

MONTANA STATE UNIVERSITY

Department of Mechanical and Industrial Engineering

ETME 489R-001 CAPSTONE: MECHANICAL ENGINEERING TECHNOLOGY DESIGN I

and

EMEC 489R-001 CAPSTONE: MECHANICAL ENGINEERING DESIGN I

Battle Bot Group 3

by

Cole Trugman

Ivan Albert

Nishagar Raventhiran

for: {Rob Larson, David Miller, Craig Shankwitz, and James Black}

Prepared to Partially Fulfill the Requirements for EMEC 489/ETME489

Department of Mechanical Engineering Montana State University Bozeman, MT 59717

December 10th, 2018

Executive Summary

This ME/MIE capstone battlebots project is intended to showcase student design and innovation in a challenging, fun, and entertaining event. The objective during the competition is to disable the opponent's battlebot while surviving to fight in the following 3-minute-long round after an allowed 5 minute "pit stop", all while being prepared to maneuver around arena obstacles designed by another group to hinder and damage the bots. The competition has 3 rounds in total. The design goal is to create an original design for a robot utilizing either new or re-purposed components.

Aside from good sportsmanship/conduct, the competition guidelines provided most of the design constraints and considerations. These constraints include but are not limited to: bot weight, bot size, weapon limitations (such as no flames, explosives, blades, or chemicals), cost (less than \$1000), and the inclusion of a master power disconnect switch.

The method used to ideate and build a formidable bot included spectating and studying televised battle bot competitions as well as professional garage-built bots on YouTube to take note of successful and unsuccessful bot shapes, sizes, weapons, defenses, and drive systems. Weighing the pros and cons of the systems seen as well as new ideas generated by the team led to the decision to use a rotational momentum based "roller" to cause damage, a short, rectangular aluminum body to resist damage, and a Bluetooth controller to communicate with and control weapon and drive motors.

Once a basic idea was decided upon, the team optimized the speed and power of the robot within the weight restrictions provided by the competition. The robot's drive system provides power to all four wheels and aluminum armor and an aluminum frame were used for structure to keep the weight of the robot within competition requirements.

The final robot uses an aluminum structure with a steel weapon that hits opponents with an array of half inch steel rods which rotates at 1600 rpm. The robot is controlled via Bluetooth by an off the shelf PlayStation 3 controller.

Table of Contents

Executive Summary.....	1
Chapter 1: Introduction	4
Chapter 2: Problem Statement	5
Level One Requirements.....	5
Chapter 3: Background	6
Chapter 4: Design Specifications.....	9
Offensive/defensive Specifications:.....	9
Assembly Specifications:.....	9
Interface Specifications:.....	9
Material Specifications:	10
Chapter 5: Design Alternatives Creation and Evaluation.....	11
Drive and Steering.....	11
Electronics.....	12
Weapon.....	13
Armor	14
Design Ideas	14
Chapter 6: Description of Project/Design	16
Chapter 7: Conclusion	23
References	24
Appendix A. Engineering Analysis.....	25
A-1: Armor Plate	25
A-2: Frame:.....	28
A-3: Roller	30
A-4: Electronics:	31
Weapon Acceleration.....	31
Power and Amperage	32
Appendix B: Manufacturing Plan	33
Appendix C: Project Schedule/Management Plan.....	44
General Roll assignment:	44
Term Meeting Schedule/ Location:.....	44
File Sharing.....	44
Group Leadership Schedule/Member Assignments:	44

Appendix D: Purchased Part List	51
Purchased Parts	51
Raw Materials	53
Appendix E: Engineering Drawings	54
Appendix F: Economic Analysis.....	81
Table D-1: Materials need to be Purchased.....	81
Table D-2: Manufacturing Cost	82
Appendix G: Project Academic Assessment.....	83

Chapter 1: Introduction

The purpose for this project is to provide ME and MET students with a fun, challenging, innovative, and entertaining way to showcase their design, analysis, and manufacturing ability. The 10 students participating among the 3 battle bot groups are presented with the task of defeating each other's bots in combat. This requires sticking to the guidelines presented by the competition, disabling opponent bots, and surviving to fight another round. In addition to the opponents, a several environmental hazards will also be present in the arena that can damage or destroy robots that get too close to them. This competition also makes this project unique because it requires teams to anticipate potential threats as well as potential defenses that their bot will have to get past.

This task of anticipating enemy bots and building something well rounded to combat them becomes especially challenging when presented with the current rules and regulations. The 25lb weight limit and 18" x 18" x 18" size limitation forces the team to optimize their bot's power, weight, armor and size within those limitations.

The timeline for this project has been divided into two 4 month-long phases aligning with the fall and spring semesters. The first phase, the design phase, began with ideation and very preliminary design packages based on the aforementioned regulations. Became more defined as more background research was completed. During November, preliminary designs were refined and more carefully thought out until a complete drawing package, manufacturing plan, functional and budget analysis were created and presented as during the Critical Design Review. By the end of finals week in December, materials will be ordered for the construction of the robot.

The project will begin its second phase in January. The redesigned robot will be machined, assembled, coded, and tested so that it is ready for the competition in May.

Chapter 2: Problem Statement

The design goal is to create a remote-controlled robot capable of immobilizing other robots. The machine must fulfill all of the level one requirements listed below. It will be placed in the ring with two other robots built by other teams for the same purpose. For three minutes the robots will fight each other attempting to render the others immobile. The competition will last for a series of three rounds each lasting three-minutes which will be separated by five-minute breaks to repair the robots. Judges will award points based on the robots' performances to determine the winner in the event of a tie.

Level One Requirements

- Less than 25 lbs
- Fits in 18 in cube
- Must be able to move under its own power
- Must be able to be controlled remotely
- Adheres to weapon limitations
 - No flames or flaming liquid
 - No chemical weapons
 - No untethered projectiles
 - No explosives or explosively-driven weaponry
 - No blades, spears, or edged weapons
- Costs less than \$1000
- Able to run for 3 minutes on one charge
- Not a pre-assembled robot or toy
- No unsportsmanlike conduct

Chapter 3: Background

From studying battlebot competitions, a few archetypes become evident among the serious competitors. One such archetype is to have a bot with a fast spinning blade to try and shred the opponent. Another common design uses a mechanism such as a claw to try and grab the other robot and move them into obstacles. Some successful bots utilize a studded roller on the front of the bot that spins at high speed and use it to charge at the opponent to try and flip them. “Spatula” style flipping bots are also common, which slip an arm or mechanism under the opposing bot and use that to flip them. Robots that hammer the opponent with a large weapon arm often do well and can cause a lot of damage. These archetypes provide not only a starting point for deciding what the team’s robot will do, but a point of reference for what the team’s robot may have to face. As these weapon systems tend to either deal damage by blunt force or by throwing or flipping over the robot, the design will have to be made to endure these kinds of attacks.

Consideration of different potential opponents lead to consideration of different materials to use in response to such opponents. These preliminary considerations include that for electronic housing, armor, chassis, and wheels. (Factors of each include Strength/durability/toughness vs weight/cost/machinability/allowance for heat flow away from electronic components). For example, using aluminum 6061 for parts of chassis which do not have to withstand much abuse is one initial idea. 6061 is lightweight and easily machined. It is also easily welded. The tradeoff is that (compared to steel or even al 7075) it has lower strength and hardness. 7075 however is much less easily machined or welded⁽¹⁾. It would be best used as an outer layer of armor which does not have to be welded to or interact with other components other than the chassis. Simple geometry could be used to limit the manufacturing of 7075. UHMWPE is also a material that could be used to make armor. UHMWPE has an extremely high yield point, and for a 25-pound bot, is nearly unbreakable yet is able to deform enough to dampen a heavy impact without fracture.

As for mobilization, after studying many battlebot competitions, it seems that the most common steering system is a dead axle “tank” type control system. Meaning that

the left and right sides are powered independently from one another and used to steer left or right based on which motor is causing the most displacement. The turn radius and response time is dictated by the distance separating inline wheels as well as distance between parallel pairs. Several sizes and materials for wheels are available. After reading blogs published by other bot builders and by going to websites such as BaneBots.com (which manufactures quality yet affordable bot components including motors, wheels, gearboxes, etc.), it seems that Colson wheels are a good option. They are made of a durable lightweight propylene core with a thermoplastic rubber tread which will provide excellent traction on the concrete/asphalt arena. Banebots also manufactures affordable motors available in a large variety of sizes, voltages, speeds, torques, and prices.

For the electronic control systems on the project, Arduino based microcontrollers are an attractive option. Many of these microcontrollers are inexpensive and Arduino is widely used by hobbyists, so resources are abundant. Arduinos also come in many shapes and sizes with different features, inputs and outputs⁽²⁾. Keeping the electronics cheap and modular will be an important aspect to pay attention to. Another alternative to Arduino is Raspberry Pi, which functions as a full microcomputer and can be programmed in Python[®]. This would provide far more processing power than is needed for the robot for an extremely low price and allow the use of a programming language that the team is more familiar with. Raspberry Pi also has a large and active hobbyist community and easily accessed resources and documentation.

Another option for the control system would be to take apart a second-hand remote-controlled vehicle and use its receiver and components. A remote-controlled plane might be a good option as they have more control surfaces and servos than a car.

Communication with the robot can be achieved in many ways. Wi-Fi, Bluetooth and radio based communication are three viable options. Transmitters and receivers for radio based controls are used by hobbyists for remote-controlled planes and cars and off the shelf parts can be found readily. Wi-Fi and Bluetooth receivers for Arduino and Raspberry Pi units are also common, and may allow control from a phone. PlayStation 3

controllers also communicate via Bluetooth, which can provide an off the shelf controller for the robot. Bluetooth protocols are well documented and widely available⁽⁴⁾.

Rather than using continuous servos to control its driving, the robot could attain more power at a lower cost by using DC motors operating off of DC motor controller boards⁽⁵⁾. They would not control the speed directly like a servo, as they have no built-in potentiometer to track their own speed, but instead vary the motor power. They can be controlled via PWM signal in a similar manner to most servos on the market and would allow us to trade an unneeded amount of extra precision for a much-wanted increase in power at a similar cost.

Chapter 4: Design Specifications

Since this project is a type of competition and lacks both a sponsor and firm/OSHA/professional/industrial standards, many specifications will be either required by the competition guidelines or the personal targets for the group. The specifications were categorized as follows;

Offensive/defensive Specifications:

- The robot must be able to push with a force of 20 lb. This is to ensure it can move opponents and obstacles. This is based on the fact that rubber on asphalt has a coefficient of kinetic friction between 0.5 and 0.8. ($25\text{lb} * 0.8 = 20\text{lb}$)
- The robot can also withstand 20 lb of pushing force from opponent, based on friction and motor stall torque.
- The robot must be able to withstand at least 25 lb added weight in case another bot gets on top of it.
- The robot must move under its own power at a minimum speed of 1 foot per second.

Assembly Specifications:

- The battery should provide enough power to run the robot for 3 minutes continuously and be replaced or charged in under 5 minutes.
- The turning radius of the robot must be at most 3 ft

Interface Specifications:

- The robot must include a master power disconnect switch
- The control system must interface with driving motors as well as a remote control, which must maintain a reliable connection over a distance of at least 33.28 ft. This was calculated by finding the corner to corner span of the arena and adding 5 feet

Material Specifications:

- Device (Not including peripheral equipment) must weigh between 20 and 25 lb in order to meet requirements and not be pushed around easily.
- Device must stow into an 18" cube.
- Device must not have sharper than 1/8" radius edge.
- Device should cost between \$500-\$1000 and include receipts.

Basic numerical values that can be achieved were assumed, and the calculations were made based on those values. Most of these values are chosen to design for a "worse-case scenario" bot/situation. The final design is expected to surpass these specifications in power and speed.

Chapter 5: Design Alternatives Creation and Evaluation

Ideas were brainstormed for each of the subsystems of the robot. These design options were then evaluated and compared to one another based on how they would perform in different areas of that system's function. A simple point scale was used which ranges from -2 to 2, where 0 shows that a design does not stand out in any meaningful way, 1 or -1 indicated that the design filled that criteria well or poorly, and 2 or -2 showed that the design especially stood out in that regard, either positively or negatively. 2 and -2 scores are also highlighted in green and red respectively as an additional visual indicator.

The robot was broken into four basic subsystems based on what subsystems the team found to exist in every battlebot concept. These subsystems are the drive system, the electronic control system, the armor and the weapon.

Drive and Steering

Drive System	Maneuverability (Weight 2)	Ease of Implementation (Weight 1)	Durability (Weight 2)	Cost (Weight 1)	Total Points
Live Axle	-1	0	1	2	2
Dead Axle	X	X	X	X	X
Wheels	1	2	2	1	9
Tank Treads	1	1	0	0	3
Omni Wheels	2	-1	-1	0	1

The live axle design is driven by a main motor and steered by changing the angle of wheels, much like how a car drives. This uses the least motors, reducing cost, but is the only option that cannot turn in place.

The dead axle design has a left and right side that are independently controlled and turns by the difference in speed between the two. This can be done with traditional wheels, or tank treads. Tank treads would be more complicated to set up and leave themselves vulnerable if the track is removed.

The omni wheels design uses four angled omni wheels to allow complete freedom of movement. It can turn in place and even drive sideways or at an angle, however it requires more motors and more involved programming to function, as well as more expensive and fragile wheels.

The team chose the dead axle design with wheels as the drive system for the robot.

Electronics

Electronic Control System	Ease of Implementation (Weight 1)	Reliability of Control (Weight 1)	Versatility (Weight 2)	Cost (Weight 1)	Total Points
Off the Shelf RC Parts	2	2	-2	1	1
Microcontroller	X	X	X	X	X
Bluetooth	1	1	2	2	8
Wi-Fi	0	1	1	1	4
Radio	-1	2	2	1	6

Using off the shelf RC parts such as from an RC car or plane would provide a proven transmitter, receiver and some motors and servos, but would be difficult to modify for a robot with more things to control or which drives differently.

Using a microcontroller would require the design and programming of the electronics needed, but would have inputs and outputs that could be easily modified to fit the needs of the robot. A microcontroller could be controlled in a few different ways. Radio would have the longest range and clearest signal but may be difficult to decode on the microcontroller's end. Bluetooth protocols are well documented and components for it are readily available for most common microcontrollers. Bluetooth is also used by off the shelf PlayStation 3 controllers.

The team selected a microcontroller communicating via Bluetooth with a PlayStation 3 controller as the control system for the robot. The microcontroller selected was the Raspberry Pi Zero W for its low cost, ease of programming, abundant documentation and resources, and onboard Bluetooth transceiver.

Weapon

Weapon System	Damage (Weight 2)	Ease of Implementation (Weight 1)	Ease of Use (Weight 2)	Cost (Weight 1)	Total Points
Hammer	2	1	1	0	7
Roller	2	1	2	0	9
Hydraulic Wedge	0	0	1	-1	1
"Hermit Crab"	1	1	-1	1	2
Spatula	1	0	0	-1	1

Hammers are mechanically simple and capable of a lot of destruction but are heavy which will affect the available weight for the rest of the robot.

Rollers use a studded cylinder that rotates at high speed on the front of the robot which can cause damage both by throwing opponents, and by tearing at them with studs. They are versatile and do their job as long as the robot drives forward into the opponent.

A hydraulic wedge design uses a wedge-shaped vehicle with a sloped face that can be tilted forward by hydraulic piston. It would attempt to drive into opponents and flip them over.

The “hermit crab” idea involves making a robot that other bots can easily drive onto and baiting them into doing so. One on top, a set of powerful magnets would trap them in place. They are then the “shell” of the hermit crab as it fights the other robot.

Spatula weapons use a flat implement which they attempt to slide under the opponent, which is then rapidly raised to flip the opponent over.

The team selected the roller as the robot’s weapon due to its track record as a mainstay of finals rounds in battlebots competitions, as well as its ease of use by the driver and high potential damage.

Armor

Armor	Strength (Weight 1)	Ease of Implementation (Weight 1)	Weight (Weight 2)	Cost (Weight 1)	Total Points
Aluminum	0	2	1	0	4
1018 Steel	1	1	0	0	2
UHMWPE	2	-1	1	-1	2
AR400 Steel	2	-2	0	0	0

Aluminum armor would be relatively easy to machine and is a light option as metal armors go.

Steel is more difficult to work with than aluminum and heavier, but also stronger.

UHMWPE (Ultra-High-Molecular-Weight Polyethylene) is a plastic which will make it harder to work with than metal with the available facilities but can have much lower density than aluminum and is notoriously durable, even being used in body armor.

Aluminum armor was chosen for its light weight and ease of availability.

Design Ideas

Design	Drive System	Electrical System	Weapon	Armor	Total Points
Design 1	Dead Axel: Wheels	Microcontroller: Bluetooth	Roller	Aluminum	
	9	8	9	4	30
Design 2	Omni Wheels	Microcontroller: Radio	Hammer	UHMWPE	
	1	6	7	2	16
Design 3	Dead Axel: Wheels	Microcontroller: Bluetooth	Hydraulic Wedge	1018 Steel	
	9	8	1	2	20

Once concepts in each category were evaluated, the various possibilities were assembled into more complete designs and compared to each other. Though the scores were used as a general yardstick, some ideas and combinations besides the optimal scoring one were also investigated, as there was a possibility of finding a design that's parts synergized to create something greater. A few of those designs are shown here.

Design 1 combines the highest scoring systems of each category.

Design 2 is an extremely maneuverable hammer bot which uses plastic armor to reserve weight for the hammer.

Design 3 is a hard steel ramming wedge.

Design 1 became the robot's primary design as, in addition to having the highest combined score, it is a design in which the components do complement each other nicely.

Design 1 became the robot's primary design as, in addition to having the highest combined score, it is a design in which the components complement each other nicely.

Chapter 6: Description of Project/Design

The final robot design combined a dead axle drive and steering system, a roller weapon, aluminum armor, and a re-programmable microcontroller. Due to short pit breaks between rounds, a focus was put on a design that could be easily and quickly opened up to access and replace damaged parts. Opening the main internal cavity can be done quickly with each group member needing to remove only three to four screws with drills to remove the top armor plate and access nearly all internal parts.

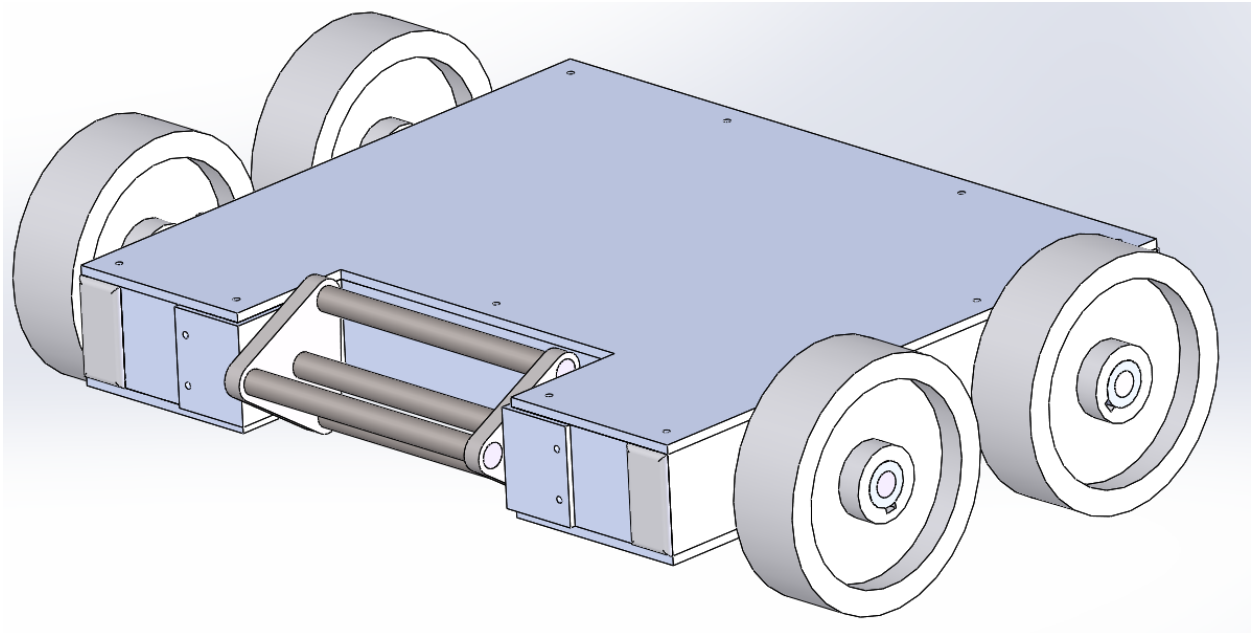


Image 1: Solid model of final robot

Using a rapidly rotating weapon as this design does and with the known arena hazards, it is probable that the robot will be flipped over at some point in the competition. Rather than design the robot to be self-righting, the team settled on a design that functions the same regardless of what side it is on. The microcontroller will be programmed to change the controls based on controller input to make it easily driven upside down.

The roller weapon uses three strong half inch steel rods as its attacking surface. Moving them away from the center of the roller allowed the team to increase the weapon's rotational moment of inertia without dramatically increasing the weight. All

connections of the half inch steel rods to the hubs are secured with a weld to ensure weapon durability.

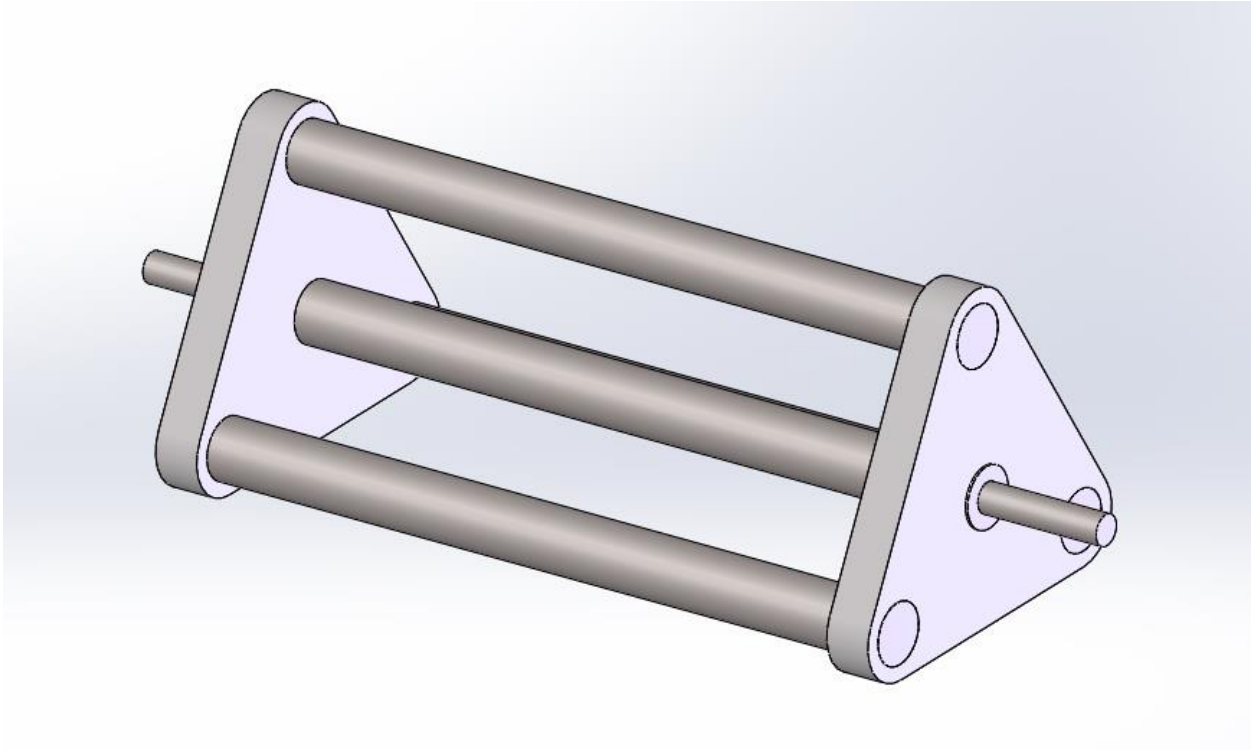


Image 2: Solid model of roller weapon

The frame can be manufactured by modifying a single length of 1 in x 2 in x $\frac{1}{8}$ in rectangular aluminum tube, keeping the manufacturing cost of the frame low. All joints between frame pieces are welded to ensure rigidity. During the competition, the connected motor rotates the weapon at 1600 RPM.

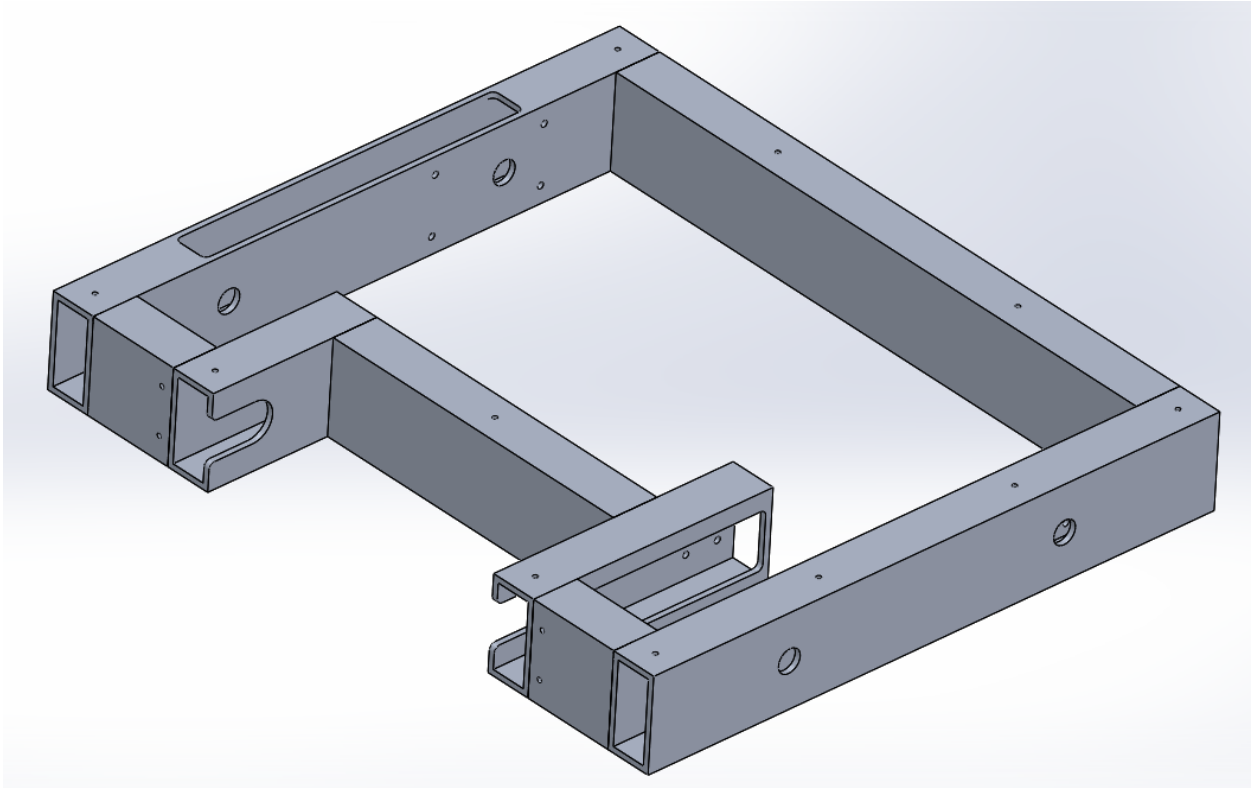


Image 3: Solid model of welded frame

The rectangular tube, in addition to adding extra rigidity to the robot, can be used to house the three belts used to transmit power in the vehicle. This keeps the weak points shielded against enemies and the environment and provides structure to keep the axles aligned. Large windows near the belts allow access during assembly but are hidden by the top and bottom armor plates during the competition. The armor mounting holes on the top and bottom of the frame will be tapped for easy assembly and disassembly.

The design of the internal layout was carefully designed to minimize the tread of armor deformation to the internal systems.

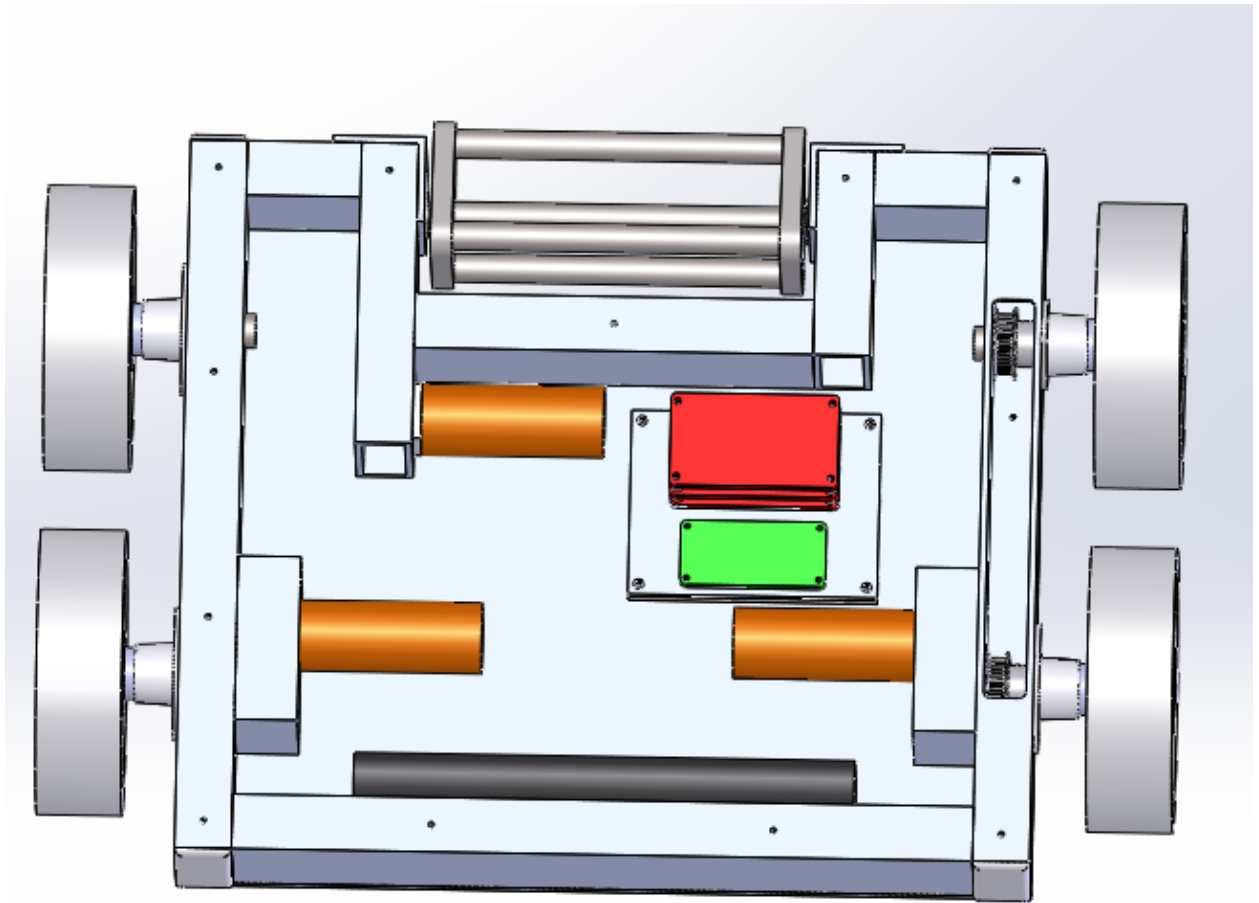


Image 4: Robot internal layout

The weapon motor is placed such that rectangular tubing close by two sides provides a brace against impact to the armor. The motor controller stack, one of the tallest internal structures, was placed next to an uncut portion of tubing behind the weapon where it would be both strong and difficult to hit. The gearboxes of the driving motors are the same width as the frame itself, giving some more structure to the vehicle near the motors. The most vulnerable part of the frame is the side pieces, as they conceal the belts that drive the front wheels. To protect them, the wheels are externally mounted and made of a thermoplastic rubber tread and a polypropylene core, making them lightweight and durable while capable of excellent traction. They are also relatively inexpensive and quickly replaceable (due to the clamping hubs). The team deemed it preferable to lose a part that could be easily replaced between rounds than to risk permanent damage that could disqualify the robot from the competition. As such the wheels double as, extra protection for the inner workings/electronics.

The electronics are mounted on an aluminum plate separated from the armor by a 0.25-inch foam pad and uses bushings in its mounting to further remove vibration.

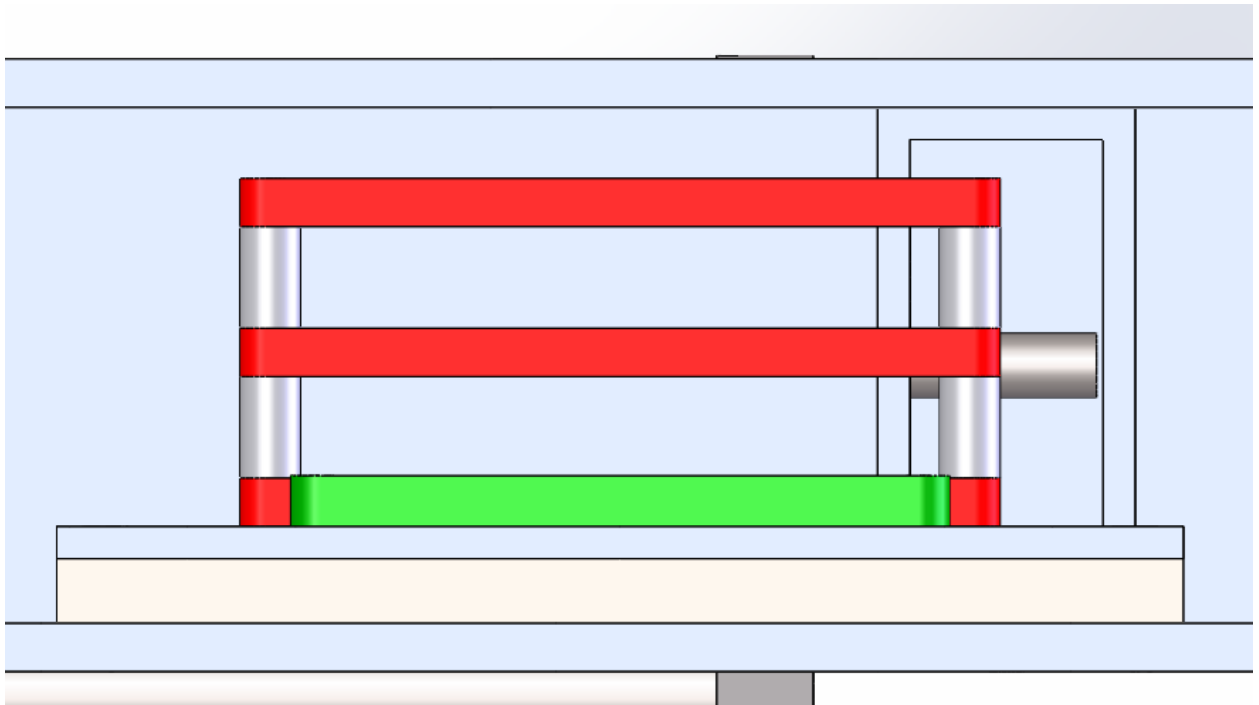


Image 5: Electronics mounting

This ensures that if the bottom armor is dented, it will affect the foam which can easily deform rather than destroying the microcontroller and motor controllers that allow the robot to function.

The drive system uses one motor to drive each side of the vehicle. This reduces the cost of the vehicle and was needed for space to allow all four wheels to be powered given the limited space available near the weapon mounting.

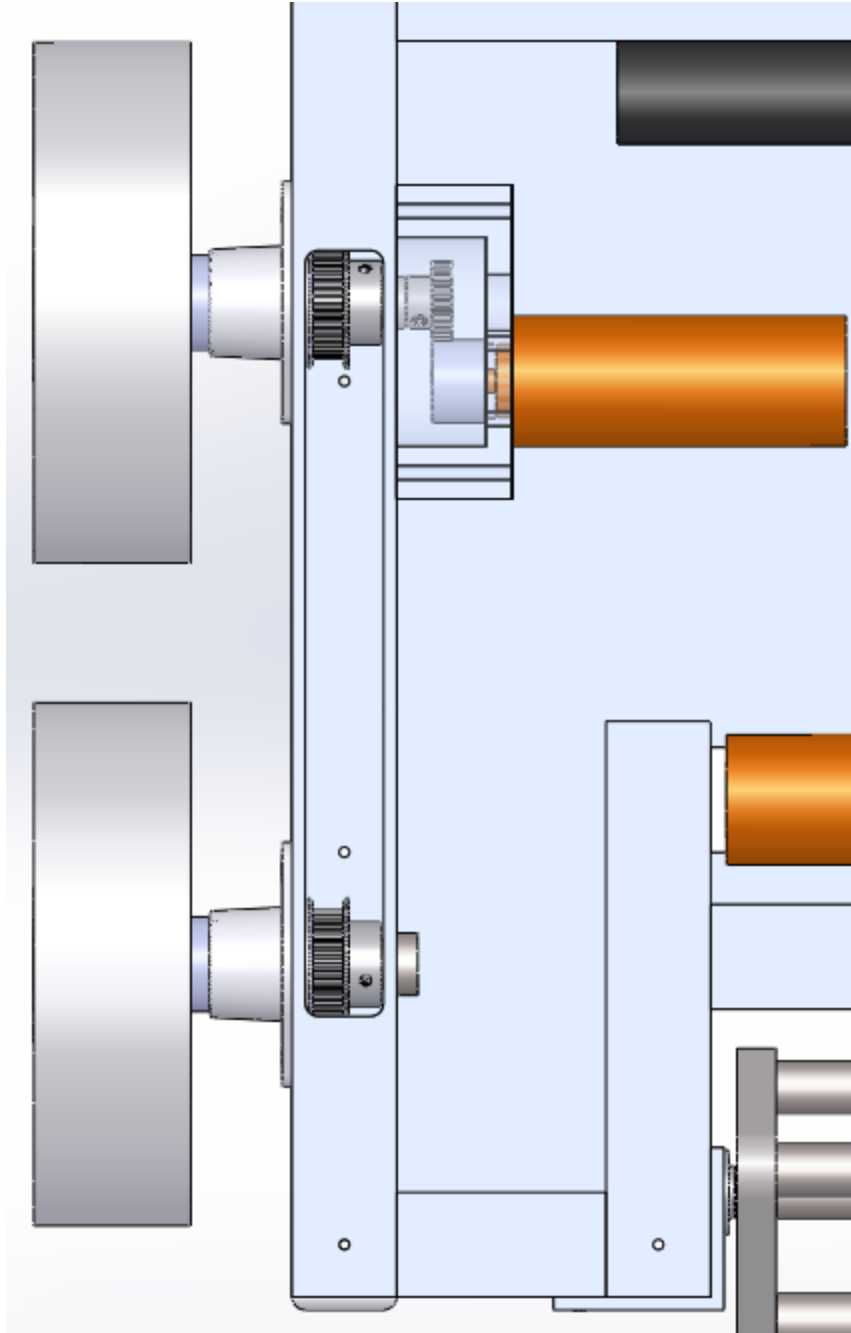


Image 6: Wheel power connection showing pulleys for timing belt

Pulleys on the front and rear axles will be connected by a timing belt which keeps them in sync with one another and transmits power from the back to the front. Even if this connection is damaged, the rear wheels will still be able to provide power from their direct geared connection to the motors. This driving configuration, often called tank controls, relies on the differential in speed between the left and right side in order to

steer. This allows the robot to turn in place and reduces the number of failure points due to fragile moving parts needed to change the angle of any wheels.

The top and bottom armor plates are cut out of 3/16 in aluminum. The material keeps them light allowing the armor to be relatively thick and strong. A comparison to other armor types investigated can be found in Appendix A.

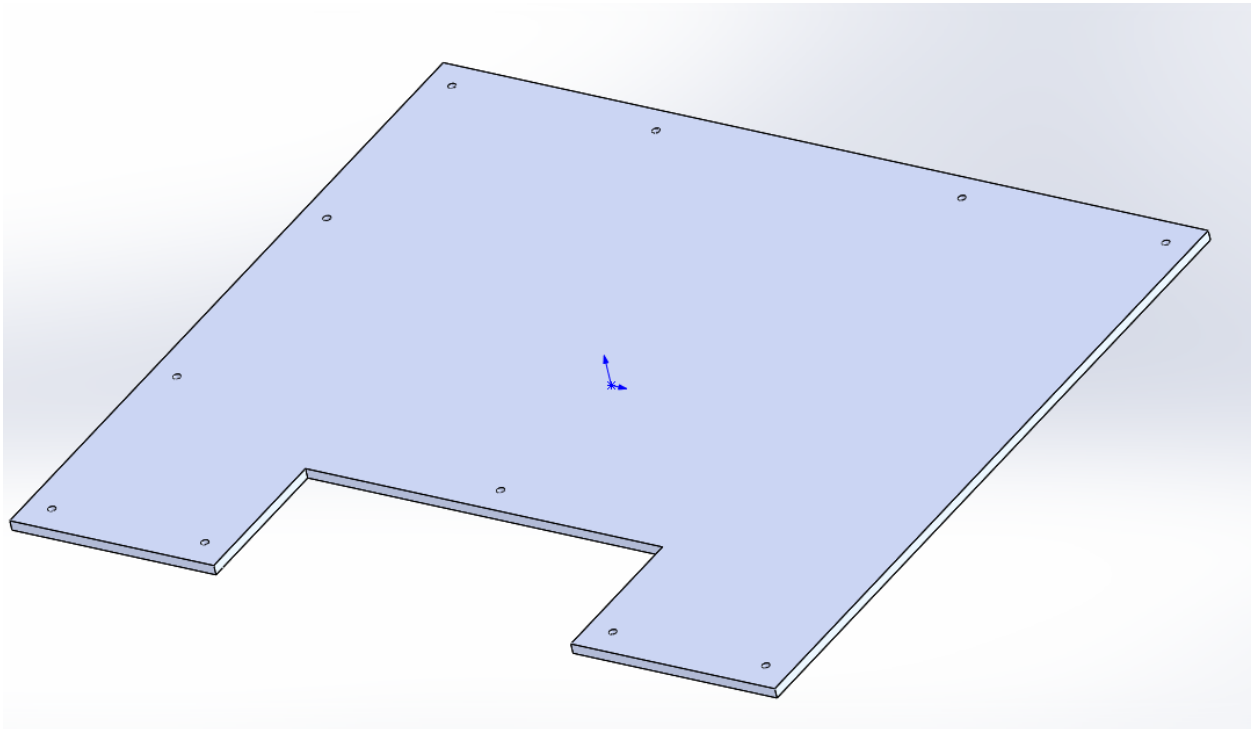


Image 7: Top Armor Plate

The combination of all of these design features results in a robot that is durable for its weight, maneuverable, and easily repaired. The weapon chosen is easy to use which is also a major consideration in competition. The driver only needs to run into opponents to use it and it can be used defensively to keep opponents at bay. The Raspberry Pi Zero W controlling the vehicle is easily programmable and replaceable if damaged. The overall design is relatively simple to manufacture and the use of welding for the frame and weapon make the parts likely to be in the most danger strong and reliable.

Chapter 7: Conclusion

The robot design fits all competition restrictions and is expected to perform well in the competition. The design of the robot lends itself well to quick construction with minimal machining and construction is expected to finish well ahead of the competition date, leaving plenty of time to test and refine the machine. The group members' skills lend themselves well to the tasks which need to be performed. Between the group members the team has ample experience with the machining, welding, electrical wiring and programming that will be required in order to build the robot.

The project is in a good place and the team is preparing to purchase all the required materials, so that it will be ready to begin manufacturing at the beginning of spring semester. Manufacturing is expected to finish at the beginning of April at which point testing will begin. This will allow plenty of time to test, troubleshoot and improve the design before the competition.

References

- 1). "6061 Vs 7075 Aluminum." *The Metal Press by Onlinemetals.com*, Npdadmin, 7 Nov. 2018, metalpress.onlinemetals.com/6061-vs-7075-aluminum-alloy/.
- 2). 'Arduino', [Online], <https://www.adafruit.com/category/17>, 12/09/2018.
- 3). 'Raspberry Pi', [Online], <https://www.raspberrypi.org/>, 12/09/2018.
- 4). 'Core Specifications', [Online], <https://www.bluetooth.com/specifications/bluetooth-core-specification>, 12/09/2018.
- 5). R. Larimer P.E., Professor of Engineering, College of Engineering, Montana State University, Bozeman, Montana. Private Communication, October 25, 2018.

Appendix A. Engineering Analysis

A-1: Armor Plate

The armor plate of the robot that protects the internal components was loaded with a 100 lbf force applied to a 1 in diameter circle in the middle of the least supported area of the plate. This represents a large force from another robot attack and tests to see if it would damage internal components. 100 lbf was settled on as it would be a large force for a 25-pound robot to be able to apply during an attack and the location was chosen to cause the maximum deflection.

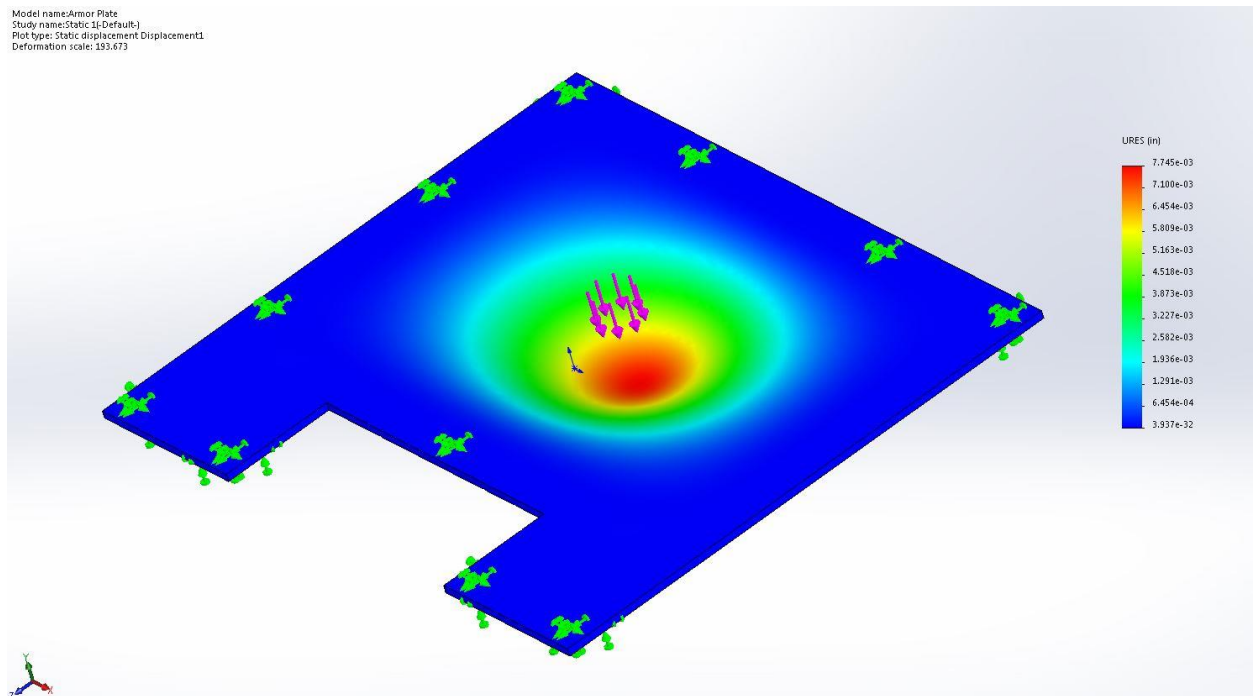


Figure 1: displacement of Armor Plate due to 100-pound force

The model was constrained in all degrees of freedom at the screw holes that hold it onto the robot, and on a 1-inch perimeter where the frame would be supporting the plate. As Figure 1 shows, the maximum deflection is 7.745e-03 inches, so this deflection does not endanger any internal components.

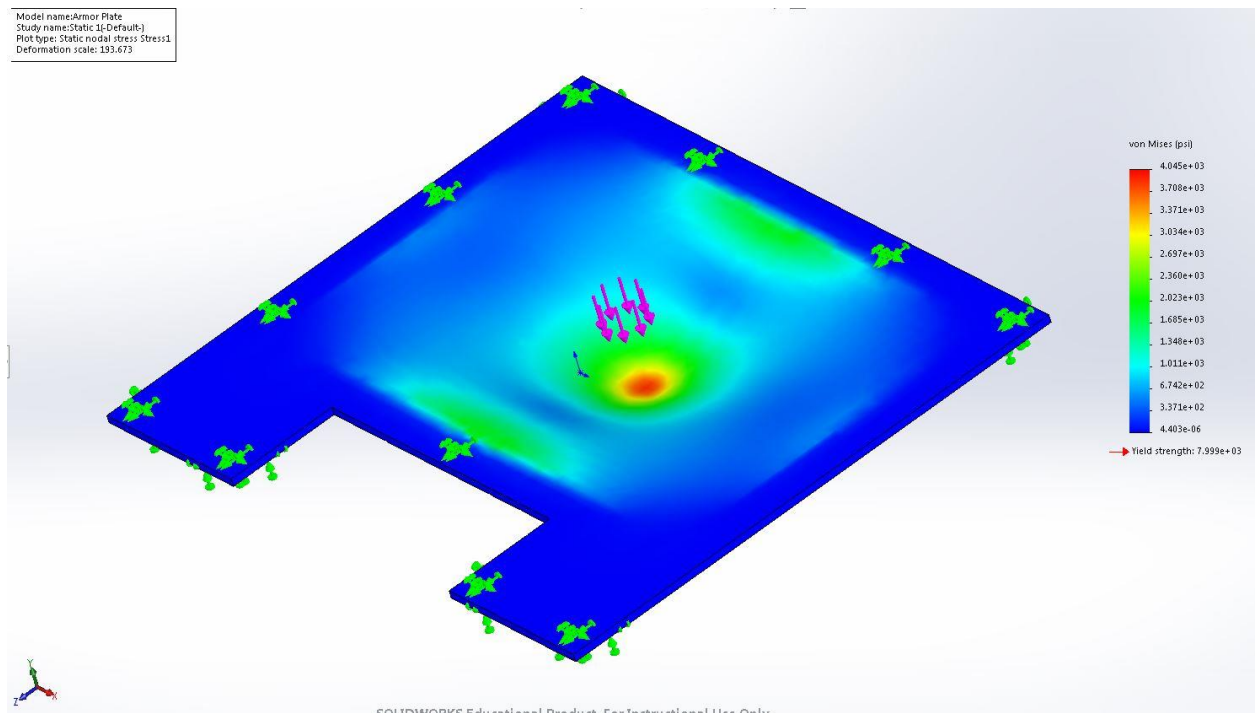


Figure 2: stress of Armor Plate due to 100-pound force

The maximum stress caused by this force is 4.045 ksi as shown in Figure 2. This gives the plate a factor of safety of 1.98 against permanently deforming from this force. This armor will do an adequate job of protecting the internal components of the robot.

The possibility of using a heavier 11-gauge steel armor plate was also investigated.

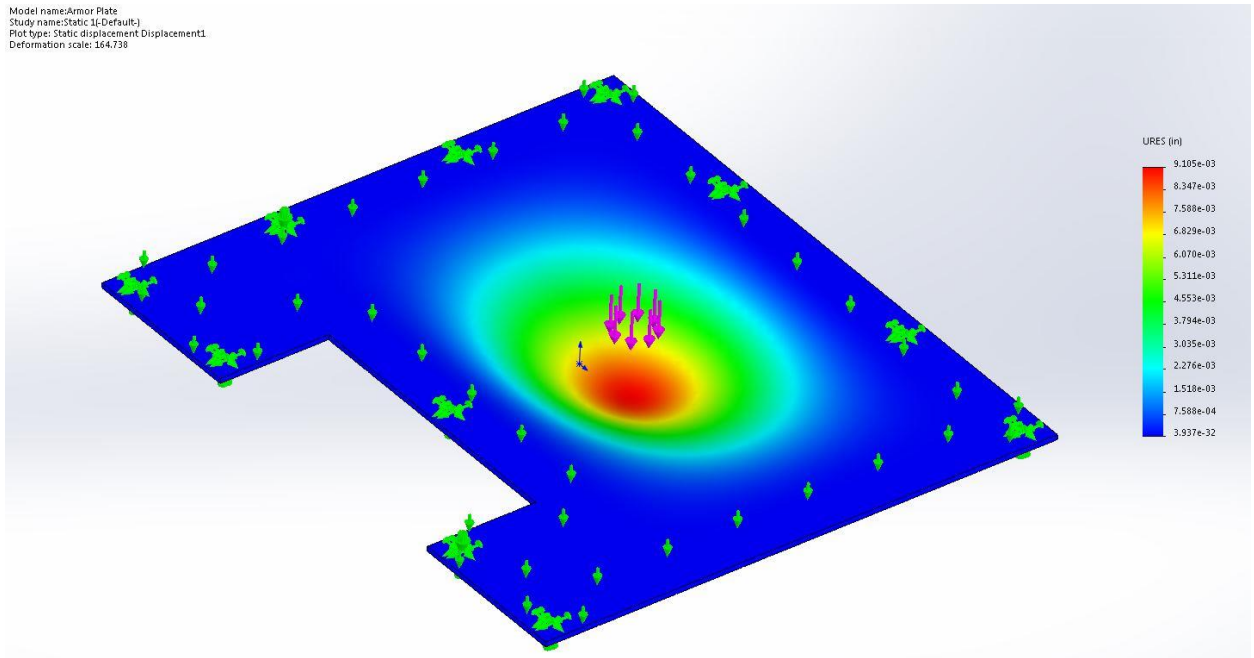


Figure 3: displacement of 11-gauge steel Armor Plate due to 100-pound

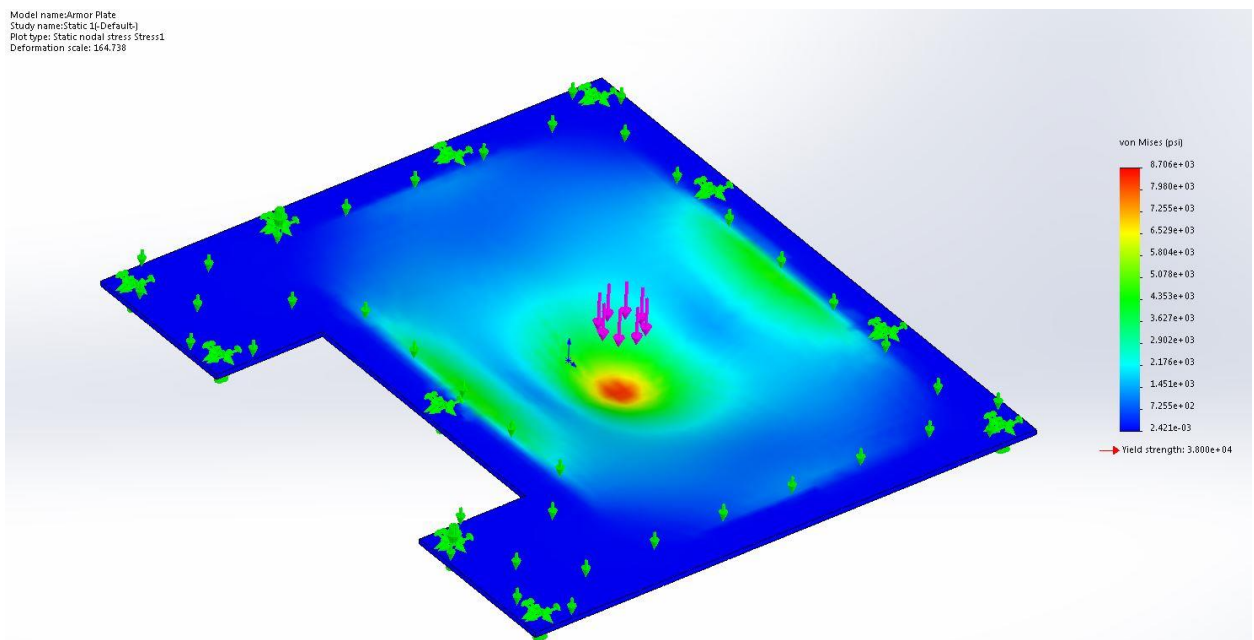


Figure 4: stress of 11-gauge steel Armor Plate due to 100-pound force

From the finite element models of armor made from an 11-gauge steel plate, though it is farther from its yield stress, the deformation it permits under the same stress is greater, making it less effective at preventing the chosen failure criteria than 3/16 in aluminum, in addition to being heavier.

A-2: Frame:

The frame provides the primary structure of the robot, so its integrity is of great importance.

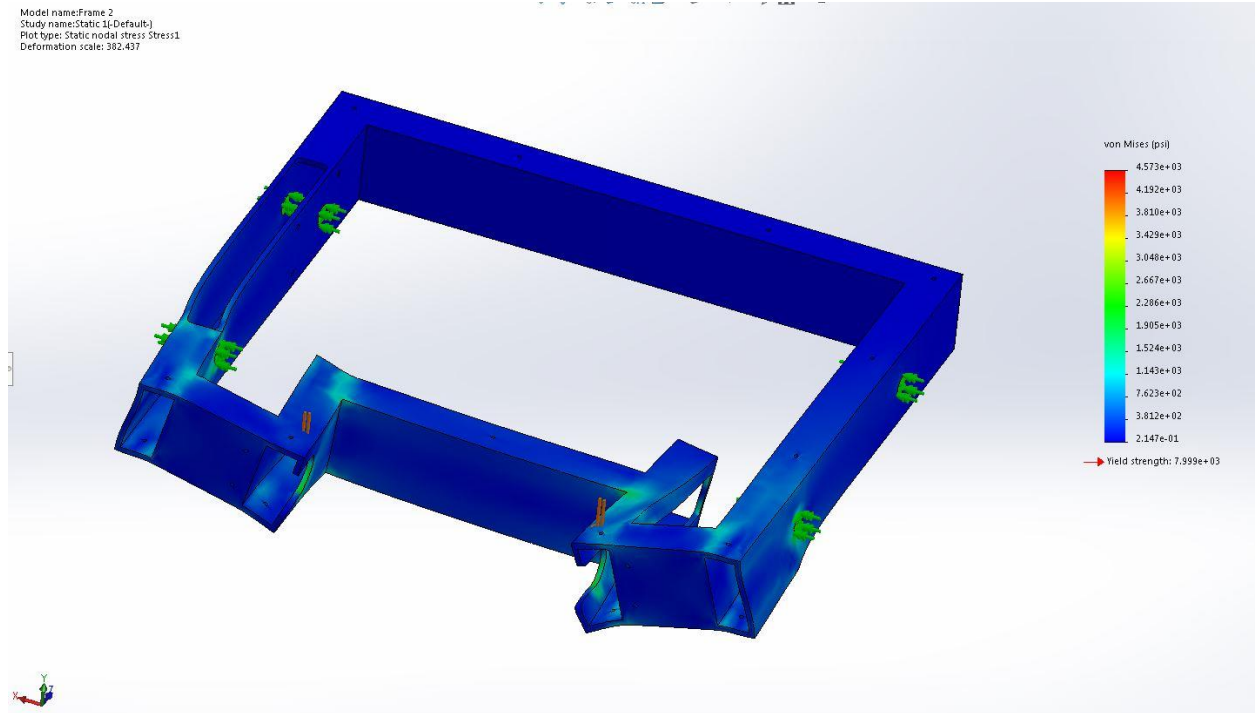


Figure 5: Stress on Frame under 200lbf force at weapon connection

To ensure the frame could withstand the force of the weapon hitting an opponent, the frame was loaded with a 100-pound force on each side where the weapon attaches to the frame, as shown in Figure 3. The axle holes were anchored in all degrees of freedom except rotation. The maximum stress appears directly below the applied forces but drops off quickly. This is likely a result of the ideal application of the force along a line rather than over an area, causing the local stress to be more concentrated. A factor of 1.75 against yielding under these conditions means that the use of the weapon is unlikely to damage the frame.

Model name: Frame 2
Study name: Rear Impact (Default)
Plot type: Static nodal stress Stress1
Deformation scale: 169.784

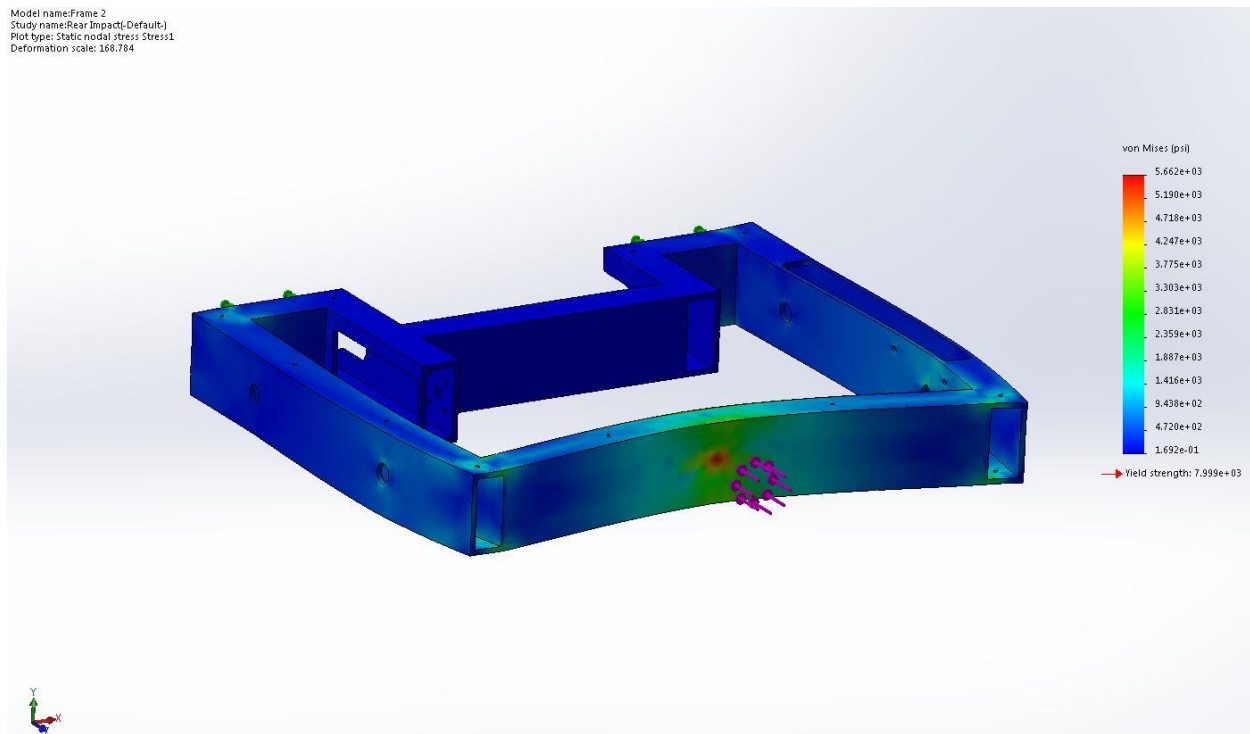


Figure 6: stress in Frame due to 100lbf force applied at rear

Analysis was also done on the frame under a 100lbf load applied to a 1-inch circle in the center of the rear of the frame to account for impacts to the back of the robot, as shown in Figure 4. The front faces were anchored in all degrees of freedom. This was chosen because the rear of the frame is its most exposed part of the structure and therefore the most likely to get hit. It is also the longest unsupported span of any piece of the frame. The analysis shows that the frame resists permanent deformation from this force by a factor of safety of 1.41. This portion of the frame is strong enough to adequately protect the robot.

A-3: Roller

The robot's weapon will be under large stresses as it impacts other robots and obstacles. As such, a large load of 300lbf was applied to one of its outer bars tangent to the weapon's axis of rotation to simulate a large strike.

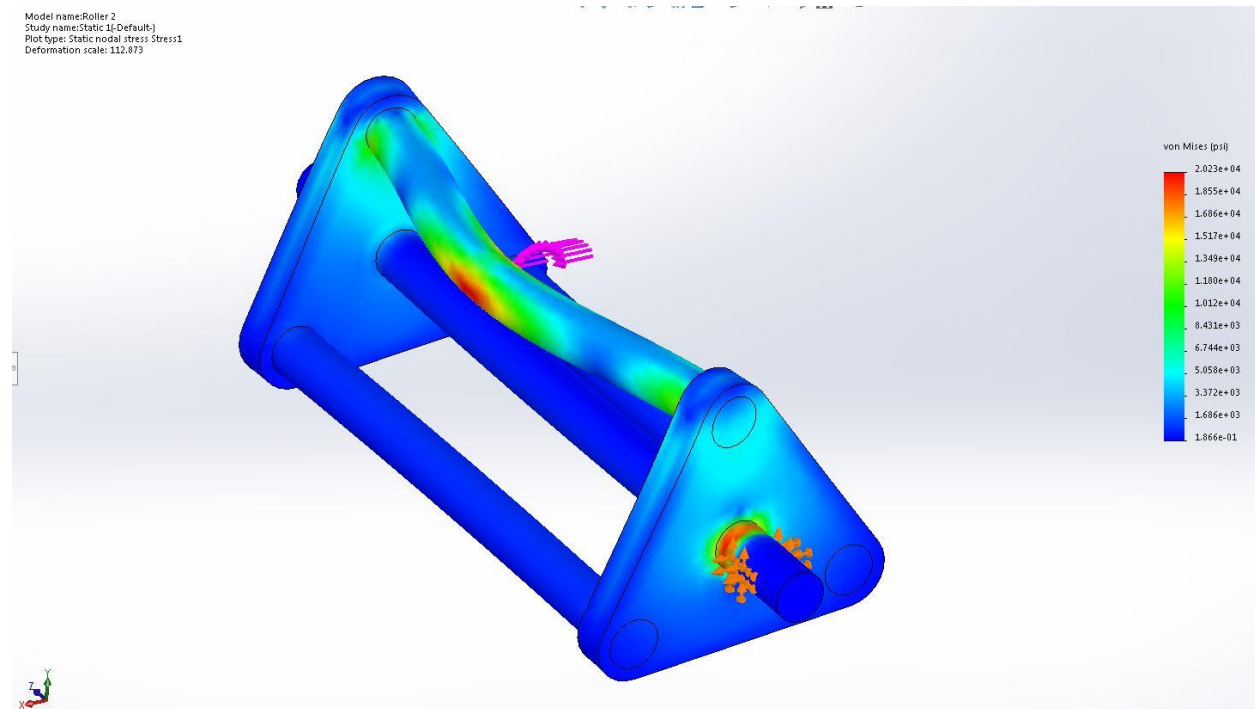


Figure 7: Stress on Roller under 300-pound force at center of striking bar

In this model, 300 lbf was applied to the center of one of the bars of the weapon and the center axle was constrained in all degrees of freedom at the points at which it attaches to the bearings. The yield strength of the steel bars is 38 ksi, giving the piece a factor of safety of 1.9 at this loading. Additionally, since in operation there is nothing attached to the roller capable of providing the 450 in-lbf (the applied motor torque at stall is 97.2 oz-in) of torque needed to resist motion under this load, the high stress area on the main axle is expected to be much lower than the conditions of this analysis predict.

Another analysis was performed using the same loading, but normal to the center axle to see how much of the main axle's stress was the result of torque.

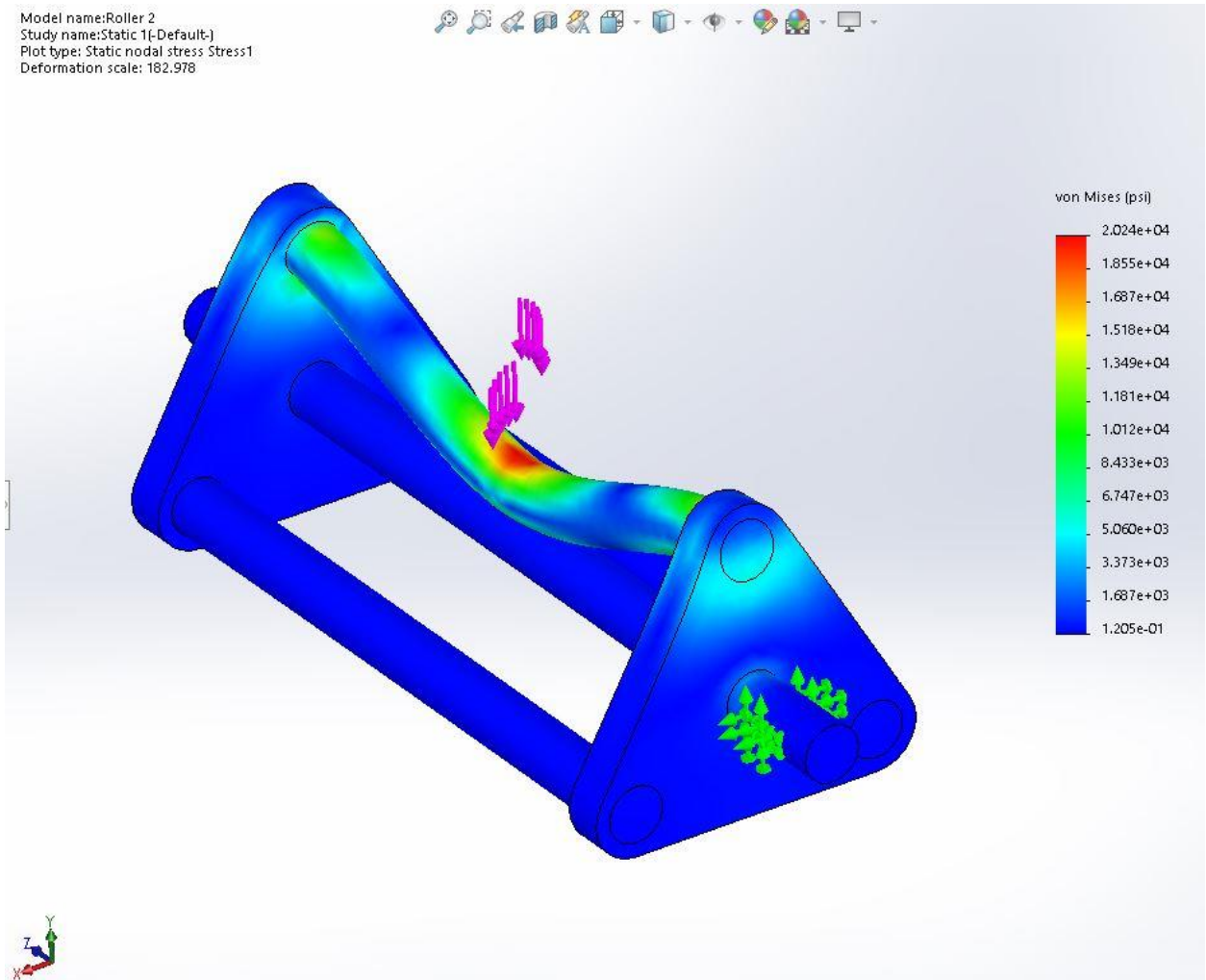


Figure 8: Stress on Roller under 300-pound force at center of striking bar, no torque

As expected, an unrealistic counter torque was the primary contributor to the stress on the center axle.

A-4: Electronics:

Weapon Acceleration

The weapon is meant to reach a top speed of 1600 RPM. Based on what data was available about our chosen motor, it provided an average torque of 55.51 oz-in and had an average speed of 800 rpm. This converts to a torque of 0.392 N*m and an angular speed of 83.776 rad/s. The average power was calculated:

$$P_{ave} = 0.392 \text{ N} * m * 83.776 \frac{\text{rad}}{\text{s}} = 32.84 \text{ W}$$

The kinetic energy was calculated from its operating speed of 1600 RPM and the moment of inertia about the axle provided by SolidWorks of 806 kg*mm².

$$KE = \frac{1}{2} * 806 \text{ kg} * \text{mm}^2 * 10^{-6} * \left(1600 \text{ RPM} * \frac{1 \text{ min}}{60 \text{ sec}} * 2 * \pi \right) = 11.3136 \text{ J}$$

And so, the estimated time to reach speed is

$$t = \frac{KE}{P_{ave}} = 0.3445 \text{ sec}$$

Power and Amperage

The power budget of the electrical systems was calculated using the length of a match and the stall amperage of the three motors. The motor stall amperage is 20A each, for a total of 60A. The raspberry pi takes a 230mA current under heavy computational load and the motor controllers did not list the amperage needed to run the control circuit. These were deemed to be negligible compared to the motors. Each round is 3 minutes, or 0.05 hours.

$$P = 60A * 0.05hr = 3Ah$$

Our battery provides 4.2Ah. This calculation is a worst-case scenario. The robot is not expected to require full stall amperage for the majority of the round and, though no power curve is given, the no-load amperage of each motor is as low as 0.51A. The power supply was designed for the worst-case, as the exact power used each round will vary widely depending on what happened in that round. Some testing will be needed to know with more certainty how much power is likely to be consumed in a single round.

Appendix B: Manufacturing Plan

In order to ensure delivery of a correctly assembled final project in a timely manner, the following manufacturing plan was developed. First instructions will be for individual parts, followed by instructions for sub and final assembly.

Section B-1: Armor plate Bottom (AP1)

AP1	Process	Tool	Time
1	Cut a piece of 3/16" aluminum to a 15"x13" rectangle	Bandsaw	5 minutes
2	Cut 2.75" recess in the sheet as shown in the AP1 drawing	Bandsaw	5 minutes
3	Drill the 11 M3 clearance holes along the edge of the piece as shown in the AP1 drawing	Mill	40 minutes
4	Drill 4 more M3 clearance holes in the rectangular pattern shown in the AP1 drawing	Mill	20 minutes

Section B-2: Armor Plate Top (AP2)

AP2	Process	Tool	Time
1	Cut a piece of 1/8" thick aluminum sheet into a 3.375 " by 4.375" rectangle	Bandsaw	5 minutes
2	Cut 2.75" recess in the sheet as shown in the AP1 drawing	Mill	5 minutes
3	Drill the 11 M3 clearance holes along the edge of the piece as shown in the AP2 drawing	Mill	40 minutes

Section B-3: Electronic Mounting Plate and Assembly (EM1/EMA1)

EMA1	Process	Tool	Time
1	Cut 4.375" by 3.375" square of 1/4" aluminum	Bandsaw	10 minutes
2	Tap 4 M3x.5 mm threads	Mill	15 minutes
3	Drill 8 6 mm holes	Mill	30 minutes
4	Insert 4 M3 press-in nuts into the 4 corner holes of part AP1, all on the same side.	Press	10 minutes
5	Insert 8 M3 press-in nuts into the 8 remaining holes of part AP1, all on the same side as each other, opposite the previous press-in nuts.	Press	
6	Secure the Raspberry Pi Zero to part EP1 using the small electronics mounting hole pattern with 4 10mm M3 bolts.	Screwdriver	5 minutes
7	Put one 40mm M3 screw through each corner of one of the motor control boards so that the components on the board are facing up and the bolts extend down.		
8	Flipping the motor control board over so that the bolts point up, add one 10mm aluminum spacer to each bolt.		5 minutes
9	Slide another motor control board onto the bolts facing the same direction as the previous one.		5 minutes
10	Repeat step 5.		5 minutes
11	Repeat step 6.		5 minutes
12	Use the large electronics mounting hole pattern to secure the stack to part AP1.	Screwdriver	5 minutes

Section B-4: Frame Back (FR1)

FR1	Process	Tool	Time
1	Cut 2x1 aluminum rectangular tube to a length of 13"	Bandsaw	5 minutes
2	Drill M3 clearance hole (3.4 mm) on centerline of tube and 3.5" from end	Mill/3.4mm drill bit	5 minutes
3	Drill M3 clearance hole (3.4 mm) on centerline of tube and 6" from first hole	Mill/3.4mm drill bit	5 minutes

Section B-5: Frame Side (FR2)

FR2 (2x)	Process	Tool	Time
1	Cut 2x1 aluminum rectangular tube to a length of 13"	Bandsaw	5 minutes
	Perform operations 2-6 on 1" wide face		
2	Tap M3x.5" thread on center line .5" from both edges	Mill (M3x.5 Tap)	5 minutes
3	Cut 7.32" x .75" rectangle (starting 2.68" from the same edge the first hole was drilled on	Mill (.25" bit)	5 minutes
4	Tap M3x.5" thread 4.25" from same referenced edge	Mill (M3x.5 Tap)	5 minutes
5	Tap M3x.5" thread 8.75" from same referenced edge	Mill (M3x.5 Tap)	5 minutes
6	Tap M3x.5" thread on center line .5" from opposite edge	Mill (M3x.5 Tap)	5 minutes
	*On 2" Wide Face		
7	Drill .5" hole 3.179" from first referenced edge (for axle)	Mill (.5" bit)	5 minutes
8	Drill .5" hole 6.321" from first .5" axle hole	Mill (.5" bit)	5 minutes
9	Moving farther from the originally referenced edge, Tap M3x.5 thread .625" above and .875" from center of previous axle hole	Mill (M3x.5 Tap)	5 minutes
10	On same horizontal line, (but on other side of .5" hole) tap M3x.5 thread 2.5" away from first tapped hole	Mill (M3x.5 Tap)	5 minutes
11	Vertical (across 2" width) tap M3x.5" thread 1.25" below previous	Mill (M3x.5 Tap)	5 minutes
12	On same line (horizontal), tap M3x.5 2.5" from previous and below/on same vertical line of first tap	Mill (M3x.5 Tap)	5 minutes

Section B-6: Frame Front (FR3)

FR3 (2x)	Process	Tool	Time
1	Cut aluminum rectangular tube to a length of 2"	Bandsaw	5 minutes
2	Tap M3x.5" thread .5" from horizontal edge and .25" from vertical edge	Mill (M3x.5 Tap)	5 minutes
3	Tap M3x.5" thread 1" below previous	Mill (M3x.5 Tap)	5 minutes

Section B-7: Frame Short Roller Arm (FR4)

FR4	Process	Tool	Time
1	Cut aluminum rectangular tube to a length of 3.75"	Bandsaw	5 minutes
2	Tap M3x.5" thread .5" from horizontal edge and .5" from vertical edge on 1" face	Mill (M3x.5 Tap)	5 minutes
3	On same side hole was tapped (but on 2" face) cut slot for RM1 (Roller/bearing bracket)	Mill	5 minutes

Section B-8: Frame Roller Space (FR5)

FR5	Process	Tool	Time
2	Cut aluminum rectangular tube to a length of 7"	Bandsaw	5 minutes
3	On centerline, Tap M3x.5" thread 3.5" from horizontal edge	Mill (M3x.5 Tap)	5 minutes

Section B-9: Frame Long Roller Arm (FR6)

FR6	Process	Tool	Time
1	Cut aluminum rectangular tube to a length of 5.5"	Bandsaw	5 minutes
2	On 1" face, Tap M3x.5" thread.5" from horizontal and vertical edge	Mill (M3x.5 Tap)	5 minutes
3	On one side of 23" face, cut 1.22" x 4" window	Mill	5 minutes
4	On other side of 2" face,(and on centerline) cut slot for roller/bearing	Mill	5 minutes
5	On same side of 2" face, drill the 4 M3 clearance holes for motor mount	Mill (3.4 mm bit)	15 minutes
6	In center of 4 clearance holes, drill .2756" hole for motor	Mill (7 mm drill bit)	5 minutes

Section B-10: Roller Mount (RM1)

RM1	Process	Tool	Time
1	Cut Aluminum block down to 2"x 1.27" (.25" thick) wall with bottom 1.625" x 2" (.125" thick) protrusion	Mill	25 minutes
2	Drill 2 M3 clearance holes as called out In RM1 drawing	Mill	10 minutes
3	Use CNC mill to cut out .125" thick, .6" wide, tab with .425" radius	CNC mill	15 minutes
4	Use 11/16" drill bit to drill hole in center of protruding tab	Mill	5 minutes

Section B-11: Roller Hub (RH1)

RH1 (2x)	Process	Tool	Time
1	Cut 3/8" steel to 2.7" x 2.7" triangle with .75" radii at edges	CNC router	30 minutes
2	Drill 4 .5" clearance holes for roller bars/axle	Mill (.5" bit)	20 minutes

Section B-12: Axle Front (AF1)

AF1 (2x)	Process	Tool	Time
1	Cut .75" stock 1020 steel rod to 3.67" length	Bandsaw	5 minutes
2	Turn rod down to .5" with the exception of .6" diameter (.2" long) end	Lathe	15 minutes
3	Cut .25" long set screw slot starting .44" from .6" diameter end	Mill	5 minutes

Section B-13: Axle Rear (AR1)

AR1 (2x)	Process	Tool	Time
1	Cut steel rod to 4" length	Bandsaw	5 minutes
2	Turn rod down to .5"	Lathe	15 minutes
3	Turn one end down to .25" diameter for .437"	Lathe	5 minutes
4	Cut set screw slot in .25" diameter	Mill	10 minutes

Section B-14: .5" Bore Pulley (P1)

P1 (4x)	Process	Tool	Time
1	Bore out (from bought pulley) .25" hole to .5"	Mill (.5" bit)	5 minutes

Section B-15: Gear Box

GB1 (2x)	Process	Tool	Time
1	Mill aluminum down to 2"x1.1"x3" block	Mill	15 minutes
2	Cut 2x1.5 (.85" deep) window	Mill	10 minutes
3	Drill outer 4 M3 clearance holes for mounting to frame	Mill (M3x.5 Tap)	10 minutes
4	Drill inner 4 M3 clearance holes for motor mount	Mill (M3x.5 Tap)	10 minutes
5	Drill .5" diameter axle hole	Mill (.5")	5 minutes
6	Drill 23/32" hole for motor mount		5 minutes

Section B-16: Roller Bar (RB1)

RB1 (3x)	Process	Tool	Time
1	Cut steel rod to 6.5" length	Bandsaw	5 minutes
2	Turn rod down to .498"	Lathe	5 minutes

Section B-17: Roller Axle (RA1)

RA1	Process	Tool	Time
1	Cut steel rod to 8.7" length	Bandsaw	5 minutes
2	Turn down to .5" diameter	Lathe	10 minutes
3	Turn one end down to .25" diameter for 1.1"	Lathe	10 minutes
4	Turn other end down to .25" diameter for 1.1"	Lathe	10 minutes

Section B-18: Tube Cap (TC1)

TC1	Process	Tool	Time
1	3d Print tube cap	3d Printer	1 hour

Section B-19: Motor Mount (MM1)

MM1	Process	Tool	Time
1	Cut 1"x1" aluminum square	Mill/Bandsaw	10 minutes
2	Drill 18 mm motor hole in center	Mill/18mm bit	5 minutes
3	Drill 4 M3 Clearance holes for motor to mount	Mill	15 minutes

Section B-20: Frame Assembly

Frame Assembly	Process	Tool	Time
1	Weld one of side frame pieces to frame back piece	SMAW	20 minutes
2	Weld second side frame to frame back	SMAW	20 minutes
3	Weld other end of frame side piece to FR3	SMAW	20 minutes
4	Weld other end of FR3 to FR4	SMAW	20 minutes
5	Weld FR4 to FR5	SMAW	20 minutes
6	Weld other end of FR5 to second FR6	SMAW	20 minutes
7	Weld FR6 to second FR3	SMAW	20 minutes
8	Weld FR3 to frame side (FR2)	SMAW	20 minutes

Section B-21: Wheel/Axle Assembly:

	Process	Tool	Time
1	Place 4 bored out pulleys (P1) inside FR2 (Frame side) windows with belts around both pairs		5 minutes
2	Insert AR1 into FR2 axle hole/bearing/pulley and tighten pulley set screw		5 minutes
3	Place gear on 1/4" part of axle and tighten set screw	Screwdriver/ Drill	5 minutes
4	Mount motor to gear boxes and tighten set screw of pinion gear onto motor shaft	Screwdriver/ Drill	5 minutes
5	Mount gear box to frame and make sure gear teeth mesh	Screwdriver/ Drill	5 minutes
6	Bolt both bearings on FR2	Screwdriver/ Drill	5 minutes
7	Press fit both wheel hubs into wheel bores	Press	10 minutes
8	Insert AR1 into FR2 axle hole/bearing/pulley		5 minutes
9	Insert all press fit hubs into wheel bores		5 minutes
10	Tighten wheel hub clamp onto axle	Screwdriver/ Drill	5 minutes
11	Repeat step 10 - 18 for other side	Screwdriver/ Drill	15 minutes
12	Insert AF1 into frame pulley and bearing from inside of frame so that .6" diameter head stops at frame		5 minutes
13	Tighten pulley set screw	Screwdriver/Drill	5 minutes
14	Clamp wheel hubs onto end of axle	Screwdriver/Drill	5 minutes
15	Repeat steps 20-22 for other side	Screwdriver/Drill	10 minutes

Section B-22: Roller Assembly

	Process	Tool	Time
1	Press fit flanged bearings into RM1 (2x)	Press	5 minutes
2	Place roller bars and roller axle into roller hub (RH1)		5 minutes
3	Weld Roller hub in place	SMAW	30 minutes
4	Place second roller hub in place at other end of roller		5 minutes
5	Weld second roller hub in place	SMAW	30 minutes
6	Slide bearings with roller mount (RM1) onto both 1/4" ends of roller axle		5 minutes
7	Slide 1/4" 24 tooth pulley onto end of roller axle and tighten set screw	Screwdriver	5 minutes
8	Place 6 mm pulley inside FR6 (long roller arm) with bet around it		
9	Secure motor mount to FR6	Screwdriver/Drill	5 minutes
10	Secure motor to motor mount through pulley bore	Screwdriver/Drill	5 minutes
11	Tighten set screw from pulley to motor	Screwdriver/Drill	<5 minutes
12	Slide roller/brackets into place at front of bot, slip belt over pulley, and screw brackets into frame	Screwdriver/Drill	10 minutes
13	Press tube caps into place		5 minutes

Section B-23: Finishing up/Making Repairs

	Process	Tool	Time
1	Bolt AP1 (with electronic panel) into frame	Screwdriver/ Drill	5 minutes
2	Mount battery (with velcro) to FR1		
3	Wire motors to raspberry pi/motor control panel		5 minutes
4	Wire battery to control panel/motors		5 minutes
5	Bolt in AP2 to frame	Screwdriver/drill	5 minutes
6	Test bot		

Appendix C: Project Schedule/Management Plan

General Roll assignment:

Based on each group members particular experience, general rolls were assigned for building/assembly of the bot.

Electronics: Assigned to Ivan for mechatronics minor/experience

Fabrication: Assigned to Cole for FEA/welding/machining through MET.

Organization/model management: Assigned to Nishagar

Term Meeting Schedule/ Location:

This varies by week due to everyone's work schedule, however all three gather every Wednesday at 2:00 pm to touch base, assign responsibility until the following meeting if we are unable to gather again, and otherwise decide our next meeting time before the following Wednesday. This time is also used to consult with our advisor, Professor James Black.

File Sharing

During the first scheduled meeting it was decided that GitHub would be the primary method of editing/sharing files via a shared repository. It is excellent at saving old versions of texts, spreadsheets, and models, and each member has an individual copy on his hard drive until they are ready to be merged.

Aside from GitHub, weekly decisions were recorded as they were made (either during group meetings or through group emails and texts) in the progress memo by that weeks assigned note taker, and were usually implemented into the final design/budget immediately.

Group Leadership Schedule/Member Assignments:

9/12/18 Leader: Cole

- Meet advisor and set up weekly meeting time/place
- Deliver first progress memo
 - Assigned to group

9/19/18 Leader: Cole

- Level 1 requirements started
- Ongoing group rules document updated
- Wrote problem statement
 - Assigned to Ivan Albert
- Started Gantt chart
 - Assigned to Cole Trugman
- Start background section
 - Assigned to Nishagar

9/26/18 Leader: Ivan

- In coming week will start on design specifications
- Combined individual background sections

10/03/18 Leader: Ivan

- Nishagar and Cole were assigned to Level 1 Design Specifications
- Ivan was assigned to Design alternatives.
 - Tables ranked -2 to 2 gives a clear picture of ideas and their effectiveness
- Discussed possible design and the requirements
 - Can have both fast rollers in the front, and the wedge in the back as a defense weapon system
 - The direction of the rollers effects the motion of the bot when hits the opponent.

10/10/18 Leader: Nishagar

- Turn in design specs and alternatives draft
- Decided to design for a minimum pushing/push resisting force of 20 lb.
- Decided to design for a minimum speed of about 1 fps both as a defensive tactic as well and a way to make the wedge offensive.
- Discussed utilizing aluminum 6063 for its light weight and easy machinability/weldability with the possibility of implementing a thin (1/8") layer of ar400 steel to protect the soft aluminum
- See "design specs" for other choices made this week.

10/17/18 Leader: Nishagar

- Update Master Project Plan (Started virtual design journal through github where it is accessible/ changeable for all members to record design ideas)
 - Assigned to Cole
- Started google doc for design journal/ place for sharing new thoughts/design ideas.
- Turn in weekly progress memo

10/24/18 Leader: Cole

- Perform peer review
 - Assigned to group
- Prepare/present preliminary design
 - Assigned to group (Meet Saturday 10/20 to finalize powerpoint)

10/31/18 Leader: Cole

- FMEA
 - Electronics Assigned to Ivan
 - Microcontroller (motor control), Battery, wiring, code, Drive/Weapon Motor, Peripheral Controller,
 - Assigned to Cole:
 - Roller failures (Bent axle, motor/roller connection,)
 - Chassis (Component protection, structural integrity)
 - Assigned to Nishagar
 - Manufacturing/Process (Tolerances, machining, assembly issues, competition rules)
 - Wheel Sub-assembly (bent/sheared axle, shape abnormalities, lost/damaged wheel, damaged bearing)

11/7/18 Leader: Ivan

- Master Project Schedule Update
 - Assigned to Ivan
- Division of jobs for the coming week
 - Nishagar assigned to failure calculations
 - Ivan assigned to component selection
 - Cole assigned to model finalization

11/14/18 Leader: Ivan

- Progress Memo
 - Assigned to Cole

11/21/18 Leader: Nishagar

- Progress Memo
 - Assigned to Ivan

11/28/18 Leader: Nishagar

- Critical Design Review (CDR)
 - Group assignment
- Draft Analysis and Manufacturing Plan Appendix
 - Assigned to Cole and Nishagar
- Progress Memo
 - Assigned to Ivan

12/5/18 Leader: Cole

- Progress Memo
 - Assigned to Nishagar
- Course Evaluation
 - Assigned to each member of the team
- Peer Evaluation
 - Assigned to each member of the team
- Advisor Evaluation
 - Assigned to each member of the team

12/12/18 Leader: Cole

- Final written report due Monday (Includes "Drawing Package" and "Manufacturing Plan" Appendices, Updated Master Project Schedule, and all other elements defined on website format guide.)
 - Assigned to group
- Complete orders and supporting documentation
 - Assigned to Ivan
- Deliver CDRs by Tuesday 6:00 pm
 - Assigned to Cole
- Progress Memo
 - Assigned to Nishagar

Gantt Chart

Legend:	Not Started	In Progress	Completed							
Task	Start	Finish	Duration	8/28/2018	9/4/2018	9/11/2018	9/18/2018	9/25/2018	10/2/2018	
Get Prjoect Assignment	28-Aug	4-Sep	1 week							
Meet Group	4-Sep	7-Sep	3 days							
Meet Advisor	11-Sep	14-Sep	3 days							
Set up Weekly Meeting Time/Place	14-Sep	14-Sep	1 day							
Weekly Progress Memo	12-Sep	N/A	Continuous							
Draft/Sign Level 1 Requirements	19-Sep	20-Sep	1 day							
Gantt Chart	19-Sep		Continuous							
Draft Backgroud	19-Sep	28-Sep	9 days							
Draft Specs	3-Oct	12-Oct	9 days							
Draft Alternatives	3-Oct	12-Oct	9 days							
Master Project Schedule Update	16-Oct	17-Oct	1 day							
Course/Peer Review										
Deliver Preliminary design presentation	17-Oct	23-Oct	6 days							
Failure Modes and Effects Analysis	23-Oct	29-Oct	6 days							
Master Project Schedule Update	7-Nov	8-Nov	1 day							
Finalize CAD Model	3-Nov	14-Nov	11 days							
Choose Electrical Components	3-Nov	14-Nov	11 days							
FEA Analysis	14-Nov	21-Nov	7 days							
Create Drawing Package	21-Nov	28-Nov	7 days							
Prepare CDR	28-Nov	3-Dec	5 days							
Draft Analysis and Manufacturing Plan Appendix	21-Nov	30-Nov	9 days							
Present Critical Design Reviews	2-Dec	3-Dec	1 day							
Final Report W/ Drawing/Manufacturing Etc	3-Dec	9-Dec	6 days							
CDR Videos	3-Dec	9-Dec	6 days							

Legend:	Not Started	In Progress	Completed								
Task	Start	Finish	Duration	10/9/2018	10/16/2018	10/23/2018	10/30/2018	11/6/2018	11/13/2018	11/20/2018	
Get Prjoect Assignment	28-Aug	4-Sep	1 week								
Meet Group	4-Sep	7-Sep	3 days								
Meet Advisor	11-Sep	14-Sep	3 days								
Set up Weekly Meeting Time/Place	14-Sep	14-Sep	1 day								
Weekly Progress Memo	12-Sep	N/A	Continuous								
Draft/Sign Level 1 Requirements	19-Sep	20-Sep	1 day								
Gantt Chart	19-Sep		Continuous								
Draft Backgroud	19-Sep	28-Sep	9 days								
Draft Specs	3-Oct	12-Oct	9 days								
Draft Alternatives	3-Oct	12-Oct	9 days								
Master Project Schedule Update	16-Oct	17-Oct	1 day								
Course/Peer Review											
Deliver Preliminary design presentation	17-Oct	23-Oct	6 days								
Failure Modes and Effects Analysis	23-Oct	29-Oct	6 days								
Master Project Schedule Update	7-Nov	8-Nov	1 day								
Finalize CAD Model	3-Nov	14-Nov	11 days								
Choose Electrical Components	3-Nov	14-Nov	11 days								
FEA Analysis	14-Nov	21-Nov	7 days								
Create Drawing Package	21-Nov	28-Nov	7 days								
Prepare CDR	28-Nov	3-Dec	5 days								
Draft Analysis and Manufacturing Plan Appendix	21-Nov	30-Nov	9 days								
Present Critical Design Reviews	2-Dec	3-Dec	1 day								
Final Report W/ Drawing/Manufacturing Etc	3-Dec	9-Dec	6 days								
CDR Videos	3-Dec	9-Dec	6 days								

Appendix D: Purchased Part List

Purchased Parts

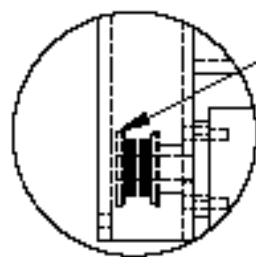
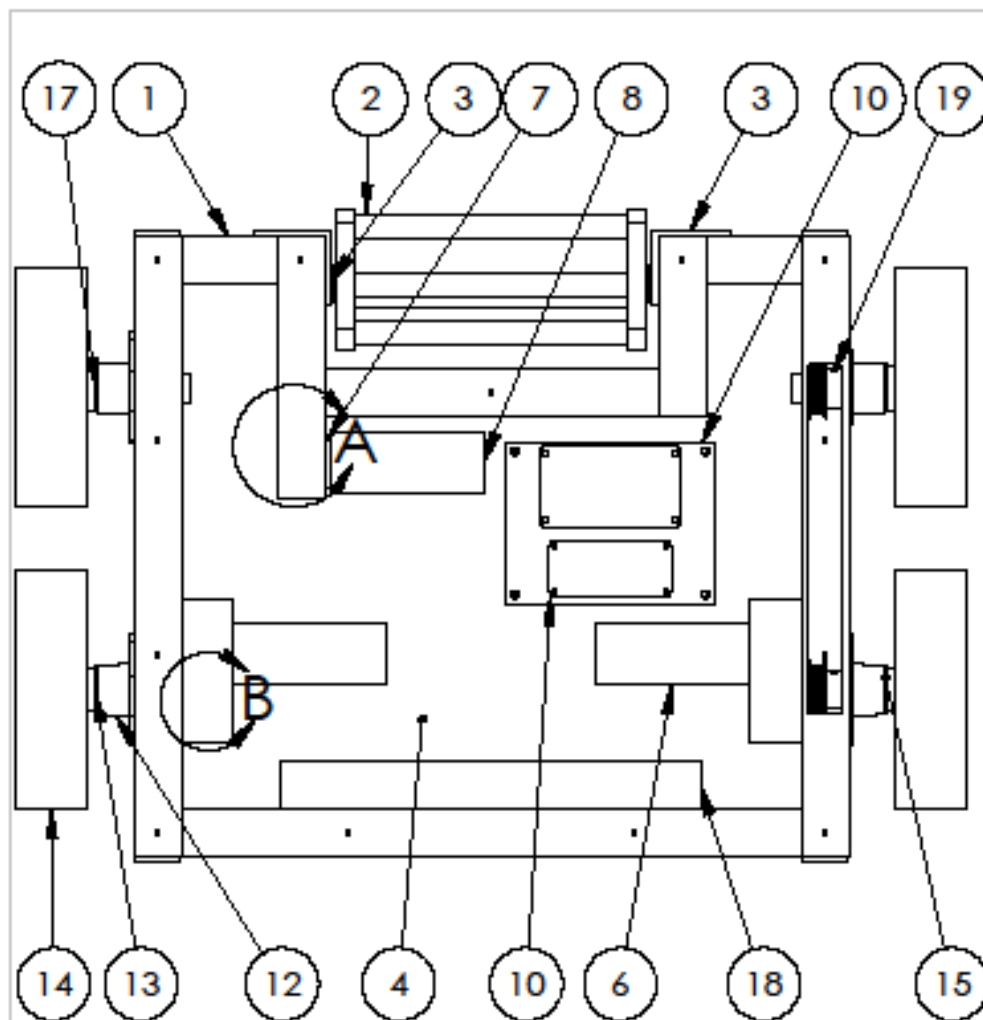
Part Number	Description	Manufacturer/Vendor	Vendor Part Number	Quantity
P0	MXL series timing belt pulley, 24 teeth, 1/4 in shaft diameter	McMaster-Carr	1375k450	1
P1	MXL series timing belt pulley, 24 teeth, 3/16 in shaft diameter	McMaster-Carr	1254N21	2
P2	MXL series timing belt pulley, 42 teeth, 1/4 in shaft diameter	McMaster-Carr	1375k560	4
P3	Mounted roller bearing with two-bolt flange for 1/2" shaft diameter	McMaster-Carr	1434k600	4
P4	Metal gear, 48 pitch, 36 teeth, round bore with set screw for 1/4" shaft diameter	McMaster-Carr	6832k44	2
P5	Flanged ball bearing for 1/4" shaft	McMaster-Carr	6383k213	2
P6	118 RPM HD Premium Planetary Gear Motor	ServoCity	118 RPM HD Premium Planetary Gear Motor	2
P7	1621 RPM HD Premium Planetary Gear Motor	ServoCity	1621 RPM HD Premium Planetary Gear Motor	1
P8	Tenergy NiMH 12V 4200mAh Rechargeable Battery Pack	All-Battery	11600	2
P9	RC Servo BEC UBEC 3A 5V for Helicopter Airplane Receiver Servo Power Supply	BW/Amazon	RC Servo BEC UBEC 3A 5V for Helicopter Airplane Receiver Servo Power Supply	1
P10	13A, 5-30V Single DC Motor Controller	Cytron/RobotShop	RB-Cyt-132	3
P11	Raspberry Pi Zero W	Raspberry Pi Foundation/Adafruit	3400	2

P12	18-8 SS 10mm long M3 spacer	McMaster-Carr	92871A013	12
P13	Metal gear, 48 pitch, 36 teeth, round bore with set screw. 6 mm shaft diameter	Servocity	RSA48-6MM-36	2
P14	Rubber tread/polypropylene core 5" diameter/1 ¼" wide wheels	Banebots.com	WC2-5	6
P15	Clamp action, press fit wheel hubs for .5" shaft and 1 ¼" wide wheel	Banebots.com	RHC2-P1-S4-C1	6
P16	200 tooth, .08" pitch, ¼" wide, MXL series belt	McMaster-Carr	7887K88	2
P17	120 tooth, .08" pitch, ¼" wide, MXL series belt	McMaster-Carr	7887K22	1

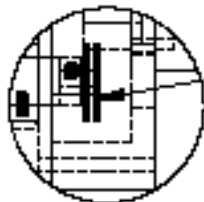
Raw Materials

Material Number	Description	Manufacturer/Vendor	Quantity
R1	10 ft 1"x2"x1/8" 6063-T52 Aluminum Rectangular Tube	Midwest Steel and Aluminum	1
R2	3/16" 6061 Aluminum Plate 2'x3'	The Metal Store	1
R3	4"x5"x0.25 foam	scrap	1
R4	PLA Filament	MSU Makerspace	4 parts
R5	2"x2"x1' 6061 Aluminum Square Bar	Metals Depot	1
R6	1/2" 1018 Cold Finish Steel Round 4ft length	Metals Depot	1
R7	5/8" 1018 Cold Finish Steel Round 2ft length	Metals Depot	1
R8	3/8"x4"x2' A-36 Steel Flat	Metals Depot	1

Appendix E: Engineering Drawings



DETAIL A
SCALE 1 : 2



DETAIL B
SCALE 1 : 2

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: $\pm 1/16"$
ANGULAR: MACH $\pm 5^\circ$ BEND $\pm 1^\circ$
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame Assembly	FRA1	1
2	Roller Assembly	RA1	1
3	Roller Bracket	RB1	2
4	Armor Plate	AP2	1
5	Armor Plate(Not Shown)	AP1	1
6	Gearbox Assembly	GBA1	2
7	Motor Mount	MM1	1
8	Motor	1,621 RPM HD Premium Planetary Gear Motor	1
9	Electronic Mounting Plate Foam	MF1	1
10	Electrical Mounting	EMA1	1
11	6832K44	48 Pitch, 36 Tooth Gear with Set Screw	2
12	1434K6	1/2" Mounted Roller Bearing	4
13	Wheel Hub	Colson Series 2 Hub, 1/2" Plane Bore	4
14	Wheel	Colson Wheel 5in x 1-1/4in	4
15	Axle Cole	AR1	2
17	Axle2 Cole	AF1	2
18	Battery Pack	AT: Tenenergy NiMH 12V 4200mAh Rechargeable Battery Pack	1
19	1375K56	42 Tooth MXL Timing Belt Pulley	2
20	1254N21	24 Tooth MXL Timing Belt Pulley	1
20	6383K213	1/4" Shaft Diameter Ball Bearing	2
21	6383K213	1/4" Shaft Diameter Ball Bearing	2
22	1375K45	42 tooth, 1/4"belt, .5" shaft	1

MSU M.& I.E. DEPT.

TITLE:

Robot Assembly

SIZE

A

DWG. NO.

Main1

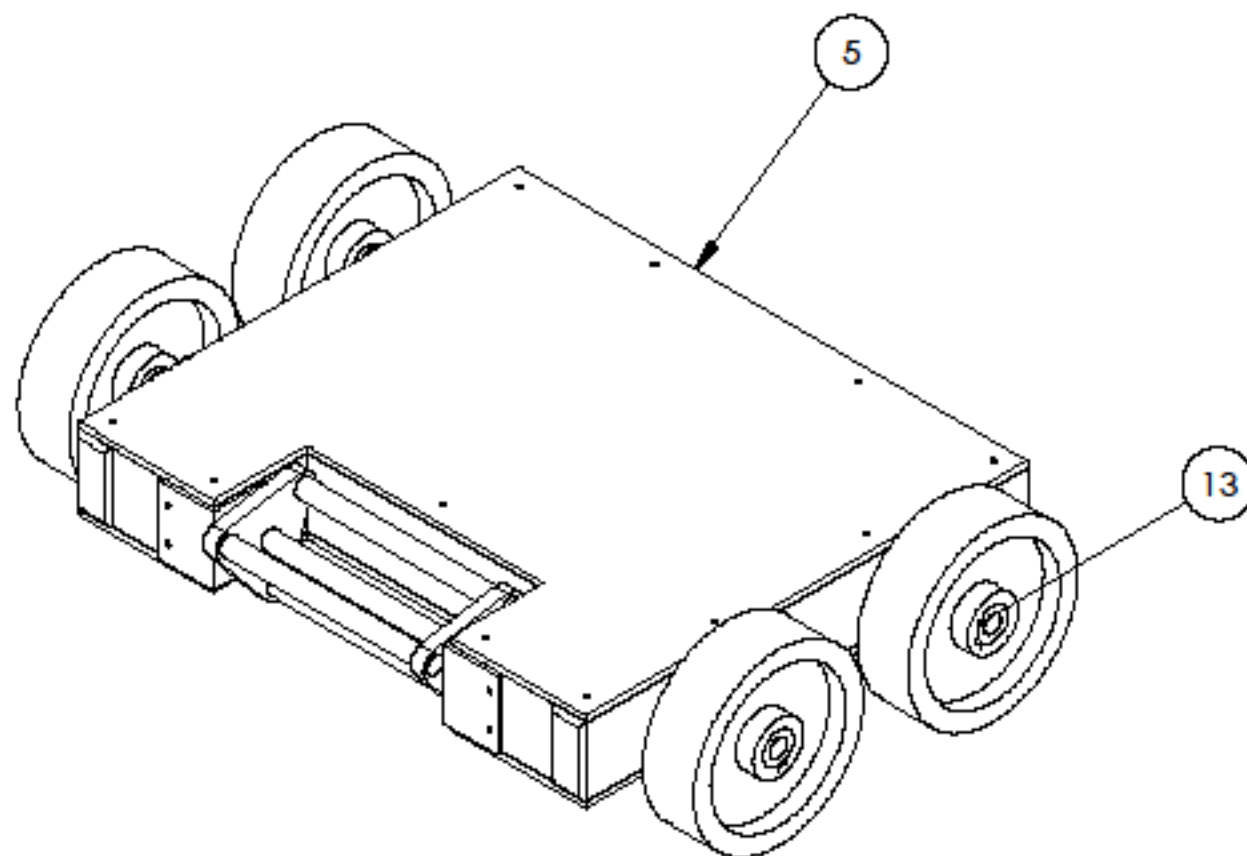
REV

1

SCALE: 1:8

WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH $\pm .5$ BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:
COMMENTS:
NEXT ASSY DO NOT SCALE DRAWING

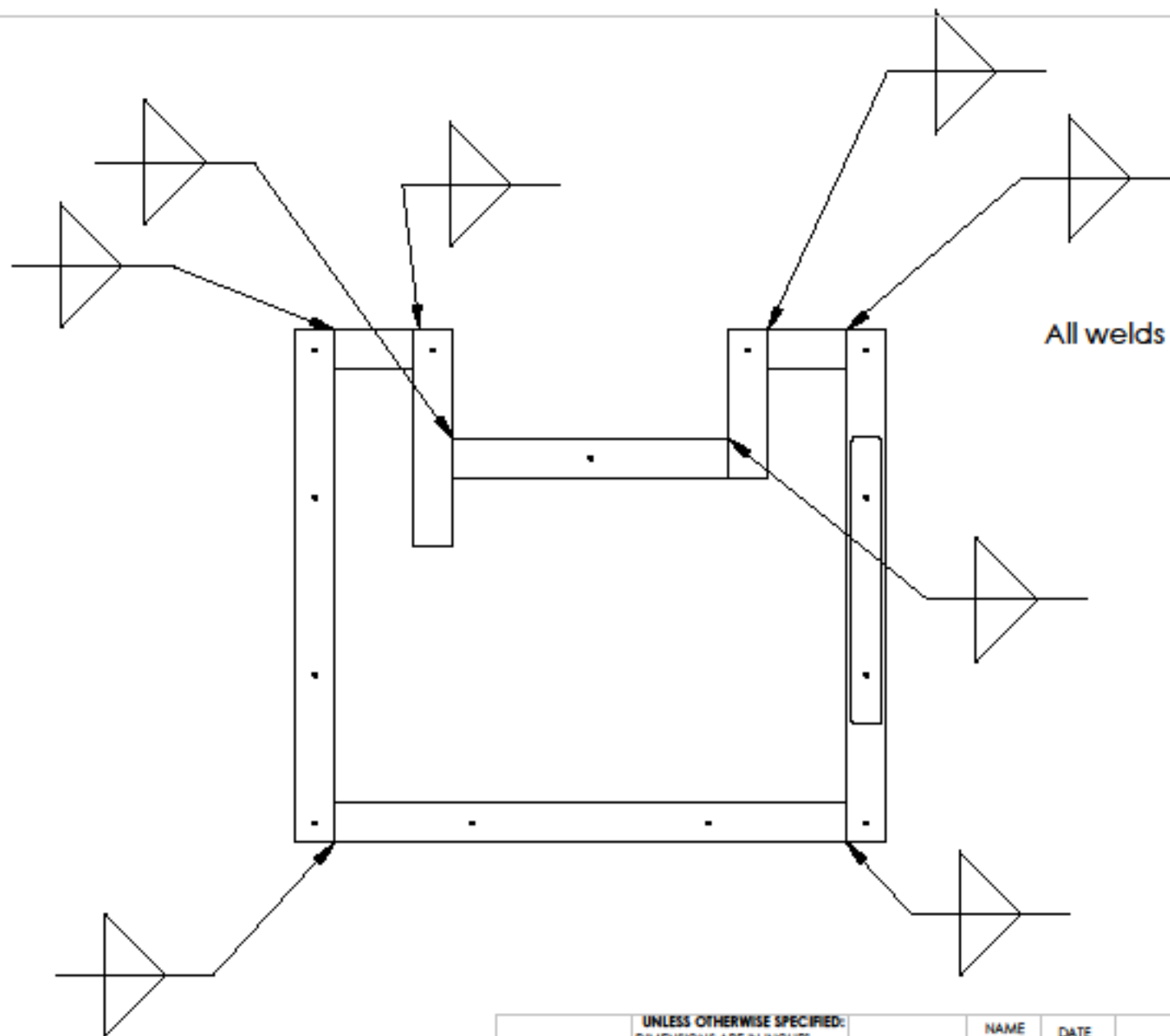
	NAME	DATE
DRAWN	KF	-
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL		

MSU M.& I.E. DEPT.

TITLE:
- Main Assembly

SIZE	DWG. NO.	REV
A	Main 2	1

SCALE: 1:8	WEIGHT:	SHEET 1 OF 1



All welds through length of frame

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

NAME

DATE

DRAWN

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

MSU M.& I.E. DEPT.

TITLE: **Frame Weld**

SIZE
A

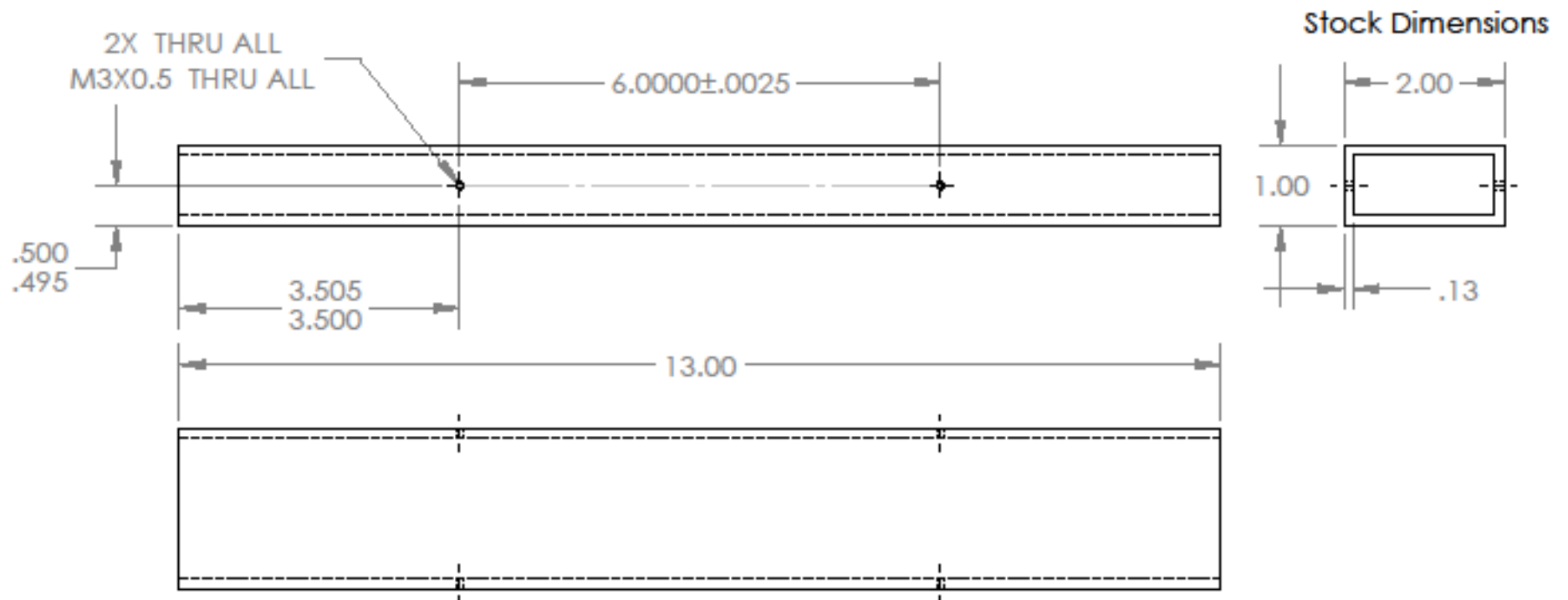
DWG. NO.
FRA1

REV
1

SCALE: 1:8

WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL ± 1/16"
 ANGULAR: MACH ± 5° BEND ± 1°
 TWO PLACE DECIMAL ± 0.03"
 THREE PLACE DECIMAL ± 0.005"
 INTERPRET GEOMETRIC
 TOLERANCING PER:
 COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

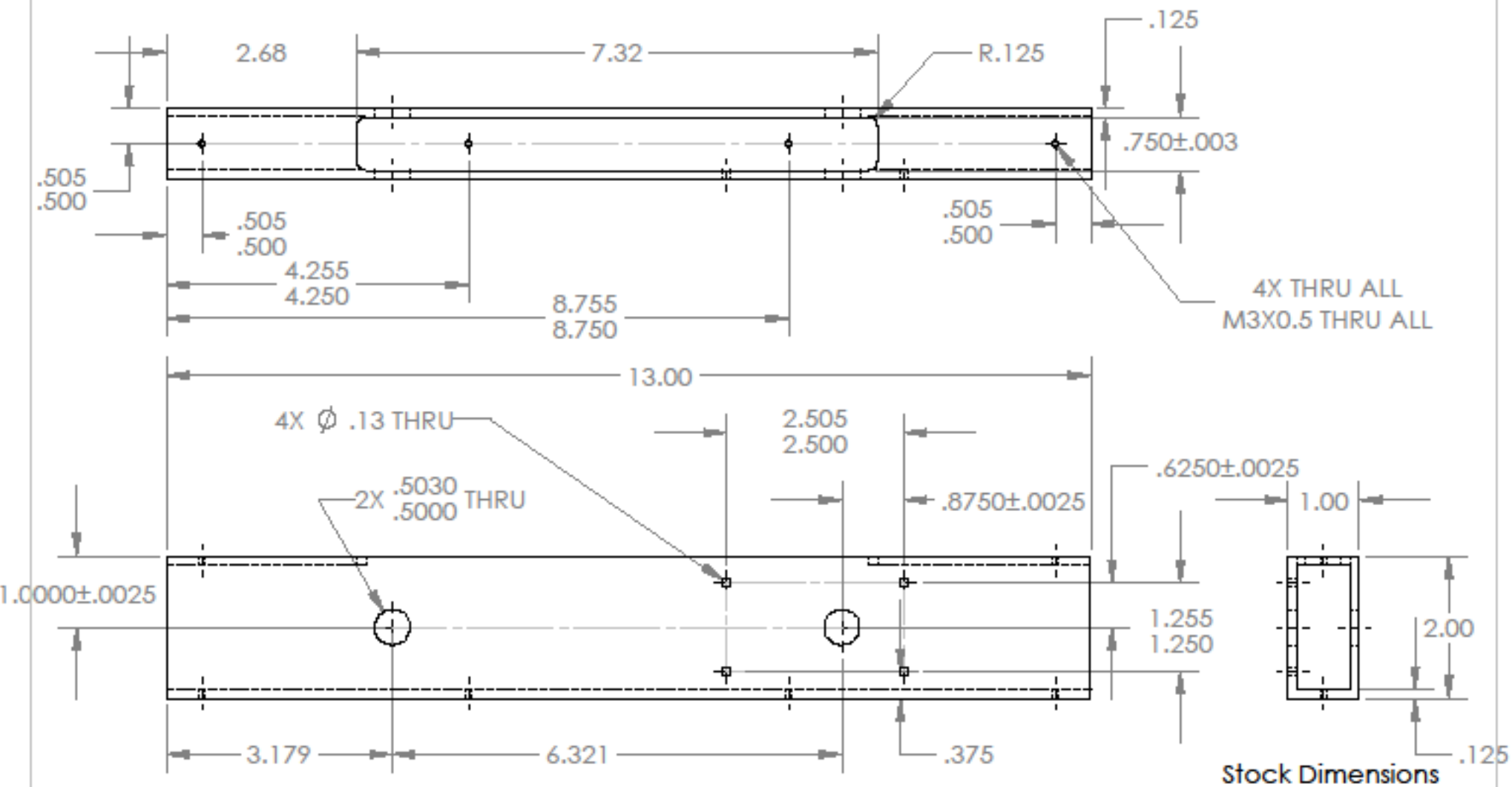
	NAME	DATE
DRAWN	Cole/Ivar	12/4/18
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	Al 6061	

MSU M. & I. E. DEPT.

TITLE: Frame Back

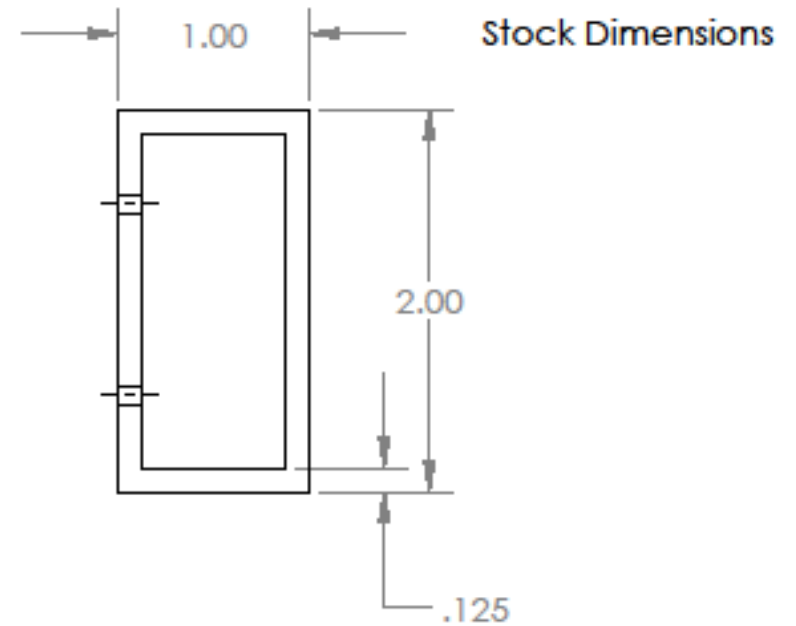
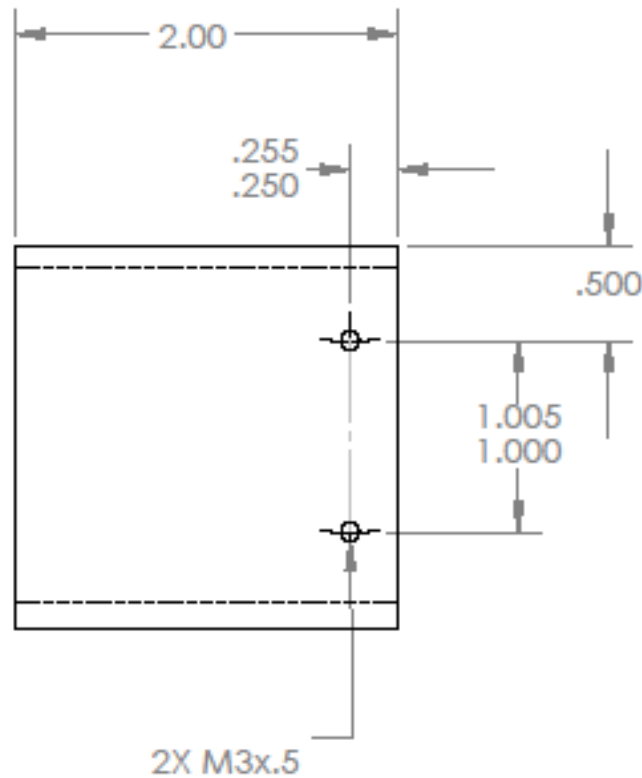
SIZE	DWG. NO.	REV
A	FR1	1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$ INTERPRET GEOMETRIC TOLERANCING PER: COMMENTS:		NAME	DATE	MSU M.& I.E. DEPT.		
		DRAWN	Cole/Ivar	11/26/18	TITLE: Frame Side 1		
		CHECKED					
		ENG APPR.			SIZE	DWG. NO.	REV
		MFG APPR.			A	FR2	1
	MATERIAL						
NEXT ASSY	DO NOT SCALE DRAWING	Al 6061			SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH $\pm .5$ BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

DRAWN

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

Al 6061

NAME

DATE

MSU M.& I.E. DEPT.

TITLE:

Frame Front

SIZE

DWG. NO.

REV

A

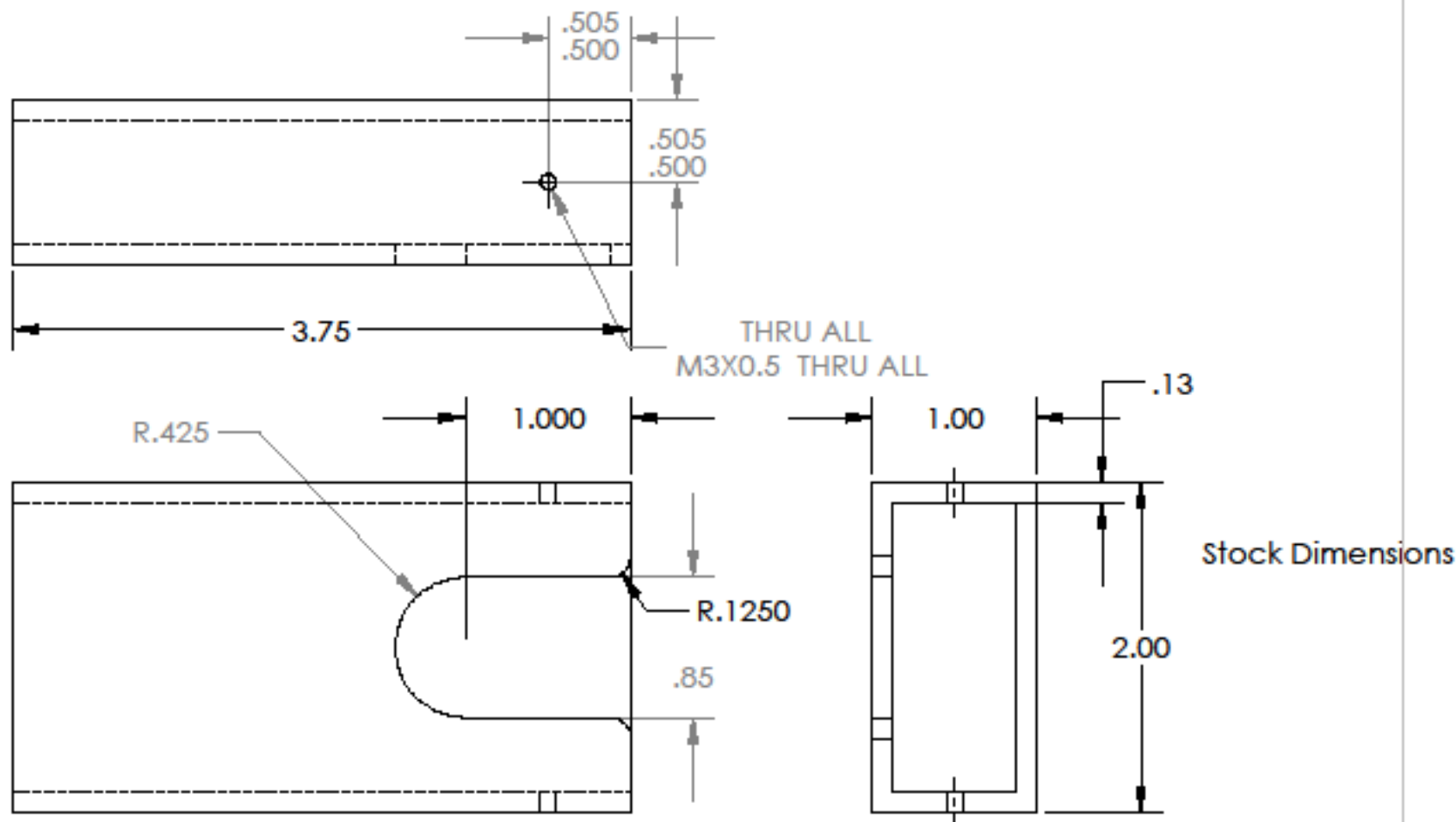
FR3

1

SCALE: 1:4

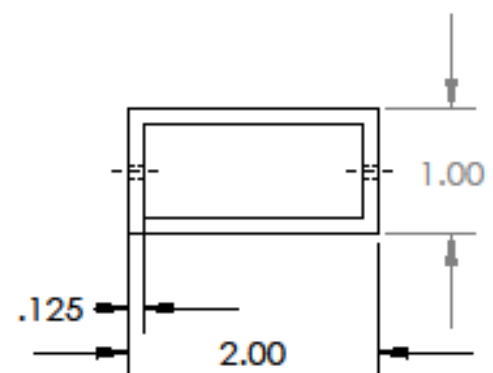
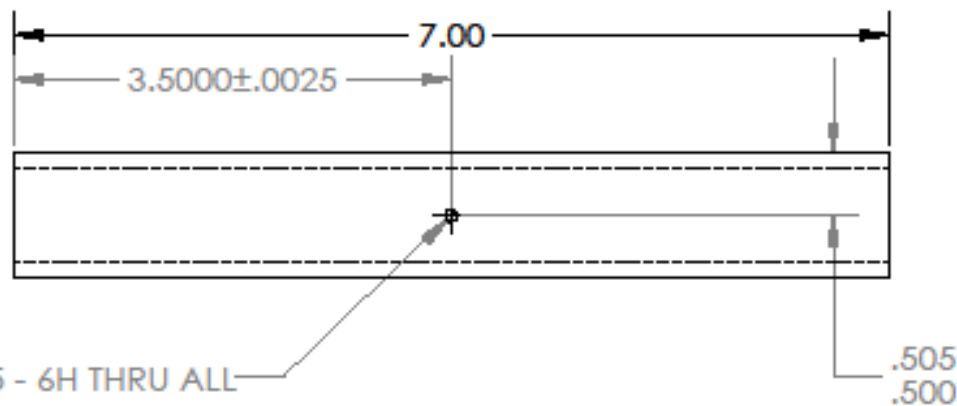
WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

NEXT ASSY	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH $\pm .5$ BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$ INTERPRET GEOMETRIC TOLERANCING PER:	NAME	DATE	MSU M. & I.E. DEPT.	
	COMMENTS:	DRAWN	Cole/Ivan	11/28/18	
	DO NOT SCALE DRAWING	CHECKED		TITLE: Frame Short Roller Arm	
		ENG APPR.		SIZE	DWG. NO.
		MFG APPR.		A	FR4
		MATERIAL	Al 6061		REV
				SCALE: 1:4	WEIGHT:
					SHEET 1 OF 1



Stock Dimensions

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH $\pm .5$ BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

NAME DATE

DRAWN Cole/tvar 11/26/18

CHECKED

BNG APPR.

MFG APPR.

MATERIAL

Al 6061

MSU M.& I.E. DEPT.

TITLE:

Frame Roller Spacer

SIZE

DWG. NO.

REV

A

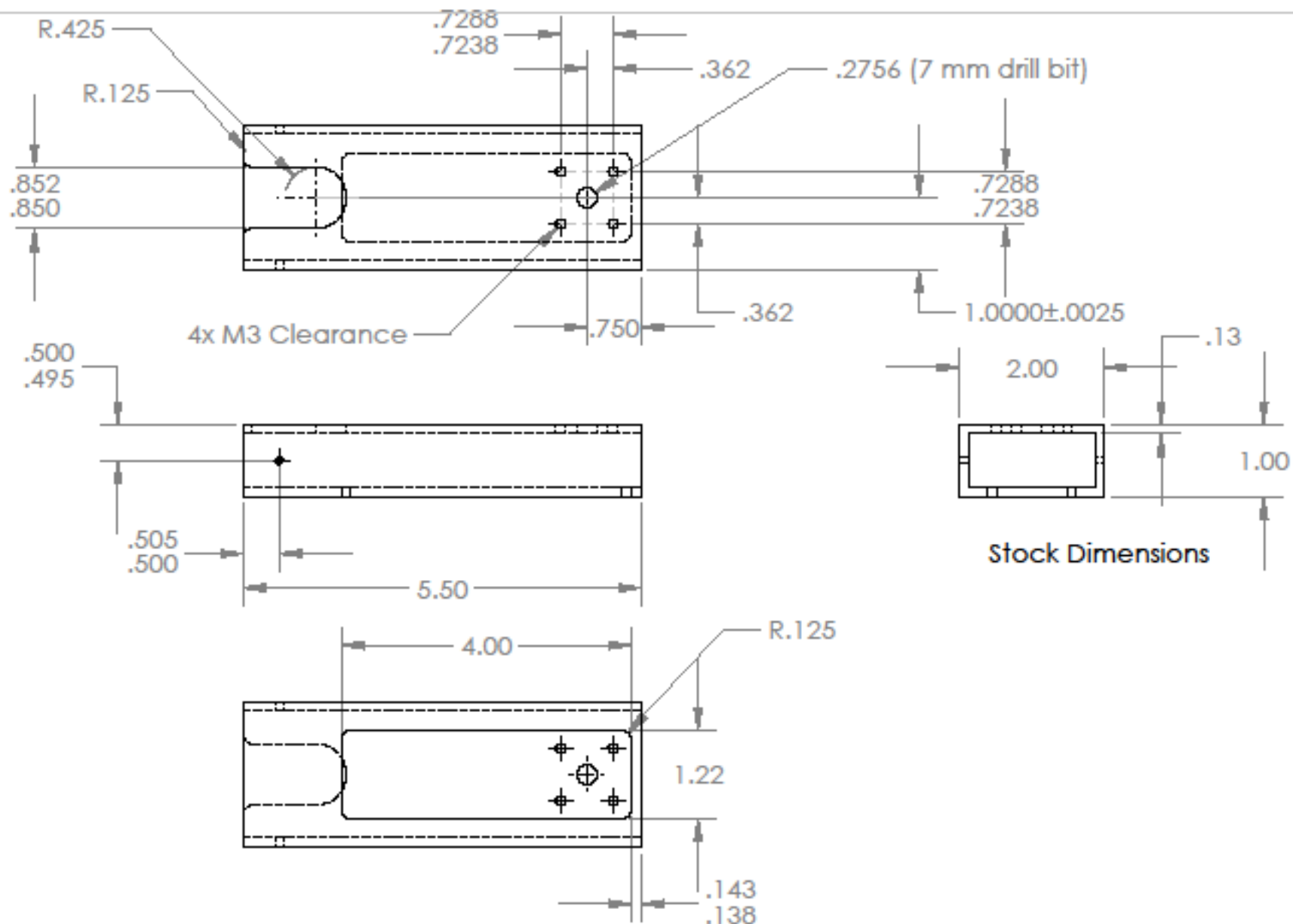
FR5

1

SCALE: 1:4

WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL $\pm 1/16"$
 ANGULAR: MACH ± 5 BEND ± 1
 TWO PLACE DECIMAL $\pm 0.03"$
 THREE PLACE DECIMAL $\pm 0.005"$
 INTERPRET GEOMETRIC
 TOLERANCING PER:
 COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

Al 6061

	NAME	DATE
DRAWN	Cole/Ivan	11/26/18
CHECKED		
ENG APPR.		
MFG APPR.		

MATERIAL

MSU M. & I.E. DEPT.

TITLE:

Roller/Belt Housing

SIZE
A

DWG. NO.

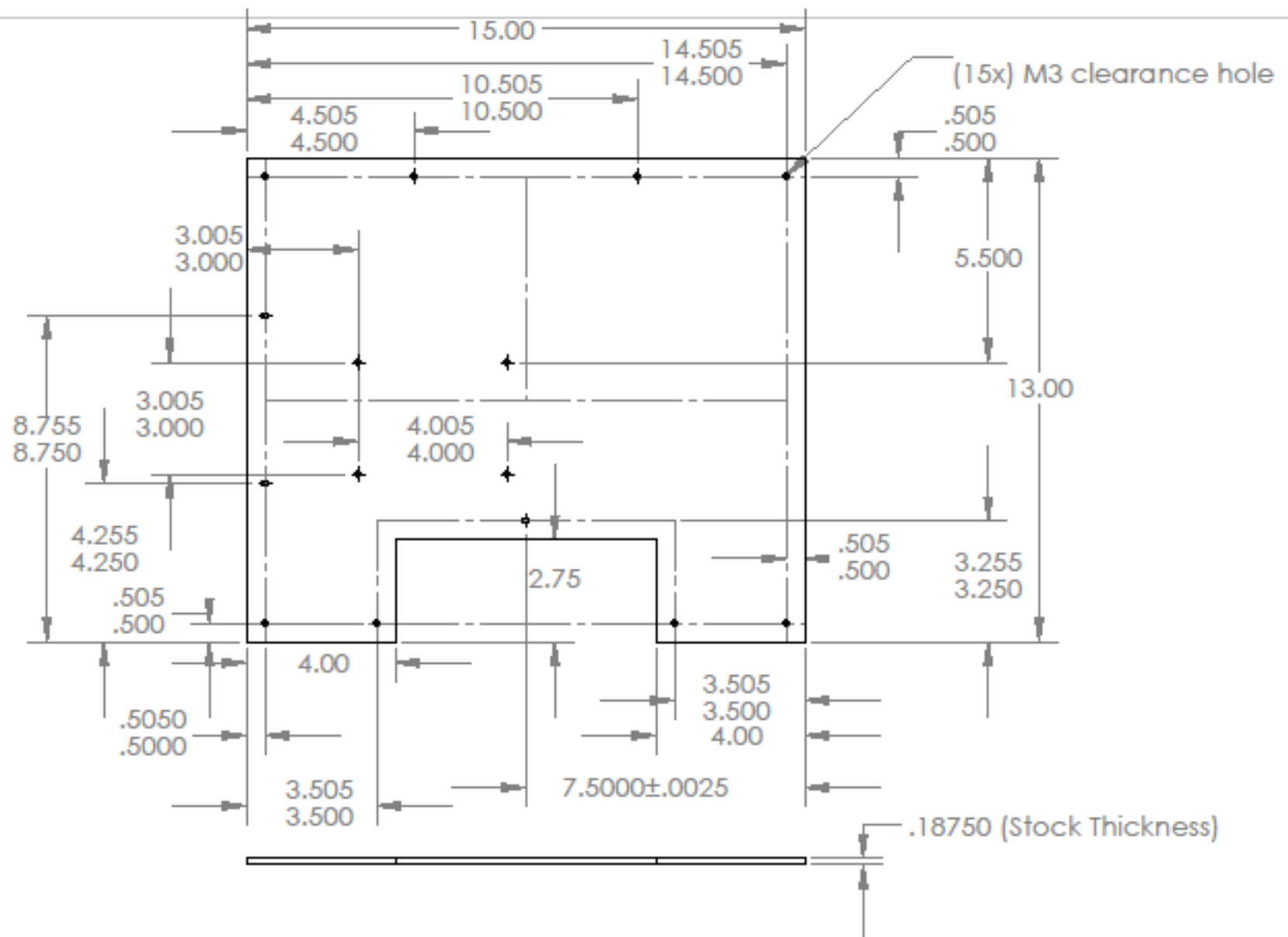
FR6

REV
1

SCALE: 1:4

WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL 1/16"
 ANGULAR: MACH 5 BEND 1
 TWO PLACE DECIMAL 0.03"
 THREE PLACE DECIMAL 0.005"
 INTERPRET GEOMETRIC
 TOLERANCING PER:
 COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Cole/Ivan	11/25
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL		
- Al 6061		

MSU M.& I.E. DEPT.

TITLE:
Armor Plate (Bottom)

SIZE	DWG. NO.	REV
A	AP1	
SCALE: 1:8	WEIGHT: 3.21	SHEET 1 OF 1

11X Ø .13 THRU ALL

12.505
12.500

8.755
8.750

.505
.500

.5050
.5000

3.505
3.500

4.00

2.75

4.00

.505
.500

3.505
3.500

4.00

13.00

.18750 (Stock Thickness)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL $\pm 1/16"$

ANGULAR: MACH $\pm .5$ BEND ± 1

TWO PLACE DECIMAL ± 0.03

THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC

TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

NAME

DATE

MSU M. & I. E. DEPT.

TITLE:

Armor Plate (Top)

SIZE

DWG. NO.

REV

A

AP2

SCALE: 1:8

WEIGHT: 3.21

SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

NEXT ASSY

DO NOT SCALE DRAWING

MATERIAL

-

AI 6061

DRAWN

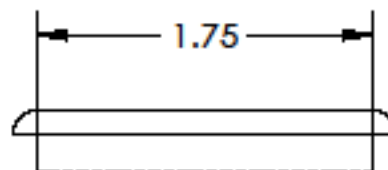
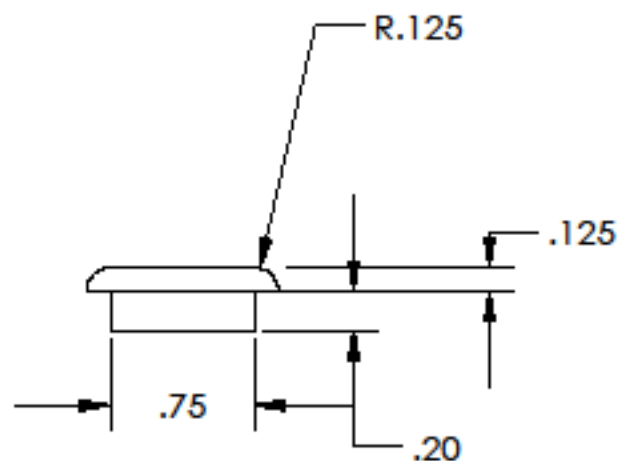
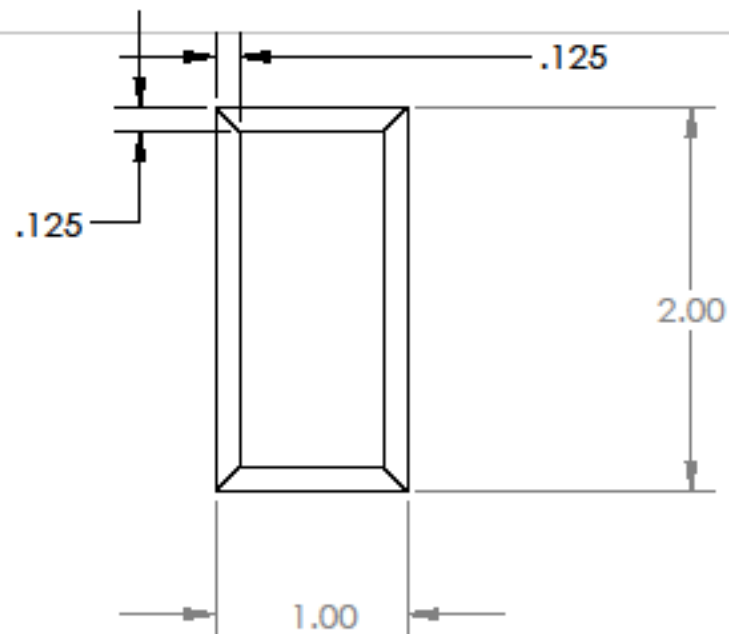
Colw/ivan

11/25

CHECKED

ENG APPR.

MFG APPR.



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS: 3D Print

DO NOT SCALE DRAWING

NAME

DATE

MSU M.& I.E. DEPT.

DRAWN

C.T

12/1/18

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

-

TITLE:

Tube Cap

SIZE

A

DWG. NO.

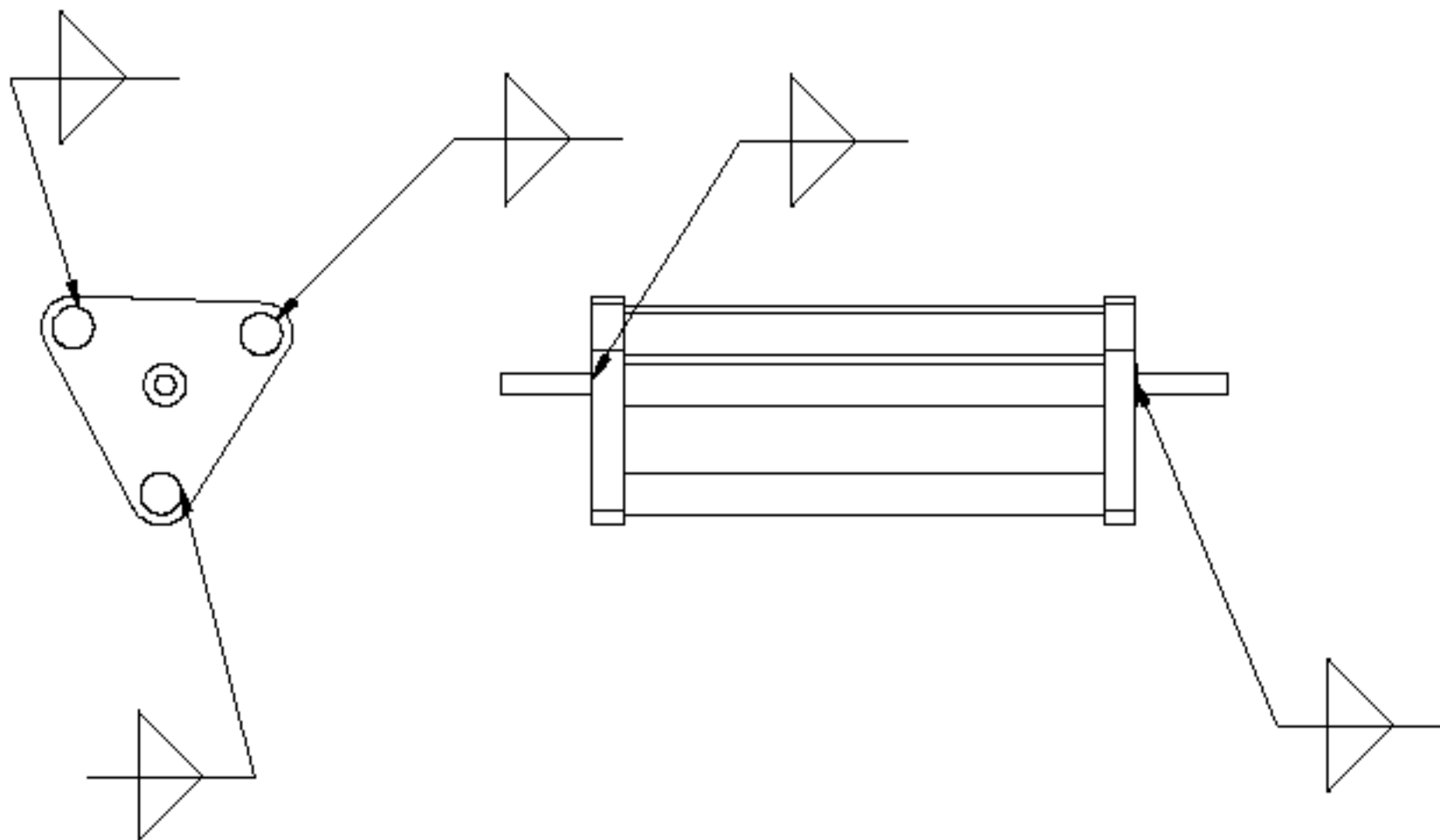
TC1

REV

SCALE: 2:1

WEIGHT: 0.02

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH $\pm .5$ BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

NEXT ASSY

NAME

DATE

DRAWN

KF

-

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

-

MSU M. & I.E. DEPT.

TITLE: Roller Weld

SIZE

A

DWG. NO.

RA1

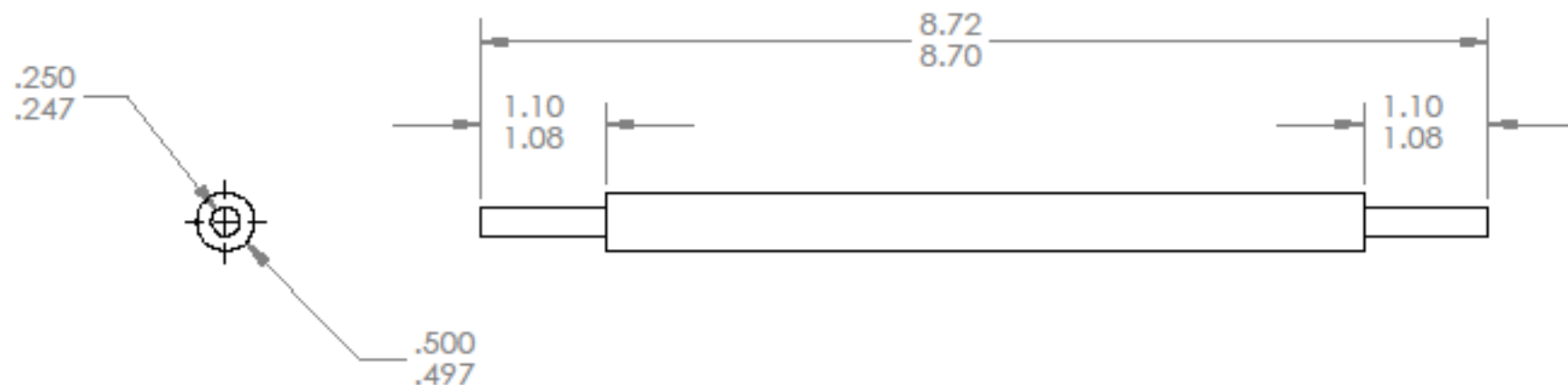
REV

1

SCALE: 1:4

WEIGHT:

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL $\pm 1/16"$
 ANGULAR: MACH ± 5 BEND ± 1
 TWO PLACE DECIMAL $\pm 0.03"$
 THREE PLACE DECIMAL $\pm 0.005"$
 INTERPRET GEOMETRIC
 TOLERANCING PER:

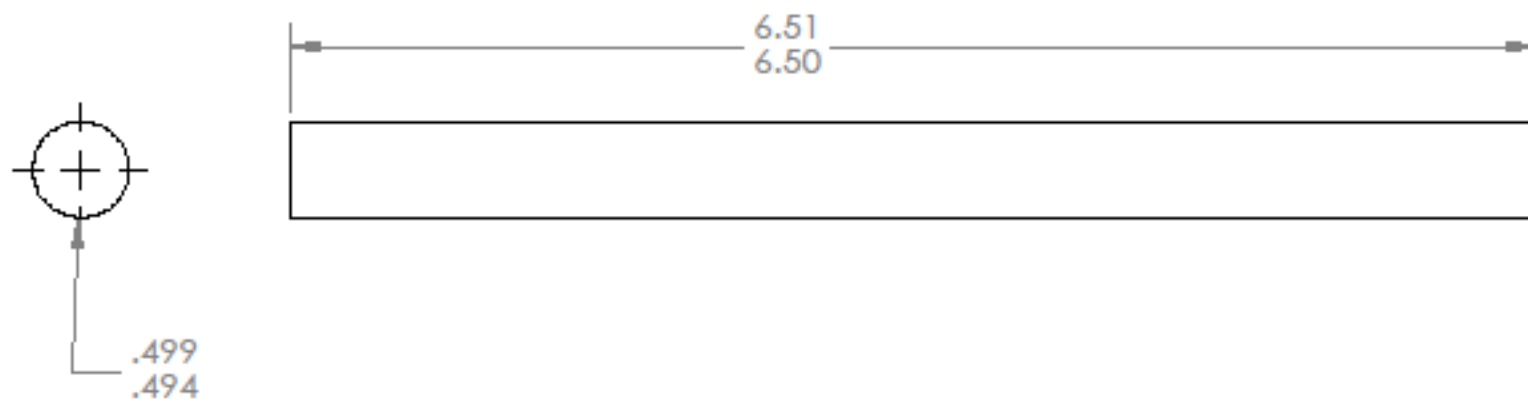
COMMENTS:
 DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.T	11/27/18
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL	1020 Steel	
	-	

MSU M.& I.E. DEPT.

TITLE:
 Roller Axle

SIZE	DWG. NO.	REV
A	RB2	
SCALE: 1:2	WEIGHT: 0.40	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL $\pm 1/16"$
 ANGULAR: MACH ± 5 BEND ± 1
 TWO PLACE DECIMAL $\pm 0.03"$
 THREE PLACE DECIMAL $\pm 0.005"$
 INTERPRET GEOMETRIC
 TOLERANCING PER:

COMMENTS:

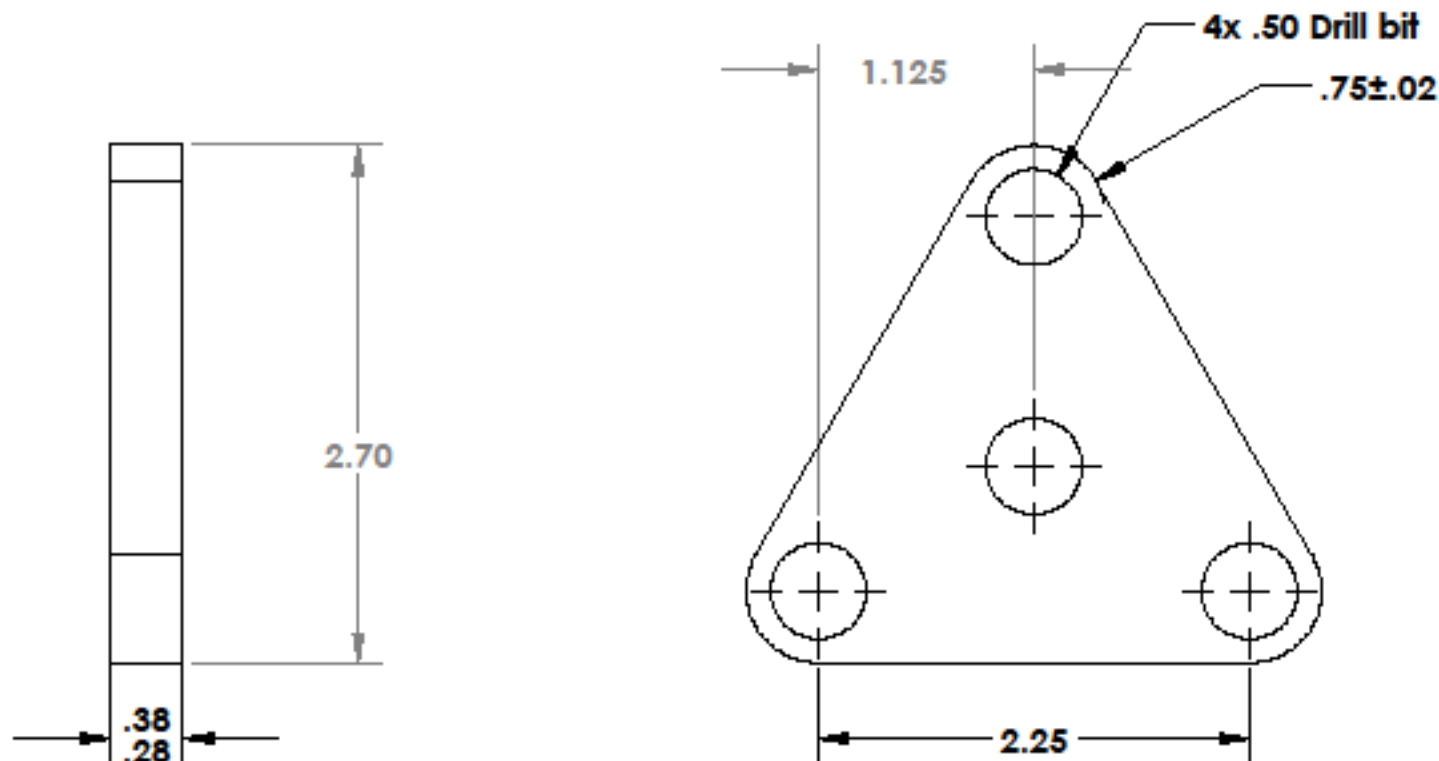
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.T	11/27/18
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL 1020 Steel		
-		

MSU M.& I.E. DEPT.

TITLE:
Roller Bar

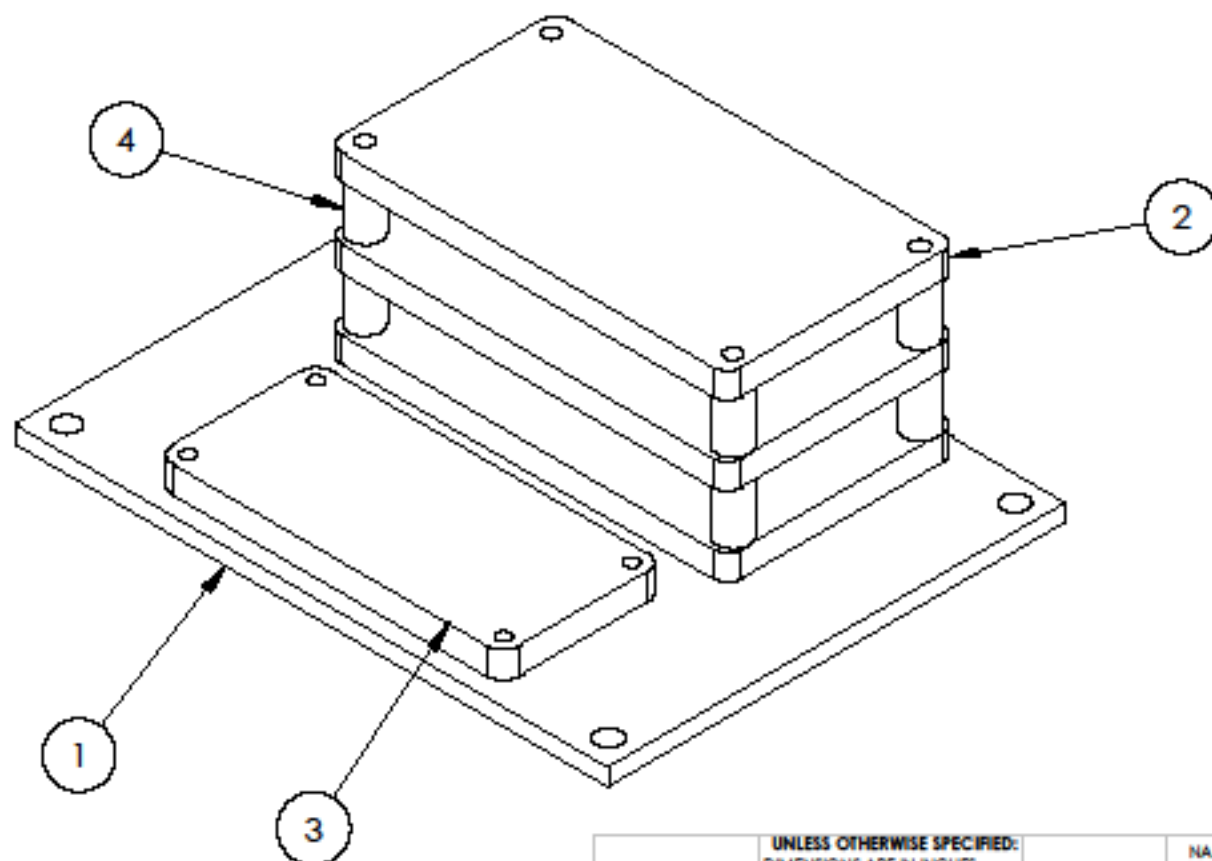
SIZE	DWG. NO.	REV
A	RB1	
SCALE: 1:2	WEIGHT: 0.40	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$ INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE	MSU M. & I.E. DEPT.	
		DRAWN	C.T	12/2/18	TITLE: Roller Hub
COMMENTS:	NEXT ASSY	CHECKED			SIZE A
		ENG APPR.			DWG. NO. RH1
DO NOT SCALE DRAWING		MFG APPR.			REV
		MATERIAL 1020 Steel			SCALE: 1:1
					WEIGHT: 0.47
					SHEET 1 OF 1

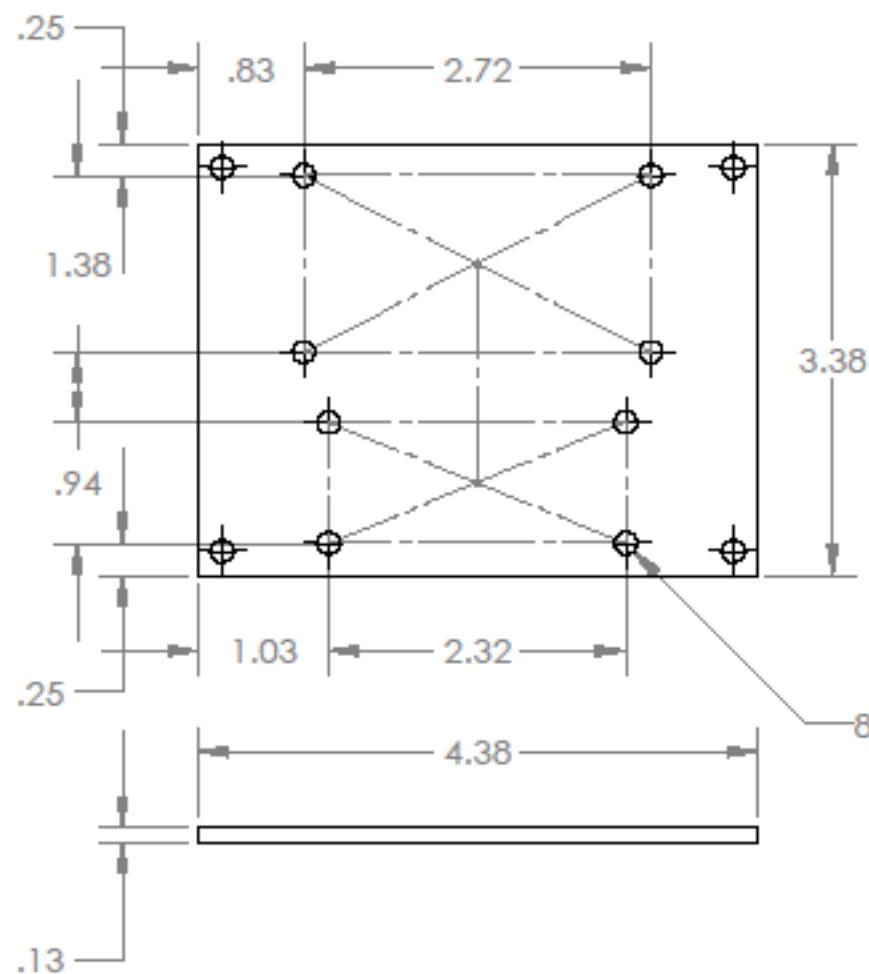
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Electronic Mounting Plate	EM1	1
2	Motor Control Board	Cytron 13A, 5-30V Single DC Motor Controller	3
3	Raspberry Pi	Raspberry Pi Zero W	1
4	92871A013	10mm M3 Aluminum Standoff	8



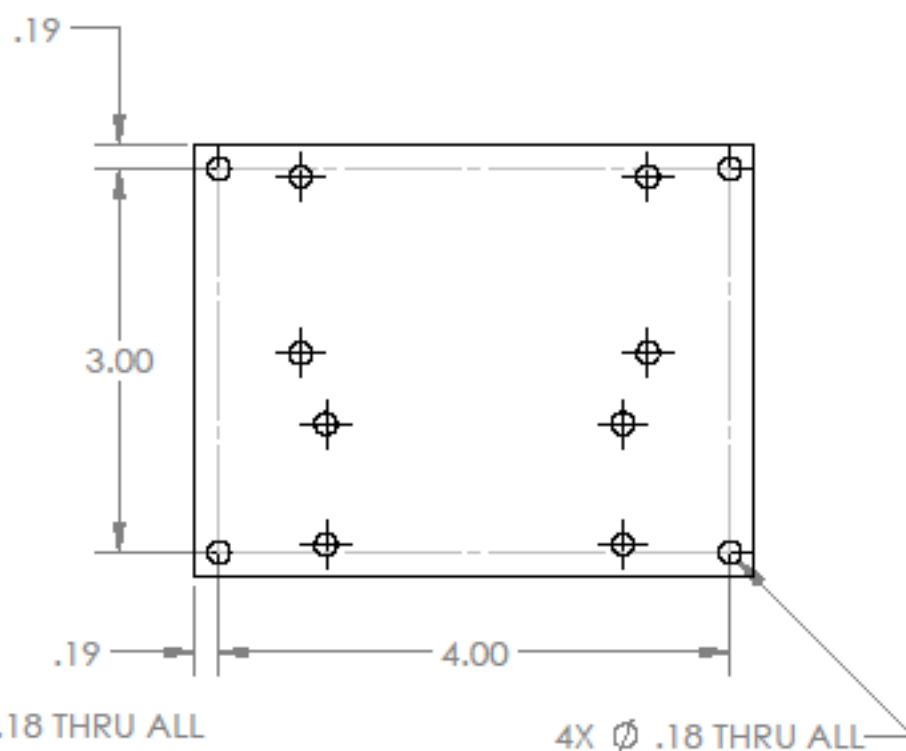
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH $\pm .5$ BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$ INTERPRET GEOMETRIC TOLERANCING PER: COMMENTS: NEXT ASSY DO NOT SCALE DRAWING			NAME	DATE	MSU M.& I.E. DEPT. TITLE: Electronical Mounting Assembly			
		DRAWN	KF	-				
		CHECKED			SIZE A	DWG. NO. EMA1	REV 1	
		ENG APPR.						
		MFG APPR.			SCALE: 1:2 WEIGHT: SHEET 1 OF 1			
		MATERIAL						

Top View: Component Mounting Holes



Top View: Frame Mounting Holes



8X \varnothing .18 THRU ALL

4X \varnothing .18 THRU ALL

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

NAME

DATE

DRAWN

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

-

MSU M.& I.E. DEPT.

TITLE:

- Electronics Mounting Plate

SIZE

DWG. NO.

REV

A

EM1

1

SCALE: 1:2

WEIGHT: 0.18

SHEET 1 OF 1

Technical drawing of a square plate with dimensions and hole locations. The plate has a total width of 3.38 and a total height of 3.38. The drawing shows a 3x3 grid of holes. The center hole is located at the center of the plate. The four corner holes are located at the corners of the plate. The four holes in the middle row and middle column are located at the intersections of the center lines. The dimensions are as follows:

- Top edge: .25 (from top edge to center line), .83 (from center line to center of corner hole), 2.722 (from center of corner hole to center of middle hole), 2.717 (from center of middle hole to center of corner hole).
- Left edge: .25 (from left edge to center line), 1.38 (from center line to center of middle hole), .950 (from center of middle hole to center of corner hole), .945 (from center of corner hole to center line).
- Bottom edge: .25 (from bottom edge to center line), 1.03 (from center line to center of middle hole), 2.32 (from center of middle hole to center of corner hole).
- Right edge: 3.38 (total height).

The drawing also shows a dashed line forming a square around the center hole, and a dashed line forming a square around the four corner holes. A leader line points to the corner hole with the label "8X".

Technical drawing of a rectangular plate with the following specifications:

- Overall width: 4.00
- Overall height: 3.00
- Corner hole diameter: $\phi .188$
- Internal hole pattern: 4X $\phi .13$ THRU ALL
- Material: 6 (6mm)

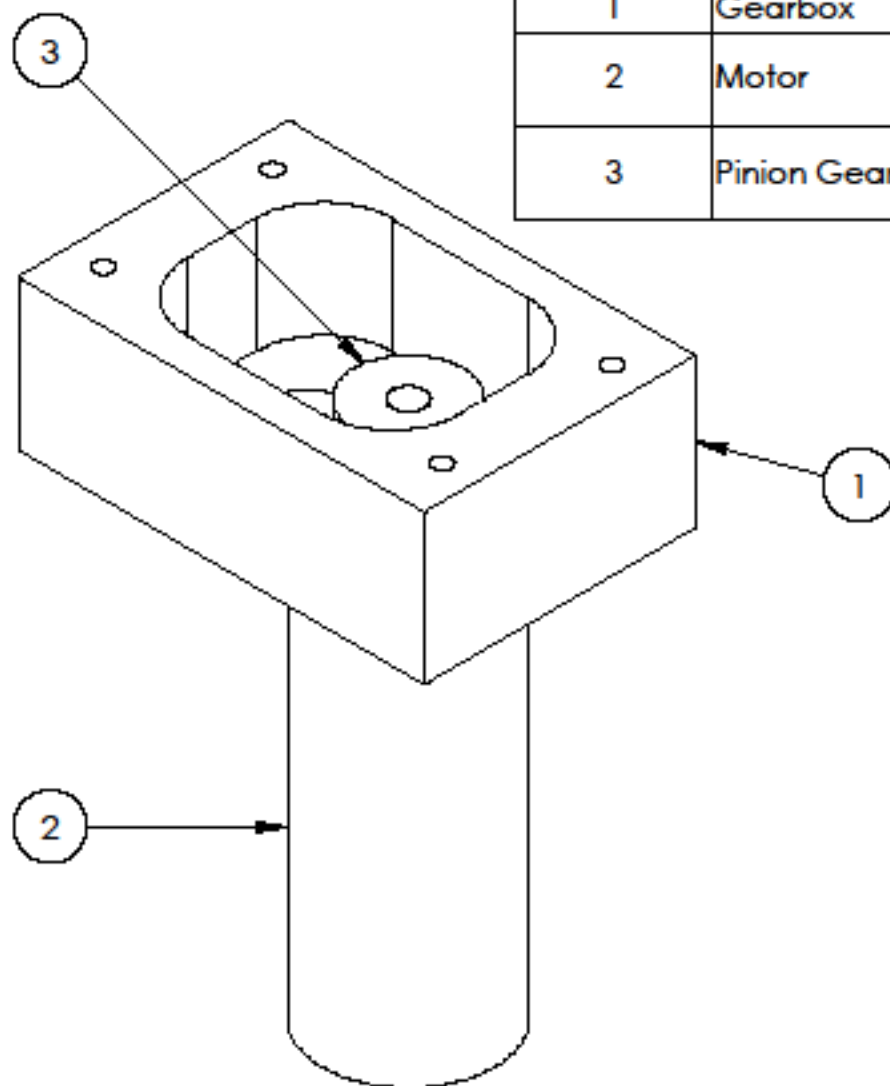
-8X .236 (6mm) 4X Ø .13 THRU ALL

Technical drawing of a mechanical part. The drawing shows a side view of a component with a horizontal length dimension of 4.38 and a vertical dimension of .25. The part has a central rectangular feature with a smaller rectangular cutout on the left side. The drawing is a black and white line drawing with dimension lines and arrows indicating the measurements.

	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH $\pm .5$ BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$		NAME	DATE
		DRAWN	Ivan	11/30/10
		CHECKED		
		ENG APPR.		
	INTERPRET GEOMETRIC TOLERANCING PER:	MFG APPR.		
	COMMENTS:	MATERIAL Foam		
NPVT ASSY	DO NOT SCALE DRAWING	-		

SCALE: 1:2 WEIGHT: 0.02 SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Gearbox	Machined Gearbox	1
2	Motor	84 RPM HD Premium Planetary Gear Motor	1
3	Pinion Gear	6mm Bore 48 Pitch Shaft Mount Pinion Gear	1



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL $\pm 1/16"$
 ANGULAR: MACH ± 5 BEND ± 1
 TWO PLACE DECIMAL $\pm 0.03"$
 THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
 TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

NAME

DATE

DRAWN

KF

-

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

-

MSU M.& I.E. DEPT.

TITLE: Gearbox Assembly

SIZE

DWG. NO.

REV

A

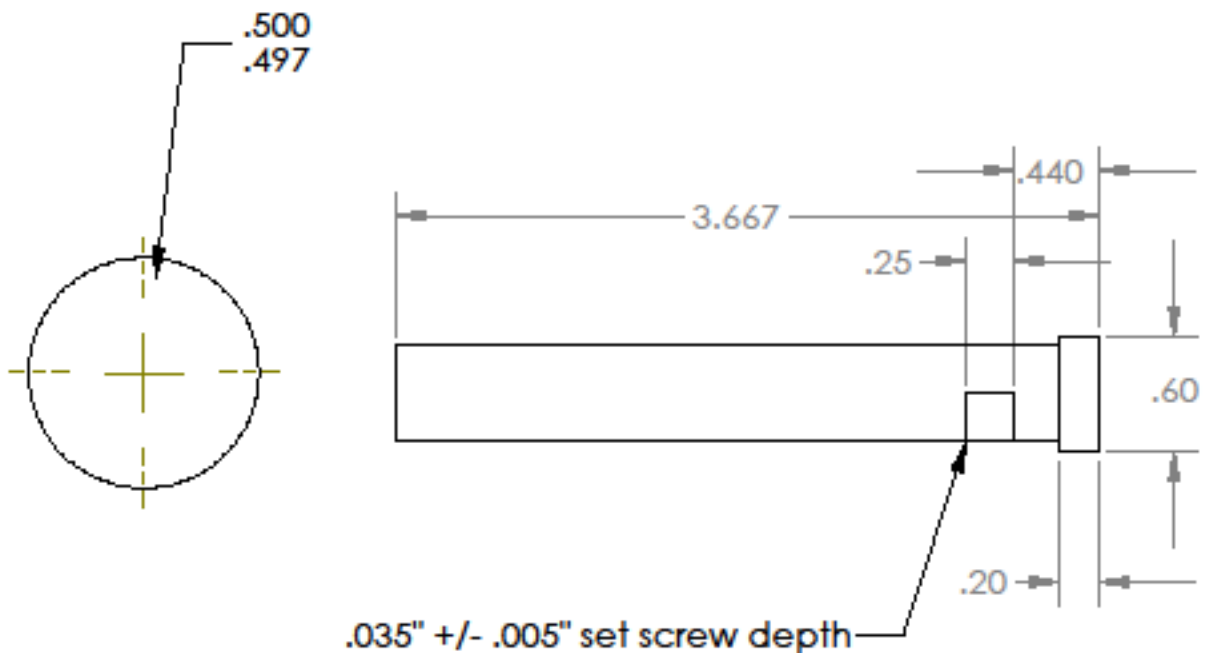
GBA1

1

SCALE: 1:2

WEIGHT:

SHEET 1 OF 1

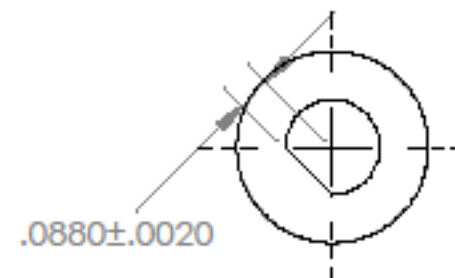
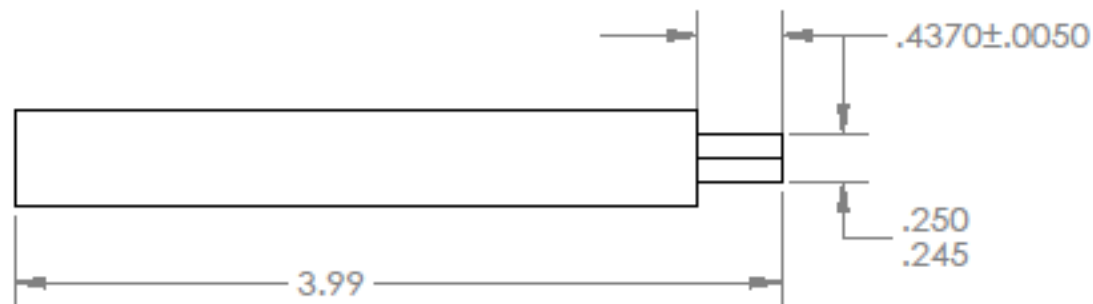
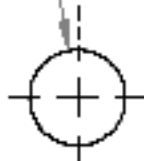


PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL $\pm 1/16"$ ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL $\pm 0.03"$ THREE PLACE DECIMAL $\pm 0.005"$ INTERPRET GEOMETRIC TOLERANCING PER:	NAME	DATE
	COMMENTS:	DRAWN	C.T
		CHECKED	
		ENG APPR.	
		MFG APPR.	
		MATERIAL	
		1020 Steel	
NEXT ASSY	DO NOT SCALE DRAWING		

MSU M.& I.E. DEPT.		
TITLE: Axle Front		
SIZE A	DWG. NO. AF1	REV
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

.4988
.4978

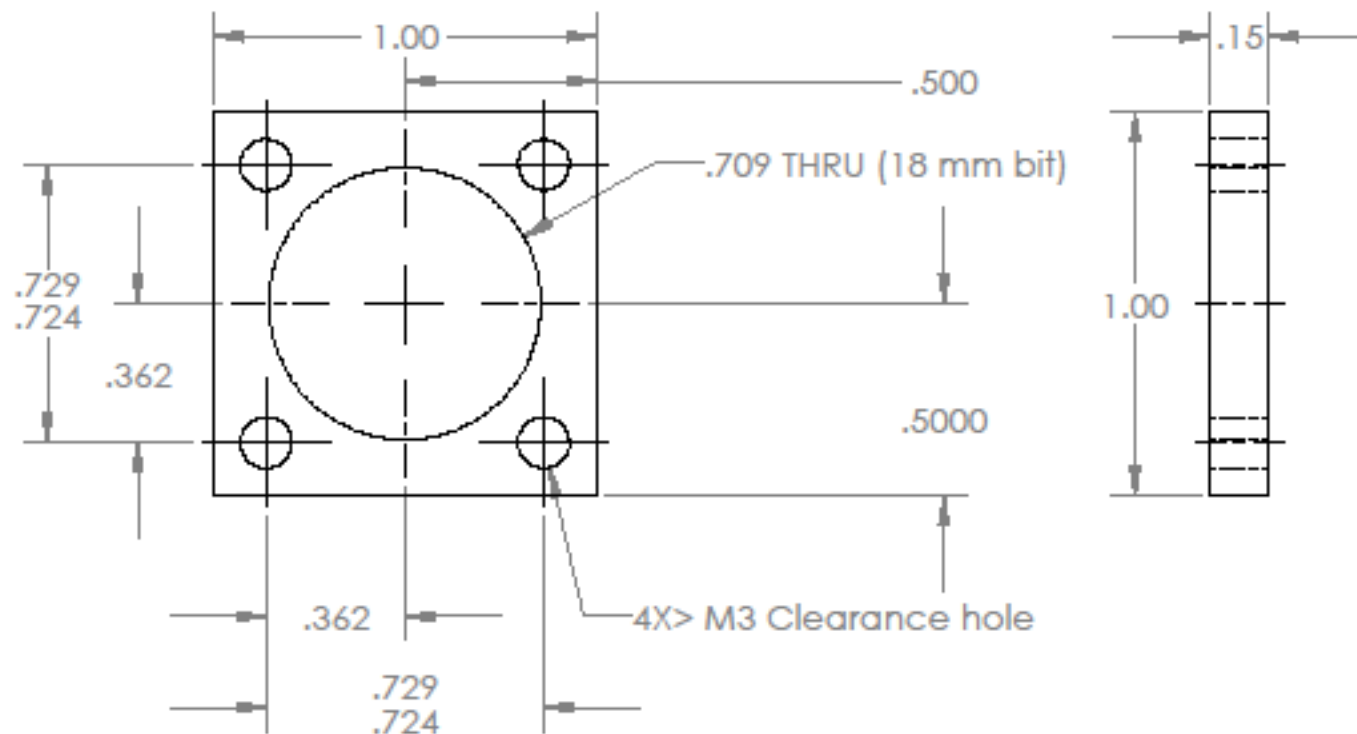


PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:
COMMENTS:
NEXT ASSY DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.T	12/2/18
CHECKED		
ENG APPR.		
MFG APPR.		
MATERIAL 1020 Steel		

MSU M. & I.E. DEPT.		
TITLE: Axle Rear		
SIZE A	DWG. NO. AR1	REV
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$
INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

NAME

DATE

DRAWN

Cole/Ivan

12/5/18

CHECKED

ENG APPR.

MFG APPR.

MATERIAL

Al 6061

-

MSU M.& I.E. DEPT.

TITLE:

Weapon Motor Mount

SIZE

DWG. NO.

REV

A

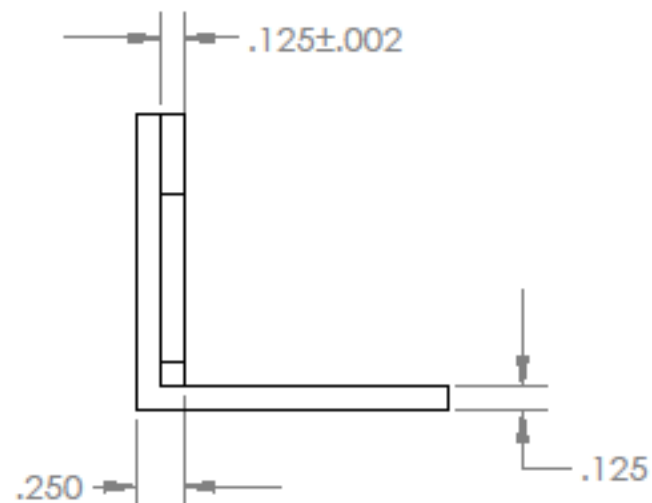
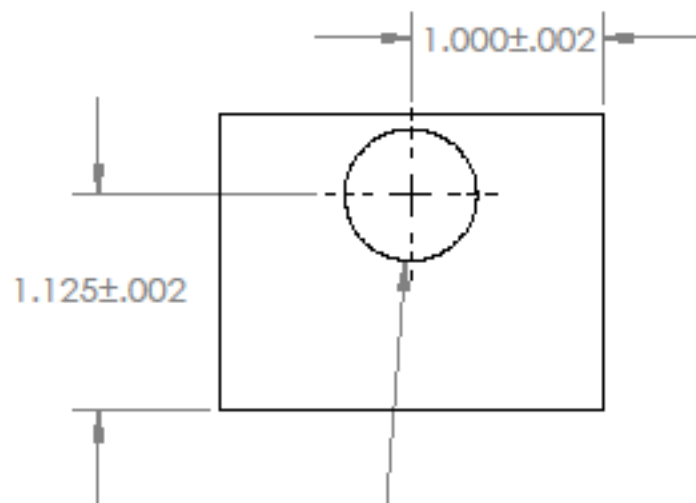
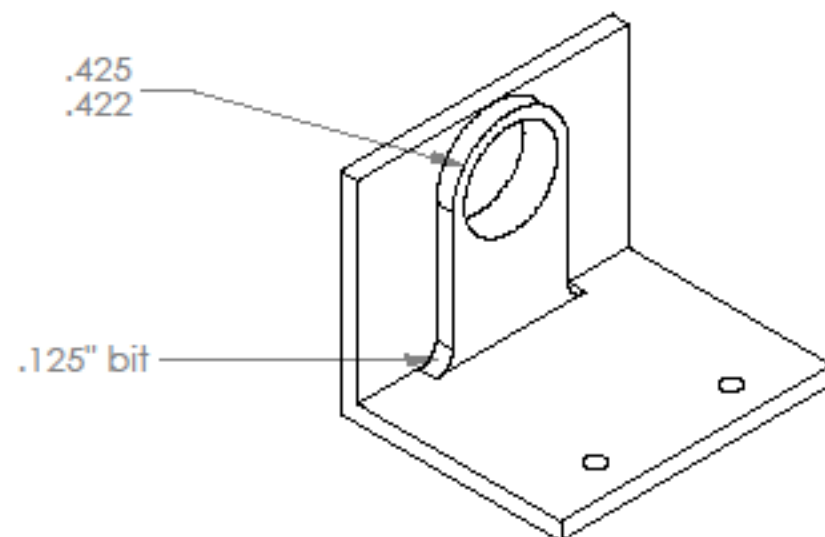
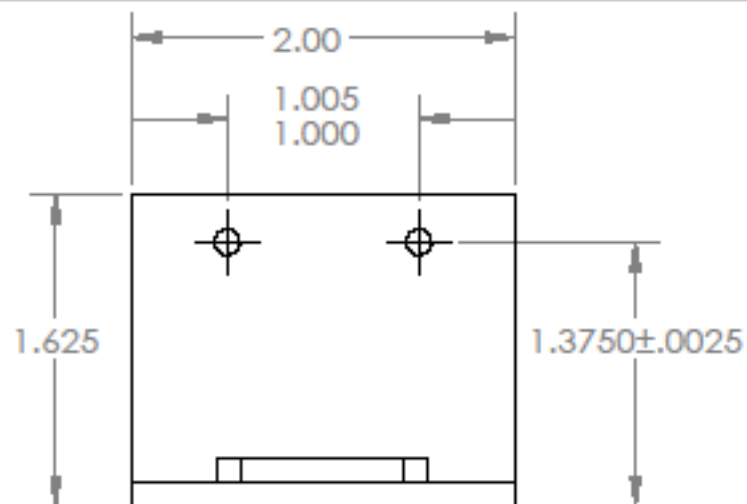
MM1

1

SCALE: 2:1

WEIGHT: 0.00

SHEET 1 OF 1



11/16" drill bit

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

DRAWN
CHECKED
ENG APPR.

MFG APPR.

MATERIAL
AL 6061

-

NAME

DATE

C.T

12/5/18

MSU M. & I.E. DEPT.

TITLE:

Roller Mount

SIZE

A

DWG. NO.

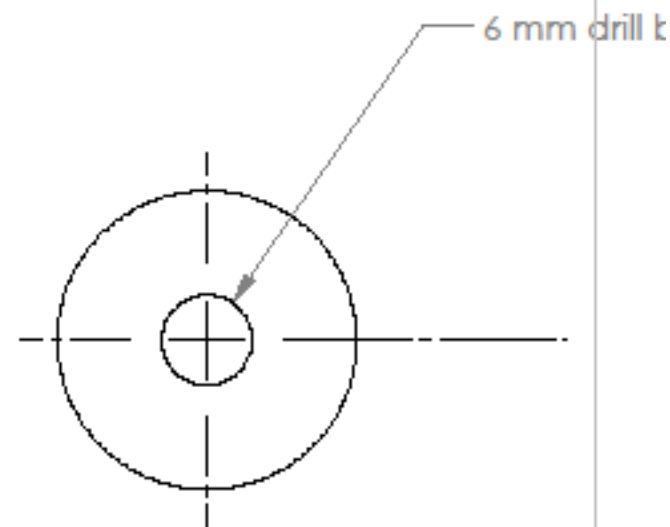
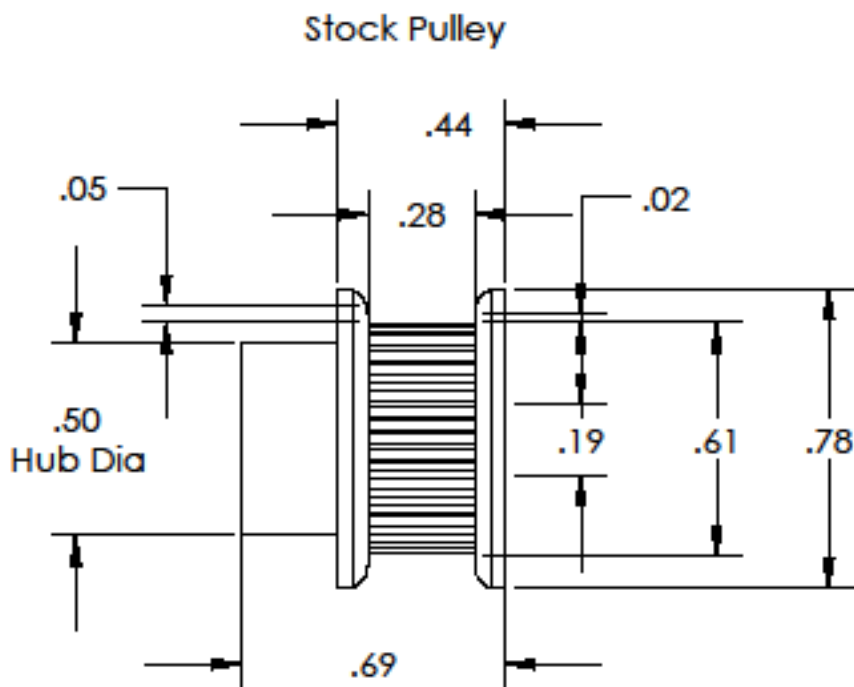
RM1

REV

SCALE: 1:1

WEIGHT: 0.08

SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
DRAWING IS THE SOLE PROPERTY OF
<INSERT COMPANY NAME HERE>. ANY
REPRODUCTION IN PART OR AS A WHOLE
WITHOUT THE WRITTEN PERMISSION OF
<INSERT COMPANY NAME HERE> IS
PROHIBITED.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL $\pm 1/16"$
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL $\pm 0.03"$
THREE PLACE DECIMAL $\pm 0.005"$

INTERPRET GEOMETRIC
TOLERANCING PER:

COMMENTS:

NEXT ASSY

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.T	12/4/18
CHECKED		
ENG APPR.		
MFG APPR.		

MATERIAL
Polycarbonate

MSU M. & I.E. DEPT.

TITLE: **Motor Puller (Roller)**

SIZE	DWG. NO.	REV
A	P2	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

Appendix F: Economic Analysis

The budget plan given in this section is the expected cost to build the battlebot. The team will start ordering the parts by the mid of December 2018: after finalizing the design.

Table D-1: Materials need to be Purchased

Part Number	Description	Quantity	Unit cost	Total Expected Cost
1	165 RPM HD Premium Planetary Gear Motor	2	\$39.99	\$79.98
2	Cytron 13A, 5-30V Single DC Motor Controller	4	\$13.82	\$55.28
3	Raspberry Pi Zero W	2	\$10.00	\$20.00
4	Tenergy NiMH 12V 4200mAh Rechargeable Battery Pack	2	\$69.99	\$139.98
5	RC Servo BEC UBEC 3A 5V (Receiver servo Power supply)	1	\$7.99	\$7.99
6	1,621 RPM HD Premium Planetary Gear Motor	1	\$39.99	\$39.99
7	6063-T52 Aluminum Rectangle Tube (2X1X1/8 Wall)	1	\$32.15	\$32.15
8	3/16" Aluminum Plate (2'x3')	1	\$107.00	\$107.00

9	5/8" Hot Rolled A-36 Steel Round	1	\$5.14	\$5.14
10	1/2" Hot Rolled A-36 Steel Round	1	\$6.60	\$6.60
11	Bearing	4	\$11.00	\$44.00
12	Roller Bearing	2	\$10	\$20.00
13	Pulley	4	\$16.00	\$64.00
14	Driving Belt	2	\$6.00	\$12.00
15	36 tooth driven gear	2	\$22.00	\$44.00
16	36 tooth pinion gear	2	\$13.00	\$26.00
17	5" wheels/hubs	6	\$16.00	\$96.00
18	Screws	1	\$20.00	\$20.00
	Total			\$820.11

The manufacturing plan is mostly based on CNC machining and welding. The screws will be used to fasten the components to the base. So, the estimated manufacturing expenses are listed below in the table. Fortunately, these manufacturing costs are waived by allowing the team to work and use the materials in the university makerspace for free.

Table D-2: Manufacturing Cost

Description	units	Unit cost	Total expected cost
CNC lathe	3 hrs	\$90/ hr	\$ 270.00
CNC milling	3 hrs	\$90/ hr	\$ 270.00
Welding	5 hrs	\$60/ hr	\$ 300.00
Electrodes for welding	2 boxes	\$19.97/ Box	\$ 39.94
Conventional milling	4 hrs	\$75/ hr	\$ 300.00
Conventional turning	4 hrs	\$75/ hr	\$ 300.00

Appendix G: Project Academic Assessment

Course #	Course	How it helped
EGEN 201	Statics	Used to calculate the friction provided, minimum force from friction
EGEN 205	Mechanics of Materials	Used to calculate torque, bending stress, shear stress of the structures
EMEC 103	Computer Aided Engineering 1	SolidWorks modelling, assemblies and drawing packages knowledge to start modelling
ETME 215	Manufacturing Processes	Understanding of how the parts are to be manufactured
EMEC 405	Finite Element Analysis	Used to calculate how failure of each selected components occur
EMEC 342	Machine component Design	Understanding of what bearings, and shaft features to be used
EGEN 310	Multidisciplinary Design	Experience working with a group, with various helpful intro to the project management
EELE 250	Circuits, Devices and Motors	Internal wiring of the vehicle
EELE 371	Microprocessor HW and SW Systems	Experience working with microcontrollers and using them to communicate with other
ETME 303	CAE Tools in Mech Design	Experience with setting up and running solidworks FEA
ETME 310	Machining/Industrial Safety	Machining (lathe,mill,tap,etc) knowledge
ETME 311	Joining Processes	Welding Knowledge
ETME 341	Machine Design	Gear/Pulley assembly knowledge