small piece of ¼" thick aluminum with bushings pressed into each end. One bushing is surrounding the axle protruding from the motor, and the other end supports the axle of the tensioner with another sprocket on it. E-clips are used here to keep the sprockets and sprocket axle positioned properly. The last sprocket is attached to the top axle with a similar key slot to the other two sprockets. The key slot for the top sprocket can be seen in Figure 14 below.

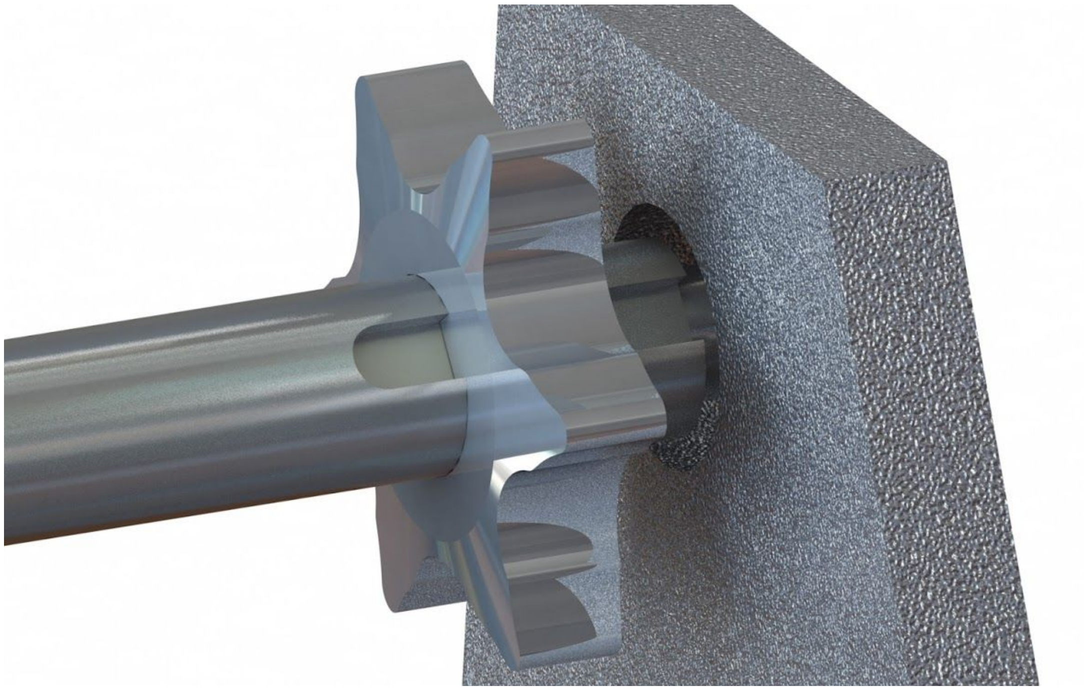


Figure 14: Top sprocket key slot. All other sprockets have slots of the same dimension

This sprocket does not have e-clips due to interference with the chain and to allow for modifications if there is misalignment. This power system is very different than than the original design sketch. Initially, we had planned on using plastic gears to transmit torque. We encountered issues with the gears going over the size limits of the RMP and the gearbox interfering with the goal while dropping cubes. The chain and sprockets do not have these issues.

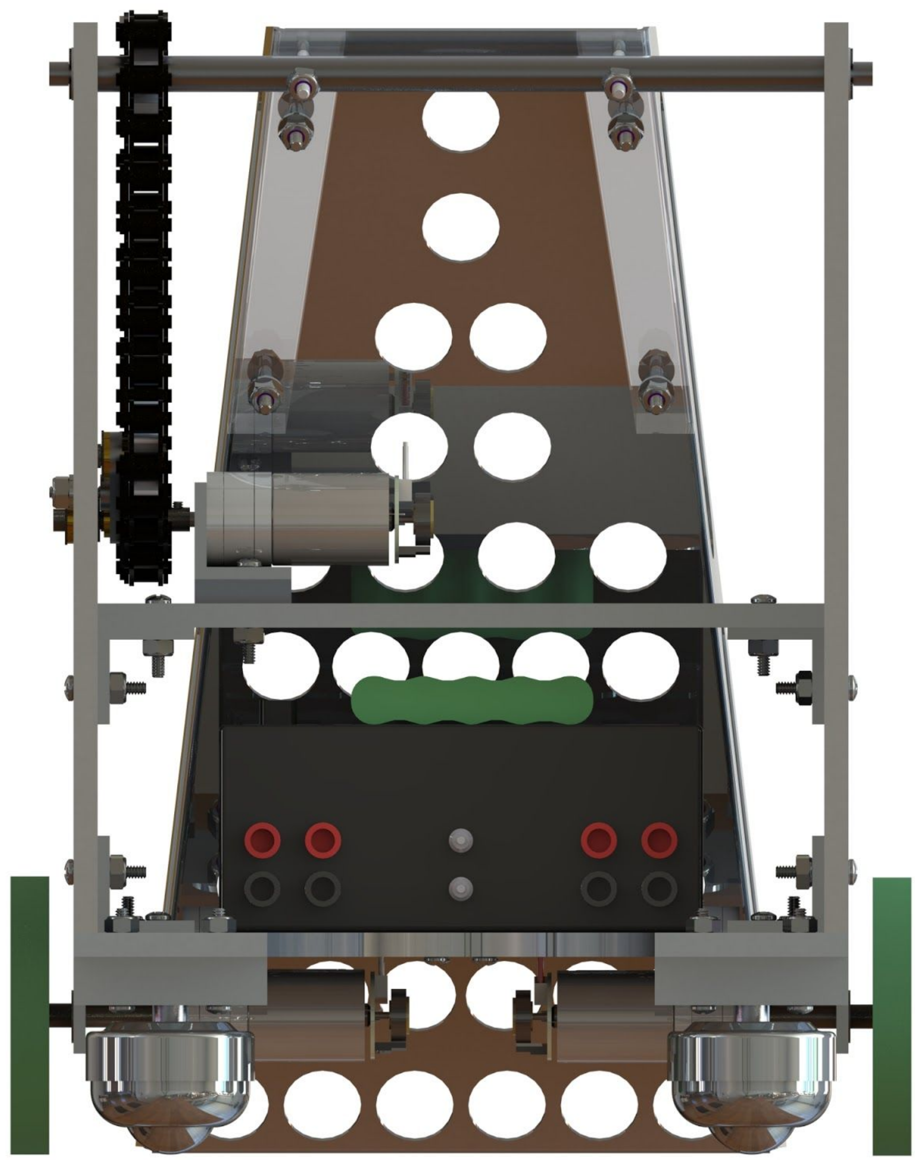


Figure 15: Rear view of *Sisyphus*

The battery is placed on the frame base of the RMP. This placement can be seen in Figure 15 above. The battery was placed here because it puts more weight above the wheels. This is ideal because this means more friction and a smaller chance of the wheels losing traction while pushing the blocks. The battery is attached to the frame base with velcro.

Sisyphus uses 6-32 bolts and locknuts to attach components. 6-32 was chosen because it is the largest bolt head that does not interfere with the metal gearmotors when mounting them to the angled brackets and frame base. Locknuts were used instead of normal nuts to make connections stronger and reduce maintenance. The chain tensioner, which is connected to the wall with a locknut, would not be able to maintain tension in the chain without a locknut to keep it in place. *Sisyphus* was designed to stay well within the maximum dimensions of 10” x 10” x 12” and measures 9.57” x 9.30” x 11.83”

4. PROTOTYPE MANUFACTURING

4.1. Bill of Materials

The bill of materials is shown in Table 2 below. A majority of the parts are made from aluminum. This was chosen because we had an abundant amount of it, and it is heavier than the acrylic and delrin given. We wanted to make *Sisyphus* heavy, so we opted to use the heavier aluminum over the lighter plastic. The only acrylic part we have is attached to the back of the tray since it is important for that part to be light so it can be lifted up easily. The axles connected to the motors were made from the ¼” steel rod instead of the ½” aluminum rod because the bearings and bushings were made for ¼” shafts and using the steel over the aluminum would require less machining.

Table 2: Bill of Materials

Wheel Assembly

								Contributors		
Part No.	Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Design/ CAD	Drawing/ Plan	Machining
1	Frame base	Aluminum plate, 1/4"	8"x6"	Kit	1	---	Water Jet	Devin	Mitch	Sarah
2	Wheel Bearing Mount	Aluminum 90 Degree Angle Stock	1" x 1" , 1/8" thick	Kit	2	---	Mill	Sarah	Nafisa	David
3	Ball Caster Mounting Base	Aluminum 1/2" Square Stock	2" x 1/2" x 1/2"	Kit	2	---	Mill	Sarah	Sarah	David

4	Ball Caster Spacer	Aluminum rod, 3/8" diameter	1/4" ID, 3/8" OD	Kit	2	---	Lathe	Sarah	Devin	Nafisa, Devin
5	Wheel Axle Rod	O1 Tool Steel	.16" ID, 1/4" OD	Kit	2	---	Lathe/ Mill	Nafisa	Devin	Nafisa, Devin
6	Wheel Axle Hex	Hex Stock for BaneBots Wheels	1/2" Hex, .3" width	Kit	2	---	Mill	David	David	Nafisa, Devin
7	Bottom Gearbox Support	Aluminum 90 Degree Angle Stock	1" x 1" , 1/8" thick	Kit	2	---	Mill	Nafisa	Nafisa	Sarah, Mitch
8	1/16" Spring Pin	18-8 Stainless Steel	3/8", 1/16" Dia	kit	2	---	---	McMaster	---	---
9	BaneBots Wheel	Polypropylene core, rubber tread	2-7/8" x 0.4", 1/2" Hex	Kit	2	---	---	David	---	---
10	1" Ball Caster	Zinc Plated Steel	1-3/8" x 1-3/4"	Kit	2	$4	---	Mcmaster	---	---
11	Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP	---	25mm x 54mm	Crib	2	---	---	Pololu	---	---
12	Flanged SS bearing	Stainless Steel	1/4" ID, 1/2" OD, 1/8" Thick	Kit	2	---	---	McMaster	---	---

13	4-40 Set Screw	Stainless Steel	4-40 x 1/8"	Crib	2	---	---	McMaster	---	---
14	6-32 Thread, 3/4" Length Machine Screw	Zinc Plated Steel	.138" x 3/4"	Crib	8	---	90272A151	McMaster	---	---
15	6-32 Thread, 1" Length Machine Screw	Zinc Plated Steel	.138" x 1"	Crib	4	---	90272A153	McMaster	---	---
16	Steel Nylon-Insert Locknut	Steel Nylon	5/16" x 11/16"	McMaster	12	$2.61 per 100	90631A007	McMaster	---	---
17	M3 Pan Head Phillips Machine Screw	Zinc-Plated Steel	3mm x 8mm	Crib	4		---	McMaster	---	---

Frame

Part No.	Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Contributors		
								Design/ CAD	Drawing/ Plan	Machining
18	Left Frame Wall	Aluminum plate, 1/4"	6"x10"	Kit	1	---	Water Jet/Mill	Devin	Sarah	Sarah
19	Right Frame Wall	Aluminum plate, 1/4"	6"x10"	Kit	1	---	Water Jet/Mill	Devin	Sarah	Sarah
20	Frame mounting brackets	Aluminum 90 Degree	1" x 1" x .125"	Kit	7	---	Mill	Devin	Nafisa	Nafisa, Mitch, Sarah

		Angle Stock								
21	Raised Gearbox Tray	Aluminum plate, 1/4"	7.5"x2"	Kit	1	---	Water Jet	David	Mitch	Sarah, Nafisa, David
22	Bottom Gearbox Support	Aluminum 90 Degree Angle Stock	1" x 1" , 1/8" thick	Kit	2	---	Mill	Sarah	Nafisa	Sarah, Mitch
23	Top Gearbox Spacer	Aluminum plate, 1/4"	1"x1"	Kit	1	---	Water jet	David	Sarah	Sarah, Nafisa, David
24	Tray Bouncer	Aluminum plate, 1/16"	1.25"x2.78"	Kit	1	---	Water jet	David	Devin	
25	6-32 Thread, 3/4" Length Machine Screw	Zinc Plated Steel	.138" x 3/4"	Crib	15	---	90272A151	McMaster	---	---
27	6-32 Thread, 1" Length Machine Screw	Zinc Plated Steel	.138" x 1"	Crib	2	---	90272A151	McMaster	---	---
26	Steel Nylon-Insert Locknut	Steel Nylon	5/16" x 11/16"	McMaster	17	$2.61 per 100	90631A007	McMaster	---	---
28	M3 Pan Head Phillips Machine Screw	Zinc-Plated Steel	3mm x 8mm	Crib	2	---	92005A118	McMaster	---	---

Tray Power System

Part No.	Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Contributors		
								Design/ CAD	Drawing/ Plan	Machining
29	Sprocket Support	O1 Tool Steel	1.41"x0.25"	Kit	1	---	Lathe/ Mill	Sarah	David	Nafisa, David
30	Bottom Sprocket	Aluminum plate, 1/4"	1.2"x1.2"	Kit	2	---	Water jet	David	David	Sarah, Nafisa, David
31	Top Sprocket	Aluminum plate, 1/4"	1.2"x1.2"	Kit	1	---	Water jet	David	David	Sarah, Nafisa, David
32	Chain Tensioner Body	Aluminum plate, 1/4"	1.8"x0.5"	Kit	1	---	Water jet /Mill	Devin	Devin	David
33	Chain Tension Spacer	Aluminum rod, 3/8" diameter	0.10"x3/8"	Kit	1	---	Lathe	Devin	Nafisa	Nafisa
34	Tensioner Shaft	O1 Tool Steel	.72"x.25"	Kit	1	---	Lathe/ Mill	Devin	David	Devin, David
35	Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP	---	25mm x 54mm	Crib	1	---	---	Pololu	---	---
36	Chain	Steel	13"	McMaster	1	7.88	6261K174,6261K192,6261K242,6261K262	McMaster	---	---

37	Flanged brass bushing	SAE 863 Iron-Copper Bronze	3/8"x1/4"	Kit	3	---	---	McMaster	---	---
38	6-32 Thread, 3/4" Length Machine Screw	Zinc Plated Steel	.138" x 3/4"	Crib	1	---	90272A151	McMaster	---	---
38	Steel Nylon-Insert Locknut	Steel Nylon	5/16" x 11/16"	McMaster	1	$2.61 per 100	90631A007	McMaster	---	---
38	4-40 Set Screw	Stainless Steel	4-40 x 1/8"	Crib	2	---	---	McMaster	---	---
39	E-Clip retaining rings - 1/4" Dia.	Zinc and Yellow Chromate Plated	.527" x .025"	Kit	8	---	---	McMaster	---	---

Tray

Part No.	Part Title	Material	Dimension(s)	Supplier	Quantity	Price	Notes	Contributors		
								Design/ CAD	Drawing/ Plan	Machining
40	Tray Body	Aluminum plate, 1/16"	11.2"X14.6"	Kit	1	---	Water jet	Mitch	Mitch	Sarah, Nafisa, David
41	Tray Axle Supports	1/4" Acrylic Plate	4.50" X 1.00"	Kit	2	---	Laser Cutter	Mitch	Nafisa	Mitch, Devin
42	Tray Axle	Aluminum rod, 3/8" diameter	8.5"x3/8"	Kit	1	---	Lathe/ Mill	Sarah	Mitch	Nafisa, Sarah, Devin

43	Flanged SS bearing	Stainless Steel	1/4" ID, 1/2" OD, 1/8" Thick	Kit	2	---		McMaster	---	---
44	E-Clip retaining rings - 1/4" Dia.	Zinc and Yellow Chromate Plated	.527" x .025"	Kit	6	---		McMaster	---	---
45	6-32 Thread, 3/4" Length Machine Screw	Zinc Plated Steel	.138" x 1/2"	Crib	4	---		McMaster	---	---
46	6-32 Thread, 1" Length Machine Screw	Zinc Plated Steel	.138" x 1/2"	Crib	2	---		McMaster	---	---
46	Steel Nylon-Insert Locknut	Steel Nylon	5/16" x 11/16"	McMaster	6	$2.61 per 100	90631A007	McMaster	---	---
47	3" extension spring	Steel	3" x .313"	Crib	2	---	---	McMaster	---	---

4.2. Manufacturing Process

The majority of the parts we used were cut from aluminum plates and sheets on the waterjet; this limited manufacturing error, gave us greater precision, and increased our productivity. Although we used the waterjet for many of the parts, we did manufacture brackets for our RMP (see figure 10), all of the axles (see figure 10), wheel attachments (see figure 10), and drilled precise holes for bearings in water jetted parts. When manufacturing the brackets, the standard process started with cutting the aluminum angle stock to length on the bandsaw. Once complete, the parts were then faced on the mill and a stop would then be added and zeroed as our datum to allow many parts to be made without having to re-zero each subsequent part. The parts would be faced down to size. Afterwards, a center drill would be used to create pilot holes for each hole in the bracket. Drill bits would follow the center drill marks and would make the holes through the brackets where the bolts would insert and where the bearings would sit (see figure 10). If needed, the holes would be precision reamed for certain fits, such as the press fit used in bearing assemblies. The manufacturing of the axles of our RMP were probably the most involved process, starting on the lathe and eventually making their way to the mill for keyways and tapped set screw holes. The preliminary step to creating our axles was simply cutting the aluminum rod stock to length. Afterwards, the pieces would be taken to the lathe, faced down to size. For our tray axle, both ends were turned down to be fit through the bearing assemblies at the top of our RMP while the wheel axles were small enough along their entire length to fit through the bearing assembly. For our wheel axles, the parts were then drilled out at one end to fit the driveshaft of the metal gearbox. After being drilled out, the piece was taken to the mill where a hole was drilled radially in the axle to act as the set screw hole for the drive shaft attachment (see figure 10). The tray axle was manufactured differently, instead, a keyway was made for the sprocket that would drive it (see figure 14). The keyway was milled using an ⅛" end mill to remove material along the length of the rod. Wheel attachments were just press fit aluminum hex stock with holes drilled into the sides for spring pins to attach the hex stock to the axles. The engineering drawings and manufacturing plans for all parts we made can be found in appendix B.

Assembly was easy for the most part, however, the sprockets we water jetted were originally too wide (see figure 14), the set screws kept falling out, our tray limiting string broke a couple of times, and the extension springs were difficult to stretch to their initial lengths. To solve these problems with assembling the RMP, the sprockets we precisely ground down to size, used extra Loc-Tite to secure the set screws, we braided our Kevlar string to withstand the forces of the tray, and we used needle nose pliers and washers to stretch the extension springs to their initial lengths.

5. PROTOTYPE TESTING

5.1. Preliminary Test

Our preliminary tests consisted mainly of testing our functional requirements. Most importantly, the RMP needed to be able to move the 14.5lb, the tray had to be able to pick up three cubes, and the tray needed to deposit the cubes into the basket. To test these criteria, we simply ran the course to see if the RMP would perform these tasks. We started in the corner, surrounded by three large 14.5lb blocks and attempted to push one of them. Initially, one wheel spun and the other driven wheel did not. We attributed this issue to the axle set screw on the stationary wheel and replaced it. After replacing the set screw, both wheels spun but the RMP could not move the 14.5lb block. This was not an issue of our torque output, but was caused by the lack of frictional force on our RMP's wheels. To counteract this slipping, counterweights were added to our RMP and attached using Velcro. This gave more weight over the RMP's wheels and increased the frictional force to the point needed to push the blocks. Our tray was able to pick up the blocks without much problem, although part of the tray was raised off of the ground more than the rest of it which made it harder to acquire blocks using that portion of the tray scoop. This issue arose because our tray was bent at a slightly incorrect angle. For the final preliminary test, the tray needed to deposit the cubes into the basket. Our chosen method of depositing the cubes was dependent on being able to lift the cubes by rotating the tray, therefore we needed the tray to lift three cubes. Our preliminary testing revealed that the lifting calculations we had performed earlier in the semester were definitely wrong. This is because we underestimated the efficiency lost through our chain and sprocket drive system. We tried greasing the chain and lubricating the system to increase our efficiency but this was ineffective and the tray was unable to overcome the torque generated by the combined moment arm of the tray and the weight of the cubes. This issue was easily the biggest problem our team had in the preliminary testing and many solutions were discussed to fix it. Eventually, our solution was to attach extension springs to the chain and the base to apply a downward force on it which would in turn rotate the sprocket at the top of the tray on the tray axle. This liner extension spring force was converted into a torque at the sprocket and helped to raise the tray. We used two extension springs in order to have more control over the rotation of the tray rather than making it rotate too quickly with three or more extension springs. This was a simple fix to our problem considering the complexity of the tray raising system. This simplicity was a good thing because it was a very easy system to maintain and fix if the springs were damaged or it stopped working.

5.2. Scrimmage Results and Redesign Based on Scrimmage

After the scrimmage, our team had very little time to modify our design which led to minimal redesigning. The designs we had chosen held up well and completed all of the scrimmage tasks without a single failure, passing each test on our first attempt. We were able to move the blocks, acquire and transport cubes, and deposit our cubes well within the time limit. The only portion that we did redesign was our tray limiting Kevlar string which we decided to reinforce. We reinforced the string by braiding more Kevlar strands into it so that it would not break when using it in the competition. This string would limit the range of motion of our tray, so that our tray would not go past the vertical position since the addition of the extension springs would make it hard to bring the tray back down from that position.

5.3. Discussion of Competition Results

The competition was an incredible success as most of our systems and groups had near flawless performances as we succeeded in setting the all-time record for the Michigan Ninja Relay. Overall, the squad strategy proved successful and cube handoffs took place which saved valuable time when trying to score points. While many of the groups were successful in transporting and depositing cubes, RMP1 had some difficulty with their control box which prevented them from moving cubes into zone 2. However, the other groups succeeded in moving most or all of their cubes into the next zone. RMP2 was able to move all of their cubes into zone 3 and RMP3 was able to move all but one of their cubes into our zone, zone 4. We prioritized other zones cubes over ours which led to one of our cubes not making it into the goal. In summary, the squad strategy was extremely efficient at moving cubes over large distances which was the key to scoring the most points. Our zone strategy worked well since we cleared a direct path to the goal that we were able to use when receiving cubes from previous zones and depositing them in the goal. We took an auxiliary strategy when higher valued cubes dropped into our zone and prioritized those cubes over depositing our final cube. This led to our victory because we would have run out of time to score if we had tried to deposit our zone's final cube. The turning point in the competition was RMP3 gently placing a stack of three red zone 2 cubes into our tray which gave us a time advantage in depositing them in the goal. The last zone 4 cube was left until the very end where our driver tried shooting the cube from distance. It missed. The score breakdown for each zone was as follows:

Zone 1: 0 points (due to control box issues)

Zone 2: 5 points

Zone 3: 3 points + 3*2 points = 9 points

Zone 4: 2 points + 3*2 points + 3*2 points = 14 points

Total: 28 points

6. DISCUSSION AND RECOMMENDATIONS

6.1. Project Summary

Overall, our design was well composed which allowed us to easily create our RMP and make changes when necessary. The good points were the detail we had in the CAD from the beginning and the uncomplicated systems of the RMP. This made manufacturing and assembly go smoothly. The bad points were the somewhat intricate parts that we needed to manufacture and the uncertain functionality of our tray's power system. With that in mind, we would definitely change our tray system. The chain and sprocket needed the help of two springs to function, therefore, it would be beneficial to either lower the weight of the tray further or find another system that can transfer more torque.

6.2. Recommendation for Mass Production

As stated above, intricate parts need to be avoided. We would change the tray axle to be the same diameter throughout its whole length (½ inch). This also means it would need to be pressed into a ½ inch diameter bearing instead of ¼ inch. We would also die cast the frame base and walls instead of water jetting them. We could die cast all of the clearance holes for the screws, but we would still have to mill and ream the bearing holes. Die casting would significantly reduce the manufacture time while maintaining function. To make manufacturing of the tray easier, a die with the outline and and holes of the tray should be used to cut the profile. This is far faster than water jetting each tray individually.

6.3. Future Project Idea

This project can be improved for future semesters to foster a more collaborative environment. In it's current form, there is not a lot of collaboration between the squads. To do this, there should be lab days dedicated to understanding and helping the other zones with their project. One member of your team will go to each zone's team, leaving two with your own zone. They will then help that zone with their project which gives each team an understanding of the strategy and design of the other RMPs.

7. REFERENCES

Sprocket Design Reference -

http://www.instructables.com/id/How-to-Draw-a-Sprocket-Gear/

Project Description and Rules-

https://docs.google.com/document/d/1RItrJzCefapRxnnvg3c4HO4sntVO38flC4QLbH7iZOA/pub

8. ACKNOWLEDGEMENTS

Thank you to our amazing GSI Wei Hon Yap for always being ready to help all around. From design considerations to technical calculations, Yap was always there to offer insight and help guide us when we were stuck. We would also like to thank the shop staff Toby, John, and Charlie for running back in forth in the shop constantly to help us clamp our piece down securely, run the machines, and solve problems we encountered. Thank you to Jesse and Mike for teaching us all the content required for us to build our successful RMP. Jesse and Mike truly believe in their students' success; after giving our mid-semester course feedback, changes were immediately made to cater to the students.

APPENDICES

A. Preliminary design concept

A.1. Preliminary Design Concept Sketch 1

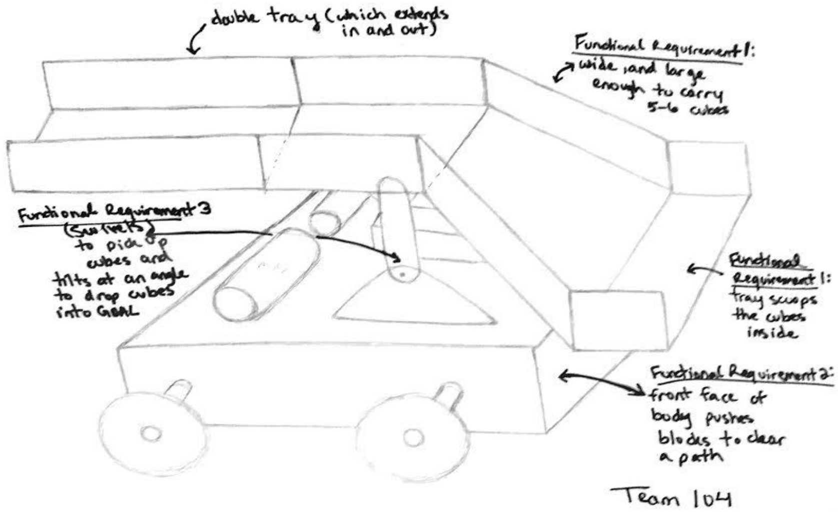


Figure A.1: Preliminary design concept sketch 1

A.2. Preliminary Design Concept Sketch 2

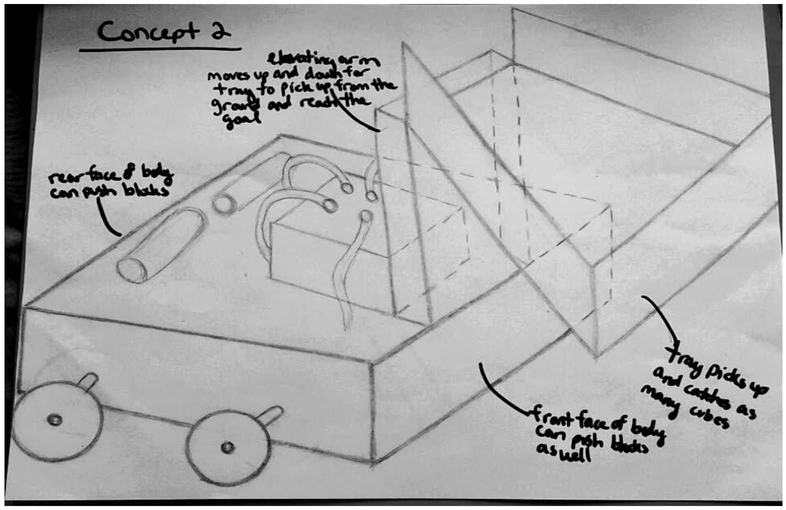


Figure A.2: Preliminary design concept sketch 2

A.3. Preliminary Design Concept Sketch 3

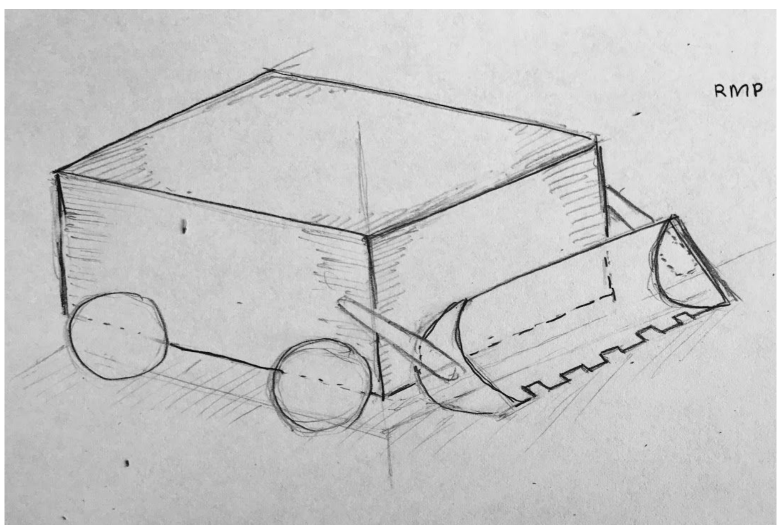
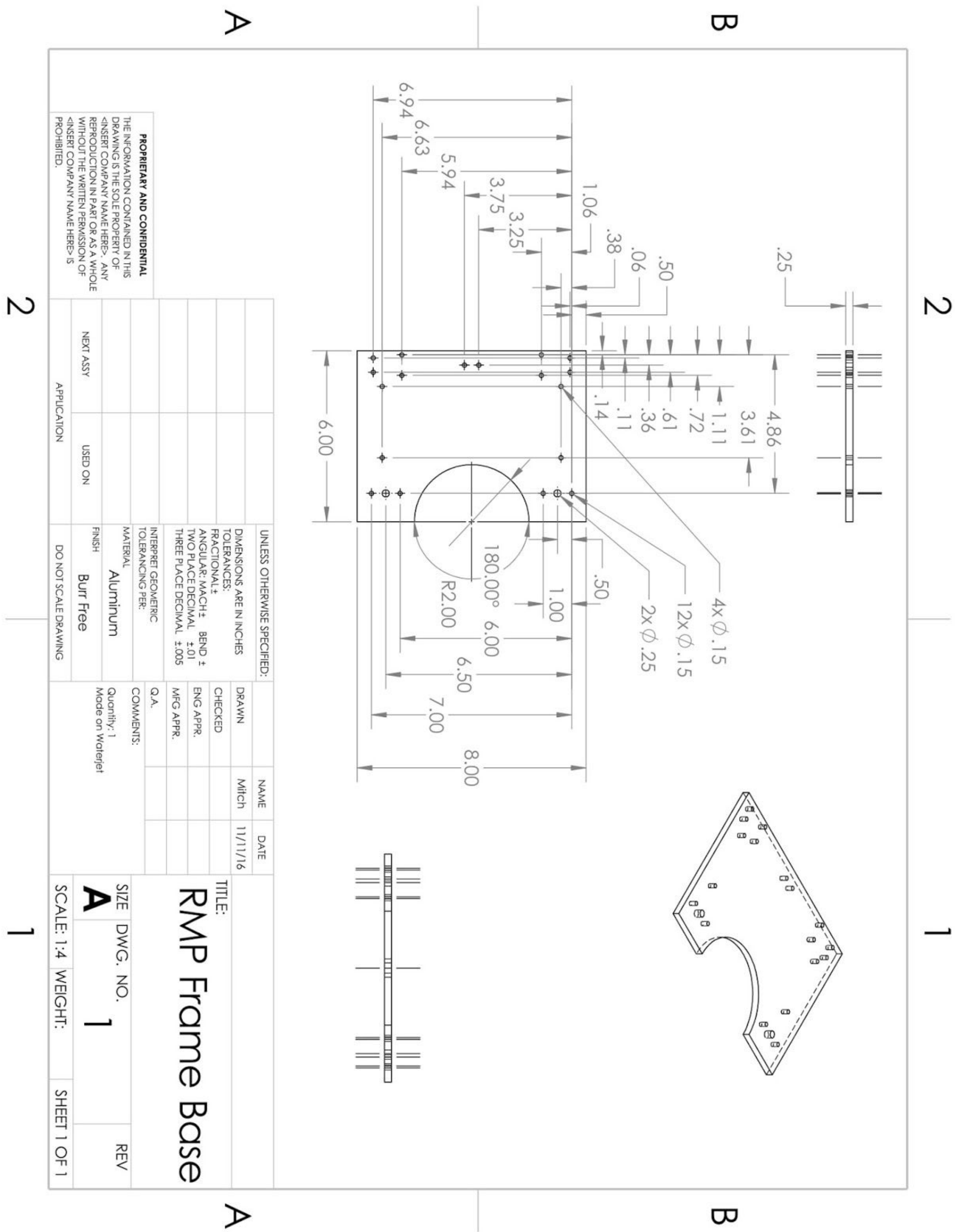
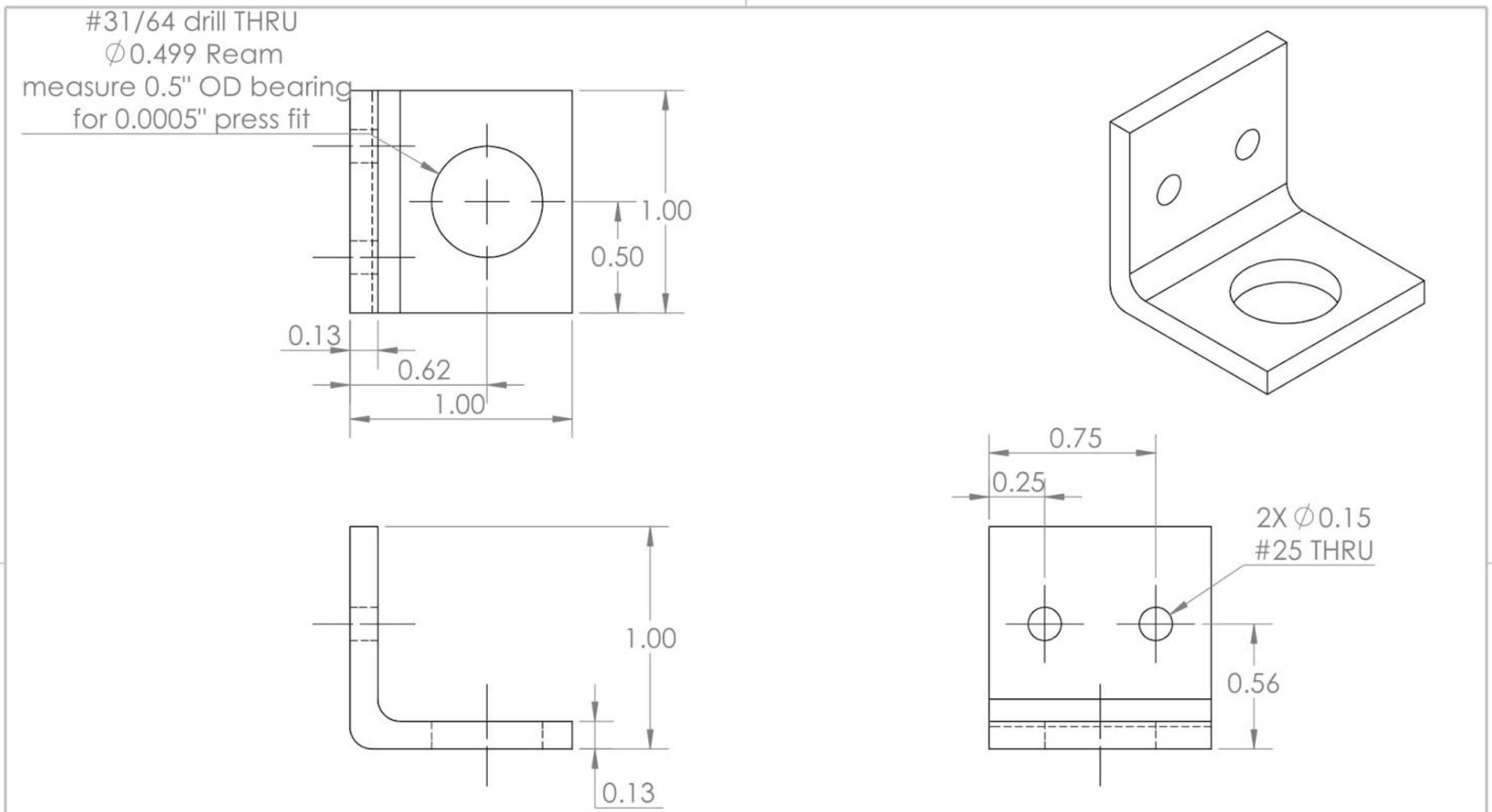


Figure A.2: Preliminary design concept sketch 3

B. Dimensioned Drawings and manufacturing plans

B.1. Dimensioned Drawings of Individual Parts





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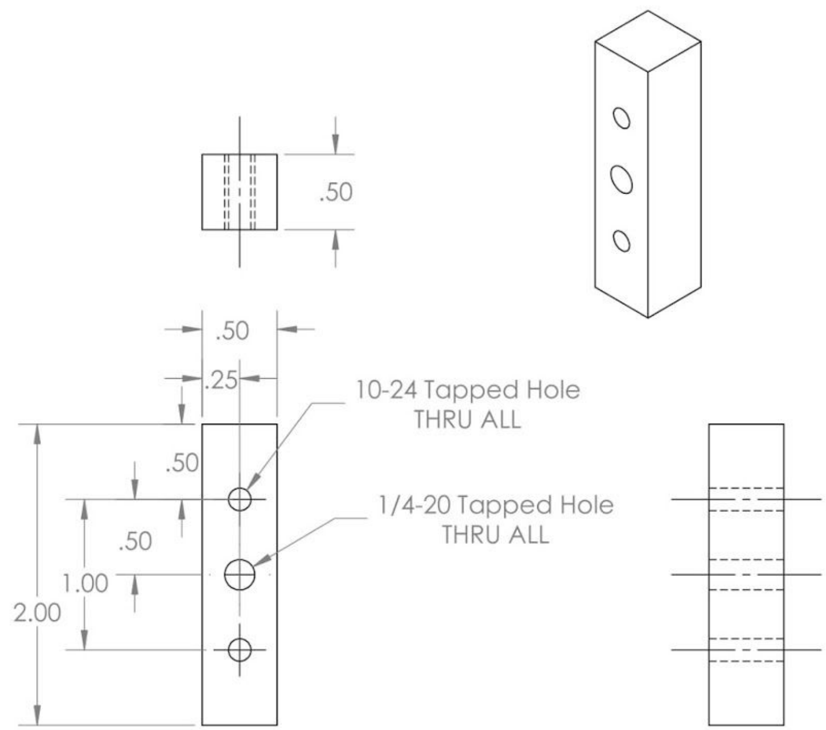

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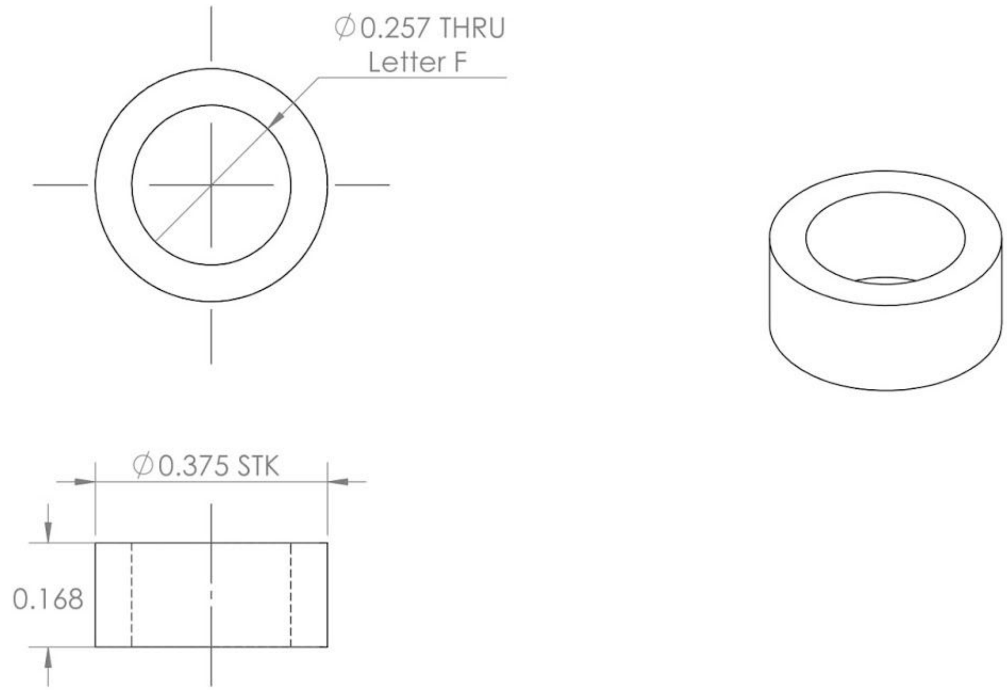

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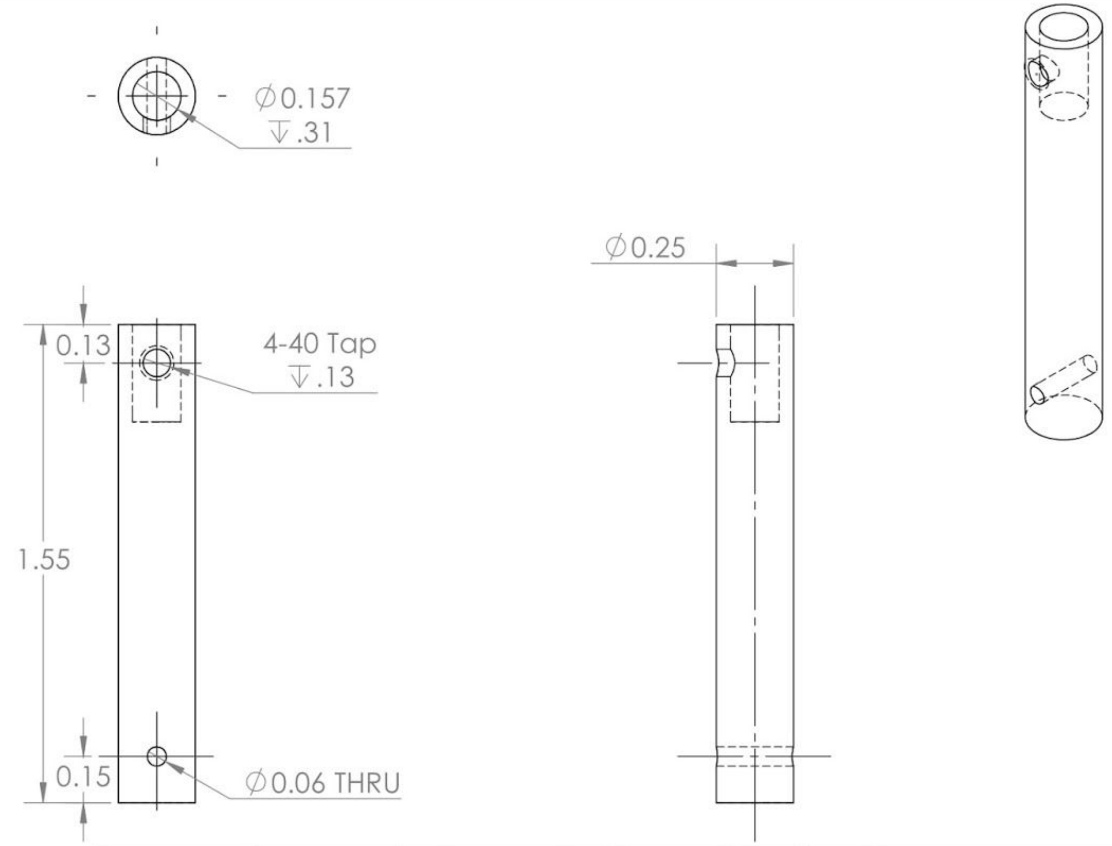
TITLE:

Ball Caster Spacer

SIZE	DWG. NO.	REV
A	4	

SCALE: 4:1 WEIGHT: SHEET 1 OF 1



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	Steel
FINISH	Burr Free
DO NOT SCALE DRAWING	

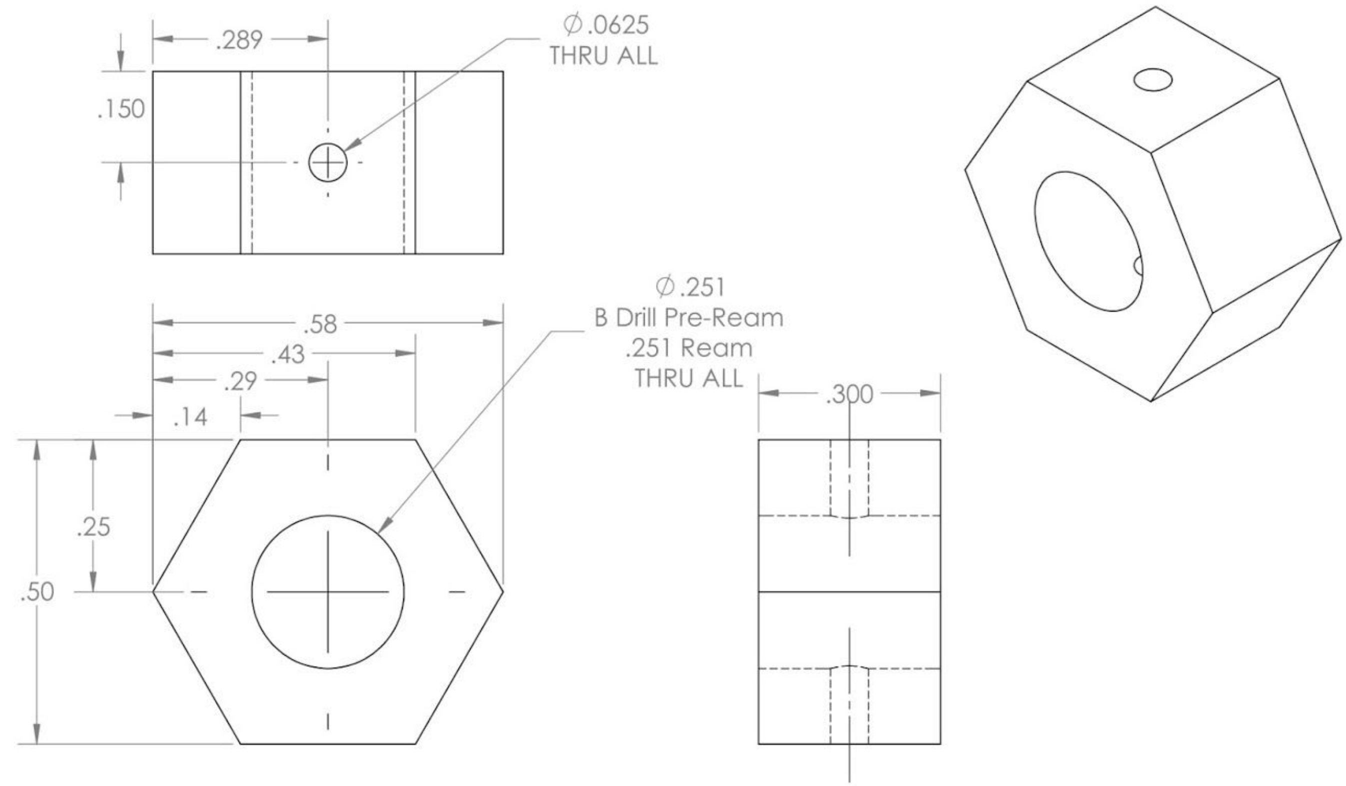
	NAME	DATE
DRAWN	Devin Stevens	11/1/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 2

NEXT ASSY	USED ON
APPLICATION	

TITLE:
Wheel Axle Rod

SIZE	DWG. NO.	REV
A	5	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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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

FINISH Burr free

DO NOT SCALE DRAWING

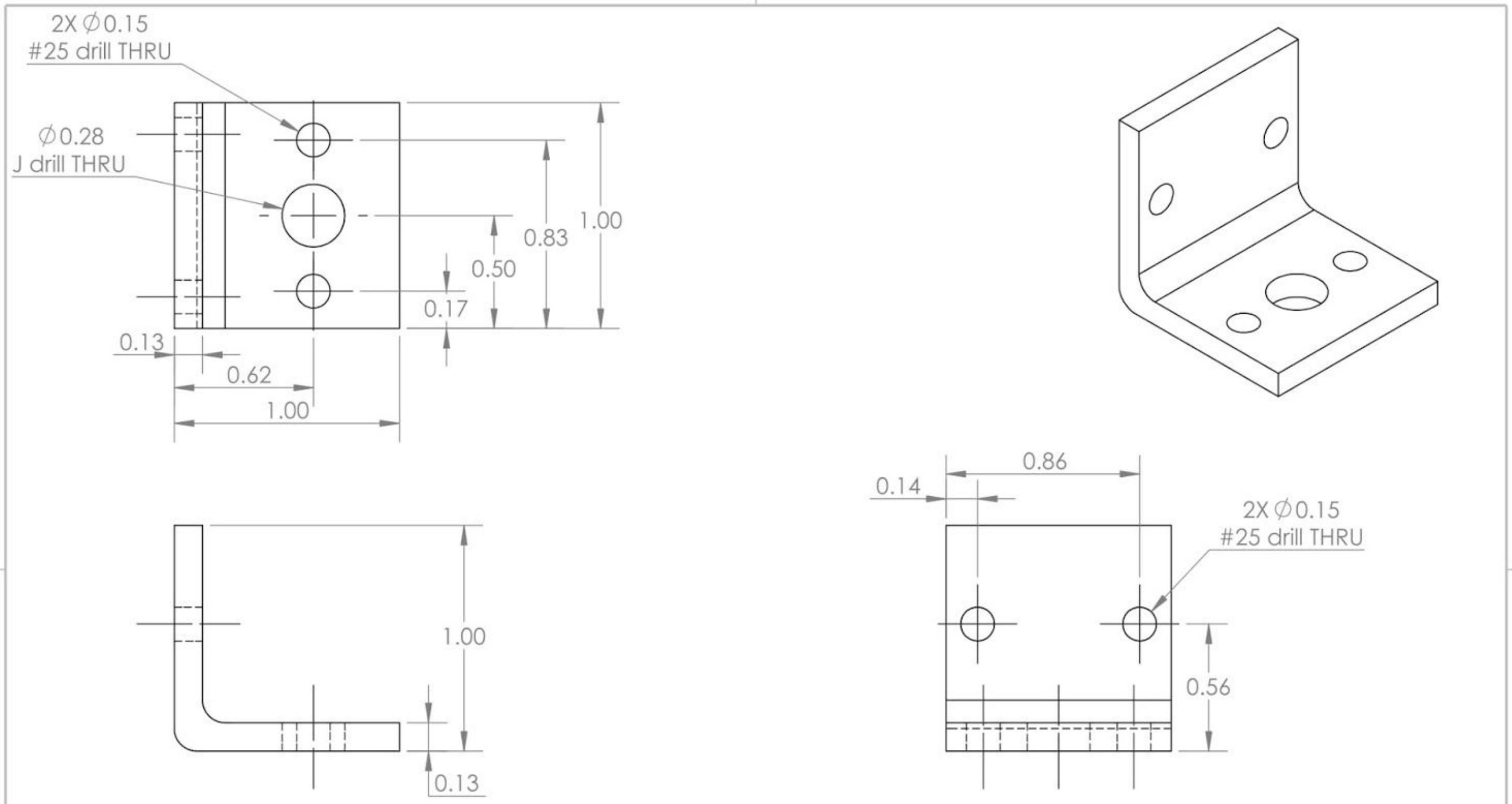
	NAME	DATE
DRAWN	David	11/1/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 2

TITLE:
Wheel Axle Hex

SIZE	DWG. NO.	REV
A	6	

SCALE: 4:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
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

FINISH: Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Nafisa	11/7/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

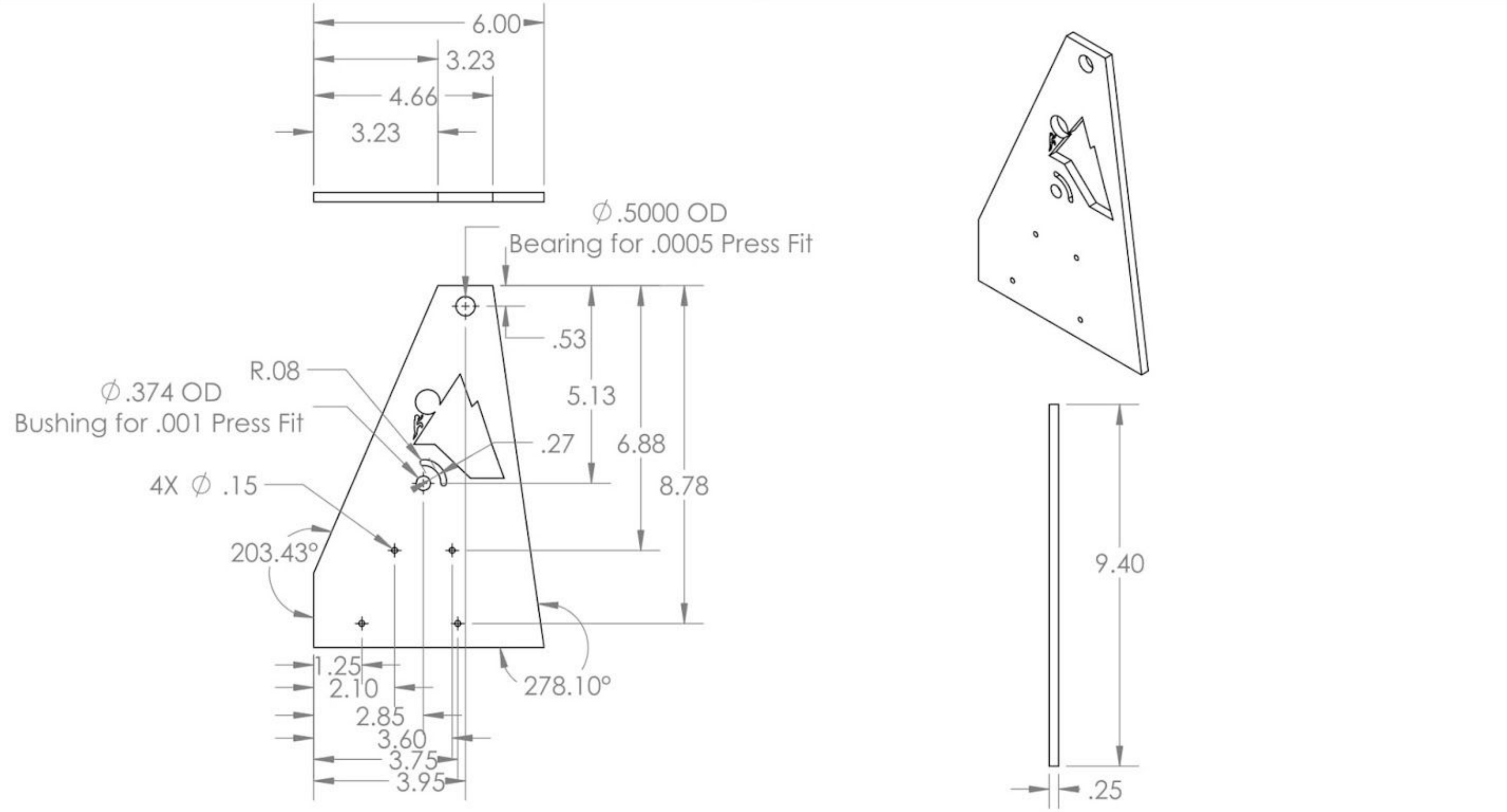
Quantity: 2

TITLE:

Bottom Gearbox Support

SIZE	DWG. NO.	REV
A	7	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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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: Aluminum Plate, 1/4"

FINISH: Burr free

DO NOT SCALE DRAWING

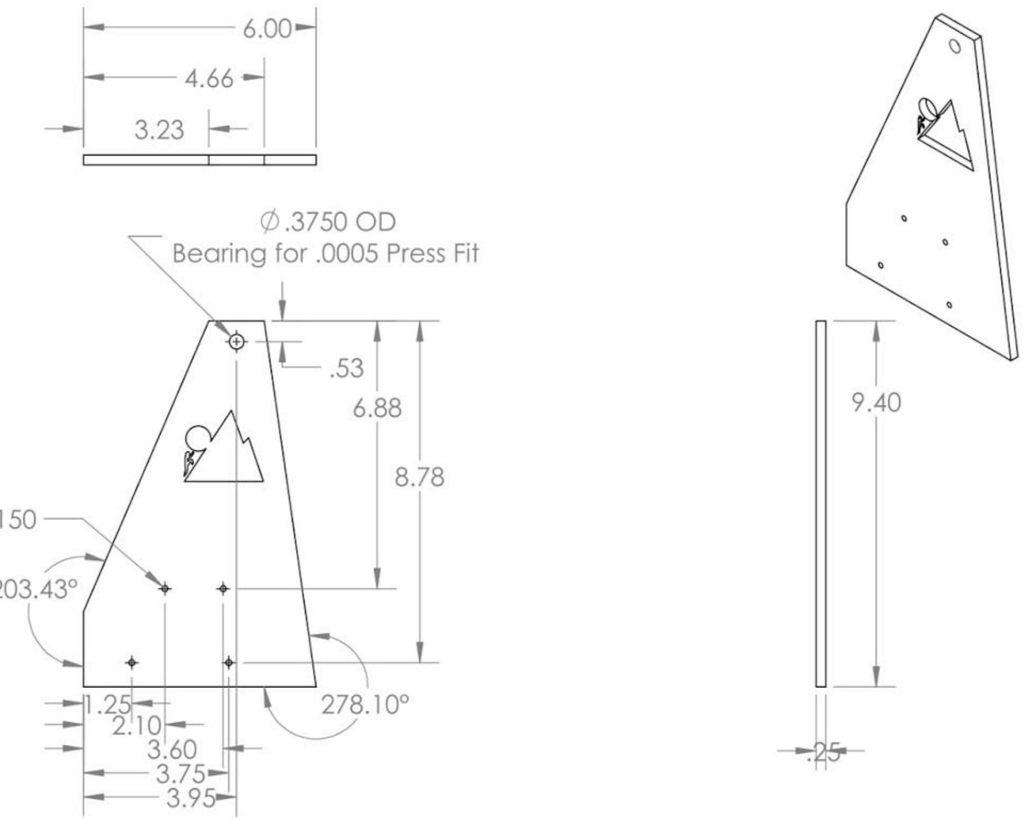
	NAME	DATE
DRAWN	Sarah	11/11/2016
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Made on Waterjet and mill. Cutout on side is our logo.

TITLE: **Left Frame Wall**

SIZE: A | DWG. NO. 18 | REV

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



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APPLICATION	

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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: Aluminum Plate, 1/4"

FINISH: Burr free

DO NOT SCALE DRAWING

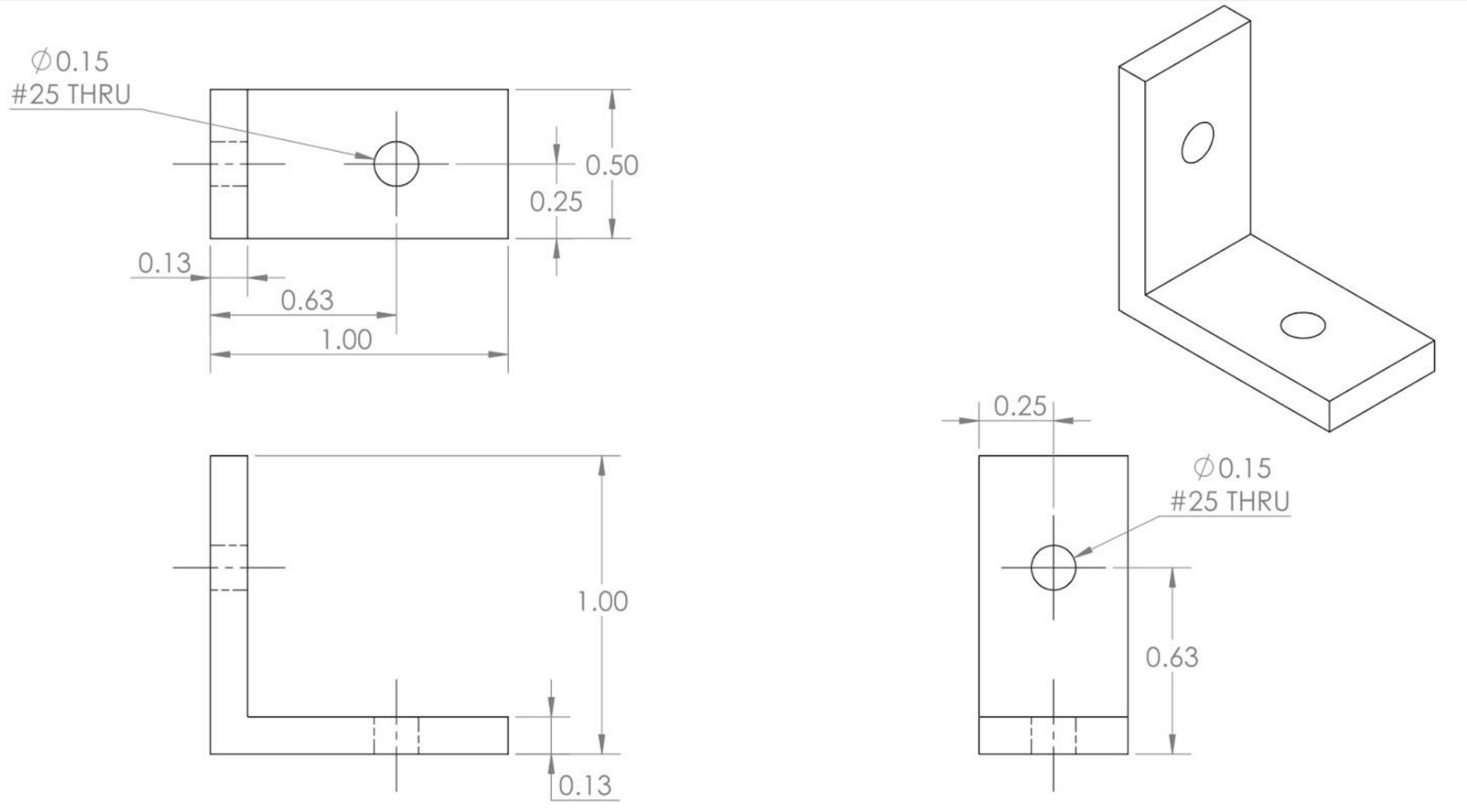
	NAME	DATE
DRAWN	Sarah	11/13/2016
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Made on Waterjet and mill. Cutout on side is our logo.

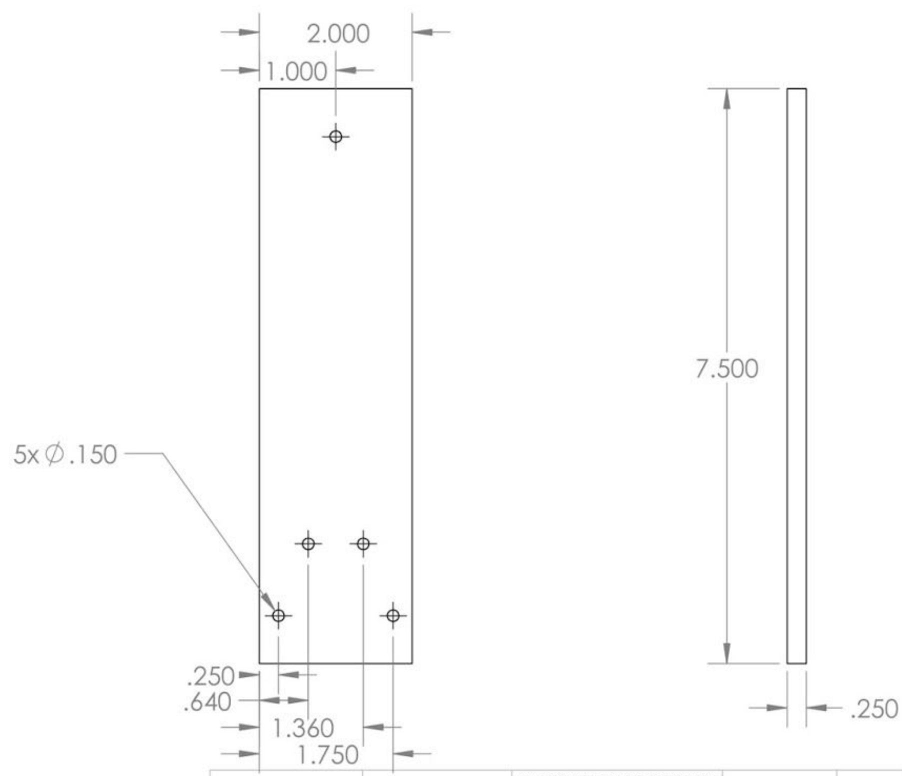
TITLE: **Right Frame Wall**

SIZE: A | DWG. NO.: 19 | REV

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



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	DRAWN	Nafisa	11/10/16	TITLE: Frame Mouting Brackets
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum	COMMENTS: Quantity: 7			SIZE A DWG. NO. 20 REV
NEXT ASSY	USED ON	FINISH Burr Free				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1 WEIGHT: SHEET 1 OF 1



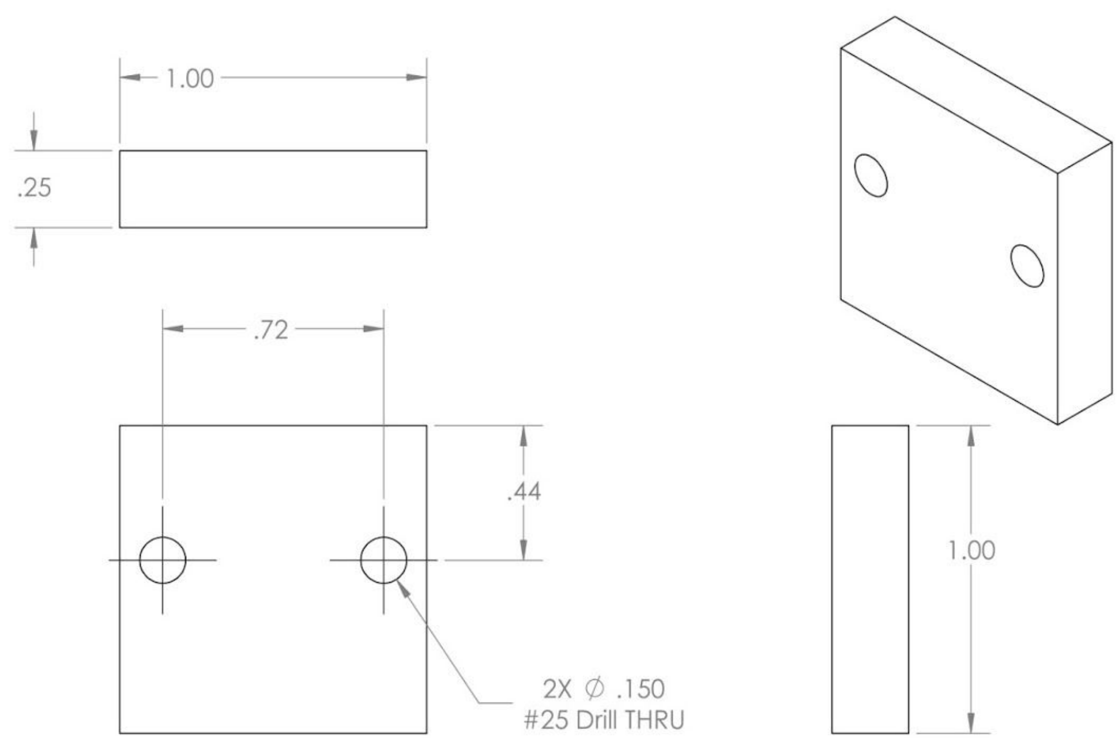
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.010 THREE PLACE DECIMAL ±.005	DRAWN	Mitch	11/14/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS: Waterjet Quantity: 1		
FINISH Burless			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

TITLE:

Raised Gearbox Tray

SIZE	DWG. NO.	REV
A	21	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



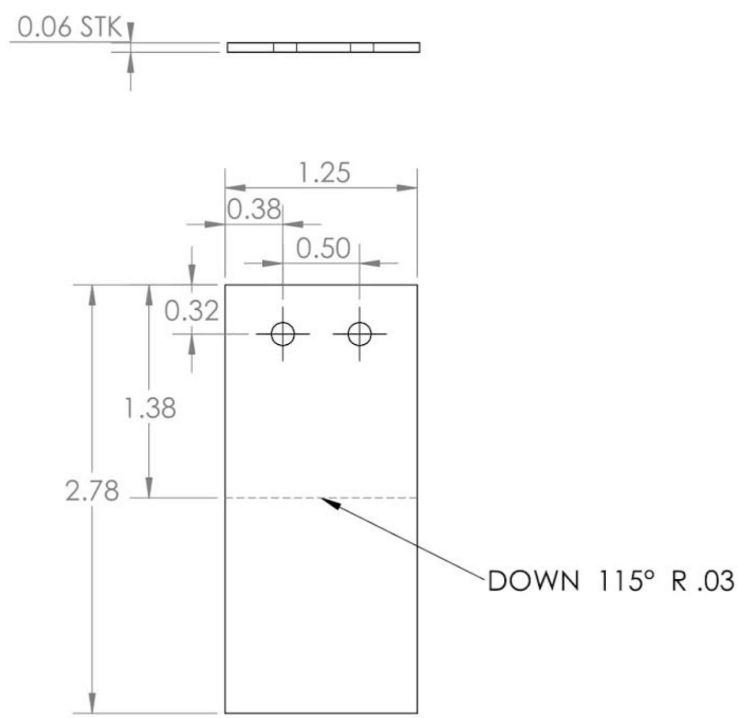
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	Sarah	05/17/1997
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum Plate, 1/4"	COMMENTS: Quantity: 2 Made on Waterjet		
FINISH Burr free			
DO NOT SCALE DRAWING			

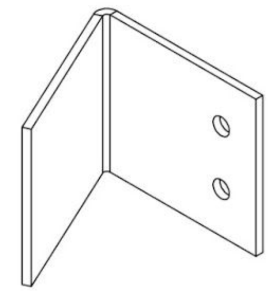
NEXT ASSY	USED ON
APPLICATION	

TITLE:

Top Gearbox Spacer

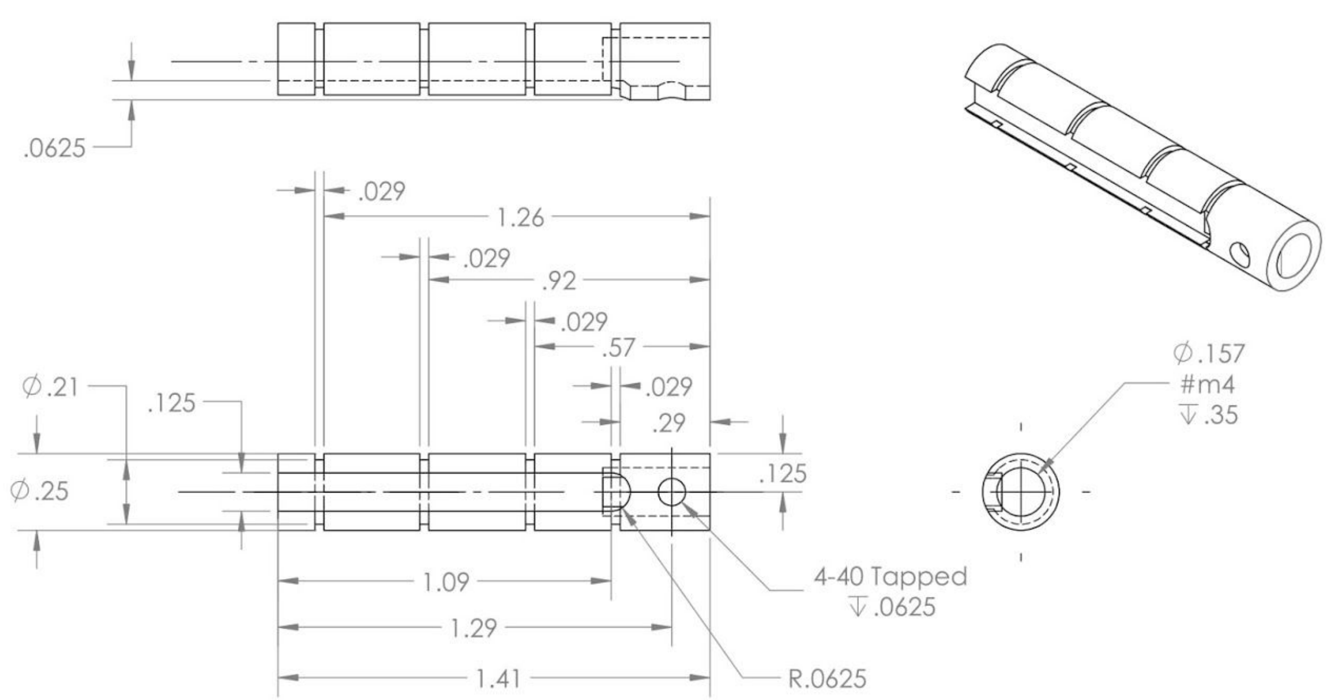
SIZE	DWG. NO.	REV
A	23	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	Devin	11/10/16	TITLE: Tray Boncer
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Aluminum	COMMENTS: Made on Waterjet Bent on hand brake			SIZE A · DWG. NO. 24 · REV
FINISH Burr Free				
DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: O1 Tool Steel

FINISH: Burr free

DO NOT SCALE DRAWING

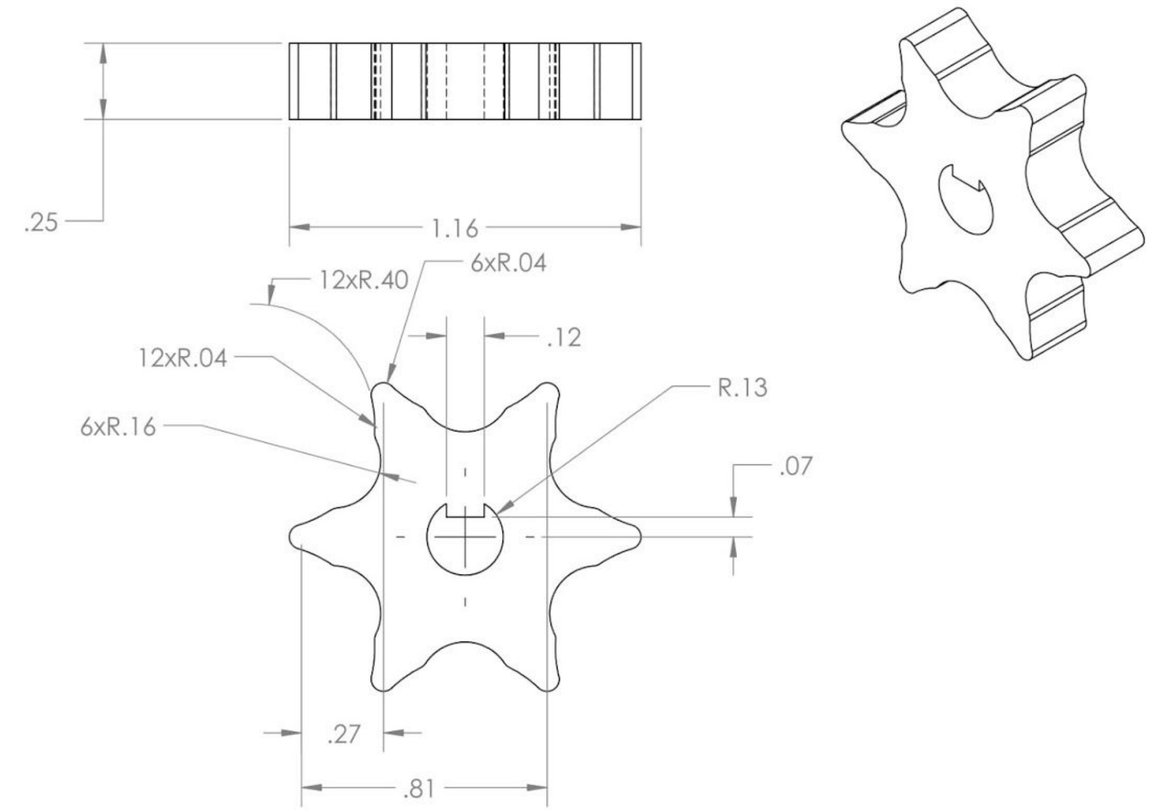
	NAME	DATE
DRAWN	David	11/8/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Use the right datum for lathing and left datum for milling

TITLE:
Sprocket Support

SIZE	DWG. NO.	REV
A	29	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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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: Aluminum

FINISH: Burr free

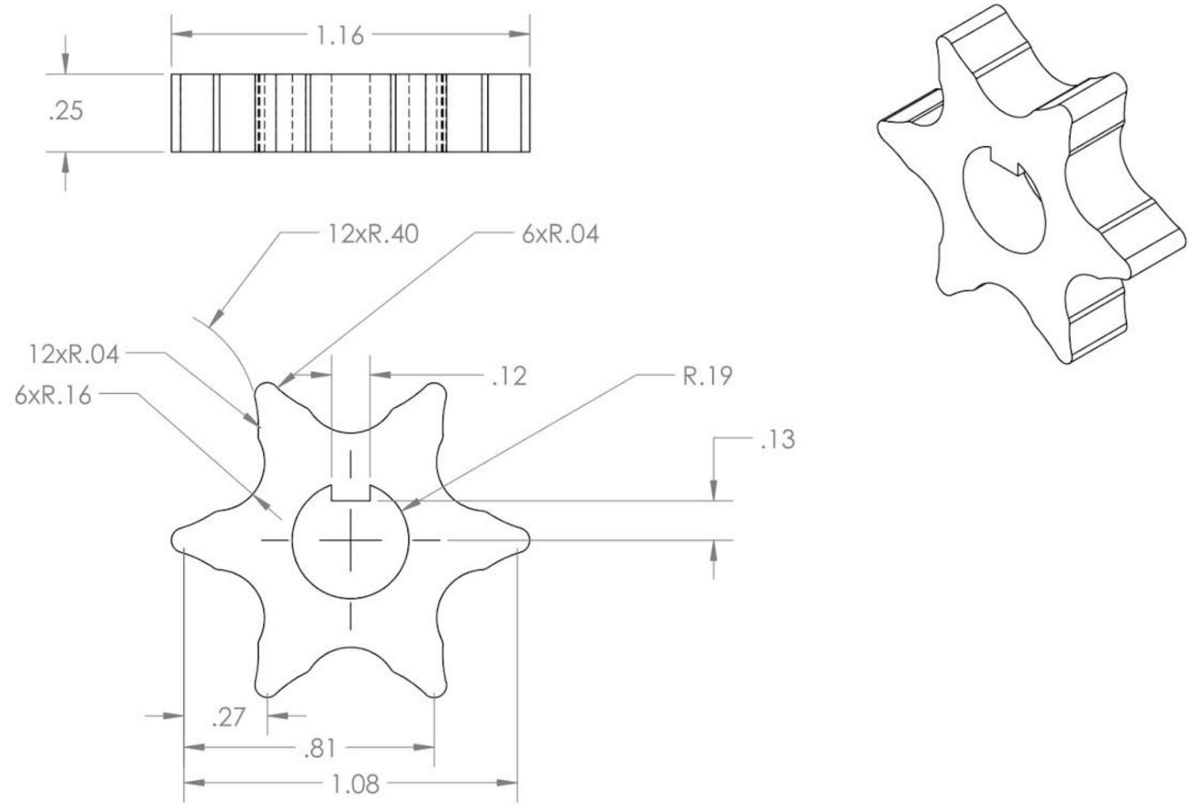
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	David	11/8/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 2
Made on Waterjet
Need high quality cut

TITLE: Bottom Sprocket

SIZE	DWG. NO.	REV
A	30	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

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: Aluminum

FINISH: Burr free

DO NOT SCALE DRAWING

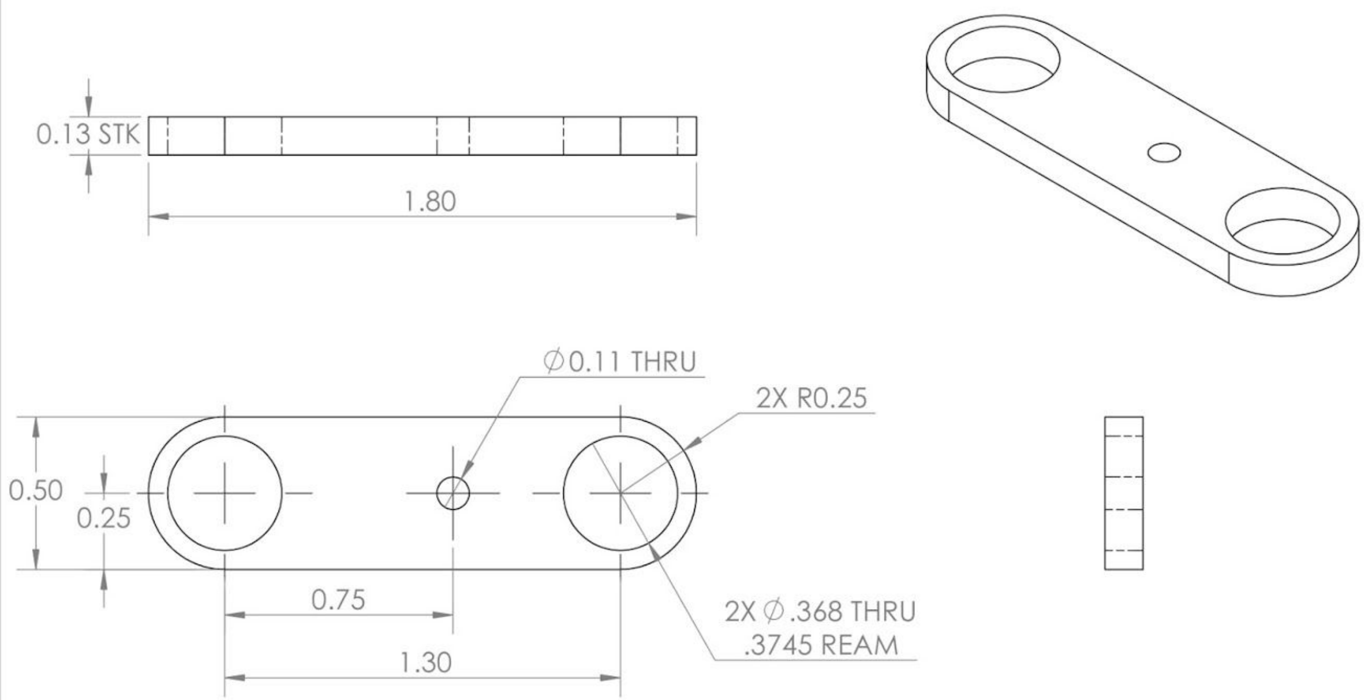
	NAME	DATE
DRAWN	David	11/8/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Made on Waterjet
Need high quality cut

TITLE:

Top Sprocket

SIZE	DWG. NO.	REV
A	31	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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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: Aluminum

FINISH: Burr Free

DO NOT SCALE DRAWING

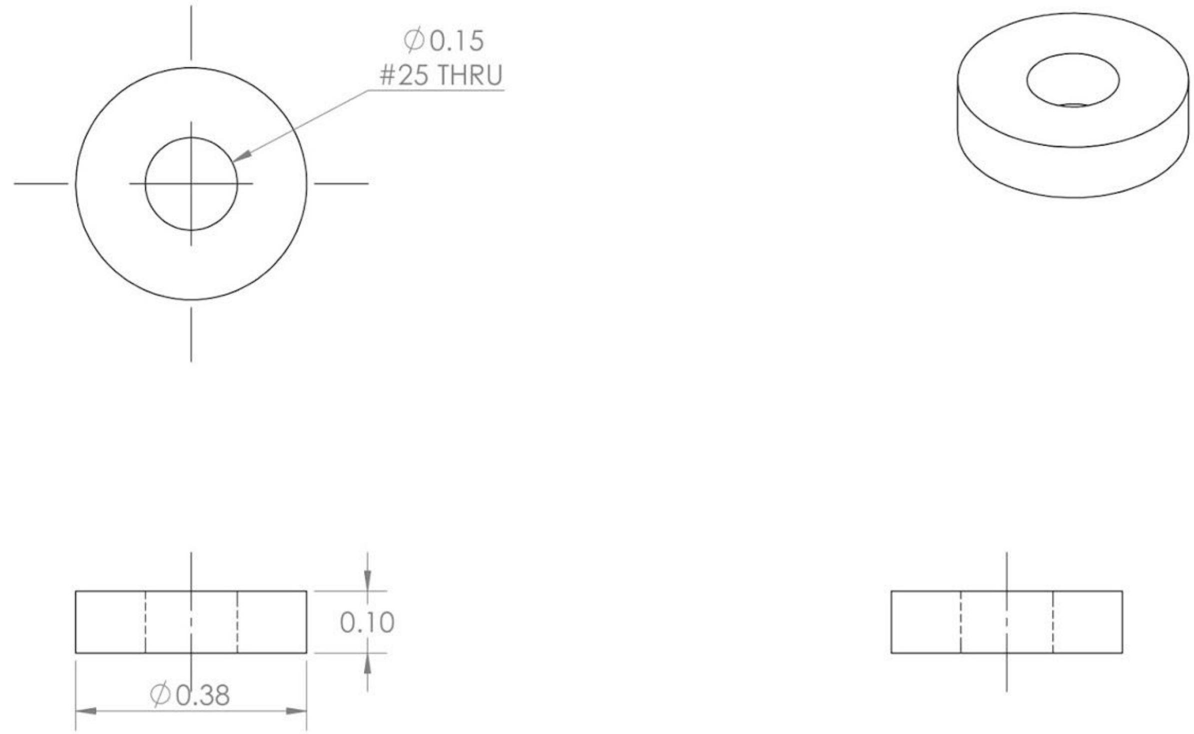
	NAME	DATE
DRAWN	Devin	11/10/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Waterjet Outline
Mill holes

TITLE: **Chain Tensioner Body**

SIZE	DWG. NO.	REV
A	32	

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 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	Aluminum
FINISH	Burr Free
DO NOT SCALE DRAWING	

	NAME	DATE
DRAWN	Nafisa	11/10/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

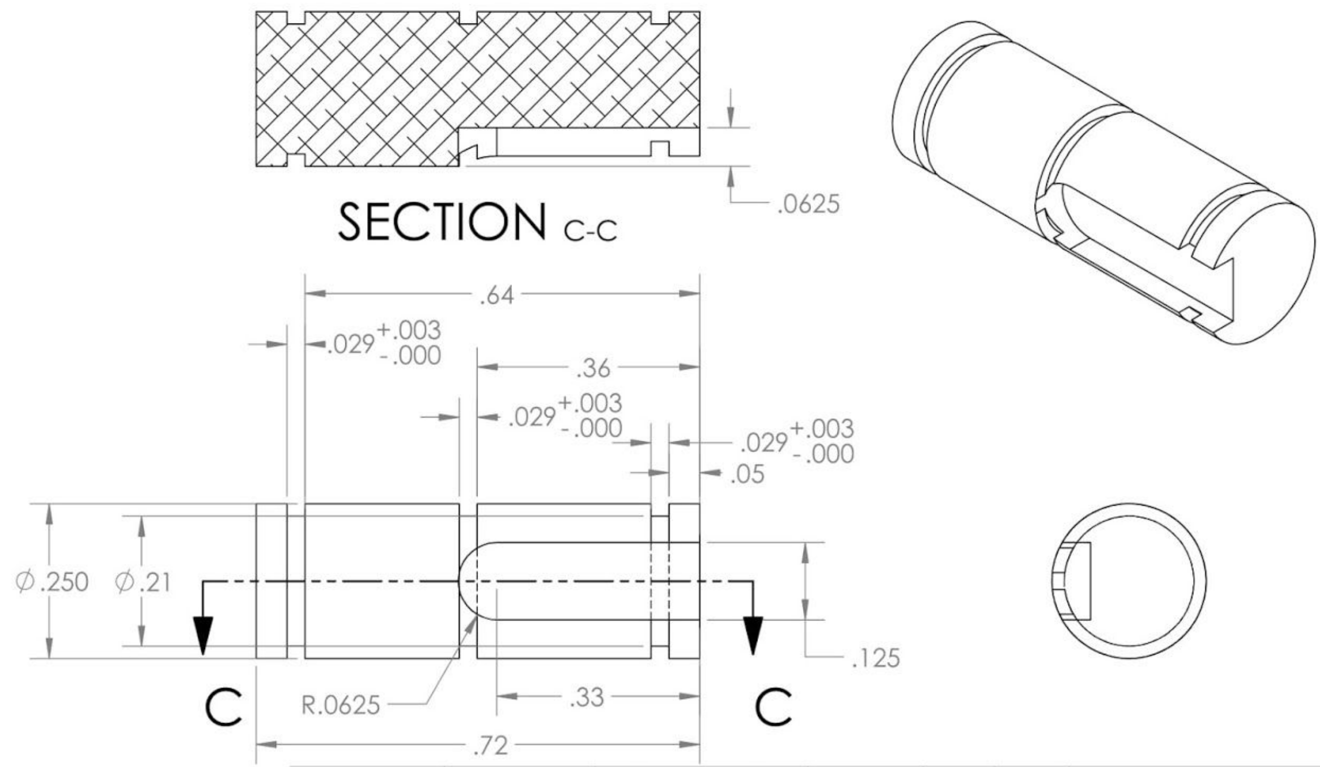
Quantity: 1

TITLE: **Chain Tension Spacer**

SIZE	DWG. NO.	REV
A	33	

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

NEXT ASSY	USED ON
APPLICATION	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	David	11/10/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS: Quantity: 1		
FINISH Burr free			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

TITLE: Tensioner Shaft

SIZE A | DWG. NO. 34 | REV

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

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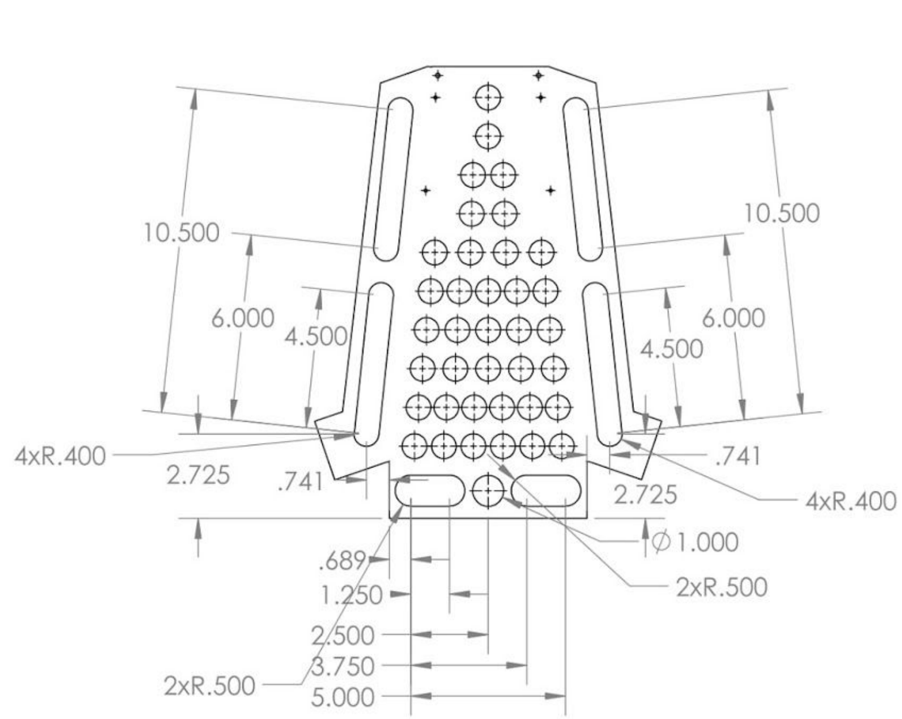

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NEXT ASSY	USED ON
APPLICATION	

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: Aluminum

FINISH: Burr free

DO NOT SCALE DRAWING

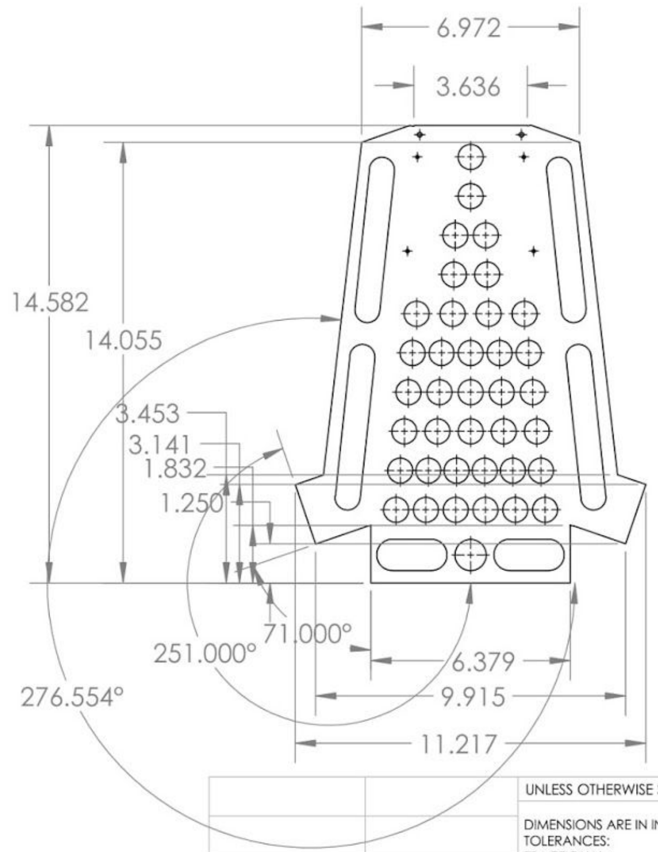
	NAME	DATE
DRAWN	David	11/22/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Cut on Waterjet
Bent on Brake

TITLE: Tray Body

SIZE	DWG. NO.	REV
A	40	

SCALE: 1:5 WEIGHT: SHEET 1 OF 4



NEXT ASSY	USED ON	
APPLICATION		

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: Aluminum

FINISH: Burr free

DO NOT SCALE DRAWING

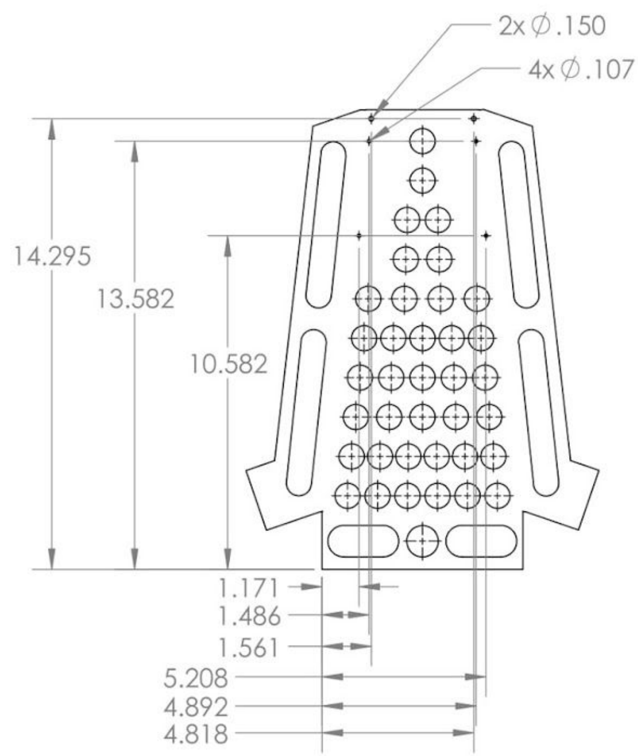
	NAME	DATE
DRAWN	David	11/22/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Cut on Waterjet
Bent on Brake

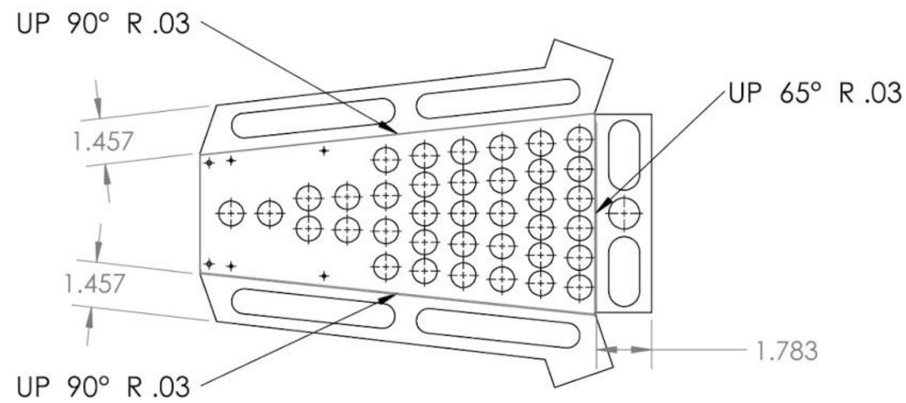
TITLE: Tray Body

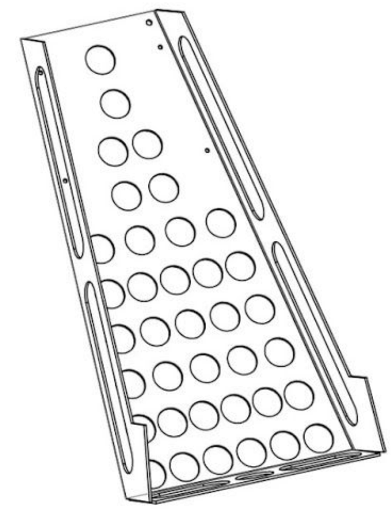
SIZE	DWG. NO.	REV
A	40	

SCALE: 1:5 WEIGHT: SHEET 2 OF 4



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	David	11/22/16	TITLE: Tray Body
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Aluminum	COMMENTS: Quantity: 1 Cut on Waterjet Bent on Brake			SIZE A — DWG. NO. 40 — REV
NEXT ASSY	USED ON	FINISH Burr free				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:5 — WEIGHT: — SHEET 3 OF 4





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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: Aluminum

FINISH: Burr free

DO NOT SCALE DRAWING

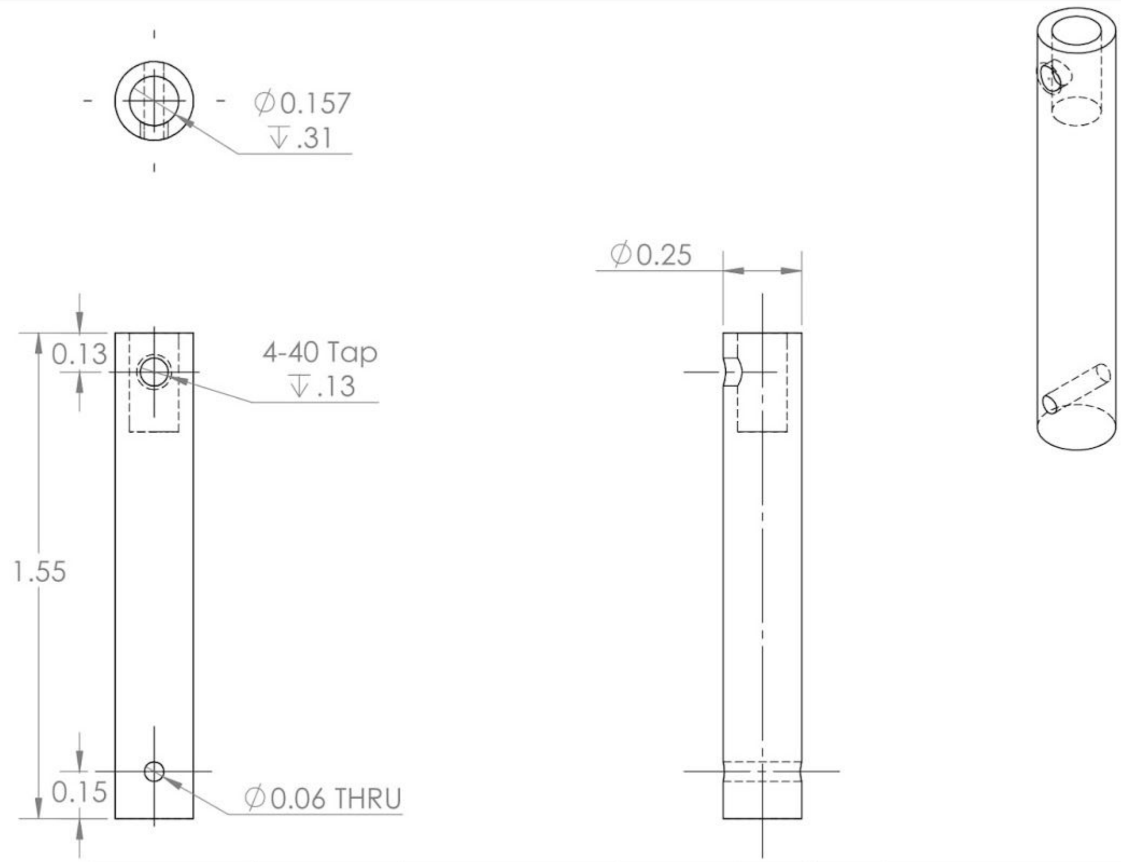
	NAME	DATE
DRAWN	David	11/22/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 1
Cut on Waterjet
Bent on Brake

TITLE: Tray Body

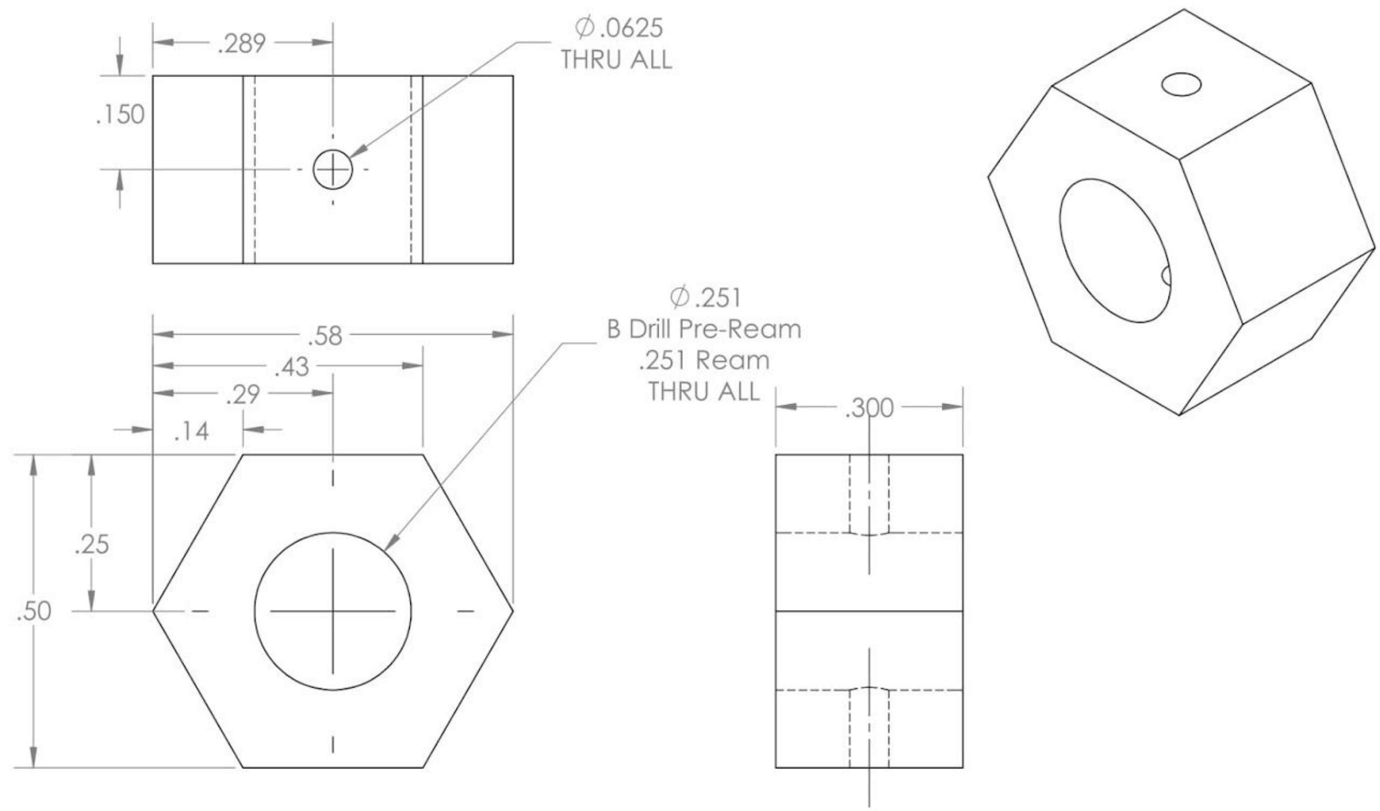
SIZE	DWG. NO.	REV
A	40	

SCALE: 1:5 WEIGHT: SHEET 4 OF 4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	Devin Stevens	11/1/16	TITLE:	Wheel Axle Rod
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL: Steel	COMMENTS: Quantity: 2			SIZE: A	DWG. NO. 5 / REV
FINISH: Burr Free					
DO NOT SCALE DRAWING				SCALE: 2:1 / WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



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NEXT ASSY	USED ON
APPLICATION	

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 Multipurpose 6061 Aluminum Bar, 1/2" Hex Size

FINISH Burr free

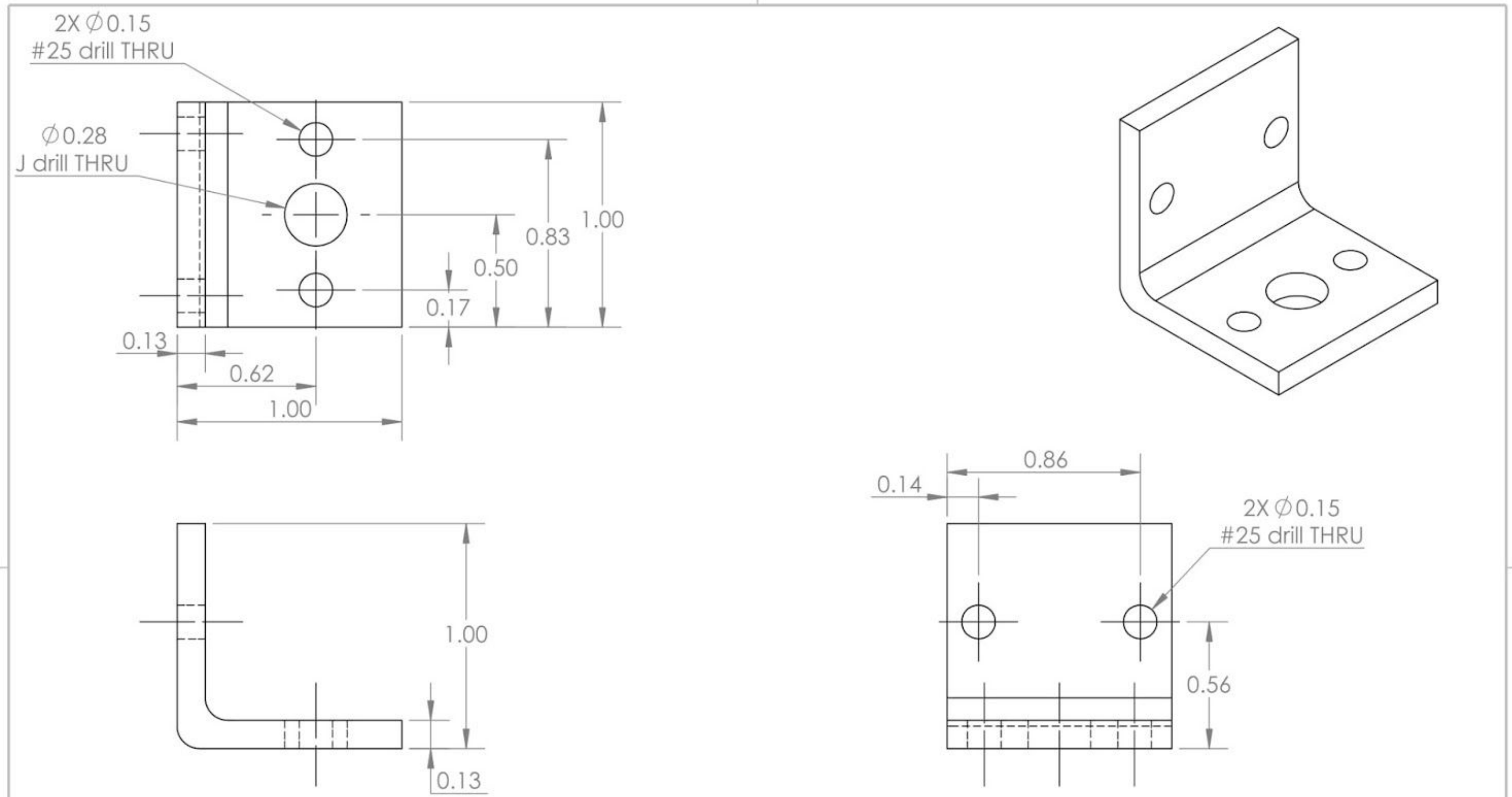
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	David	11/1/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Quantity: 2

TITLE:
Wheel Axle Hex

SIZE	DWG. NO.	REV
A	6	
SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



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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

FINISH: Burr Free

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Nafisa	11/7/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Quantity: 2

TITLE:

Bottom Gearbox Support

SIZE: A | DWG. NO.: 7 | REV

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

B.2. Manufacturing plans

.

Manufacturing Plan					
Part Number:	2				
Part Title:	Wheel Bearing Mount				
Team Name:	Team 104				
Raw Material Stock:	Aluminum 90 Degree Angle Stock 1/8"				
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Cut 1" square aluminum > 0.125 of finish length and deburr.	Band Saw		File	300
2	Hold part in vise on top of parallels with >0.125 material sticking out	Mill	Vise	1.375 Parallels	
3	Mill one end of the part, just enough to provide a fully machined surface	Mill	Vise	3/4 inch 2-flute end mill, collet	840
4	Remove part from vise and file all burrs.			File	
5	Machine the other end of the part, Repeat step 3 and 4	Mill	Vise	3/4 inch 2-flute end mill, collet	840
6	Measure the part with calipers and bring it to 1.00" length, taking	Mill	Vise	3/4 inch 2-flute	840

	several passes at 0.050 or less per pass			end mill, collet	
7	Measure and bring part to size in both Z and X planes with passes no more than 0.050	Mill	Vise	3/4 inch 2-flute end mill, collet	840
8	Remove part from vise and file all burrs.			File	
9	Remove cutter and collet. Install edgefinder into drill chuck. Zero the x-axis at the end of the vise	Mill	Vise	Drill chuck, edgefinder	1000
10	Remove the edgefinder and install the drill chuck and a center drill. Center drill and peck drill the hole.	Mill	Vise	Drill chuck, Center drill	1200
11	Remove center drill and install a 31/64 drill bit into the drill chuck and drill all the way through.	Mill	Vise	Drill chuck, 31/64 drill bit	1200
12	Remove the drill bit and use reamer on hole	Mill	Vise	Drill chuck, .4995" off-size reamer	1200
13	Remove part from vise and position to the other surface against the parallels.	Mill	Vise	1.375 Parallels	
14	Repeat steps 9-12 for two holes on other face	Mill	Vise	Drill chuck, edgefinder, Center	1000-1200

				drill, #25 drill	
15	Remove the part and file all burrs.			File	

Manufacturing Plan					
Part Number:		3			
Part Title:		Ball Castor Mounting Base			
Team Name:					
Raw Material Stock:		Aluminum 1/2" Square Stock			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Locate the Aluminum 1/2" Square stock. Measure approximately 2 1/8" and cut off using the bandsaw. Afterwards, deburr the part.	Band Saw		File	300
2	Put the part in the vise by putting them on top of the 1.125" parallels. Have the	Mill	Vise	1.125" Parallels	

	end of the part stick out the side of the vise with at least .125" sticking out.				
3	Mill one end of part, just enough to provide a fully machined surface.	Mill	Vise	3/4 inch 2-flute end mill, collet	1000
4	Remove part and debur.			Files	
5	Put the part back in the vise on top of 1.125" parallels and have the part stick out at least .125". Measure the part with calipers and bring the part to a length of 2" with passes no larger than 0.050".	Mill	Vise	3/4 inch 2-flute end mill, collet	1000
6	Remove the part from the vise and debur.			Files	
7	Put the part back in the vise on top of 1.125 " parallels and have the end of the part matchup with the end of the vise.	Mill	Vise	1.125" Parallels	
8	Install the edgefinder into the mill. Zero the x-axis at the end of the vise, which is	Mill	Vise	Edgefinde r, collet	

	also the end of the part.				
9	Remove the edgefinder and install the drill chuck with a #3 center drill installed. Center drill in the center of the part and .50" from either end in the center of the width of the piece, so that there are a total of 3 holes center drilled.	Mill	Vise	Drill chuck, #3 center drill, 1.125" parallels	1200
10	Install a #7 drill bit into the drill chuck and drill all the way through at center hole previously center drilled.	Mill	Vise	Drill chuck, #7 drill bit	1200
11	Install a #25 drill bit into the drill chuck and drill all the way through the other two locations that were just center drilled.	Mill	Vise	Drill chuck, #25 drill bit	1200
12	Remove the part and file all the burrs.	--	--	File	--
13	Tap the 1/4-20 center hole and the 10-24 side holes. Remove the part from machine.	Tapping Machine	Vise	1/4-20 and 10-24 taps	--

Manufacturing Plan					
Part Number:		4			
Part Title:		Ball Caster Spacer			
Team Name:					
Raw Material Stock:		3/8" Aluminum Rod			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Obtain 3/8" Aluminum Stock and cut to 1/5" length. Debur Part	Lathe	Collet	Parting Tool	1200
2	Face the part removing .01" at a time until total length is 0.168" and deburr part	Lathe	Collet	Lathe, facing tool, file	750
3	Assemble the Center Drill in the Tailstock	Lathe	Collet, Tailstock	Centerdrill	1200
4	Remove center drill and assemble F drill bit. Drill through part fully	Lathe	Collet, Tailstock	F bit	1200

5	Remove part and debur			File/ deburring tool	

Manufacturing Plan					
Part Number:	5				
Part Title:	Wheel Axle Rod				
Team Name:	Team 104				
Raw Material Stock:	Steel rod, 1/4" diameter				
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Cut 1.55" steel rod >.125 of finish length and deburr	Band Saw		File	300
2	Install part into lathe with > .125" material sticking out	Lathe	1/4" collet		
3	remove excess material to achieve finish length and machined surface. Deburr part	lathe	1/4" collet	cutting tool, file	1200
4	Center drill and drill hole on circular face	lathe	1/4" collet	center drill, #20 drill	750

5	Remove part from lathe and deburr hole			hole deburring tool	
6	Install part into mill and find datum lines for X and Y	mill	vise	drill chuck, edge finder	1000
7	Center drill and drill spring pin hole	mill	vise	center drill, 1/16" drill	750
8	center drill and drill setscrew hole	mill	vise	center drill, #36 drill	750
9	remove part and deburr holes			hole deburring tool	
10	tap 6-32 hole for setscrew	tapping machine	vise	6-32 tap	

Manufacturing Plan					
Part Number:		6			
Part Title:		Wheel Axle Hex			
Team Name:					
Raw Material Stock:		Multipurpose 6061 Aluminum Bar, 1/2" Hex Size			
Step #	***Process Description***	***Machine***	***Fixture (s)***	***Tool(s)***	***Speed (RPM)***

1	Locate the Multipurpose 6061 Aluminum Bar, 1/2" Hex Size stock. Measure approximately .425" and cut off using the bandsaw. Afterwards, deburr the part.	Band Saw		File	300
2	Hold the part in the vise on top of parallels such that the flat hex ends are on the faces of the vise and the rough cut end is sticking out of the vise. Put a spare piece of hex stock in the opposite end of the vice to keep it balanced.	Mill	Vise	1.25" Parallels	
3	Mill one end of the piece just enough to provide a fully machined surface	Mill	Vise	3/4 inch 2-flute end mill, collet	100 0

4	Remove part from vise and debur			File	
5	Place the part back in the vise such that the machined end is facing the inside of the vice and the unfinished end is facing the end mill. Install the stop on the vise such that it is touching the machined end of the part.	Mill	Vise	Stop	
6	Mill the end of the piece just enough to provide a fully machined surface	Mill	Vise	3/4 inch 2-flute end mill, collet	1000
7	Measure the part with calipers and bring the part to a length of 0.300 inches with passes no larger than 0.050.	Mill	Vise	3/4 inch 2-flute end mill, collet	1000

8	Remove the part from the vise and debur			File	
9	Put the part back in the vise such that the finished ends are facing the walls of the vise. Install it such that the edge of the hex piece is in line with the end of the vise.	Mill	Vise	1.125" Parallels	
10	Install the edgefinder into the mill. Zero the x-axis at the end of the vise, which is also the end of the part	Mill	Vise	Edgefinder, collet	1000
11	Remove the edgefinder and install the drill chuck with a center drill installed. Center drill in the center of the part. Install a 1/16" bit into the drill chuck and drill all the way through at	Mill	Vise	Drill chuck, 1/16" drill bit	1600

	this same location				
12	Remove the part and file all burrs			File	
13	Put the part into the spindle of a lathe. Drill a hole directly in the center of the part using a letter B drill	Lathe	Chuck	Letter B drill bit	1200
14	Remove the drill bit and install a 0.251 reamer. Ream the hole that was just drilled	Lathe	Chuck	0.251 reamer	150
15	Remove the part and file all burrs			File	

Manufacturing Plan					
Part Number:	7				
Part Title:	Bottom Gearbox Support				
Team Name:	Team 104				
Raw Material Stock:	Aluminum 90 Degree Angle Stock 1/8"				

Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Cut 1" square aluminum > 0.125 of finish length and deburr.	Band Saw		File	300
2	Hold part in vise on top of parallels with >0.125 material sticking out	Mill	Vise	1.375 Parallels	
3	Mill one end of the part, just enough to provide a fully machined surface	Mill	Vise	3/4 inch 2-flute end mill, collet	840
4	Remove part from vise and file all burrs.			File	
5	Machine the other end of the part, Repeat step 3 and 4	Mill	Vise	3/4 inch 2-flute end mill, collet	840
6	Measure the part with calipers and bring it to 1.00" length, taking several passes at 0.050 or less per pass	Mill	Vise	3/4 inch 2-flute end mill, collet	840
7	Measure and bring part to size in both Z and X planes with passes no more than 0.050	Mill	Vise	3/4 inch 2-flute end mill, collet	840
8	Remove part from vise and file all burrs.			File	

9	Remove cutter and collet. Install edgefinder into drill chuck. Zero the x-axis at the end of the vise	Mill	Vise	Drill chuck, edgefinder	1000
10	Remove the edgefinder and install the drill chuck and a center drill. Center drill and peck drill the hole.	Mill	Vise	Drill chuck, #2 or #3 Center drill	1200
11	Remove center drill and install drill bit into the drill chuck and drill all the way through.	Mill	Vise	Drill chuck, #18 drill bit	1200
12	Remove part from vise and position to the other surface against the parallels.	Mill	Vise	1.375 Parallels	
13	Repeat steps 9-12 for the four smaller holes.	Mill	Vise	Drill chuck, edgefinder, Center drill, #25 drill bit	1000-1200
14	Remove the part and file all burrs.			File	

Manufacturing Plan					
Part Number:		18			
Part Title:		Left Frame Wall			

Team Name:					
Raw Material Stock:		Aluminum Plate, 1/4"			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Waterjet the frame, logo cutout, slot, and 4X 0.15 inch diameter holes.	Waterjet			
2	Put the part in the vise by using step clamps to clamp down the part on top of the vise.	Mill	Vise	step clamps	
3	Install the edgefinder into the mill. Zero the y-axis at the top side of the part.	Mill	Vise	Edgefinder, collet	1000
4	Remove the edgefinder and install the drill chuck with a #3 center drill installed. Center drill the top hole	Mill	Vise	Drill chuck, #3 center drill, step clamps	1200

	and the hole right below the slot.				
5	For the top hole, measure .50000" bearing, drill a hole all the way through .015" undersize, and ream to a .0005 press fit. For the hole under the slot, measure .375" bearing, drill a hole all the way through .015" undersize, and ream to a .001 press fit.	Mill	Vise	Drill chuck, step clamps	1200
6	Remove the part and file all the burrs.			File	

Manufacturing Plan					
Part Number:		19			
Part Title:		Right Frame Wall			
Team Name:					
Raw Material Stock:		Aluminum Plate, 1/4"			

Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Waterjet the frame, logo cutout, and 4X 0.15 inch diameter holes.	Waterjet			
2	Put the part in the vise by using step clamps to clamp down the part on top of the vise.	Mill	Vise	step clamps	
3	Install the edgefinder into the mill. Zero the y-axis at the top side of the part.	Mill	Vise	Edgefinder, collet	1000
4	Remove the edgefinder and install the drill chuck with a #3 center drill installed. Center drill the top hole.	Mill	Vise	Drill chuck, #3 center drill, step clamps	1200
5	Measure .5000" bearing and drill a hole all the way through .015" undersize (the hole previously center	Mill	Vise	Drill chuck, step clamps	1200

	drilled). Ream to a .0005 press fit.				
6	Remove the part and file all the burrs.			File	

Manufacturing Plan					
Part Number:	20				
Part Title:	Frame Mounting Brackets				
Team Name:	Team 104				
Raw Material Stock:	Aluminum 90 Degree Angle Stock 1/8"				
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Cut 1" square aluminum > 0.125 of finish length and deburr.	Band Saw		File	300
2	Hold part in vise on top of parallels with >0.125 material sticking out	Mill	Vise	1.375 Parallels	
3	Mill one end of the part, just enough to provide a fully machined surface	Mill	Vise	3/4 inch 2-flute end mill, collet	840

4	Remove part from vise and file all burrs.			File	
5	Machine the other end of the part, Repeat step 3 and 4	Mill	Vise	3/4 inch 2-flute end mill, collet	840
6	Measure the part with calipers and bring it to 1.00" length, taking several passes at 0.050 or less per pass	Mill	Vise	3/4 inch 2-flute end mill, collet	840
7	Measure and bring part to size in both Z and X planes with passes no more than 0.050	Mill	Vise	3/4 inch 2-flute end mill, collet	840
8	Remove part from vise and file all burrs.			File	
9	Remove cutter and collet. Install edgefinder into drill chuck. Zero the x-axis at the end of the vise	Mill	Vise	Drill chuck, edgefinder	1000
10	Remove the edgefinder and install the drill chuck and a center drill. Center drill and peck drill the hole.	Mill	Vise	Drill chuck, Center drill	1200
11	Remove center drill and install a #25 drill bit into the drill chuck and drill all the way through.	Mill	Vise	Drill chuck, #25 drill bit	1200

12	Remove part from vise and position to the other surface against the parallels.	Mill	Vise	1.375 Parallels	
13	Repeat steps 9-12 for the hole on other face	Mill	Vise	Drill chuck, edgefinder, Center drill, #25 drill	1000-1200
14	Remove the part and file all burrs.			File	

Manufacturing Plan					
Part Number:		24			
Part Title:		Tray Bouncer			
Team Name:		104			
Raw Material Stock:		1/16" Aluminum Sheet			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Cut part on waterjet	waterjet			
2	Bend part 115 degrees on hand brake	hand brake			

Manufacturing Plan					
Part Number:		29			
Part Title:		Sprocket Support			
Team Name:		104			
Raw Material Stock:		01 Tool Steel 1.41"x0.25"			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Locate the O1 Tool steel stock. Measure to 2" and cut off using the bandsaw. Afterwards, deburr the part.	Band Saw		File	100
2	Insert the part into the collet with a stop into the Lathe spindle. Face one end to create a flat surface	Lathe	Collet	Cutting Tool	1000
3	.29" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000
4	.57" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000

5	.92" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000
6	1.26" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000
7	Using the drill chuck, center drill into the center of the part. Then drill a hole with a #21 bit .35" deep into the part	Lathe	Collet, Tailstock	Drill Chuck, Center drill, #21 Drill bit	800
8	Part off the piece at 1.41"	Lathe	Collet	Parting Tool	1000
9	Remove part and debur			File	
10	Mount part in mill in a triangular vise	Mill	Triangular vise		
11	Find datum	Mill	Triangular Vise	Collet, Edge Finder	1000
12	Using a 1/8" endmill create a slot that is 1/16" deep and 1.09" long by using the plunge drilling technique. The slot is centered on the part along the y-axis.	Mill	Triangular Vise	Collet, 1/8" 4-flute Endmill	1000
13	Drill a center drill 1.29" away from the left end of the part while centered on the part along the y-axis. Drill	Mill	Triangular Vise	Drill Chuck, Center drill, #43 Drill bit, 4-40 Tap	1000

	this hole with a #43 drill through one wall and use a 4-40 tap. Do not drill all the way through the part				
14	Remove part and debur			File	

Manufacturing Plan					
Part Number:		32			
Part Title:		Chain Tensioner Body			
Team Name:		104			
Raw Material Stock:		1/8" Aluminum Sheet			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Waterjet profile of part	waterjet			
2	Hold part in vise on top of parallels	Mill	vise	1.375 parallels	
3	Use edgefinder to zero axes on edges of part	mill	vise	drill chuck, edge finder	1000

4	Remove edgefinder and install center drill. Center drill all three holes	mill	vise	drill chuck, center drill	1200
5	Remove center drill and install drill bit. Drill two holes that are the same size	mill	vise	U bit, drill chuck	1200
6	Switch out drill bits to drill final hole	mill	vise	#36 bit, drill chuck	1200
7	Remove drill bit and use reamer on larger holes	mill	vise	.3745 reamer, drill chuck	1200
8	Remove part and deburr holes			hole deburring tools	

Manufacturing Plan					
Part Number:		33			
Part Title:		Chain Tension Spacer			
Team Name:		Team 104			
Raw Material Stock:		3/8" Aluminum Rod			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Spee d***

					(RPM)
1	Obtain 3/8" Aluminum Stock and cut to 1/5" length and deburr.	Band Saw		File	300
2	Lathe one end of the part, just enough to provide a fully machined surface.	Lathe	Collet	Lathe, facing tool	750
3	Remove part from vise and file all burrs.			File	
4	Machine the other end of the part and repeat steps 3 and 4	Lathe	Collet	Lathe, facing tool	750
5	Face the part removing .01" at a time until total length is 0.100"	Lathe	Collet	Lathe, facing tool	750
6	Remove part from vise and file all burrs.			File	
7	Assemble the Center Drill in the Tailstock and peck drill a hole.	Lathe	Collet, Tailstock	Centerdril l	1200
8	Remove center drill and assemble #25 drill bit. Drill through part fully	Lathe	Collet, Tailstock	#25 bit	1200
9	Remove part and debur			File	

Manufacturing Plan

Part Number:		34			
Part Title:		Tensioner Shaft			
Team Name:		104			
Raw Material Stock:		01 Tool Steel .72"x0.25"			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	Locate the O1 Tool steel stock. Measure about 1.5"and cut off using the bandsaw. Afterwards, deburr the part.	Band Saw		File	100
2	Insert the part into the collet with a stop into the Lathe spindle. Face both ends to create flat surfaces	Lathe	Collet	Cutting Tool	1000
3	.05" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000
4	.36" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000
5	.64" from the end of the piece, turn down the piece to .21" for .029"	Lathe	Collet	Cutting Tool	1000

6	Part off the piece at .72"	Lathe	Collet	Parting Tool	1000
7	Remove part and debur			File	
8	Mount part in mill in a triangular vise	Mill	Triangular vise		
9	Find datum	Mill	Triangular Vise	Collet, Edgefinder	1000
10	Using a 1/8" endmill create a slot that is 1/16" deep and .33" long by using the plunge drilling technique. The slot is centered on the part along the y-axis.	Mill	Triangular Vise	Collet, 1/8" 4 flute Endmill	1000
11	Remove part and debur			File	

Manufacturing Plan					
Part Number:		40			
Part Title:		Tray Body			
Team Name:					
Raw Material Stock:		Aluminum plate, 1/16"			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Spee d (RPM)***

1	Cut the Profile of the tray on the waterjet	Waterjet			
2	Deburr all holes and file edges			Deburring tool, file	
3	Use the sheet metal brake to bend one wall of the tray up 90 degrees and be 2" tall	Brake			
4	Use the sheet metal brake to bend the end of the tray up 65 degrees and 1.8" long	Brake			
5	Bend the other wall of the tray up 90 degrees and be 2" tall	Brake			

Manufacturing Plan					
Part Number:		42			
Part Title:		Tray Axle			
Team Name:		104			
Raw Material Stock:		3/8" Aluminum Rod			
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***

1	Obtain 3/8" Aluminum Rod and cut to a length of 8.625	Band Saw	Vise	N/A	N/A
2	Face each side of the 3/8" stock using the lathe Facing Tool and Zero the part with a stop installed	Lathe	Collet	Facing/ Turning Tool	1200 or less
3	Begin Turning the part removing 0.05" Maximum material per pass to 0.50" from the free end	Lathe	Collet	Facing/ Turning Tool	1200 or less
4	Remove the part from the collet, flip it and Turn the part removing 0.05" maximum material per pass to 0.50" from the free end	Lathe	Collet	Facing/ Turning Tool	1200 or less
5	Using the grooving tool, groove the part from a diameter of 0.25"to a diameter of 0.21" with a length of 0.029"	Lathe	Collet	Grooving Tool	1600 or less

6	Flip the part and repeat Step 5	Lathe	Collet	Grooving Tool	1600 or less
7	Remove the part and secure it in a triangular vise in the mill	mill	triangular vise	N/A	
8	Using the edge finder, locate the exposed edges on the widest diameter and zero the part	mill	triangular vise	edge finder	1000
9	Using a center-drill, two center holes in the rod at the specified locations	mill	triangular vise	center drill	1200
10	Using a .1065 diameter drill bit, drill through the part where the center holes were drilled	mill	triangular vise	#36 drill bit	1400 or less
11	Zero the Z axis and using a .125" diameter end mill, use the plunge drilling method to remove material to create the keyway slot	mill	triangular vise	.125" diameter endmill	840 or less
12	Make a final pass in the keyway to ensure a smooth face	mill	triangular vise	.125" diameter endmill	840 or less
13	Remove the part from the vise and	mill	Vise	6-32 Tap	

	insert it into the tapping vise. Tap all the way through the two .1065 holes with a 6-32 tap				
14	File and deburr the part			file	

C. PURCHASED AND TRADED ITEMS

C.1 Purchased parts

Supplier	Part name/number	Dimensions	Total quantity	Price	Description
McMaster	Low-Strength Steel Nylon-Insert Locknut (90631A007)	5/16”x 11/64”	100	$2.61	Used in place of the standard nuts provided to prevent possible issues caused by nuts loosening
McMaster	Roller Chain ANSI Number 41, ½” Pitch (6261K174)	.386”x12”	1	$4.40	Used to transfer torque from the motor to the tray system
McMaster	Connecting Link for ANSI Number 41 Roller Chain (6261K192)	.5”x.578”	1	$0.87	Used to connect and modify the length of the roller chain
McMaster	Adding Link for ANSI Number 41 Roller Chain (6261K242)	.5”x.35”	1	$0.64	Used to connect and modify the length of the roller chain
McMaster	Add-and-Connect Link for ANSI Number 41 Roller Chain (6261K262)	.5”x.578”	1	$1.97	Used to connect and modify the length of the roller chain
Crib	Pololu 1576 99:1 Metal Gearmotor 25D x 54L mm HP	25mm x 54mm	2	$19.76	Used to power the wheels of the RMP. Traded the planetary and double gearbox for two of these
Crib	1” Ball Caster	1-3/8" x 1-3/4"	1	$4.00	One extra was required for the back wheels of the RMP

C.2. Traded parts (inter-squad)

Trade-in Part	Trade-out parts(s)	From	Positive Trade Deficits	Description
2 3” Extension Spring	None	Team 102	$2.44	We accidently deformed one of our springs and traded within our squad for a replacement and a spare