2018 UC BattleBot Team
60 lb Competition

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
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in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

The Mechanical Engineering Technology (MET) program at the University of Cincinnati requires all students to complete a senior design project to graduate. The students are expected to apply their curriculum knowledge to design and build a physical product to present to the University staff. The faculty members approve and advise projects for every student in our class. Each team is assigned an advisor that is available for guidance and ultimately grades our project. We have selected the 2018 Battlebot team (60 lb robot) as our senior design project.

We designed and manufactured a 60 lb Battlebot to adhere to and maintain all rules and standards of the RoboGames competition annually held in Pleasanton, CA. This robot attacks and defends itself during a one-on-one combat fight with the competitor's robot. At this point the Battlebot will not be competing as the competition is the same day as our college's graduation ceremony. What we have accomplished is a successful display of our well rounded basis of skill learned in the last five years. By utilizing all of these techniques learned at the University and in Co-ops we have successfully created a complete Battlebot.

Our BattleBot has four main areas of focus:

1. Weapon
2. Drive Train
3. Electronics/Controls
4. Frame/Armor

The team responsibilities are divided between the two team members:

1. Ryan South: Weapon and Electronics/Controls
2. Carson Burden: Drive Train and Frame/Armor

INTRODUCTION

PROBLEM STATEMENT

To design and manufacture a functional 60lbs Battlebot that adheres to RoboGames rules and regulations.

BACKGROUND

The RoboGames began in 2004, founded by David Calkins, then president of the non-profit Robotics Society of America (RSA). The goal was to create a ROBO Olympics in order to allow all different types of robots to compete on one stage (1). Today RoboGames hosts over seventy competitions for robot builders to showcase their skills. There are many competitive divisions other than fighting robots such as robot soccer, art bots, and sumo bots only to name a few. The new platform created by RoboGames has allowed collaboration of robot builders to be at the forefront. By builders of one discipline being in the same competitive room as builders of another discipline the RoboGames hopes to advance the technology used in every competitive class and therefore grow the robot community as a whole. Although currently leading the competition front, RoboGames does not cover the history of fighting robots. The start of fighting robots began in 1994 with garage built robots in San Francisco (2). The televised experience of combat robots began in 1998 and lasted for five years, here Kelsey Atherton believes the wedge style robot was the demise of the new show 'Robot Wars' success (2). The wedge bot is extremely effective yet extremely boring to watch. Boring to watch does not lead to a TV series remaining for very long. For now the combat robot arena does not receive major television coverage but is still a huge part of the robot building community. The RoboGames competition in San Francisco every April attracts competitors from around the world.

SCOPE OF THE PROBLEM

The problem addressed in this project is to compete and win the RoboGames 60lb combat class. This is being addressed in order to fulfill our requirements to graduate from the University of Cincinnati College of Engineering and Applied Sciences; as well as serve as an outlet to apply our knowledge learned from four years of being students in the Mechanical Engineering Technology Program. This project is important for us to not only graduate but to gain experiences in taking classroom knowledge and utilizing it to solve a complex problem. The ability to apply classroom knowledge is extremely important to develop before graduating. The jobs available to us upon graduation do not require high level 'book smarts' yet require an in-depth ability to use available resources to solve problems and design their solutions. The completion of this RoboGames competition will serve as our final test to certify ourselves as Mechanical Engineers.

The problem being addressed is not the typical senior design project problem. There is not a real-world problem that a BattleBot will fix. However, we are looking to design and manufacture a BattleBot that uses known design concepts that have been successful. We want to apply the knowledge gained during our classwork at the University of Cincinnati to build upon these successful design concepts and improve them. Robots are the future of the world. They are currently being implemented in many professional and personal settings. Robots have greatly improved productivity in the workplace (mostly in manufacturing). This project is displaying how robots are improving and become more advanced. We want to gain knowledge of robotics because the future holds many opportunities in the robot industry.

CURRENT STATE OF THE ART

UnMakerBot

This bot won Gold (1st Place) in the 2015 and 2017 RoboGames in the 60 lb combat weight class. It currently has 10 wins and 1 loss. The main features of this bot include:

- Four wheels
- Invertible
- Weapon: Drum Spinner

Figure 1: Drum Spinner

Federal M.T.

This bot received Gold (1st place) in the 2013 and 2016 RoboGames. It also received Silver (2nd place) in the 2015 and 2017 RoboGames. This robot competes in the 60lb combat weight class. It currently has 26 wins and 7 losses. This has been a very successful bot. The main features of this bot include:

- Two Wheels
- Box Shape
- Weapons: Wedge and Spinning Flywheel

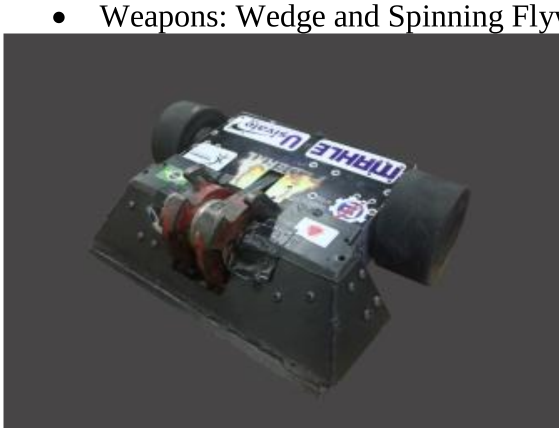

Figure 2: Wedge and spinning flywheel

Tastes Like Burning

This bot received Silver (2nd place) in the 2016 RoboGames. This bot competes in the 60 lb combat weight class. It currently has 5 wins and 4 losses. The main features include:

- Two cambered wheels
- Invertible
- Weapons: Lifter/grabber and Flamethrower

Figure 3: Lifter grabber and flamethrower

These successful robots have very different design concepts and weapons. However, the main similarities include the ability be invertible and a spinning weapon. The number of wheels are not crucial but should be considered in our design. Two out of the three Battlebots had only two wheels.

CUSTOMER REQUIREMENTS

INTERVIEW RESULTS

This is the compilation of three interviews to gain a better understanding of what our 'customer' would like to see in a Battlebot design. Another Battlebot team was interviewed as well as two other engineers (one who has competed before) to have a well-rounded perspective of what the customer would prefer. For the full interviews see appendix A.

- Large weapon attack area
- Zero degree turning
- Durable frame construction
- Weapon puts on show
- Wheels or tracks covered from outside
- Bot is drivable from both sides
- Increased drivability (user friendly to operate)

END USER

The customer would be considered the RoboGames competition. We must design a 60 lb Battlebot to compete in this competition. We must satisfy all design requirements and impress the judges and competition with a new BattleBot that can compete at a high level. According to the rules, competition judges are not only looking for the opponent to be disabled. Disabling the opponent is the main goal but if that is not possible points can be awarded and ultimately a match won by putting on an exciting show for the crowd as well. We are expecting to design and manufacture a robot that will do well in the competition. Our goal is to get Gold!

SUMMARY OF CUSTOMER REQUIREMENTS

- Must meet weight standard
- Controlled mobility
- Approved radio control in acceptable frequency
- Approved battery that cannot spill or spray if damaged
- Main power on/off light
- Spinning weapons must be self-breaking
- Power to weapons must have manual disconnect

ENGINEERING REQUIREMENTS

Engineering requirements being based on the customer requirements are a simple transformation of each customer need into a quantifiable statement. Each engineering requirement comes with a specific measurable component that should be met in order to create the best Battlebot design. The engineering requirements are as follows.

- Weight (< 60lbs)
- Controlled Mobility (yes/no)
- Controlled Frequency (Hz, 900/2400)
- Voltage (< 48V)
- Battery cannot spill or spray if damaged (yes/no)
- Stopping time (sec)
- Disable time (sec)
- Approved battery type (yes/no)
- Power on/off light (yes/no)

The House of Quality is used to generate feasible engineering characteristics to comply with customer requirements. It is a tool used to compare the various requirements and understand how our engineering characteristics affect them. This concept was made by Mitsubishi in 1972. It is "conceptual map that provides the means for interfunctional planning and communications." (3)

Table 1: House of quality

			Engineering Requirements (units)													
		Importance wt.	Weight (< 60 lbs)	Controlled mobility (yes/no)	Controlled frequency (Hz, 900/2400)	Battery voltage (< 48V)	Battery cannot spill or spray if damaged (yes/no)	Stopping time (sec)	Disable time (sec)	Approved battery type (yes/no)	Power on/off light (yes/no)	Battery life while operating (min)	Zero degree turning (yes/no)	Drivable from both sides (yes/no)		
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Must meet weight standard		9	3						3						
2	Controlled mobility		3	9									9	9		
3	Approved radio control				9											
4	Approved battery		3			9	9			9		1				
5	Main power on/off light										9					
6	Spinning weapons must be self breaking		1					9								
7	Power to weapons have manual disconnect								9							
8	Long battery life					1				1		9				
9	Zero degree turning			3									9			
10	Drivable from both sides			3										9		

WEAPON RESEARCH

Related Rules about weapons according to the RoboGames Combat Robot Rules:

“10. Rotation robots or full body spinning robots are allowed:
10.1. Spinning weapons that can contact the outer arena walls during normal operation must be pre-approved by the event. (Contact with an inner arena curb, or containment wall is allowed and does not require prior permission.)
10.2. Spinning weapons must come to a full stop within **60 seconds** of the power being removed using a self-contained braking system.

11. Springs and Flywheels
11.1. N/A
11.2. Any large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robots power.
11.2.1. Under no circumstances must a large spring be loaded when the robot is out of the arena or testing area.
11.2.2. Small springs like those used within switches or other small internal operations are excepted from this rule.
11.3. Any flywheel or similar kinetic energy storing device must not be spinning or storing energy in any way unless inside the arena or testing area.
11.3.1. There must be a way of generating and dissipating the energy from the device remotely under the robots power.
11.4. All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.}

12. Forbidden Weapons and Materials. The following weapons and materials are absolutely forbidden from use:
12.1. Weapons designed to cause invisible damage to the other robot. This includes but is not

limited to:
12.1.1. Electrical weapons
12.1.2. RF jamming equipment, etc.
12.1.3. RF noise generated by an IC engine. (Please use shielding around sparking components)
12.1.4. EMF fields from permanent or electro-magnets that affect another robots electronics.
12.1.5. Weapons or defenses that stop combat completely of both (or more) robots. This includes nets, tapes, strings, and other entanglement devices.
12.2. Weapons that require significant cleanup, or in some way damages the arena to require repair for further matches. This includes but is not limited to:
12.2.1. Liquid weapons. Additionally a bot may not have liquid that can spill out when the robot is superficially damaged.
12.2.2. Foams and liquefied gasses
12.2.3. Powders, sand, ball bearings and other dry chaff weapons
12.3. Un-tethered Projectiles (see tethered projectile description in Special Weapons section 13.5)
12.4. Heat and explosions are forbidden as weapons. This includes, but is not limited to the following:
12.4.1. Heat weapons not specifically allowed in the Special Weapons section (13.2)
12.4.2. Explosives or flammable solids such as:
12.4.2.1. DOT Class C devices
12.4.2.2. Gunpowder / Cartridge Primers
12.4.2.3. Military Explosives, etc.
12.5. Light and smoke based weapons that impair the viewing of robots by an Entrant, Judge, Official or Viewer. (You are allowed to physically engulf your opponent with your robot however.) This includes, but is not limited to the following:
12.5.1. Smoke weapons not specifically allowed in the Special Weapons section (13.3)
12.5.2. Lights such as external lasers above class I' and bright strobe lights which may blind the opponent.
12.6. Hazardous or dangerous materials are forbidden from use anywhere on a robot where they may contact humans, or by way of the robot being damaged (within reason) contact humans.
13. Special weapon descriptions allowed at this event:
13.1. Tethered Projectiles are not allowed at this event.
13.1.1. If allowed tethered projectiles must have a tether or restraining device that stops the projectile and is no longer than 8 feet.
13.2. Fire / flame throwers are allowed at this event. Flame weapon rules are subject to change to comply with local fire regulations and fire officials.
13.2.1. Fuel must exit the robot and be ignited as a gas. It cannot leave the robot in a liquid or gelled form or use oxidizers.
13.2.2. Fuel types allowed are propane and butane, the maximum quantity allowed is 16 fl oz for robots 60 lbs and above.
13.2.3. The fuel tank must be as far from the outer armor of the robot as practicable and be protected from heat sources within the robot.
13.2.4. The ignition system must have a remotely operated shut-off that allows the operator to disable it using the radio control system.

13.3. Smoke Effects are not allowed at this event.
13.3.1. Small smoke effects may be not used, please contact the event if you plan on using it. (1)"

There are many different types of combat robots. There are advantages and disadvantages of each different type. Ultimately, the better designed robot should win, regardless of weapon types. According to Marco Antonio Meggiolaro, the Head of the RioBotz team from PUC-Rio University there are basically 16 types of robots used for combat: rammers, wedges, lifters, launchers, thwackbots, overhead thwackbots, spearbots, horizontal spinners, sawbots, vertical spinners, drumbots, hammerbots, clampers, crushers, flamethrowers and multibots (4). Figure 1 below shows trends for the various robot types (4). The robot has a tendency to win against the other robot if it has an arrow pointing at it.

Figure 4: Robot Weapon Tendencies

As a team we have selected three different combat weapon types to research. We made this decision based on watching videos of various BattleBot fights and also keeping the budget and schedule in mind. The three weapon types to be researched will be:

1. Horizontal Spinner
2. Sawbot
3. Drumbot

We will use the research results to finalize a weapon choice to design, fabricate, and assemble.

Horizontal Spinner:

Overview: These are considered one of the most destructive types of weapons. The photo below shows Tombstone (S2), this BattleBot has been very successful (10 wins - 1 loss). It also received an award for the Most Destructive Robot. This type of robot has an object (usually a bar) that spins at a high speed. This weapon acts as an attack and as defense. The opposing robot cannot get close to it without getting hit by the spinner.

Advantages:

- Powerful
- 2 in 1 offense and defense

Disadvantages:

- Can be self-destructive
- Not invertible if spinner mounted on top
- Large Profile
- Poor Mobility

Figure 5: Horizontal Spinner Bot

Sawbot:

Overview: This weapon uses a disc (usually with sharp teeth or jagged edges) that spins fast to cut the opponent. This requires a strong motor to allow a high spinning speed for maximum damage. They do well cutting thin materials or weak materials but do not cause much damage to strong or think material that is generally used as armor on a BattleBot. Typically, this type of robot needs to be paired with another weapon to be successful. The photo below shows SawBlaze (S2). This robot has not been very successful (0 win – 1 loss).

Figure 6:Saw Bot

Advantages:

- Cosmetic Damage
- Shower of sparks (visually appealing to viewers)

Disadvantages:

- Difficulty causing serious damage
- Can easily break teeth
- Can get stuck in opponent

Drumbot:

Overview: This weapon incorporates a horizontal spinning drum that is typically mounting on the front of the robot. This weapon tends to send the opponent soaring through the air. The damage occurs from repeated slamming into the ground or when the opponent comes into contact with the spinning drum.

Figure 7:Drum Bot

Advantages:

- Invertible
- Compact
- Stable

Disadvantages:

- Difficult to maneuver
- Struggle against a heavy armored opponent

RESEARCH MATRIX

Table 2: Weapon decision matrix

		Weapon Concepts					
		Horizontal Spinner		Saw		Spinning Drum	
Criteria	**Weight %**	**rating**	**wt. rating**	**rating**	**wt. rating**	**rating**	**wt. rating**
cost	**9**	2	0.18	1	0.09	3	0.27
maneuverability	**15**	1	0.15	2	0.3	3	0.45
size	**8**	1	0.08	2	0.16	3	0.24
reliability	**20**	2	0.4	1	0.2	3	0.6
efficiency	**15**	3	0.45	1	0.15	2	0.3
force	**15**	3	0.45	1	0.15	2	0.3
ease of use	**10**	2	0.2	1	0.1	3	0.3
customer appeal	**8**	1	0.08	3	0.24	2	0.16
	100	n/a	1.99	n/a	1.39	n/a	2.62

WEAPON DESIGN

The design of our weapon includes a combination of multiple sections of research for the Battlebot. A weapon that fulfilled not only our weapon requirements but also was compatible with the chosen box style frame and armor was essential. Based on the weapon design matrix we have chosen a spinning drum for the Battlebot’s weapon. This drum will be made of shock resistant S7 tool steel in order to best perform in the conditions of a battle. The weapon drum will be machined to hold two teeth that will serve to inflict damage on our opponents. The teeth will be recessed into the drum as well as welded. This will improve strength and rigidity. The drum will also have grooves machined for the weapon motor and pulley assembly to spin the drum. A stainless-steel shaft with an arrangement of shaft collars, bearings, and bushing will be used to support the weapon.

Table 3: Weapon Material

S7 Tool Steel			
Tensile Strength (psi)	Modulus of Elesticity (ksi)	Brinell Hardness	Density (lb/in^3)
293,700	30,000	187-220	0.283

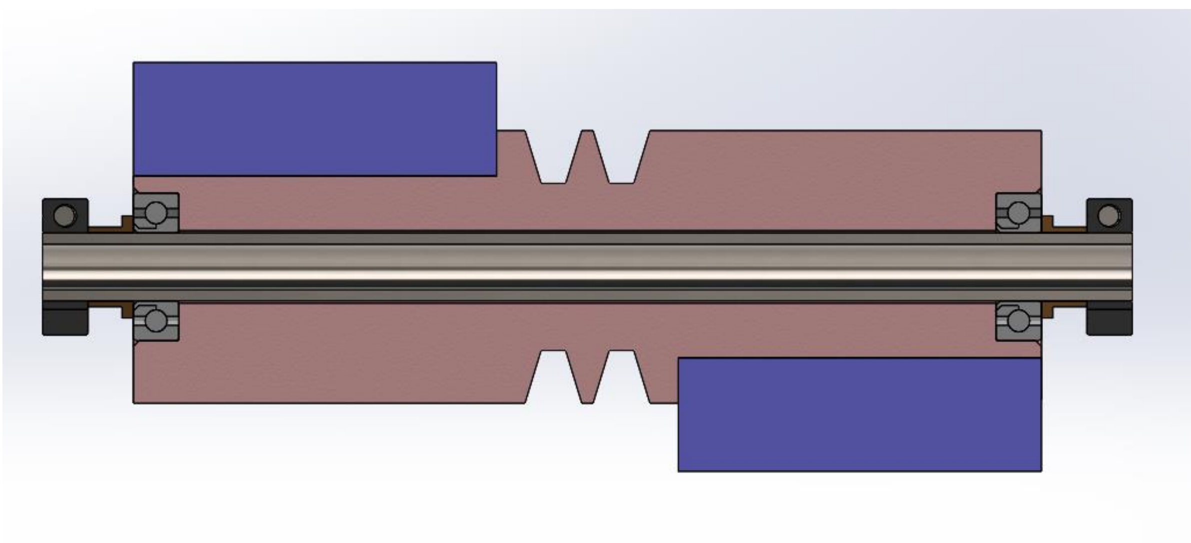

Figure 8: Weapon Assembly section view

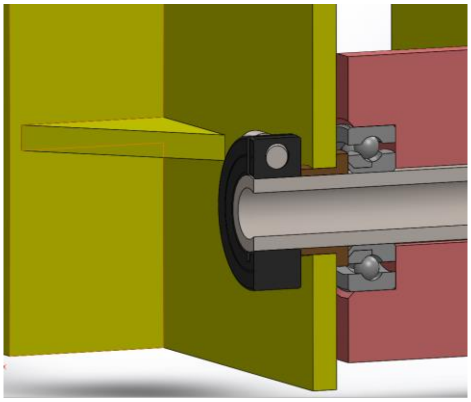

Figure 9: Weapon assembly section view #2

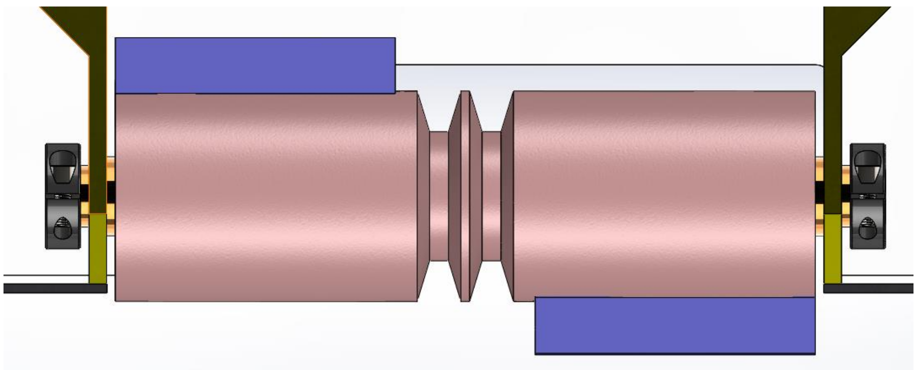

Figure 10: Weapon assembly top view

Weapon drum FEA

- Stress @ 5000 lbs Force
- Yield Strength – 220,000 psi
- Max Stress – 3,000 psi

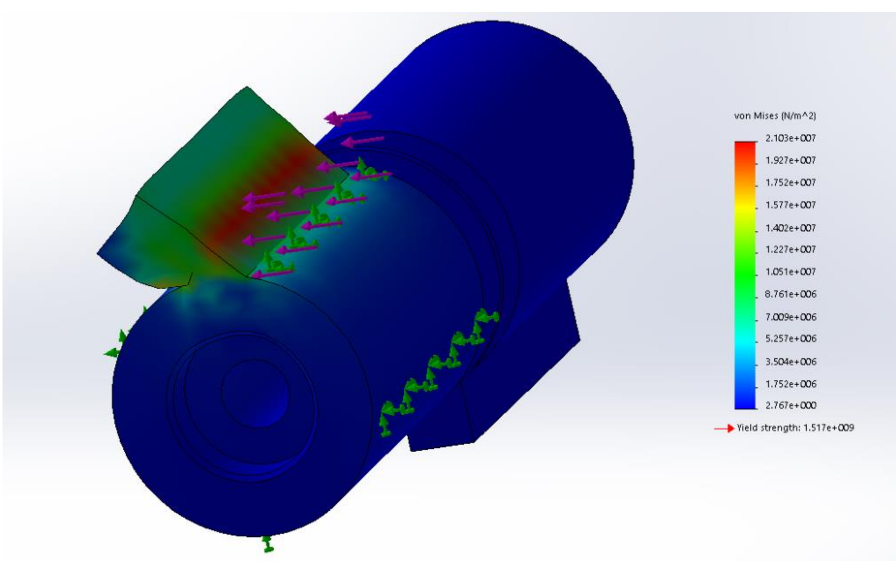

Figure 11: Weapon FEA #1

- 5000 lbs Force applied to edge
- Yield Strength – 220,000 psi
- Max Stress – 25,700 psi

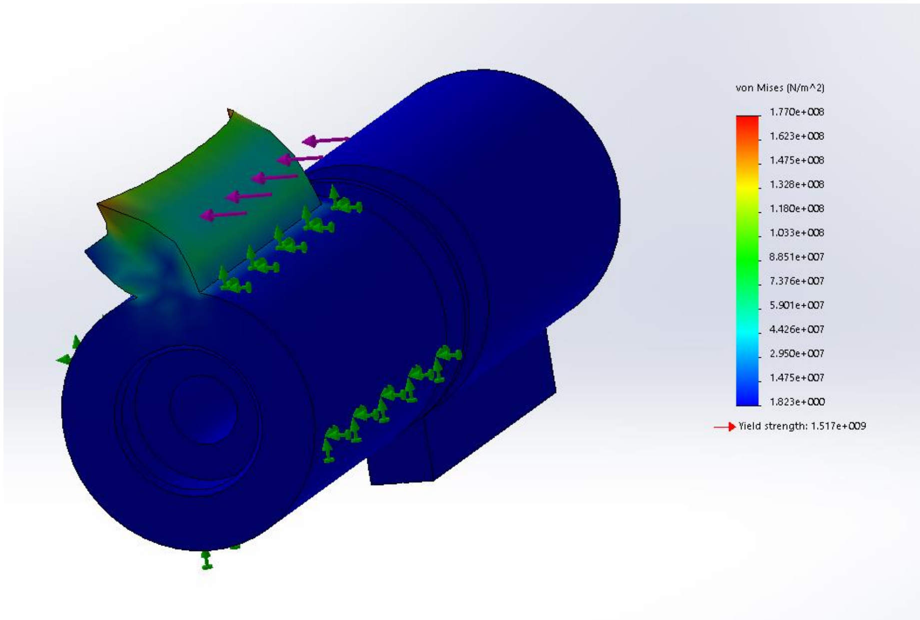

Figure 12: Weapon FEA #2

WEAPON FABRICATION

The fabrication of our weapon was completed by Unique Metal Design in Fredericktown, Ohio. They purchased the materials and did all required machining on the weapon drum. The key ways for the weapon teeth were machined using a mill, the grooves for the drive pulley and bearing housings were machined using a lathe. The weapon teeth were also welded into the key ways using a special technique to prevent the unique material of S7 from shattering or fracturing when heated rapidly. This consisted of heating both pieces to a uniform 500 degrees Fahrenheit and then welding the two components with a special wire material in the mig welder. There was no other machining needed to complete the components of the shaft and bearing assembly.

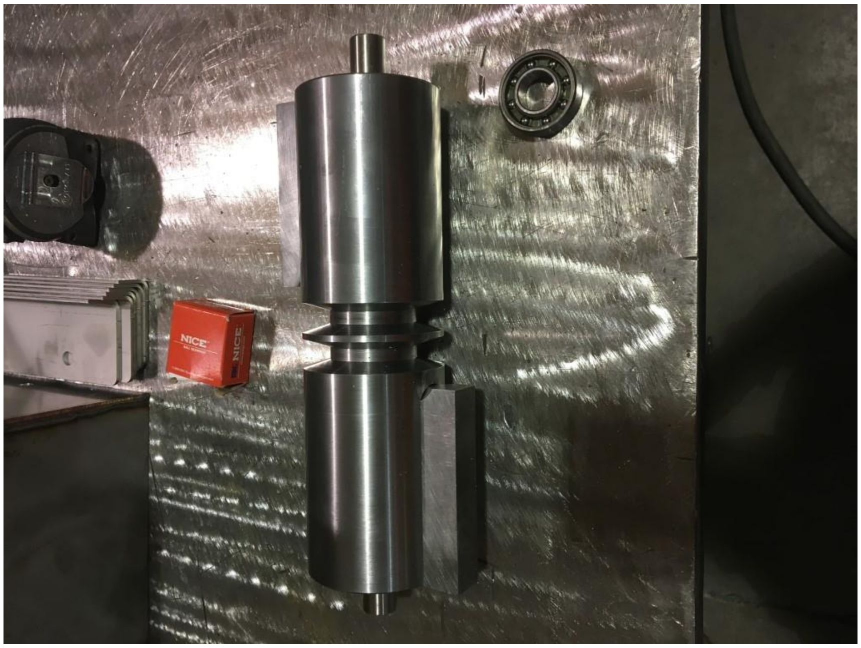
Figure 13: Weapon fabrication #1


Figure 14: Weapon fabrication #2

DRIVETRAIN RESEARCH

Related Rules about drivetrain/mobility according to the RoboGames Combat Robot Rules:
“3. Mobility
3.1. All robots must have **easily visible and controlled mobility** in order to compete. Methods of mobility include:
3.1.1. Rolling (wheels, tracks or the whole robot)

3.1.2. Non-wheeled: non-wheeled robots have no rolling elements in contact with the floor and no continuous rolling or cam operated motion in contact with the floor, either directly or via a linkage, but are not true walkers as defined below. Motion is "continuous" if continuous operation of the drive motor(s) produces continuous motion of the robot. Linear-actuated legs and novel non-wheeled drive systems are examples, but do not qualify for the "walking bonus."
3.1.3. Walking: Walking robots are defined as those with linear-actuated legs which operate independent of each other. That is, any given leg must be able to move laterally and vertically with no cause and effect from another leg. Only walkers as defined by this section qualify for the weight bonus, and only as designated by a tournament official.
3.1.4. Shuffling (rotational cam operated legs) is allowed.
3.1.5. Gyroscopic procession is allowed.
3.1.6. Ground effect air cushions (hovercrafts) are allowed.
3.1.7. Jumping and hoppin is allowed.
3.1.8. Flying (airfoil using, helium balloons, ornithopters, etc.) is not allowed. (1)"

After reviewing the competition rules on robot mobility options there are many possibilities. Focusing on options available for an electric motor drive the drivetrain research will be reviewed based on the factors power transmission and motor layout. By analyzing each drivetrain concept based on these two factors we will be able to select the best option to suit our battlebots' needs. In order to determine the best functions in these areas, research will be conducted on previous competition reports and video footage as well as literature analyzing drivetrain components strength and weaknesses. Potential drivetrain options are belt drive, chain drive, and gear drive.

Gear Drive

Gears are very common in day to day life. Gears can be found in small electrical appliances like blenders or large vehicle transmissions. The material of gears can range from various metals to plastics depending on the use. The versatility of gears is very beneficial, gears can convert drive directions, convert drive speeds using ratios, and attached to many different kinds of shafts going through the gear or remaining on the end of the shaft. Utilizing the different types of gears, worm gears, bevel or spiral bevel gears, and pinion gears only to name a few of the many options out there can provide even more versatility of a gear drive is selected. This allows for many motor layout options which will help in the battlebot design. Power transmission and reliability of gears is the best of the three possible drivetrain options. As gear operation uses the tooth to tooth contact in order to transfer power there is very little power lost to things like slippage.

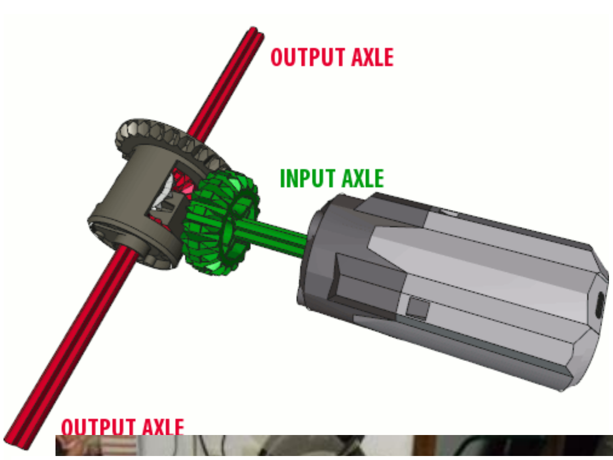

Figure 15: Gear Drive

Chain Drive

Chain driven drivetrains are common in many varying motor shapes and sizes. Chains can


Figure 16: Chain Drive

be used with small electric engines, large motorcycle engines, vertical output engines, and horizontal output engines. A typical application of chain drives is scenarios where low speeds and high power outputs are required but the option for high speed is still possible. Chain drives are versatile in applications where multiple shafts are present as well as drive shaft at both sides of the chain. Chain drives are practical in continuous speed and power transmission. Scenarios where drive reversal and starting/ stopping frequently are present is not for chain drives because of the slack found in between the chain and sprocket. The power transmission for chains is high but has areas where power can be leaked if sprocket teeth break or the chain become lose/ stretched (5). Potentials for failure or more likely with chains also, they have potential to fall of sprockets and become misaligned. A typical chain drive arrangement is a bicycle, a drive sprocket, one chain, and the output gear driven by the chain.

Belt Drive

Belt drives are common in many applications similar to chains. Belts are lighter in weight but sometimes require more space than gears to arrange the setup. The versatility of motor arrangement will not be as high when utilizing a belt driven system. Belts have other options such as shape (v-shaped or flat) or teeth or no teeth. Belts with teeth require different pulleys than a belt with no teeth. The reliability of belt drives is affected by factors like stretching and temperature. Which can all affect power transmission of the belt but if guidelines are maintained belt drive power transmission is very competitive with that of gear and chain drives (6).

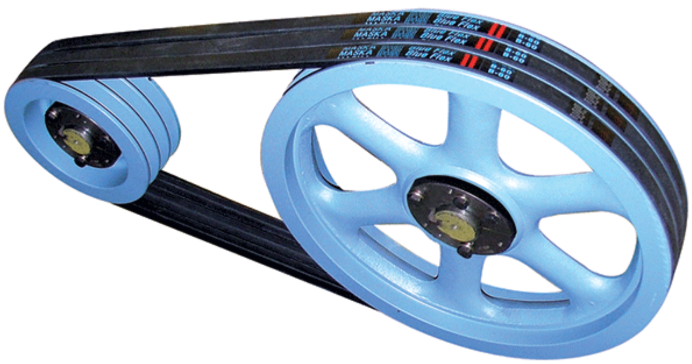

Figure 17: Belt Drive

Belts are also able to operate lubricant free and are quitter in operation.

Research Matrix

Table 4: Drivetrain decision matrix

		Drivetrain Concepts					
		Gear Drive		Belt Drive		Chain Drive	
Criteria	**Weight %**	**rating**	**wt. rating**	**rating**	**wt. rating**	**rating**	**wt. rating**
cost	**15**	1	0.15	3	0.45	2	0.3
complexity	**11**	1	0.11	3	0.33	2	0.22
size	**14**	1	0.14	3	0.42	2	0.28
reliability	**20**	3	0.6	1	0.2	2	0.4
efficiency	**15**	3	0.45	2	0.3	1	0.15
force	**15**	3	0.45	1	0.15	2	0.3
maintenance	**10**	1	0.1	3	0.3	2	0.2
	100	n/a	2	n/a	2.15	n/a	1.85

DRIVETRAIN DESIGN

Based on our research of potential drivetrain options we have selected to go with belt drives as our preferred choice. Although in our research for motors we found a motor with a premade gear box assembly that provided our desired wheel speed and torque outputs. This will allow us to assemble a direct drive system for our Battlebot wheels. For the weapon drive system, we will still be going with the belt drive. This is ideal for our weapon because of the desired high speed for the weapon. We have found a weapon motor with a 5400 RPM and a very low torque. This is wear a belt drive will allow the pulleys to slip and allow the weapon to continue to spin instead of burning up our motor. Which is a likely scenario in a battle as our weapon would be hitting opponents and potentially being slowed to a complete stop rapidly. A belt drive design is also cheap to purchase and an achievable option for us to machine into our desired weapon system. We have also chosen to make this belt drive system a dual belt system. This gives the Battlebot a redundancy in operating the main weapon. If one belt was to fail or break it will not take the Battlebot out of the fight.

Table 5: Motor selection

Motor Data			
	Part #	**RPM**	**Torque (in-lb)**
Weapon Drive	AmpFlow E30-150	5600	44
Wheel Drives (x2)	BaneBot PDX104	230	595

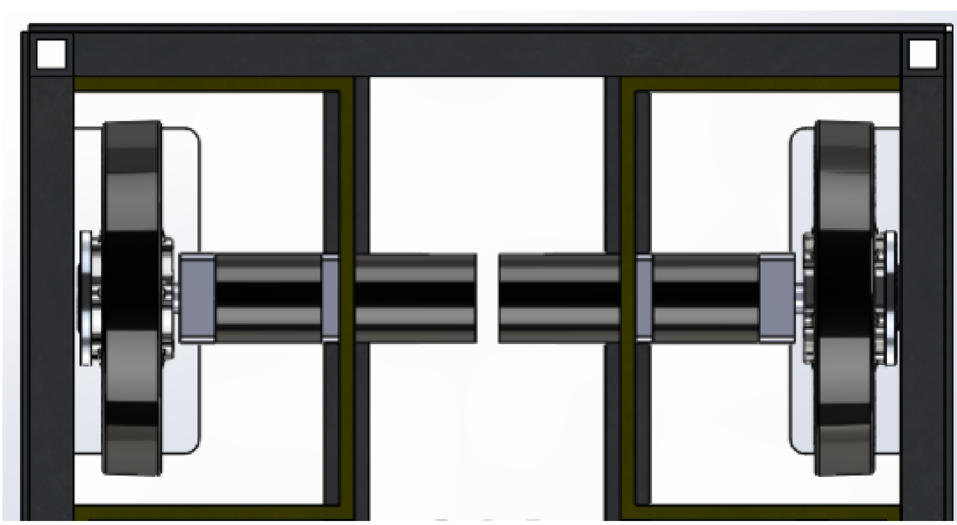

Figure 18: Drive assembly

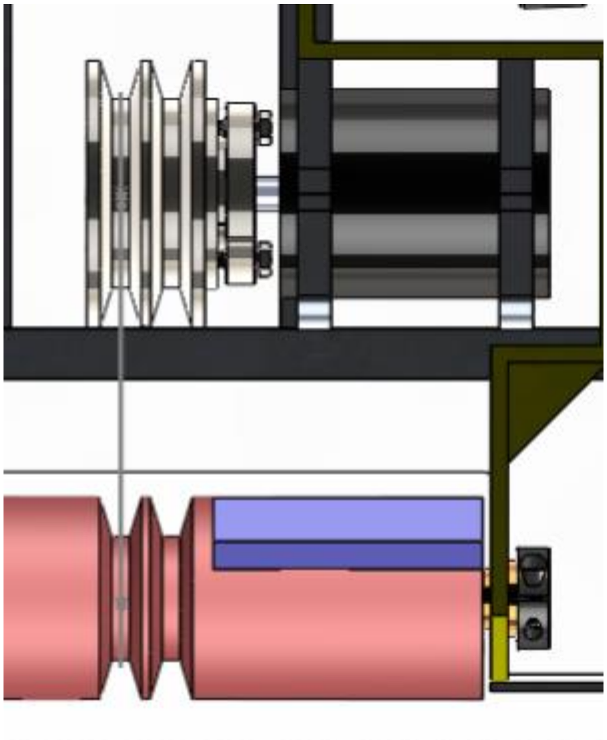

Figure 19: Weapon drive assembly

DRIVETRAIN FABRICATION

The only fabrication required for this system is the machining of the belt grooves into our weapon which can been seen below. The other components that will transfer the motor drive into a belt drive system are shaft bushings and pulleys that will be purchased from McMaster-Carr.

Figure 20: Weapon belt grooves

ELECTRONICS AND CONTROLS RESEARCH

Related Rules about electronics and controls according to the RoboGames Combat Robot Rules:

“4. Robot control requirements:

4.1. Tele-operated robots must be radio controlled, or use an approved custom system as described in 4.4.3. Radio controlled robots must use approved ground frequencies in the 900/2400 for the United States.

4.2. Tethered control is not allowed.

4.3. Pre 1991 non-narrow band radio systems are not allowed.

4.4. Radio system restrictions for this event with corresponding weight and or weapon restrictions:

4.4.1. Radio systems that stop all motion in the robot (drive and weapons), when the transmitter loses power or signal, are required for all robots with active weapons. This may be inherent in the robots electrical system or be part of programmed fail-safes in the radio.

4.4.2. All robots (including insect classes) MUST use a radio system with digitally coded, mated pairs between transmitter and receiver. This means that no other transmitter, operating on the same frequency, can communicate with your receiver, and your transmitter cannot send signals to any receiver other than your own. Examples of such systems are Spektrum, IFI, and XPS XtremeLink - these are just examples and should not be taken as a comprehensive list or an endorsement.

4.4.3. If you are using a home built control system, or a control system not covered here, you must first clear it with this event.

4.4.4. Toy radio systems are not allowed at this event for any robots.

4.4.5. RC systems on the AM band are not allowed at this event for any robots.

4.5. This event does not require a separate power switch for the radio, but it is encouraged.

4.6. This event has not reserved frequencies/channels for testing and safety.

5. Autonomous/Semi-Autonomous Robots: Any robot that moves, seeks a target, or activates weapons without human control i

considered autonomous. If your robot is autonomous you are required to contact this event before registration.

5.1. Autonomous robots must have a clearly visible light for each autonomous subsystem that indicates whether or not it is in autonomous mode, e.g. if your robot has two autonomous weapons it should have two "autonomous mode" lights (this is separate from any power or radio indicator lights used).

5.2. N/A

5.3. The autonomous functionality of a robot must have the capability of being remotely armed and disarmed. (This does not include internal sensors, drive gyros, or closed loop motor controls.)

5.3.1. While disarmed, all autonomous functions must be disabled.

5.3.2. When activated the robot must have no autonomous functions enabled, and all autonomous functions must failsafe to off if there is loss of power or radio signal.

5.3.3. In case of damage to components that remotely disarm the robot, the robots autonomous functions are required to automatically disarm within one minute of the match length time after being armed.

6. Batteries and Power
6.1. The only permitted batteries are ones that cannot spill or spray any of their contents when damaged or inverted. This means that standard automotive and motorcycle wet cell batteries are prohibited. Examples of batteries that are permitted: gel cells, Hawkers, NiCads, NiMh, dry cells, AGM, LIon, LiPoly, etc. If your design uses a new type of battery, or one you are not sure about please contact this event.
62. All onboard voltages above 48 Volts require prior approval from this event. (It is understood that a charged battery's initial voltage state is above their nominal rated value)
6.3. All electrical power to weapons and drive systems (systems that could cause potential human bodily injury) must have a manual disconnect that can be activated within 15 seconds without endangering the person turning it off. (E.g. No body parts in the way of weapons or pinch points.) Shut down must include a manually operated mechanical method of disconnecting the main battery power, such as a switch (Hella, Wyachi, etc) or removable link. Relays may be used to control power, but there must also be a mechanical disconnect. Please note that complete shut down time is specified in section 1.6.
6.4. All efforts must be made to protect battery terminals from a direct short and causing a battery fire.
6.5. If your robot uses a grounded chassis you must have a switch capable of disconnecting this ground. ICE robots are accepted from this rule if there is no practical way to isolate their grounding components. It is required to contact this event for this exception.
6.6. All Robots must have a light easily visible from the outside of the robot that shows its main power is activated. (1)"

Permitted Batteries include:

1. Gel cells
2. Hawkers
3. Nickel Cadmium (NiCads)
4. Nickel-Metal Hydride (NiMh)
5. Dry cells
6. Absorbent Glass Mat (AGM)
7. Lithium Ion (LIon)
8. Lithium Polymer (Li-Po)

Nickel-Metal Hydride:

Overview: These batteries are commonly used in high-drain applications. The Nickel-metal hybrid battery when compared to a typical alkaline battery has a low internal resistance which allows the battery to discharge a more constant voltage until the battery is nearly out of power. These batteries have a typical discharge rate of one hour and are rechargeable. A self-discharging rate is found to be about 30% per month.

Figure 21: Nickel-Metal hybrid battery

Lithium Ion:

Figure 22: Lithium Ion battery

Overview: Lithium Ion batteries are very common and used for many applications today. Common items include power tools, electric cars, and laptops. These batteries are known for their high density of energy while remaining at a light weight. They are also easily wired together in parallel in order to power much larger objects like the electric car. Lithium ion batteries are rechargeable and are able to run many full discharge cycles before losing any significant storage decreases. The lithium ion battery only sees a self-discharging rate of 1-2.5% over the course of a month making them able to be stored for a longer period of time compared to other batteries.

Lithium Polymer:

Figure 23: Lithium Polymer battery

Overview: The lithium polymer are another commonly used rechargeable battery option. The main benefit of the polymer electrode versus a typical lithium ion battery is the weight reduction and high specific energy capabilities. They are commonly used in cell phones and radio-controlled aircraft. The lithium polymer batteries are more expensive but give a higher capacity to weight ratio than a traditional lithium battery.

RESEARCH MATRIX

Table 6: Battery selection matrix

		Power Supply Concepts					
		Nickel-metal hybrid		Lithium Ion		Lithium Polymer	
Criteria	**Weight %**	**rating**	**wt. rating**	**rating**	**wt. rating**	**rating**	**wt. rating**
cost	**30**	2	0.6	1	0.3	1	0.3
size	**20**	1	0.2	2	0.4	3	0.6
reliability	**10**	1	0.1	3	0.3	3	0.3
recharging	**10**	1	0.1	2	0.2	2	0.2
voltage	**10**	2	0.2	3	0.3	3	0.3
discharge	**20**	2	0.4	3	0.6	3	0.6
	100	n/a	1.6	n/a	2.1	n/a	2.3

ELECTRONICS AND CONTROLS DESIGN

Power Supply:

The batteries are the most important aspect of the electronics and controls of the Battlebot. The weapon and drive cannot function properly without the appropriate battery to provide the necessary power to operate efficiently. First, we had to calculate the current draw from our selected drive motors and weapon motors. We estimated the current draw based on five different criteria. This includes stall (max), pushing, accelerating, cruising, and stopped. These conditions were weighted accordingly based on what we thought we would encounter during the competition. The stall condition is when the motor is not in use but 100% of the power is available for use. The pushing condition is when the motor draws 80% of the power that is available for use. The accelerating condition is when the motor draws 40% of the power that is available for use. The cruising condition is when the motor draws 15% of the power that is available for use. Lastly, the stopped condition is when the motor draws 0% of the power that is available for use. In order to calculate the estimated amp hours for each motor we also need to estimate the amount of time that the Battlebot would be in each condition during the duration of the match. The total match time is 3 minutes. We estimated that we would be in stall condition for 25 seconds, pushing condition for 45 seconds, accelerating condition for 35 seconds, cruising condition for 60 seconds, and stopped for 15 seconds. Finally, using the motor rated stall current, scaled rating, and estimated time for each condition we were able to estimate the amp hours needed for each motor. We estimated that the weapon motor would need 2.917 Ahr and the drive motor would need 3.453 Ahr each (2 total drive motors). We also included a factor of safety of 1.5 to give us an adjusted total of 14.735 Ahr needed for all the motors.

The next step was to determine how many batteries will be needed to provide this amount of amp hours. We decided to use a Floureon 6S 22.2V 4500mAh 45C LiPo Battery Pack. This battery will safely provide us 202.5 amps continuously. This is calculated by multiplying the discharge capacity (45C) and the rated amp-hours (4.5Ahr). This represents the absolute maximum current we can draw from the battery. Therefore, one battery would be sufficient because we will not exceed 202.5 amps. We also needed to confirm that the battery can provide us enough amp-hours for the duration of the match. The battery can provide 4.5 amps for the duration of one hour. However, the match is only 3 minutes. We decided to calculate how many amps could be provided for 3.75 minutes to be safe. This correlates to 72 Ahr which is more than enough since we needed a total of 14.735 Ahr. This concludes that one battery will be sufficient for our battlebot.

Figure 24: Battery used

Speed Controller:

Sabertooth 2X60 V1.00 is a dual motor driver that is suitable for robots up to 120 lbs (in combat) or 1000 lbs (general purpose). It can provide two DC brushed motors 60A each and 120A peak current for a few seconds. This was perfect for our battlebot because we used two DC brushed motors to drive the wheels and one DC brushed motor to drive the weapon. Therefore, we were able to use one speed controller to operate the drive motors and another speed controller to operate the weapon motor. It also has a 5V 1A switch-mode BEC that supplies the power to the receiver. The versatility of this speed controller made the wiring of the motors simple, clean, and compact.

Figure 25: Speed controller used

Controller & Receiver:

Spektrum DX6i controller and Spektrum AR6115e receiver were used to control the battlebot. The Spektrum DX6i is a 6-channel 2.4GHz controller that was made to control an RC airplane. This presented some difficulties because plane controls differ from what we were trying to accomplish. We want to use each stick to control one individual wheel. This would allow us to have good control and zero degree turning capabilities. We had to modifying the wiring inside of the controller to make this controller work as we intended. This modified controller would allow us to use each stick to move the wheels respectively in the forward and reverse directions. This would make it operate like an RC car. This is ideal for our battlebot since we have two wheels in the rear. The controller also needed to control the weapon motor. We decided to wire this to an on/off toggle switch. This would allow us to easily toggle the weapon on and off during the match.

Figure 26: Power switch used

Power Switch:

Hella master switch rated for 100 amps at 24 volts. This switch is required per competition rules. It includes a 90 degree on/off key that controls all power throughout the battlebot. This mechanical switch connects directly to the battery so that it must be turned on to allow any current to run into the speed controllers/motors.

ELECTRONICS AND CONTROLS FABRICATION

Electrical Assembly:

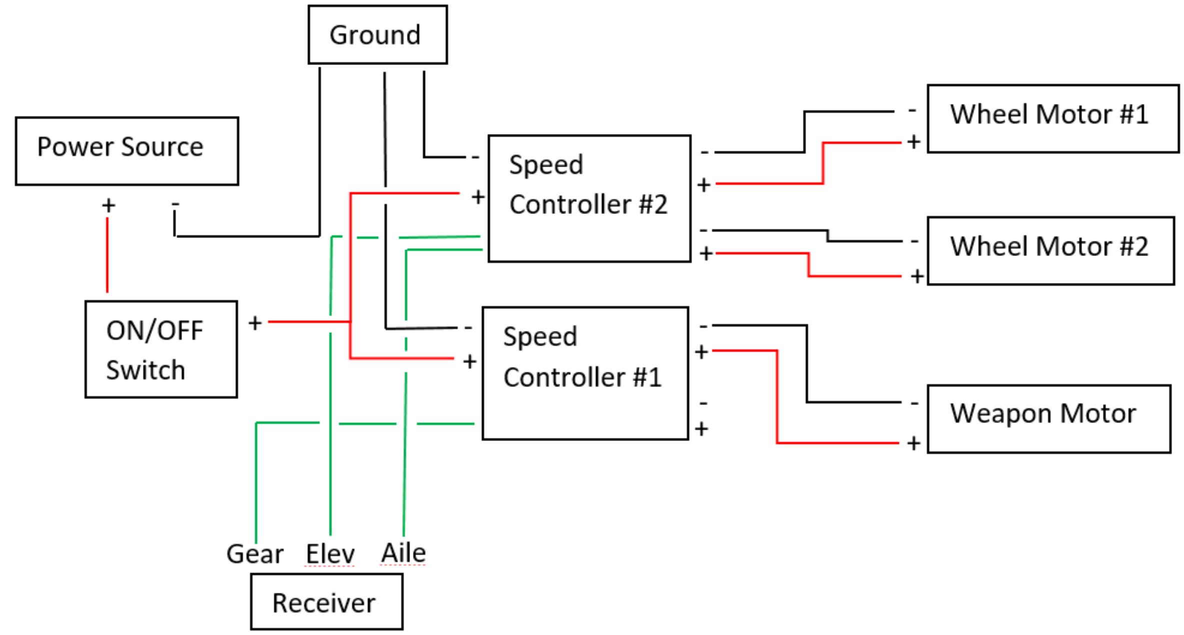

Figure 27: Wiring diagram

FRAME AND ARMOR RESEARCH

Frame and armor design is key in the functionality of our robot. The shape of our frame will affect the robots weight, capabilities, internal space, and weapon possibilities. When selecting a frame and armor design it must encompass all previous stages of design so that it is able to facilitate the drivetrain, weapon, and controls that have been selected. Many different style robots have been used in competition many designs are seen repeated each year because of their effectiveness in the arena. Three robot frame styles will be reviewed.

Box or Wedge Frame

A boxed BattleBot frame is the most simple and most common design. It has many advantages and few disadvantages. A box design has increased space for internal components this will be very helpful when trying to formulate a drivetrain and controls design. The most common weapon for a box fame is the wedge which becomes part of the frame/ armor (7). The box/ wedge design allows for heavy armor and drivetrain components due to its simplicity making it one of the more robust robots. The wedge however can be an ineffective weapon not directly inflicting any damage to the opponent but only being able to push or flip the opponent. The box/ wedge BattleBot itself may be difficult to flip in battle but if it is turned over there could issues with immobility depending on drivetrain design or no way of correcting itself to right-side up.

Figure 28:Box/ Wedge Bot

Advantages
- Internal room
- Heavy armor
- Simple to make

Disadvantages
- Little offense

TRIPOD FRAME

The tripod battle bot is much less common than the box/ wedge robot in the arena. There are major pros and major cons to the tripod frame/ armor design. The tripod design if raised as seen in figure 9 allows for various weapon options that can be very effective as well as functionality from either side it is laying on. Only requiring drive to one axle is also a large weight saver. The downfall of the tripod design is ruggedness and durability. There are possible weak points and much less space for internal components. The added ability of the tripod shaped design to handle a vertical spinning weapon is the largest benefit of the design. Spinning weapons are often more effective than other more simple weapons.

Figure 29: Tripod Framed Bot

Advantages
- Weapon possibilities
- Both side functionality
- Two-wheel drive

Disadvantages
- Weak points in frame
- Little internal component room

- Two-wheel drive

SPINNING FRAME

Spinning frame BattleBots are often most appealing to the crowd for their aggressive offense and defense. The 2-in-1 (weapon and armor) design captured in a full body spinning robot is a huge weight saver. Some teams focus on the armor others focus on the weapon but this design encompasses both (7). This means durability of the armor will be top notch because the armor is the weapon. The internal components of the robot though are more difficult to design and assemble than most others. Being able to control the bots weight will almost all of the weight is rapidly spinning in a circle can be difficult.

Figure 30: Spinning Frame Bot

Advantages
- Weapon and armor combined

- Aggressive offense

Disadvantages

- Drivetrain design/ Control

RESEARCH MATRIX

Table 7: Frame/Armor decision matrix

		Frame/ Armor Concepts					
		Box/Wedge		Tripod		Spinning	
Criteria	**Weight %**	**rating**	**wt. rating**	**rating**	**wt. rating**	**rating**	**wt. rating**
cost	**15**	3	0.45	2	0.3	1	0.15
maneuverability	**15**	3	0.45	2	0.3	1	0.15
size	**10**	3	0.3	1	0.1	2	0.2
reliability	**20**	3	0.6	2	0.4	1	0.2
resilient	**25**	3	0.75	1	0.25	2	0.5
manufacturability	**10**	3	0.3	2	0.2	1	0.1
customer appeal	**5**	1	0.05	3	0.15	2	0.1
	100	n/a	2.9	n/a	1.7	n/a	1.4

FRAME AND ARMOR DESIGN

The layout of the frame and armor design was chosen from the design matrix, which selected a box frame. This frame will be created from 6061 Aluminum which will provide enough stability and support to the Battlebot while remaining light enough for the Battlebot to meet the 60lb requirement. In order to design this frame, we went through several iterations of tube sizing and arrangements for the internal frame and different thicknesses of plate for the armor. This best strength to weight ratios came from using ¾" tubing with an 1/8" thick plates covering all sides of the frame. We recognize that selecting larger tubing or thicker plates would support and protect our internal components better but the 60lb weight requirement of our class plays a large role in our selection and overall design of these components.

Table 8: Frame and armor material selection

	Material Selection			
	Tensile Strength (psi)	**Modulus of Elesticity (ksi)**	**Brinell Hardness**	**Density (lb/in^3)**
6061 AL	45,000	10,000	95	0.0975
1020 STL	55,100	29,000	121	0.2844
6063 AL	35,000	10,000	73	0.0975

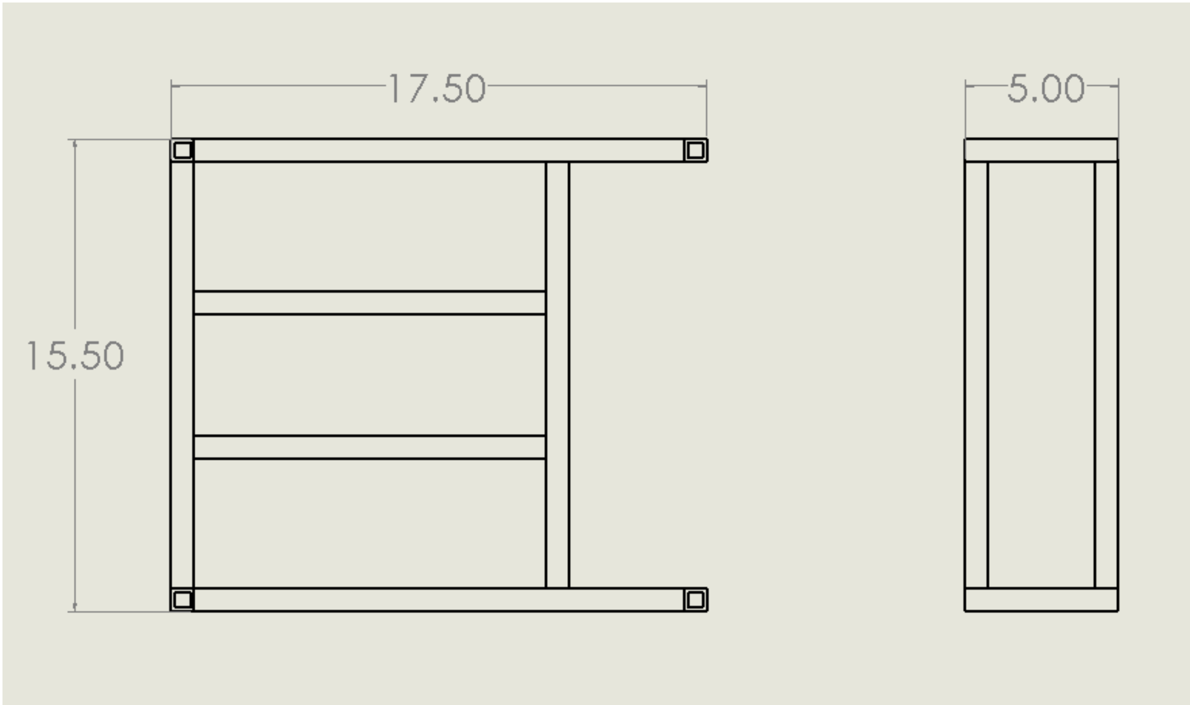

Figure 31: Frame dimensioned drawing (in inches)

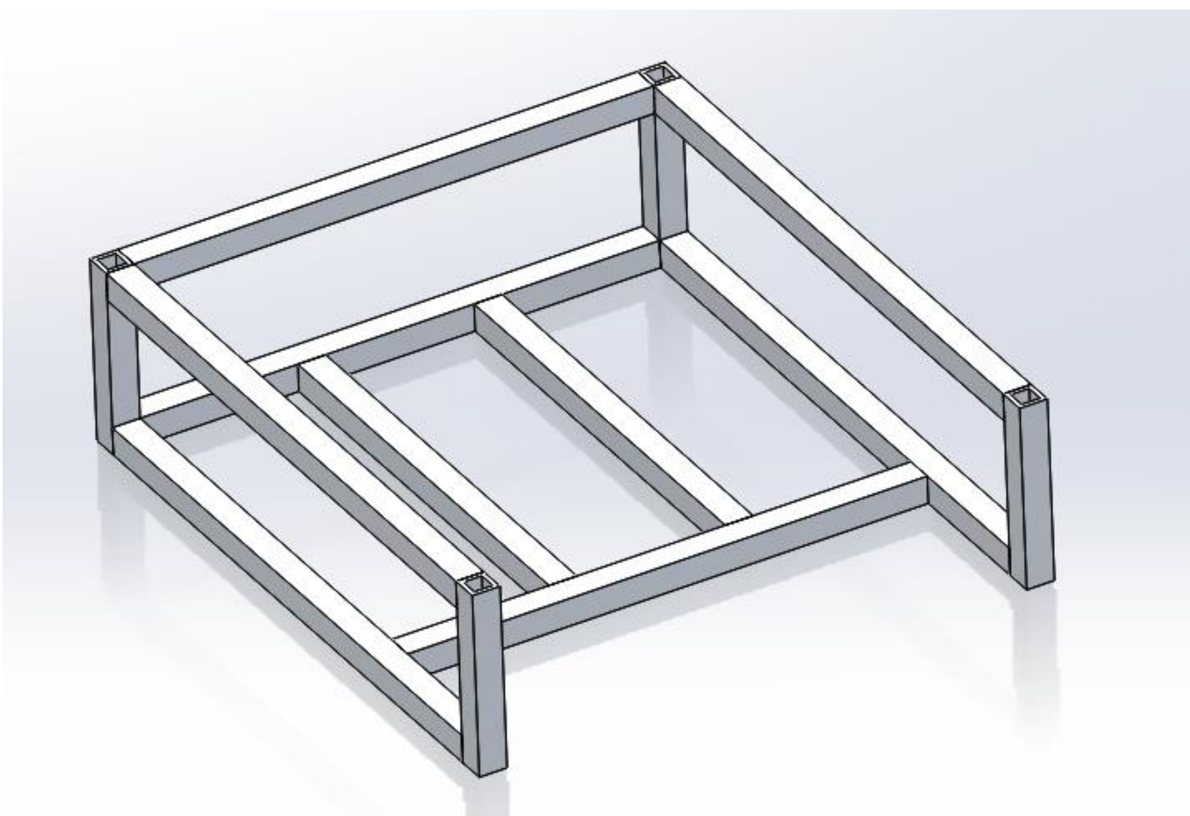

Figure 32: Frame isometric view

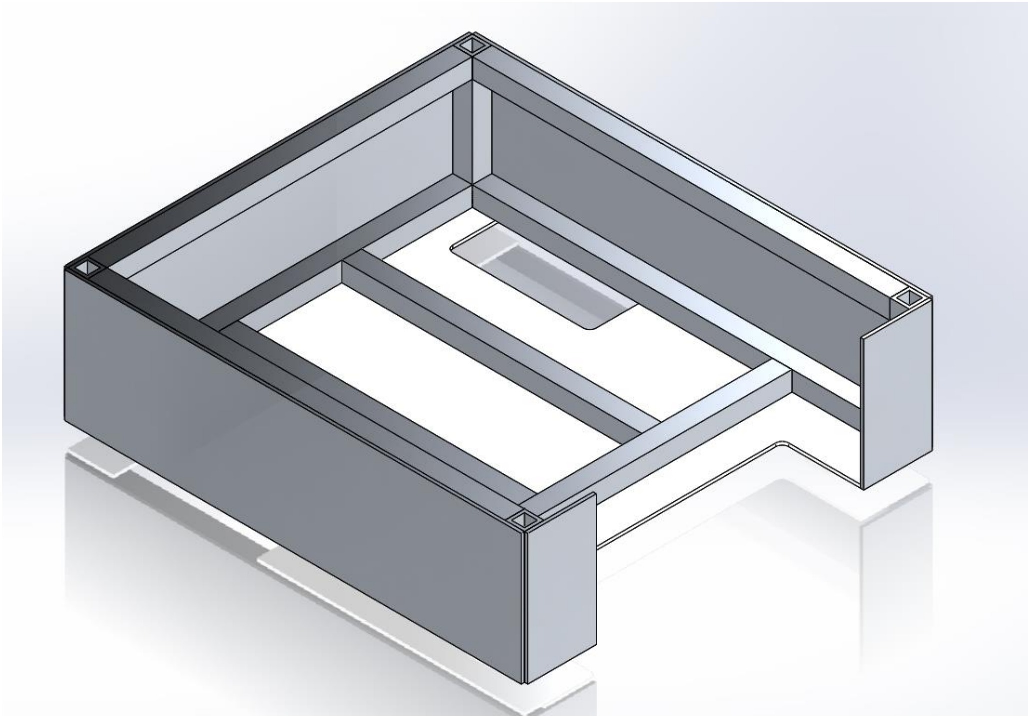

Figure 33: Frame isometric view w/ armor

Frame & Armor FEA

- 1000lbs force applied to side of frame
- Yield Strength – 8,000 psi
- Max Stress – 2,500 psi

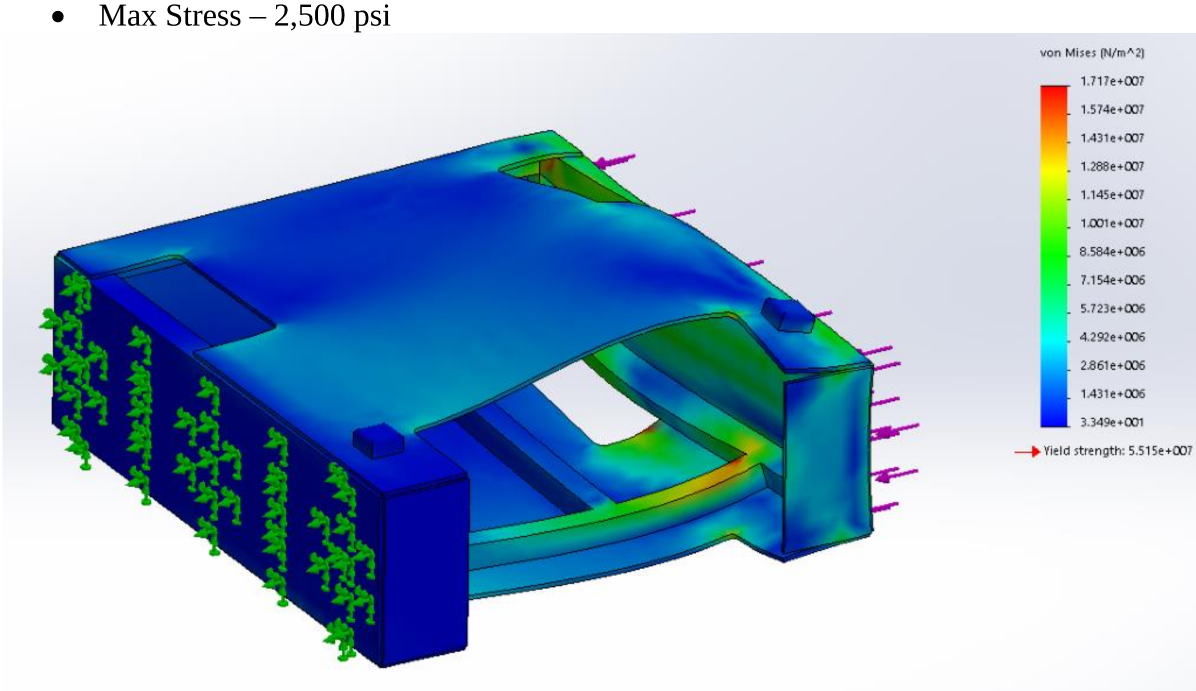

Figure 34: Frame and armor FEA #1

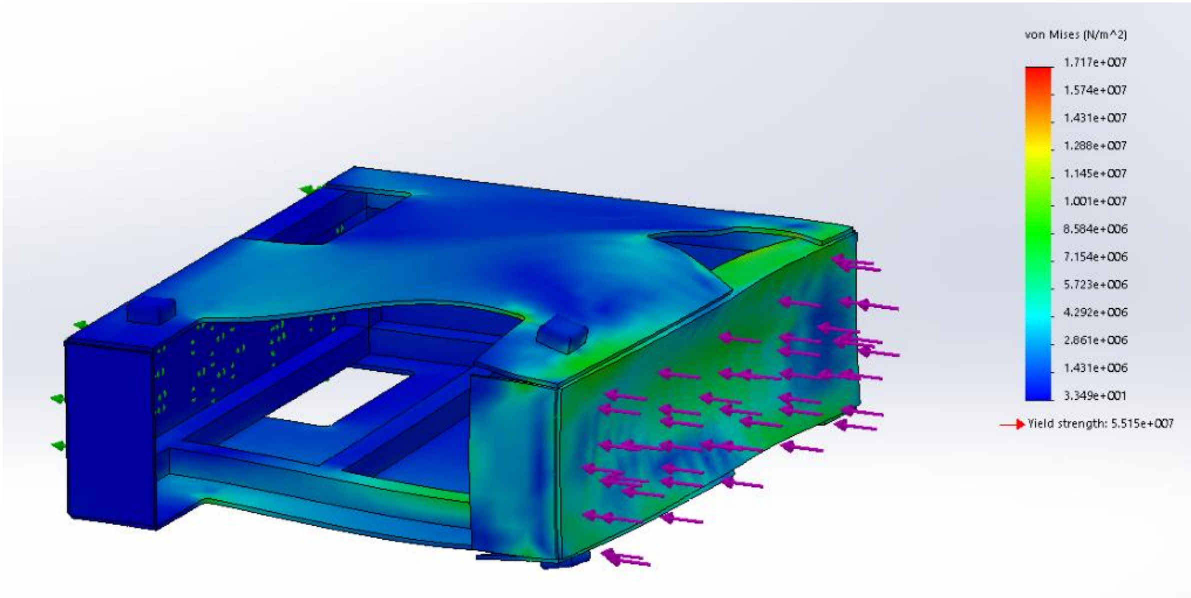

Figure 35: Frame and armor FEA #1a

- 1000 lbs force applied within the weapon shaft support
- Yield Strength – 8,000 psi
- Max Stress – 3,000 psi

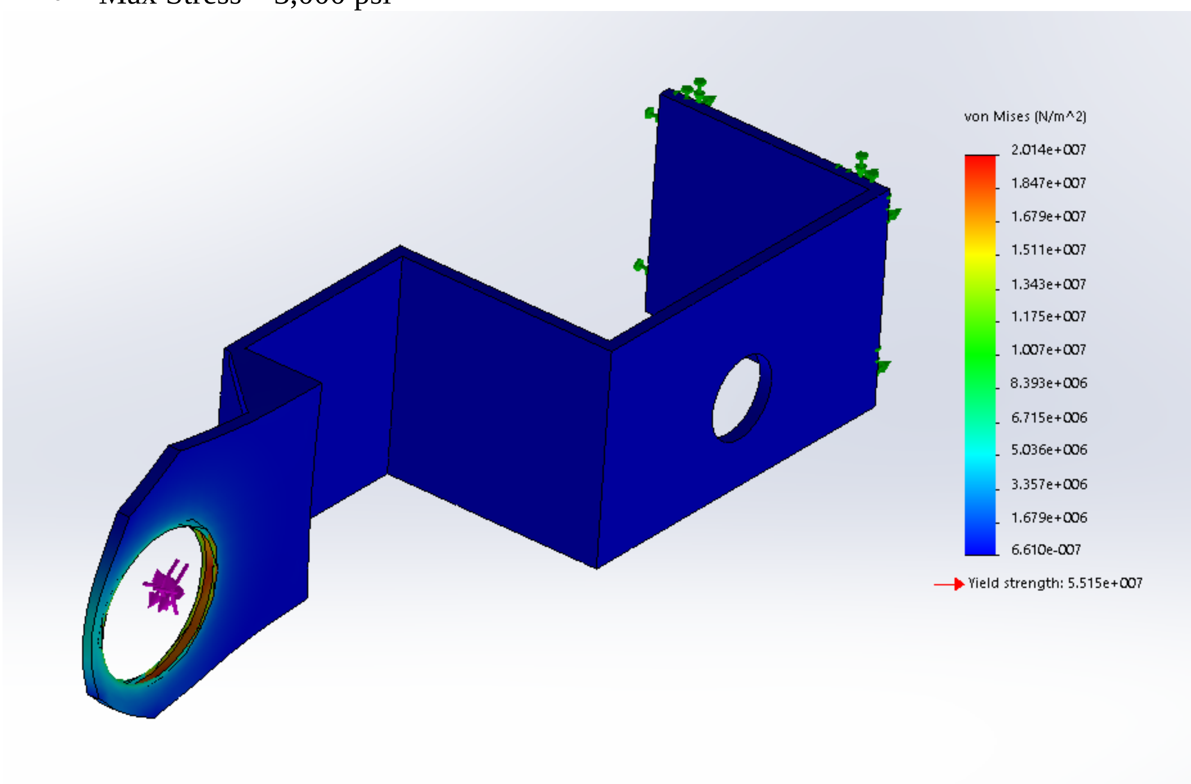

Figure 36: Internal rail FEA #1

- 500 lbs force applied at front of internal rail support system
- Yield Strength – 8,000 psi
- Max Stress – 20,000 psi
- Fix – will add additional mount from frame tubing to internal rail at front of battlebot in order to distribute this force better and keep the rails from failing

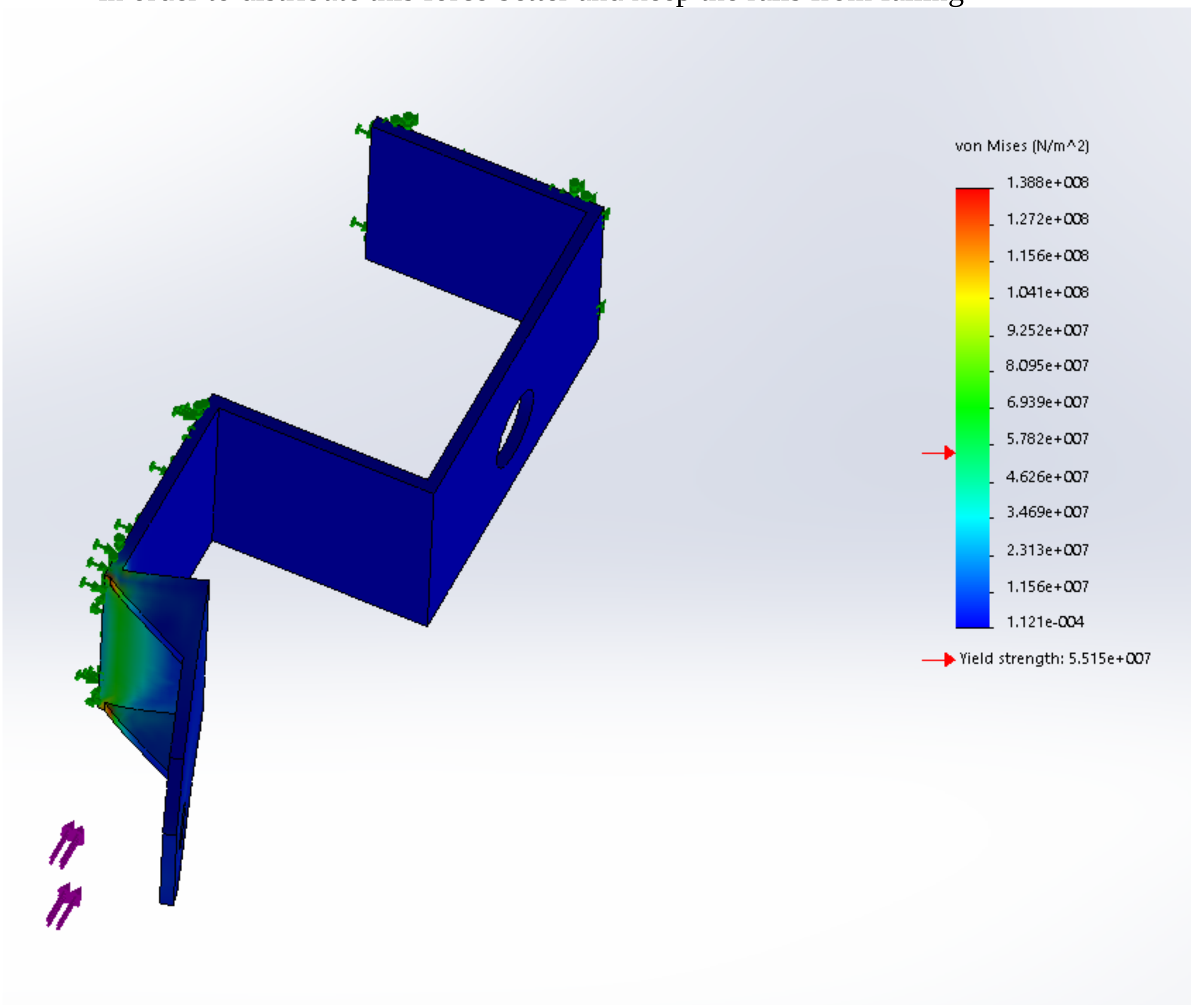

Figure 37: Internal rail FEA #2

FRAME AND ARMOR FABRICATION

The fabrication of this frame and armor assembly like the weapon was completed by Unique Metal Design in Fredericktown, Ohio. The aluminum tubing was cut to length with a band saw and then tig welded together. Then, the three sides and bottom of the Battlebot frame was covered with the aluminum plating by welding the plates to the bars. The top plate of the armor will be attached to the frame using rivet nuts paced on the top of the square tubing frame. Then we will drill matching through holes in the top plate so that we can screw button head screws into the rivet nuts and secure the lid. The other essential part to the frame is the internal rails. These have also been fabricated by our sponsor by bending the ¼" aluminum plates into the proper configuration using a press. The drive motor holes and weapon shaft holes were created using a laser.

Figure 38: Frame and armor fabrication

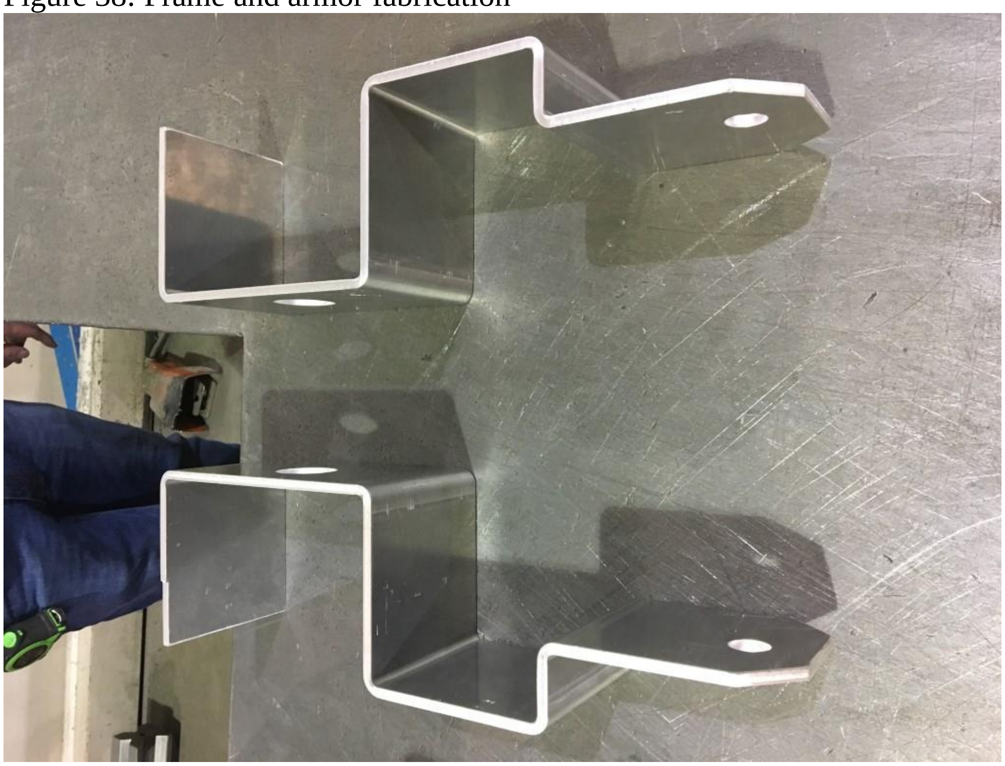

Figure 39: Internal rail fabrication

CONCEPT SELECTION MATRIX

The common themes are a compact, invertible BattleBot with an effective weapon. The RoboGames competition has requirements on some components (electrical weapons, radio frequencies) but they are looking for the teams to be creative and come up with new ideas and designs. We will keep these successful BattleBots in mind when finalizing our design.

Table 9: Overcall concept selection matrix

		Overall Design Concepts					
		Box w/ drum		Box w/ wedge and drum		Box w/ 4 wedges and drum	
Criteria	Weight %	rating	wt. rating	rating	wt. rating	rating	wt. rating
cost	15	2	0.3	2	0.3	1	0.15
maneuverabilty	10	3	0.3	3	0.3	2	0.2
size	15	3	0.45	2	0.3	2	0.3
reliability	15	3	0.45	3	0.45	3	0.45
Defense	15	1	0.15	2	0.3	3	0.45
Offense	20	3	0.6	2	0.4	2	0.4
Manufacturability	10	2	0.2	1	0.1	1	0.1
	100	n/a	2.45	n/a	2.15	n/a	2.05

FULL ASSEMBLY

SOLIDWORKS

Components:

1. Internal rail (left)
2. Internal rail (right)
3. Frame and armor
4. Weapon
5. Weapon shaft
6. Weapon shaft collar (typ. x2)
7. Weapon shaft bushing (typ. x2)
8. Weapon drive belt (typ. x2)
9. Weapon motor
10. Weapon motor pulley
11. Wheel motor (typ. x2)
12. Wheel (typ. x2)
13. Weapon speed controller
14. Wheel speed controller
15. Battery
16. ON/OFF Switch

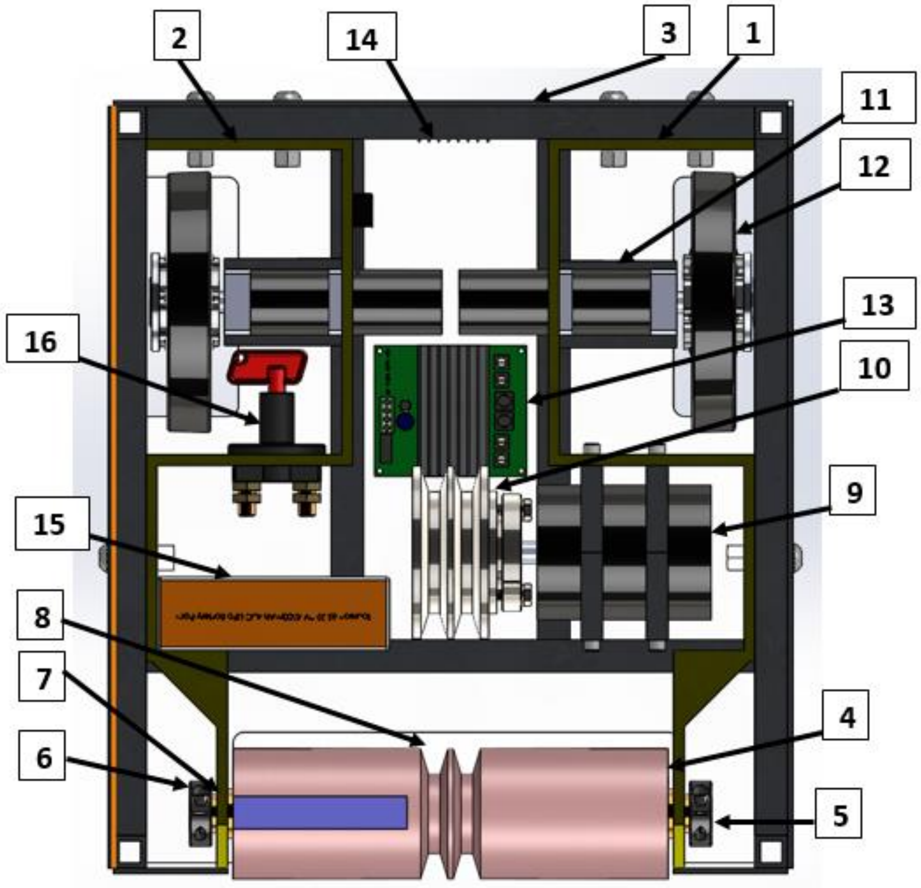

Figure 40:Full assembly top view w/ labeled parts

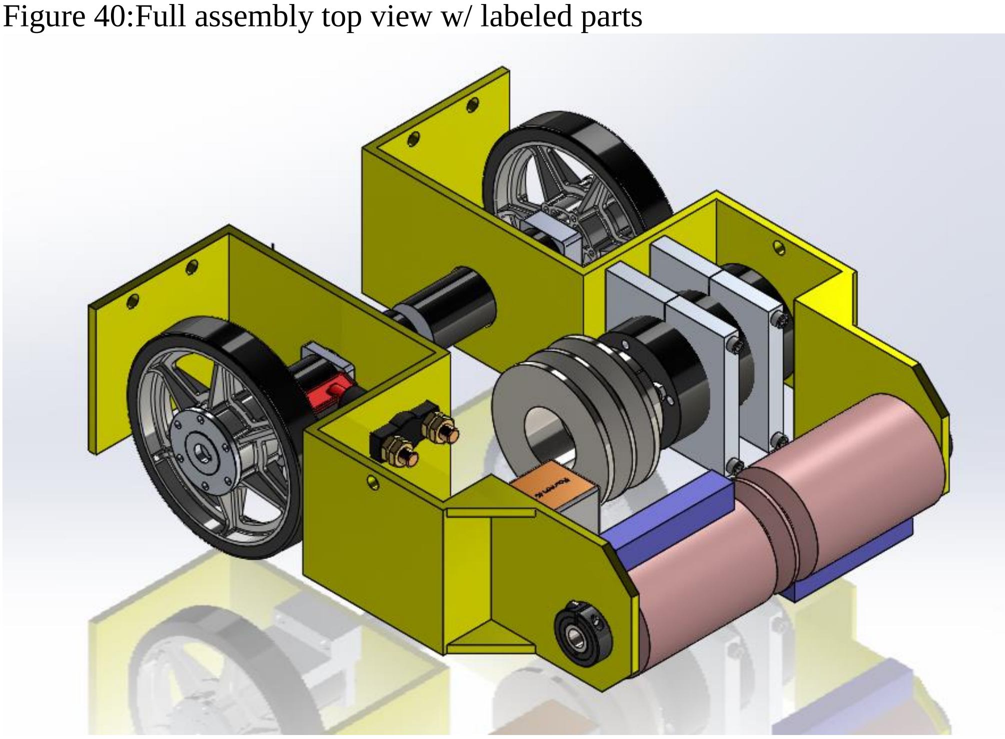

Figure 41: Internal rail assembly isometric

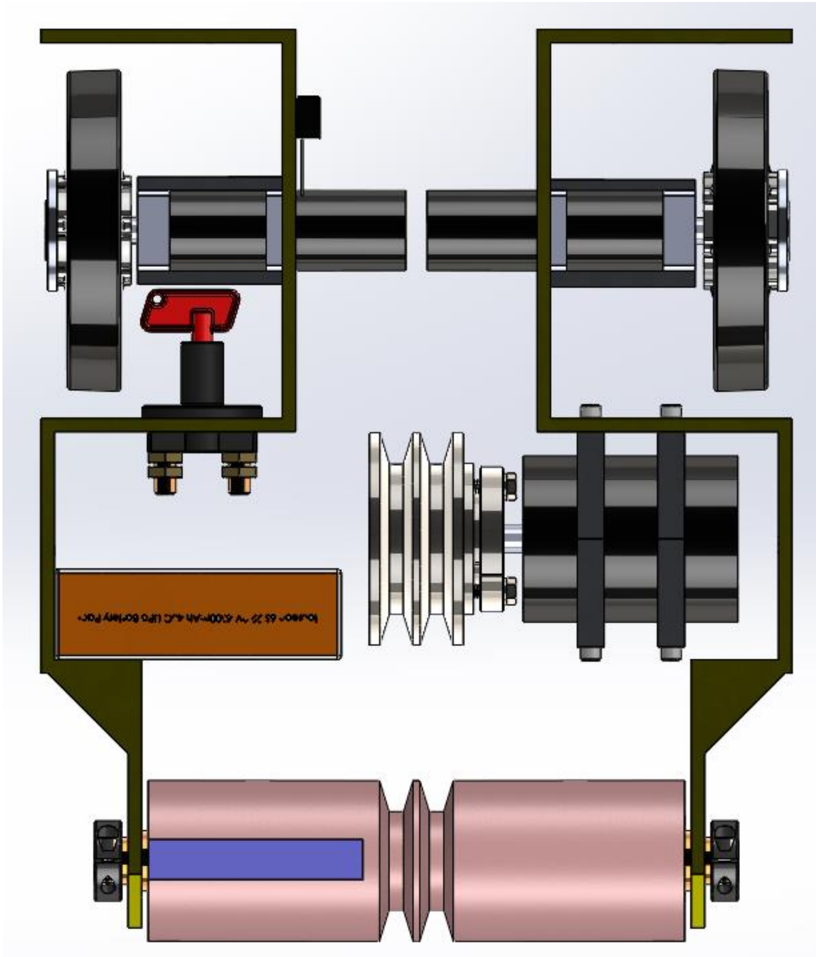

Figure 42: Internal rail assembly top view

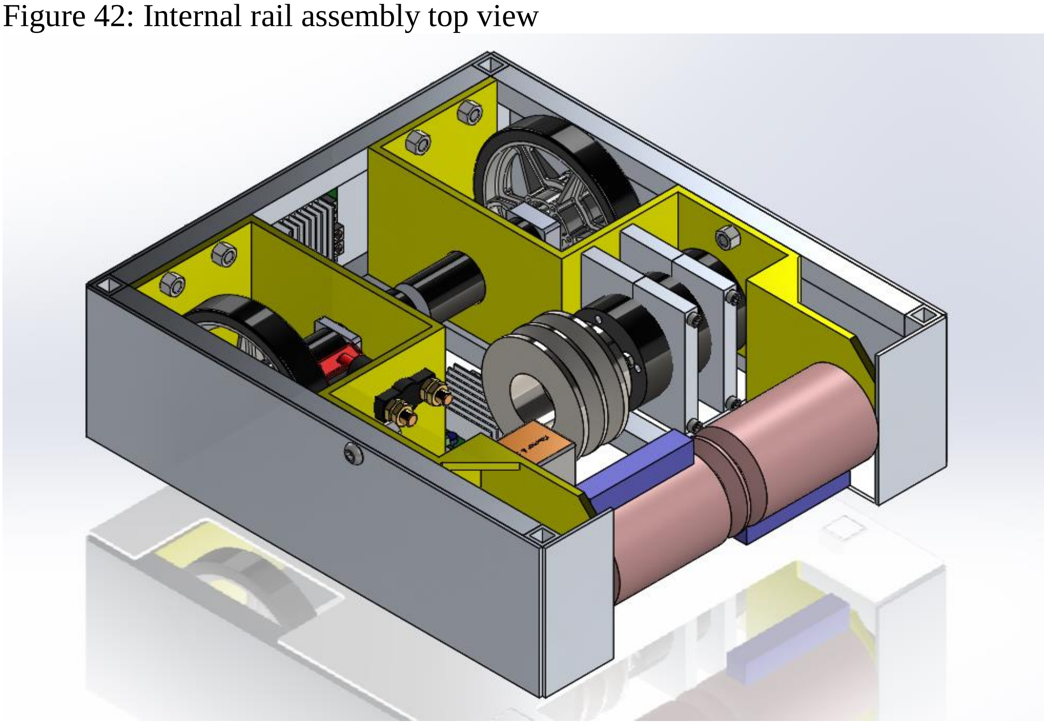

Figure 43: Full assembly isometric

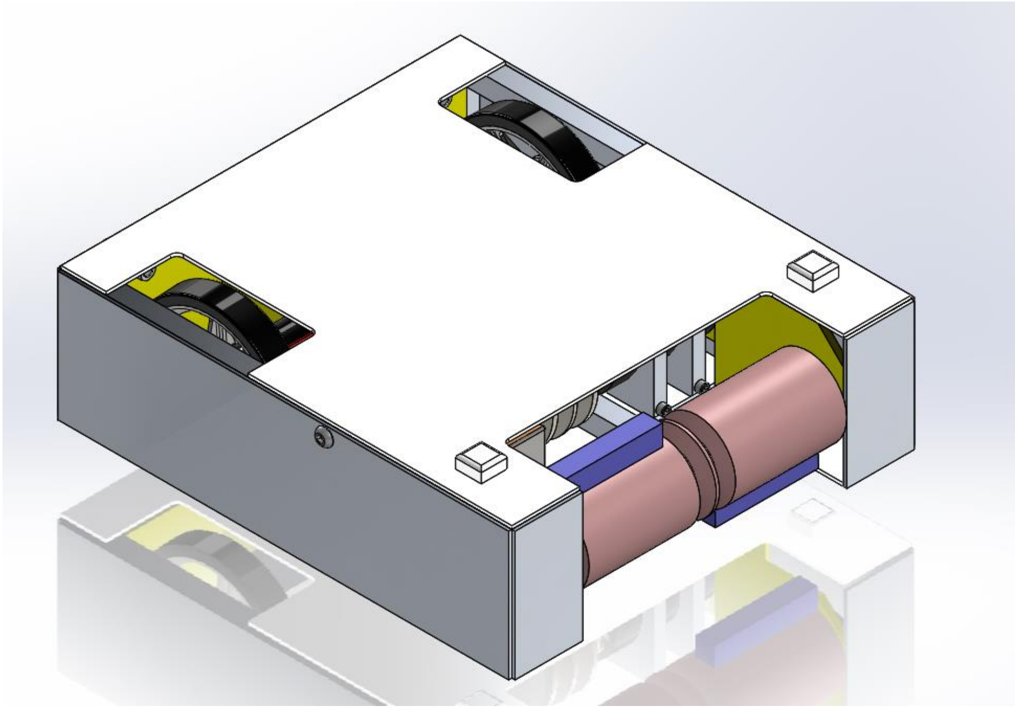

Figure 44: Full assembly isometric w/ lid

ACTUAL ASSEMBLY

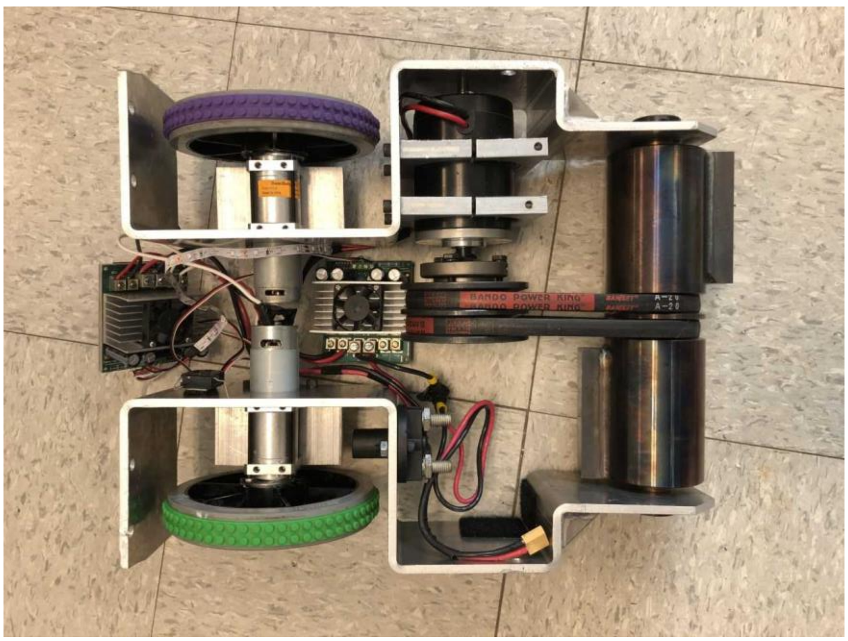

Figure 45: Internal rail assembly

Figure 46: Full assembly w/ lid

BILL OF MATERIALS

Table 10: Bill of Materials

BattleBot Bill of Materials	
Item	**Quantity**
AmpFlow E30-150 (weapon)	1
BaneBot PDX256 (wheels)	2
AndyMark 6'' Rubber wheel	2
1/2" keyed hub	2
screws for wheel hub	1
key for wheels	2
2200mah Battery	2
Bearing (Weapon)	2
Shaft Collar (weapon)	2
Drive pulley (weapon drive)	1
Weapon mtrl main (ft)	1
Weapon Mtrl Edge (ft)	1.5
Shaft bushing (weapon drive)	1
Weapon Shaft (ft)	1
Weapon belt	2
3/4" AL tube 1/8" thick (ft)	15
outer shell & rail mtrl AL 1/8x6x48 (ft)	10
Weapon Shaft Rail bushing	2

TESTING & PROOF OF DESIGN

PHASE I – MARCH 20TH, 2018

Assembly of the robot was completed on this date and preliminary testing was completed. The tests conducted were a full driving functions check including remote operation and Battlebot handling, as well as a weapon functions check. The results of this testing gave us great feedback of our design and allowed us time to make critical adjustments before the project deadline. The remote operation was operable while not completely stable. We struggled with the remote joysticks maintaining a constant zero while operating the wheel motors. This caused the wheel motors to be receiving power even when the joysticks of the remote were at the “Zero” position. This issue was resolved by changing certain settings within the remote that we found in the remote owner’s manual. Next, the driving test revealed that the wheels did not possess a high enough friction coefficient to effectively move the Battlebot as we intended. The wheel motors were producing enough torque but the wheels were not producing enough force into the ground. In order to fix this issue we have ordered additional treads to place on the wheels and increase the friction coefficient. Lastly, the weapon testing allowed us to see if our theoretical weapon design in fact would operate as we calculated. Upon providing power to the weapon motor we knew that it clearly had enough power to spin the weapon in its current arrangement. As the weapon began to build speed the drum created an extreme vibration that would effectively render the Battlebot useless. Our current fix for this issue is to arrange the remote controls in order to allow the operator to control the weapon speed so that it does not reach the higher speed that creates a vibration. An alternative fix to this issue is to add in the wiring of the weapon motor a voltage limiting device that controls the max speed of the weapon. In all our first round of testing and proof of design proved to be successful in allowing us to identify the current issues with the design after manufacturing and make plans to correct each issue accordingly.

Phase II – April 3rd, 2018

This round of testing was completed after adding the adjustments and additional parts needed from phase one testing. The additional traction needed was accomplished using stick on rubber Lego material. This addition increased our traction capabilities but still did not completely fix the issue. The Battlebot is now drivable but doesn't not have the handling at as high of a level as we would like. At this point our driving test was successful and the Battlebot is operational for a fight. All other issues identified in phase one testing have not been fully addressed due to budget and time limitations. For testing video link see appendix C.

RECOMMENDATIONS

- Weight distribution when using two wheel design
    - We added additional weight (5 lbs) to rear to improve traction
- Third point of contact when using 2-wheel design
    - We used two feet on the front which caused it to wobble a bit due to machining imperfections
- Weapon speed (faster is not always best)
    - We had to run our weapon motor at a much slower speed due to vibration at high speeds
- Symmetry for spinning weapons
    - Weapon symmetry could have reduced the amount of vibration when spinning at a high speed
- Minimize tight dimensioning to ease assembly process
    - We designed the internal rail system to sit perfectly flush with the frame. We also did not consider weld beads. This made it difficult to assemble. We had to grind some material off to fix this issue.
- Traction is very important in wheel selection
    - We Added silicon Lego strips to wheels. This helped tremendously.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Table 11: Estimated Budget

Estimated Budget	
Frame & Armor	$ 1,000.00
Weapon	$ 500.00
Electronics & Controls	$ 500.00
Drivetrain	$ 500.00
Manufacturing	$ 500.00
Total	**$ 3,000.00**

Table 12: Actual Budget

BattleBot Actual Budget			
Item	**Quantity**	**Price per**	**Total cost**
Weapon motor	1	$ 79.00	$ 79.00
Drive motor	2	$ 99.99	$ 199.98
Wheel	2	$ 9.00	$ 18.00
Wheel hub	2	$ 11.00	$ 22.00
Wheel hub screws	1	$ 8.50	$ 8.50
Wheel shaft key	2	$ 0.70	$ 1.40
Battery	2	$ 15.29	$ 30.58
Weapon Bearing	2	$ 16.98	$ 33.96
Weapon shaft collars	2	$ 2.60	$ 5.20
Weapon drive pulley	1	$ 35.81	$ 35.81
Weapon material	1	$ 141.84	$ 141.84
Weapon material (teeth)	1	$ 79.76	$ 79.76
Weapon drive shaft bushing	1	$ 17.48	$ 17.48
Weapon Shaft	1	$ 11.02	$ 11.02
Weapon belt	2	$ 6.33	$ 12.66
Frame material	1	$ 53.00	$ 53.00
Armor material	-	-	Scrap
Weapon Shaft Rail bushing	2	$1.95	$ 3.90
Labor			Donation
Total Item Cost			**$ 754.09**
Support from sponsors (UMD)			**$ 754.09**
Cost to Team			**0**

SCHEDULE, PROPOSED /ACTUAL

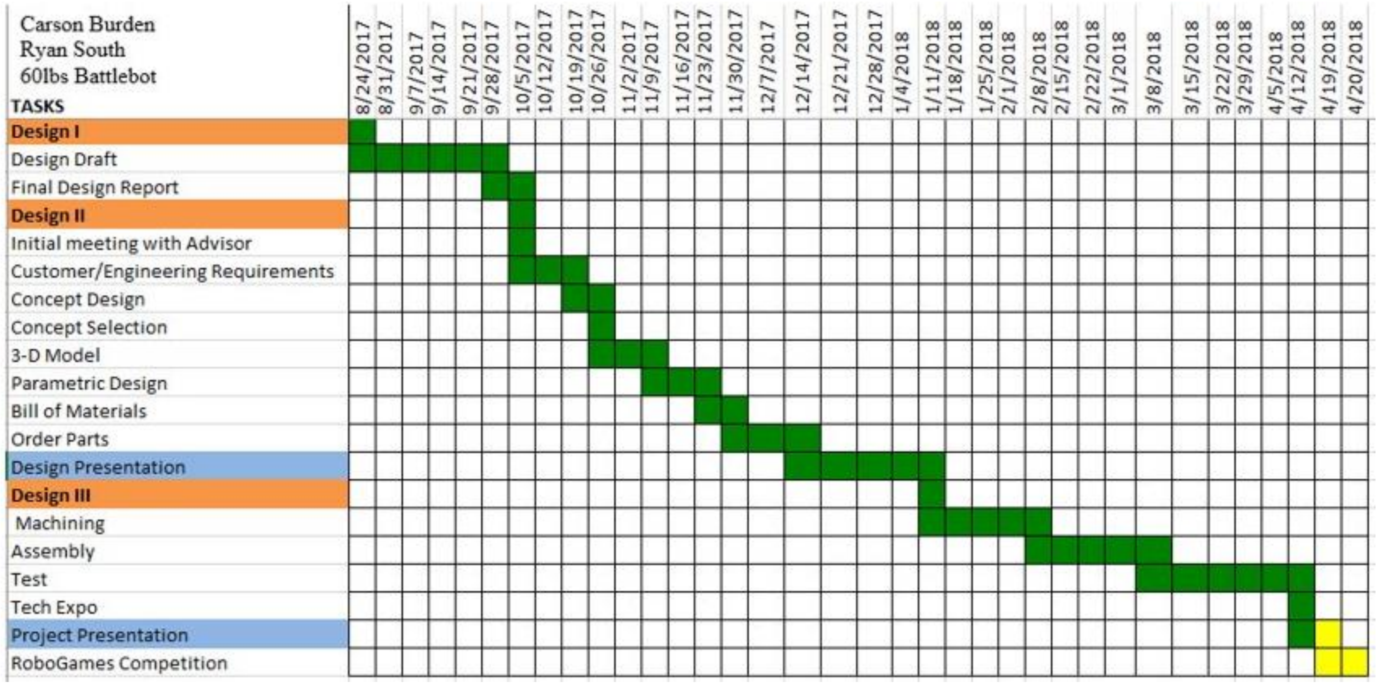

Figure 47: Project schedule

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APPENDIX A - INTERVIEWS

Interview 1 – 10/20/2017
-Nick Henwood (Construction Management 5th year at UC)

Q: What specific weapon types would you like to see on a battlebot at the RoboGames?
A: "I think that a weapon that puts on more of a show would be ideal, something that has flames or creates a lot of sparks would be my preferred choice."

Q: What are some common pitfalls you think happen in the arena during a battle?
A: "The big down side for competitors would be not having protection over the wheels or method of moving about the arena. I think that if wheels are used they definitely need to be covered with armor in order to be more difficult to disable."

Q: As a battlebot operator what would you like to see?
A: "Zero degree turning is a feature I think is necessary in a battle. The spped and agility of the battlebot would be important as an offense and defense."

Interview 2 – 10/23/2017
-Matt Denlinger (Previous battlebot competitor and Mechanical Engineering 5th year at UC)

Q: What specific weapons types would you like to see on a battlebot at the Robo games?
A: "The big thing I saw winning battles when competed was spinning weapons. They could have been spinning horizontally or vertically, either way they created the most damage in the arena."

Q: What are some common pitfalls you think happen in the arena during a battle?
A: "Being flipped over is a huge issue for some designs. A design that is able to operate no matter what side of its frame that it is laying on is crucial."

Q: As a battlebot operator what would you like to see?
A: "When driving our battlebot in competition it was difficult for all team members to operate. A feature that helped control the speed of the battlebot or sensitivity of the control to reacting to the user input could be a big help when maneuvering in a battle."

Interview 3 – 10/24/2017
-James Brickell (Mechanical Engineering Technology 5th year at UC, 120lb Battlebot team leader)

Q: What specific weapons types would you like to see on a battlebot at the Robo games?
A: "Based on all of our team's research we are going with a drum bot design. A vertically spinning weapon that has a large surface area to grab opponents seems to be most effective."

Q: What are some common pitfalls you think happen in the arena during a battle?
A: "A strong and durable armor/ frame is going to be key in our design. We have seen that a lot of battle end quickly because a battlebots' armor is not secure properly or simple not

strong enough."

Q: As a battlebot operator what would you like to see?
A: "A weapon system that does not require a precision attack, something that has a larger area for making contact with the enemy will increase the operator's ability to damage the opponent."

APPENDIX B – CALCULATIONS

Weapon Motor
Motor RPM – 5400
Drive Pulley (d1) – 2.79” Dia.
Driven Pulley (d2) – 1.84” Dia.
Center Distance (C) – 6”
Belt Speed

$$V_b = \frac{\pi d_1 n_1}{12}$$

$$3{,}944\ ft/\min = \frac{\pi * 2.79 * 5400}{12}$$

Center Distance

$$d_2 < C\ < 3(d_1 +\ d_2)$$

$$1.84"\ < C\ < 13.89"$$

C = 6”

Belt Length

$$L = 2C + 1.57(d_2 +\ d_1) + \frac{(d_2 + d_1)^2}{4C}$$

$$20.16"\ =\ 2(6)\ +\ 1.57(1.84 + 2.79)\ +\ (1.84 + 2.79)^2/4(6)$$

Torque on Drum

Motor Torque = 44.38 in-lb

$$F\ = T\left(\frac{d_2}{2}\right)$$

$$48.24\ lbs\ = 44.38(\frac{1.84}{2})$$

$$T_w\ = F(\frac{d_1}{2})$$

67.29 in-lb = 48.24(2.79/2)

Speed of Bot
Wheel Circumference

$$C\ =\ \pi D$$

$$18.85"\ =\ \pi(6)$$

Max Speed

$$V = C * RPM$$

$$V = (18.85") *\ 230\ rpm$$

V = 4,335.5 in/min

$$V = 6.02\ ft/sec$$

Battery Info:	Floureon Lithium Polymer RC Battery Pack
Individual capacity (Ahr)	4.5
Cell Number	6s
Peak continuous current (A)	202.5
Nominal Voltage (V)	22.2
Discharge Capacity (C)	45
Weight (lb)	1.4

Battery Capacity	(1 Battery)
Minutes	Ahr
60	4.5
30	9
15	18
7.5	36
3.75	72

Weapon:	Ampflow E30-150				
Stall Current (A)	125				
Condition	Scale	Current (A)	Time (sec)	Asec	Ahr
Stall	1	125	25	3125	0.868
Pushing	0.8	100	45	4500	1.250
Accelerating	0.4	50	35	1750	0.486
Cruising	0.15	18.75	60	1125	0.313
Stopped	0	0	15	0	0.000
Total			180		2.917

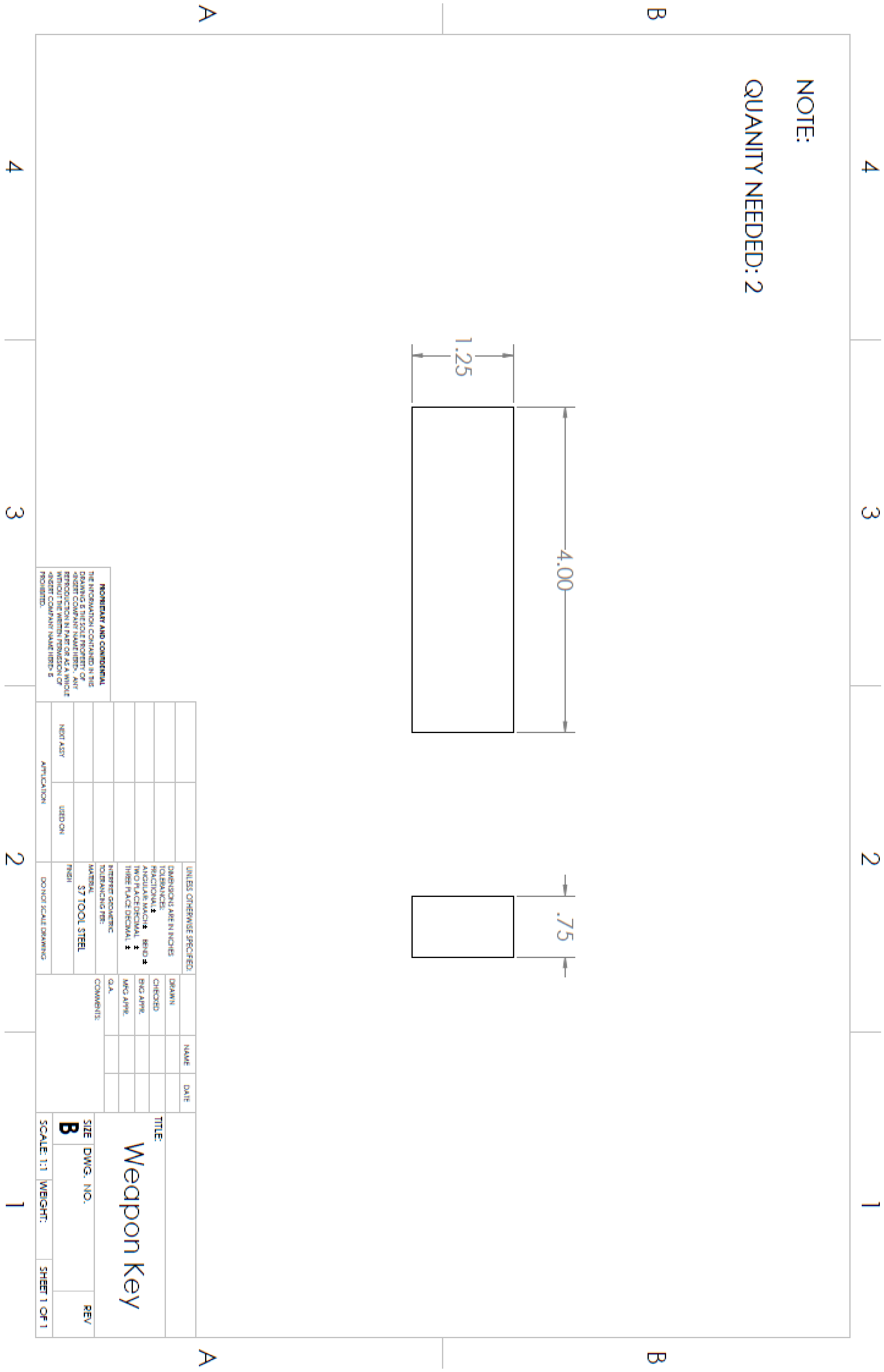
Drive:	BaneBot PDX-104				
Stall Current (A)	148				
Condition	Scale	Current (A)	Time (sec)	Asec	Ahr
Stall	1	148	25	3700	1.028
Pushing	0.8	118.4	45	5328	1.480
Accelerating	0.4	59.2	35	2072	0.576
Cruising	0.15	22.2	60	1332	0.370
Stopped	0	0	15	0	0.000
Total			180		3.453

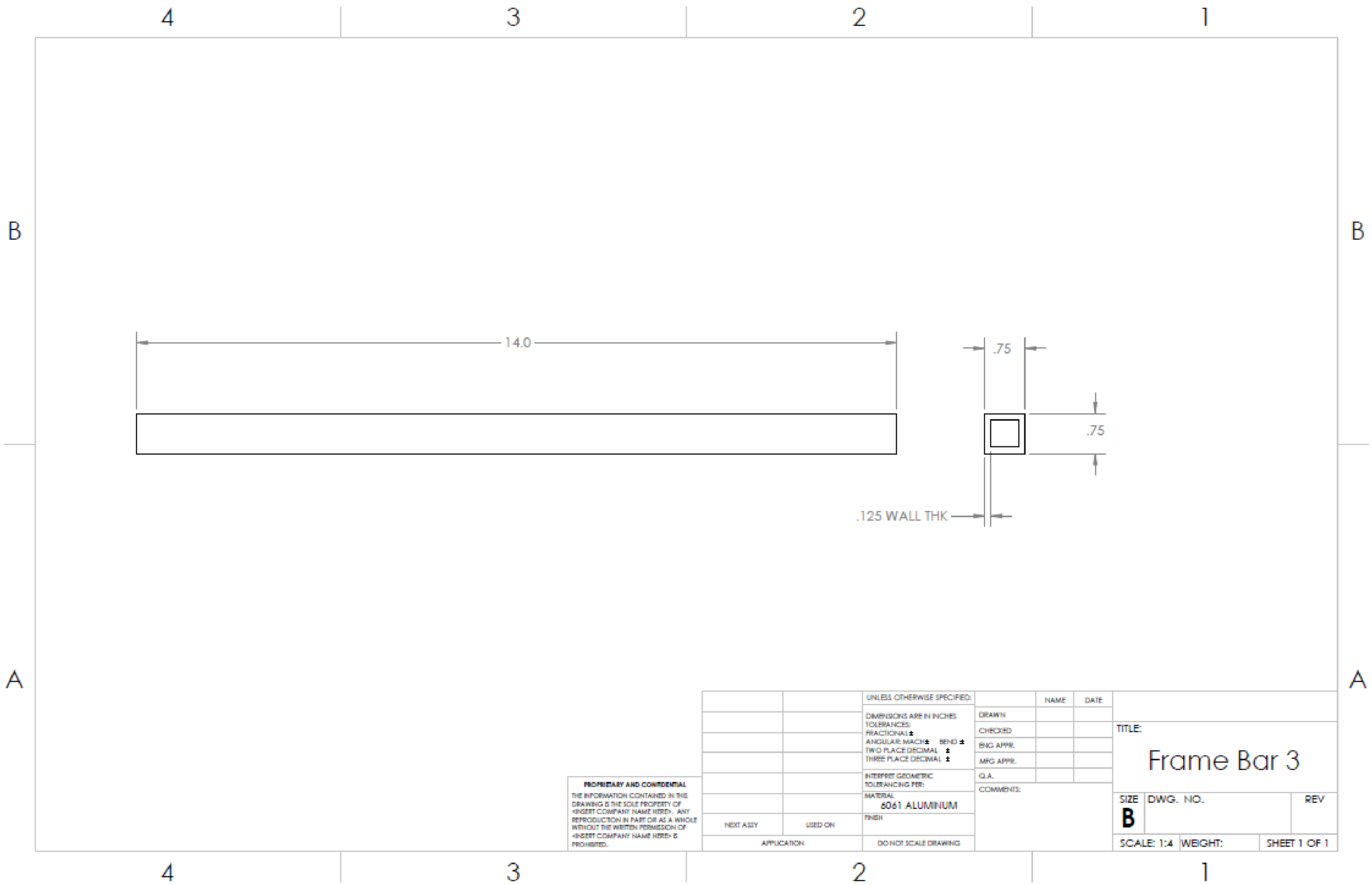
Motor Current Draw		
Weapon	2.917	Ahr
Drive	6.907	Ahr
Total	9.823	Ahr
Design Factor	1.5	
Adj. Total	14.735	Ahr

APPENDIX C – TESTING VIDEO LINK

Phase II testing:
https://www.youtube.com/watch?v=xu58opgVsMc&lc=z22bzxtanoqnuhntvacdp431aqhbyw0zxg3fpns3a5lw03c010c

APPENDIX D – MANUFACTURING DRAWINGS





14.0
.75
.75
.125 WALL THK
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061 ALUMINUM
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REV
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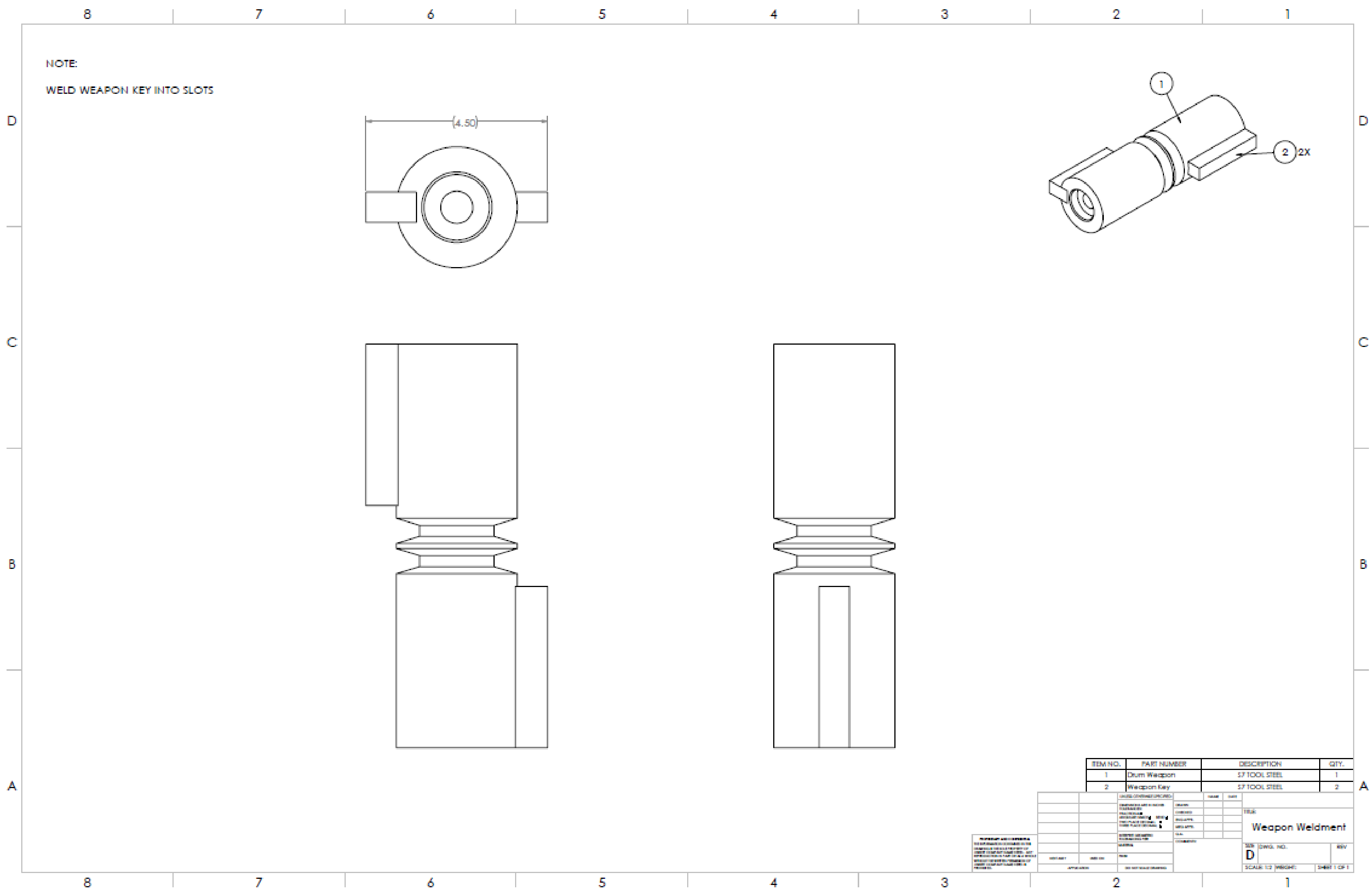
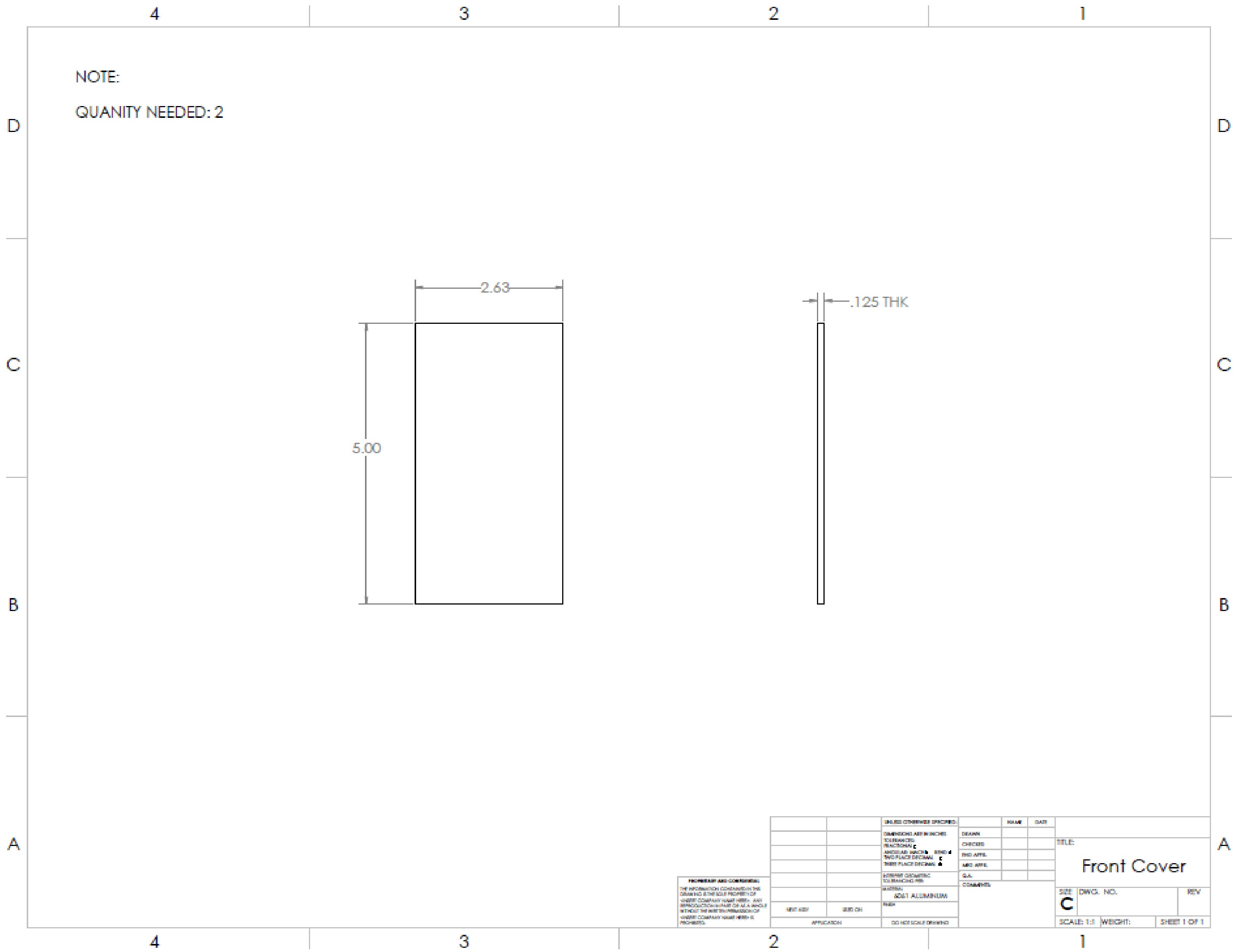
WEIGHT:
SHEET 1 OF 1


NOTE:
WELD WEAPON KEY INTO SLOTS
(4.50)
1
2 2X
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | Drum Weapon | S7 TOOL STEEL | 1
2 | Weapon Key | S7 TOOL STEEL | 2
TITLE:
Weapon Weldment
SIZE D
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


NOTE:
QUANITY NEEDED: 2
2.63
5.00
.125 THK
TITLE:
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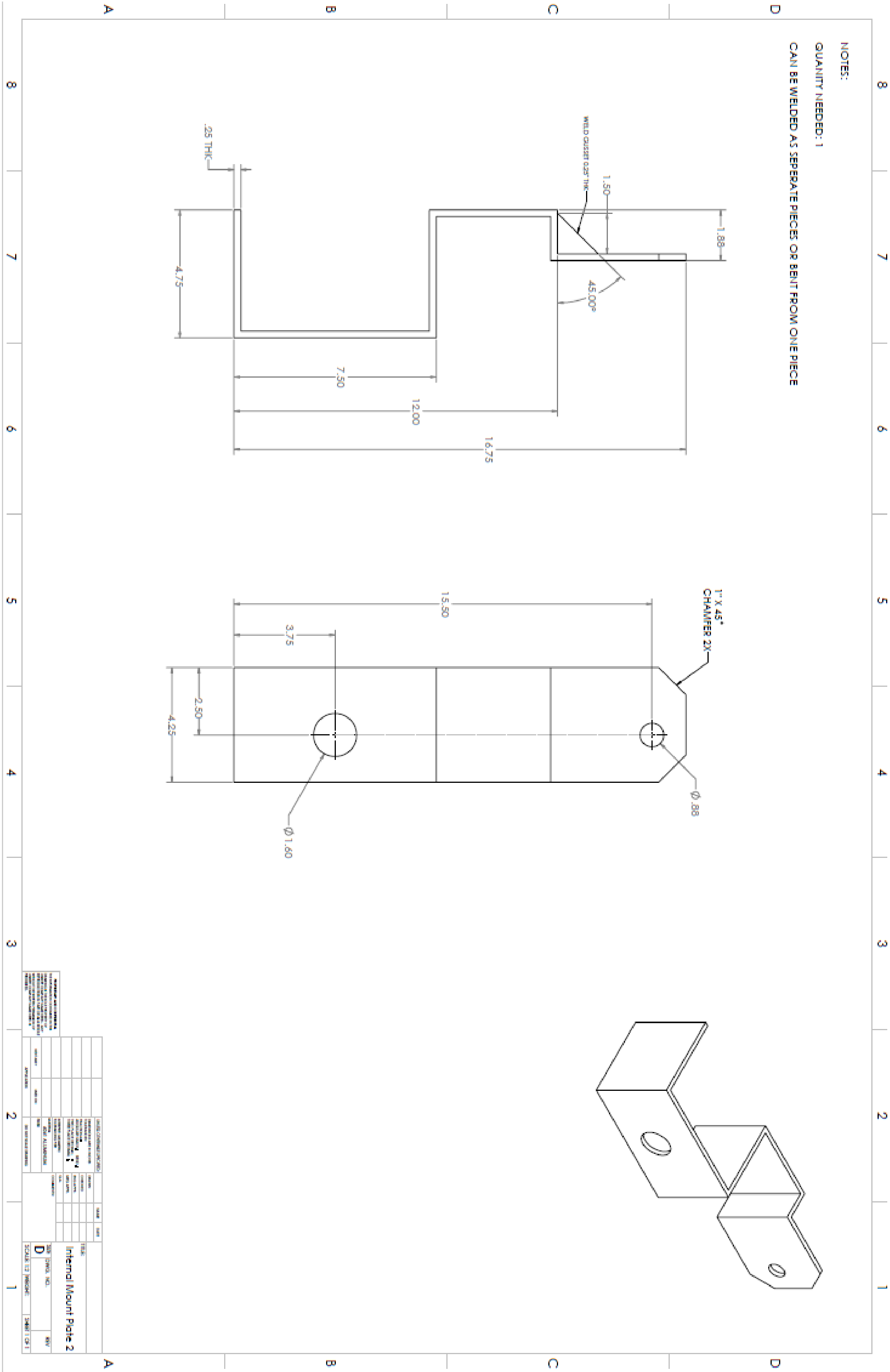
6061 ALUMINUM
SIZE
C
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


NOTES:
QUANITY NEEDED: 1
CAN BE WELDED AS SEPERATE PIECES OR BENT FROM ONE PIECE
WELD GUSSET 0.25" THK
1.50
1.88
45.00°
.25 THK
4.75
7.50
12.00
16.75
1" X 45°
CHAMFER 2X
15.50
3.75
2.50
4.25
Ø.88
Ø1.60
TITLE:
Internal Mount Plate 2
SIZE
D
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REV
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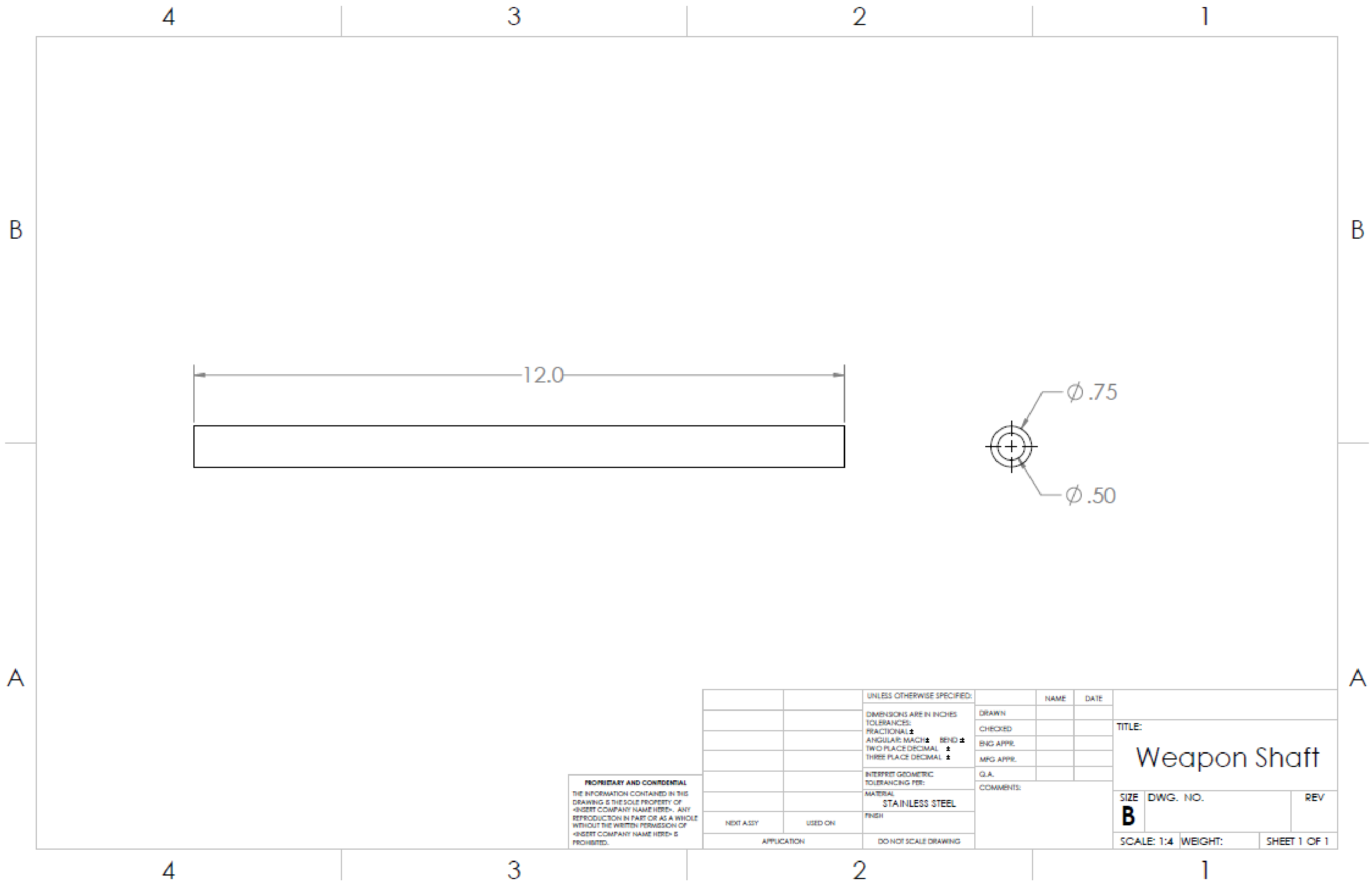
WEIGHT:
SHEET 1 OF 1


12.0
Ø .75
Ø .50
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
STAINLESS STEEL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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.
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DWG. NO.
REV
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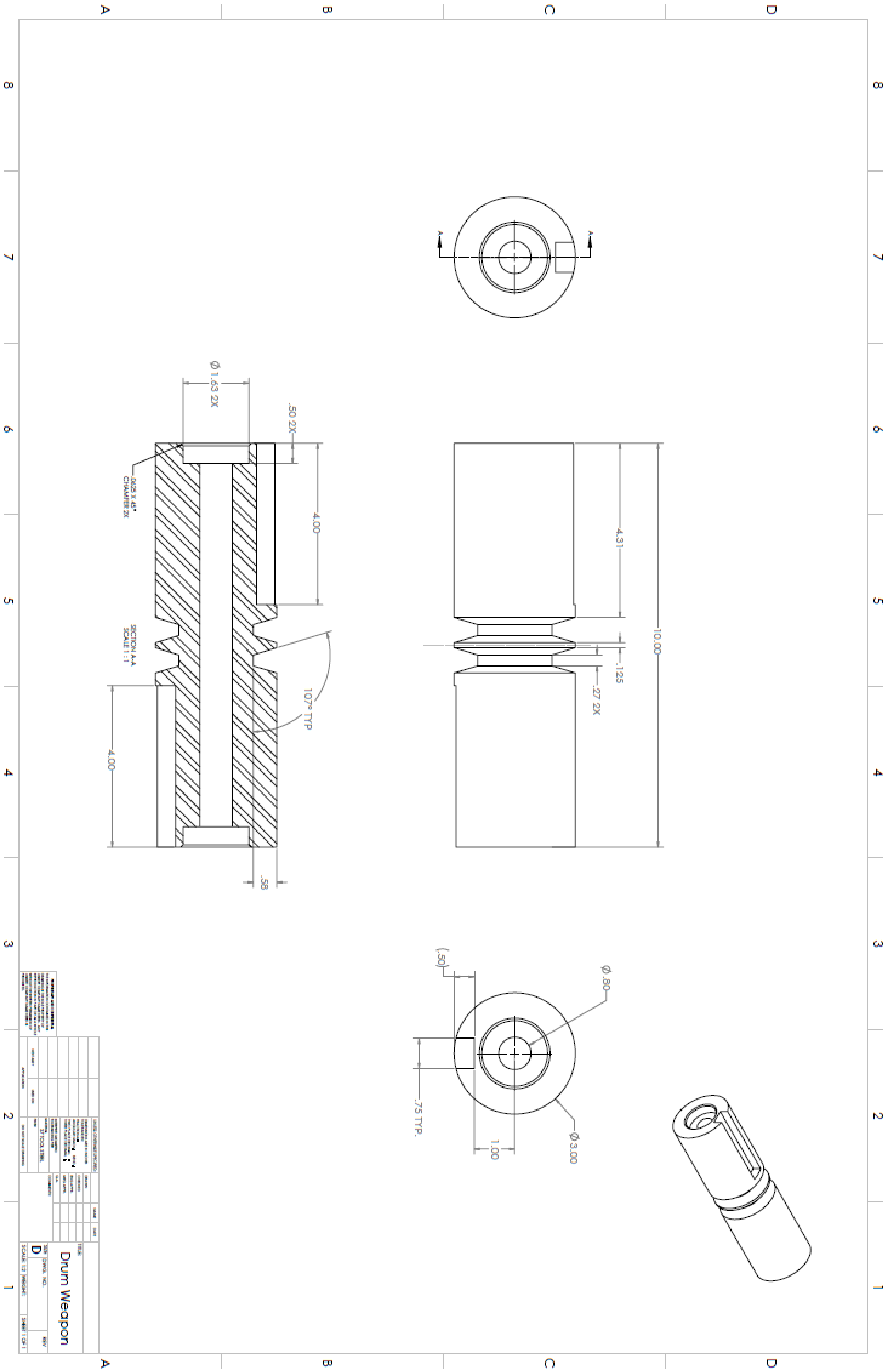
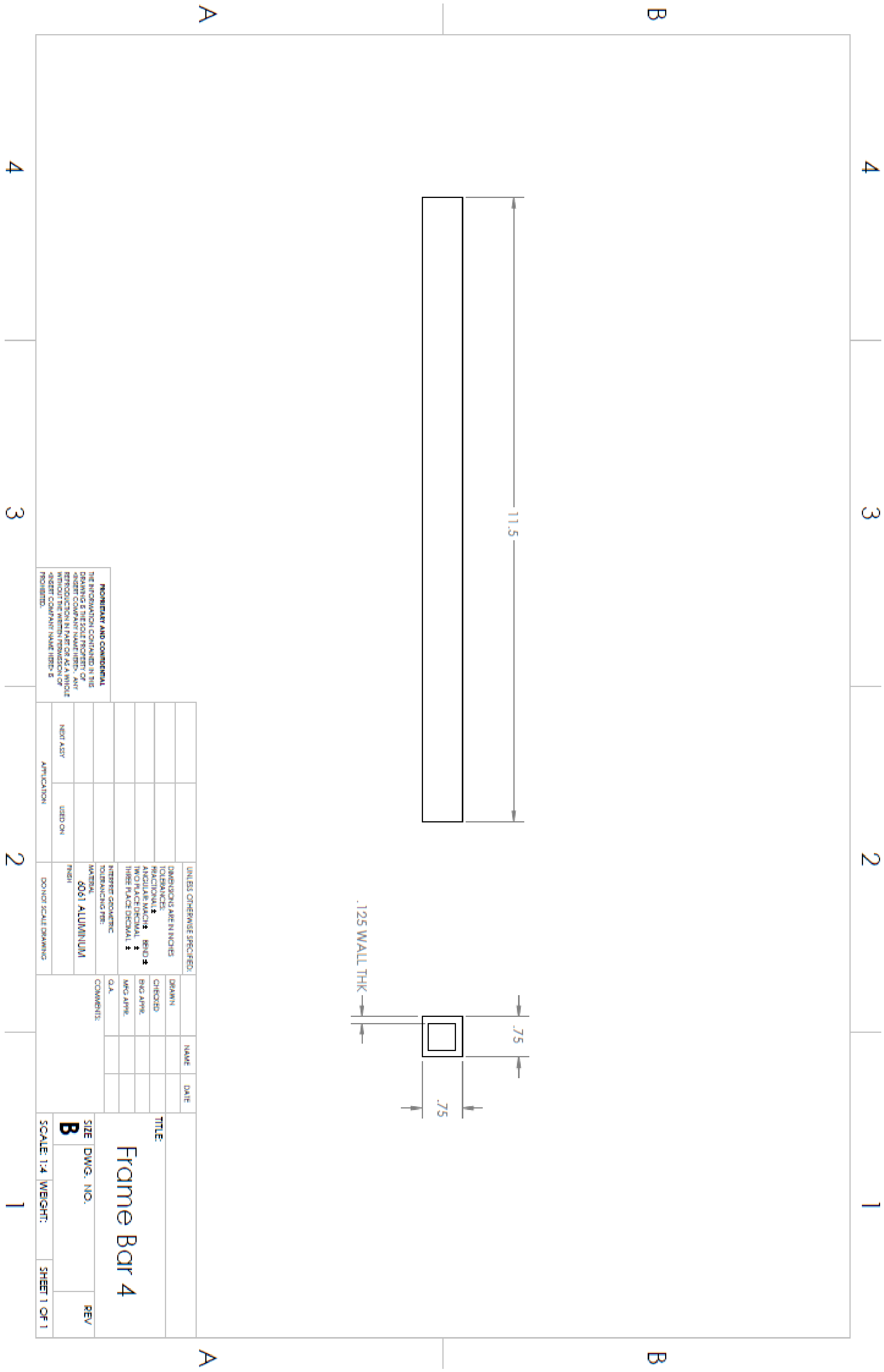
WEIGHT:
SHEET 1 OF 1



Drum Weapon
Ø1.63 2X
.50 2X
.025 X 45° CHAMFER 2X
4.00
4.00
SECTION A-A SCALE 1 : 1
107° TYP
.58
4.31
10.00
.125
.27 2X
(.50)
Ø.80
.75 TYP.
1.00
Ø3.00


11.5
.75
.75
.125 WALL THK
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
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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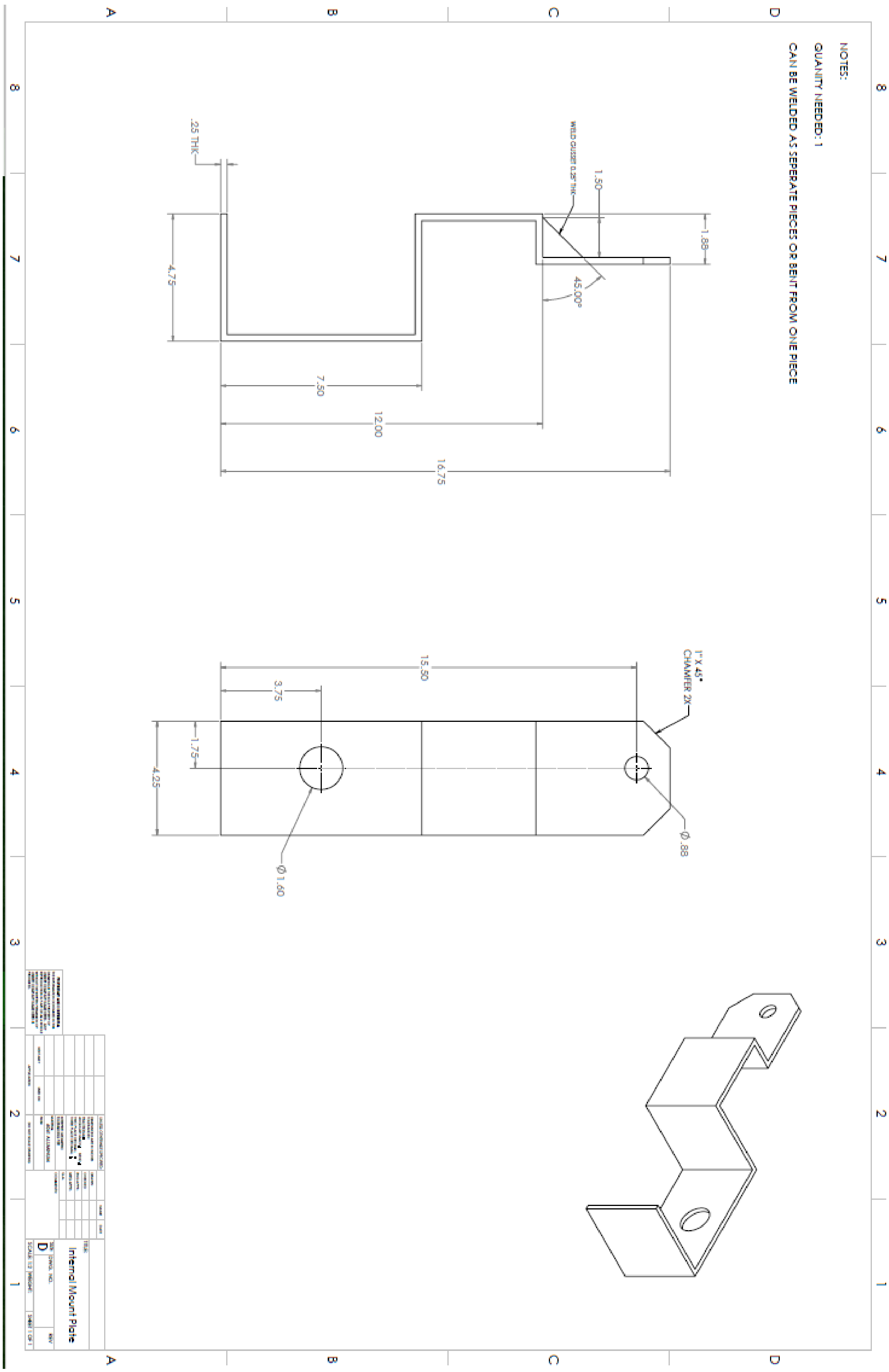
SHEET 1 OF 1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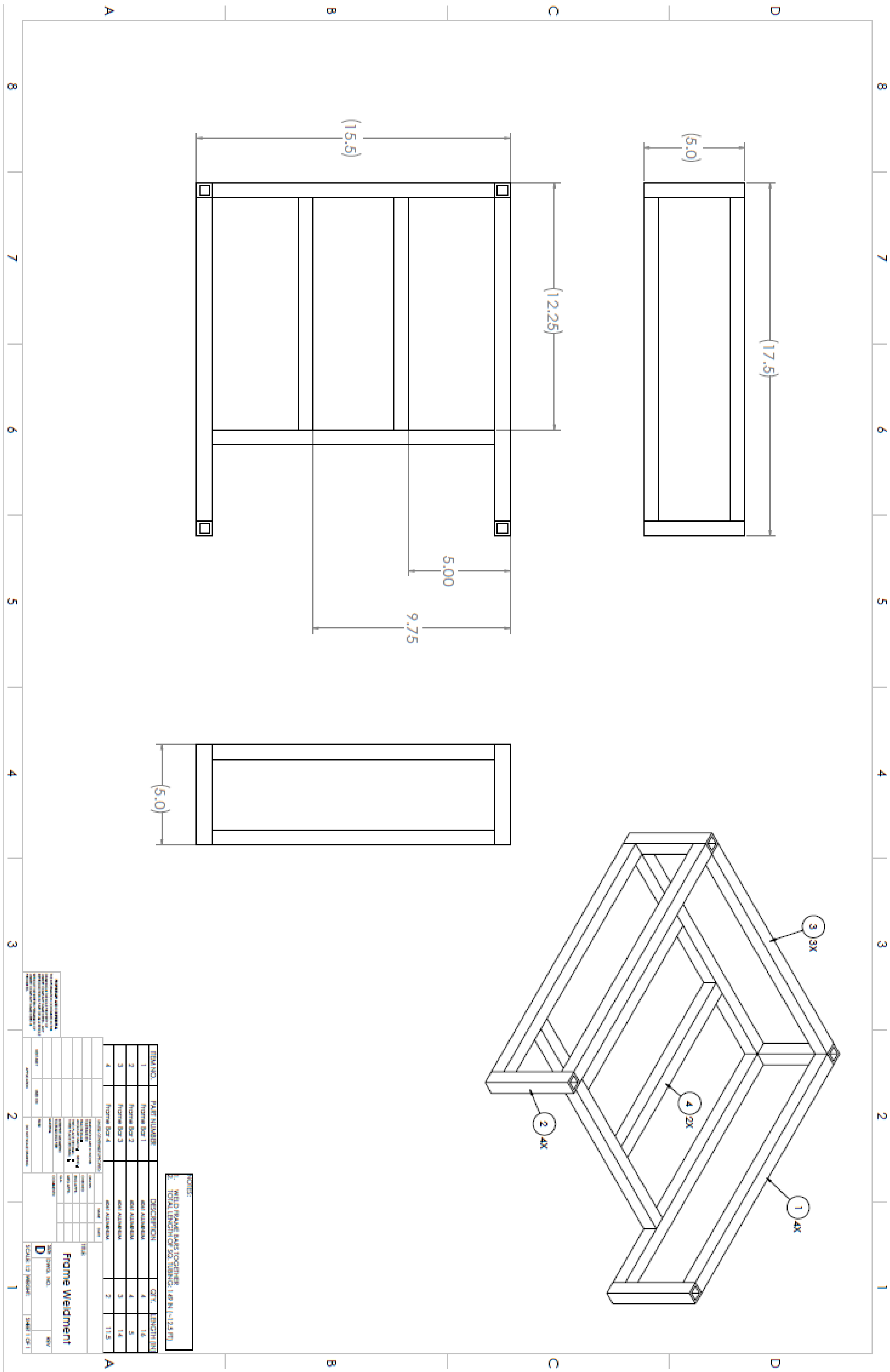
CAN BE WELDED AS SEPERATE PIECES OR BENT FROM ONE PIECE
WELD GUSSET 0.25" THK
1.50
1.88
45.00°
.25 THK
4.75
7.50
12.00
16.75
1" X 45°
CHAMFER 2X
15.50
3.75
1.75
4.25
Ø.88
Ø1.60
Internal Mount Plate
D
A
B
C
1
2
3
4
5
6
7
8


(15.5)
(12.25)
(5.0)
(17.5)
5.00
9.75
(5.0)
1 4X
2 4X
3 3X
4 2X
NOTES:
1. WELD FRAME BARS TOGETHER
2. TOTAL LENGTH OF SQ. TUBING: 149 IN (~12.5 FT)
ITEM NO. PART NUMBER DESCRIPTION QTY. LENGTH (IN)
1 Frame Bar 1 6061 ALUMINUM 4 16
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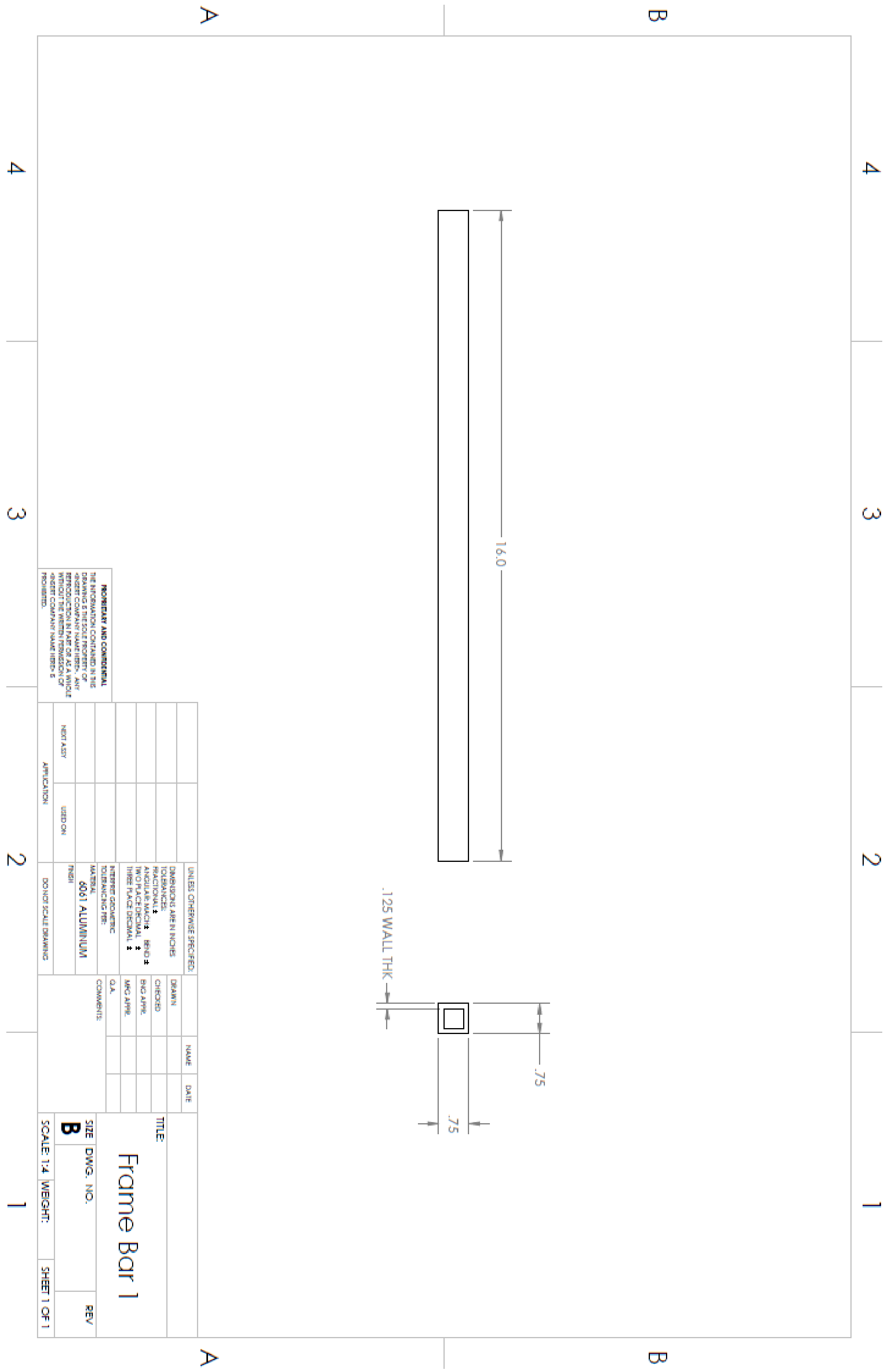
3 Frame Bar 3 6061 ALUMINUM 3 14
4 Frame Bar 4 6061 ALUMINUM 2 11.5
Frame Weldment
D


16.0
.75
.75
.125 WALL THK
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061 ALUMINUM
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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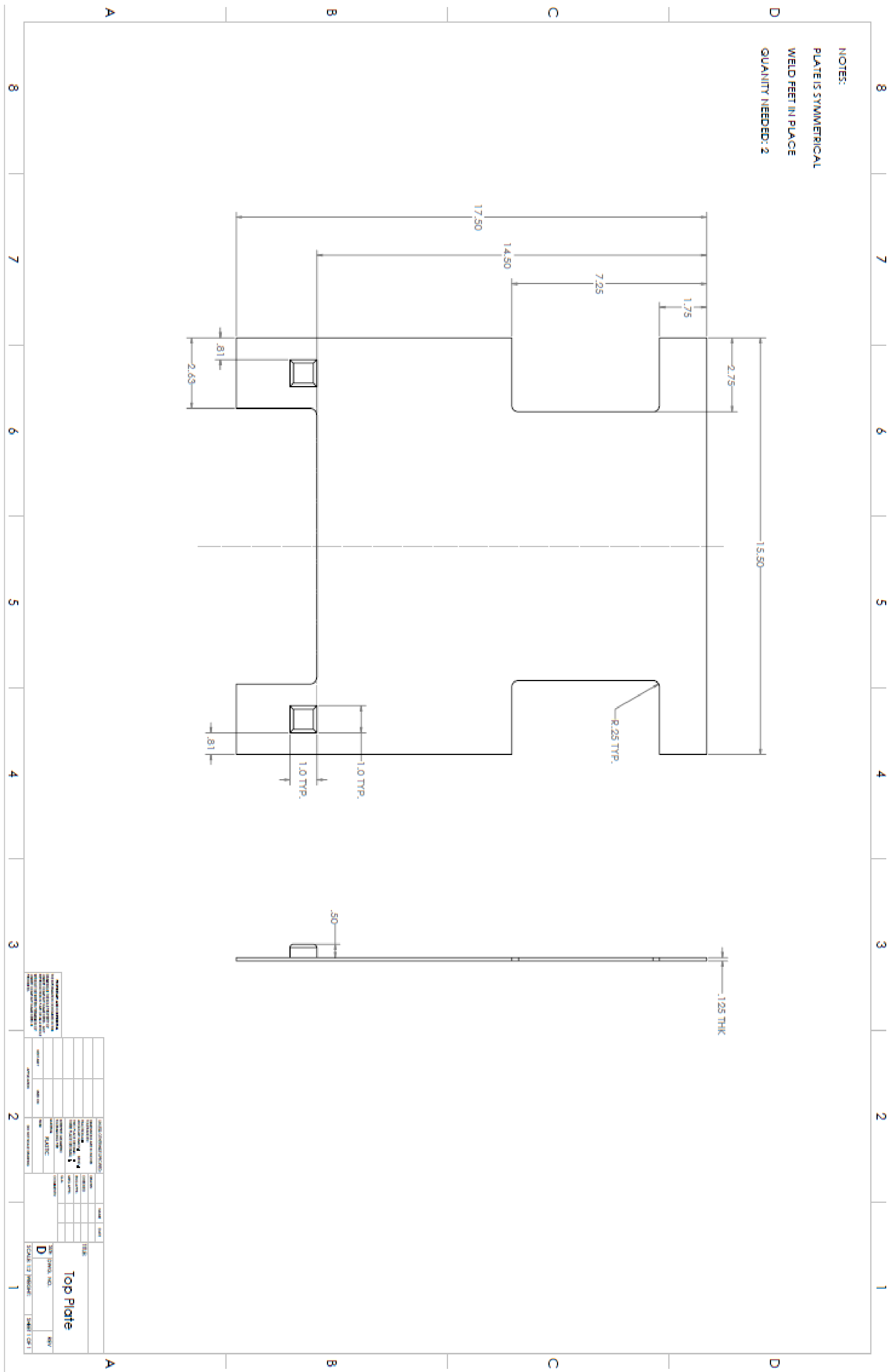
SHEET 1 OF 1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QUANITY NEEDED: 2
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14.50
7.25
1.75
2.75
15.50
R.25 TYP.
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1.0 TYP.
.50
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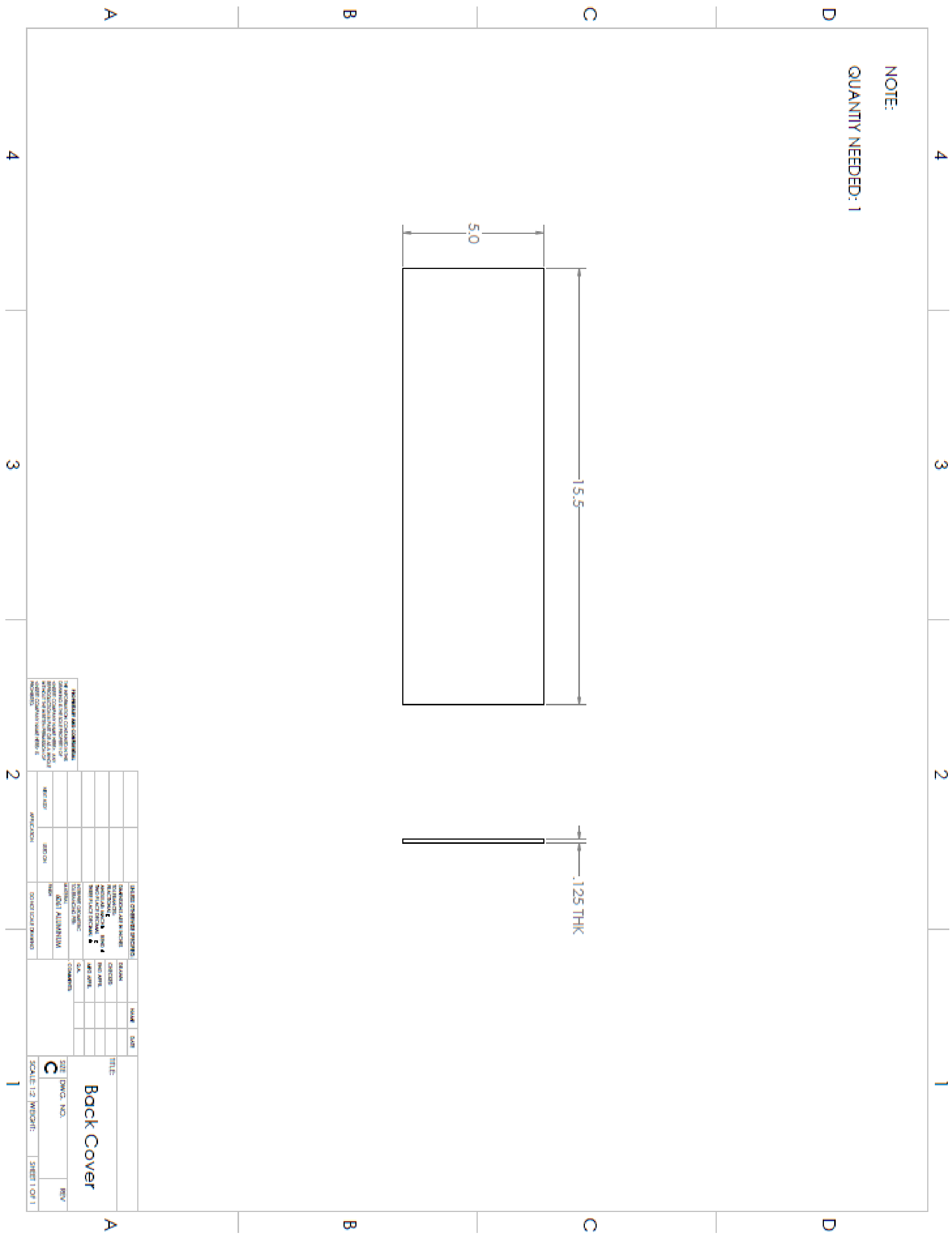
Top Plate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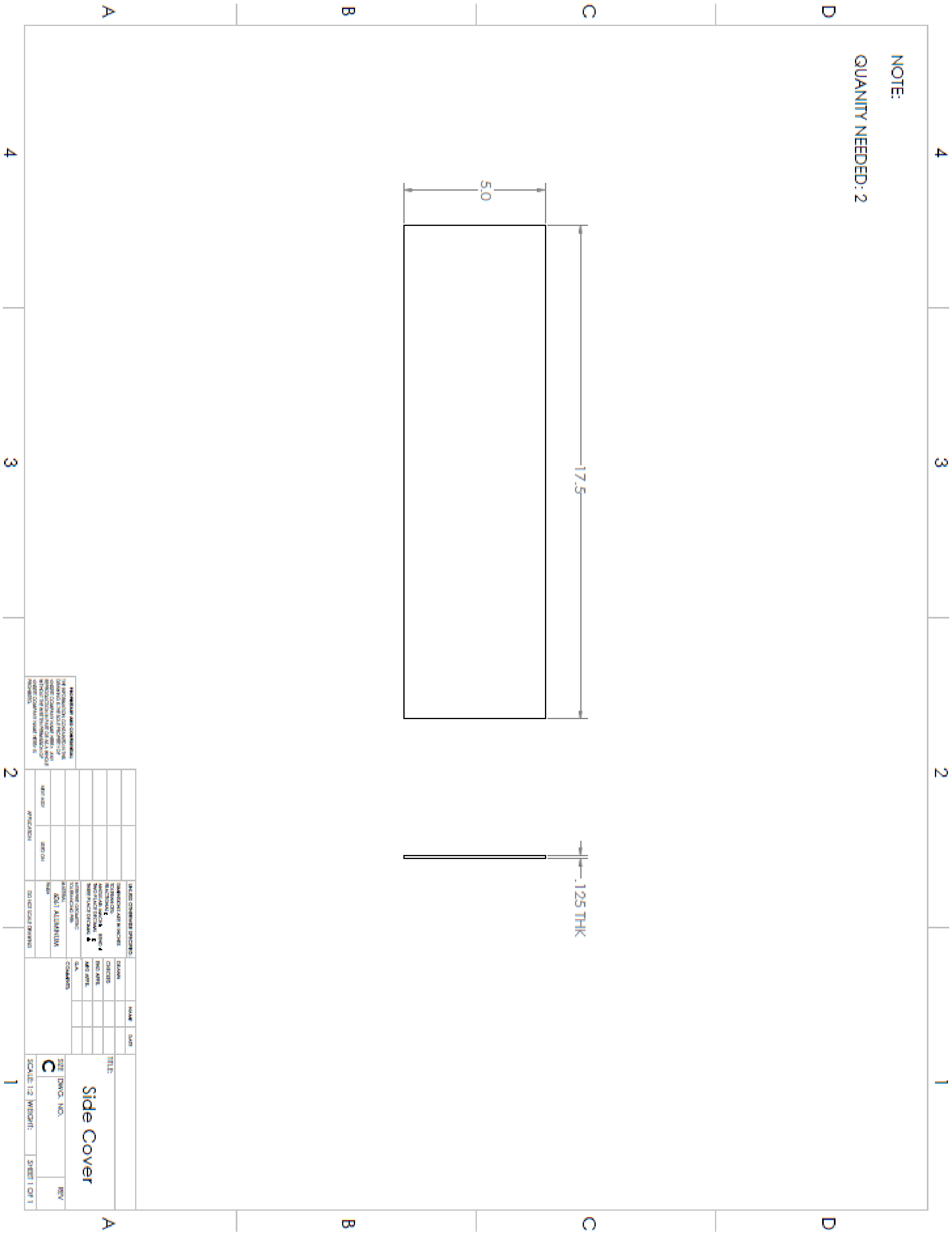
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SHEET 1 OF 1
DO NOT SCALE DRAWING