2008 CAS BattleBot

by

DAVID BAILEY

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Signature of Author ____________________
Mechanical Engineering Technology

Certified by ____________________
Janet Dong, PhD,
Thesis Advisor

Accepted by ____________________
Muthar Al-Ubaidi, PhD, Department Head
Mechanical Engineering Technology

University of Cincinnati
College of Applied Science
Middleweight BattleBot – Defense and Armor
David A. Bailey

ABSTRACT

The University of Cincinnati's College of Applied Science (CAS) has no competitive representation for BattleBot competitions. A BattleBot is a robot that competes against other robots with the intent to disable its opponent. Designing and constructing a BattleBot for competition will lay a foundation for future Mechanical Engineering Technology Students from CAS to compete in other national competitions. When designing the BattleBot one of the most important attributes is the ability to deflect and absorb energy from the opposing BattleBot, without becoming disabled. In order to build a competitive BattleBot research was conducted to identify the best material for armor, as well as, defensive attributes that are desirable for a BattleBot. By using a titanium honeycomb shell for the armor, the bot was able to have high strength armor, while having a very low weight. The BattleBot competed in the BotsIQ Spring 2008 national competition in Miami Beach, Florida. The 2008 CAS BattleBot team was awarded "1st Place, 120lb Collegiate Division," "Best Engineered," and "Best Driver."

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INTRODUCTION

Currently, the University of Cincinnati's College of Applied Science (CAS) has no competitive representation for BattleBot competitions on the national level. The BotsIQ national competition for collegiate and high school levels was held in Miami Beach, Florida in the spring of 2008 and would be an opportunity for a team to represent CAS (1). The team built and competed in the 120lb weight class collegiate competition.

Designing and constructing a sturdy, competitive BattleBot for this competition was done in order to lay a foundation for future Mechanical Engineering Technology (MET) students and for the college. The CAS BattleBot team consisted of Dave Bailey - Defense and Armor, Jake Barnhorst - Main Weapon, Tim Meyer - Drive Train and Control, and John Taphorn - Chassis. This report focuses on the armor and defensive capabilities of the BattleBot.

The primary defense of the BattleBot is a titanium honeycomb shell. BattleBots compete one on one and the winner is determined by the amount of damage inflicted to the opponent. By using a titanium honeycomb shell, the amount of transferable energy from the opponent will be minimized.

A set of objectives were developed in order to test the capabilities of the CAS BattleBot. To prove these objectives a combination of observations during the National Competition as well as controlled laboratory style testing were documented and recorded.

The preliminary budget for the armor of the BattleBot was an estimated $8227 out of a total project budget of $20,000. The sponsors have donated cash funding in the amount of $13,600 as well as various amounts of material and service donations totaling approximately $6400. The sponsors have provided all of the projected costs for the project.

RESEARCH

When researching ideas for the armor of the BattleBot, the internet and interviews with experts in the area proved to be the most beneficial resource. In the internet research section of Appendix A, five designs are shown which give a good representation of the different designs of armor used during tournaments. The best way to research what shape of and material of armor should be used was to research the types and styles of weapons that the BattleBot would be facing in the tournament. By doing this the armor can be designed to defend against a majority of weapon designs and tactics. The weapon types in this section are classified into three categories: flippers, spinners and dead blows. A flipper BattleBot is one whose primary form of attack is to flip its opponent on its back disabling it from competition. Figure 1 shows a typical Flipper Bot (2). The mechanical arm on the front of the robot uses pneumatics or a

Figure 1 - Flipper Bot

high torque motor to create a strong vertical thrust which is capable of throwing the opponent up into the air. Flipping an opponent over usually disables robots which are not capable of driving upside down. In order to defend against a Flipper Bot, the CAS Battlebot's armor must have minimal clearance with respect to the ground, and also be able to either right itself if inverted, or operated when inverted.

A Spinner Bot is one that uses a high speed spinning weapon to deliver repeated blows to its opponent using inertia. In Figure 2, three common forms of spinning weapons are seen (3). Each of the designs has a rotating mass on the front end of the robot. The purpose of this rotating mass is to use the rotational inertia created by the spinning mass to transfer a massive blow to the competitor. Large forces are usually delivered by these types of weapons and when designed properly they can potentially create the most damage of any of the weapon types. The large amount of force delivered by these weapons makes this a hard Bot to defend against. However, by developing armor with an ability to dissipate or redirect a large amount of energy, the damage sustained to the BattleBot will be minimal.

Figure 2 - Spinner Bots

Another type of BattleBot weapon is the dead blow. A dead blow BattleBot uses a heavy solid object attached to a mechanical arm which swings back and forth hitting its opponent with the intent of damaging it. Dead blow bots can utilize tremendous amounts of force to either pierce through or crush the opposing robot's armor and damage its internals and possibly disable it. The BattleBot named "Dead Blow" can be seen in Figure 3 (4). Dead blow type BattleBots are difficult to defend against because they work on the principal of transferring kinetic energy in a single blow; however, they are hard to control, and the weapon can be deflected through armor design or maneuverability.

Figure 3 - Dead Blow Bot

On September 14th, 2007 the CAS team went to the home of a BattleBot Champion and builder of two BattleBots, Matt Lukes. At his home in Erlanger, Kentucky, Matt showed his championship BattleBot Hworf. The interview can be found in the Appendix A. Hworf seen in Figure 4 (5) is classified as a spinner BattleBot because it uses a heavy solid steel manufactured blade which spins at 1300 rpms. The team witnessed the main weapon of Hworf in person and through watching recorded DVD matches to see the full potential of a spinner bot in a match (6). The advice which the team received from Matt through the interview was "The key to winning is spinning" (5). Matt explained that in over seven years of experience, the robots which cause the most damage in his opinion are the Spinning Bots. Matt also recommended designing the armor to be easily replaceable. Being able to easily replace the armor is beneficial because the armor receives the most damage in battle and will need to be replaced often. Also the frame needs to be modular, with the ability to replace individual components, so that if one is damaged a replacement can be fitted to the Bot within 20 minutes.

Figure 4 - "Hworf" Matt Lukes

ANALYSIS OF RESEARCH

The features of the armor developed for the survey are listed in Table 1 and result in the objectives for the armor.

Armor Features	Description
Inversion is non-disabling	If the Battlebot is flipped, it can either operate upside down, or right itself
Armor is capable of sustaining/deflecting damage	The armor will be able to completely absorb or redirect the energy of an opponent's attack
Armor is modular	All armor pieces can be easily replaced
Frame is modular	All frame pieces can be easily replaced

Table 1 Armor Features

DEFENSIVE ARMOR ANALYSIS

In order to gain information on defensive attributes that competitors find necessary a survey was generated and distributed to several BattleBot competitors as well as on internet forums for BattleBot competitors. Table 2 shows the summary of those surveyed and the results pertaining to the armor of the BattleBot.

Note all values on a scale of 1-5 with 1 being the least important and 5 being the most important.

2.615	Defensive Capabilities	Averages from Frequencies
	• Inversion is non-disabling	3.077
	• Armor is capable of sustaining/ deflecting damage	3.000
	• Armor is modular	2.358
	• Frame is modular	1.538

Table 2 Defensive Capabilities Survey Results Summary

The important feature for the armor and defensive capabilities were influenced by thirteen experienced designers, builders, and competitors in the field of BattleBots. The experienced designers and builders concluded that the "Inversion is non-disabling" was the most important feature to have with an average score of 3.077 out of 5 with a relative weight of approximately 8%. The complete project survey can be found in Appendix B. When compared to the three other areas of BattleBot's features, the armor and defensive capabilities was second out of the four with an average score of 2.615 out of 5.

The results for the weighting factor calculations can be found in the Survey Results Analysis of Appendix B. The method used to obtain a useful weighting factor for each subcategory can be found in the Sample Calculations section of Appendix B.

DEFENSIVE CHARACTERISTICS

All characteristics which relate to the Defensive Capability features can be seen in Table 4. Only engineering characteristics with the strongest relationship in each category were listed. At 16% relative importance, the "time it takes to fully change out components" was determined to be the most important characteristic. In Table 3 the engineering characteristics are sorted from having the least relative importance value to the most. The larger the value of relative importance means that those characteristics have a greater effect on customer satisfaction. To view the complete relationship matrix and the QFD see Appendix C.

Features (Customer Requirements)	Engineering Characteristic	Relative importance
Inversion is non-disabling	Number of sides robot can operate on	7%
Armor capable of sustaining deflecting damage	Properties of Materials	8%
Armor is Modular Frame is Modular	Number of independent subsystems	10%
	Number of back-up components	11%
	Time it takes to fully change out components	16%

Table 3 QFD Results

DEFENSE AND ARMOR OBJECTIVES

The objectives for the defense and armor upon completion were the following:

- Armor will be able to sustain a direct hit from an opponent's weapon and still function
- If flipped upside down, the BattleBot will still be able to operate
- Armor will be able to deflect or absorb a majority of the energy from an opponent's attack and allow a minimum of transference to the inner components.
- All repairs to armor can be completed within 20 minutes.
- Robot will be able to drive and maneuver if the armor is penetrated.
- Armor has complete back-up to be changed if damaged.
- All armor pieces can be completely replaced within 20 minutes.

The objectives for the defense were proven primarily through observation during the competition in Miami. For records, each match will be recorded. The objectives for the capabilities "Inversion is non-disabling" and "Armor is capable of sustaining/ deflecting damage" were proven through controlled tests which demonstrated each of the remaining objectives shown in Table 4. The controlled tests were performed in a laboratory setting as described and documented. Tests were conducted on the break down time and reassembly time of the subsystems to test if the armor and frame are of a modular configuration. The research concluded that there are three primary types of BattleBot weapons: Flipper Bots, Spinner Bots, and Dead Blow Bots. Table 5 shows the features developed from the research for a strong competing BattleBot. This resulted in determining that the most important aspect of a BattleBot's defensive capability is to not be disabled by being flipped over (Inversion), with the highest relative weight of 8%. The "time it takes to switch out components" is the most important engineering characteristic relating to the design of the armor and defensive capabilities, having an overall importance rating of 16%.

Features (Customer Requirements)	Feature
Inversion is non-disabling	Bot will operate / right itself when flipped
Armor capable of sustaining deflecting damage	Armor will deflect damage, Bot will not be disabled by direct hit
Armor is Modular Frame is Modular	No component or subsystem will take over the minimum repair time of 20 minutes. Most components will be replaceable without removing multiple subsystems

Table 5 Defense Objectives

Defensive Capabilities	Relative Weight
Inversion is non-disabling	0.080
Armor capable of sustaining deflecting damage	0.079
Armor is Modular	0.062
Frame is Modular	0.040

Table 4 Defense Capabilities Relative Weights

DESIGN

DESIGN ALTERNATIVES

Many alternatives were considered for both the shape of the armor as well as the material of the armor. For the shape of the armor there are three major design styles: rounded or concave, angled, and flat. One of the desired characteristics of the BattleBot that was chosen was the ability to operate when inverted. Maintaining this ability eliminated the option for curved armor. When reviewing angled armor, it was decided that there would be a large gap between the bottom of the BattleBot and the arena floor, allowing the BattleBot to be lifted easily, so flat armor was finally chosen.

For choosing the material for the armor, three materials were researched: aluminum, steel, and titanium. Certain criteria were chosen for the weighted material selection matrix. Focusing on the density (because weight is one of the most important factors), ultimate strength, modulus of elasticity and shear modulus, a β of 0.4, 0.2, 0.2, 0.1, and 0.1 respectively, a material of titanium was chosen for the armor. Table 6 shows the associated values and calculations for the selection of titanium.

Table 6 Weighted Decision Matrix

[redacted]

LOADING CONDITIONS / DESIGN ANALYSIS

In order to analyze the design of the honeycomb armor it was assumed that the frame allows the armor to act as a simple beam in loading. Assuming that it acts as a simple beam simplifies the force calculations for the armor. In order to find the maximum amount force transmitted to the frame, the longest unsupported section (6.5”) of the armor was used in the calculations. Since no definitive numbers were given for the amount of force an opponent could apply to the armor, a force of 12,000lbs was used for calculations. Assuming that the maximum force that would be applied was 12000lbs (Figure 5), a loading condition of 24,000psi of actual stress was calculated. By using the formula to calculate the intra-cell buckling of the titanium honeycomb armor, with a design factor of 12 for impact loading an allowable stress of 322,000psi was calculated (all calculations regarding honeycomb armor is proprietary to Aeronca

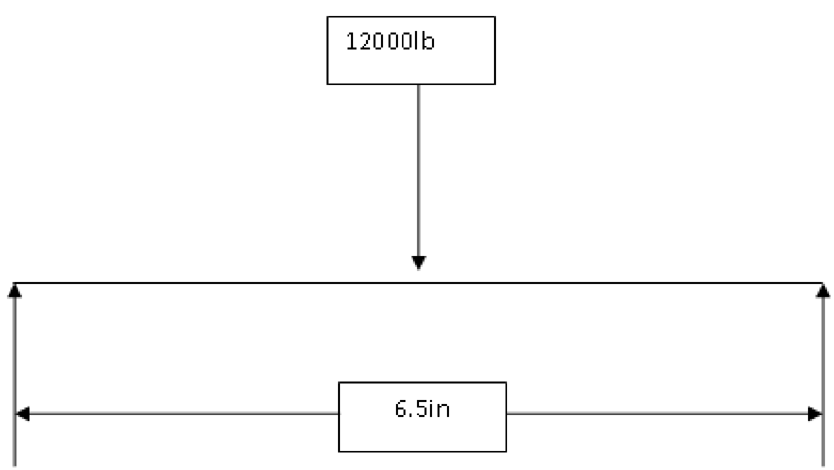

Figure 5 – Free Body Diagram

Inc.). Using the actual stress of 24,000psi and 322,000psi, allowable stress, a factor of safety of 13 was calculated. With a design factor of 13 the armor should be capable of withstanding repeated impacts from an opponent's weapon without failing.

FABRICATION

The armor was fabricated from a titanium outer and inner sheet brazed to a titanium honeycomb core. The process of fabrication is complex and time consuming. First a sheet of titanium is laid out, then a sheet of braze is placed onto it. The titanium honeycomb core is then laid on top of the braze and another sheet of braze is placed on top of it. The final sheet of titanium is laid on top, and the entire structure is placed into a vacuum form. A pure argon atmosphere is pumped into the vacuum form, and then a vacuum is pulled sandwiching the honeycomb structure. The form is placed into a furnace and the entire structure is brazed together. After fabrication the honeycomb armor material was sent to a machine shop where a Water-Jet® was used to cut the pieces to the proper size, and holes were cut in.

ASSEMBLY

Using the pre-cut holes, the armor was assembled and affixed to the frame of the BattleBot using ¼-20 countersunk bolts.

PROJECT MANAGEMENT

BUDGET

Armor/Defense (Dave Bailey)	
Armor Material	$8,000.0
Fasteners	$30.0
Titanium (36"x24")	$197.1
Armor/Defense Total	$8,227.1

Table 7 Budget

Table 7 shows the breakdown of the cost of various components needed for the construction of the armor. The armor cost approximately $8300 without backup armor pieces. The titanium honeycomb armor has an estimated cost of approximately $1000/ft^2$. The largest portion of the budget was to the armor material because it is assumed multiple backups will be needed for these components (3). Of the total budget the armor accounts for 41.9%. The armor was completely donated by a sponsor (Aeronca), and will truly account for only 1.1% of the total budget. Sponsors were solicited for funding and material donations. They have provided the group with all of the funding required to complete the project. The complete project budget breakdown is found in Appendix D. Appendix E shows the individual sponsors as well as their contributions and pledge statements if their donations have not yet been received. The preliminary budget for the armor of the BattleBot was an estimated $8227 out of a total project budget of $20,000. The $20,000 budget also included $4913 for the drive train of the BattleBot, $420 for the frame, and $3590 for the total cost of the trip and associated expenses to Miami, Florida. The armor accounts for 41.43% of the total project budget; however, the majority of the armor materials were donated.

The sponsors listed below have all donated or pledged funding in the amount of $13,600 as well as various amounts of material and service donations totaling approximately $6400. The sponsors have provided all of the projected costs for the project.

Sponsers	
Aeronca Inc.	SolidWorks EDU
Avenue Fabrication	Tische Environmental
Duke Energy	UGS
F & M Mafco	UGS/ Engineering Methods
Makino	University of Cincinnati Mechanical Engineering Technology Department
Meritor Webco	
RA Jones	

SCHEDULE

Table 8 Project Major Milestones

Major Milestone	Target Date	Date Completed
Preliminary Design Calculations Completed	13-Nov	13-Nov
Proof of Design Statement	30-Nov	1-Dec
Design Freeze	14-Dec	20-Dec
Ordering of Components	14-Dec	4-Jan
Completion of armor fabrication	28-Jan	14-Apr
Assembly of Robot Complete	29-Feb	28-Apr
Testing of Robot begins	1-Mar	7-Apr
End of Testing	26-Apr	29-Apr
National Competition	30-Apr	30-Apr

Table 8 shows the major milestones for the design, construction, and testing of the armor and defensive capabilities of the BattleBot. The complete schedule for the armor can be found in Appendix F. Due to problems in the designing of components the design freeze was pushed back. The manufacturing process while fabrication of the armor initially had a short lead time, the manufacturer shuts down operations the last two weeks of December. After the order was placed problems arose with the materials, and changes were made to the design. Once the armor material was on hand, there were problems having it machined to the proper design. However, the armor was not key to testing the functionality of the frame, drive-train, and weapon. The armor was completed and mounted before the competition.

COMPETITION

The 2008 CAS BattleBot team competed at the BotsIQ national championship and came in first place. After a loss in the first round due to ground clearance issues, the armor was modified to give greater clearance. The armor was subjected to pneumatically actuated arena hammers, spinning weapons, and wedge weapons. As a result of combat the armor's only damage was light scuffing. Some peeling of the titanium sheet from the honeycomb was noticed around some of the edges. This however is attributed to a manufacturing defect. As a result of the competition the BattleBot team won six straight matches to win first place overall in the competition. Due to the engineering of the BattleBot, the award of "Best Engineered" was given to the team.

REFERENCES

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APPENDIX A – RESEARCH

INTERNET RESEARCH

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

Dead Blow from BattleBots
Project Muthar report
http://en.wikipedia.org/wiki/Deadblow

- Four wheels
- Impact damage
- Weapon can flip bot over
- Angled armor

- Easily flipped
- Wheels exposed

War Head from Project Muthar report
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

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

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http://www.robotbooks.com/biohazard.htm 10/01/07

When building BattleBot the most important factor is your weight limit. When building a BattleBot you want to put the most power, thickest armor, and biggest weapon. Winner of BattleBot competition.

220 lbs.
Battery powered
Titanium, Magnesium, Aluminum, Steel
Heavy-duty frames
Light-weight base plates and bulkheads
Complete drive trains
Built-in motor and speed controller mounting
Custom wheels

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Battery powered
Constructed of light materials
Weapon powered linear actuators
Mag motors
Chain driven

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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.

APPENDIX B – SURVEY RESULTS

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 collected from various builders and competitiors who have had numerous years of experience in the area

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

Main Category (1-least important, 5-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 opponent.	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 damage.	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)

[redacted]

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SURVEY RESULTS ANALYSIS

Note: All data frequencies below correspond to the survey questions above

Frequencies (x)												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

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Appendix B3

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

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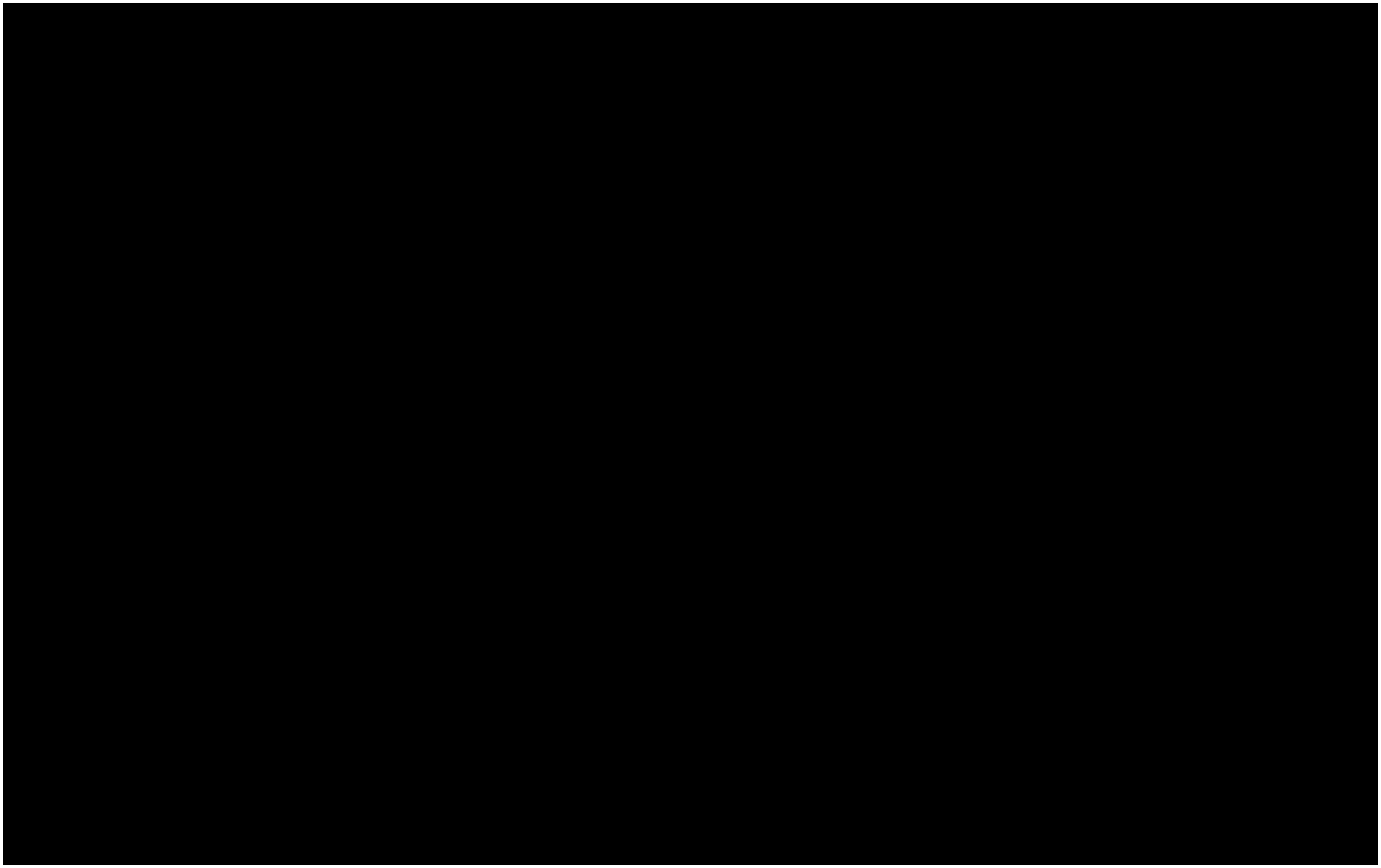
APPENDIX C – BATTLEBOT QFD



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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 (After Donations)	
Competition Entry fee	N/A
Hotel Expense - 2 rooms @ 150/night -5 nights	N/A
Rental Van + Insurance	N/A
Gas @ 3.00/gal assumed 2400 miles @ 10mpg	N/A
Team shirts	N/A
Total Trip Expenses	$0.0

BattleBot Expenses (Before Donations)	
Drive Train	
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/Fabrication)	$45.0
Drive Train Total	$4,913.0
Main Weapon	
Weapon Motor	$750.0
Weapon Motor Mount Material	$15.0
Weapon Motor Mount Fabrication	$30.0
Weapon sheaves and belts	$50.0
Weapon material	$100.0
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	$2,558.0
Frame	
Chassis material	$300.0
Chassis Fabrication	$100.0
Fasteners	$20.0
Frame Total	$420.0
Armor/Defense	
Armor Material	$8,000.0
Fasteners	$30.0
Titanium (36x24)	$200.0
Armor/Defense Total	$8,230.0
Total Robot Cost	$16,121.0
Total Project Cost	$19,711.0

BattleBot Expenses (After Donations)	
Drive Train	
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/Fabrication)	$45.0
Drive Train Total	$4,913.0
Main Weapon	
Weapon Motor	$750.0
Weapon Motor Mount Material	$15.0
Weapon Motor Mount Fabrication	N/A
Weapon sheaves and belts	$50.0
Weapon material	$100.0
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	$2,378.0
Frame	
Chassis material	$300.0
Chassis Fabrication	$100.0
Fasteners	$20.0
Frame Total	$420.0
Armor/Defense	
Armor Material	N/A
Fasteners	$30.0
Titanium (36x24)	N/A
Armor/Defense Total	$30.0
Total Robot Cost	$7,741.0
Total Donation Received	$13,600.0
Total "Out of Pocket" Project Cost	$0.0

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APPENDIX E – PROJECT SPONSORSHIP

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**	

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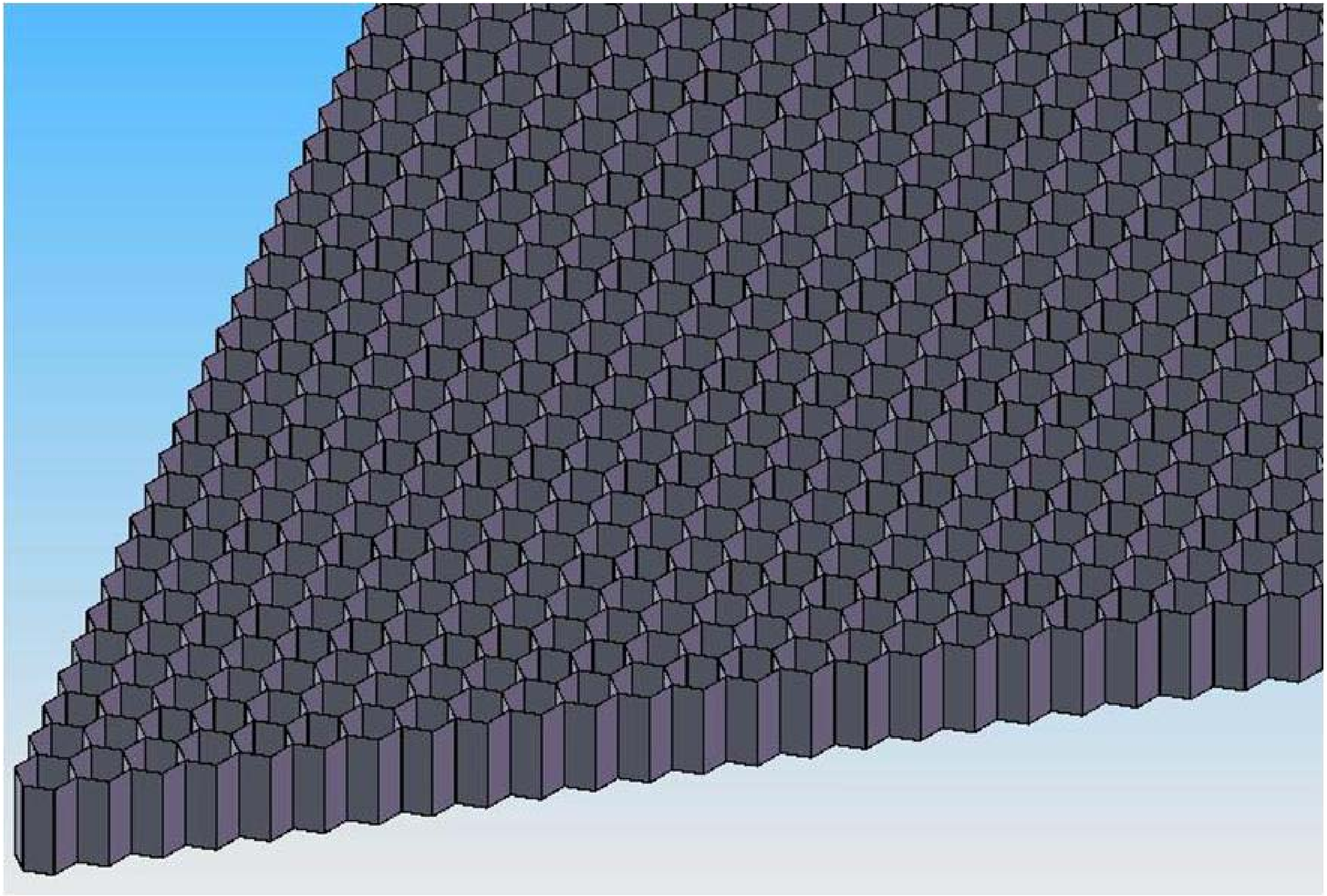
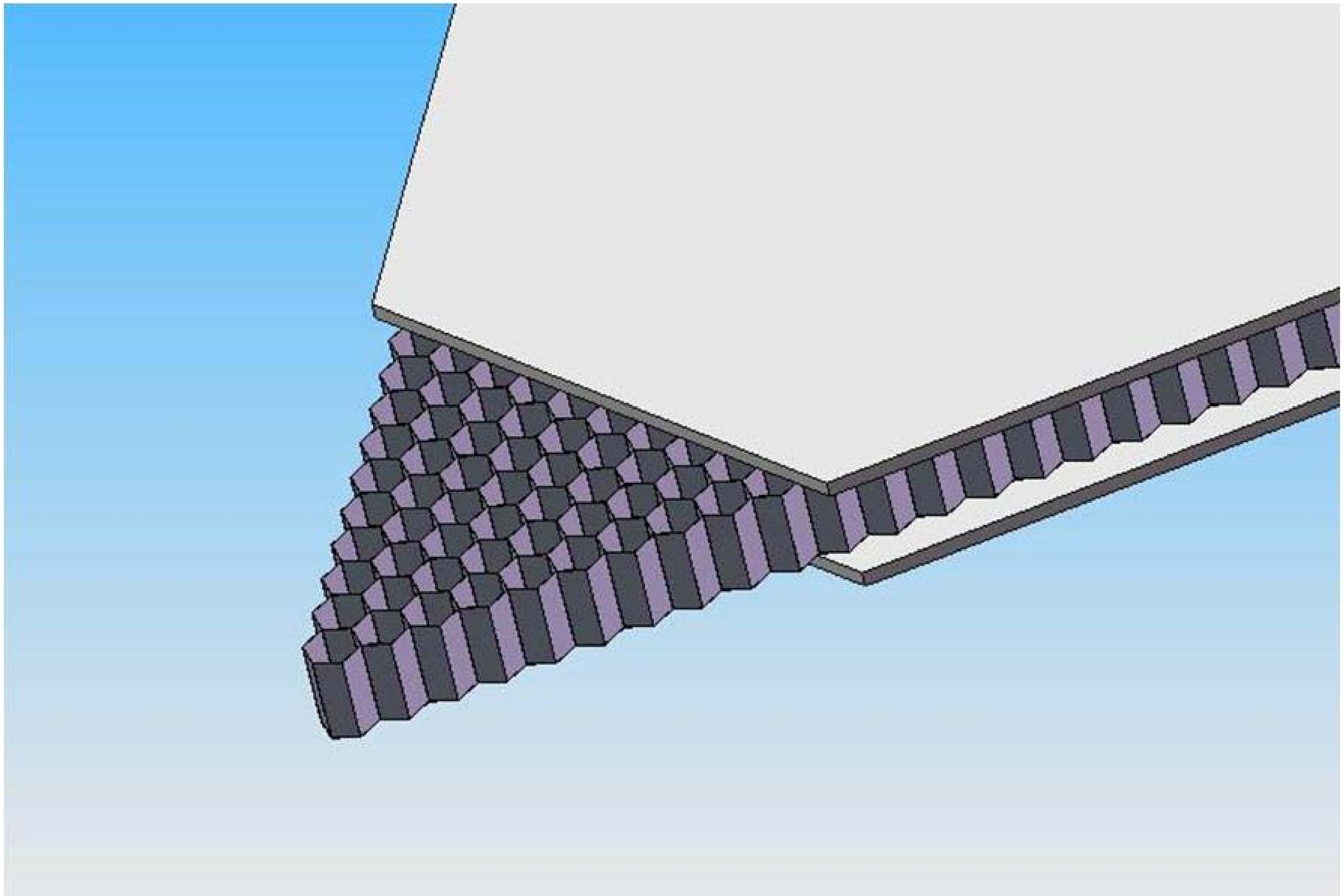
Sponsor	Pledge Statement
University of Cincinnati Mechanical Engineering Technology Department	Jake Barnhorst, This email is to confirm that the MET Department will cover the expenses of the team trip to Miami for the National Competition. Good Luck! Muthar Al-Ubaidi Department Head
Tisch Environmental	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 F – SCHEDULE (ARMOR/DEFENSE)

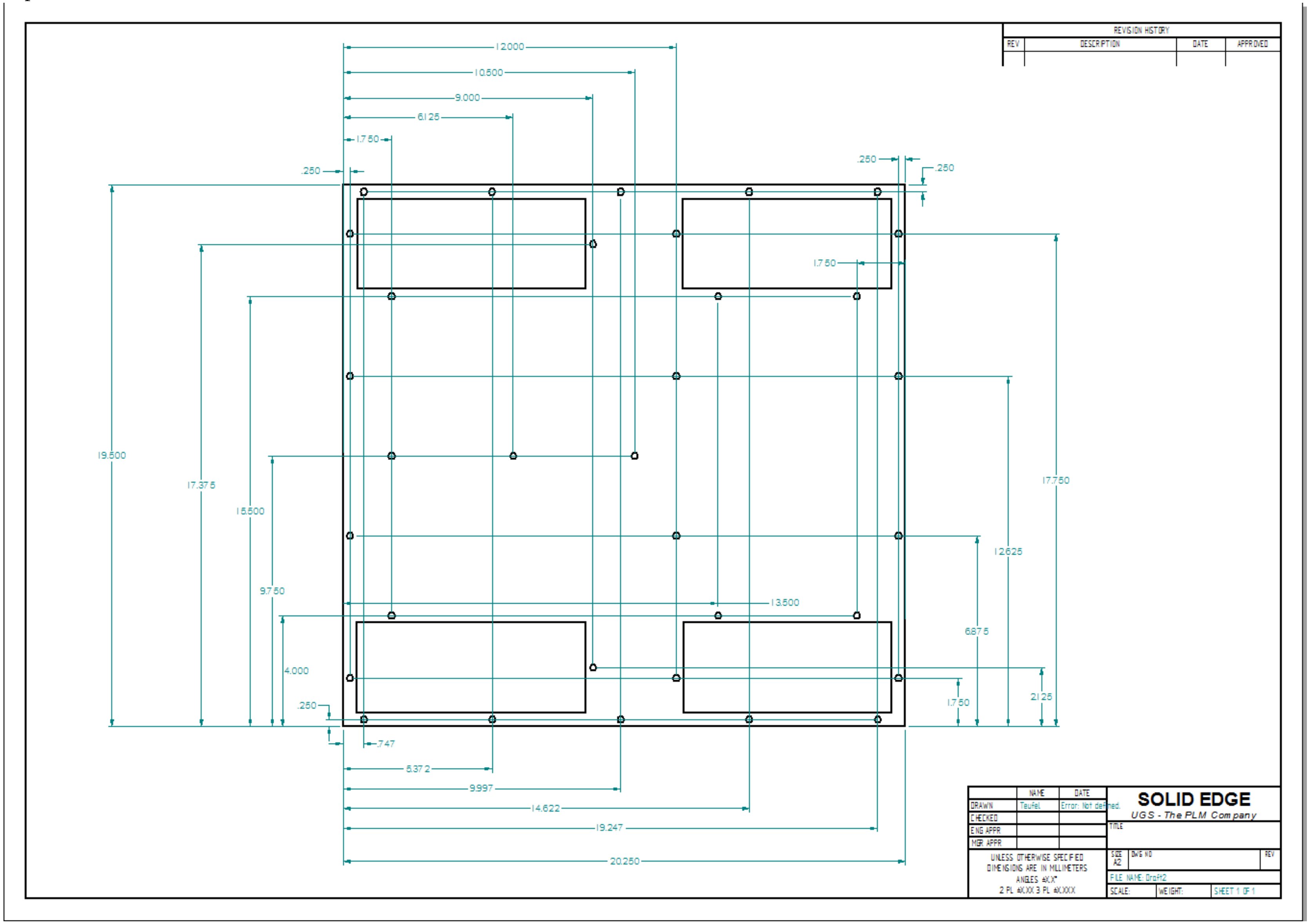
BattleBot																														
Quarter	Fall Quarter				Winter Break				Winter Quarter											S. Break	Spring Quarter									
Week Number	8	9	10	Exams	1	2	3	4	1	2	3	4	5	6	7	8	9	10	Exams	1	1	2	3	4	5	6	7	8	9	10
Dates	11/10-11/17	11/18-11/24	11/25-12/1	12/2-12/8	12/9 - 12/15	12/16 - 12/22	12/23-12/29	12/30 - 1/5	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	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																														
Brainstorming to meet requirements of "Hows"	10-Nov																													
Engineering Characteristics "Hows" Completed	11-Nov																													
Survey Results analyzed ; QFD completed	12-Nov																													
preliminary Design Calculations (all components)	13-Nov		25-Nov																											
proof of design statement			30-Nov																											
Design Freeze					14-Dec																									
Amor Design																														
Discuss Armor Design with Rob Garret					10-Dec																									
Select Titanium and honeycomb for design criteria					10-Dec																									
Discuss final design schematics					10-Dec																									
Design of armor completed					13-Dec																									
Design freeze					14-Dec																									
Order material for armor						17-Dec																								
Manufacturing of armor						17-Dec								4-Feb																
Go over Final Design drawings with Rob Garrett						17-Dec																								
Aeronca will custom make Brazed Titanium Honeycomb into sheets						17-Dec																								
Order Titanium sheet from Aeronca for corners						17-Dec																								
Order all common "shelf" parts (fasteners)						17-Dec		5-Jan																						
assembly of robot											25-Jan					29-Feb														
testing/troubleshooting/competition practice																1-Mar								26-Apr						
oral design presentation																		14-Mar												
design report due																		14-Mar												
drive to competion																									29-Apr					
BotsIQ National Competition Miami Beach, FL																									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 G – ASSEMBLY DRAWINGS

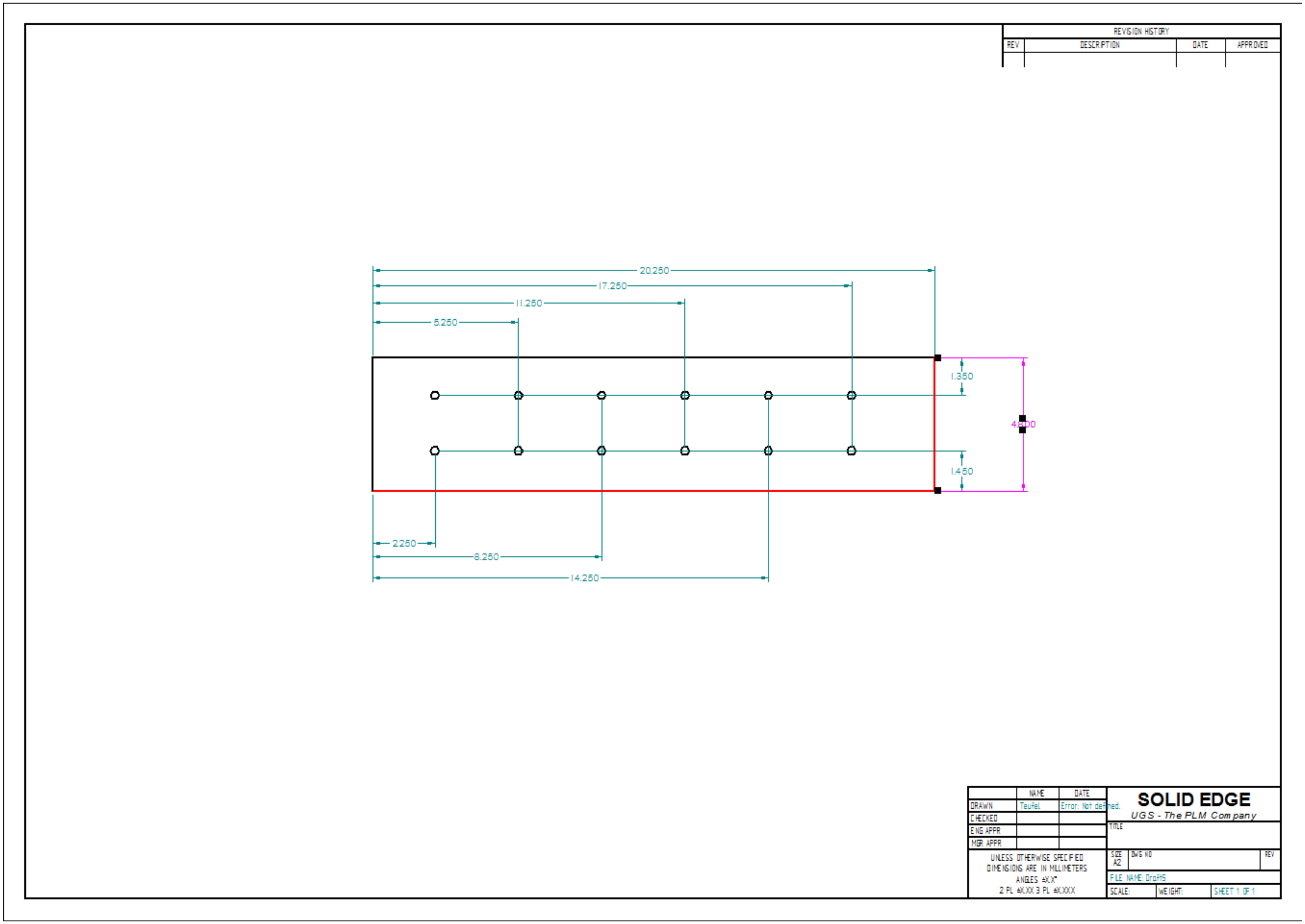




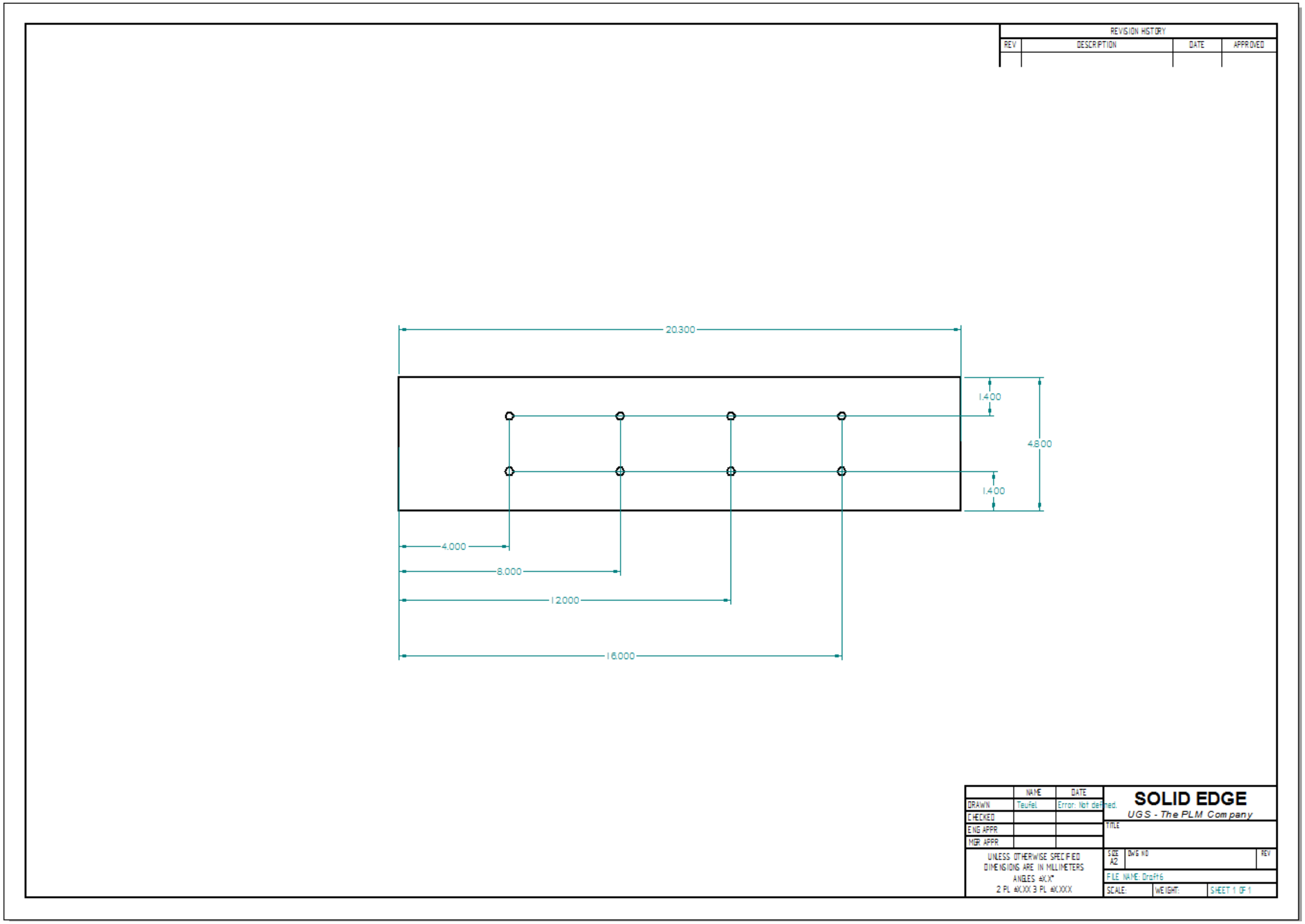
Top and Bottom Armor



Left and Right Side Armor



Back Armor


REVISION HISTORY
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SOLID EDGE
UGS - The PLM Company
TITLE
SIZE
A2
DWG NO
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FILE NAME: Draft6
SCALE:
WEIGHT:
SHEET 1 OF 1