2008 CAS BattleBot

by

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2007-2008 Battlebot Frame
University of Cincinnati College of Applied Science
Middleweight competitor in BotIQ

Jonathan Taphorn

ABSTRACT

The University of Cincinnati as of fall 2008 has yet to compete on the national level of a battlebot competition. Four senior from the college of Applied Science successfully designed and constructed a 120 pound battlebot, for BotsIQ. BotsIQ is a national battlebot competition for college students.

A box-shape frame with internal wheels is the best building platform for a well designed battlebot. The box-shape frame helps hold and protect the components. The box-shape allows the wheels to be protected from damage, by only allowing a minim distance protruding out of the frame. This style of frame also allows multiple types of weapon to be equipped.

The customer importance was determined by posting a survey on battlebot posts websites, thirteen battlebot builders responded to the survey. The results were close to one another showing that all categories offensive, defensive, maneuverability and control, and maintenance are equally important. From the survey maneuverability and control, was the most important with the rank of 3.15 out of 5 possible points. In the frame category they felt that the frame should be quick and easily repairable and that the weapon should be interchangeable out of the frame.

Giving similar characteristics that all the features were equal important in the building of the battlebot frame. The most important characteristic for the frame was frame repair made quick and easy at 5.12%.

The objective of the frame is to deflect all damage and house all components of the bot. The frame itself should weigh less than 30 pounds. The frame should withstand forces from its own weapon as well as forces from opponent's bot. The frame should also take less than twenty minutes to assemble and with only two tools. The frame should be able to be taken apart and replace the weapon in less than twenty minutes.

The frame was designed out of 7075-t6 four inch wide by a ½ inch thick aluminum is a square shape with internal wheels. The mount for the weapon is a two inch diameter hole in front. The frame is held together by ¼-20 cap head bolts. The frame weighs 29 lbs.

The frame of the bot will took less than 2 weeks to manufacture. The manufacturing was done on a CNC mill taking twenty hours to machine and program the frame pieces. Hand tapping was performed to ensure tap did not break inside the frame pieces.

The assembly took less than a day to complete. The biggest problem was some of the tapped holes were not deep enough resulting in the need to tap them deeper.

Testing of the robot was done at the competition because of the cost and time required to make the frame. During the competition the frame received no significant damage. The only damage was minor scratches to the front of the frame.

The cost for the trip and the competition was $3300.00. The cost of manufacturing the frame was estimated to be $420.00, which is only 2.6% of the total budget for the battlebot. The battlebot cost $13,500.00 for the complete battlebot and all of it back ups. The total cost of building the frame was $28.39 resulting in a 0.26% of total budget.

The battlebot proved it was a good design and withstood the punishment of the competition. There are a couple of improvements that can be done to the battlebot such as making it four-wheel drive. To do so the frame would need to be retrofitted and lightened.

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PROBLEM STATEMENT & RESEARCH

INTRODUCTION

The University of Cincinnati, College of Applied Science (CAS) Mechanical Engineering department has not been recognized for its battlebot design capabilities, seeing that the college has never competed. Every year, colleges meet in Miami, Florida to compete in a BotsIQ competition. BotsIQ is a robot competition where the robots battle one another for three minutes inside a ring. The winner is decided by whose bot is still operational or has inflicted the most damage. The project was broken into four main parts. Dave Bailey constructed the armor to protect the battlebot, Jake Barnhorst designed the weapon that the battlebot will use in the competition, Tim Meyer designed the drive train to move the battlebot, and Jonathan Taphorn will design the frame to house all of the components and have a place for the armor to attach. A solution to this problem is to design and build a 120 pound bot to compete in the BotsIQ competition, opening the door for future generation of CAS students to improve the bot and competition in the completion year after year.

RESEARCH

Research was done by watching videos, searching websites, and studying previous projects. The research showed that battlebot shapes are broken down into three categories: odd shape frames, boxes with exposed wheels, and boxes with internal wheels. Each type has variations but the structure is similar.

Figure 1-Micronightmare

Figure 2-Warhead

Figure 3-Spare Part

Battlebots with odd shapes are particularly vulnerable to attacks and inversions. Bots such as Micronightmare (1) as seen in Figure 1 leave a vital component (speed controls, batteries, receiver, motors) exposed to attack.   See Appendix A for more details. Others are more vulnerable to attack such as Warhead as seen in Figure 2; the wing can easily ripped off causing damage. Spare Part (2) as seen in Figure 3 shows the drive train chain exposed on the outside of the bot, which, if hit, could break leaving the bot unable to move. These types also cannot run if flipped on their back.

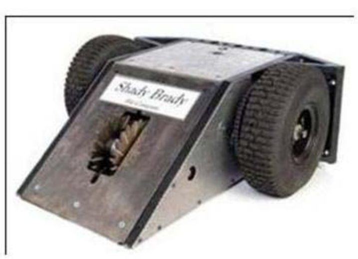

Figure 4-Ankle Biter

Figure 5-Windchill

Figure 6-Flipper Bot

Battlebots that have box frames with exposed wheels house all of their vital components, but with the wheels exposed they are left vulnerable to attack or being torn off. Ankle Biter (2) as seen in Fiqure 4, is a box frame with a wedge ingerated into the frame which can be used as a weapon. Windchill (2) as seen in Figure 5, is a box frame with angled sides to deflect opponent attacks.

Flipper Bot (3) as seen in Figure 6, is a standard rectangular box, but it leaves the wheels exposed to attack and they could easily be torn off in combat.

Figure 7-Bad Attitude

Figure 8-Garm

Figure 9-Nippler

The final shape of frame, which also has the best advantage is the box frame with internal wheels. The components are all housed inside the proctection of the frame, which can house a variety of weapons. Bad Attitude (2) as seen in Figure 7, is a box frame with internal wheels that are proctected and allow the bot to still run if flipped on its back. Garm (2) as seen in Figure 8, has a side skirt atached to its frame which does not allow the flipper bot to get undeneath the frame to flip the bot. Nippler (2) as see in Figure 9, has a box frame that houses a different types of weapon, showing the variety of weapons that the box frame can house.

The materials used to make the frames are steel, titanium, and aluminum, and each has its own advantages and disadvantages. The advantages of steel are that it is relatively inexpensive to purchase and has high strength and versatility, but the main disadvantage is its weight. The advantage to using tititatium is that it is relatively light-weight and has a great strength ratio. The disadvantages are that it is expensive to purchase and hard to weld. Aluminum is lightweight and not too expensive, but unfortunately the material is nott very strong.

The box frames are the best design for a battlebot frame, because they can mount a variety of different weapons and proctect all the vital componets. Box frames are also the easiest to fix and repair. The aluminum seems to be the best material for construction of the frame because of its lightweight, cost, machinability, and is weldability.

CUSTOMER VALUES

After the final feature list was determined, the features were then used to create a survey, in which respondents were asked to rank the main categories and sub categories according to their importance. The survey was then posted on a website where people who have battlebot chats. Thirteen battlebot builders responded to the post, and the results were tabulated and are shown in Appendix B.

Table 1-Main Category from Survey

Main Category	Rank
Maneuverability and Control	3.15
Defensive Capabilities	2.62
Offensive Capabilities	2.34
Maintenance	1.85

The main categories Table 1 that relate to the battle bot frame are defensive capabilities, offensive capabilities, and maintenance. After being ranked the main categories were very separated by 1.3 points from highest to lowest.

The sub categories that are related to the frame are listed in order from highest to lowest. The highest value that could be

Table 2-Sub Category Related to Frame

Subcategory	Rank
repairs made quick and easily	2.77
part are easily removed	2.31
weapon system is interchangeable	2.00
Frame is Modular	1.54

achieved from the survey was a five and the lowest was a one. Table 2 shows that the battlebot builders felt that the frame should be quickly and easily repairable; and the parts including the weapon should be easily removable.

The survey results show that all of the features are important because of how close all the results were. The survey showed that there is no one important feature for the battlebot and this causes the battlebot to be equally balanced in all features.

FRAME CHARACTERISTIC

The relative importance ranged from 3% to 8%. For the complete QFD see Appendix B. The most important feature of the frame is that repairs are quickly and easily made. The engineering characteristics that can help achieve the material and a reduced numbers of components in the frame are; easily removable parts can be made possible by the number of subsystems that attach to the frame, the modular frame can be attained by having back-up components for the frame, and the interchangeable weapon system can be done by making the weapon a subsystem that bolts onto the frame. You can see also from the QFD that there must be an equal balance in characteristics.

Table 3-Relative Weight

Features	Relative Weight
repairs made quick and easily	5.12%
part are easily removed	4.27%
Frame is Modular	4.02%
weapon system is interchangeable	3.20%

FRAME OBJECTIVE

The frame objective is to house all the vital components of the bot, as well as to provide a mounting point for the drive train and weapon. The frame needs to be able to withstand the forces of the weapon being applied to the frame to prevent twisting or damage by the weapon. The frame also needs to be able to support the armor so that it can take the damage inflicted from other bot. The frame should takes less than the twenty minutes permitted to dismantle and reassemble.

Table 4-Frame Objectives

Features	Objective	Measurable
Frame strength	With stand forces delivered by its own weapon	LBF
	With stand forces from other battlebots	LBF
Frame characteristics	Weigh less than 30 pounds	LB
Frame made quick and easy	Frame should take less than 20 min to assemble	Time
Parts are easily removed	Two tools or less to assembly frame	Visual
Frame is modular	Frame should be able to come apart	Visual
Weapon system is interchangeable	Be able to replace weapon in twenty min.	Time

DESIGN

The robot frame needs to withstand 13,000 pounds of force being applied to it. The 13,000 pounds of force comes from the calculated force from the weapon of this battlebot. Using the direct stress formula, a material with an ultimate stress of 78,000 psi was required for the frame and you can see the direct stress formula is on page F1. Knowing the amount of direct stress being applied to the

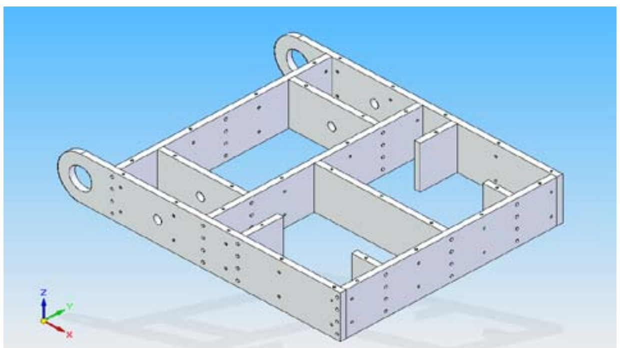

Figure 10-Frame Design

robot there were several choices of material; titanium, aluminum, and steel. Steel and titanium were not used because of the density of the material and due to the weight requirement for the competition. The robot frame will be made of aluminum 7075-t6 rectangular bar stock. The height of the sides was determined by the height of the tallest component of the battlebot which was the batteries, measuring 3.8 inches. A four inch height allows padding to be put on top and bottom of the batteries preventing damage. A ½ inch thick and four inches high frame pieces gives an ultimate stress of 83,000 psi; this calculation can be seen on page F1.

Using aluminum the frame will weigh about 28 pounds. The weight was determined by using solid edge software. The frame itself will be square in design with the wheel location incased in the robot frame, as you can see from Figure 10. For a more detailed drawing of the frame componets see Appendix G. The frame was designed around the components of the battlbot, insuring that they would fit as best as possible with little wasted space. The weapon itself is a drum spinner and needs to be attached to the frame by means of a hole for the spinner to ride in. To support the weapon the size of the hole was determined by using bending momentum formula found on page F1. It was determined that the greatest diameter was 2 ¼ inches. A two inch diameter hole was put into the frame to support the weapon because of the bearing with the proper inside diameter had a 2 inch outside diameter. There were several choices for attaching the frame rails together: welding or bolting. Welding gives the greatest amount of strength but would not allow the changing out of the weapon. With the frame having to be modular, bolting was decide to be the best idea.The frame will be bolted together to allow the replacing of weapon and switching of damaged frame parts. A strength of 184,000 psi was required for the bolts. A ¼-20 bolt was to be used for the bolting of the frame together with a strength of 185,000 psi. The bolt will weigh two pounds, bringing the frame total weight to 30 lbs.

MANUFACTURING

The manufacturing process took twenty hours to produce the frame. The frame pieces were first cut to a rough length on a cut off saw. The pieces were rough cut an eighth of an inch longer than the actual length of the part, allowing the finish operation to take place. There were two choices for the finishing of the frame rails: manual machining or CNC machining. The accuracy of the frame pieces was an important part of the bolting of the frame together and cutting down the number of hours needed to produce the parts. With this in consideration CNC machining was decided. The pieces were programmed on a Hoss CNC machine, producing the parts to the exact shape and size. The tapping was done by hand because of the material breaking after several taps when trying to use the CNC machine. Two sets of frames were produced so there would be extra pieces in case of damage was sustained that the piece had to be replaced. One problem that arose during manufacturing was the inside support lengths were too long for the CNC machine and any milling machine. The part had to be done on a drill press, making it take longer for setup and less accurate.

ASSEMBLY

Assembly of the frame was smooth and the frame bolted together easily with the ¼ -20 bolts. The only problem was some of the holes were not tapped deep enough causing the problem of the bolt not tightening down all the way. This was resolved by re-tapping the holes and making them deeper. The frame aligned correctly because of the work being done on a CNC machine. The frame was built from the inside out. The assembly process started with the frame rail that sits in between the two drive motors, attaching the back plate then attaching the center plate. After that was completed the wheel support frame rails were attached. With the completion of that the front frame piece was attached. Then the bushings were pushed into the side rails. With the side rails having their bushings the side could then be put on. With this completed the next step was to put on the transmission mounts. With the transmission mount being assembled the frame was completed.

TESTING

The price and time required for building the frame determined that no destructive testing would be done. The destructive testing would be done at the competition. The battlebot was tested several times with the weapon engaged smacking into object such as brake drums and transmissions. Smacking into the object resulted into no damage to the frame. A second test was done with a second battlebot in a pushing competition. A pushing competition is a fight without weapons being on, resulting in less damage but allowing for driver to get practice for competition. The pushing match resulted in no damage to the frame even thought it was tested without armor to the battlebot.

COMPETITION

The competition had eight college team participating. During the competition the battlebot faced two front spinning drums, several wedge, and the arena hazard. The competitor's battlebot did not cause any significant damage to the frame of the battlebot. The only damage suffered to the frame was scratches marks on the front of the frame where the weapon attaches to the frame. The arena hazards hammers did not cause any damage to the frame even with a direct hit to the battlebot. The competition resulted in a six win and one loss during the competition. The battlebot team won the competition and received best engineered.

PROJECT MANAGEMENT

SCHEDULE

The frame was designed simultaneously with the rest of the bot, adapting to meet the requirements of the other team member's parts. After the bot design was finished, the ordering of material will begin. Then the frame material was cut into rough pieces, making it easier to transport and machine the frame pieces. After the frame pieces were machined they were then fitted together, while working out kinks in assembling. See Appendix E for a complete schedule.

Table 5-Major Milestones

Major Milestone	Estimated	Actual
Preliminary design calculations (all components)	25-Nov	25-Nov
Design of frame completed	13-Dec	13-Dec
Design freeze	14-Dec	4-Jan
Assemble of frame	22-Jan	3-Feb
Assembly of robot	29-Feb	27-Apr
Testing/troubleshooting/competition practice	1-Mar	N/A
BotsIQ national competition Miami Beach, FL	30-Apr	30-Apr

The schedule fell behind for several reasons. The material was late being ordered because it was hard to find the 7075-t6 aluminum, and if you did find a company that sold it was very expensive. The way this problem was fixed one of the sponsors called around and bought the material adding a couple of day on to the schedule. The final assembly of the robot was another major milestone missed and this was because of the armor not being completed on time. This resulted in the testing of the assembled robot never being tested until the day of the competition.

BUDGET

The budget consists of two categories shown in Appendix D. Traveling to the competition was 2400 miles round trip and cost $1300.00 to drive down to the competition. The hotel

Table 6-Trip Expenses

Trip Expenses (Before Donations)	Estimated	Actual
Competition Entry fee	$500.0	$500.0
Hotel Expense - 2 rooms @ 150/night -5 nights	$1,500.0	$1,500.0
Rental Van + Insurance	$500.0	$500.0
Gas @ 3.00/gal assumed 2400 miles @ 10mpg	$840.0	$800.0
Team shirts	$250.0	$0.0
Total Trip Expenses	$3,590.0	$3,300

cost and entry fee was $2000. The team also needs team shirts to wear during the competition were donated. This results in a total estimated cost of $3,590 for the trip expenses and the actual cost was $290.00 dollar cheaper resulting in an actual cost of $3,300.00.

Table 7-Total Frame Cost

Frame (Jon Taphorn)	Estimated	Actual
Chassis material	$300.0	$0.00
Chassis Fabrication	$100.0	$0.00
Fasteners	$20.0	$28.39
Frame Total	$420.0	$28.39

The cost of the chassis material was figured to cost around $300.00 dollars, assuming it to be two ½ thick by 4" wide by 7' plate for the frame. The reason aluminum was chosen for the frame was because of the low density of the material. The material for the frame was donated resulting in zero dollars for material and shipping. The frame was fabricated by the Joe Taphorn with no need to purchase tooling such as drills, end mill, and taps. The battlebot was bolted together attaching the frame members together. The method of fastening the frame together was done by bolting. The bolts were more expensive then original estimated but only by $8.39. The reason they were more expensive is because of the higher grade strength bolt. The frame was 0.21% of the estimated total budget for the building of the bot.

Table 8-Battlebot Total Cost

Battlebot build cost	Estimated	Actual
Drive Train Total	$4,913.0	$3,500.0
Main Weapon Total	$2,558.0	$1,494.51
Frame Total	$420.0	$28.39
Armor/Defense Total	$8,227.1	$8,277.1
Misc. Total	$150.0	$200.0
Project Total=	$16,268.1	$13,500.0

The total drive train cost was $3500.00. This includes motor, gearboxes, batteries, and wheels. The main weapon total cost was $1494.51. Included in the price of the weapon are the materials for fabrication, fabricating, motor, pulleys, batteries, and speed control. The cost of armor was $8227.10. The armor price includes the titanium honey comb armor and the fasteners required to attach it to the frame. The total cost of building the robot was $13,500.00. The trip and robot was estimated to cost a total of $16800.00 to build and compete in the competition.

CONCLUSION

The research determined the best design for the battlebot frame was a box shape with internal wheels and a frame that could be quickly and easily repaired. The frame also needed to be modular. The frame construction cost twenty seven dollars to create.

The frame was a good design and held all of the vital components inside the frame. The frame assembly went together smoothly and allowed quick changes to components to be done in less than twenty minutes.

During the competition the need for better handling arose. The way of correcting this problem would be making it four wheel drive. To correct this problem changes to the frame will need to be made. One possible way of going about this would be removing the front gearboxes supports. After doing so the batteries will need to be relocated. Then new holes will need to be cut in the center support to connect the wheels together by chains. The relocating of the batteries might not allow enough room for everything to sit inside the frame. This would result in the frame side rail needing to be lengthened, but the lengthening would add extra weight to the frame resulting in holes needing to be drilled in the frame to lighten the overall weight of the frame.

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2. **Garrett Robert, Jason Heuker, Karen Rangi, Nathan Wright.** *Project Muthar.* Cincinnati : OMI, College of Applied Science, University of Cincinnati, 2002.
3. [Online] [Cited: 10 1, 2007.] http://www.battlebots.com/meet_the_robots3/meet_robot_specs.asp?id=531.

APPENDIX A – RESEARCH

INTERVIEW - MATT LUKES

9/14/07
Matthew Lukes
Interview

Hworf

Battlebot champion and creator of two battlebots. Armor for bottom made of a sheet of titanium and upper armor was Lexan. The frame was made of aluminum extrusion. Powered by three batteries. Weapon was a 60 lbs swinging lawn mower blade. Drive train was driven by chains.

- 120 lbs
- Swinging blade
- Bot should be able to push 240 lbs
- Can be flipped
- Be able to be flipped
- Meet weight requirement
- Swinging blade
- Able to push competitor bot

Interview notes with Matt Lukes; building BattleBots for 7 years, competed in BotsIQ, won multiple tournaments at the Robot Club and Grill

- “ The key to winning is spinning”
- Spinning weapons need to be up to fighting speed in under 2 seconds
- The robot must be able to continue to fight even if being flipped
- A good type of armor Matt has used with experience is one which has air gaps in the middle which tend to be more rigid than just a solid piece of material.
- The design of the robot should incorporate ease of repairs to benefit the competition.
- Practice with the robot for numerous weeks and in different situations to prep for battle.
- Have lots of spare parts on hand.

ABSTRACT: BATTLEBOT PROJECT MUTHAR; 2002

A Battlebot is a remote controlled robot designed to compete in gladiatorial style combat against competitor robots. Team MET is a group of four seniors who decided to do a group project in order to simulate the working environment seen in industry. Team MET chose to build a middleweight class Battlebot, named *Muthar*, as its group project because it is complex enough for four individuals to work on yet cheap enough for college students to afford. *Muthar* is a fully functional Battlebot that is eligible to compete in middleweight tournaments.

This report addresses *Muthar* as a whole. Topics that will be covered include design, construction, and testing. For this project certain aspects do not need to be considered such as commercial standards. Battlebots Inc. has clearly defined all necessary standards regarding the construction of entrants to their competition. Therefore external industry standards that might apply if the project were designed commercially will not be considered. The body of this document is separated into four sections: Design, Manufacturing, Testing, and Management. The report concludes with recommendations for further product development and conclusions on the entire project.

Muthar was divided into four areas of design. These areas were Locomotion, Offense, Defense, and Chassis. The highest governing factor in design of the four systems was the Battlebots Inc. Technical Regulations. These regulations dictate permissible materials and safety regulations used for competition. Team MET determined other criteria used in design after researching Battlebots *Muthar* may potential see in competition.

Testing showed that *Muthar* was capable of pushing, lifting, holding, and ejecting a 150 lb test sled. Muthar maintained continuous motion for three (3) minutes. *Muthar*'s armor was able to withstand a dynamic impact of a simulated Battlebot. Muthar was also able to rectify itself when placed on its top.

Muthar will be entered into Season 6.0 of the Battlebot tournament. Team MET concluded team projects in the future should start the design process sooner than individual projects. In addition, team projects should span multiple class levels to maintain project expertise within the department.

BattleBots: Project Muthar

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Garrett, Robert; Jason Heuker, Karen Rangi, Nathan Wright. Battlebots: Project Muthar. OMI College of Applied Science, University of Cincinnati. 2002. 10/1/07

INTERNET RESEARCH

Ankle Biter from BattleBots Project Muthar report

- Angled design for flipping bots
- Two wheeled
- Buzz saw weapon
- Hard to flip
- Chain drive

- Hard to control
- Not very stable with only 2 wheels.
- Exposed wheels
- Pneumatic tires

Windchill from BattleBots Project Muthar report

- Four wheels
- Short wheelbase
- Spiked weapon
- Solid tires
- If flipped can be run upside down

- Easy to flip
- Exposed wheels
- Doesn’t look as if it will do lots of damage
- Short wheelbase

 Bad Attitude from BattleBots Project Muthar report • Four wheels • Heavy Duty • Basic wedge design • Protected tires • Flips other bots with wedge	If flipped no rectification Doesn’t look as if it will do lots of damage only flips other bots

 Spare parts from BattleBots Project Muthar report • Two wheels • Spinning weapon (cutting damage) • Chain drive • Maneuverable	• If flipped no rectification (may run upside down) • Doesn’t look to be heavily armored

 Garm from BattleBots Project Muthar report • Four wheels • Spinning weapon (cutting damage) • Protected wheels	• If flipped no rectification (may run upside down) • Doesn't look to be heavily armored

 Nibbler from BattleBots Project Muthar report • Protected wheels • Grasper arm • Easily built	• Easily flipped • Weapon not strong

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http://www.battlebots.com/meet_the_robots3/meet_robot_specs.asp?id=531
Battlebots.com 120 lb robot class

This battlebot is classified as a "flipper bot" which means that its primary form of attack is to flip its opponent and disable it.

- Pneumatic flipper
- 3000lbs of flipping force
- 115lb total weight
- Simple yet proven design

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- Inflatable tires – prone to damage
- If robot is flipped, it cannot run upside down
- Weapon is ineffective if battling robot that is duel sided

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http://images.google.com/imgres?imgurl=http://www.robotcombat.com/images/warhead_hole1.jpg&imgrefurl=http://www.robotcombat.com/nightmare_sf02.html&h=542&w=720&sz=64&hl=en&start=10&um=1&tbnid=riOYaG4qa0QwJM:&tbnh=105&tbnw=140&prev=/images%3Fq%3Dbattlebot%2Bwarhead%26svnum%3D10%26um%3D1%26hl%3Den%26sa%3DG
Robot Combat.com

This is classified as a "spinner bot". Won many competitions. Unique design

- High speed, high inertia spinning weapon
- Actuated arms for flipping back over
- Highly destructive

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- Extremely complex – lots can go wrong
- Slow moving, lacks maneuverability
- Gyroscopic force tends to flip robot

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www.robotcombat.com/micronightmare.html
Robot Combat.com

Team nightmare's robot has a unique weapon. Their weapon is a 15 inch diameter stainless steel blade that spins at high speeds to damage their opponent.

- High speed cutting action weapon
- Can cause lots of damage when attacked correctly
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- Weapon highly vulnerable for damage from side impacts
- Drive belt for weapon is exposed which could cause it to snap during combat
- High center of gravity, easily flipped
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APPENDIX B – SURVEY RESULTS

SURVEY

CAS BattleBot

We are a group of seniors from the University of Cincinnati studying Mechanical Engineering Technology. We are developing a BattleBot to compete at the 2008 BotsIQ competition. Please take a moment to review the following survey and in your best opinion, rank the importance of each item.

A total of 13 completed surveys were obtained from various builders and competitors with numerous years of experience.

Please rank each category. Once you have ranked the category rank each rank each subcategory within the main category.

Main Category (1-least important, 4-most important)

• Offensive Capabilities	2.385	1 (4) 2 (2) 3 (5) 4 (2)
• Defensive Capabilities	2.615	1 (3) 2 (3) 3 (3) 4 (4)
• Maneuverability and Control	3.154	1 (1) 2 (2) 3 (4) 4 (6)
• Maintenance	1.846	1 (5) 2 (6) 3 (1) 4 (1)

2.385 **Offensive Capabilities (1-least important, 5-most important)**

• Weapon causes extensive damage to	3.769	1 (2) 2 (1) 3 (1) 4 (3) 5 (6)
• Weapon will not stall.	3.385	1 (1) 2 (1) 3 (5) 4 (4) 5 (2)
• Weapon operates seperately from all other systems	2.615	1 (3) 2 (4) 3 (2) 4 (3) 5 (1)
• Weapon system is interchangable.	2.000	1 (6) 2 (5) 3 0 4 0 5 (2)
• Weapon system is repairable.	3.231	1 (1) 2 (2) 3 (5) 4 (3) 5 (2)

2.615 **Defensive Capabilities (1-least important, 4-most important)**

• Inversion is non-disabling.	3.077	1 (3) 2 0 3 (3) 4 (7)
• Armor capable of sustaining/deflecting	3.000	1 0 2 (3) 3 (7) 4 (3)
• Armor is modular.	2.385	1 0 2 (10) 3 (1) 4 (2)
• Frame is modular.	1.538	1 (10) 2 0 3 (2) 4 (1)

3.154 **Maneuverability and Control (1-least important, 6-most important)**

• Able to keep opponent in front at all times.	3.385	1 (1) 2 (1) 3 (5) 4 (4) 5 (2) 6 0
• Control system is adaptable.	2.615	1 (3) 2 (5) 3 (3) 4 0 5 0 6 (2)
• Robot should be easy and simple to control.	4.308	1 (1) 2 (1) 3 0 4 (5) 5 (3) 6 (3)
• Drive system able to move opponent.	3.692	1 0 2 (2) 3 (4) 4 (3) 5 (4) 6 0
• Power Supply is able to last 3 minutes.	4.615	1 (1) 2 (2) 3 (1) 4 0 5 (2) 6 (7)
• Electrical systems are redundant.	2.154	1 (8) 2 (2) 3 0 4 0 5 (2) 6 (1)

1.846 **Maintenance (1-least important, 4-most important)**

• Repairs completed quickly and easily.	2.769	1 (2) 2 (3) 3 (4) 4 (4)
• Battery supply charges in 20 minutes.	2.154	1 (5) 2 (4) 3 (1) 4 (3)
• Battery supply is easily replaced.	2.769	1 (2) 2 (4) 3 (2) 4 (5)
• Parts are easily removed.	2.308	1 (4) 2 (2) 3 (6) 4 (1)

Thank you for taking the time to fill out the survey, we appreciate your time and effort.

-University of Cincinnati College of Applied Science BattleBot Team

SURVEY RESULTS ANALYSIS

Survey Raw Data Frequencies ()												Total	Mean
1	(4)	2	(2)	3	(5)	4	(2)					13	2.385
1	(3)	2	(3)	3	(3)	4	(4)					13	2.615
1	(1)	2	(2)	3	(4)	4	(6)					13	3.154
1	(5)	2	(6)	3	(1)	4	(1)					13	1.846
1	(2)	2	(1)	3	(1)	4	(3)	5	(6)			13	3.769
1	(1)	2	(1)	3	(5)	4	(4)	5	(2)			13	3.385
1	(3)	2	(4)	3	(2)	4	(3)	5	(1)			13	2.615
1	(6)	2	(5)	3	(0)	4	(0)	5	(2)			13	2.000
1	(1)	2	(2)	3	(5)	4	(3)	5	(2)			13	3.231
1	(3)	2	(0)	3	(3)	4	(7)					13	3.077
1	(0)	2	(3)	3	(7)	4	(3)					13	3.000
1	(0)	2	(10)	3	(1)	4	(2)					13	2.385
1	(10)	2	(0)	3	(2)	4	(1)					13	1.538
1	(1)	2	(1)	3	(5)	4	(4)	5	(2)	6	(0)	13	3.385
1	(3)	2	(5)	3	(3)	4	(0)	5	(0)	6	(2)	13	2.615
1	(1)	2	(1)	3	(0)	4	(5)	5	(3)	6	(3)	13	4.308
1	(0)	2	(2)	3	(4)	4	(3)	5	(4)	6	(0)	13	3.692
1	(1)	2	(2)	3	(1)	4	(0)	5	(2)	6	(7)	13	4.615
1	(8)	2	(2)	3	(0)	4	(0)	5	(2)	6	(1)	13	2.154
1	(2)	2	(3)	3	(4)	4	(4)					13	2.769
1	(5)	2	(4)	3	(1)	4	(3)					13	2.154
1	(2)	2	(4)	3	(2)	4	(5)					13	2.769
1	(4)	2	(2)	3	(6)	4	(1)					13	2.308

C1	Sxx	C1 x Sxx .	Weighted Value to be submitted in QFD
23.8%	25.1%	6.0%	3.72
23.8%	22.6%	5.4%	3.34
23.8%	17.4%	4.2%	2.58
23.8%	13.3%	3.2%	1.98
23.8%	21.5%	5.1%	3.19
26.2%	30.8%	8.0%	5.00
26.2%	30.0%	7.8%	4.88
26.2%	23.8%	6.2%	3.88
26.2%	15.4%	4.0%	2.50
31.5%	16.3%	5.1%	3.19
31.5%	12.6%	4.0%	2.47
31.5%	20.7%	6.5%	4.06
31.5%	17.8%	5.6%	3.48
31.5%	22.2%	7.0%	4.35
31.5%	10.4%	3.3%	2.03
18.5%	27.7%	5.1%	3.18
18.5%	21.5%	4.0%	2.47
18.5%	27.7%	5.1%	3.18
18.5%	23.1%	4.3%	2.65

SAMPLE CALCULATION

$$C_1 = \frac{main\ category\ mean}{sum\ of\ main\ category\ means} \quad S_{11} = \frac{sub-category\ mean}{sum\ of\ sub-category\ means}$$

$$C_1 \frac{2.385}{10} = 23.8\% \qquad S_{11} = \frac{3.769}{15} = 25.1\% \qquad S_{11} \times C_1 = 6\%$$

$$Weighted\ Value\ to\ be\ submitted\ in\ QFD = \left(\frac{S_{11} \times C_1}{Largest\ \ S_{11} \times C_1\ percentage}\right) \times 5$$

$$Weighted\ Value\ to\ be\ submitted\ in\ QFD = \left(\frac{6\%}{8\%}\right) \times 5 = 3.7$$

APPENDIX C – BATTLEBOT QFD

9=Strong 3=Moderate 1=Weak	delivered by weapon	available to rotating components	Number of independent subsystems	Number of back-up components	Time it takes to fully change out components	Number of sides robot can operate on	Properties of Materials	Number and size of robot components	Turning speed of robot	Programability	Friction coefficient of tires	Battery rating	Time required to completely charge battery	Customer Importance	Relative Weight
Offensive Capabilities															
Weapon Causes extensive damage to opponent	9	9					3					3		3.72	0.0599
Weapon will not stall	3	9										3		3.34	0.0538
Weapon operates seperately from all other components			9	1		1								2.58	0.0415
Weapon system is interchargable			3	9	3									1.98	0.0319
Weapon system is repairable				3	9		9	3						3.19	0.0513
Defensive Capabilities															
Inversion is non-disabling						9				3				5	0.0805
Armor capable of sustaining deflecting damage							9	3						4.88	0.0785
Armor is Modular			3	9	9			3						3.88	0.0624
Frame is Modular			3	9	9			3						2.5	0.0402
Maneuverability and Control															
Able to keep opponent in front at all times		3							9	3	1			3.19	0.0513
Control system is adaptable			3							9				2.47	0.0398
Robot should be easy and simple to control									3	9	3			4.06	0.0653
Drive system is able to move opponent		9									9	3		3.48	0.0560
Power supply is able to last 3 minutes		3										9	3	4.35	0.0700
Electrical systems are redundant			9	3				1						2.03	0.0327
Maintenance															
Repairs completed quickly and easily			3	3	9	9	3	3						3.18	0.0512
Battery supply charges in 20 minutes												9	9	2.47	0.0398
Battery supply is easily replaced				3	9			3						3.18	0.0512
Parts are easily removed			9	3	9			3						2.65	0.0427
Absolute Importance	0.70	1.89	1.73	1.94	2.79	1.23	1.50	1.17	0.66	1.34	0.75	1.50	0.57	62.13	1
Relative Importance	0.0394	0.1065	0.0973	0.1092	0.1570	0.0691	0.0846	0.0656	0.0371	0.0755	0.0423	0.0843	0.0320		

APPENDIX D – BUDGET

Trip Expenses (Before Donations)	
Competition Entry fee	$500.0
Hotel Expense - 2 rooms @ 150/night -5 nights	$1,500.0
Rental Van + Insurance	$500.0
Gas @ 3.00/gal assumed 2400 miles @ 10mpg	$840.0
Team shirts	$250.0
Total Trip Expenses	$3,590.0

Trip Expenses (Before Donations)	
Competition Entry fee	$500.0
Hotel Expense - 2 rooms @ 150/night -5 nights	$1,500.0
Rental Van + Insurance	$500.0
Gas @ 3.00/gal assumed 2400 miles @ 10mpg	$840.0
Team shirts	$250.0
Total Trip Expenses	$3,590.0

BattleBot Expenses (Before Donations)	
Drive Train (Tim Meyer)	
Batteries (4 @ $172/pack)	$688.0
Battery Chargers (2 @ $100)	$200.0
Remote control	$300.0
Speed Controllers (4 @ $215)	$860.0
Gear Boxes (3 @ $450)	$1,350.0
Drive motors (4 @ $315)	$1,260.0
Drive wheels	$100.0
Fasteners	$30.0
Bearings	$50.0
Motor Mounts	$30.0
Axle Material	$15.0
Axle Fabrication	$30.0
Drive Train Total	$4,913.0
Main Weapon (Jake Barnhorst)	
Weapon Motor	$750.0
Weapon Motor Mount Material	$15.0
Weapon Motor Mount Fabrication	$30.0
Weapon sheaves and belts	$50.0
Weapon material	$50.0
Weapon fabrication	$150.0
Batteries (4 @ $172/pack)	$688.0
Speed Controllers 3 @ $215	$645.0
Bearings	$50.0
Fasteners	$30.0
Wiring	$50.0
Main Weapon Total	$2,508.0
Frame (John Taphorn)	
Chassis material	$300.0
Chassis Fabrication	$100.0
Fasteners	$20.0
Frame Total	$420.0
Armor/Defense (Dave Bailey)	
Armor Material	$8,000.0
Fasteners	$30.0
Titanium (36"x24")	$197.1
Armor/Defense Total	$8,227.1
Misc.	
Electrical wiring (Power System Wiring, switches and terminals)	$150.0
Misc. Total	$150.0
Total Robot Cost	$16,218.1
Total Project Cost	$19,808.1

BattleBot Expenses (After Donations)	
Drive Train (Tim Meyer)	
Batteries (4 @ $172/pack)	$688.0
Battery Chargers (2 @ $100)	$200.0
Remote control	$300.0
Speed Controllers (4 @ $215)	$860.0
Gear Boxes (3 @ $450)	$1,350.0
Drive motors (4 @ $315)	$1,260.0
Drive wheels	$100.0
Fasteners	$30.0
Bearings	$50.0
Motor Mounts	$30.0
Axle Material	$15.0
Axle Fabrication	$30.0
Drive Train Total	$4,913.0
Main Weapon (Jake Barnhorst)	
Weapon Motor	$750.0
Weapon Motor Mount Material	$15.0
Weapon Motor Mount Fabrication	N/A
Weapon sheaves and belts	$50.0
Weapon material	$50.0
Weapon fabrication	N/A
Batteries (4 @ $172/pack)	$688.0
Speed Controllers 3 @ $215	$645.0
Bearings	$50.0
Fasteners	$30.0
Wiring	$50.0
Main Weapon Total	$2,328.0
Frame (John Taphorn)	
Chassis material	$300.0
Chassis Fabrication	$100.0
Fasteners	$20.0
Frame Total	$420.0
Armor/Defense (Dave Bailey)	
Armor Material	N/A
Fasteners	$30.0
Titanium (36"x24")	$197.1
Armor/Defense Total	$227.1
Misc.	
Electrical wiring (Power System Wiring, switches and terminals)	$150.0
Misc. Total	$150.0
Total Robot Cost	$8,038.1
To Date Received Cash Donation as of 11/12	$5,600.0
Total "Out of Pocket" Project Cost	$6,028.1

Company	Donation	Amount	Donation Received?
Avenue Fabricating	cash	$4,000.00	Yes
Makino	cash	$2,500.00	Yes
RA Jones	cash	$2,000.00	Yes
Duke Energy	cash	$500.00	Yes
F & M Mafco	cash	$100.00	Yes
Aeronca Inc.	Titanium Honeycomb armor and other sheet material	N/A	Yes
UGS	Solid Edge Version 20	N/A	Yes
Meritor Webco	Tools and miscellaneous equipment.	N/A	Yes
UGS/Engineering Methods	Solid Edge Training		Yes
Solid Works EDU	Solid Works and Cosmos Software	N/A	Yes
University of Cincinnati Mechanical Engineering Technology Department	Will cover complete competition and travel expenses including but not limited to hotel, entry fee, and transportation costs.	$4,000.00	No
Tische Enviromental	cash	$500.00	No
	Total Cash Donation:	**$13,600.00**	

Sponsor	Pledge Statement
University of Cincinnati Mechanical Engineering Technology Department	Jake Barnhorst, This email is to confirm that the MET Department will cover the expenses of the team trip to Miami for the National Competition. Good Luck! Muthar Al-Ubaidi Department Head
Tisch Environmental	Jonathan Taphorn, Please use this email as a commitment on behalf of Tisch Environmental to sponsor the University of Cincinnati CAS effort to compete in Battlebot competition in the amount of $500. Please provide date, payee and mailing address for the donation. Thanks, John Tisch

APPENDIX E – FRAME SCHEDULE

Quarter	Fall Quarter							Winter Break			
Week Number	5	6	7	8	9	10	Exams				
Dates	10/21-10/27	10/28-11/3	11/4-11/10	11/11-11/17	11/18-11/24	11/25-12/1	12/2-12/8	12/9 - 12/15	12/16 - 12/22	12/23-12/29	12/30 - 1/5
weighted objective method					19-Nov						
proof of design statement						30-Nov					
proof of design agreement						30-Nov					
design of frame completed								13-Dec			
design freeze								14-Dec			
order material for frame and motor mounts											
manufacturing of frame											
rough cut frame pieces											
finish frame Pieces											
assembly of robot frame											
assembly of robot											
testing/troubleshooting/competition practice											
oral design presentation											
design report due											
drive to competition											
competition											
drive home from competition											
construct tech expo display											
tech expo											
Final Oral Presentation											
Final Project Due											

Quarter	Winter Quarter											S. Break
Week Number	1	2	3	4	5	6	7	8	9	10	Exams	
Dates	1/6-1/12	1/13-1/19	1/20-1/26	1/27-2/2	2/3-2/9	2/10-2/16	2/17-2/23	2/24-3/1	3/2-3/8	3/9-3/15	3/16-3/22	3/23-3/29
Task												
weighted objective method												
proof of design statement												
proof of design agreement												
design of frame completed												
design freeze												
order material for frame and motor mounts		17-Jan										
manufacturing of frame			21-Jan									
rough cut frame pieces			20-Jan	30-Jan								
finish frame Pieces				30-Jan								
assembly of robot frame					3-Feb							
assembly of robot												
testing/troubleshooting/competition practice												
oral design presentation										14-Mar		
design report due										14-Mar		
drive to competition												
competition												
drive home from competition												
construct tech expo display												
tech expo												
Final Oral Presentation												
Final Project Due												

Quarter	Spring Quarter									
Week Number	1	2	3	4	5	6	7	8	9	10
Dates	3/30-4/5	4/6-4/12	4/13-4/19	4/20-4/26	4/27-5/3	5/4-5/10	5/11-5/17	5/18-5/24	5/25-5-31	6/1-6/7
Task										
weighted objective method										
proof of design statement										
proof of design agreement										
design of frame completed										
design freeze										
order material for frame and motor mounts										
manufacturing of frame										
rough cut frame pieces										
finish frame Pieces										
assembly of robot frame										
assembly of robot										
testing/troubleshooting/competition practice					28-Apr					
oral design presentation										
design report due										
drive to competition					29-Apr					
competition					30-Apr	4-May				
drive home from competition						5-May				
construct tech expo display						7-May		21-May		
tech expo								22-May		
Final Oral Presentation										30-May
Final Project Due										30-May

APPENDIX F – FRAME DESIGN CALCULATIONS

MATERIAL SELECTION CALCULATION

Applied Strength of Material, pg 95

Stress analysis: $\theta = \frac{f}{A}$

Area=.5in X 4 in

Area= $2in^2$

F= 13000 lbf

N=12

$$\theta = \frac{13000\ lbf}{2in^2}$$

$$\theta = 6500\ psi$$

6500=$\frac{su}{12}$

Su=78000 psi ultimate strength required

STRESS IN HOLE CALCULATIONS

7075-T6 83,000 psi ultimate stress

θd = $\frac{83,000}{12}$

θ d= 6917 psi max psi

θd =$\frac{kt \times 6 \times Mw}{(w^3 \times d^3)t}$

Kt=1 from chart c pg 657

T=.5 in.

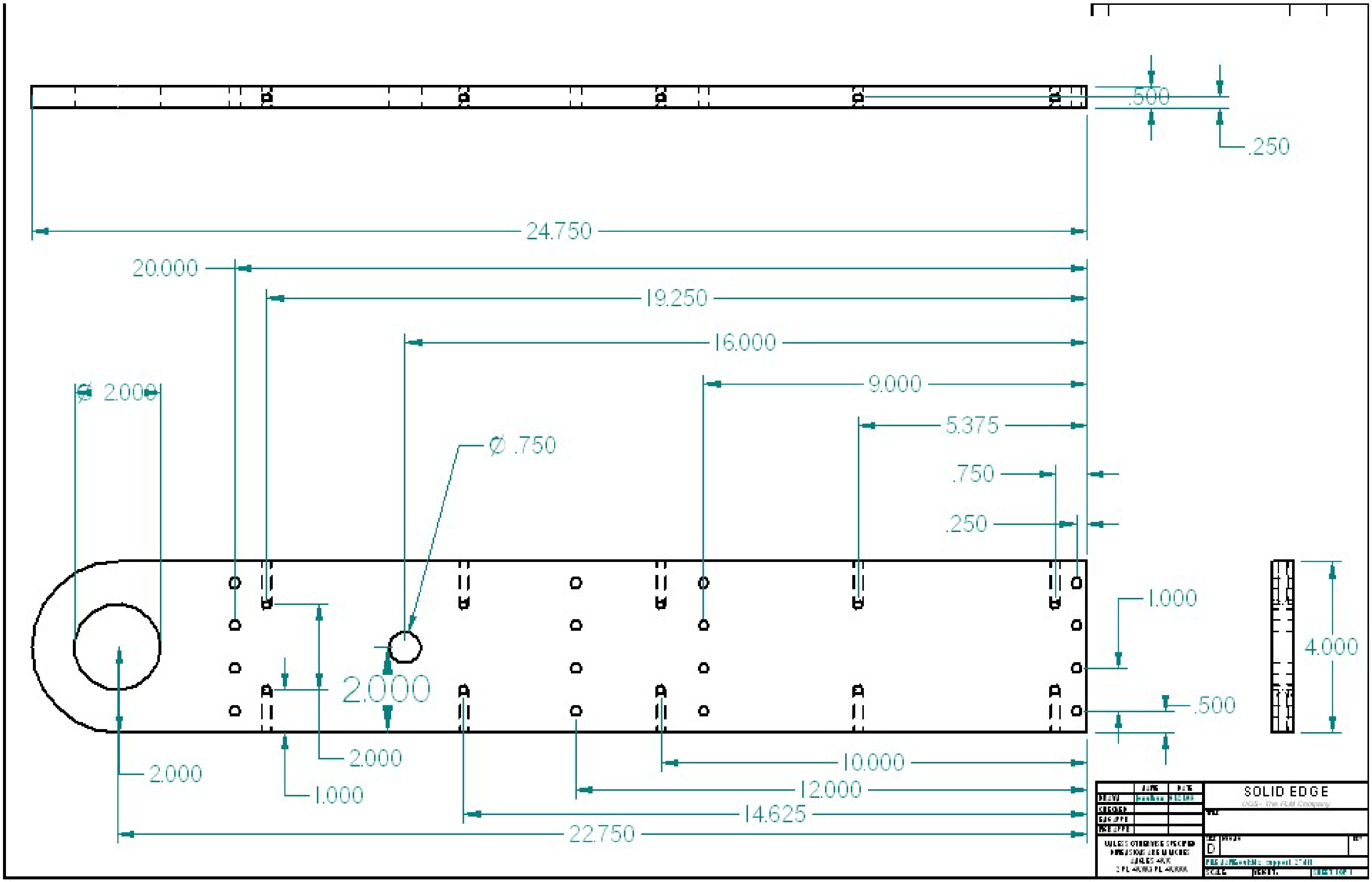
W=4 in.

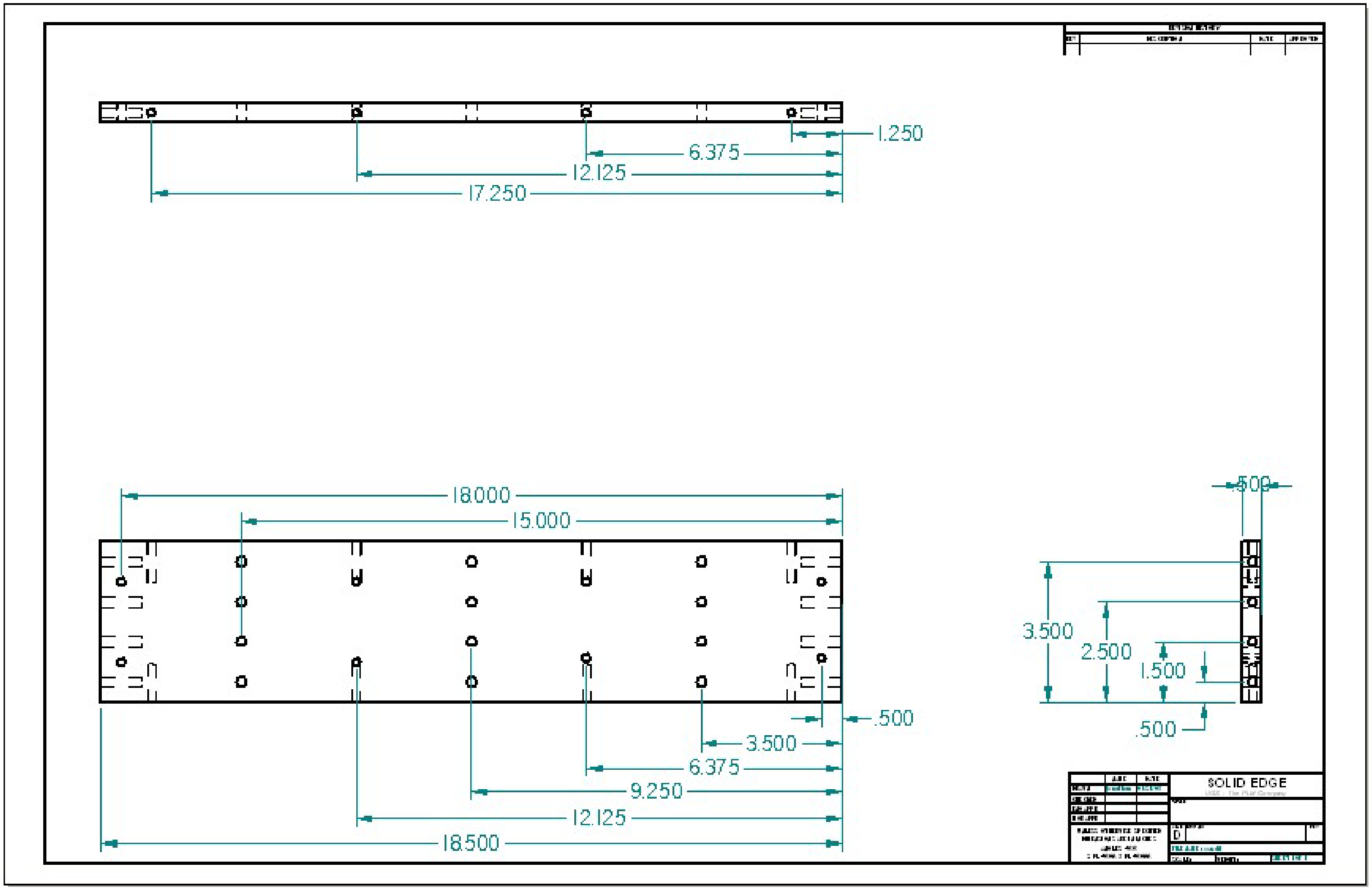
D=2 in.

θ =$\frac{1 \times 6 \times (\frac{13000}{2\Pi})^4}{(4^3 \times 2^3).5}$

θ= 1917 psi

APPENDIX G – FRAME DRAWINGS

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6.375
12.125
17.250
18.000
15.000
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3.500
6.375
9.250
12.125
18.500
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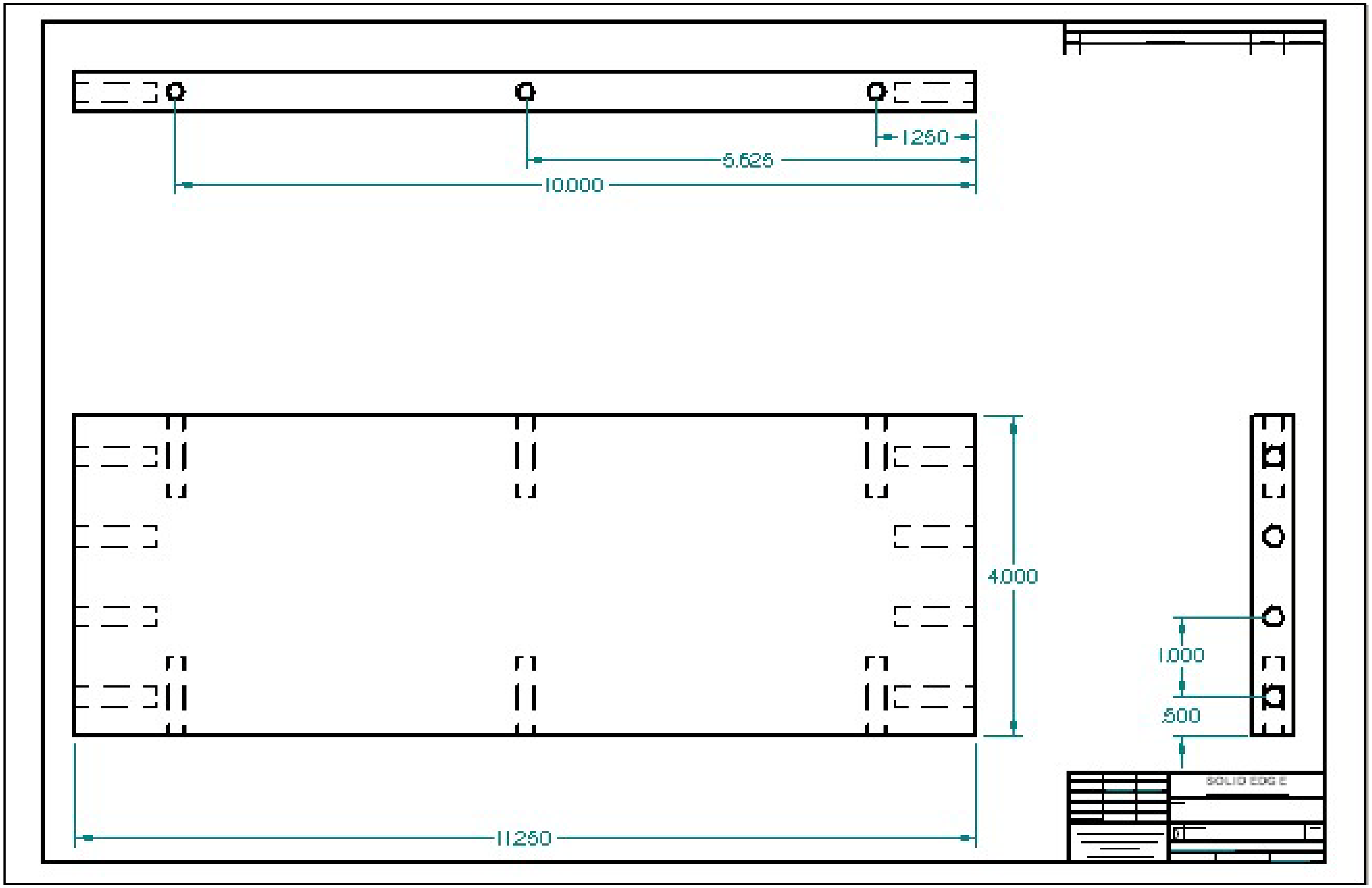
3.500
2.500
1.500
.500
SOLID EDGE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4.000
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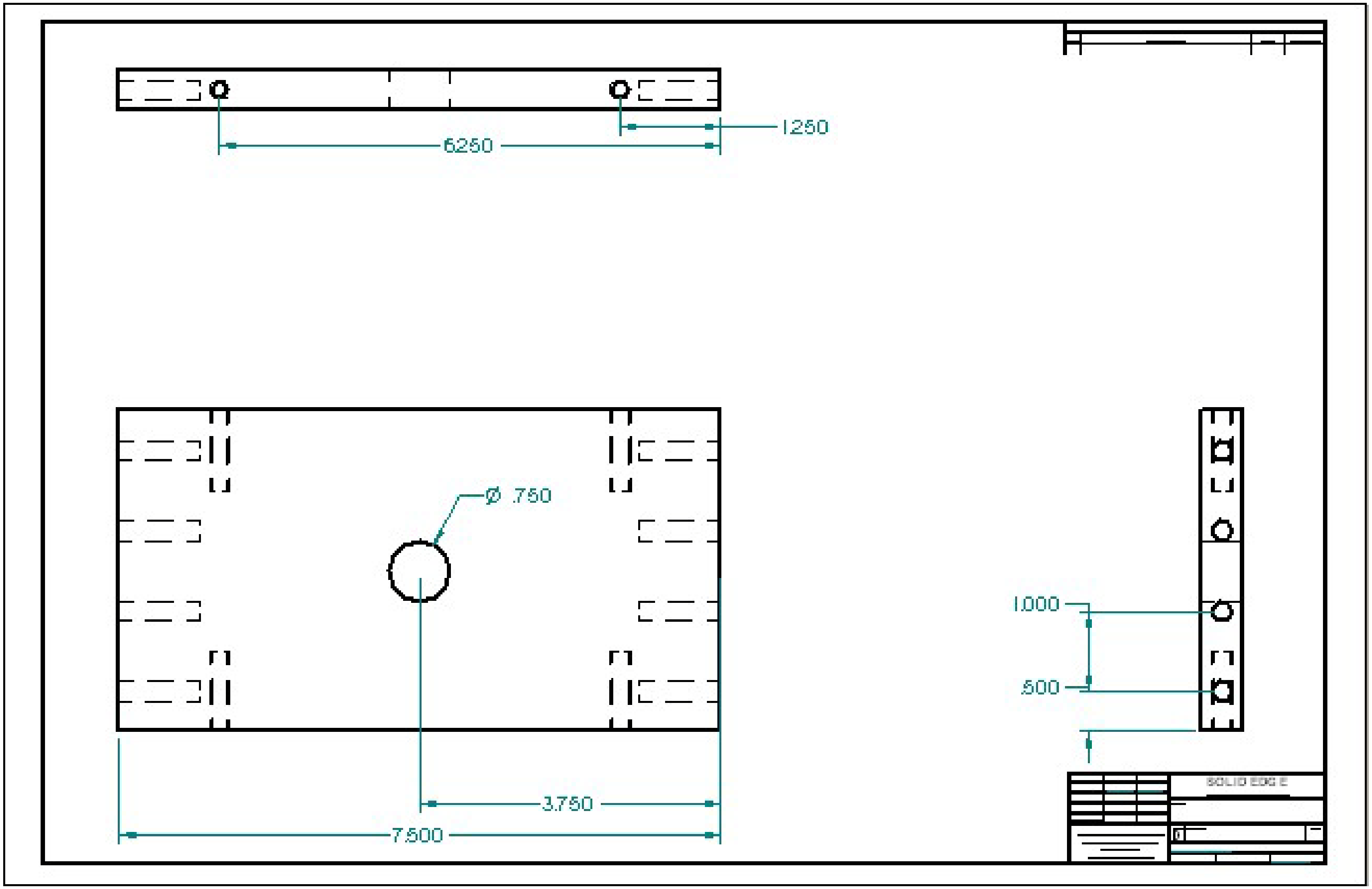
11.250
SOLID EDGE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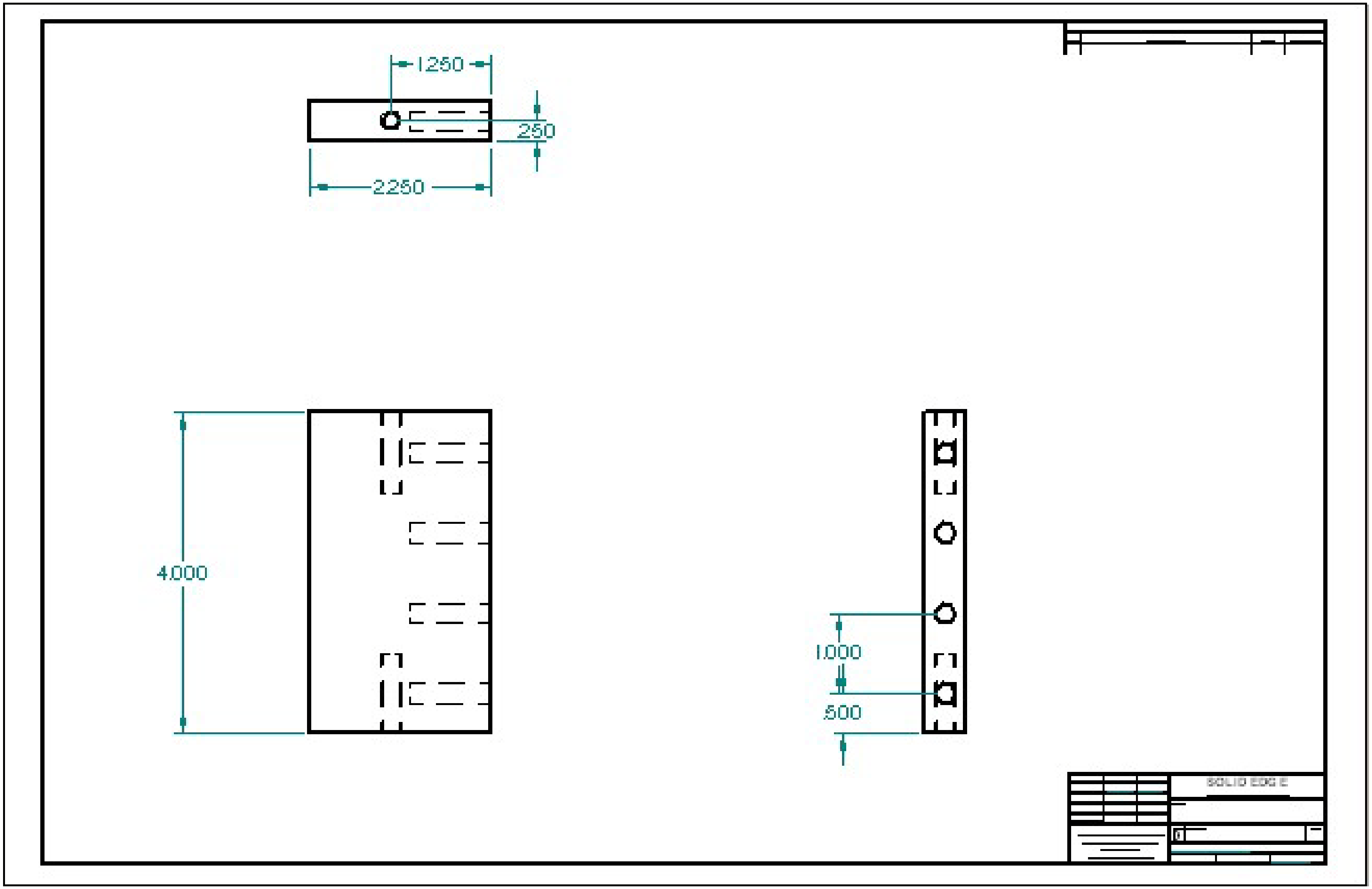
6.250
Ø .750
1.000
.500
3.750
7.500
SOLID EDGE



1.250
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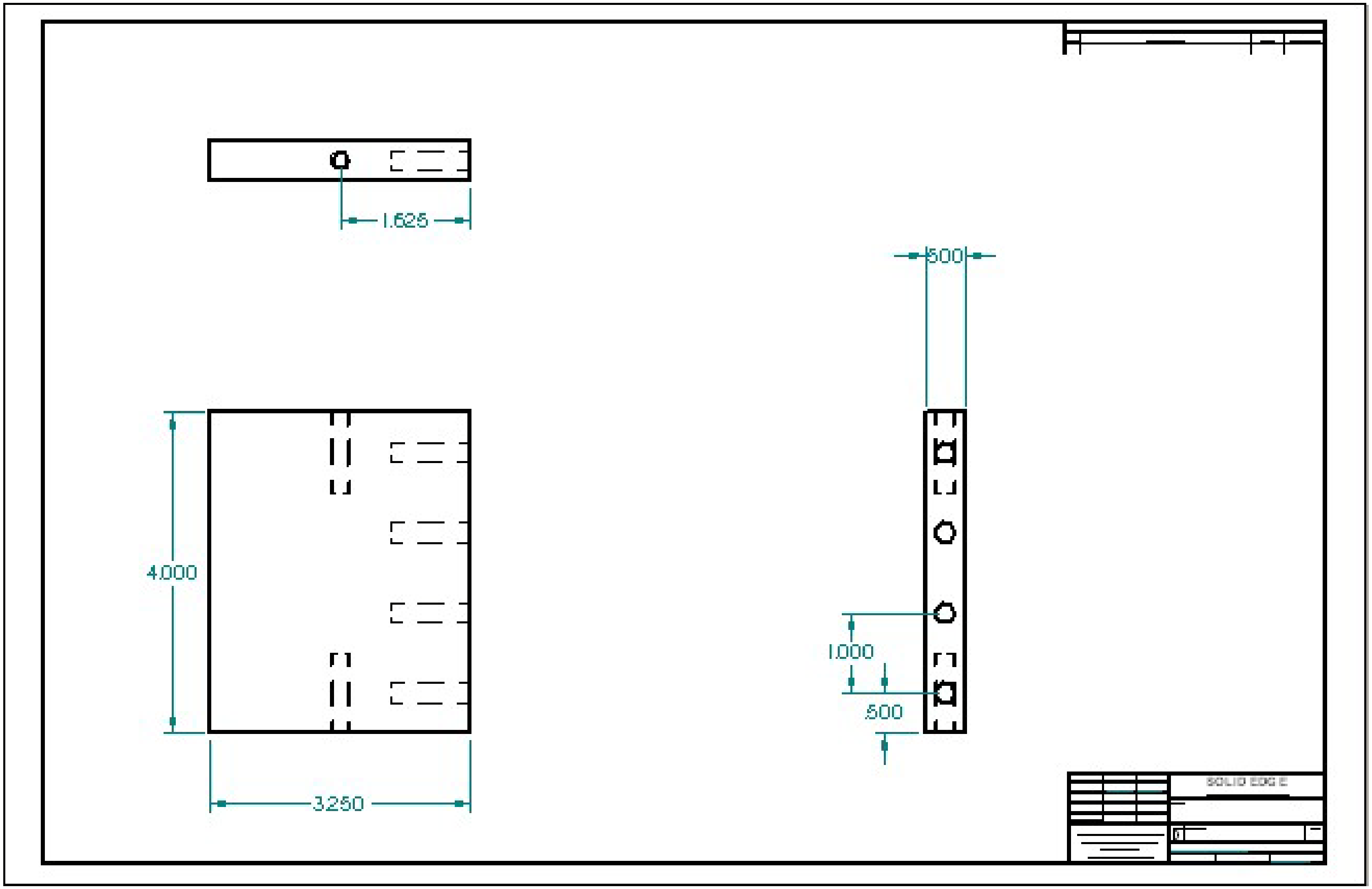
2.250
4.000
1.000
.500
SOLID EDGE


1.625
.500
4.000
1.000
.500
3.250
SOLID EDGE