2018 UC 120 lb. BattleBot Team

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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April 2018

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ABSTRACT

For seniors in the College of Engineering and Applied Science to graduate from the University of Cincinnati, they must complete a required Senior Design Project. This project can range from individual-based to team-based such as BUV and Baja. The project will first be approved by the faculty. The project will progress through the manufacturing phases of research, idea conception, design, manufacturing, assembly, and testing. For our Senior Design Project, we chose to the 2018 University of Cincinnati 120-pound Battlebot team.

Our ultimate goal for this project is to design, manufacture, and build a functioning battlebot to compete in arena matches with other battlebots. This project will prove to be a challenge for us as our knowledge for mechanical systems, electrical systems, materials, and machining will be tested.

We divided the project into four major components with each team member responsible for one. James Brickell oversaw the weapon system, Bryant Himes designed the drive system, Grace Pharo oversaw the inner frame, and Markus Peoples worked on the armor.

We were not able to compete in the competition for this year due to scheduling issues. Our team was able to manufacture our design completely on campus with the machines we had at our disposal. We believe our design would have performed very well in our competition and within our design criteria.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

At the University of Cincinnati, each graduating senior must take part in a senior design project to fulfill all requirements for graduation from the College of Engineering and Applied Science. The goal of our project is to fundraise, design, build and compete in a 120 lb. battlebot competition. To do we must be able to design, manufacture and assemble our robot before our competition.

BACKGROUND

When looking to design a battle bot one of the hardest things is to make your robot efficient and effective, which is what our team strives to do. We plan to create a battle bot that is extremely effective in the fighting ring, as well as efficient in terms of budget.

There are many different types of battle bot design. The most common types are wedges, spinners, drums, crushers, flippers, and hybrids (6). Each type of battle bot has its own pro's and con's, so there is not one that is technically superior to the other. In the long run we, the battle bot team, are the customers and must create a battle bot that serves our main purpose; to be better than everyone else's battlebot. To do this we must consider cost, weapon style, frame, and many other components that go into creating a battle bot.

To research this project, we watched several battle bot competitions and found documents that contained design criteria. We also had to set a reasonable budget to work within. This meant we might have to fundraise our money so we could bring forward an idea that would do the most damage while providing support to protect our electrical components.

Our project will be divided up into 4 subsystems, with each member being responsible for their own subsystems.

Team Member	System Responsibility
James Brickell	Weapon
Bryant Himes	Drive
Markus Peoples	Armor
Grace Pharo	Frame

Table 1. Shown above outlines each team member and their robot subsystem responsibilities.

RESEARCH

SCOPE OF THE PROBLEM

The current state of battlebots is they are becoming more and more competitive due to the hit TV show called "BattleBots" (5). The designs shown throughout the show use simple mechanisms, such as hydraulics, pneumatics, and electronic motors, to "battle" against other robots. These mechanisms are used to power the robots' weapon(s) and to mobilize them throughout the arena.

CURRENT STATE OF THE ART

Over the years there have been many new designs and weapon configurations that have been attempted across all competitions. Although, there have been a few designs that have proven to be more successful than the others (6). These designs are as follows; the wedge design, the spinner design, and the drum design. Each of these designs have their pros and cons.

The wedge design battlebot is one of the more structurally sound design making it hard to be destroyed, this is the biggest pro to the wedge design. The wedge design battle bot has an incline plane on the front of it to allow it to get underneath the competition and move them into the wall of the arena or into a hazard. The wedge design is also easy to design, many newcomers to the battlebot scene will first try and build a wedge design. Although there are many advantages to the wedge design, there are a few cons that make this design unappealing. The first and one of the most important aspects of a successful battlebot is the ability to maneuver. The wedge design is one of the hardest designs to control, you must have a very skilled driver to be successful with this design. This is due to the lack of weaponry on the wedge design (6).

The spinner design battlebot is the "king of offense and defense" if it doesn't destroy itself. The spinner design is easy to classify, either the entire robot spins or just the top part spins. These battlebots are considered the "king of offense and defense" because their offense is also their defense. When the spinner design is spinning at top speeds, any bot that will try to inflict damage to it will also inflict damage to itself. The spinner design is one of the most complex battlebots to design due to the self-destructive nature of this design (6).

The drum design battlebot is the heavy hitter of the battlebot community. The drum design has a huge rotating mass mounted at the front with teeth that are either machined or welded onto the drum. These teeth will inflict the most damage to the other bot and can cause the enemy bots to fly into the air and out of the arena. The drum design can cause devastating damage to the other bots, however; this design can be difficult to control. The drum rotates at very high revolutions per minute (rpms) causing a high moment of inertia that will want to make the battlebot flip over when turning. This design has proven to be successful over the years and has seen high placement in competitions (6).

END USER

After researching various designs for previous battlebots, we decided who our customer would be. Since, this problem statement is designing and building a functional battlebot to compete in the RoboGames 120 lb. Weight Class, we concluded that our customer is the RoboGames organization itself. We then researched and studied the rules of the competition to get a clear customer profile of the RoboGames (2).

The customer profile was made from the research conducted on the rules of the competition. According to the information provided by the RoboGames website, the rules are very similar to the those of mixed martial arts or boxing. These rules helped define the needs of customer and what they were looking for in our battlebot's design. The rules state that our battlebot can weigh in less than or equal to 120 pounds to be qualified to compete (2). The rules also state that if our battlebot knocks out the opposing bot or renders them immobile, we win the match indefinitely (2). However, if our battlebot is unable to complete this task in the allotted amount of time for the match, a three-panel judging system will determine the winner of the match. Many of the rules, provide by the organization's website, outlined what was allowed and what was forbidden in our design. The things included the types of weapons that could be used, the type of power source to power our bot, the control requirements, the mobility, and many other crucial factors.

Upon further review of the RoboGames rulebook, we looked at a section for the judging panel. This section provided crucial information about what the judge's panel and what the judge foreman would look for when judging a match. Some important aspects that stood out were the scoring system, the judges needing to keep track of competitors' bots and how the judges need to be conservative when examining a battlebot's design and construction (2). The scoring provided our team with an explanation of how a judge will score our bot's performance in a match. The next aspect helped defined a new customer need. Since the judges needed the ability to keep track of opposing competitors' battlebots during a match, it would be great to make our bot's appearance stand out from the rest (2). This would allow for the judges to easily identify our bot during a match.

After reviewing these rules extensively, we narrowed down what our customer was ultimately looking for and need in our battlebot's design. One major customer need is that our battlebot must weigh less than or equal to 120 pounds. This would include the armor, weapon, frame, driving system, and anything else that would be needed to for our bot to function. Another customer need is our battlebot must be durable and be able to withstand attacks from aggressors, while also being able to attack and damage opponents effectively and efficiently throughout the duration of the match. There is also a need for our bot to have visible and controllable mobility.

CONCLUSIONS AND SUMMARY OF RESEARCH

For our design problem, we were tasked to design, manufacture and compete in a 120-lb. battlebot. For our design, we wanted to focus on a proven design concept with a focus on durability. We chose to create a robot that uses the concept of a wedge and a spinning drum. By having our design feature a wedge, we provide a defense in case of weapon failure and provide a low center of gravity making it difficult to damage our battlebot. We hope by having a wedge in front of the weapon will provide lift to push our opponents into the attack radius of our weapon design. As we move forward with this concept, we are looking to begin fundraising to begin purchasing raw material. Our budget will vary based on our abilities to reach sponsors.

CUSTOMER FEATURES

For our battlebot, our customer features and requirements must fit the rules and regulations dictated by our competition. Our robot will compete in the 2018 RoboGames Competition in Pleasanton, California at the Alameda County Fairgrounds. This competition will be a 3-day event in April of 2018. Our team must design, manufacture, assemble and test our combat robot while meeting all the requirements for competition. Each team member will oversee the design and assembly of a specific system of design such as the weapon, drive, armor and drivetrain. Our robot must follow the following rules to compete in design competition (1):

1. All robots must be able to be FULLY deactivated, which includes power to drive and weaponry, in less than 60 seconds by a manual disconnect.
2. Moving weapons that can cause damage or injury must have a clearly visible locking device in place at all times when not in the arena. Locking device must be clearly capable to stopping, arresting, or otherwise preventing harmful motion of the weapon.
3. Weapon locking pins must be in place when weapon power is applied during a robot’s power-on procedure. This includes all weapons regardless of the power source or weight class.
4. Robots must stop motion and weapons when failsafe is activated, for safe removal from arena.
5. Spinning weapons that can contact the outer arena walls during normal operation must be pre-approved by the event.
6. Spinning weapons must come to a full stop within 60 seconds of the power being removed use a self-contained braking system.
7. All large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robot’s power.
8. The following weapons and materials are absolutely forbidden from use
    a. Weapons designed to cause invisible damage
        i. Electrical weapons
        ii. RF jamming equipment, etc.
        iii. RF noise generated by an IC engine
        iv. EMF fields from permanent or electro-magnets that affect another robot’s electronics

v. Weapons or defenses that stop combat completely of both robots

9. Nets, tapes, strings, and other entanglement devices

b. Weapons that require significant cleanup

i. Liquid weapons

ii. Foams and liquefied gasses

iii. Powders, sand, ball bearings and other chaff weapons

c. Untethered projectiles

d. Explosives

i. DOT Class C devices

ii. Gunpowder/cartridge Primers

iii. Military Explosives

e. Light and smoke based weapons that impair the viewing of robots by an entrant, judge, official, or viewer

Our battlebot must also weigh less than or equal to 120 lbs., have visible mobility, incorporate an aggressive weapon design that can effectively cause damage and have durable armor than can withstand enemy attacks while protecting vital components. Our team's main goal is to win our competition and to complete this task; our bot's design may vary from previous years.

PRODUCT OBJECTIVES

We will address the customer features by applying the rules of the competition while designing our battlebot. The team will consider every rule for the different components we'll be working on independently. Our biggest issue is just making sure the battlebot stays under 120lb, so that is the main component we will have to work around.

QUALITY FUNCTION DEPLOYMENT

			Engineering Requirements (units)																	
		Importance wt.	weight(lbs)	speed(RPM)	impact force(lbf)	angle of incline(degrees)	speed(MPH)	assembly time (min)									Customer Satisfaction Rating (0.00 - 1.00)			
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B	C
1	≤120 lb weight	0.05	9														1	1	1	1
2	aggressive weapon	0.25		9	9												0.8	1	0	1
3	controlled drive	0.20					9											0.8	1	0.7
4	protective armor	0.25				9											0.3	0.7	1	0.7
5	visable mobility	0.05																1	1	1
6	durable design	0.10			9	3		3										1	1	1
7	service-ability	0.10						3									0.8			
8																				
9																				
10																				
	Total Importance	1.00																		
	Engineering requirement importance																			
Performance	2017 UC MET 120 Battlebot		120				40													
	General-Gold		120			45	40													
	Nighthawk-Silver		120			45	40													
	Touro-Bronze		120				40													
	New Product Targets		120			45	40													

Interaction Matrix

	Engineering Requirements	weight(lbs)	speed(RPM)	impact force(lbf)	angle of incline(degrees)	speed(MPH)	assembly time (min)	0	0	0	0	0	0	0	0
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14
weight(lbs)	1														
speed(RPM)	2			9											
impact force(lbf)	3														
angle of incline(degrees)	4														
speed(MPH)	5														
assembly time (min)	6														

Table 2. The house of quality listed above features our customer requirements for competition and our engineering requirements to compete effectively.

DESIGN

DESIGN ALTERNATIVES AND SELECTION

In conclusion to our research phase, our team brainstormed design concepts for our battlebot. In consideration of our design, we wanted to incorporate a low center of gravity. This feature would provide our bot with a way to defend from being flipped by an opponent. Another feature was durable armor. We also decided having a secondary weapon, a wedge design at the front of the bot, would be beneficial to our design as well. This secondary weapon would be utilized as a backup weapon in case the main weapon failed during a match. We also noted what drive systems would be particularly good for this type of competition. The final feature we considered in our design concepts was the primary weapon. Our team envisioned a weapon capable of causing significant amounts of damage to opponents, while also not impeding the steering and control of the bot during matches. Our team spilt these four aspects between ourselves. Markus Peoples was in charge of the design of the armor, Grace Pharo was in charge of the frame, James Brickell was in charge of the weapon, and Bryant Himes designed the drive system for the battlebot.

ARMOR & FRAME

The armor and frame of our battlebot were treated as one. Our team researched and contemplated what we wanted our battlebot to look like. We compiled all the customer requirements into four design alternatives. These requirements included being durable, protection from flipping, and all around defense. These design alternatives took into account the profile of the frame and the material of the frame.

The first design concept incorporated sloped sides in all directions. Our team liked this concept for various reasons. One reason was the slope design of the sides and flank provided defense against flipping. It also has a low center of gravity, which added to the defense against flipping. This design incorporated a secondary wedge-like weapon located at the front of the battlebot. The armor also provided optimal protection of all vital components, since all would be located at the center of the bot. This design was also ideal for drum-like weapon variations. This concept also provided a multitude of options for different drive systems as well due to the consideration of four-wheel motion. The con of this concept we saw was the designing, manufacturing and machining of the slope sides. We believed there could be mistakes made during the manufacturing process, which would increase the budget allocated to materials.

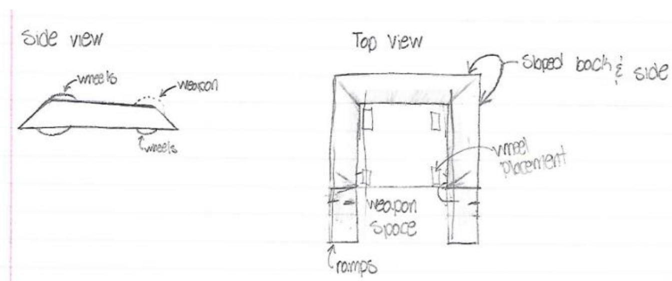

Figure 1 Armor/frame Concept #1

The next alternative involved a rectangle shaped armor frame. The design utilized two-wheel rear drive system. The wheels were protected on all sides from punctures. This design also provided a central location for all vital components and was ideal for drum-like weapon variants as well. The downside to this design was the drive system and weapon variants. Due to its configuration, only two-wheel drive systems would work and all potential weapons would need to be drum variants to provide our bot with an optimal weapon to damage opponents with.

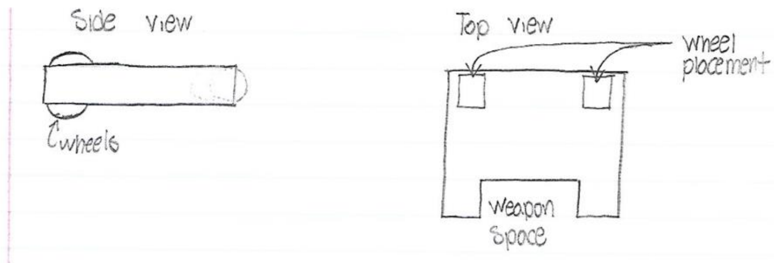

Figure 2 Armor/frame Concept #2

The third armor and frame concept utilized four-wheel movement similar to Concept #1. The design also provided multiple options for drive systems. It also incorporated a sloped back plate to add to its inversion defense. It also had a low center of gravity too. The most unique aspect of this concept was the fork-like structure located at the front of the bot. This structure would act as a secondary weapon used to push and corner opponents into obstacles in the arena. One aspect our team didn't like about this design was the wheel locations. After reviewing the concept, we concluded this design attribute would be detrimental to our success in matches, especially against opponents with spear-like weaponry.

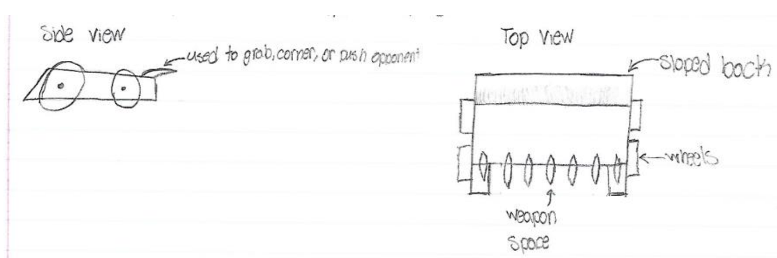

Figure 3 Armor/frame Concept #3

The last design alternative incorporated a three-wheel design. It would utilize a two-wheel rear drive system, while having a swivel wheel at the front of the robot. The back wheels would be protected by armor on all sides. This design allowed our team to consider a new type of weapon, spinner, due to its unique configuration. The major con we observed with this concept was the maneuverability of it. The swivel wheel would impact steering significantly during a match. We also observed the drive system could not have many variants for our team to consider as well.

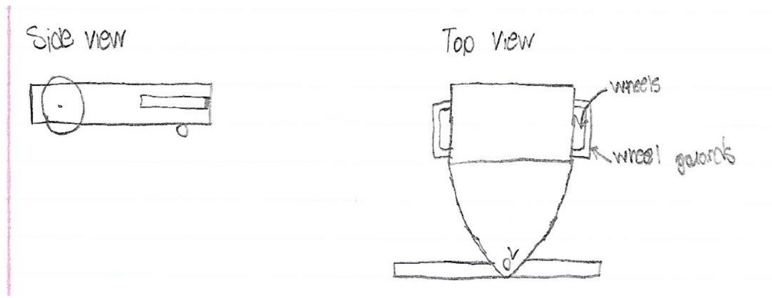

Figure 4 Armor/frame Concept #4

WEAPON

Our team then selected a weapon our bot could utilize in competition. For us to select a suitable weapon, our team researched previous competition winners' weapons, battlebot design guide books, and the weapons selected by previous UC Battlebot teams. We also considered what we wanted in the weapon as well, which included: durability, weight, and repair time. In doing so, our team came up with three weapon design alternatives.

The first design was a drum-like variant weapon. We liked this design due to a few of its features. One feature was the utilization of interchangeable teeth. This design aspect would allow our team to repair damaged teeth from matches easily and maintain optimal performance for our weapon. This design also provided our bot with a large weapon area. Another aspect our team noted was the design incorporated a hollowed drum. This feature made the weapon lightweight and allowed for the elimination of a center shaft for it to function.

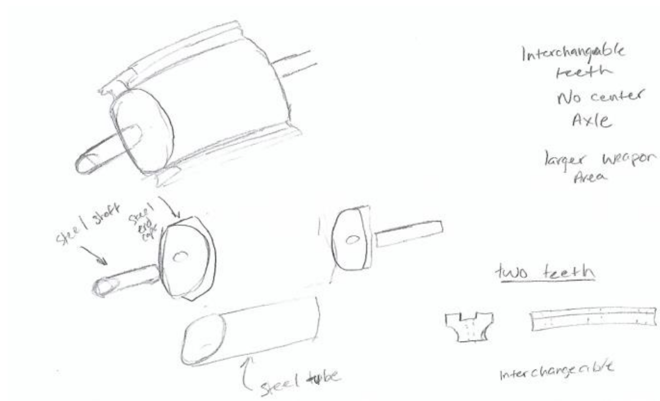

Figure 5 Weapon Concept #1

The next concept was another drum-like variant weapon. However, this design was not hollowed. It would be made from a solid bar of steel and have a keyed center through hole. This center hole would have a center shaft ran through it to allow for operation of the weapon. The major downside of this weapon variant is the weight of it. Due to its significant weight, we would have to consider the weight of the armor, the drive system, and the frame, more carefully before proceeding onwards to the manufacturing phase of the project.

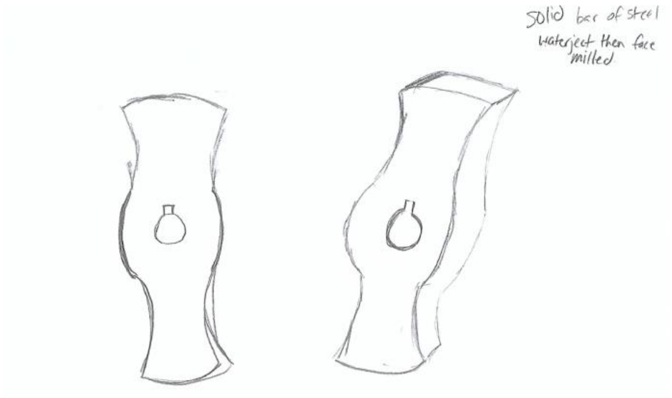

Figure 6 Weapon Concept #2

The last weapon alternative includes a design similar to weapon concept #2. The shape of the weapon is the only aspect that changes between the two. Other than that, this concept is still made from a solid bar of steel. It would also still incorporate a keyed center through-hole and require a center shaft to operate. This concept would most likely weigh about the same as Concept #2.

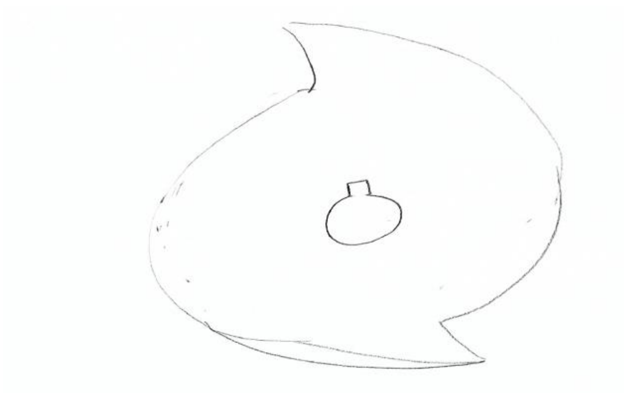

Figure 7 Weapon Concept #3

DRIVE SYSTEM

The research we conducted on the drive system aligned with what type of weapon we envisioned our robot having. We determined our bot's weapon would be drum-like and this information allowed us to narrow down our concepts into four distinctive systems.

The first drive system concept was a v-belt and wheel drive combination. This system would include 4 motors in total and each of these motors would have 2 speed controls. The v-belt would be used to operate the weapon during matches. The system would provide good maneuverability for our robot, but the cost of the system would be expensive for our budget.

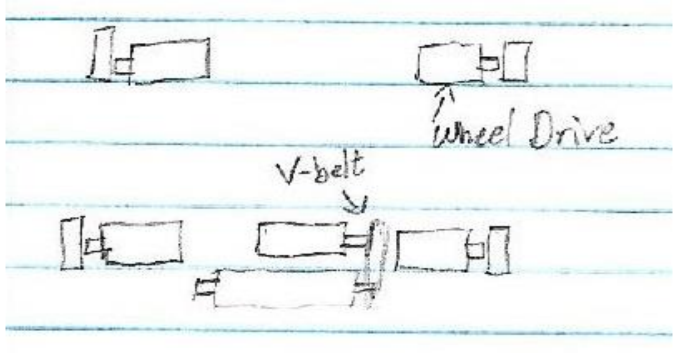

Figure 8 Drive System #1

The next drive alternative was a belt and chain combination. The setup of this system would have belts driving the wheel and a chain operating the weapon. This combination would be lighter than Concept #1. However, we reviewed this concept more in depth and determined it would be very hard to steer or maneuver around the arena during matches. We believe our bot needs to be quick and maneuver efficiently during matches, so we may achieve our goal of winning in the competition.

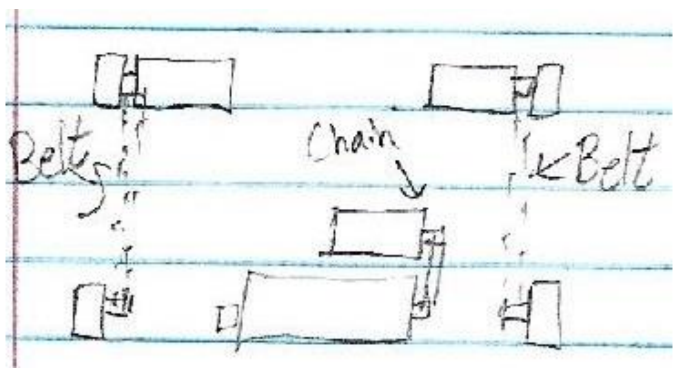

Figure 9 Drive System #2

The third concept alternative was completely driven by gears. The gears would be used to drive each of the four wheels in the picture below. Gears would also be used to drive the weapon as well. There were three major flaws we observed in this concept. The first was the weight of it. We determined using gears for the entire drive system would add too much weight to our design. The next was the maneuverability of the system. It was very rigid and because of this it could potentially cause our team to loss from being unable to move away from an opponent. The last flaw was the complexity of design for this system. It would take considerable time to calculate the gear ratio and other aspects involved, which could impact our predetermined schedule.

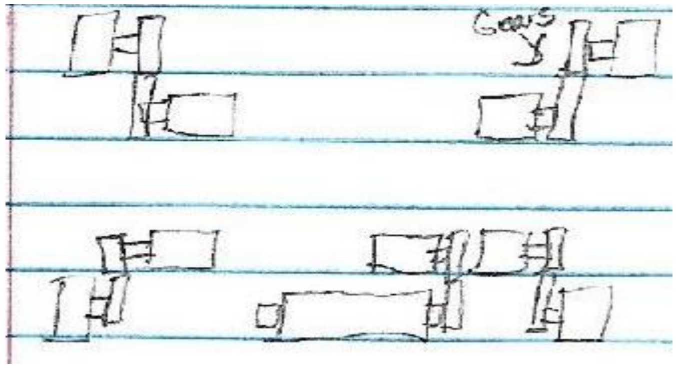

Figure 10 Drive System #3

The last drive concept was a cogged belt and wheel drive combination. This system provided good maneuverability and only used 2 motors to drive the bot. The motors would be attached to the 2 rear wheels of the bot. The motors would also have 2 speed controls and due to this would allow our team to steer the bot like a skid of some sort. The cogged belts would be aligned from the rear wheels to the front wheels to provide this motion for our bot. This option was also lighter due to excluding the use of chains and gears.

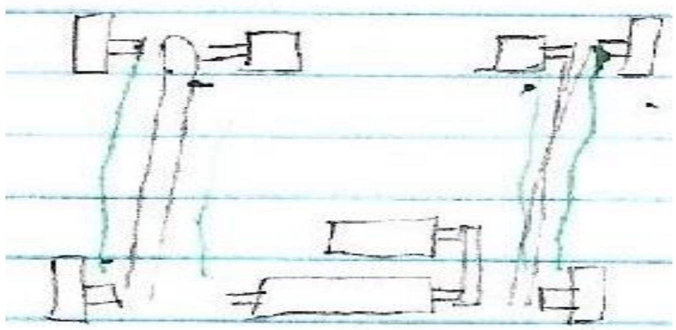

Figure 11 Drive System #4

CONCEPT SELECTION

The selection of the different concepts for each of the components was based off their compatibility with one another. We reviewed each component's concepts and selected the one we felt would be the best overall design to meet the specified requirements. We first reviewed the armor and frame concepts.

After in-depth analysis of the pros and cons of each concept and their compatibility with the other components, we determined Armor and Frame Concept #1 was most suitable. It met our design requirement for defense in all directions. The low center of gravity would make it difficult for opponents to flip the bot as well. The concept was also chosen due to it providing ample protection of all vital components, which were located at the center of the frame. Also, as stated before, we were pleased with this concept due to it being compatible with all weapon and drive system concepts.

Our team then analyzed which weapon concept would be for our battlebot. Since all of the weapon concepts centered around a drum-like variant, we considered weight to be a vital part of the decision. We chose Weapon Concept #1 due to its lightweight frame from being a hollow drum compared to the other two concepts. We also liked the idea of interchangeable teeth. This feature would make it easier to maintain our weapon's performance in multiple matches during the competition. The interchangeable teeth would be bolted directly to the drum and would hit the opponents during a battle. The bolts would act as a method to secure the teeth but also a failsafe if needed. Our team also took note of how this concept didn't require a center shaft to operate and function as well.

Lastly, we evaluated the concepts for the drive system. Our main requirements were the drive system needed to be lightweight and provide good maneuverability. Due to these requirements, we noted Drive System Concept #4 was the best option. It provided good maneuverability due to its skid steering. It was also lightweight because it utilized only 2-wheel motors to drive our bot and because it eliminated the use of chains and gears, which freed up weight. Our team concluded, the weight could be added to the thickness of the armor and frame.

FINAL DESIGN MODEL

After our concept selection, we designed a model of our desired bot in Solidworks. We made a few changes to the overall design of the armor and frame. One change was due to the complexity of designing sloped side edges. The more we designed with this aspect in mind, the more difficult we found to manufacture later on. Another change we implemented was for the frame. We sought to reduce weight, while still keeping our overall integral strength. To do this, we designed a honeycomb pattern in the material used to make the inner frame work. Since, the structure pattern is used in many applications and has been proven to produce maximum strength with minimal weight. We also used this pattern based on the researched conducted on it for its high compression and shear properties. (7)

The figures below show the overall design of our team's battlebot utilizing the changes explained in the paragraph above.

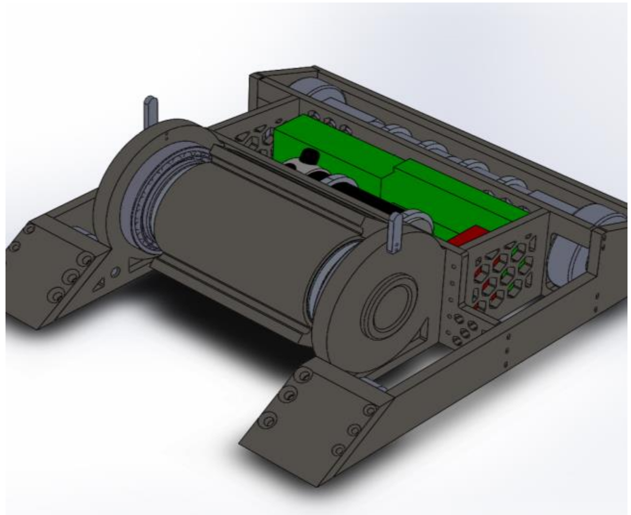

Figure 12 3-D Isometric view of "Ravager"

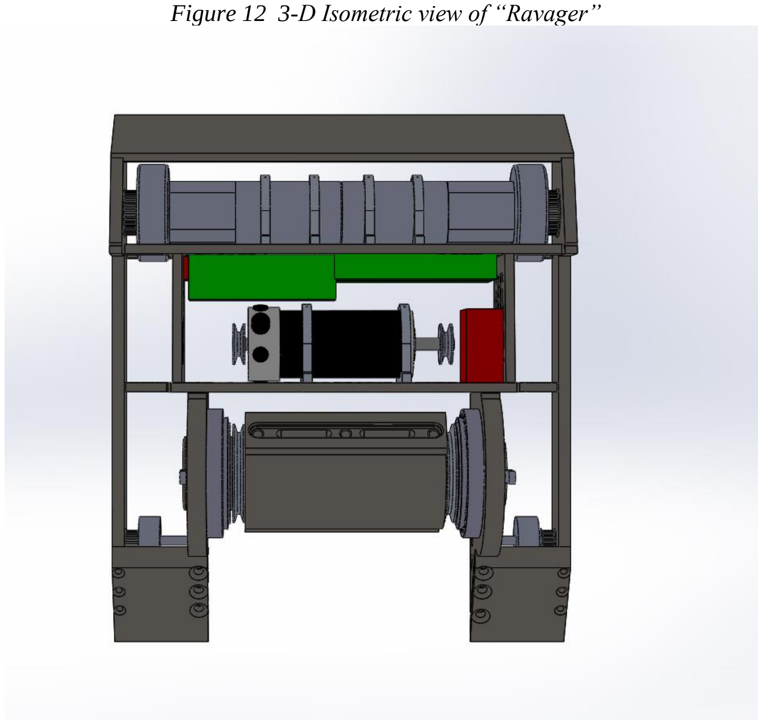

Figure 13 3-D Top view of "Ravager"

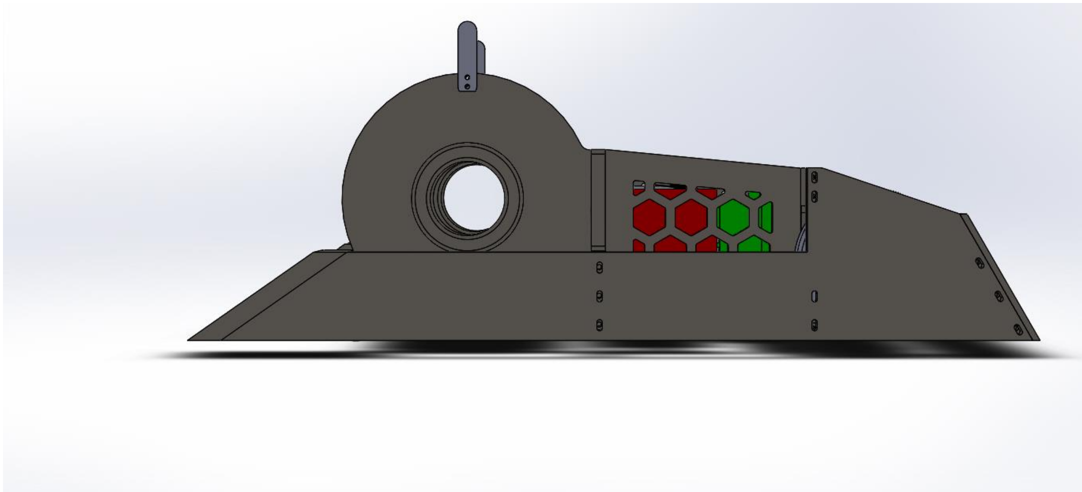

Figure 14 3-D Side view of "Ravager"

LOADING CONDITIONS

All our loading conditions were processed using FEA on SolidWorks. Please note that deformation is exaggerated.

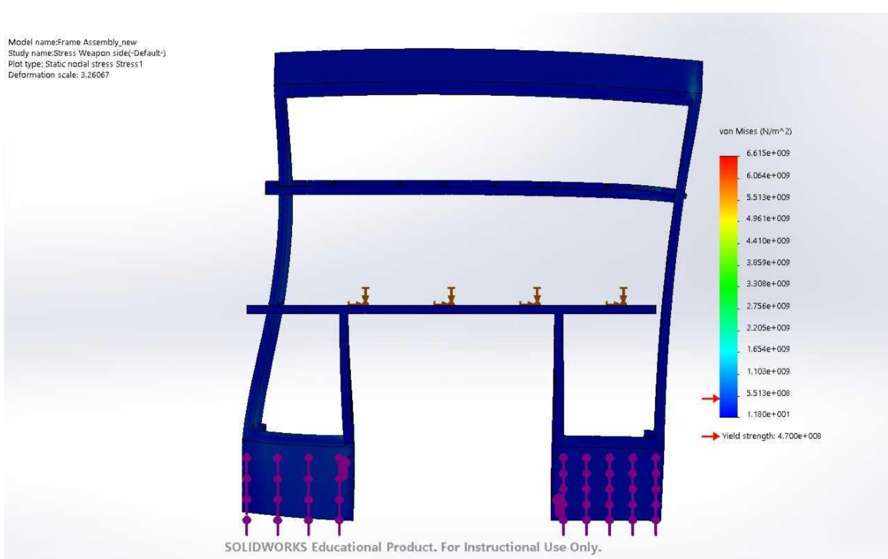

Figure 15 FEA shows side impact force on armor and frame.

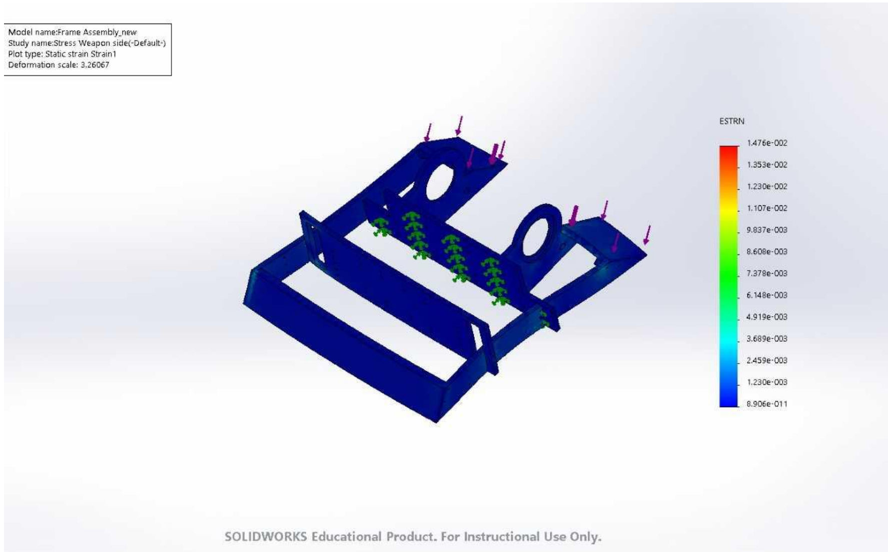

Figure 16 The front plate was static point of the structure.

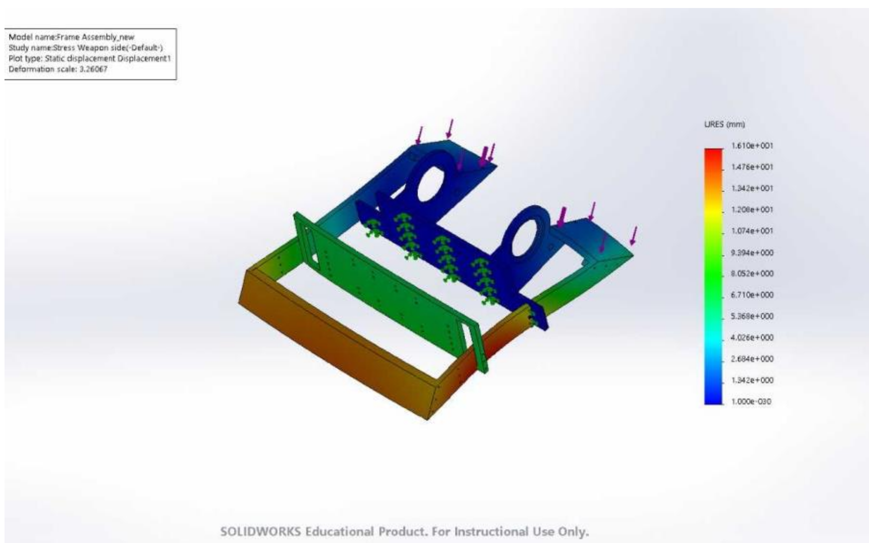

Figure 17 FEA from side force impact.

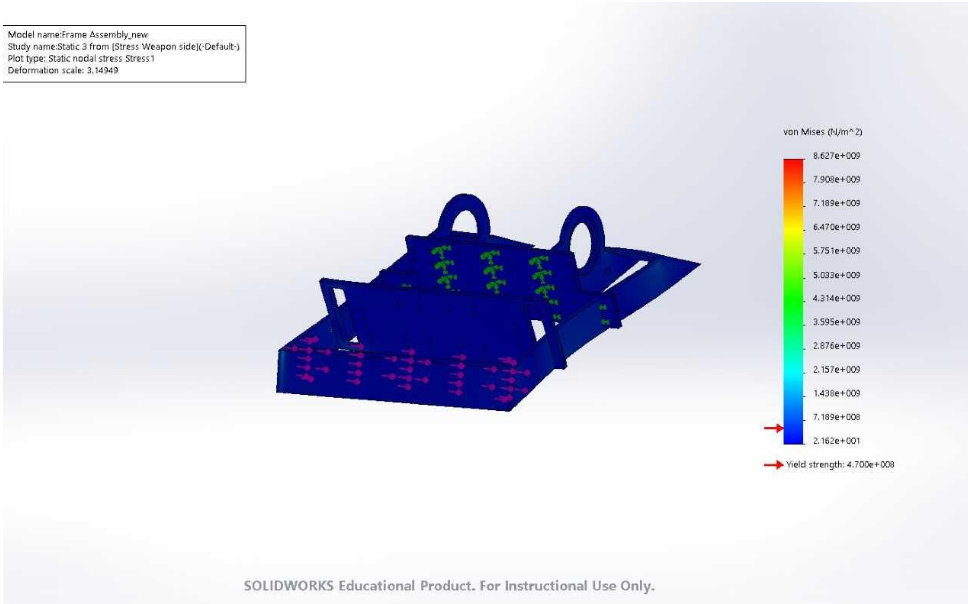

Figure 18 Flank impact on sloped back plate of the bot. Front inner frame plate remains static.

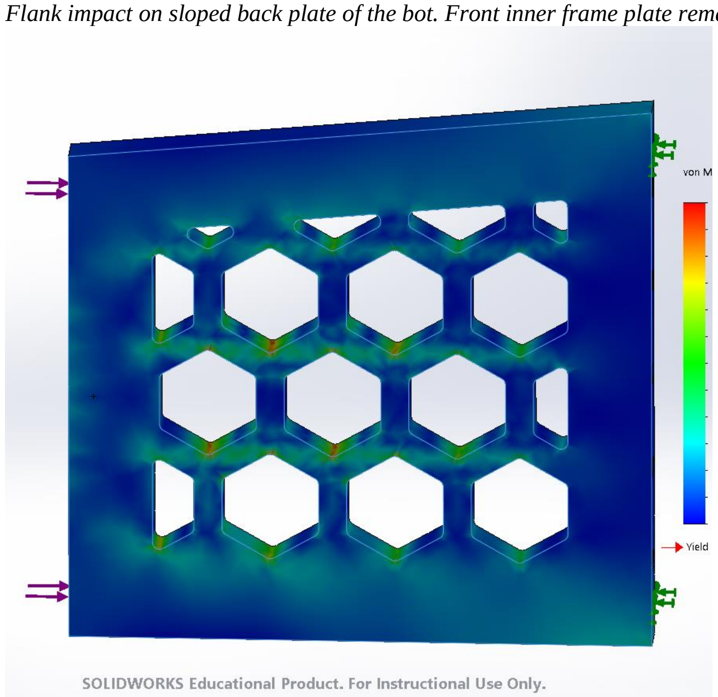

Figure 19 Inner support frame static force impact from sloped back plate being impacted.

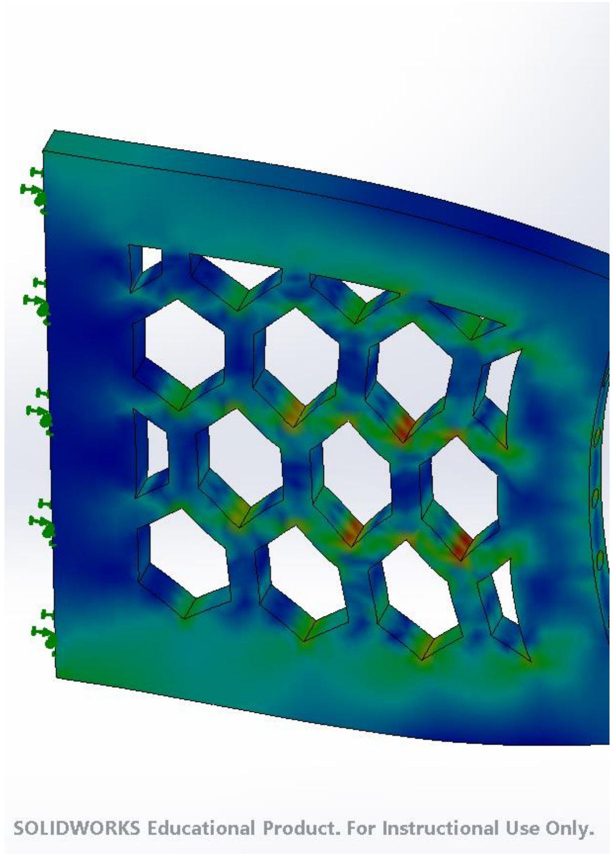

Figure 20 Deformation in this FEA is exaggerated.

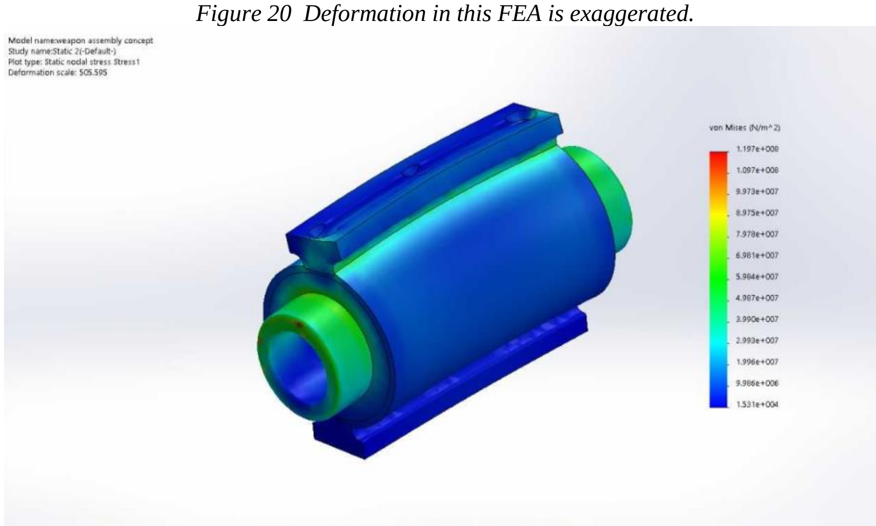

Figure 21 FEA of the drum and interchangeable teeth from the side impact.

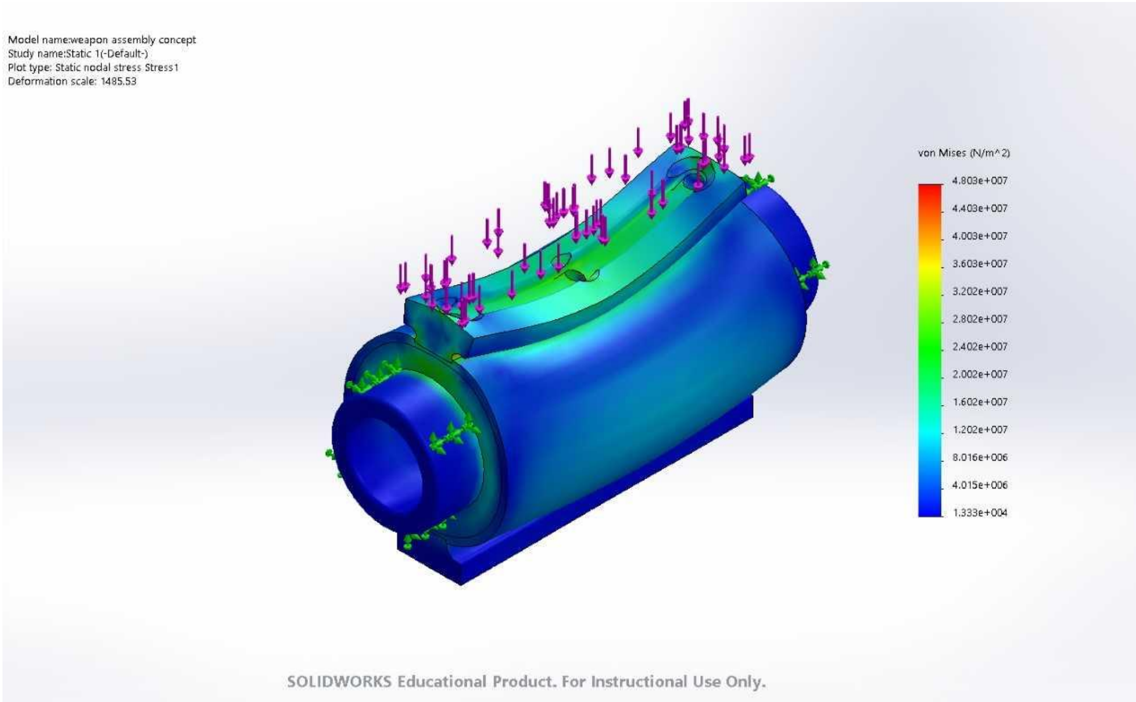

Figure 22 Impact force downward on one interchangeable tooth.

DESIGN ANALYSIS

Weapon Motor

$$V_{input} = 24V$$
$$n = 1$$
$$K_t = 6.57 \text{ oz} - \text{in}$$
$$A = 0.046 \frac{Nm}{A}$$
$$R_{motor} = 0.042\Omega$$
$$I_{no-load} = 4.5A$$
$$K_v = \frac{1}{K_o} = 21.55 \frac{rad}{sec} = 206 \frac{RPM}{V}$$
$$R_{system} = 0.042 + 0.004 + 0.04 = 0.086\Omega$$
$$w_{no-load} = K_v\left(V_{input} - \left(R_{system} * I_{no-load}\right)\right)$$
$$= 206\big(24 - (0.086 * 4.5)\big) = 509 \frac{rad}{sec}$$
$$I_{stall} = \frac{V}{R} = \frac{24}{0.086} = 279A$$

$$Weapon\ Capacity = 40A * 180s + 10 * 377As$$
$$= 10970As - 3.14h = \ 3.100mAh$$
$$peak\ Amp = 390 \sim 24V$$

Drive System

$$n = 4\ (gear\ ratio)$$
$$mass = 120\ lb = 54.4311\ kg$$
$$wheel\ load = 60lb = 27.2155kg * 9.81 = 266.9841\ N$$
$$friction = 0.9$$
$$largest\ traction\ force = 240.256\ N$$
$$wheel\ \emptyset = 4" \ = \ 101.6mm\ \rightarrow\ r = 50.8mm$$
$$\tau = LTF * r = 240.256 * 0.0508 = 12.205Nm$$
$$\tau_{max} = \ \frac{\tau}{n} = \frac{12.205}{4} = 3.05125\ Nm$$
$$I_{max} = \frac{\tau_{max}}{K_t} + \ I_{no-load} = \frac{3.05125}{0.0182} + 2.7 = 107.4A$$
$$K_t = 0.02Nm$$

Battery Usage

$$How\ much\ energy\ needed\ to\ run\ for\ 3\ minutes{:}\ 2 * 107.4 * 0.05 * 50\% =$$
$$8.518\ Ah = 8518\ mAh \sim 12V\ motor$$
$$w_{no-load} = \ K_v * \left(V_{input} - \left(R_{system} * I_{no-load}\right)\right)$$
$$w_{no-load} = \ 443\frac{rpm}{V} * \left(12V - \left(R_{system} * 2.7\right)\right) \rightarrow R_{system} = \ 0.148\ \Omega$$
$$w_{no-load} = 5103.0942\ RPM = 534.395\frac{rad}{sec}$$
$$V_{max} = \left(\frac{w_{no-load}}{n}\right) * r = \ \left(\frac{534.395}{4}\right) * 0.0508 = 6.79\frac{m}{s} = 15\ mph$$

Weapon

$$R = 6 = 152.4$$
$$r = 3.75 = 95.25$$
$$L = 8 = 203.2$$
$$m = \ \pi * (R^2 - r^2) * L * 7.8x10^{-6}$$
$$m = \ \pi * (152.4^2 - 95.25^2) * 203.2 * 7.8x10^{-6} = 24.82\ lbs = 11.34\ kg$$
$$I_{zz} = \frac{m*(R^2-r^2)}{2}$$
$$I_{zz} = \frac{11.34*(152.4^2-95.25^2)}{2} = 80249\ kg * mm^2 = 0.083\ kg * m^2$$

Weapon Calculations

Input Parameters	
Rated Motor RPM	4900
Rated Motor Amperage	4.5
Rated Motor Voltage	24

Motor Output Wattage	900
Drive Pulley Diameter (in)	1
Driven Pulley Diameter (in)	3.3
Weapon Diameter (in)	6.22
Weapon Assembly I (lbmxin^2)	3028.58
Weapon Assembly Weight (lb)	27.1
Impact Duration (sec)	0.01

Constants	
g (ft/sec^2)	32.17
Watts per HP	745.7
HP Constant	5252

Table 3 Input Values for Weapon Calculations

Calculated Values	
Motor HP	4.50
Motor Torque (ft-lbf)	4.82
Watts Consumed	108
Weapon Assembly I (lbmxft^2)	21.03
Pulley Reduction (_:1)	3.30
Weapon RPM	1484.85
Weapon ω (rad/sec)	155.49
Torque Applied to Weapon (ft-lbf)	15.92
Weapon Tip Speed (mph)	27.48
Weapon KE (ft-lbf)	7903.46
Weapon L (lbf-ft-sec)	101.66
Impact Force (lbf)	39224.47
Weapon Startup Time (sec)	6.39

Table 4 Calculated values for Weapon Assembly

$$Motor\ Torque = \frac{4.50 * 5252}{4900} = 4.8\ ft * lbf$$

$$Watts\ Consumed = 24 * 4.5 = 108\ W$$

$$Weapon\ Assembly = \frac{3028.58}{144} = 21.0\ lbm * ft^2$$

$$Pulley\ Reduction = \frac{3.3}{1} = 3.3{:}\ 1$$

$$Weapon\ RPM = \frac{4900}{3.3} = 1484.85$$
$$Weapon\ \omega = \frac{1484.85*2*\pi}{60} = 155.5\,\frac{rad}{sec}$$
$$Torque\ Applied\ to\ Weapon = 4.8 * 3.3 = 15.9\ ft*lbf$$
$$Weapon\ Tip\ Speed = \frac{1484.85*\pi*6.22*60}{12*5280} = 27.48\ mph$$
$$Weapon\ KE = \frac{21.03*(155.49^2)}{2*32.17} = 7903.46\ ft*lbf$$
$$Weapon\ L = \frac{21.03*155.49}{32.17} = 101.7\ lbf*ft*sec$$
$$Impact\ Force = \frac{21.03*\left(\frac{155.49}{.01}\right)}{\frac{\left(\frac{6.22}{2}\right)}{12}*32.17} = 39224.5\ lbf$$
$$Weapon\ Startup\ Time = \frac{21.03*155.49}{15.92*32.17} = 6.4\ sec$$

Motor Power

$$T = I*\propto\ = 1.093937 * 628.3 = 687.3Nm$$
$$T_m = 687.32 * (.74) = 508.6\ ft*lbs$$
$$Motor\ Power\ (hp) = \dot{W} = \frac{T_m*(n)}{5252} \rightarrow n = 6$$
$$\dot{W} = \frac{508.617*6}{5252} = .6hp$$

Shaft Design

$$T_{max} = maximum\ twisting\ moment$$
$$\tau_{max} = maximum\ sheer\ stress$$
$$R = radius\ of\ shaft$$
$$T_{max} = \frac{\tau_{max}*J}{R} \ \rightarrow\ T_{max} = \left(\frac{\pi}{16}\right) * \tau_{max} * D^3$$
$$Twisting = \frac{T*r}{J}$$
$$Diameter\ solid\ shaft = 1.72\left(\frac{T_{max}}{\tau_{max}}\right)^{1/3}$$
$$Rotational\ speed = 6000\ rpm$$
$$Axil\ force = 0$$
$$Torque = 4928.65\ in*lbs$$
$$K_t\ sledrunner\ Keyseat = 1.6$$
$$m = 25000 * 1.25" = 31250$$
$$Shaft\ material = 4340$$
$$Design\ Stress = (Shock)\ n = 8$$
$$Bending\ force\ v-belt = F_B = 1.5FN = \frac{1.5*T}{\left(\frac{D}{2}\right)}$$
$$Required\ Diameter = \frac{\sqrt{2.94*(K_t)*(V)*(N)}}{S'_n}$$
$$S'_n = S_n * C_s * C_R$$
$$S_n = .5 * S_u$$
$$S_y = 158000\ psi$$

$$S_u = 171000\ psi$$
$$\%e = 16\%$$
$$S'_n = \frac{171000}{2} = 85500$$
$$S_n = 57000 \rightarrow psi = 57\ ksi$$
$$C_m = 1$$
$$C_{st} = 1\ rotating\ bending$$
$$.99\ or\ .999 \rightarrow C_R = .81\ or\ .75$$
$$S'_n = S_n * C_m * C_R * C_s * C_{st} = 35.5\ ksi$$
$$For\ Bending\ \&\ Torsion\ only$$
$$D = \left[\frac{32(N)}{\pi} * \sqrt{\left(\frac{K_t * m}{S'_n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\right]^{1/3}$$
$$D = \left[\frac{32(8)}{\pi} * \sqrt{\left(\frac{1.6*31250}{35500}\right)^2 + \frac{3}{4}\left(\frac{5000}{158000}\right)^2}\right]^{1/3} = 4.9''$$

We ended up picking 3" *because we used a lower rotational speed and we assumed not all the kenetic would be transfered through the shaft.*

FACTORS OF SAFETY OR CONCERN

There are no factors of safety for our battlebot project. Due to the nature of our design and competition there was no effective way to know a designed load for the armor and frame. The forces generated by the weapon system itself would be if the weapon transferred all of its energy but in competition this would not be the case due to losses.

COMPONENT SELECTION

Motors

The motors are one of the most important aspects when building and designing battlebots. They are the muscles of the machine, what allow the robot to move and the weapon to spin. We will be using DC brushed motors for both the drives and weapon. The weapon motor is one that previous teams have used, we wanted to use this motor for the weapon due to the cost. The motor we used was an AmpFlow A28-400, this motor is designed for top performance with the use of neodymium rare-earth magnet material. The overall specification for this motor is as follows; 24V, 4.3 peak HP, 83% efficiency, 4900 RPM, and 6.58 oz-in/Amp. We will be using a 2:1 ratio for motor to weapon RPM with the pulleys we are using.

Figure 23 Weapon Motor

Figure 24 Drive Motor

The drive motors we selected are the BaneBot First CIM motors. These are both light weight with a high torque/power rating. The overall specifications for the First CIM motor is as follow; 12V, 65% efficiency, 5310 RPM, and 2.58 oz-in/Amp. We did not want the wheels spinning at 5310 RPM so we decided to go with a Building Block 220 Gearbox 4:1 ratio. We felt these motor/gearbox pair would be a great fit for our battlebot.

Power Supply

The power supply is one of the most important aspects to building/designing a battlebot. The power supply selected will determine the overall time allotted for the robot to function during battle. Our team wanted to find the most reliable and cost-efficient batteries available, due to allotted funds. We needed to select two different voltages for the drive motors (12v) and the weapon motor (24v). Our team selected the PULSE 5000mAh 3S 11.1V 35C – LiPo battery for the drive motors, and the PULSE 5000mAh 6S 22.2V 45C – LiPo battery for the weapon motor. Once the batteries were selected, we needed to calculate the overall current usage that would be

Figure 25 Drive System Battery

Figure 26 Weapon System Battery

required by both the drive system and weapon system in the three minute match. The calculations were acquired from the formulas found in the Riobotz tutorial. We determined that we will be driving the robot at full speed just under 50% of the battle to determine our power consumption. For the weapon system, we determined that the weapon would need to reach top speed at a max of four times during the match. This means that we will be hitting the opponent at most 4 times during the match and the weapon motor would need to reach max speed from a complete stop after the impact. These batteries would allow our battlebot to function fully under these estimated conditions and withstand the three-minute battle.

Speed Controllers

The speed controllers that our team selected will work the best with our battlebot due to the use of different voltage batteries. For the drive system, we are going to use two Talon SRX VEX speed controllers. These speed controllers are light weight, full aluminum case, passive cooling fins, which make external fans not needed. These speed controllers allow the motors to run in both forward and reverse without additional relays or controls. For the weapon speed controller, we also selected a VEX speed controller. This speed controller was used on last year's team battlebot. This speed controller will be able to withstand the high current that the weapon motor will be continually outputting.

Figure 28 Drive Motor ESC

Figure 27 Weapon Motor ESC

Control System

The transmitter used for our project was the FrSky Taranis X9D Plus. This transmitter is well known for the frequency hopping ACCST technology which takes advantage of the entire 2.4GHz band. This allows the controller to remain in connection with the receiver with excellent range and reliability. This transmitter allowed for us to control all three of our motors independently from one another. We wanted to have this function because this would allow the wiring of the motors and speed controllers to be easier. We wanted to control our bot using one stick so the overall maneuverability of the bot was not a problem. We had our speed controllers connected to channel 2 and channel 3 which were both mapped to the right stick. This allowed us to control the bot with ease.

Figure 29 RC Radio Used

Figure 30 Transmitter

The next decision we needed to make in regard to the control system was the receiver. The receiver that we decided to go with was the FrSky X8R. This receiver is compatible with our transmitter and has the ability to have an 8-channel setup. We were only needing to have 3 channels so this receiver allowed for that. The overall weight of this receiver was super light, weighing only 16.6g. The overall operating voltage range was 4.0~10V. To allow for our receiver to gain power, we needed to connect a 4.8V NiCd battery to it. Through our testing with this setup, we were able to maintain connection to the bot with no interference.

Electric Assembly

We designed our robot to contain all of the vital electrical components inside the internal frame. This would prevent other robots from damaging these components if our armor was to fail during battle. We used heavy duty Velcro along with zip ties to hold the batteries and speed controllers in place. All connections were crimped and sealed with heat shrinking.

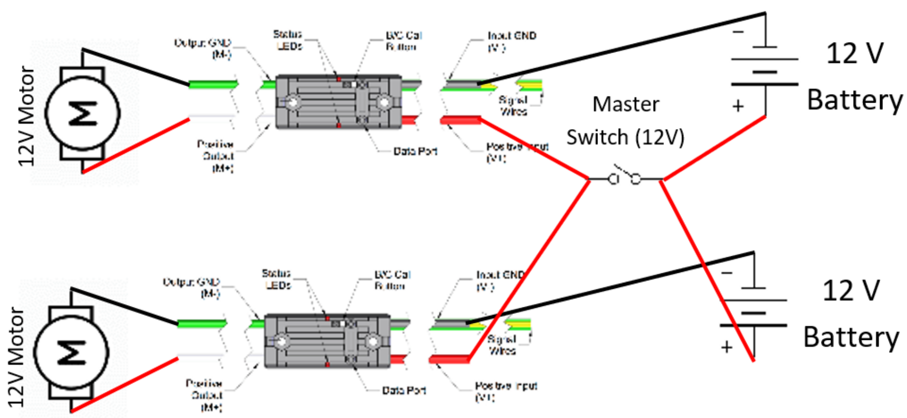

Figure 31 Drive System Schematics

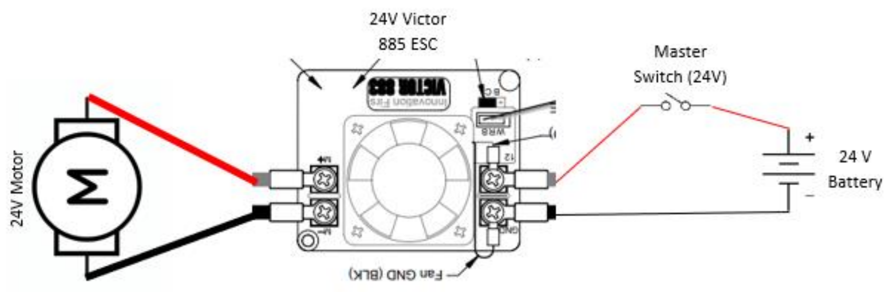

Figure 32 Weapon System Schematic

We needed to use two separate master cut-off switches due to the two different voltages our bot was running on, 12V and 24V.

Bill of Material

BOM				
	Description	Part Number	Supplier	Quantity
1	Wheel Motor	M4-R0062-12	BaneBots	2
2	Gear Box	BB220S-4-4	BaneBots	2
3	Rear Wheel	WC1-4	Colson	2
4	Front Wheel	WC1-2	Colson	2
5	Rear Wheel Hub	HC1-PC-KS4	Colson	2
6	Front Wheel Hub	HC1-P1-KS3	Colson	2
7	Rear Pulley	1428N33	McMaster-Carr	2
8	Front Pulley	1428N22	McMaster-Carr	2
9	Battery Pack (12V)	PLU35-50003	Pulse	2
10	Speed Controller (Drive)	217-8080	VEX	2
11	Motor Mount (Drive)	N/A	Custom	6
12	Drive Belt	1679K527	McMaster-Carr	2
13	Battery Pack (24 V)	PLU45-45006	Pulse	1
14	Weapon Motor	A28-400	AmpFlow	1
15	Speed Controller (Weapon)	217-4891	VEX	1
16	Motor Mount (Weapon)	N/A	Custom	4
17	Weapon Pulley	N/A	Custom	4
18	Motor Pulley	N/A	Custom	4
19	Weapon Motor Protection Plate	N/A	Custom	3
20	Drive Motor Protection Plate	N/A	Custom	3
21	Inner Frame Support	N/A	Custom	6
22	Side Armor Plate	N/A	Custom	6
23	Back Armor Plate	N/A	Custom	3
24	Front Armor Plate	N/A	Custom	6
25	Inner Rail Plate	N/A	Custom	6
26	Spool 8 Gauge Wire	8AWG [5ft Black + 5ft Red]	Amazon	2
27	Dowel Pins (0.1875)	6023071	MSC	100
28	Front Wheel Axel	N/A	Custom	4
29	3/8 Retaining Rings	9968K42	McMaster-Carr	25
30	12-24 Socket Head Screws	91251A453	McMaster-Carr	12
31	1/4-20 Flat Head Screws	91253A537	McMaster-Carr	6
32	3/8-16 Socket Head Screws	91251A619	McMaster-Carr	6

Table 5 Battlebot Bill of Materials

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

PROPOSED

Estimated Budget	
Weapon	2,000
Frame	2,000
Armor	1,500
Electronics	1,500
Total:	7,000

Table 6 Initial Budget

ACTUAL

Actual Budget	
Weapon	718.03
Armor/Frame	701.78
Electronics	1,814.64
Misc.	300.00
Total:	3,534.45

Table 7 Final Budget

Note: Final Budget was adjusted for the battlebot project due to not attending competition.

Component	Brand	Model	Cost	Weight	
Wheel Drives					
Wheel Motor	BaneBots	M4-R0062-12	$28.00	46	oz
Wheel Motor	BaneBots	M4-R0062-12	$28.00	46	oz
Gear Box	BaneBots	BB220S-4-4	$90.00	28	oz
Gear Box	BaneBots	BB220S-4-4	$90.00	28	oz
Rear Wheel	Colson	WC1-4	$4.57	4.05	oz
Rear Wheel	Colson	WC1-4	$4.57	4.05	oz
Front Wheel	Colson	WC1-2	$2.92	1.2	oz
Front Wheel	Colson	WC1-2	$2.92	1.2	oz
Rear Hub	Colson	HC1-PC-KS4	$6.50	0.44	oz
Rear Hub	Colson	HC1-PC-KS4	$6.50	0.44	oz
Front Hub	Colson	HC1-P1-KS3	$6.00	0.33	oz
Front Hub	Colson	HC1-P1-KS3	$6.00	0.33	oz
Rear Pulley	McMaster	1428N33	$12.50		
Rear Pulley	McMaster	1428N33	$12.50		
Front Pulley	McMaster	1428N22	$9.36		
Front Pulley	McMaster	1428N22	$9.36		
Battery Pack	Pulse	PLU35-50003	$57.99	13.23	oz
Battery Pack	Pulse	PLU35-50003	$57.99	13.23	oz
Motor Mount					
Motor Mount					
Speed Controller	VEX	217-8080	$89.99	4.16	oz
Speed Controller	VEX	217-8080	$89.99	4.16	oz
Weapon Motor					
Battery Pack	Pulse	PLU65-45006	$150	23.64	oz
Weapon Motor	AmpFlow	A28-400	$399.00	110.4	oz
Speed Controller	VEX	217-4891	$399.99	19.2	oz
		Total	$1,564.64	348.06	oz
				21.754	lbs

Table 8 Initial Cost and Calculated Electronic and Drive Weight

SCHEDULE, PROPOSED /ACTUAL

PROPOSED

Timeline	
Task	**Date**
Concept Design	9/22/2017
Preliminary Design	10/27/2017
Fundraising	12/5/2017
Order Material	11/10/2017
Manufacture	3/23/2018
Testing	3/30/2018
Competition	TBD(4/2018)

Table 9 Initial Timeline Used at Beginning of Project

ACTUAL

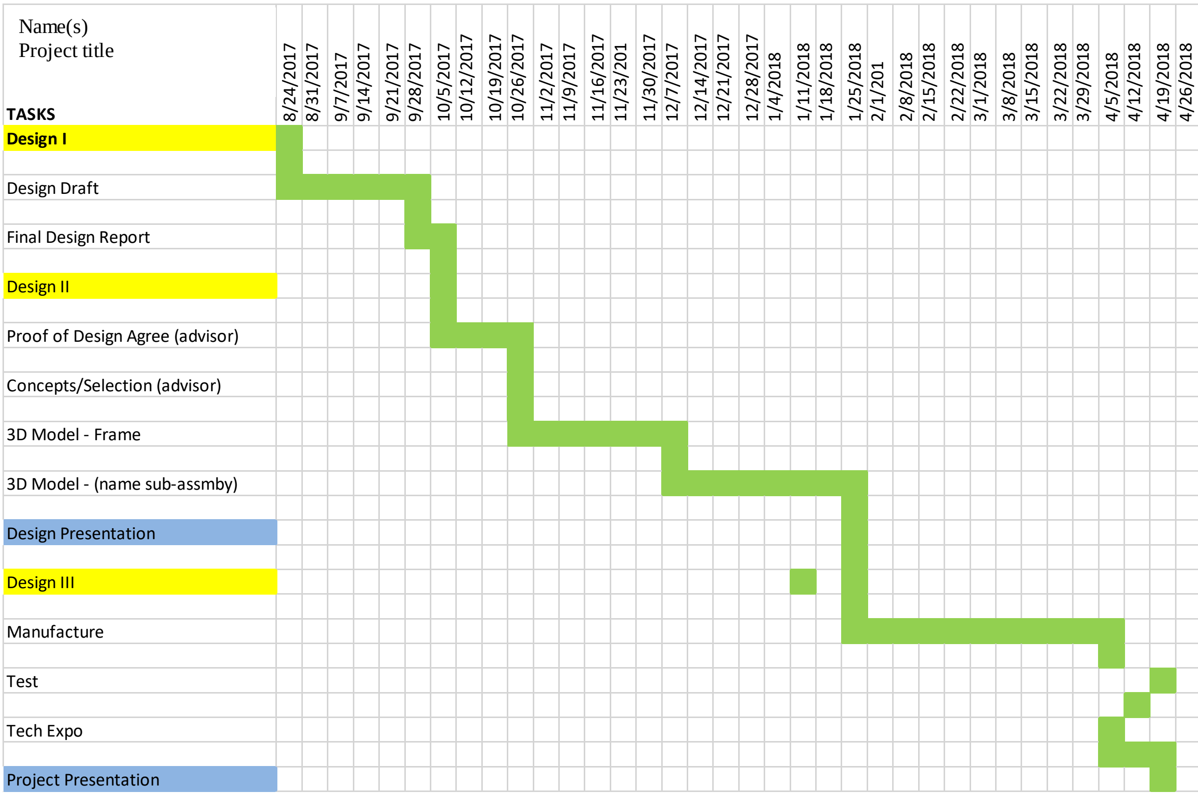

Table 10 Final Timeline of the Project

MANUFACTURING AND ASSEMBLY

The next phase for our team, after designing a complete model of our desired robot, was to machine and manufacture the many components that would make up our bot. These components would include all the armor plating, the inner framework, the weapon, and the mounts for the weapon and drive motors for our bot. All of our assembly and machining were completed on campus at the Victory Parkway and Uptown Campuses.

ARMOR

Our team first began our machining phase with the armor. The material for this structure of our bot was ½" 4140 Steel. In our design, our battlebot utilized two front armor plates, two side armor plates, and one sloped back armor plate. For our team to make these components, we used a horizontal band saw, a Bridgeport vertical mill, a plasma cutter, a sanding belt and a hand grinder.

First, our team cut the front armor plates to rough overall length using a band saw. We, then, used a vertical mill to square up their overall dimensions to our design specifications. After, we continued to use the vertical mill to drill slots for mounting to the overall assembly of our bot. After this was completed, our team rearranged the assembly of the vertical mill, so that we would be able to mill at an angle per our design. After we finished this, the front plates were complete. Our next objective was the two side armor plates.

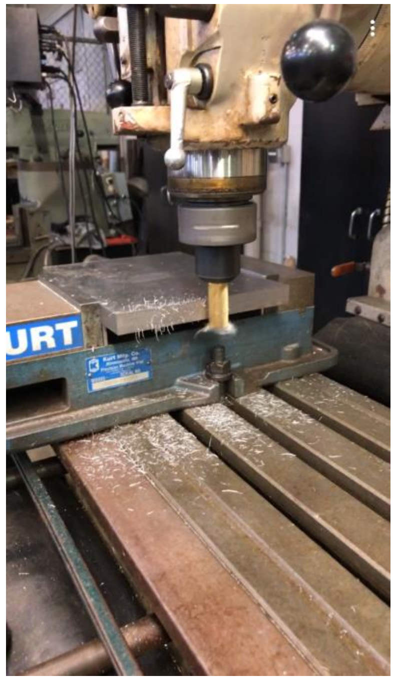

Figure 33 Vertical mill milling the front armor pieces

As with the front armor plates, we first cut the raw material to rough overall length using the band saw. Once this action was completed, we moved the pieces to the plasma cutter in the welding lab. We cut the two plates to their rough dimensions with an offset due to the poor dimensional tolerancing. We then used the CNC mill to drilled slots for mounting each of the plates to our assembly. The last armor piece we machined was the back-armor plate.

The back-armor plate produced a minor machining difficulty because of the size of it. In our bot design, we wanted to incorporate a sloped back armor plate to negate being flipped from behind. Due to this design requirement, we had to figure out a way to accomplish this and make this feature a reality. Similar to how we machined the front armor plates, we first cut this plate to the rough overall length using the band saw and then used a vertical mill to square up and mill the plate to our specified dimensions. After we completed this, we continued to use the vertical mill to carve out slots for the side armor plates to slide into for our assembly. Our last action, with the vertical mill, was drilling and tapping the mounting holes to hold the aide armor plates in place. Our team, then, ran into a dilemma. The Bridgeport could only be reassembled and angled to a 45° angle, we needed the angle to be 60°. We decided to run the Bridgeport mill, until we reached the 45°. However, we then started to notice signs of the cutting coming too close to a drilled mounting hole. To combat this issue, we moved from the Bridgeport mill to the sanding belt and air grinder. We marked off how much material we still needed to take off the piece and went on to remove it.

FRAME

The next big component, our team worked to machine, was the inner framework of our bot. The inner framework is composed of six sub-components: two weapon-mounting plates, two inner frame plates, the weapon motor frame plate, and the drive motor frame plate. All of these components were made from 4140 Annealed Steel, just like the armor plates. During the design phase, our team looked for ways to reduce weight where ever we could. Due to this we designed the inner framework with a honeycomb pattern, which allowed us to reduce weight, while still having sound structural strength to protect our vital components and allowed us to use steel throughout the frame and armor of our robot.

The first sub-component, our team started with, was the two weapon-mounting plates. These plates featured thicker material with 3/4" plate that would house the weapon bearings and drive bushings. We, first, used the horizontal band saw to cut the two pieces to rough overall length. After, we plasma cut rough outer dimensions and inner clearance hole for the bearings. We then utilized the vertical mill to mill the pieces to our design specified dimensions. We also used this machine to mill the front angle and to mill bore bearing pockets too. This process proved to be tedious as the bearing pockets had to be precise to press fit our races into them and support the weapon system. We, then, used the mill to drill and tap the mounting holes for the pieces. The next sub-component was the inner side frame plates.

Identical to the start of our all machine processes, we first cut the raw material to rough overall length using the horizontal band saw. Then, our team utilized the vertical mill to square up and cut the sidepieces to their specific dimensions. We, then, milled the top of the two plates at slight angles using Sine Bar. After, we drilled and tapped the mounting holes of both plates. Finally, we used a CNC mill, which we programmed via Sprutcam to cut the honeycomb pattern into the plates. The weapon motor frame and drive motor frame plates were next.

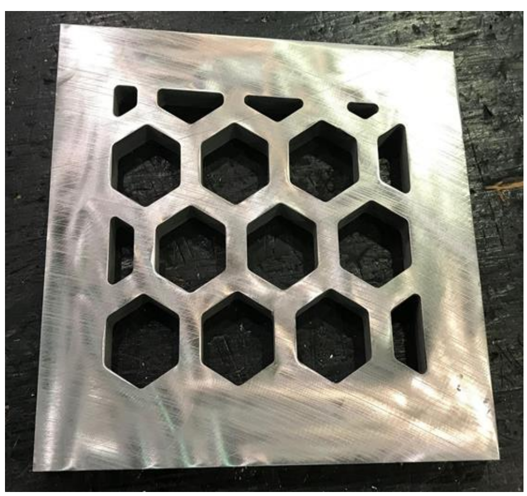

Figure 34 Finished Inside Frame Plate with honeycomb pattern cut into it

Just like with the other operations, our team started by cutting the pieces to rough overall length using the horizontal band saw. We, then, used the vertical mill to square up and mill the pieces to their specified lengths. After, we moved the pieces to the CNC mill and programmed it, via Sprutcam, to cut the honeycomb pattern into the two plates and drill the mounting holes for holding the motors. Once this was complete, we moved the plates back to the vertical mill to drill and tap the mounting holes for the side armor plates.

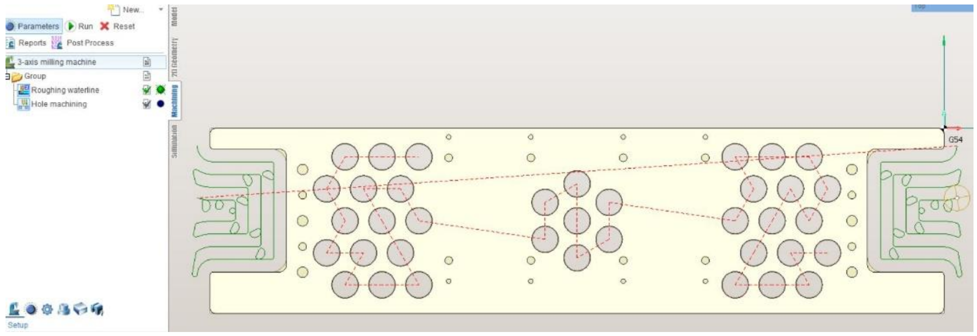

Figure 35 Drive motor mount Sprutcam photo

Figure 36 Drive Motor Plate in CNC Mill after drilling operation

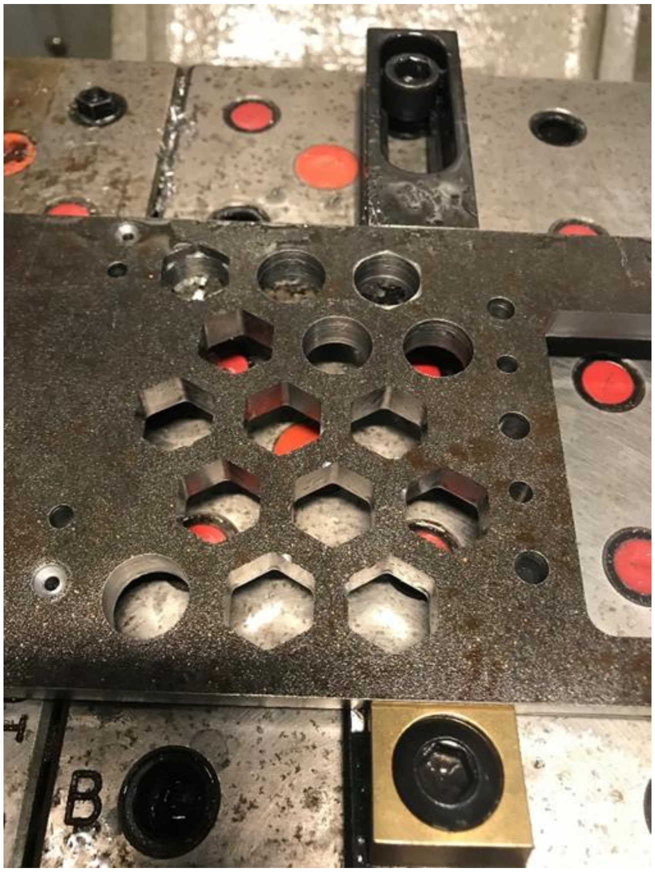

Figure 37 Drive Motor Mounting plate after honey comb operation endmill failed

WEAPON

The weapon was the third major assembly to be machined. It consisted of five sub-components which include the weapon drum, the two end caps, and the two teeth. The weapon teeth were made out S7 Tool Steel that if we had competed would have been heat treated for a tougher hardness. The drum and the end caps were made of 4340 steel so that the pieces could be welded together to make the assembly one full piece. This proved to be the most difficult material to source in the dimensions we wanted and had to source it as a solid bar which significantly increased our machining time.

We began by using the band saw to cut the bar of material to slightly over our specified length, this began the process of machining our weapon drum. Once this action was completed, we moved our newly cut bar to the two-ton drill press and drilled an overall inside diameter. After the drilling was done, we moved to the lathe and bored our inside diameter to its final dimensions. We also used the lathe to turn the outside diameter to its final dimensions as well. Afterwards, we used the vertical mill to cut slots for the weapon teeth to mount to the overall weapon assembly. Finally, we used the mill to drill and tap the holes for the teeth.

Next, we cut our end caps from the same material and completed the same process, on the lathe, as we did for the weapon drum. We then used the lathe to turn the v-belt sheaves directly into the endcaps. We intended for the two endcaps to work as the overall shaft for weapon. After completing the machining for the endcaps, our team moved into the next manufacturing process for our weapon. Our team took the three-machined pieces of our weapon system and welded them together using T.I.G. welding, which was no small feat, since there was a very close tolerance between the wall of the drum and the beginning of the v-belt sheave.

The last sub-components machined for our weapon system were the two teeth. First, we used the band saw to cut slightly over our specified design length. Next, we used the Bridgeport mill to square up and bring the overall dimension of the steel to our design specifications. After this step, we used a ball end mill to achieve the radius specified in our model design. Once this was completed, we drilled the through holes for mounting the teeth to the weapon drum and slotted the teeth to allow for socket cap screw heads to fit into. The weapon shaft was driven by the v-belt sheaves directly machined into the end caps as a shaft. These endcaps were supported by roller taper bearings that could support our designed load from a large impact force. By using a roller taper bearing this provided us the ability to have the bearings align the weapon with its own support provided by two bearings pushing upon each other. This gave us good stability and eliminated the need for a shaft collar. The bearings we selected were used primarily in the automotive industry and proved to be much cheaper than other bearings of a similar size. This saved us money and time since they could be quickly sourced. The last major component was the drive system.

Figure 38 The welded weapon drum and the weapon-mounting plates with the bearings press fit inside

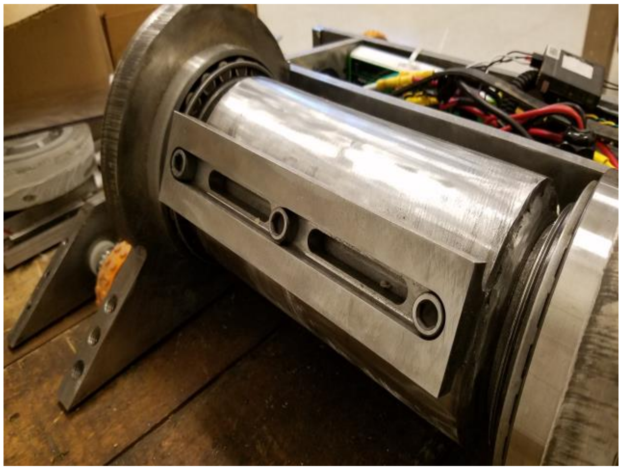

Figure 39 Weapon mounted to the overall bot assembly

DRIVE SYSTEM

The overall assembly of our drive system was fairly simple to complete due to our bot's design and the part selection. We envisioned our bot being driven by two independent rear-wheel drive motors. We also had a motor to drive the weapon as well. The design challenge we ran into was how to mount these motors on our bot. To accomplish this task, we machined motor housing rings that would be bolted to the back of the back inner framework plate and also to the back of the front inner framework plate. We machined these housing rings two ways. In the first method, we plasma cut the pieces of aluminum and milled them to size. However, we noticed this process was time consuming and the cleanup became an issue. So in the second method, we fully milled the parts to size, which alleviated and solved the problems that arose with the first method. After we completed this process, we drilled and tapped the mounting holes and securing holes using a manual mill.

TESTING

Fully testing our battlebot was the final stage for this project. Upon fully assembling our bot, we needed to make sure all the components worked as designed. This meant turning on the bot and making sure all vital components worked and everything was wired correctly. The next step was actually testing our bot's major components to assure that what we envisioned in our design had been realized. The testing was done in stages for each component of our bot which included the armor and frame, the weapon, and the drive system.

The first stage of testing was conducted on the armor and frame. During the machining phase, our team made two sets of the armor plates and inner framework pieces. One set was for the final bot assembly and the other was for impact tests and drop testing. The impact test was performed in a certified battlebot cage. Our team used a 30-pound drum bot to impact and hit our test frame. We noticed light scratching on the surface from the impacts. However, the armor and frame withstood the attacks with ease. Our team was pleased with these results, but the impact force from the 30-pound bot is not the same as that of a 120-pound one. The drop test would assure the durability and overall rigidity of our armor and frame. We conducted the drop test by dropping the frame from a two-story building. Upon completing the test, our team observed slight bending in the inner frame plates. However, the rest of the frame and armor were intact. We observed that the plate that had bent was directly behind where our weapon would be mounted and was cantilevered during our drop test as it hit from the side. We felt that this test showed how important our weapon was to the frame design as the weapon itself would provide support and strength to the frame during an impact.

Figure 40 Test frame after drop test

The next testing we conducted was on our bot's weapon. Our team travelled to Cleveland to test the weapon in a safe environment, which was a certified battlebot cage. However, the cage was designed for smaller competitions and the organization did not want the weapon hitting anything due to the risk of damaging the cage. We decided to conduct an endurance and reliability test. During our project research, we used a benchmark of 3 minutes as the length of our battle and assumed the drum would have to be started from a complete stop multiple times during the match. To test the weapon system, we ran the weapon at full speed, starting and stopping multiple times along with changing the direction of rotation and it exceeded our expectations by running over 5 minutes. However, we did notice minor issues with the v-belt wearing against the frame and concluded that additional machining could take care of this clearance issue.

The last stage of testing was for the drive system and the electronics. We used a straight hallway for us to conduct the testing. During our initial testing, we observed that traction was an issue for our bot. For the ground clearance available, the wheels we had used were slipping on the surface and did not have as much ground contact as we originally believed. However, this was quickly remedied by using a strong adhesive and rubber tracks. Once we had solved this issue, we observed that our bot had good speed and maneuverability on the floor.

CONCLUSIONS

For this senior design project, our goal was to design, manufacture, build, and test a fully functional 120-pound battlebot for competition. To accomplish this task, our team worked together extensively to bring our design to life. However, we faced many obstacles in accomplishing this endeavor. Some of the obstacles we faced were making deadlines, making precise engineering assumptions, designing the four major components of our battlebot, procuring money for the project, accurately machining our parts, and electrical calibration difficulties. However, through all these obstacles, our team was able to design and build our ideal version of a battlebot.

This project also taught us many different aspects, which would not have been seen in individual-based projects. We believe this is because this project is a more real world experience, since most times you will be working in a team to accomplish engineering tasks. One aspect, in particular, was communication. During the entire length of the project, our team had to communicate effectively with each other to get all of our ideas across whether it was for how each of the major components should fit together or who would be machining what on a particular day. Communication was an important key to us being able to accomplish our task. Another aspect was designing an action plan and making deadlines for when things needed to be completed by. This allowed our team to design a timeline and give us an overall view of the how much truly needed to be done to bring our project to fruition.

The design and machining phases of the project were also learning experiences for our team as well. During the design phase, we worked cohesively to bring each of our component designs together and through effective communication, we were able to create a well-designed 3-D model. The machining phase presented us with a few timing issues. One, in particular, was the inner frame of our bot. When our team first started to machine the honeycomb pattern in the frame pieces, we had not taken into account how much time it would take to accomplish this. Nor did we know how difficult it would be to program the CNC mill to do. Through trial and error, we lost a little bit of valuable machining time, but we were able to get the pattern cut after being advised by the staff for how to make the process faster.

Our team encountered many obstacles throughout this project. However, in the end, we accomplish our ultimate goal of designing and building a fully functional 120-pound battlebot for competition. Although, our team will not be competing in the 2018 RoboGames due to the competition being held the same day as graduation, we were able to have a meaningful experience and utilize the knowledge we gained from the university and apply to a real world application.

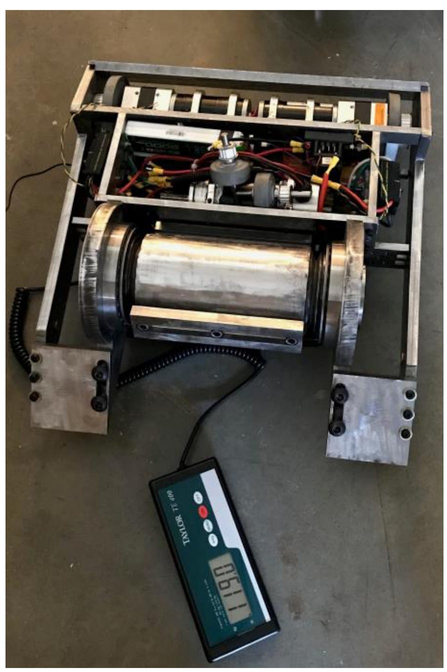

Figure 41 Fully assembled "Ravager"

RECOMMENDATIONS

In review, our team faced many obstacles during this project; we recommend future Battlebot teams to do the following:

- Be prepared for unexpected issues and adjust accordingly
- Do adequate research on multiple victorious bots prior to Senior Design 1
- Be prepared for long machining days
- Contact companies and co-ops for sponsorship and funding early
- Emphasize weight restrictions
    - As with boxing, make sure your bot is either equal to or just under the weight limit
- Utilize machining time wisely
- Plan for machining even after the bot is assembled
- Have an action plan for everything that needs to be done for your bot
- Teamwork is important and everyone needs to help each other to meet deadlines
- Once the bot is assembled, testing of various kinds needs to be conducted
- If your team does compete, plan on machining multiple spare parts for competition
    - Also make components interchangeable to save time between matches

Recommendations for what our team would have done with additional machining time:

- Used the programmable CNC mill to remove material around the weapon mounting plates to provide additional clearance for the teeth to engage rival battlbots
- Adjust the front drive wheels to have bearings rather than bushings for less friction, so they roll easier
- Adjust the weapon motor frame plate to have more clearance in the v-belt slots so they do not rub and have additional wear
- Utilized the mounting threads on the gearboxes and slotted the drive motor frame plate to adjust the motor heights.
- Find a way to cover our electronic speed controls mounted on the side of the frame using Lexan covers

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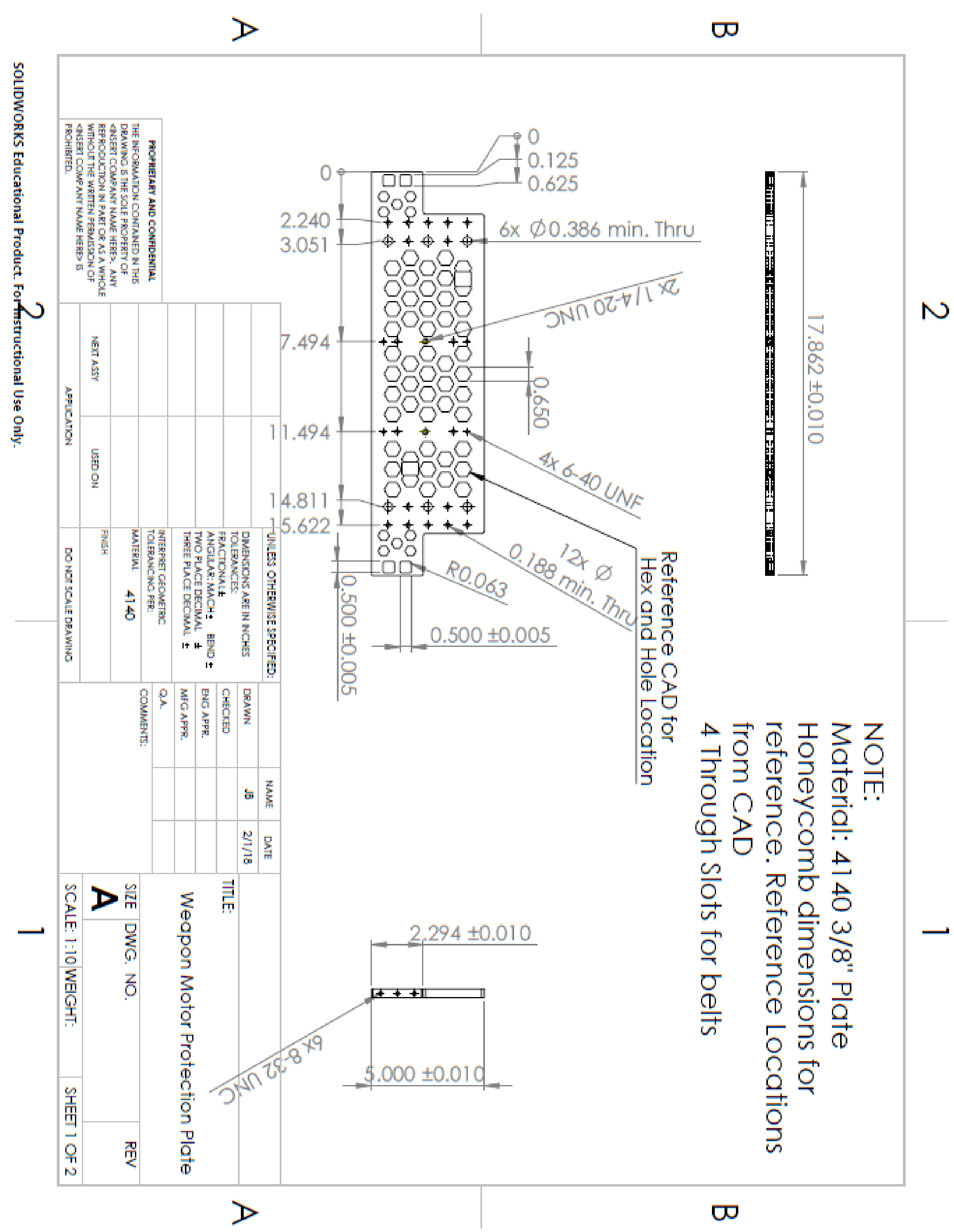
APPENDIX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Reference CAD for Hex and Hole Location
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2x 1/4-20 UNC
4x 6-40 UNF
12x ∅ 0.188 min. Thru
R0.063
0.500 ±0.005
2.294 ±0.010
5.000 ±0.010
6x 8-32 UNC
Weapon Motor Protection Plate
MATERIAL 4140
DRAWN JB 2/1/18
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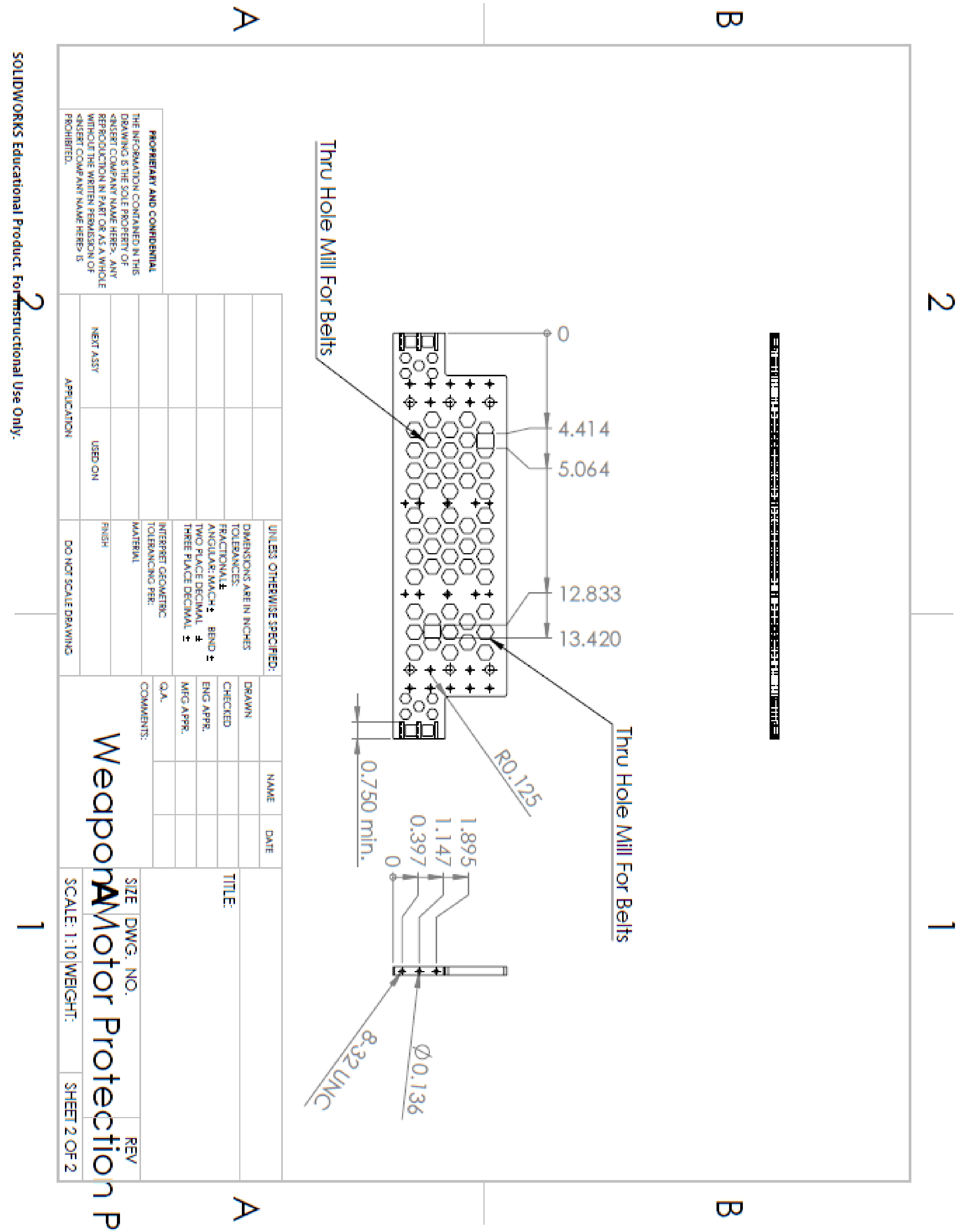
Thru Hole Mill For Belts
Thru Hole Mill For Belts
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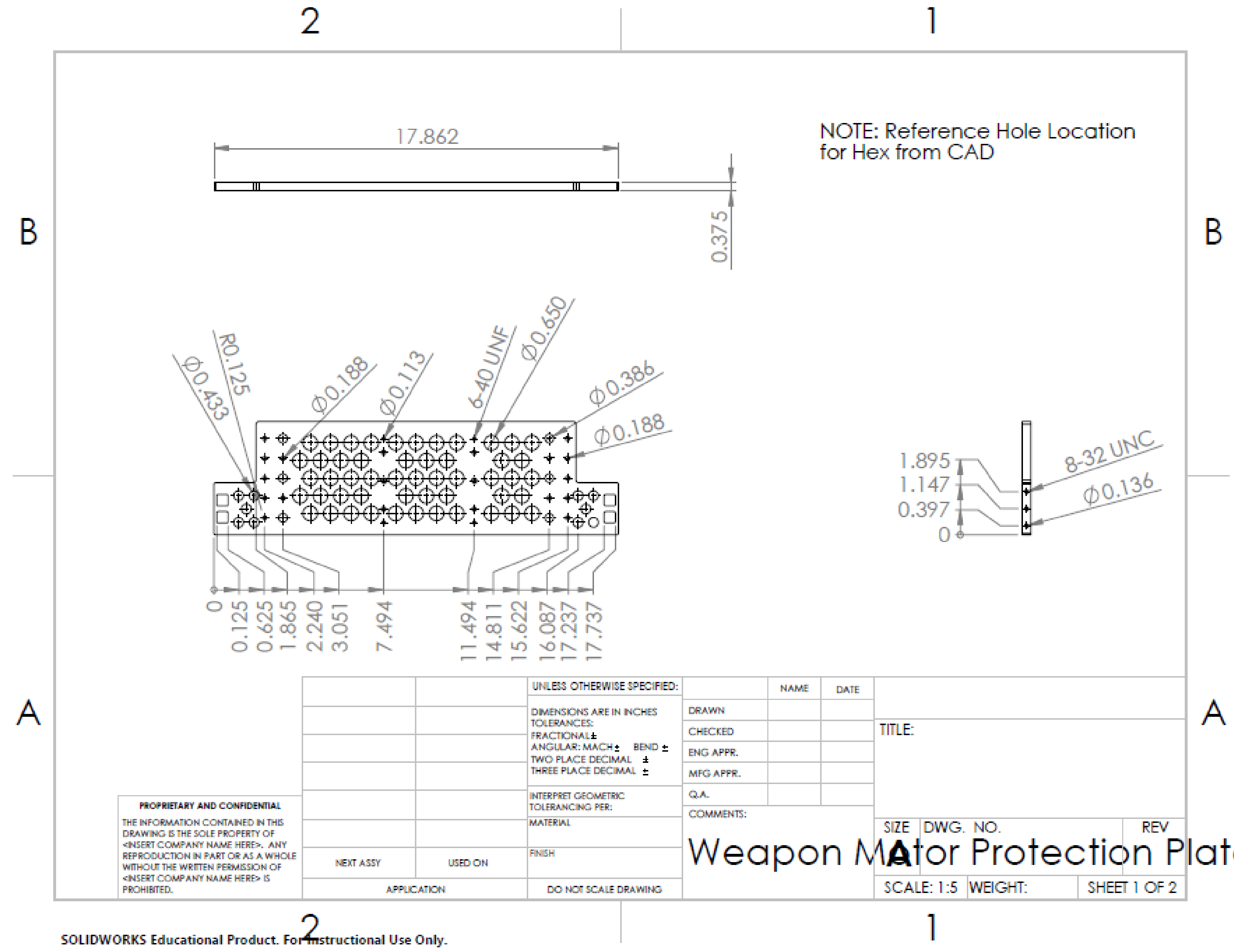

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Ø0.113
6-40 UNF
Ø0.650
Ø0.386
Ø0.188
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0.125
0.625
1.865
2.240
3.051
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11.494
14.811
15.622
16.087
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17.737
1.895
1.147
0.397
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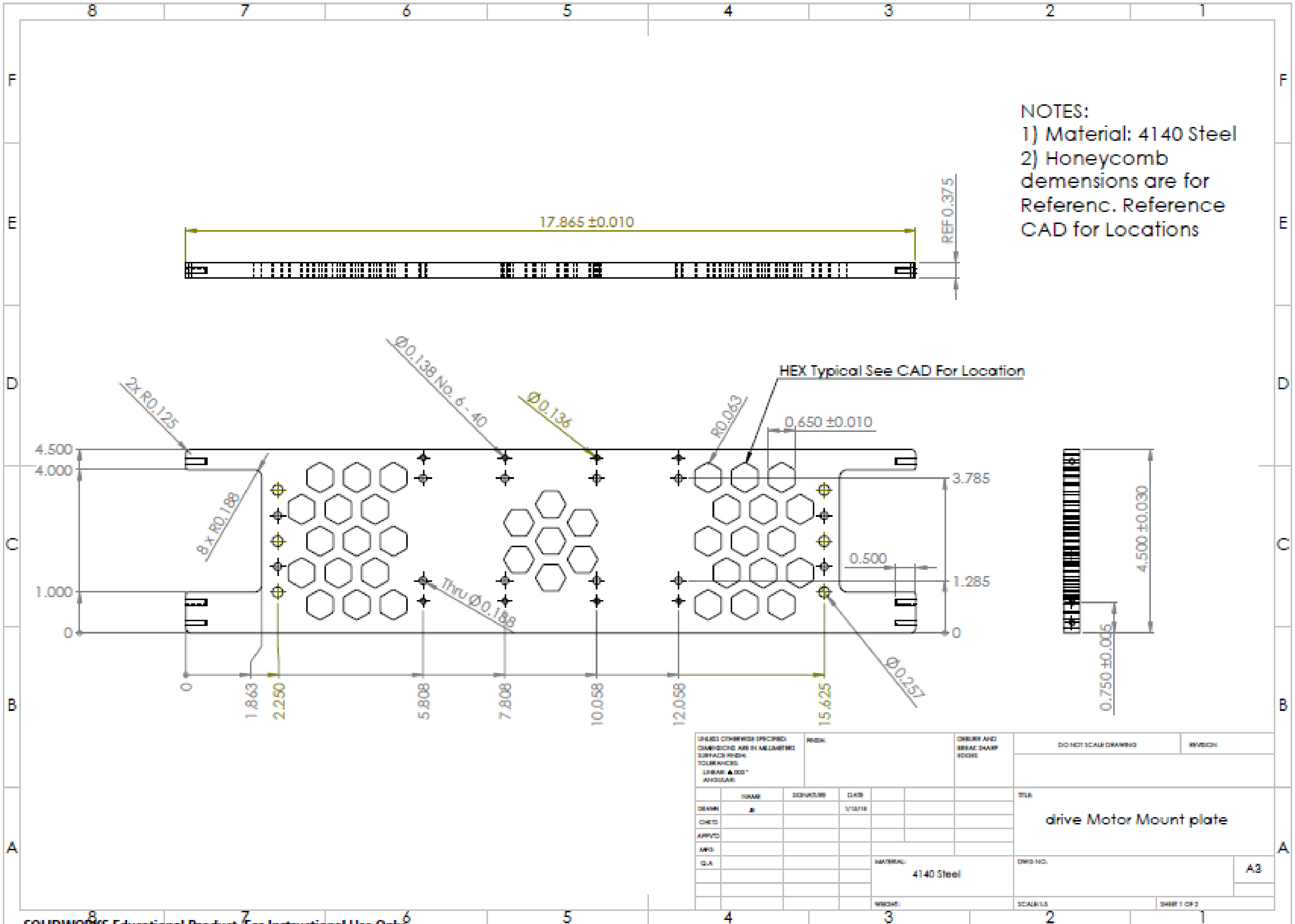
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Ø0.136
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HEX Typical See CAD For Location
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7.808
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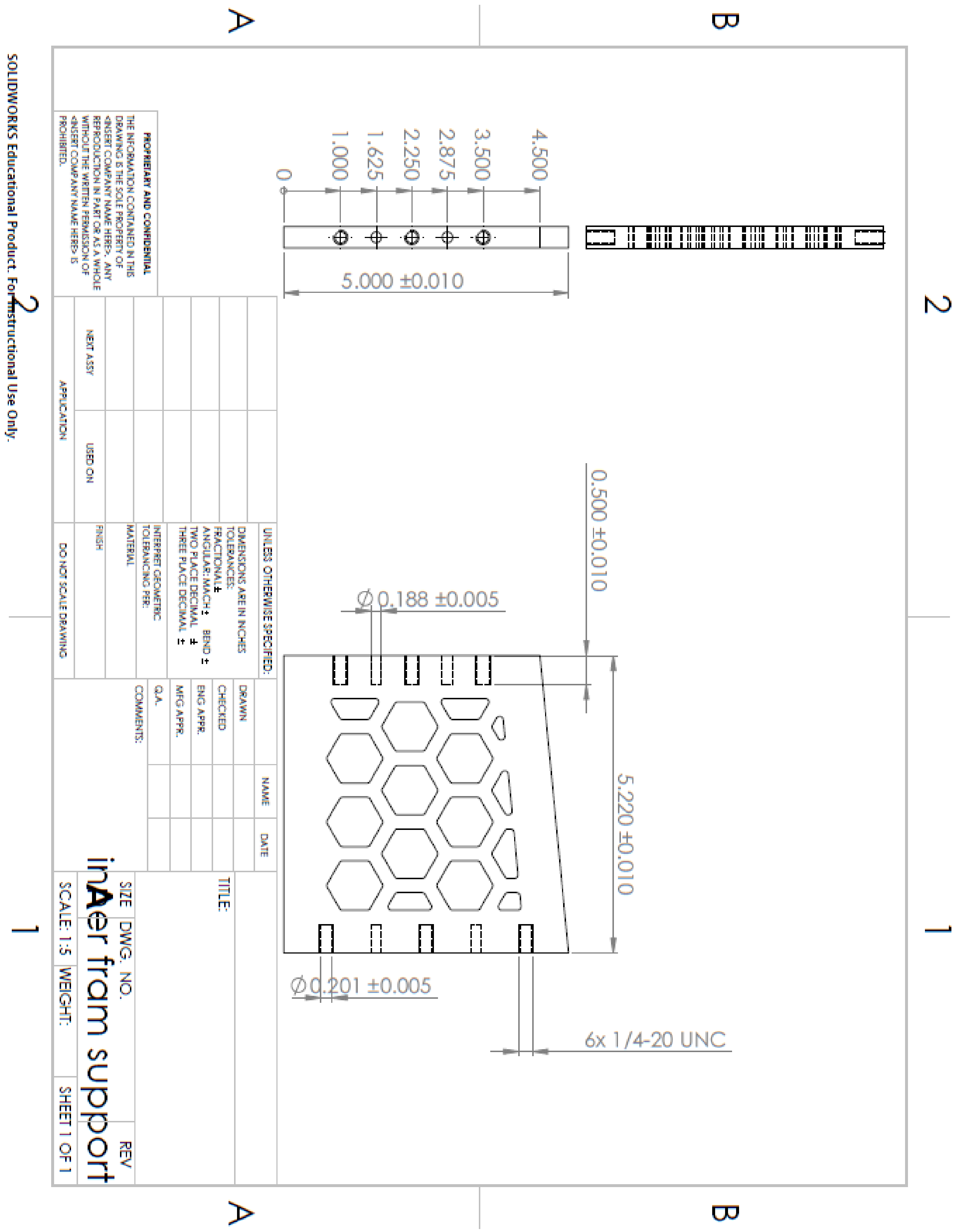

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2.250
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0.500 ±0.010
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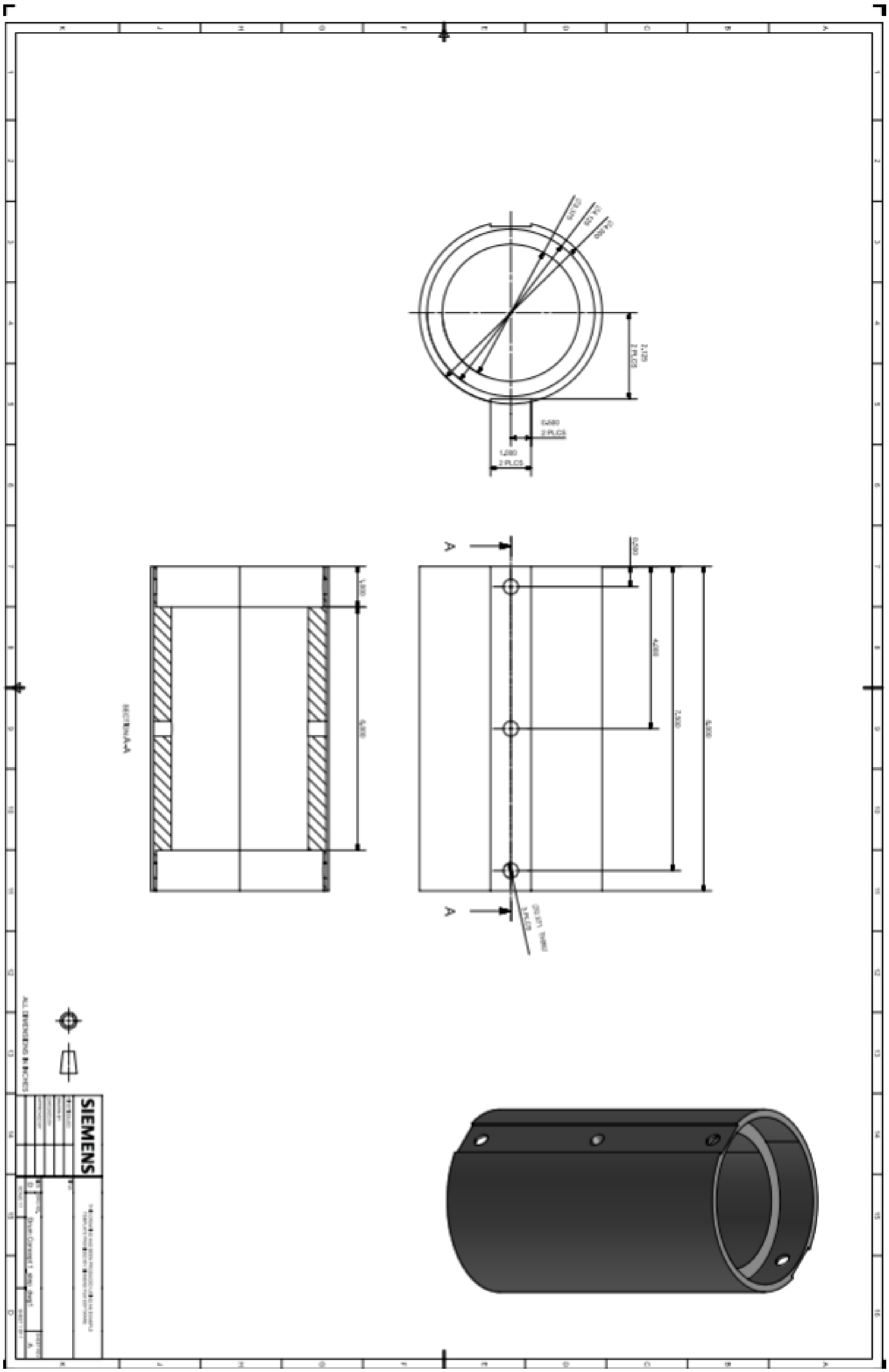
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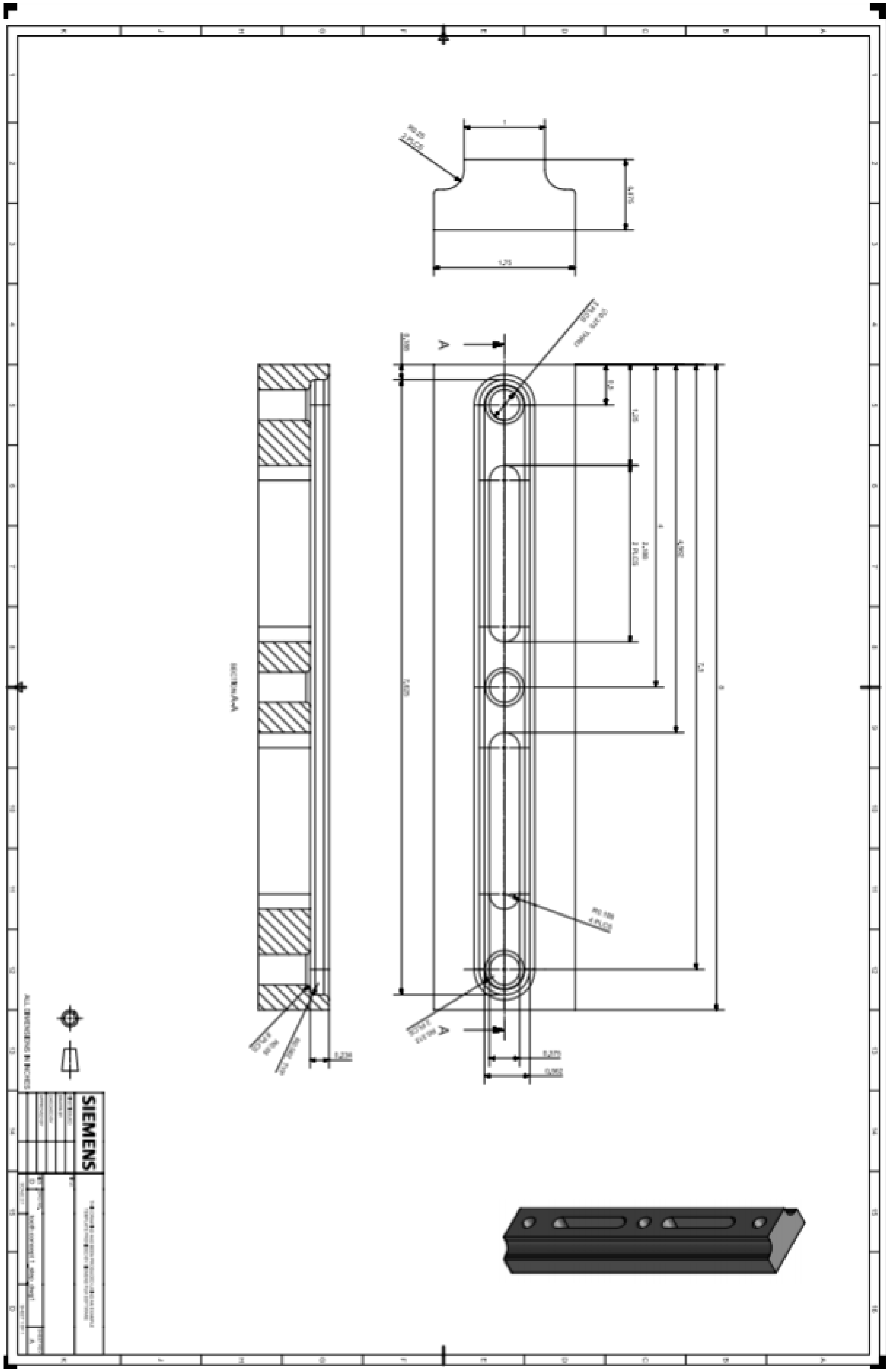

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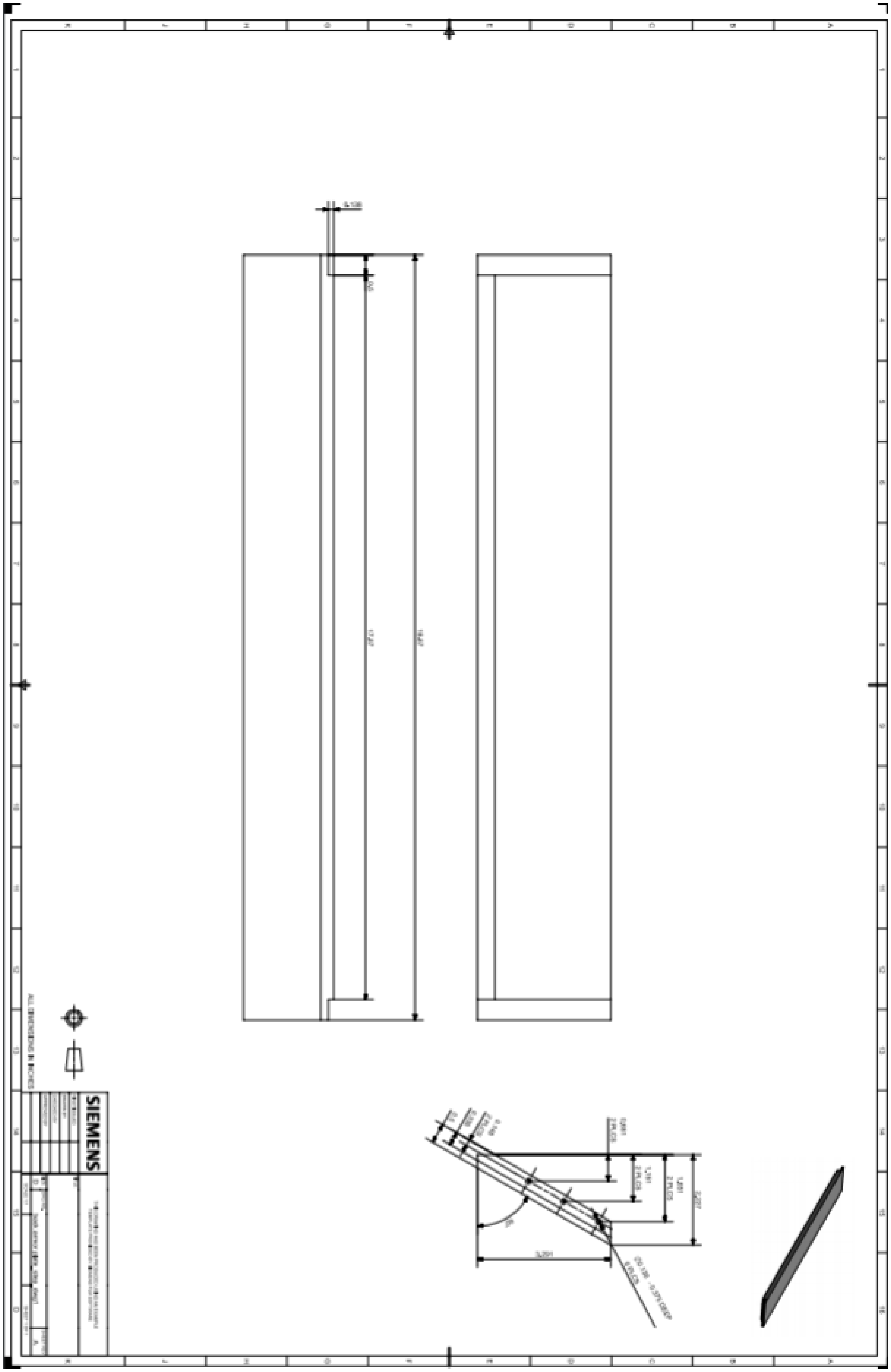
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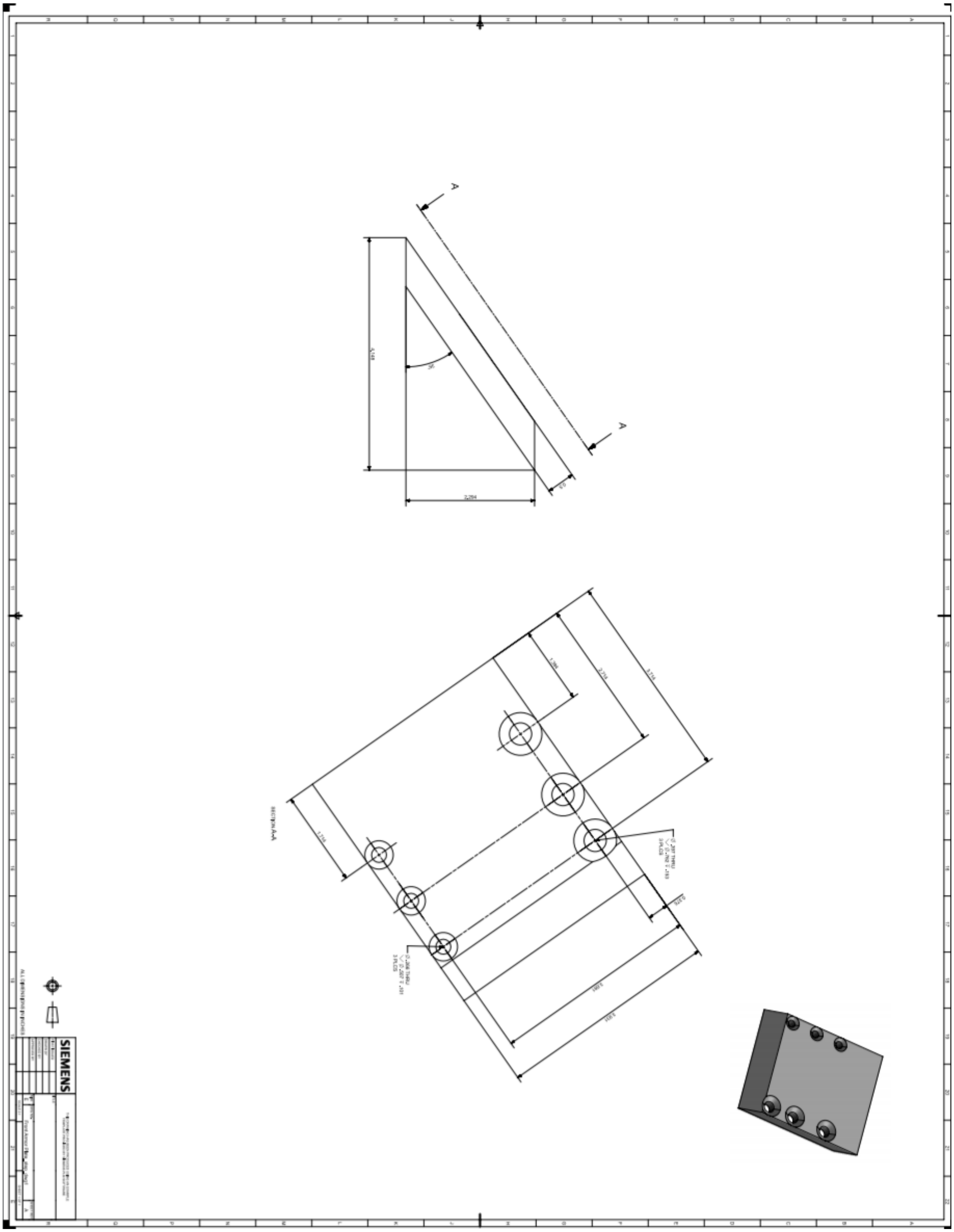
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