Variable Angle Target Training System (V.A.T.T.S.)

Spring Final Report

Team 16
Submission Date: April 8 2016
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Abstract

Stationary Infantry Targets (SIT) have been used in the past to give a more realistic training experience to military and law enforcement. Many of these targets employ the same overall target actions, but actions such as “pop-up” or rotation have recently been implemented in order to create a more robust training model. Specifically Lockheed Martin’s version of the SIT does not have the capability to rotate the attached target while being lifted to an upright position. The team’s objective is to create a lifting bracket to mount on Lockheed Martin’s current SIT design. The lifting bracket will accommodate various types of standard targets, as well as rotate the target using standard Future Army Systems of Integrated Targets (FASIT) regulations. Following the prototypical design process, the team has developed a prototype which functions and meets the desired specifications. This report presents some future considerations for designing new components to the system, as well as the process to achieve the successful prototype.

1.0 Introduction

Military and law enforcement organizations have always attempted to simulate realistic scenarios while training in order to be more prepared for real life situations. Targets that vary from simple paper and cardboard posters, to more complicated molded silhouette targets have been used to simulate real life situations where there is a need to distinguish between a hostile and a friendly entity. Coupling these target presentations with realistic spatial movements provides a robust model for what one might encounter in real life. There are various mechanisms available on the market that fully simulate an encounter where there is a need to discern friend from foe. One of those systems is the Stationary Infantry Target or SIT. The SIT system raises a concealed target up 90 degrees and presents the trainee with a target which can be either friend or foe. There are limitations of the SIT such as, the time to switch the physical target between a friendly target and a foe target and the manner in which the target is attached to the system. Currently, the presented target cannot rotate and is fixed in a fully presented position, limiting the realistic simulation of a quartering body.

The objective of this project is to implement a new bracket and target arm to the SIT, which alleviates many of the shortcomings of the original design. The new bracket and arm will make replacing used targets quicker and easier, accommodate various standard training targets, be able to rotate the target between a range of quartering angles once fully deployed in its upright position, as well as rotate a full 180 degrees to reveal a second, different presentation.

2.0 Project Scope

Team 16 has developed a target turner for Lockheed Martin's Live Training organization for domestic and international military practices. An arm and bracket mechanism with turning function for "pop-up/rotation" is pictured below in Figure 1.

Figure 1. Stationary Infantry Target in the up position.

2.1 Background research

The Stationary Infantry Target, or SIT, has been used for many years and is a staple of live training equipment. They are primarily used in infantry platoon/squad battle courses but can also be used at gun ranges as well **[1]**. A picture of the mechanism can be seen below in Figure 2 **[2]**. The SIT mechanism has gone through many iterations over the years, making it more reliable, flexible, and simple to use. Therefore, the SIT systems that exist today are very robust. There are many different companies who design and market SIT systems, these companies include Strategic Systems, Meggitt, Lockheed Martin, and more. All the different SIT systems these companies produce essentially perform in the same way. Therefore, to incentivize organizations into buying their SIT systems, engineers are required to innovate and constantly improve their designs. These improvements are not just limited to the operation of the system but also to things such as portability, reliability, and cost **[3]**.

The competition between companies as well as increasing requirements from clients has given rise to complex SIT systems that provide more variable training. These variables add additional stress and also simulate real combat more closely giving rise to better trained personnel. Some examples include thermal targets which are used for night training, hit detection, and muzzle flash. However, the feature that the design team is primarily interested in is the rotation of a mounted target. Theissen already implements a friend/foe SIT on their MOUT (Military Operations in Urban Terrain) courses **[4]**. Also, Meggitt has a product called the MF-SIT which has the ability to raise and rotate the target a complete 360 degrees in less than a second **[2]**. This is of interest to the team since outperforming this feature is one of the goals of this project. Also, it can be seen that a rotating target has already been done and is currently in use.

It has been seen that SITs can vary in their combat simulation variability, but beyond these aspects, many systems follow a standard. For example, all SITs present the same basic targets. These include E-type, F-type, and Ivan-type targets. Also, all target systems run on FASIT 2.0 compliant firmware. FASIT is a set of regulations that helps simplify programming, a training routine by keeping a universal set of commands among differing targets, and target manufacturer hardware on a range. More can be learned in the FASIT 2.0 Interface Control Document. The team will have to take these given factors into consideration in order to meet the project requirements.

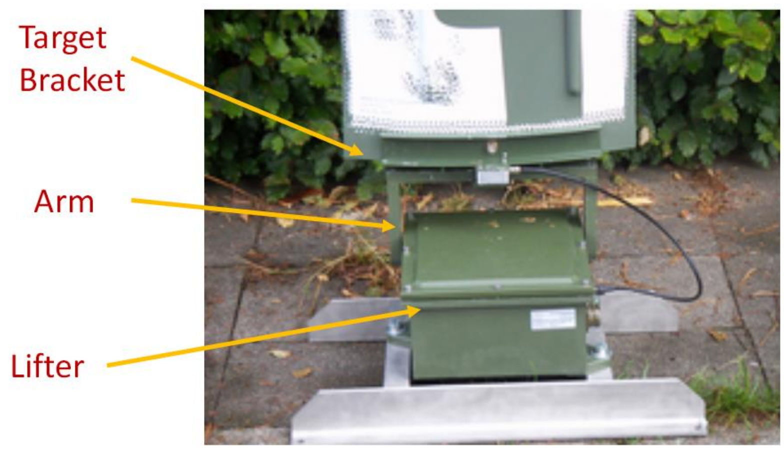


Figure 2. Example of SIT

2.2 Need Statement

Lockheed Martin's Live Training organization specializes in training domestic and international ally militaries. Currently Lockheed supplies live fire "pop-up" targetry training systems for military target identification purposes. The new target training system requires the ability to rotate the target through various angles in either direction once the operator has given the command, in order to present a friendly or foe target.

"Lockheed Martin's current Stationary Infantry Target does not allow for suitable target presentations"

2.3 Goal Statement & Objectives

"To create a target system that can deploy a variety of targets from a resting position, and rotate to a friendly or foe position on command."

Objectives:

- Lift and rotate targets on command
- Firmware interface with FASIT
- Create a universal mount for variety of targets
- Easily attach and detach various types of targets
- Withstand 35 mph crosswinds
- The motor may not be back driven
- Motor will be unaffected by heat, sand, dust, and rain
- Use “Type 11”, “Ivan”, “Type E” and “Type 12” type targets

3.0 Constraints and Requirements

- The total cost may not exceed $3,000.
- Motor must meet FASIT requirements. **[5]**
- Distance from bottom of lifter to top of the arm shall be no more than 18 inches.
- Weight of lifter arm with turner motor shall be no more than 10 lbs.
- Time to install new target shall be less than 10 seconds
- Motor shall rotate the target up to 90 degrees in either direction within 1 second of receiving turn command.
- Motor housing/enclosure shall be rated to at least IP67.
- Arm shall survive a loose cargo test (details TBD).
- Target arm shall operate -20^{o}C to 50^{o}C and shall have a minimum storage temperature range of -40^{o}C to 60^{o}C.
- Target arm shall accommodate an Ivan-style target (Figure 2a.), a Type E (Figure 2c.) and Type F (Figure 2d.) target, and a Figure 11 target (Figure 2a.) without reconfiguration.
- Target arm shall fit on the new Lockheed Martin Stationary Infantry Target (SIT) – part number 15721510G1 (dimensions provided).
- Arm shall not impede functionality of muzzle flash feature on the SIT.
- The new bracket and arm must be able to hold the target in wind conditions up to 35 miles per hour
- Firmware shall be compatible with all applicable FASIT 2.0 commands (Refer to Table 1)

Figure 2a." Type 12" Target Face

Figure 2b. "Ivan" Type 3D Target

Figure 2c. “Type E” Style Target

Figure 2d. “Type 11” Style Target

Figure 2a-d. Target Examples

Table 1. FASIT 2.0 PD IDC calls out ASPECT field: values 0 through 6

FASIT 2.0 PD IDC Command	Target Action
0	Concealed
1	Simple Hostile
2	Restricted Hostile Left
3	Restricted Hostile Right
4	Simple Neutral
5	Restricted Neutral Left
6	Restricted Neutral Right

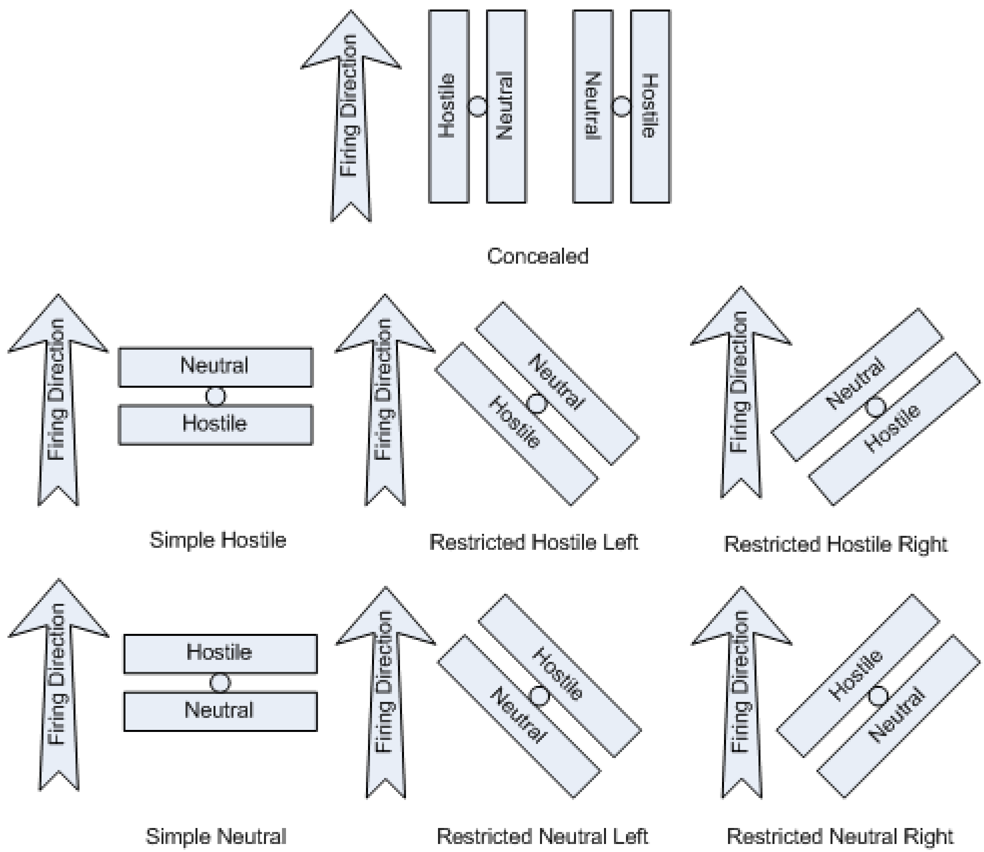
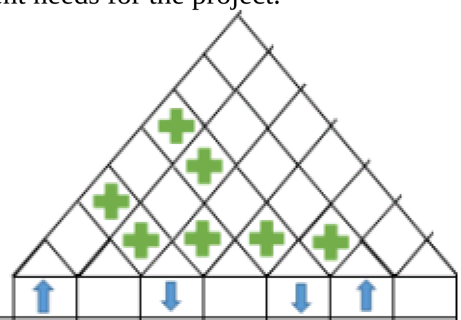


Figure 3. FASIT Target Actions

3.1 House of Quality

Based on the customer requirements and given project constraints a house of quality was constructed to better observe the importance of different needs for the project.



	Customer Requirements	Weight Factor	Motor Speed/ Torque	Dimensions/ Shape	Weight	Materials	Manufacturing Cost	Clamp Force	Electronics/ Programming
Performance	Low Installation Time	5						2	
	Rotation Angle	4	3						1
	Compact Lifter Arm	3		3		2	2	1	2
	Low Weight	1	2	2	3	3	3	1	1
	Target Security	5		2		1	2	3	
	Rotation Time	3	3		2				
Features	Target Accommodation	5		3				2	
Durability	Wind-Resistant	2	1					1	
	Loose Cargo Test	1			1	2			2
	Temperature Resistance	3	1			2	1		3
	Weather Resistance	3				3	1		3
Serviceability	FASIT 2.0 compatible	5							3
Conformance	Meets Firmware Standards	5							3
	SIT integration	5		3	2		1		
	Flash Feature of SIT	4		2					
	Motor Meets Standards	2	3				2		
	Mass Producibility	2	1		1	3	3		
	Technical Priority		36	59	22	37	40	40	51

Figure 4. Constructed House of Quality

4.0 Methodology and Approach

Currently the team meets with each other on a weekly basis. The team also meets with the sponsor, Chris Isler, on a weekly basis via conference call. Anything that is discussed about in the meeting is written down by the historian, Andrew Bellstrom. Also, any documents that are given to us by the sponsor goes to the team leader directly who can then decide to delegate it among the members. This way, information sharing is more streamlined. Below are the year's Gantt Charts, scheduling the work for both semesters.

4.1 Fall 2015 Gantt Chart

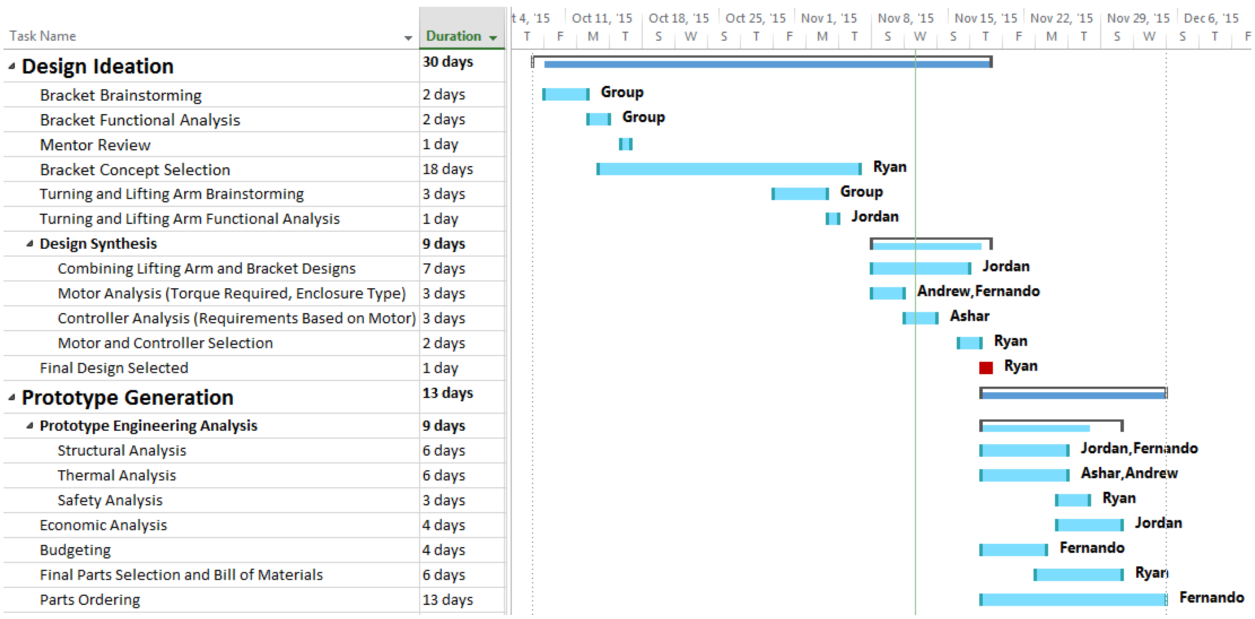


Figure 5. Fall 2015 Semester Gantt Chart

4.2 Spring 2016 Gantt Chart

The team produced a Spring Gantt chart to help plan the remaining work on this project. The time allotted to work on deliverables are concrete due to deliverable deadlines. The time allocated to the design process is more flexible, but will be followed as stringently as possible. Below, the beginning of the Spring semester's Gantt Chart may be found in Figure *.

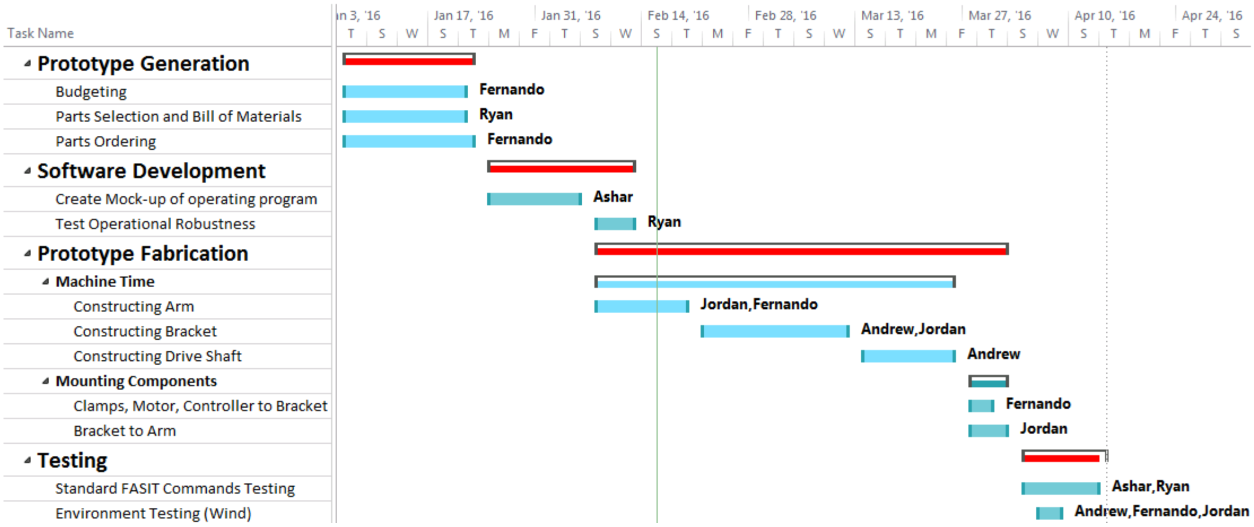


Figure 6. Spring 2016 Gantt Chart

As it can be seen in the variation between the two Gantt charts, the team did not strictly adhere to the proposed schedule. This was mostly due to conflicts with other coursework the students were taking and turnaround time on purchase orders and system fabrication. As will be shown, the team found sufficient time between coursework to complete a successful prototype, while also taking on personal coursework.

5.0 Environmental and Safety Assessment

5.1 Risk Assessment

As with most any project, there is a risk element. The team has performed a risk assessment and submitted the document to the Senior Design Capstone advising faculty. In said risk assessment, the team outlined the potential risks presented by this specific project. The main risks were found to be in the Prototype Construction and Prototype Testing phase of this project. Where construction of the prototype would present risks such as machine tools, and prototype testing risk would involve potential bodily injury from moving parts on the prototype. In order to reduce the risk the team will take appropriate steps to avoid injury. Steps include being certified for use of required machining tools, deferring to experts in the machine shop for majority of the machining process and following Lockheed Martin's safety guidelines for use of their provided Stationary Infantry Target system. All members of the group understand proper emergency procedures and all potential risks will be reported to group mentors as well as senior design faculty. In the event of an accident, or close call, the group understands that it has a responsibility to inform its project advisors.

5.2 Environmental Impact Assessment

This project involves the manufacturing of many different components that might eventually reach the end of their life cycle. It is important to ensure that the retirement of such a system is handled properly. The components of the system, such as the battery used for the turning mechanism, must be disposed of in regulation with proper safety and recycling standards. The electrical components, such as the microcontroller, motor driver and motor should also be disposed of or recycled in a proper manner. At the end of this product's life cycle it would be greatly suggested that the recycling of materials take place. The plastic housing of the lifter, as well as other aluminum parts may be recycled to lessen the impact on the environment to produce more of the same parts from scratch.

6.0 Concept Generation

Before the team reached its final design for the intended prototype, there were multiple design iterations on most of the proposed components. Through sponsor feedback and analysis through simulation, many of the proposed designs were eliminated until a final design was selected for each major component of the prototype.

6.1 Bracket Design

6.1.1 Bracket Design A

This bracket design is based on minimum weight and cost. The first thought was to measure all the targets and put them together to visualize a pattern between them. As one can see from Figure 7, there is a pattern between the flat targets. The "Ivan" target can be seen with the small hole in the back at an estimate of 80 degrees from the other targets. The next step was to conceptualize the locking mechanism, which is a main challenge in this project. There are many locking mechanism to choose from, but only one will be chosen based on sponsor feedback and design constraints. Examples of these mechanisms are Line Actuators, clamps, Pneumatics or even motors with gears. Some of this will increase the price and/or the weight. The best choice in this case are clamps, specifically toggle clamps, pictured in Figure 8, or bicycle seat clamps, seen in Figure 9. The toggle clamp is better suited for the ability to lock after the rotation, making this the choice for this design. For Bracket Design A, three of these clamps will be placed on the target rack, one in the middle and the other two located seven inches from the center. The side clamps will have the ability to rotate 80 degrees inward in order to accommodate the Ivan style target. Design A can be seen in Figure 11. Figure 10 shows the maximum clearance for the turner bracket which must be met by this design. As one can see, the height up from the pinch point of this mechanism must be less than 3.8”.

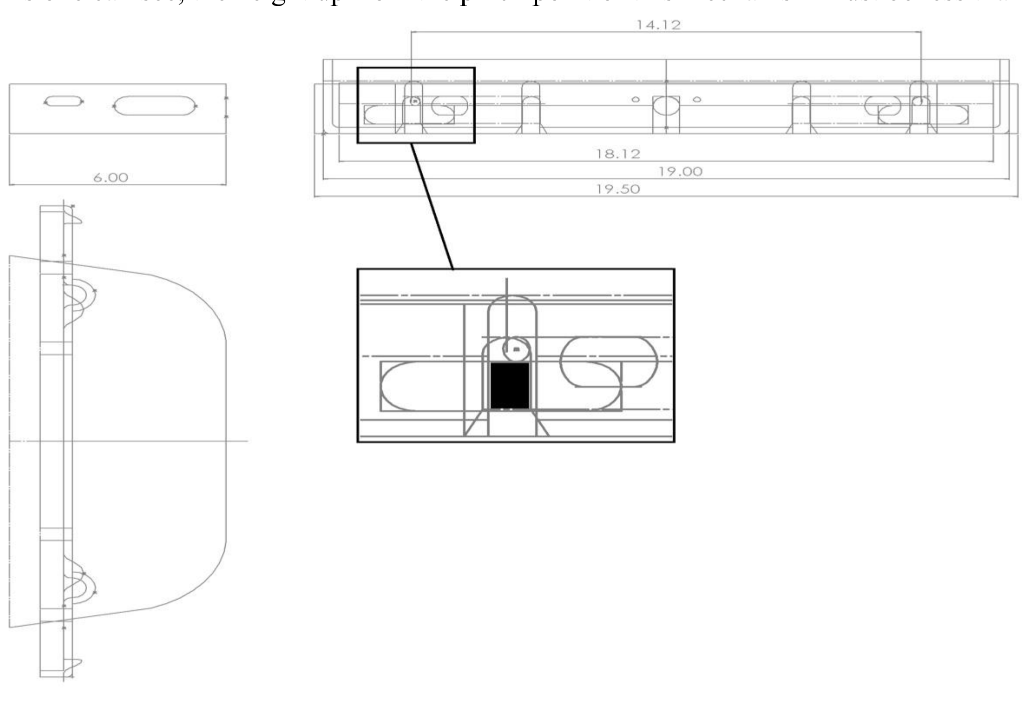


Figure 7: CAD of Overlapped Targets showing universal gap

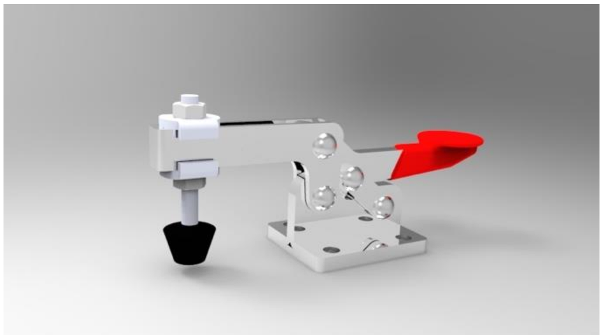


Figure 8: Toggle clamp CAD

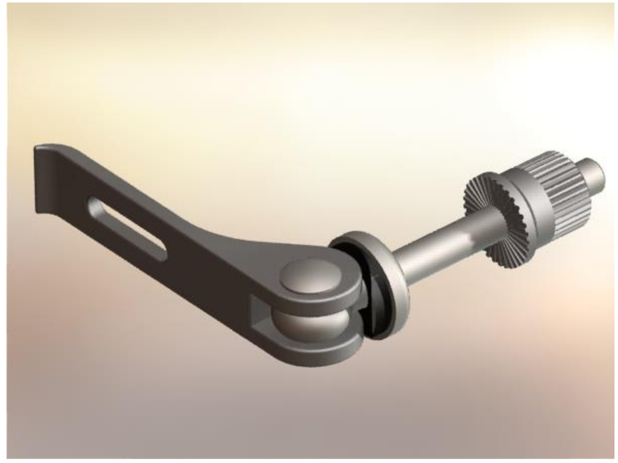


Figure 9: Bicycle seat clamp CAD

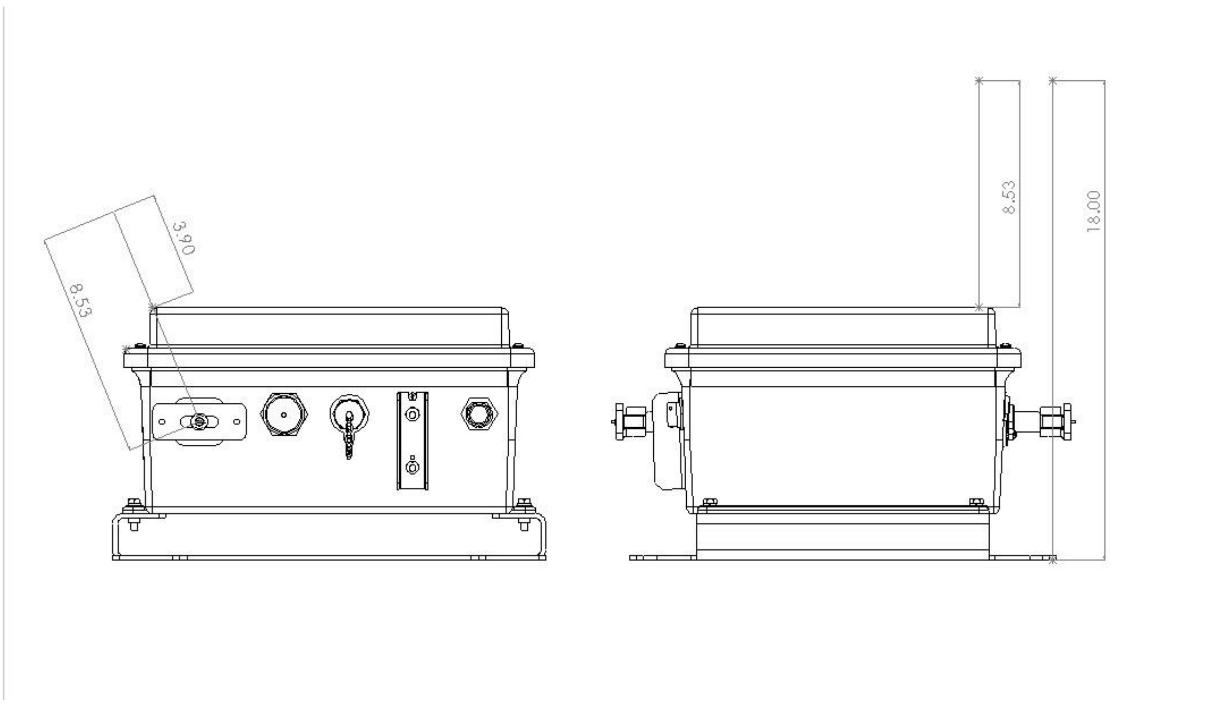


Figure 10: Limiting height of lifting arm on SIT

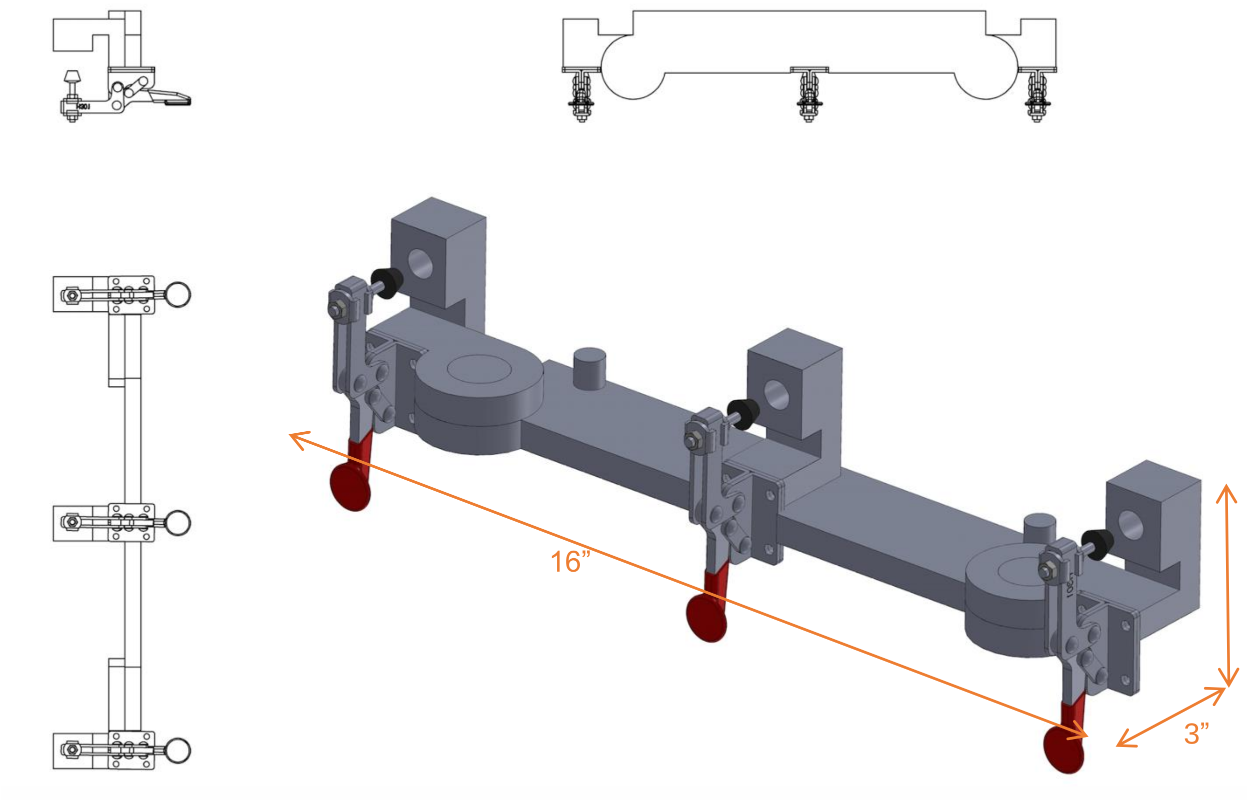


Figure 11. Design A

6.1.2 Bracket Design B

This is a preliminary design concept of the target bracing mechanism. The goal of this design is to securely hold all 4 target types while the lifter operates. This design features a swinging gate attached by a hinge, which will rotate upward and be clamped to the back of the bracing mechanism. Bracket Design B will operate similar to the tailgate of a truck. To lock/unlock the system, a clamp can be utilized. To incorporate the Ivan, target the back of the target brace will be slotted to allow the Ivan to fit securely in place. In order to connect the brace to the motor/gearbox a pin and collar can be used on the bottom plate.

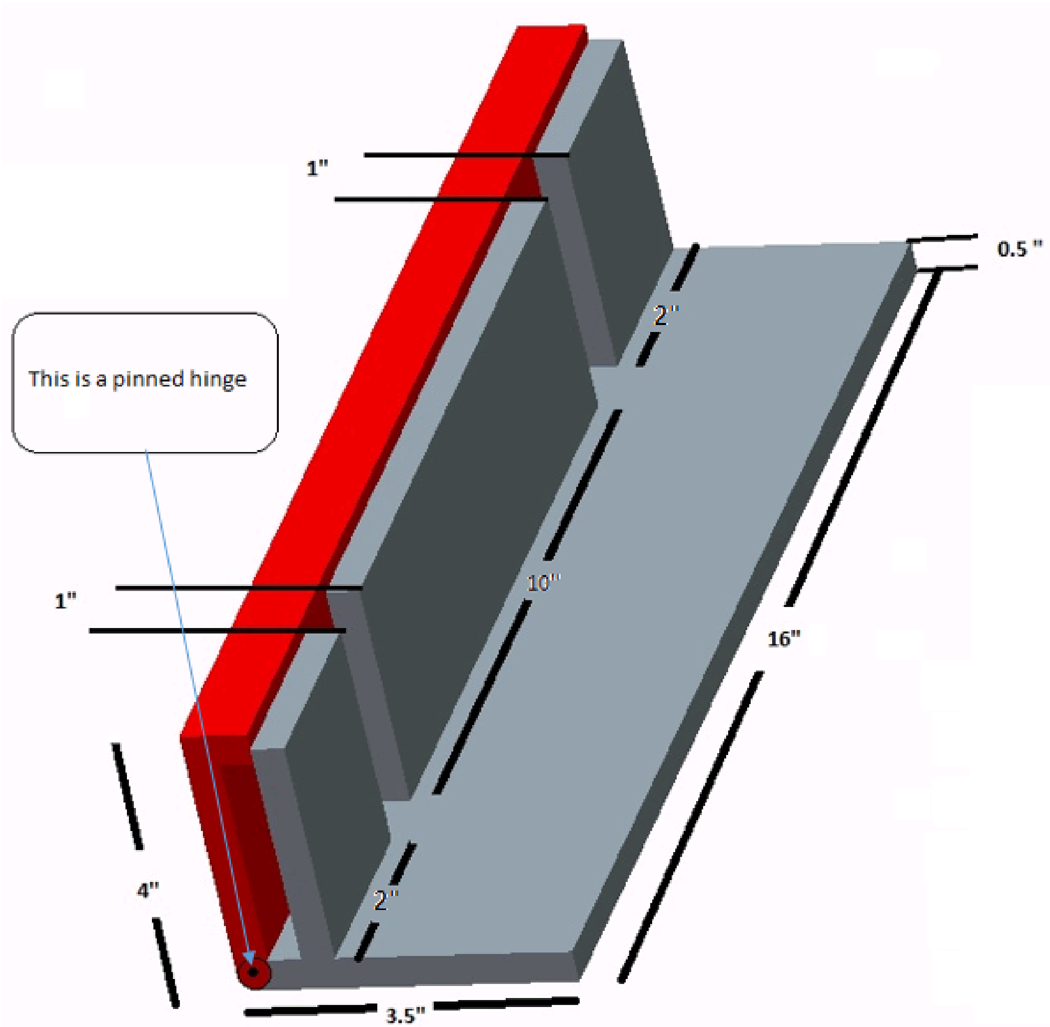


Figure 12. Bracket Design B

6.1.3 Bracket Design C

Bracket Design C implements a toggle mechanism coupled with a simple one point bracing against a plate. The toggle mechanism used would be similar to that of vice grip pliers. The benefits of this include increased speed of interchanging targets and firm locking. However, the one-point brace may present a problem for ensuring a suitable target hold. This design would work on all targets utilized in the project by bracing only the front part of the target, not the sides, such as those on the "Ivan" style target.

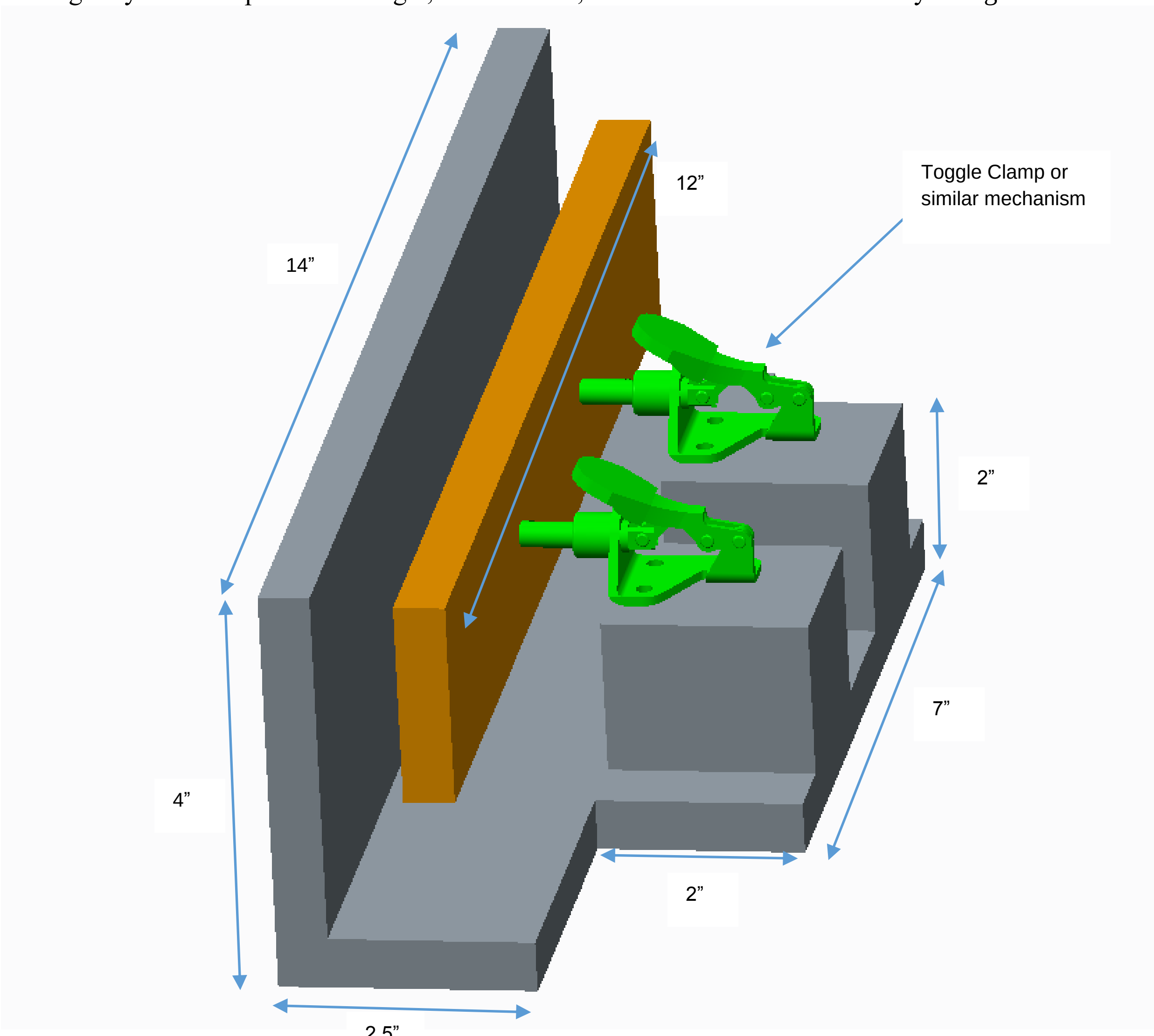


Figure 13. Bracket Design C

6.1.4 Bracket Design D

Bracket Design D is very similar to Bracket Design C, but instead of a toggle mechanism, screw-in bolts are utilized to brace the target against the front plate. This design is simple, but the screw-in bolts increase the time to interchange targets. Also, the sponsor has communicated issues in the past systems where weathering of bolts contributes to difficulty of target removal.

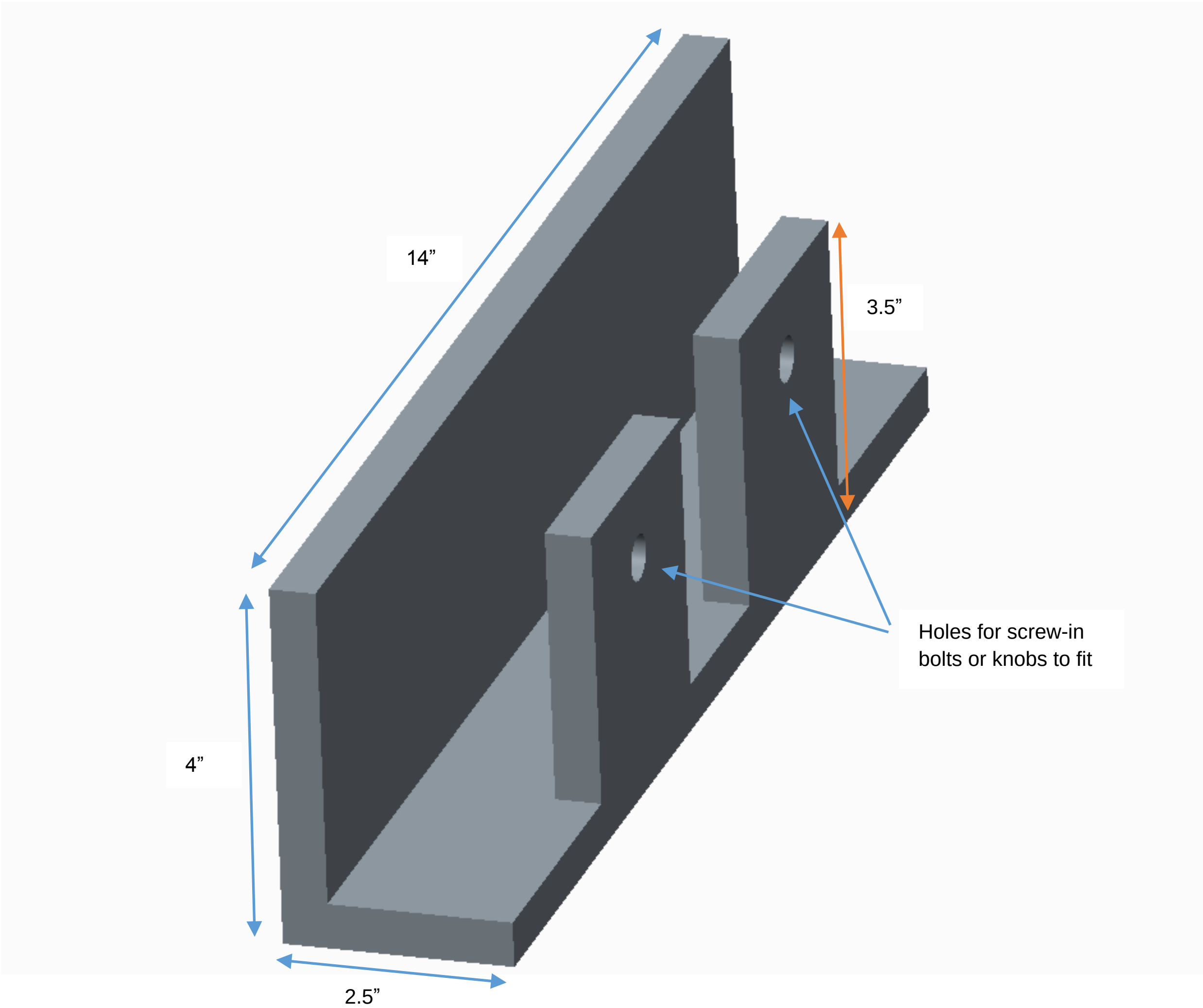


Figure 14. Bracket Design D

6.1.5 Bracket Design E

The image below in Figure 15 is a conceptual idea more than a design. It pays no heed to any of the constraints but it does provide a possible solution to the problem at hand. Further iteration would require the design to be more viable.

This design accommodates all four targets without any reconfiguration. The Ivan and Waffle Board targets are held against the back plate with a help of a cord. The end pieces swivel back to accommodate the Ivan target. The “Type 11” and “Type 12” standard targets are clamped to the front plate and held in by the rectangular slots shown. The sprung pin/threaded knob would come in from the front and would hold the target against the back of the rectangular slot.

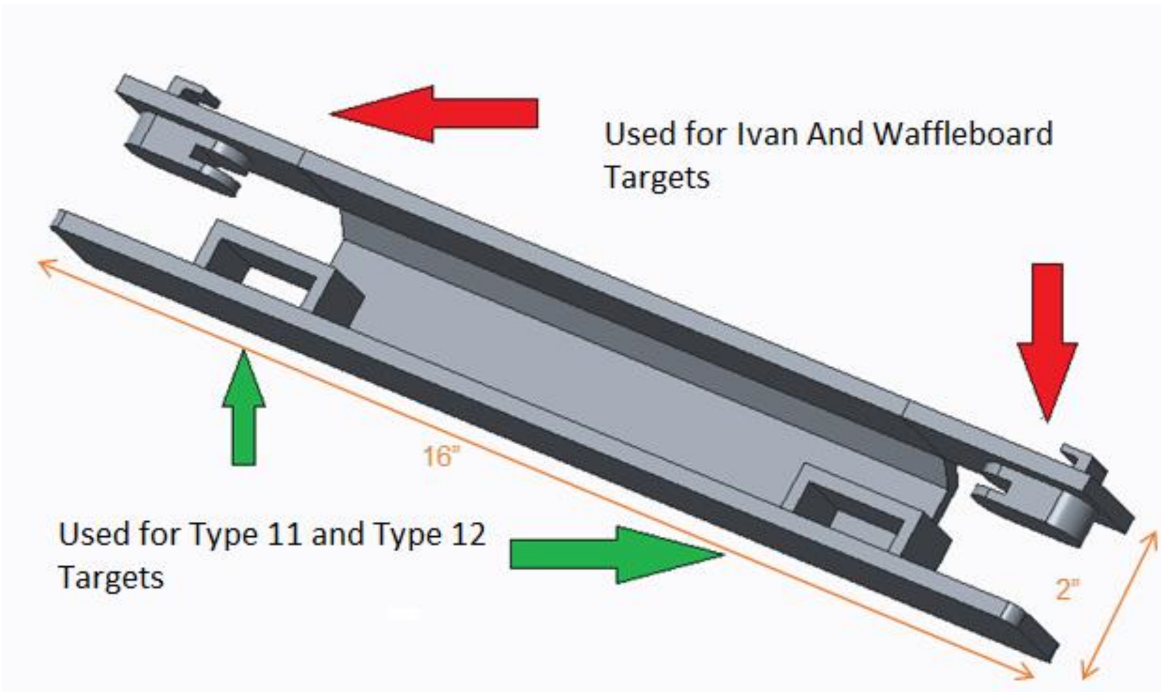


Figure 15. Bracket Design E

6.2 Revised Bracket Design

After review with the sponsor, it was determined that many of the previously shown designs were unsuitable due to the use of various types of hinges. The sponsor indicated to the team that the use of a hinge has regularly caused problems on current systems they already employ. Given the feedback, the team modified and adjusted the previous designs to produce the following ideas. It was important to eliminate all moving and threaded parts from the previous bracket designs. Hinges, swivels, threaded fasteners, and rubber materials will not last when exposed to sand, wind, rain and mud. Descriptions and illustrations of Bracket Designs F and G can be seen in the figures below.

6.2.1 Bracket Design F

Bracket Design F features a front plate that holds each of the targets in place with two bicycle seat clamps that force the adjustable front plate to the back of the bracket. This design is very simple and inexpensive, however the design doesn't allow for as easy of a secured universal fit when compared to Bracket Design G. Bracket Design F is also an all-aluminum bracket and its dimensions are a bit larger than Bracket Design G. The height of Bracket Design F allows for a larger maximum clearance for the needed arm attachment.

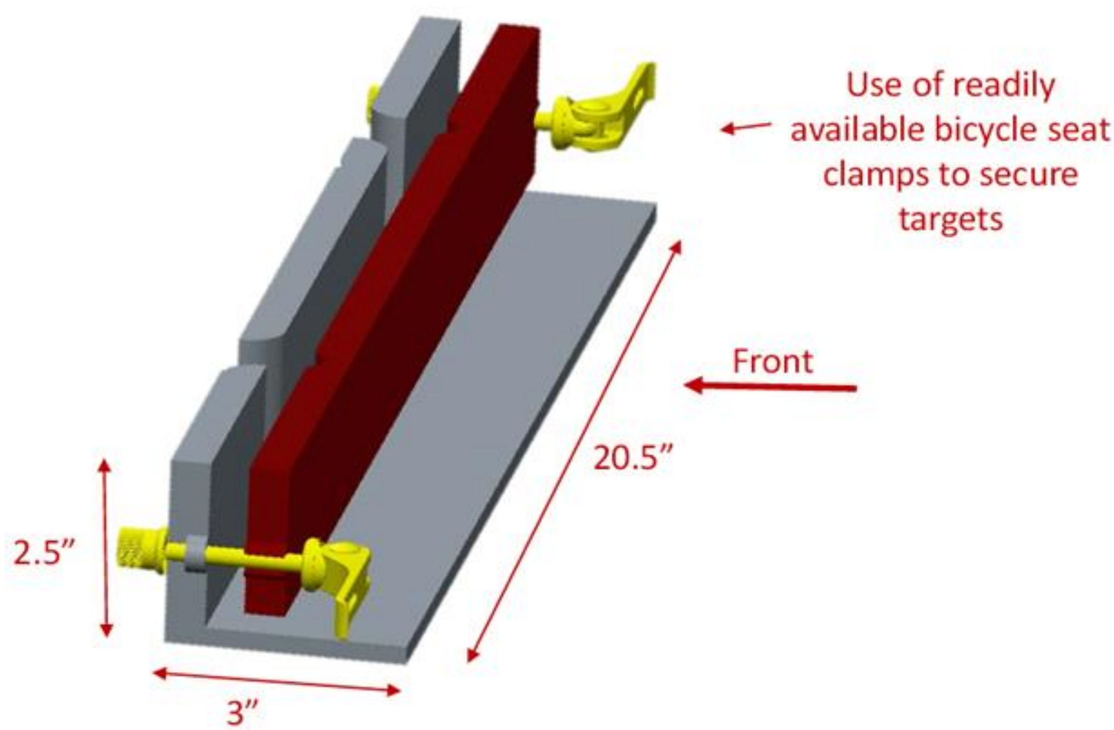


Figure 16. Bracket Design F

As seen below in Figure 17, the targets fit in between the adjustable front plate and the back of the bracket. The targets are held between these two plates using an applied friction force created from using two bicycle seat clamps. The concept is very simple, however the slight rivet difference between the "Type 11" and "Type 12" target may be enough to cause the smaller of the two to slip out when the lifter operates with the added rotational factor. An additional factor of concern with this design is that the adjustable front plate may not operate when the bracket becomes caked with mud or sand.

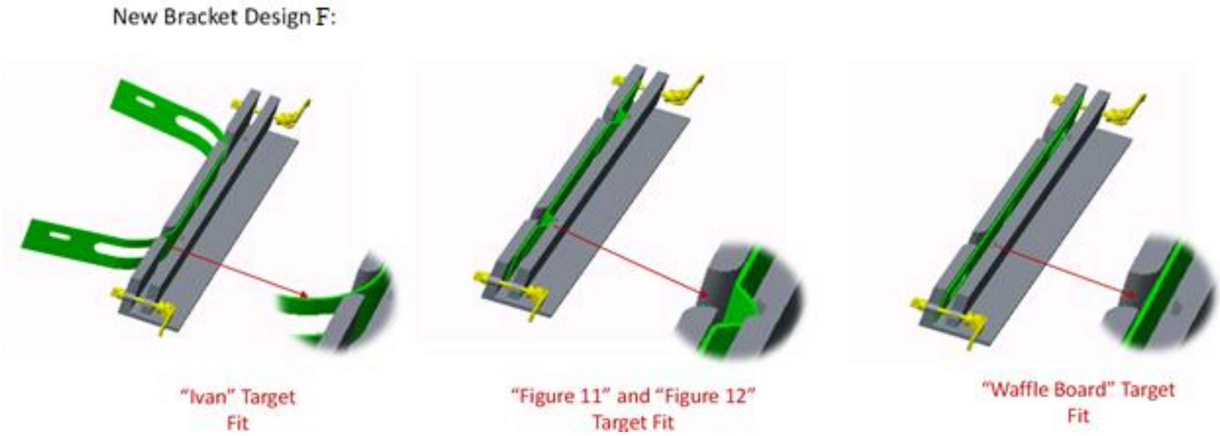


Figure 17. How the various required targets fit into Bracket Design F

6.2.1 Bracket Design G

Bracket Design G shown in Figure 18 below is an all-aluminum bracket that uses two toggle lever clamps to brace the various targets against the front plate. This design allows for a maximum arm attachment height of 14 inches which can provide about a 5 inch clearance for the motor housing, when the arm is sitting above the lifter in the up position. This bracket is more complex than Bracket Design F but it allows for a more secure universal fit for each of the 4 targets. This design is also lighter in weight, smaller in size and has a fewer number of parts increasing both the reliability and loading time of the bracket.

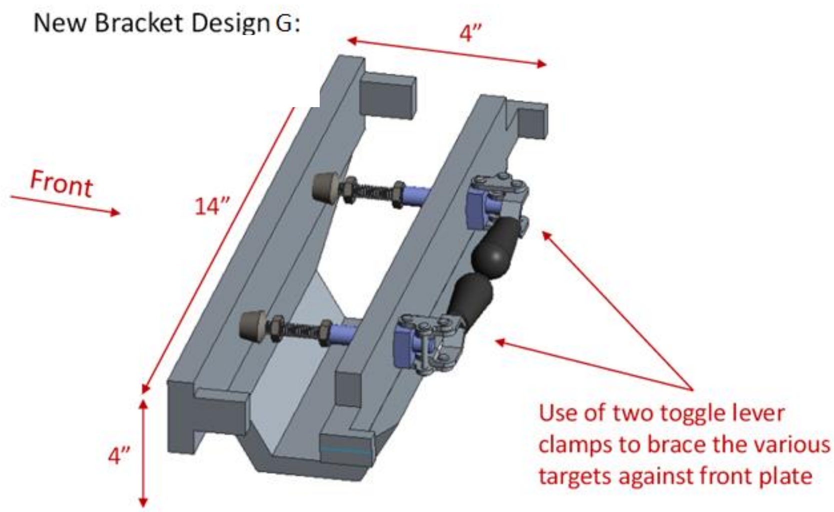


Figure 18. Bracket Design G

As seen below in Figure 19, the targets fit into the bracket design according to the shape and profile of the target. The targets are held between these two plates using an applied friction force created from using two toggle lever clamps. This bracket design is more complex than Bracket Design F, however this bracket allows for a more secure universal fit.

Figure 19. How the various required targets fit into Bracket Design G

6.3 Bracket Design Selection

Table 2. Design Matrix for Bracket Designs F and G

Target Bracket Design Matrix			
	Weighted	Bracket Design F	Bracket Design G
Simplicity	5	4	2
Cost	3	4	2
Size	1	2	4
Weight	2	3	4
# of parts	4	3	5
Loading time	4	3	3
Reliability	5	2	4
Total Point Value		74	80

The Design Matrix, seen in Table 2 above, compares the two final bracket designs conceptualized by team 16. For this matrix each of the engineering factors have been weighted numerically from 1 to 5. A weight of 1 implies that the factor is of little concern and a weight of 5 indicates that the engineering factor is very important.

The goal of these two mechanical bracket designs is to hold each of the 4 standard targets securely while the lifter operates. The engineering factors have been weighted based on the customer's specifications and the lifters constraints. Lockheed Martin's current mechanical bracket is inefficient and inconvenient for the user when loading each of the four different types of targets into the lifter.

Simplicity, reliability, loading time, and number of parts were determined to be the highest weighted and most important factors of our preliminary designs. The loading time was presented to be one of the more important constraints, as our design must allow for each target to be changed and loaded within 10 seconds. Each Bracket Design F and G incorporate toggle clamps or bicycle clamps to securely hold the 4 standard target types.

Reliability is weighted as very important due to the fact that the mechanical bracket design must be able to withstand variable environmental elements including water, dust, wind, and sand. The design must also be reliable to ensure that the bracket will continually hold the targets as they are shot at repeatedly. Due to the greater number of parts and the adjustable sliding front plate, Bracket Design F received a lower score in the reliability section. The sliding front plate may allow for mud or other debris to prevent the plate from adjusting or functioning properly.

Weight, cost, and size are other factors that our team took into account while designing the mechanical target arm. These factors happen to be weighted lower than the previously discussed factors but are still necessary design elements to consider. Using all weighted factors, it was determined the best design was Bracket Design G.

6.4 Arm Design

In order to attach the bracket to the lifter an arm is needed, as seen in Figure 1. This arm must also house the motor, gearbox and microcontroller. As stated previously in the constraints, the top of the bracket must not be more than 18 inches above the ground. The motor or motor housing must also meet IP 67 requirements. These requirements state that the motor must be able to operate in dusty or wet conditions. With the final selected bracket, Bracket Design G, the arm must not extend more than 13 inches above the ground in order to provide the needed clearance for the lifter. During the lifting process, the arm must also clear the top of the lifter. The top of the lifter is 9.5 inches above the ground, this means that the motor housing and arm attachment must fit between a space of 3.5 to 4 inches if the arm is to sit over the top of the lifter. The arm may sit centered over the lifter or the arm and may sit behind the lifter after the target is raised. In order to complete the arm design selection, the motor analysis must be completed and a motor must be selected to determine the dimensions of the motor housing and the placement of this motor housing on the arm attachment.

6.4.1 Arm Design A

Arm Design A, as seen below in Figure 20 is a simple U-shaped arm that sits over the center of the lifter when raised. The arm houses the motor and its internals in an area that runs along the underside of the top of the arm attachment. In this design the back of the motor housing is left exposed for ventilation and easy access to the motor and gearbox. In order for this housing to work, the motor and electronics must meet IP 67 requirements individually. This is not cost effective so an alternative IP 67 housing should be used.

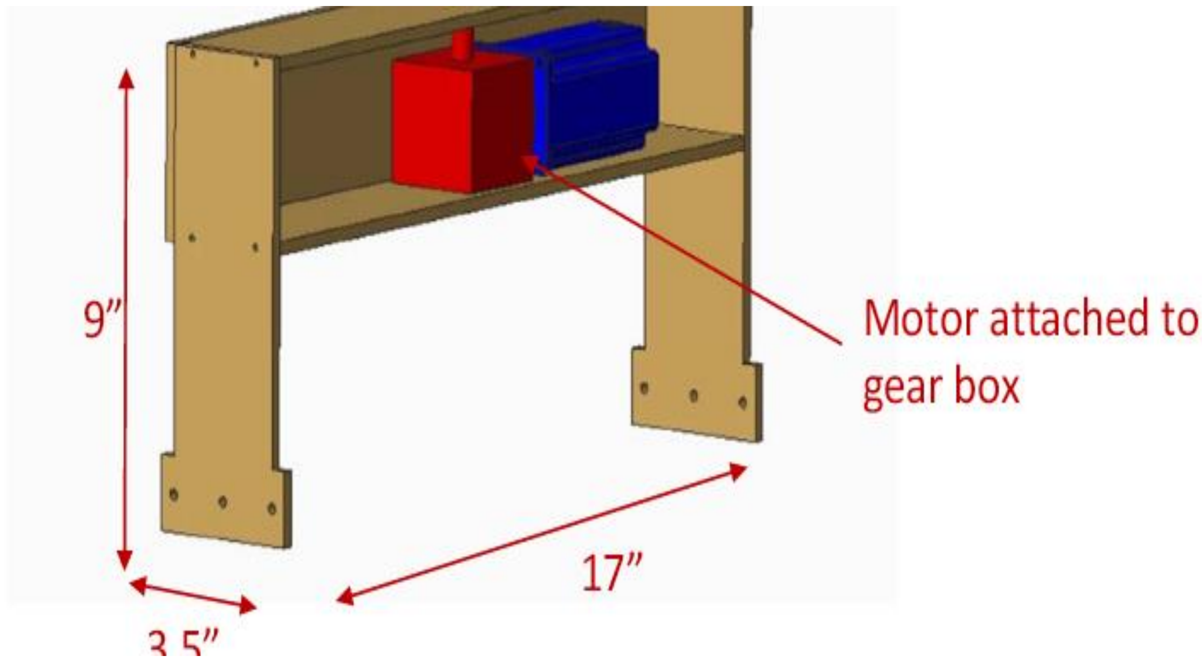


Figure 20. Arm Design A

6.4.2 Arm Design B

Arm Design B is very similar to Arm Design 1, however it has a curved profile and features a motor housing that sits on top of the arm attachment. The dimensions of the motor housing are still to be determined based upon motor selection. Depending on the selected motor, this design may or may not be suitable for the lifter. The motor housing in this design is fully enclosed and features a detachable plate that allows technicians to access the internals of the housing.

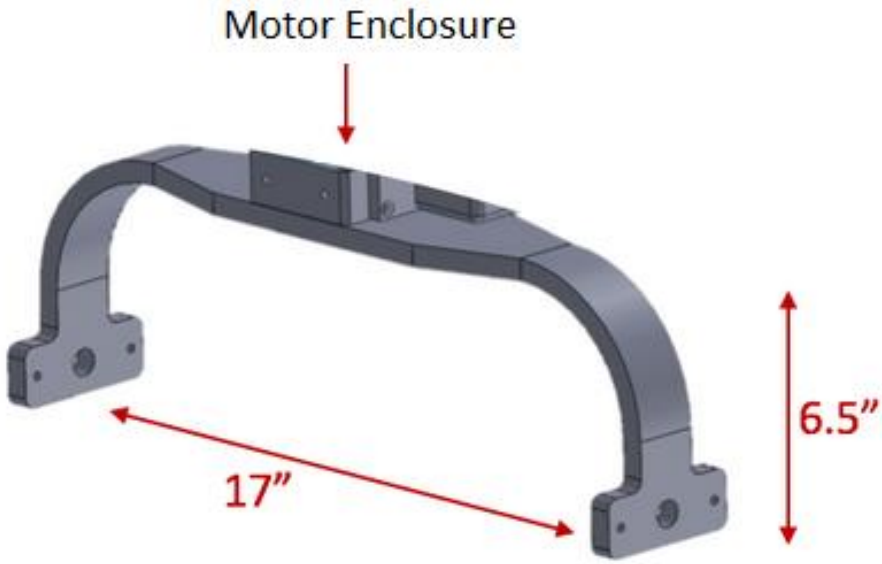


Figure 21. Arm Design B

6.4.3 Arm Design C

Arm Design C sits behind the lifter when the arm is raised. This design eliminates the pinch point problem that occurs when the arm sits directly over the lifter. In order to achieve the desired positioning behind the lifter, the arm is angled back to provide a gap between the arm and the lifter. The arm also holds the motor housing in this design. The motor housing is attached with two bolts from the top of the arm. This allows the motor housing to be taken off of the arm completely for maintenance. The motor housing also features vents and fins in order to keep the motor from overheating. Technicians can access the internals of the housing by simply removing the back plate with a Philips head.

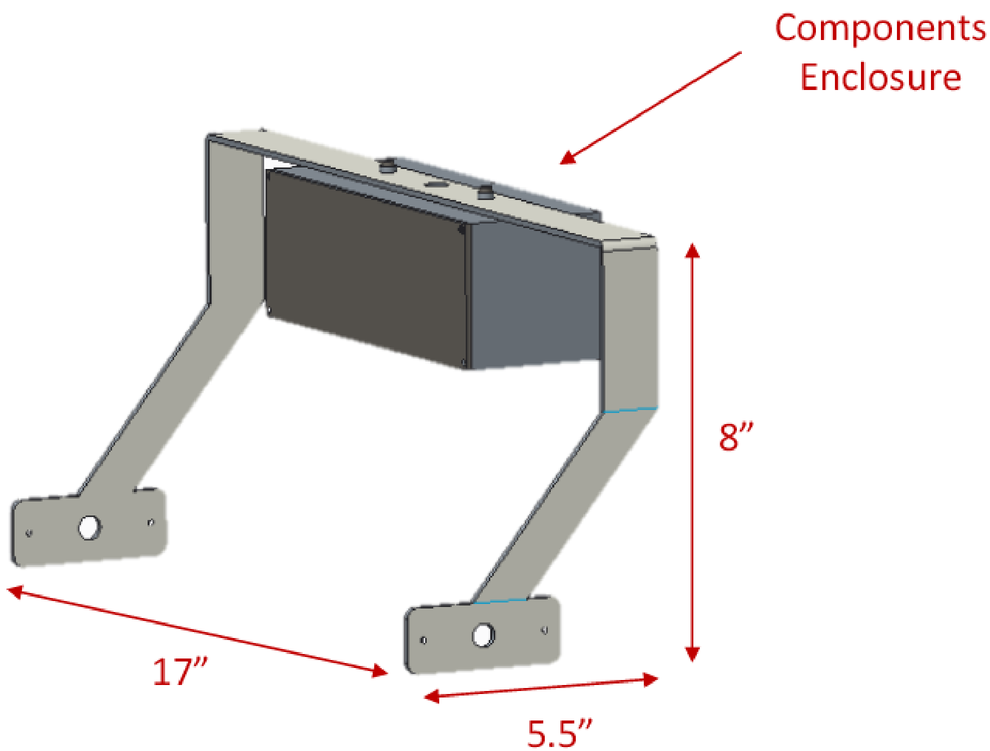


Figure 22. Arm Design C

6.5 Arm Design Selection

Table 3. Design Matrix for Arm Designs A – C

Target Arm Design Matrix				
	Weighted	Arm Design A	Arm Design B	Arm Design C
Simplicity	5	4	2	2
Cost	3	4	2	2
Size	1	2	3	3
Weight	2	2	4	3
# of parts	4	4	3	3
Reliability	5	4	3	4
Total Point Value		74	54	57

The Design Matrix, seen in table 3 above, compares the three preliminary mechanical arm designs conceptualized by team 16. For this matrix each of the engineering factors have been weighted numerically from 1 to 5. A weight of 1 implies that the factor is of little concern and a weight of 5 indicates that the engineering factor is very important.

The goal of these three mechanical arm designs is to hold the motor housing and its internals while lifting the bracket and each of the 4 standard targets. The engineering factors have been weighted based on the customer's specifications and the lifters constraints.

Simplicity, reliability, and number of parts were determined to be the highest weighted and most important factors of our preliminary designs. The simplest design with the fewest amount of parts is design 1. The problem with Arm Design A is having the motor housing meet the required IP 67 statute. This can be solved by combining the motor housing from arm design 3 with the arm from the first design.

The greater the number of parts, the less simple the design, and the higher the risk that the design will not withstand the elements or required testing. Arm Designs B and C were considered less favorable do to the number of parts associated with the motor housing and arm attachment.

Reliability is weighted as very important due to the fact that the mechanical arm design must be able to withstand variable environmental elements including water, dust, wind, and sand. The design must also be reliable to ensure that the bracket will continually hold the targets as they are shot at repeatedly. The designs that scored the best in this area were Arm Designs A and C.

Weight, cost, and size are other factors that our team took into account while designing the mechanical target arm. These factors happen to be weighted lower than the previously discussed factors but are still necessary design elements to consider. Using all weighted factors, it was determined the best designs were Arm Designs A and C.

Due to its simplicity, Arm Design A was selected. If future iterations of arm designs are needed, Arm Design C's principal design elements will be taken into account due to its high rating with respect to the team's weighting factors.

7.0 Final Design

7.1 Bracket Design

The selected final bracket design was design G, due to its advantage in weight, reliability, and cost. To test the design before manufacturing, a prototype was produced to ensure proper placement and fit of all targets, a 3D model was printed courtesy of Lockheed Martin. Photos of the initial test fit can be found in Appendix G. Based off measurements from this 3D printed prototype, an updated version of the bracket was created and used for the final design. The main characteristics changed were the overall height of the bracket, the angled base, and the spacing of the tabs to allow for better placement of targets Type 11, and Type 12. The final design is shown below in Figure 23

7.1.1 Structure

The new design of the bracket, shown in Figure 23, allowed for better placement of the targets as well as a greater ease in their installment. The bracket was constructed out of three mating plates and these 3 plates were welded together. The tabs on either end were machined out of a piece of aluminum stock and welded in place. A complete set of machinist drawings for the bracket are located in Appendix A The new design required a revamped structural analysis. Analysis of this bracket can be found in section 7.1.2 which shows the effects of the applied forces.

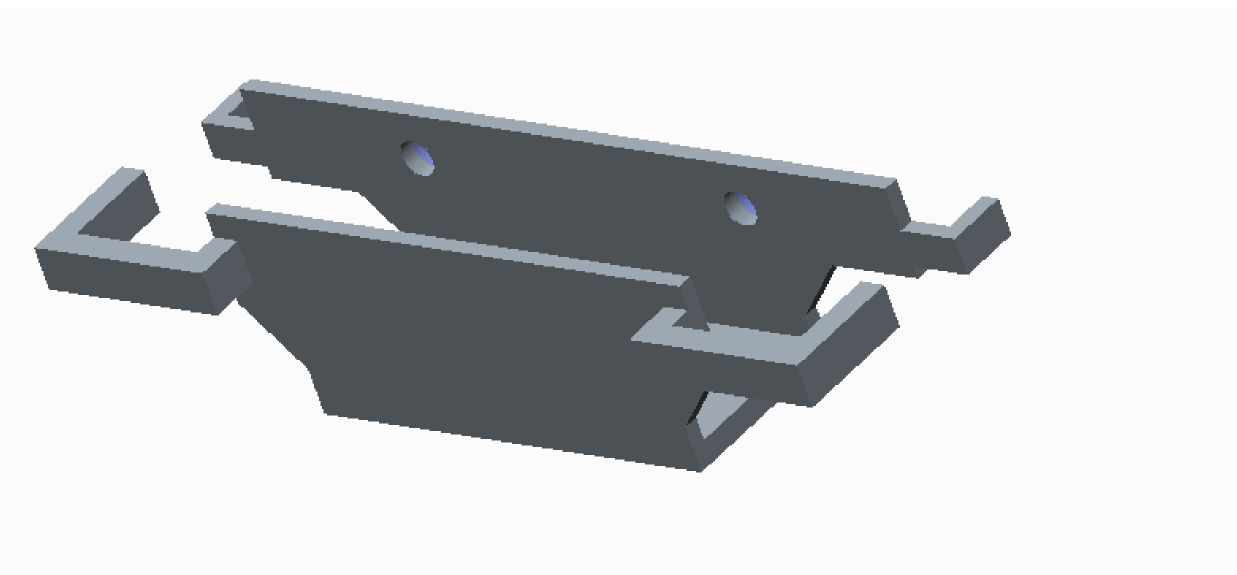


Figure 23. Final bracket design

7.1.2 Analysis

Figure 24 shows the effect of the forces being applied to the bracket. The forces being applied include the loading force of the clamps as well as the force from a wind gust of 35 mph while the Ivan style target is mounted in the bracket. This 35 mph gust of wind on the backside of the Ivan style target is the most amount of stress that the bracket will feel. Figure 24 shows the results of the analysis.

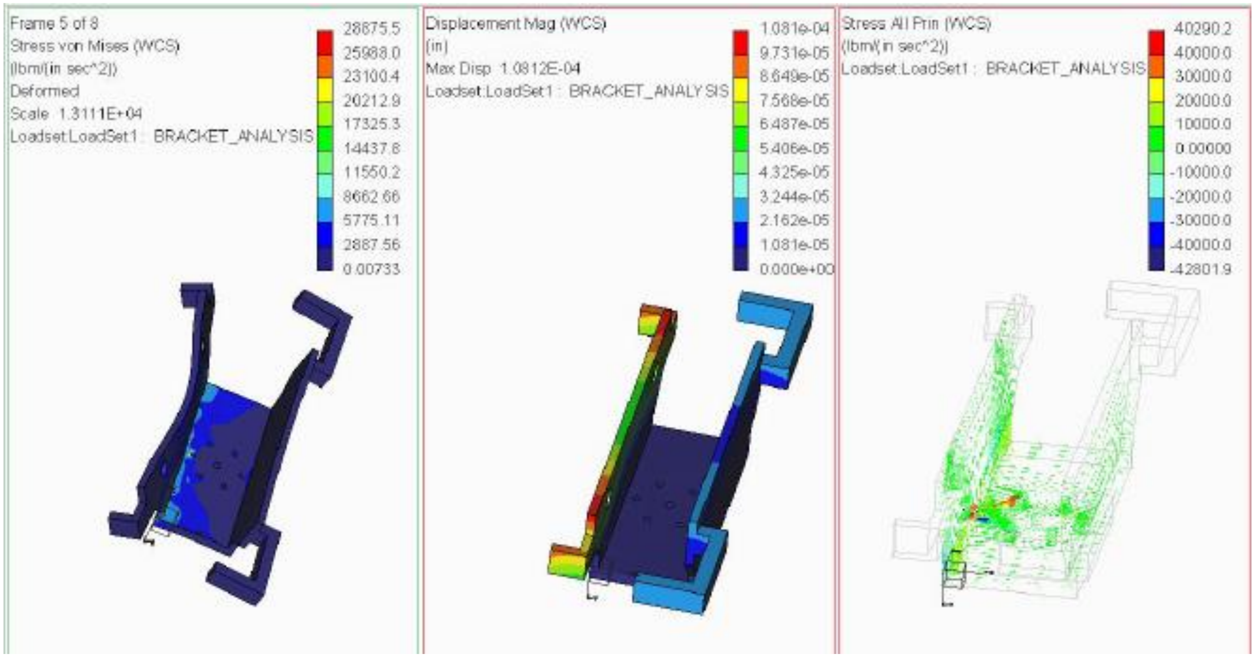


Figure 24. Static Analysis of bracket

The bracket will experience a maximum of 28,875 psi with a maximum deflection of less than 0.001 of an inch. The bracket was composed of Al6061 with a yield strength of 45,000 psi. The yield strength of 6061 is well over the point of deformation. The model did however reveal that certain stress points would occur and approximately reach 40,000 psi. Being so close to the yield stress it is important to perform a fatigue analysis and ensure the longevity of the design. These are shown in Figure 25 and Figure 26.

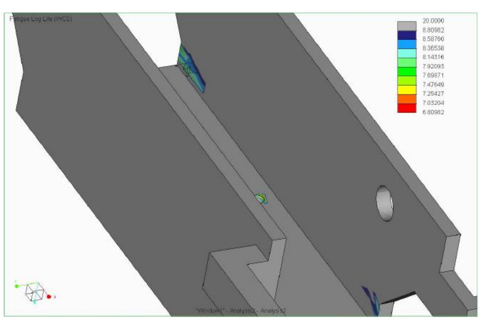


Figure 25. Fatigue analysis of Bracket

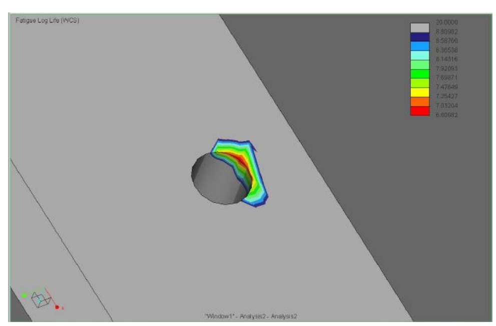


Figure 26. Main stress concentration of cyclic on

The fatigue analysis shows that the main stress concentration occurs where the hub meets the bracket, shown in Figure 26. At this point the cyclic loading will last to a minimum of 10^6 cycles before the bracket experiences failure. Lockheed Martin estimates that the bracket will go through an average of 65,000 cycles over the course of 25 years.

7.2 Arm Design

In order to attach the bracket to the lifter an arm is needed. This arm must also house the motor, gearbox and micro-controller. As stated previously in the constraints, the top of the bracket must not be more than 18 inches above the ground. The motor or motor housing must also meet IP 67 requirements. These requirements state that the motor must be able to operate in dusty or wet conditions. With the final selected bracket, Bracket Design G, the arm must not extend more than 13 inches above the ground in order to provide the needed clearance for the lifter. During the lifting process, the arm must also clear the top of the lifter. The top of the lifter is 9.5 inches above the ground, this means that the motor housing and arm attachment must fit between a space of 3.5 to 4 inches if the arm is to sit over the top of the lifter. The arm may sit centered over the lifter or the arm can sit behind the lifter after the target is raised. In order to complete the arm design selection the motor analysis must be completed and a motor must be selected to determine the dimensions of the motor housing and the placement of this motor housing on the arm attachment.

7.2.1 Structure

Manufacturing the arm involved welding a pair of legs to the top of the arm, one on either end. In order to insert the bearings required to keep the drive shaft from wobbling a bearing block was added to the top of the arm. Ideally, the bearing block and top of the arm would be machined from the same piece of aluminum stock, however, due to a time constraint a bearing block was fastened on using 10-32 x ¾ phillips screws. The arm design is a critical part of the SIT's operation. It has to connect the lifter to the bracket and provide clearance for the motor enclosure when the SIT moves from the vertical to horizontal position shown in Figure 10. The arm houses the motor enclosure which is attached underneath the top of the arm with ¼-20 bolts. This motor enclosure houses the motor, motor driver, microcontroller, and gearbox. The forces acting on the arm are greatest when the wind is blowing at 35 mph and the bracket and target are positioned at an angle of 45 degrees, this is shown in Figure 28.

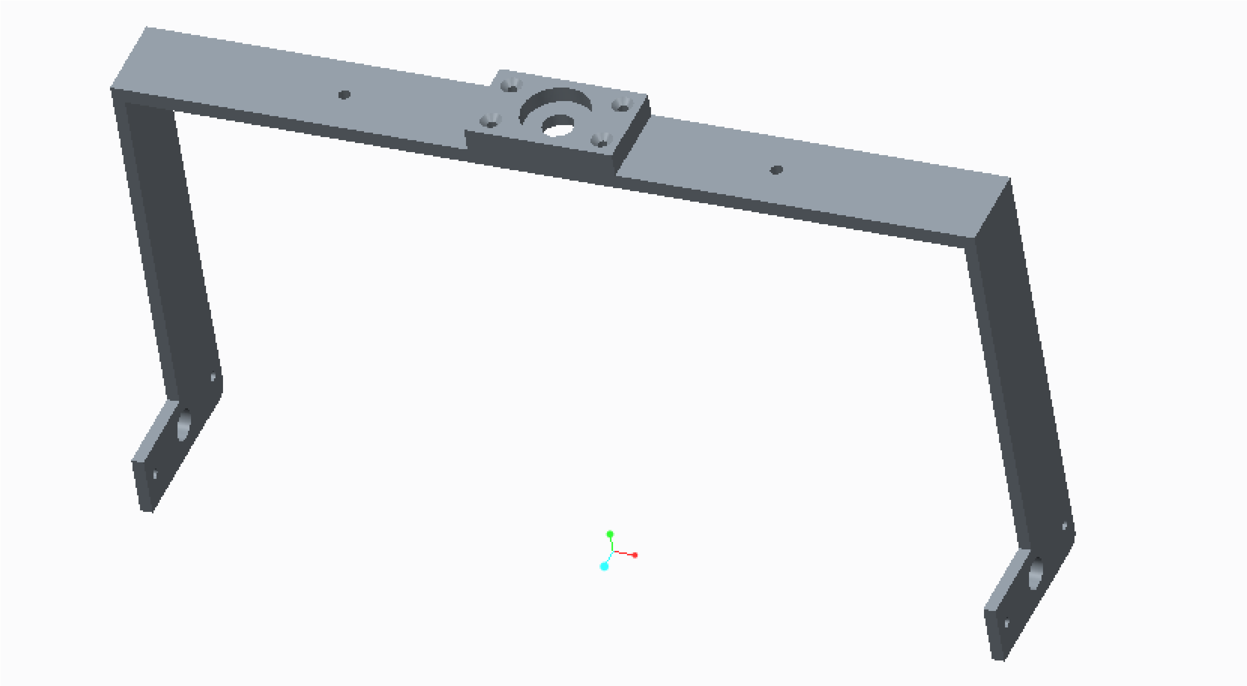


Figure 27. Final arm design.

7.2.2 Analysis

The force analysis of the arm shown below, in Figure 28, illustrates a 35 mph gust of wind blowing across the arm at a 45 degree angle on the backside of the Ivan style target. The arm was machined with aluminum 6061 metal and has the greatest amount of stress, approximately 20,000 psi, due to a torsional component in the arm. As previously mentioned, the yield strength of Al6061 is 45,000 psi. It is also important to look at the stress points the arm will experience. The greatest stress will occur along the bolt holes connecting the arm to the lifter. Since these stress point concentrations are around 20,000 psi, for the worst case scenario, a detail cyclic loading analysis was not preformed due to the minimal amount of stress and the rarity of the occurrence.

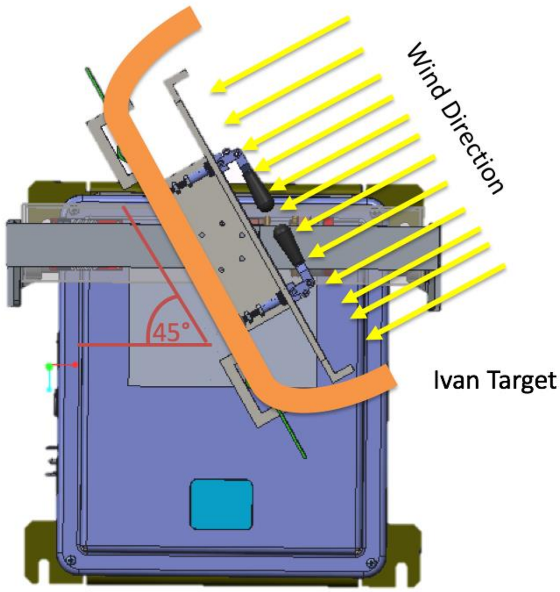


Figure 28. A wind blowing across the target at 45 degrees.

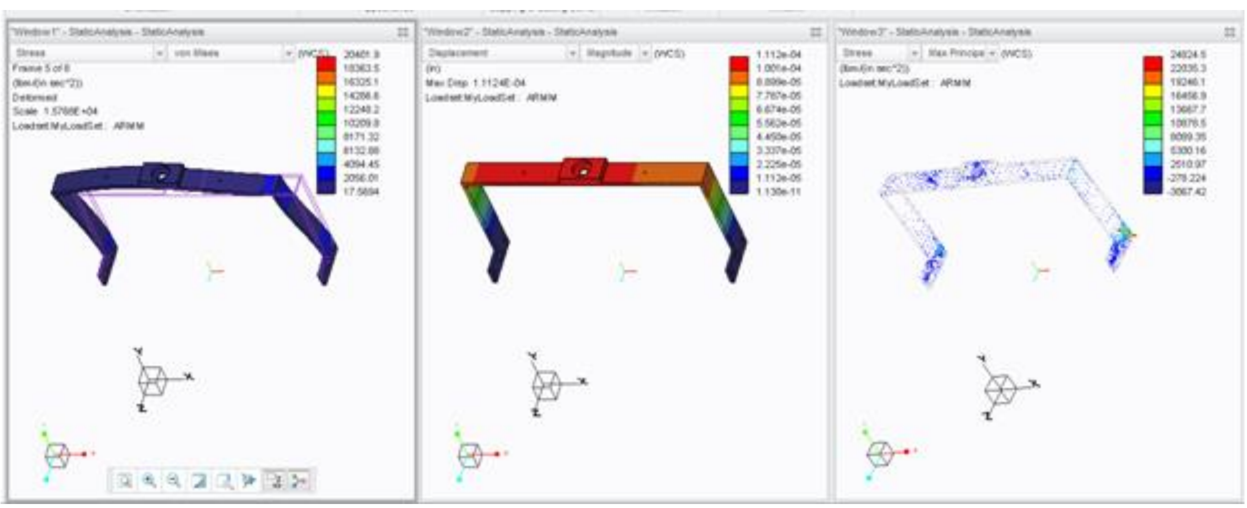


Figure 29. Static analysis of final arm design

7.3 Turning Mechanism

7.3.1 Flow Analysis

In order to determine the required output torque from our turning mechanism for proper target presentation, the team simulated a wind flow of 35mph on all of the required targets at various angles. This 35mph was a given design requirement. SolidWorks was used to provide basic simulation for gusts of wind on targets. The simulation was done on the largest flat, fiberglass "Type 11" target and the scooped frame "Ivan" three-dimensional target. These were chosen due to their large cross section and high drag geometry. These simulations were run at various angles with respect to the flow of wind to determine the maximum force and torque. The maximum force measured was the wind force on the target in the direction of the lifting action. This value was used to determine the stresses on the arm and bracket that the team must design for. The maximum force seen on any target was 21.3lbf, generated from Figure 30 on the Type 11 target. This target was oriented completely perpindicular to the oncoming wind.

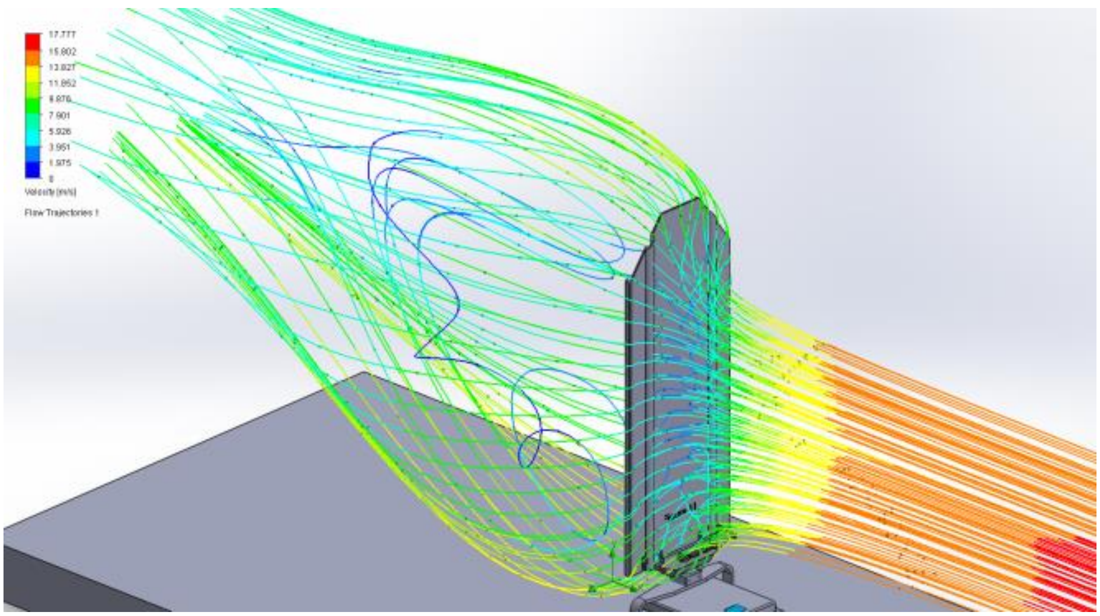


Figure 30. Flow Simulation for maximum force on Type 11 target

The maximum wind torque that could potentially twist the mechanism was determined to be 11.5 ft-lb on the "Ivan" type target. This torque was seen when the target was oriented 135 degrees to the flow, as can be seen in Figure 30. This torque could potentially change the orientation of the target so it must be accounted for. Force and torque values for both targets in all the positions can be seen in Table 3. A full data sheet of the forces and torque in all three vectors can be seen in Appendix H.

From these simulations, the team was able to begin designing for the turning mechanism given these determined constraints.

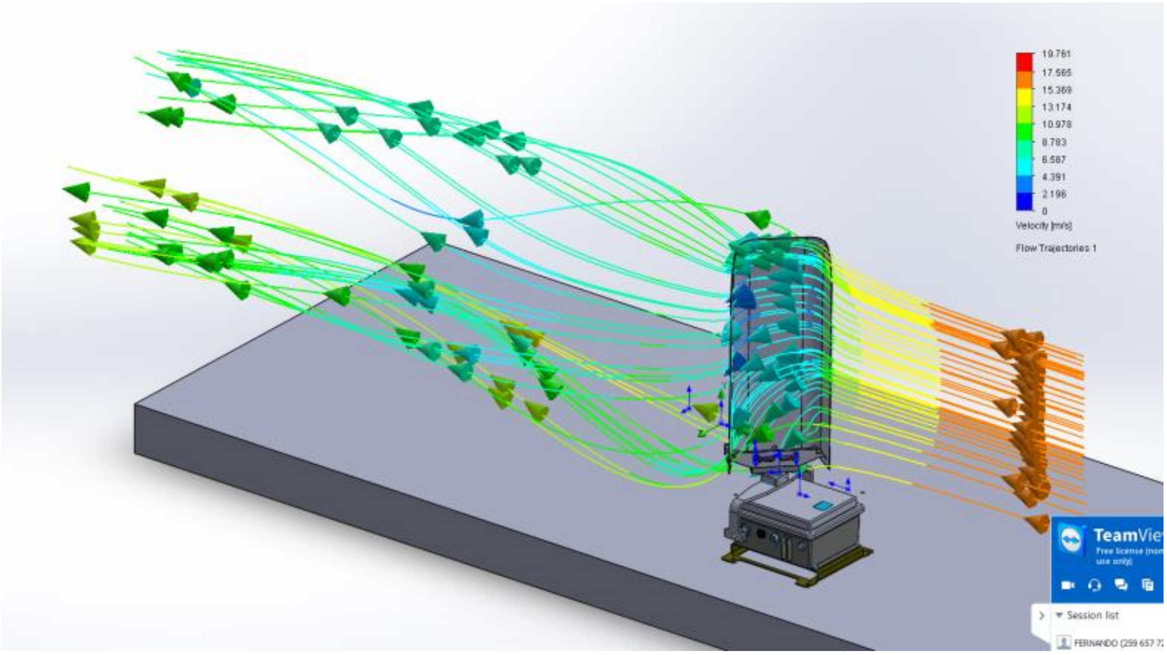


Figure 31. Simulation for determination of maximum torque on scooped “Ivan” geometry

Table2. Design Matrix for Bracket Designs F and G

	Flat ("Type 11")		Ivan	
Target Orientation	Torque (ft*lbf)	Wind Force (lbf)	Torque (ft*lbf)	Wind Force (lbf)
0	0.496555128	-20.41727697	-0.433172772	-9.90357535
22.5	8.433826929	-20.16032383	-2.254546714	-9.106846662
45	10.85162964	-10.64542797	-3.142180928	-7.065746034
67.5	8.628485904	-0.040957194	-0.301622704	-4.927292128
90	-1.152802341	-0.456811964	0.245513217	-2.913801289
112.5			8.505929792	-5.735019996
135			11.50034865	-12.73711637
157.5			9.340363253	-14.16619008
180			0.865094986	-16.32183157

7.3.2 Mechanical Components Selection

With a safety factor of 1.25 the team found that the mechanism needed to provide 3000 ozf-in at 40 rpm in order to meet the torque specification, as well as the turning time requirement. Through background research on many different motors and gearing, the team settled on a system of components from what turned out to be one of our main vendor's, AndyMark. After analyzing the data sheets for the motor and respective, compatible gearing, the AM-0912 motor was selected, providing about 60 oz-in of torque at stall, and 30 oz-in of torque at maximum power.

Figure. 32 CCL-9015 12VDC Brushed Motor

This motor obviously needed to be geared in order to meet the torque requirement. To do so, the team selected the compatible AM-0002 planetary gearbox from AndyMark. This gearbox provided modularity and simplicity of integration.

Figure 33. AM-0002 Planetary Gearbox

This gearbox allows for multiple stages to be added at a ratio of 3.67:1, and most importantly, was compatible with the right angle bevel gearbox AndyMark supplies. The team searched for a right angle gearbox to implement. This right angle gearbox would allow to change the direction of the output to turn the targets, while still staying within the height constraint. Figure 30 shows the selected right angle gearbox.

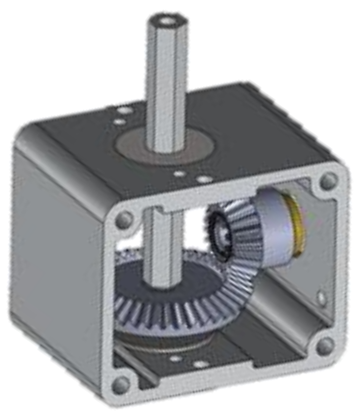


Figure 34. LJ Bevel Right Angle Gearbox

This right angle gearbox also had an additional gear ratio of 2:1 on top of the linear planetary gear stages. To provide the 3000 oz-in required torque, the team would employ the motor, 3 planetary gearbox stages and the right angle gearbox, bringing the provided output torque to 3000 oz-in at 80 rpm, successfully meeting our design criteria. Below is the assembly of the components in their entirety, as well as an exploded view. All of the mechanical drawings for the components mentioned can be found in Appendix C

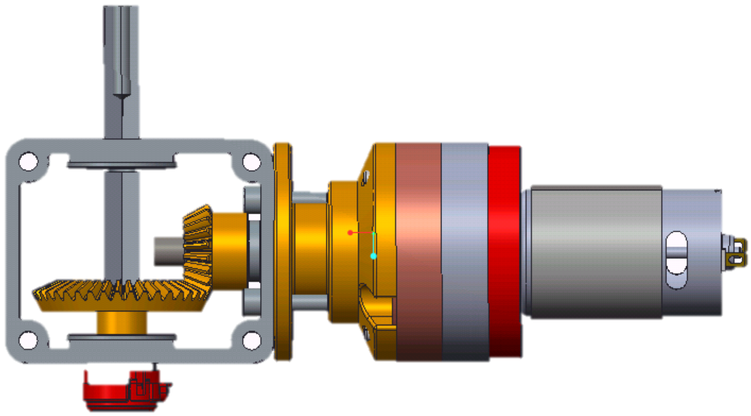


Figure 35. Assembled motor, planetary gearbox stages and right angle gearbox

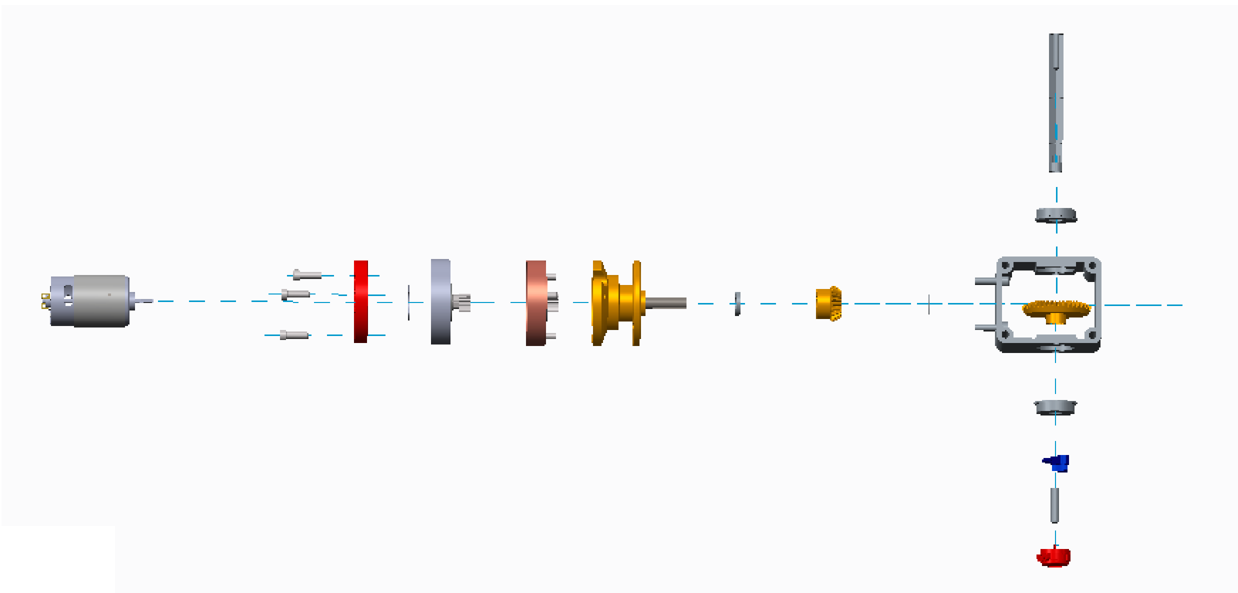


Figure 36. Exploded view of turning mechanism

7.3.3 Electrical Components Selection

To be able to implement position, velocity and acceleration control, a US Digital E4T encoder was employed. This encoder was compatible with our system and would mount to the bottom of the right angle gearbox. The encoder is an incremental quadrature type, with 1440 quadrature pulses per revolution. Since the encoder will be mounted directly to the output shaft, meaning that each pulse of the encoder induced by the rotating output shaft, corresponds to 0.25 degrees of target rotation. This will be useful when programming the turning control. Figure 37 shows the E4T encoder.

Figure 37. US Digital E4T optical encoder

In order to supply the required voltage and current to the motor, given a user input, the team searched for a microcontroller and motor driver capable of running the desired position control of our system. To demonstrate the functionality of our prototype, the Arduino Uno and Roboclaw 2x45A motor controller were selected. Figures * and * picture the selected boards.

Figure 38. Roboclaw 2x45A Motor Controller

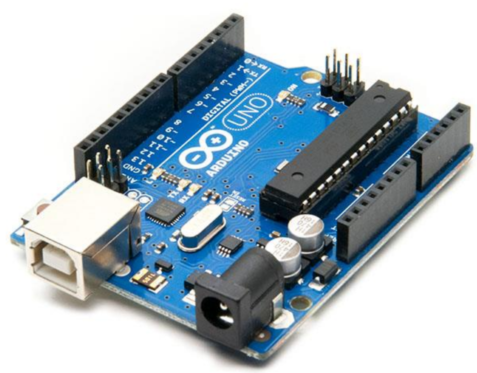


Figure 39 Arduino Uno R3

The primary function of the Arduino Uno will be to take the input from the user on an interface terminal, and relay those input commands to the Roboclaw via packet serial communication. The selected version of the Roboclaw is able to handle 45 amperes continuously, and 60 amperes peak, which is ideal for our motor and gearing selections. Most importantly, the Roboclaw is a very versatile motor driver and controller. It is capable of taking in multiple encoder signal inputs and controlling motors via PWM signals. The controller will also provide PID and PD control for a given application, making it an ideal selection for this prototype. The Roboclaw comes with its own Arduino Libraries, which will be explained in the programming section of this report. Since this system will require 12V at 30A or more, the team acquired a 12V, 30A power supply to power the motor and gearing for our position control. Figure * pictures a similar power supply to the one our team utilized.

Figure 40. 12V-30A (360W) Power supply

Because so much current might be drawn from the power supply, the wires used to connect the supply to the Roboclaw, and the Roboclaw to the motor, were chosen to be AWG12. These electrical components are able to power the turning system with the accuracy needed to complete the sponsor's requirements. The mechanical drawings for all of the listed electrical components can be found in Appendix C.

7.3.4 Programming

The programming component was completed in the Arduino Integrated Development Environment (IDE) where the team made use of the open source interfacing between the Roboclaw and Aruino Uno. IonMotion provides Roboclaw libraries for the Arduino, so that certain built in functions may be used to control various aspects of the Roboclaw. The Arduino IDE's serial monitor was used to take inputs form the user in the form of character inputs '0' – '6' for the different target positions. Appendix E has the position control code and explanations of how all PID constants were found and explains the use of all Roboclaw Arduino library functions. It is also noted that the team used the IonMotion control application to tune the control settings on the Roboclaw via the use of USB.

7.3.5 Turning System Mock-Up

To test the feasibility of our system, a mock up was constructed using a DC motor, quadrature encoder, lower power supply battery and gearing. Figure* depicts the mock up employed.

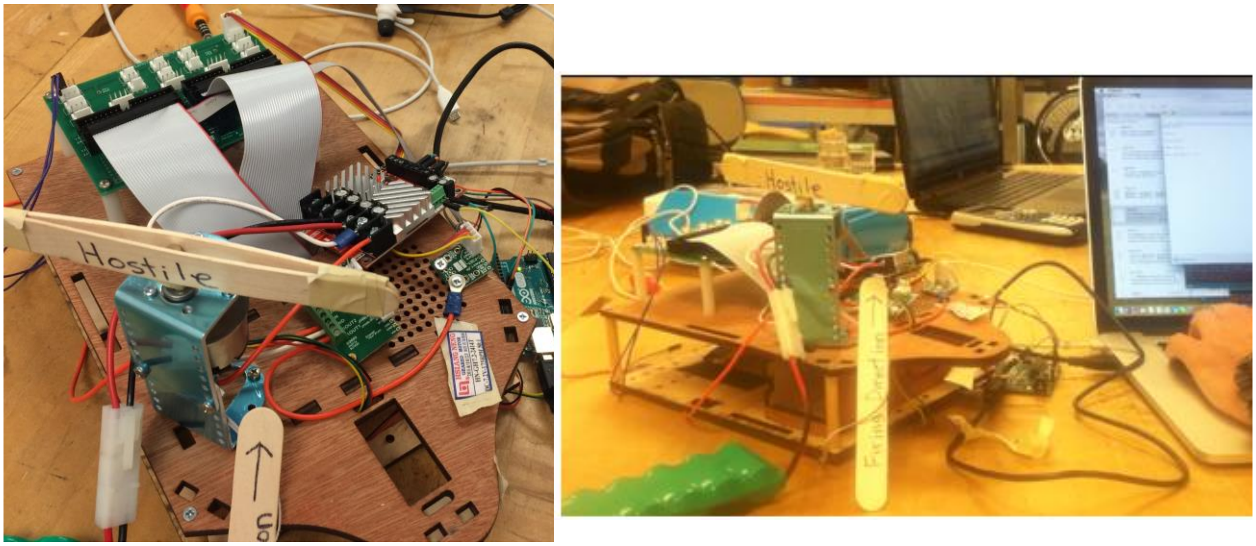


Figure 41. Mock up of prototype

Although the system was much less powerful, it allowed the team to develop the turning code to implement on the final system. The integration with the final system only required the changing of some system constants and PID/PD control values based upon the tuned settings in the IonMotion control application. Refer to Appendix E for more explanation of constants and prototype functionality.

7.4 Enclosure

The motor enclosure was designed to protect the electrical components and prevent water, dust, sand, and debris from damaging the motor, gearbox, microcontroller, and motor driver. This enclosure is thoroughly sealed in order to meet IP67 requirements which states that the enclosure must be "protected from total dust ingress and protected from immersion between 15 centimeters and 1 meter in depth." The enclosure is sealed using a silicone gasket on the situated in a gland on the bottom of the box. Silicon was used because of its extended life and very reliable seal it provides. Only about 30% compression of the gasket is needed to ensure a water tight seal **[6]**. This compression will be provided by 14 10-24 bolts situated around the lip. These bolts should be evenly torqued to ensure protection of the electrical components inside the enclosure. On the top side, which is flush against the arm, an O-Ring is used to seal the drive shaft hole. The dash number for the O-Ring is 223.

The material for the enclosure is plastic, this was selected based upon the weight constraint of the system, which must be lighter than 10 pounds. To meet this constraint the original aluminum design was avoided which helped drop the weight of the original aluminum enclosure from 2.5 pounds to a final acrylic enclosure weight of just 1.2 pounds. The choice of plastic also simplified the manufacturing process as it could be 3D printed.

Four thru holes are drilled in the sides of the enclosure to mount the bevel gearbox to the inside. Proper bolts with washers must be used to ensure a seal. Also, for the purposes of this project, a hole is drilled into the lid to allow power and signal wires to run into the enclosure. This allows the team to perform a full demonstration of the prototype. The correct connector plug can be substituted for this hole while still keeping the overall enclosure water-tight.

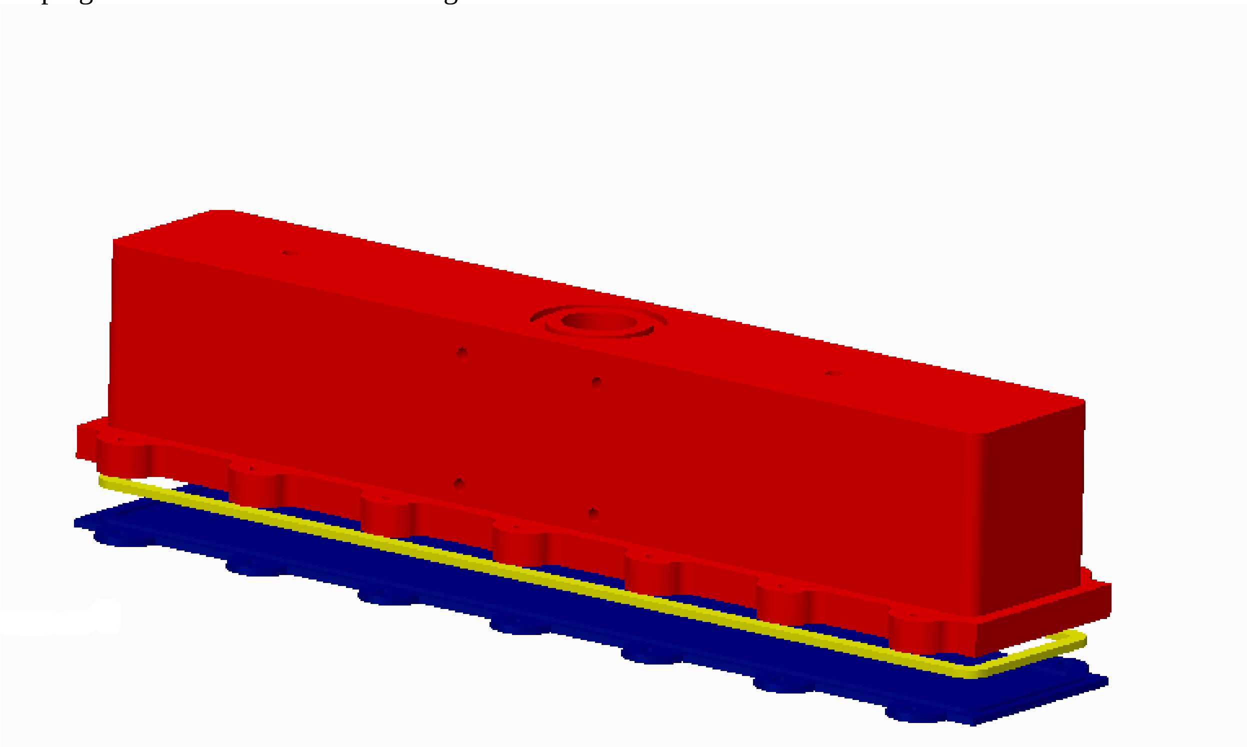


Figure 42. Close up view of enclosure

7.5 Manufacturing Considerations

The prototype built by Team 16 took manufacturing considerations into account for casting purposes. Lockheed Martin request the team to have a casting mold ready for future manufacturing process. A contact was given to us by our project advisor to have the prototype ready for Aluminum injection mold. The team established a communication with Rob Gusman, V.P - Sales and Marketing individual from Aluminum Die Casting Co., Inc. There are two key design elements to take into consideration when preparing a prototype for injection mold. First is known as draft, this is whenever the parts have enclosure long walls a minimum of 1 degree from ground reference need to take into consideration, because when aluminum colds down it tends to shrink making the part molded very difficult to extract from the mold. An example of this are ice cubes, if you notice they are not perfectly square, the addition of an angle make them easy to take off from the plastic mold. The Second design element is known as Radii/Fillets, and this means avoid any right angle edges on the entire part. This comes into consideration since this will be injected molded, air will be trap inside the mold and it tends to get in the corners when an edge is present, so the addition of radii is necessary to avoid unwanted bubbles in the corners. Also, we can see from Figure ## the comparison from the prototype to the ready for manufacturing part.

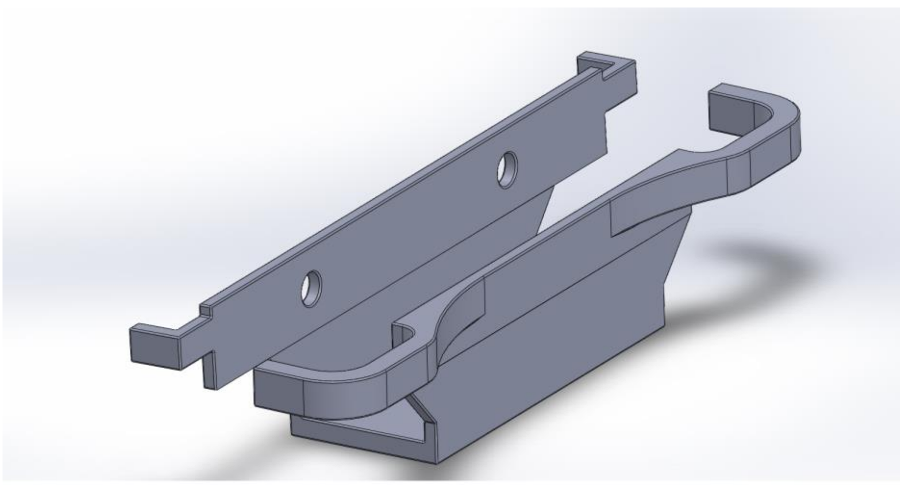


Figure 43: Aluminum Casting CAD

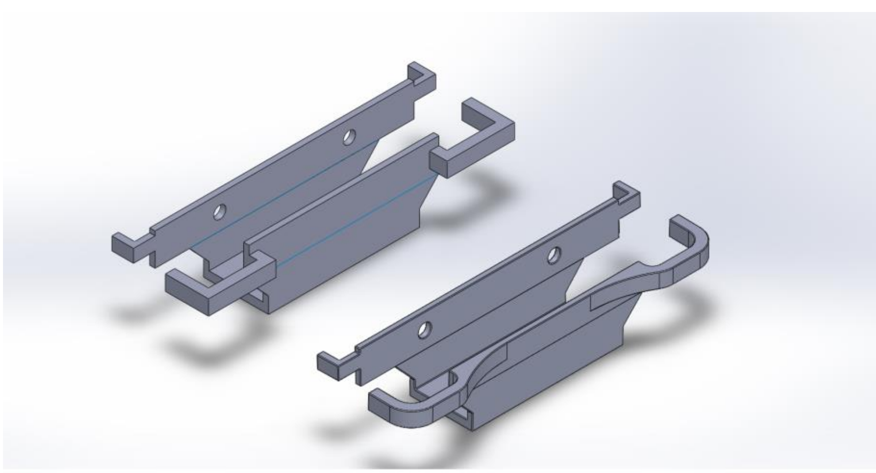


Figure 44: Aluminum Casting CAD and Prototype comparison

8.0 Results

8.1 Prototype

The entire assembly is designed to endure strenuous outdoor conditions in different locations throughout the world. The system will operate outdoors and will be exposed to fluids, debris, sand, dust, rain and strong gusts of wind. This prototype will be made in order to be mass produced in hopes of distributing the prototype to various training ranges throughout the world. An exploded view of the completed prototype can be found in 8.1.1.

8.1.1 Physical System

The physical system is represented below in Figure 45. This shows an exploded view of the complete assembly with the motor enclosure, electrical components, arm, bracket, lifter and target.

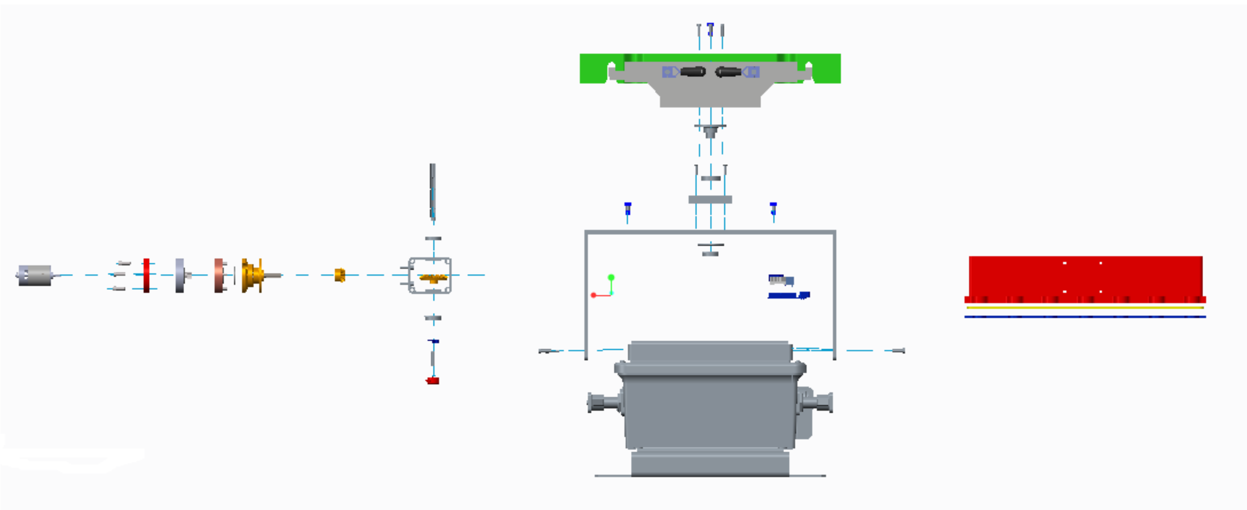


Figure 45. An exploded view of our complete assembly

8.1.2 Observations

After assembling the prototype, the team made observations, noting the details of the finalized design. Firstly, it was noticed that the bevel gearbox output shaft had slack in it. This was due to the gears from the right angle gearbox not being in perfect mesh. The slack is attributed to large manufacturing tolerances with which AndyMark produces their gearboxes. Also, the shaft key which was sent in order to mount the planetary gearbox to the 90 degree bevel gearbox was too large, and had to be sanded down 0.002 in order to fit in the keyway. This produced a small amount of slack in the motor to pinion attachment to the right angle gearbox. The accumulation of this slack results in a slight error in the final target position of about +/- 5 degrees. When observing the target from a distance, the error is unnoticeable.

When the arm was completed, the team noticed a few slight errors. One slight error is fitment of the legs on the lifter. Due to the welding of the two lets to the top arm plate, the top plate is slightly bowed, causing the legs to be slightly angled outward from an orthogonal position to the top pate. This is not a major issue, as the arm is still allowed to slide over the lifter mounting plates on either side of the lifter. Secondly, the bottom hex bearing seated in the arm is slightly pinched due to the force fitting. The team had the bearing punched out and reseated after reaming the hole, and the bearing turns more smoothly, but still has slight friction in it. The top bearing however was seated correctly and has no issue rotating. The most major issue when the team first received the arm was the placement of ¼-20 holes for the motor enclosure housing. Due to the size of the motor and gear stages, the hole did not provide enough clearance for a securing nut inside of the enclosure. This meant that the team had to drill another ¼-20 hole further to the outside of the arm to allow for a securing nut to clear the motor and gearbox underneath the enclosure. Another error in the arm manufacturing process was the alignment of the secured bearing block on top of the arm. Originally, it was intended that the machine screw holes be symmetric so that the orientation of the block would not matter, but due to a slight drawing error, the orientation of the bearing block is critical. The machinist noticed a 0.004 inch error and fixed the tolerance problem by adjusting the orientation of the screws in the bearing block. The 0.004 inch error stems from the part file of the provided Lockheed Martin Lifter. The distance between both lifting rotation points is 17.004" on the part file. This dimension was then imported into some of the submitted mechanical drawings, but neglected in others. This caused confusion, and the machinist decided to fix it himself. The part files and drawings for the arm have since been corrected, making sure this extra 0.004" inch dimension has been taken into account, and can be found in Appendix B.

The day of receiving the bracket, it was noticed that two of the four targets fit in perfectly. However, the thicker Type 12 and rigid aluminum Type 11targets did not fit perfectly. This was due to the tabs on the end of the bracket being slightly too wide for the targets to fit. To alleviate this problem, the inside edges of the outer, front tabs of the bracket were slightly filed down until the targets could easily fit. This error could possibly be due to imprecise welding, or warping of the metal when welding the small aluminum securing tabs. After securing the clamps to the bracket, the function of one of the clamps was noticed to be intermittent. One of the toggle clamps will lock fully back into the recessed position, but it is difficult to push it into its furthest travel position from the fully recessed position. The team simply added grease to the clamp to make it function properly. The target fitment in the bracket for the Type E, waffle board, target does sag slightly due to its lack of rigidity. This is due to the small surface area of the rubber stoppers on the end of the toggle clamps. Larger surfaces area clamps will alleviate the problem. The team came to the conclusion that the bracket could have been constructed out of less material, although the geometry and position of all features are critical. Furthermore, the securement of the hex hub/flange to the bottom of the lifter could be secured with less than six 10-32 screws, as this was determined to be overdesigned. In the future, it might be useful to cast the bracket in such a way that the bracket cast includes the slot for the output shaft directly out of the cast, rather than securing a completely separate part with screws.

The turning and position control was completed on a mock up as to save us time in implementing it on the final system. It was seen that the transfer from the mock up to the actual system was smooth. There only needed to be changing of gain values based on how precise our control was going to be. However, there were some slight inherent errors in the system design. The encoder selected was an incremental quadrature encoder, which must be homed to a zero positon before powering down, and after powering on the system, should be checked. This may be fixed by adding an incremental encoder as mentioned before in the 7.3.3 Design Section for the electrical components. Further, there is slight error in the position control due to the placement of the encoder in the gear train. The encoder is currently in position on the output shaft, far away from the motor. This means the position of the output shaft is being traced directly with a 1:1 ratio of quadrature pulses to output rather than being behind the gear train, mounted on the motor. This has caused the position control system to lose resolution. The system error comes in the selection of the motor. Due to the motor's size and compatibility with gearing, we selected it, but it is not compatible with any direct encoder mounting. The team decided that we could sacrifice some resolution in the position control for higher torque and holding force. Even with this slight error in the final design, the final output is only approximately 1 to 2 degrees. This meaning that the majority of error in the final commanded target position is still attributed to the slack in the bevel gearing. The slack in the bevel gearing also causes unnecessary load on the motor due to the position reading of the encoder. The motor is constantly trying to achieve the desired position, but since there is slack in the gearing, the encoder may or may not hit the intended position with precision, causing the motor to draw a load from the power supply, even when the target position is stationary. Once again, this can be fixed by placing the encoder on the motor, rather than further down the gear stages, as we have designed.

8.1.3 Risk Mitigation

In order to complete our project on time an aluminum motor enclosure was manufactured to operate and house the electronics of the turning mechanism. This was done to mitigate the risk of not receiving our 3D printed housing and gasket back in time for the final presentations. The aluminum housing serves as a backup and allows the team to stabilize the motor and gearboxes while testing the angular position controls.

In addition, extra sheets of aluminum were purchased in case there were any mishaps during the manufacturing process. These extra sheets of aluminum allowed for the aluminum motor enclosure to be built without having to create and place an additional purchase order. This saved the team an estimated two weeks time which would of been spent waiting for the arrival of these materials.

8.2 Budget

A $3,000.00 budget was provided by Lockheed Martin at the beginning of the fall semester. This $3,000.00 budget enabled the team to order metal to fabricate the arm and bracket, purchase the electronics necessary for angular position control, and build any 3D prototypes needed for testing. All parts ordered by the team during prototype development are located on the Bill of Materials under Figure 46. In addition a pie chart has been created to easily show the amount of funds allocated for different purchases. From the pie chart in Figure 46 these allocations can be visualized in terms of percentages. A third of the budget was left unused in case there were any last minute purchases that needed to be made or if the were any electrical issues with the motor driver, microcontroller, or motor during the testing stages. The Gearbox and the electronics were the most expensive parts for the project.

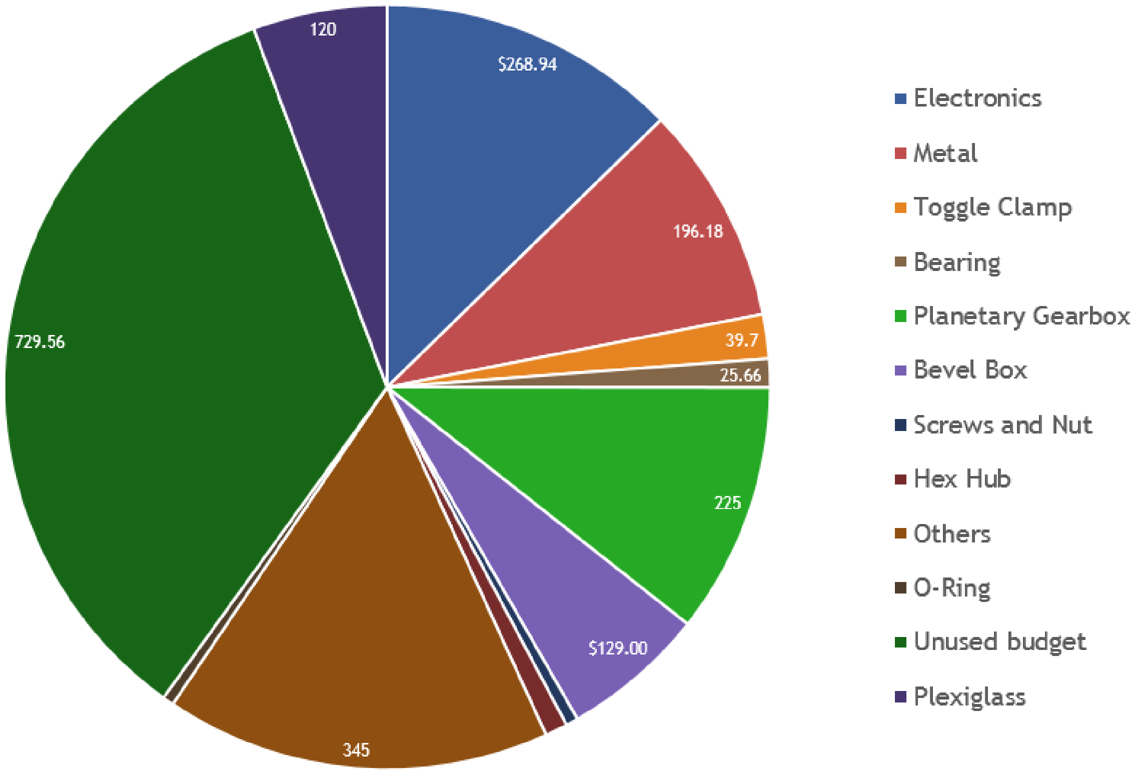


Figure 46: Cost of production

8.2.1 Bill of Materials

Part Name	Description	Qty	Item #	Supplier	Unit Cost	Cost
Aluminum 6061T651 Plate	0.3125" Cut to: 1.75" x 18"	1	N/A	OnlineMetals	$ 12.92	$ 12.92
Aluminum 6061T651 Plate	0.375" Cut to: 7.25" x 3.25"	1	N/A	OnlineMetals	$ 8.01	$ 8.01
Aluminum 6061T651 Plate	0.25"Cut to: 4" x 15"	3	N/A	OnlineMetals	$ 13.20	$ 39.60
Aluminum 6061T651 Plate	0.5"Cut to: 1" x 1"	6	N/A	OnlineMetals	$ 0.45	$ 2.70
Aluminum 6061T6 Sheet	0.125"Cut to: 16.25" x 5.25"	4	N/A	OnlineMetals	$ 13.65	$ 54.60
Aluminum 6061T6 Sheet	0.125"Cut to: 5" x 3"	3	N/A	OnlineMetals	$ 2.40	$ 7.20
Aluminum 6061T651 Plate	0.25”Cut to: 9” x 8”	1	N/A	OnlineMetals	$ 15.84	$ 15.84

Cut fee		1	N/A	OnlineMetals	$ 12.00	$ 12.00
Toggle Clamp	200 lb Max Capasity, 3-1/8" Height	2	5093 A56	McMaster	$ 16.51	$ 33.02
Toggle Clamp Screw	Flat-Tipped, 1/4"-20x 1-5/8" Size, Steel	2	5147 A63	McMaster	$ 3.34	$ 6.68
Bearing	Permanently Lubricated Ball Bearing	1	2342 K187	McMaster	$ 20.66	$ 20.66
Planetary Gearbox	Single stage 3.67:1 Ratio	1	AM-2491	AndyMark, Inc	$ 45.00	$ 45.00
Planetary Gearbox	3 stage 49.4:1 Ratio	1	AM-2547	AndyMark, Inc	$ 180.00	$ 180.00
Sun Gear	15 Tooth, 32 dp	1	AM-0040	AndyMark, Inc	$ 9.00	$ 9.00
Bevel Box	3/8 Hex Output Shaft 2:1	1	AM-2622	AndyMark, Inc	$ 129.00	$ 129.00
Encoder	Mount Pad	1	AM-0208	AndyMark, Inc	$ 4.00	$ 4.00
Encoder	Miniature Optical Encoder Kit	1	AM-3132	AndyMark, Inc	$ 42.00	$ 42.00
Bearing	Hex Bearing	1	AM-0692	AndyMark, Inc	$ 5.00	$ 5.00
Screw	#1/4-20 x 5/8" SHCS	1	AM-1203	AndyMark, Inc	$ 2.00	$ 2.00
Motor	AndyMark 9015 Motor 12VDC	1	AM-0912	AndyMark, Inc	$ 14.00	$ 14.00
Hub	375 Hex Hub	2	AM-2231a	AndyMark, Inc	$ 10.00	$ 20.00
Screw	#10-32 x 3/4" SHCS	1	AM-1191	AndyMark, Inc	$ 2.50	$ 2.50
Nut	10-32 Nylock Nut, Steel, Zinc Plated	1	AM-1212	AndyMark, Inc	$ 2.00	$ 2.00
Screw	M3 x 10mm SHCS	1	AM-1210	AndyMark, Inc	$ 4.50	$ 4.50
Aluminum 6061-T651 Plate		3	N/A	OnlineMetals	$ 5.70	$ 17.10
Aluminum 6061-T651 Plate		4	N/A	OnlineMetals	$ 0.57	$ 2.28
Aluminum 6061-T651 Plate		1	N/A	OnlineMetals	$ 2.93	$ 2.93
Aluminum 6061-T651 Plate		1	N/A	OnlineMetals	$ 16.50	$ 16.50

Cut fee		1	N/A	OnlineMetals	$ 4.50	$ 4.50
Motor Controller	Roboclaw 2x45A (Screw Terminal)	1	605104	Servocity	$ 169.99	$ 169.99
Microcontroller	Arduino Uno R3	1	2191	Pololu	$ 29.95	$ 29.95
Team Travel	Travel to Lockheed Martin	1	N/A	N/A	$ 345.00	$ 345.00
O-Ring	1/16 in Diameter, 13 length feet	1	31959372	MSC	$ 3.12	$ 3.12
O-Ring	1/8 in Diameter, 12 length feet	1	31959398	MSC	$ 6.84	$ 6.84
Plexiglass		1	N/A		$ 120.00	$ 120.00
Total		**55**				**$ 1,390.44**

9.0 Future Considerations

As the team has worked on this project, we have made note of certain considerations which anyone redesigning should consider. Some issues which may not be clear at first to the designer will be mentioned below and proposed solutions for future designers will be presented.

9.1 Bracket

Future considerations for the bracket design would be optimizing the design for casting for a final production model. The main component that needs to be addressed are the wall angles. In order to allow for a model to be cast the wall mating plates can't be at a 90 degree angle. Doing so would prevent a proper extrusion from the mold. This was concept was applied to the casting model but no prototype was produced to ensure proper placement of the targets. Another factor to consider is the faceplate on which the claps are applying pressure to. To produce a casting model, a portion was removed from the top. This reduction in height may cause interference with a proper mating of the claps against the bracket wall. The clamps used in the design applied enough pressure to hold all the targets securely and allow for their easy removal. The feature that allowed for this was the rubber stoppers at the end of the clamps. Although the stoppers are easily removed and replaced their ability to sustain adverse weather conditions were not verified.

9.2 Arm

The arm produced was fabricated using a water jet cutter, the joining pieces were then welded together. To apply this system on a wide scale this current method wouldn't be cost effective. The allow for better production the arm could be bent and shaped out of a single piece of aluminum and the joining holes could be drill after. Our current arm design has multiple holes on the top to allow for different gearing stages to be applied and proper mounting with clearance from the motor. Our final design used 3 gearing stages, so the hole closest to the leg plate and the hole on the opposing would be needed. Another notable factor that can be approved is the height of the arm. Increasing the overall height of the arm would allow for more clearance and more options for enclosure design.

9.3 Turning Mechanism

In the future, the gearboxes must be worn in by running them for an extended period of time. Also, the correct torque must be applied to all of the gear stages securing bolts before running the gearbox. Appropriate amounts of grease should be applied to the gear stages in order to run correctly. In the future, If there is a more robust modular design, it should be implemented. AndyMark’s products in the turning mechanism have worked for us, but for future permanent designs, there may be a more viable option for a powerful, high torque gear motor.

9.4 Enclosure

The motor enclosure was required to be IP67 rated to withstand the harsh conditions the lifter would be operated in. Many IP67 rated electronics enclosures exist on the market and the team took many design points from these products in designing the prototype. However, due to not being able to access the inside of the lifter box, the team was forced to run wires from a computer into the enclosure. This caused the enclosure to lose this rating as there was now a hole in the lid. In the future, a method to connect the lifter internals to the motor while still keeping the enclosure sealed must be designed. Also, the designed motor enclosure can be readily casted out of aluminum with a few minor modifications.

10.0 Conclusion

The SIT system is part of Lockheed Martin live training exercises. Used for training domestic and ally international militaries. This system is being improved upon by the addition of a rotational feature that will allow a single unit to be a potential friend or foe target. Through communication with the team's sponsor, a house of quality was constructed based on presented requirements and constraints. The team set attainable goals and organized a schedule with respective task responsibilities assigned to each member. The team began design on the target bracket, which accommodates various standard target types, as this was stated to be the most important outcome of the project by the sponsor. Moving forward, the team plans to incorporate the turning element into the lifting arm. Designs were conceptualized and based on a design matrix constructed by the team, an optimal design was chosen for the target bracket. These designs, and respective selection matrix, were submitted to the sponsor and project advisor for review. The team is currently waiting on detailed feedback to proceed with a final design selection. A final prototype was developed based on the selected designs. The turning component of the prototype functions well and can be implemented to position targets at all required positions. Future considerations have been listed for any designers wanting to have a better understanding of the process the team went through to arrive at the final design and eventual prototype. The team developed the prototype under budget and provided the sponsor with manufacturing considerations for our designs. The project challenged the team to be creative and innovative. As a whole, the members are very satisfied to the work completed to arrive at this point and hope Lockheed Martin is satisfied with the product which we have produced.

11.0 References

[1]Infantry Squad Battle Course, Army Engineers
[2]Meggitt MF-SIT Specification Document
[3] MS Instruments Stationary Infantry Target Specifications
[4]Theissen GSA Federal Supply Schedule Price List
[5] Future Army System of Integrated Targets: Presentation Devices Interface Control Document 2.0
[6] Rogers Corp. Technical Sealing Guide

12.0 Acknowledgements

Team 16 from FAMU - FSU College of Engineering would like to express the deepest appreciation to all those who helped during Fall and Spring semester on this senior design project. A special gratitude to our advisor Dr. Patrick Hollis whose advice and knowledgeable skill help guide us the right direction towards our goal. Another special thanks to Dr. Nikhil Gupta for providing feedback, stimulating suggestions, and helping coordinate our presentations, reports and ideas. Furthermore, we would like to acknowledge Chris Isler the Lead Hardware Engineer for his many useful inputs, also for taking the time to communicate with the team every week. Last but not least, many thanks to our teaching assistants who have provided helpful tips and feedback on our presentations, assignments and deliverables.

13.0 Team Biography

Ashar Abdullah (Lead Programmer)

Senior at Florida State University majoring in Mechanical Engineering. He is currently involved with SAE and has been charged with designing Drivetrain/Ergonomic components. He is also involved with research in Ceramic materials, specifically for the purpose of creating a wireless Temperature sensor for use in nuclear reactors. Ashar hopes to go into industry after he graduates in May of 2016.

Andrew Belstrom (Web Design / Historian)

Andrew Bellstrom is a senior in mechanical engineering at Florida State University. He is going for a specialization in thermal fluid science track and is due to graduate Spring 2016 with a minor in physics and mathematics. Previous work experience includes an internship for Source Refrigeration where he contributed to optimization of components. His future plans include entering the workforce in the field of fluid science.

Ryan D'Ambrosia (Team Leader)

A senior in the mechanical engineering department, Ryan has achieved his minor in both physics and mathematics and is due to graduate in April 2016. Ryan has participated in a variety of research at Florida State University's Aeropropulsion Mechatronics and Energy Center (AME) , and participated in the National Science Foundation (NSF) funded Research Experience for Undergraduates Program (REU-MASS) over the Summer 2015 term. As a Research Assistant, Ryan has been involved in various topics including the National Parks Service Penetrometer Capstone Project, Autonomous Quadcopter projects and Embedded Smart Material Sensing for Aerospace Structures, Wind Energy, and Legged Robotics Applications. Ryan has also been a Teaching Assistant for the graduation prerequisite Mechatronics 1 course, where students are introduced to the basics of C programming and hardware integration through integrated development environments (IDEs). Ryan intends to pursue a graduate degree in Mechanical Engineering after graduating from Florida State University.

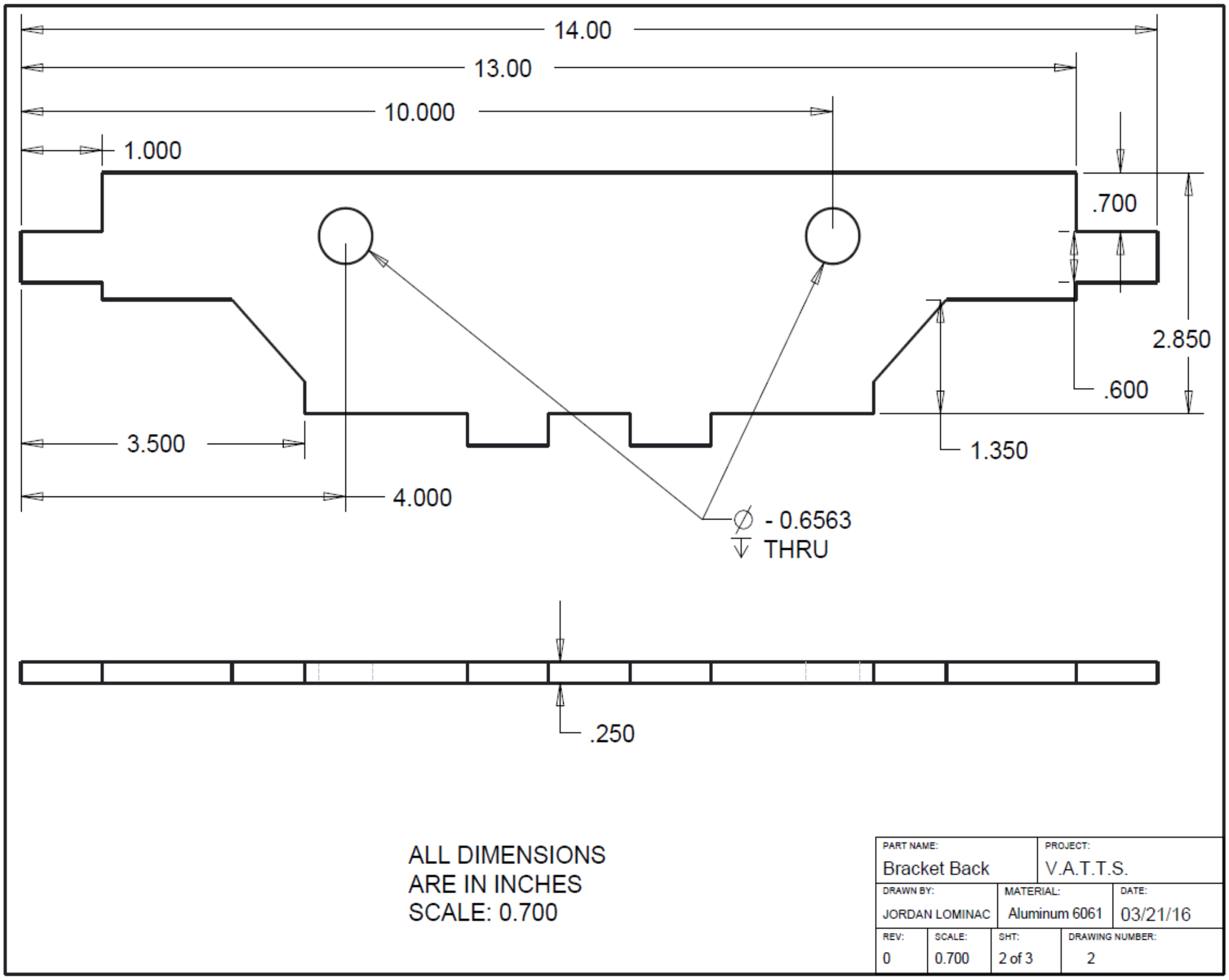
Jordan Lominac (Lead Mechanical Engineer)

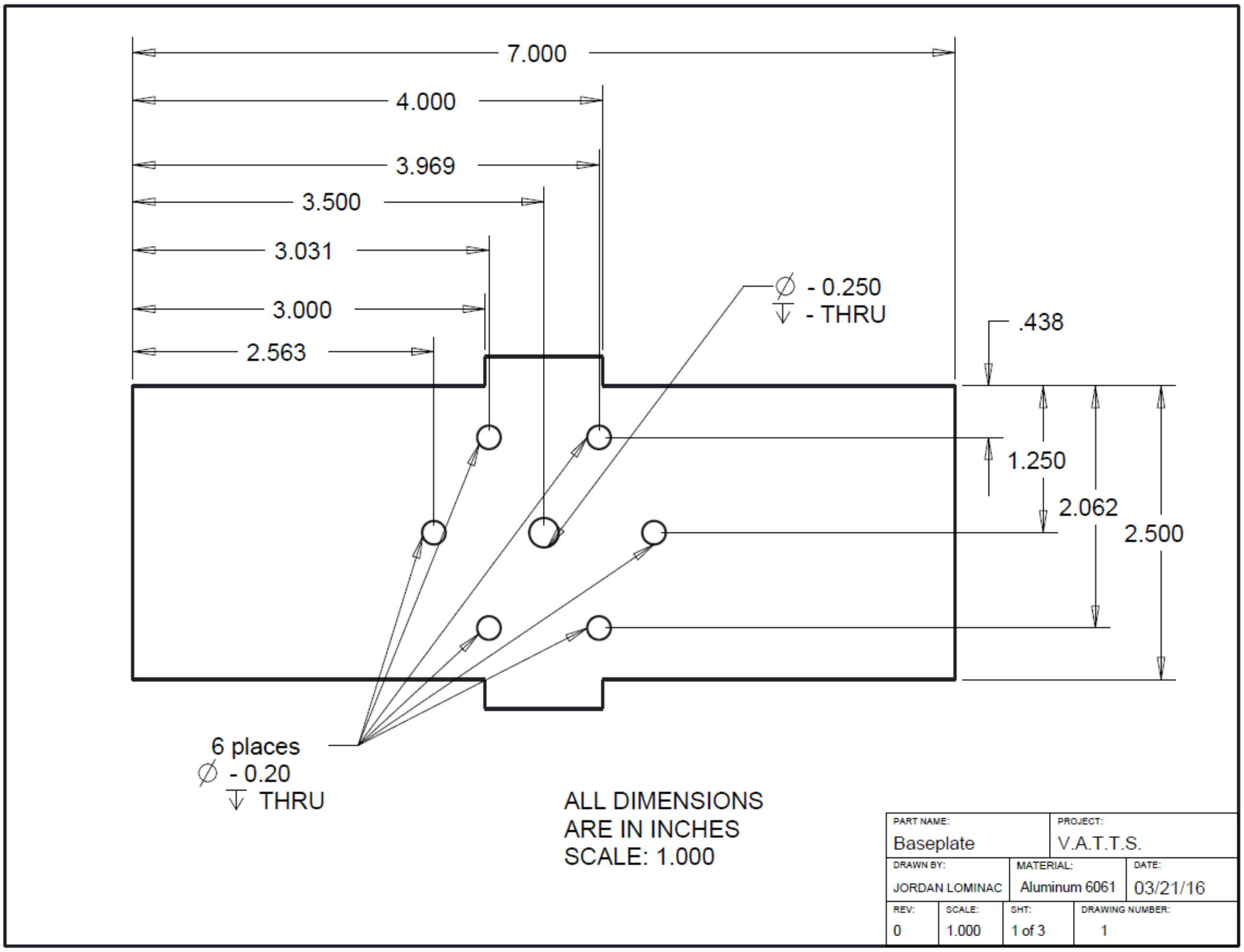
Jordan Lominac is a senior at Florida State University and will be graduating with his Bachelor's of Science Degree in Mechanical Engineering Spring of 2016. This past summer Jordan worked as a Supply Chain Engineer for Johnson&Johnson where he gained experience in project management and continuous improvement methodologies. Jordan focused on developing a round wire fixture to improve the efficiency of Cordis' Receiving Inspection and supported the Shelf Life Extension Project for Listerine and Reach Dental products. Jordan is currently in progress of receiving his Thermal Fluids Specialization from Florida State. After receiving his degree, Jordan plans to be working full time and plans on receiving his Professional Engineering License.

Fernando Rodriguez (Financial Advisor)

Fernando Rodriguez currently senior undergraduate student on Mechanical Engineering (ME) from Florida State University (FSU). Born and raised in Cuba, came to the United State of America at the age of fourteen. Pursuing his goal in science let him be a part of Miami Dade College from 2010 to 2012. Transfer to Florida State University to continue his studies as undergraduate ME from 2012 up to 2016. Had opportunity to be a part of Florida Center for Advanced Aero-Propulsion (FCAAP) as research assistance during the Summer 2015. Helped and learned from graduate students with new experiment with Particle Image Velocimetry (PIV) in the supersonic, and subsonic wind tunnel facility. As of Fall 2015 Fernando is working under Dr. Kumar's research for Asymmetric Vortex Control of Slender Body at High Angle of Incidence. Also, working on Variable Angle Target Training System (VATTS) for Senior Design, sponsored by Lockheed Martin.

Appendix A (Bracket Components and Parts Drawings)

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3.500
3.031
3.000
2.563
∅ - 0.250
- THRU
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2.500
6 places
∅ - 0.20
THRU
ALL DIMENSIONS
ARE IN INCHES
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PART NAME:
Baseplate
PROJECT:
V.A.T.T.S.
DRAWN BY:
JORDAN LOMINAC
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03/21/16
REV:
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SCALE:
1.000
SHT:
1 of 3
DRAWING NUMBER:
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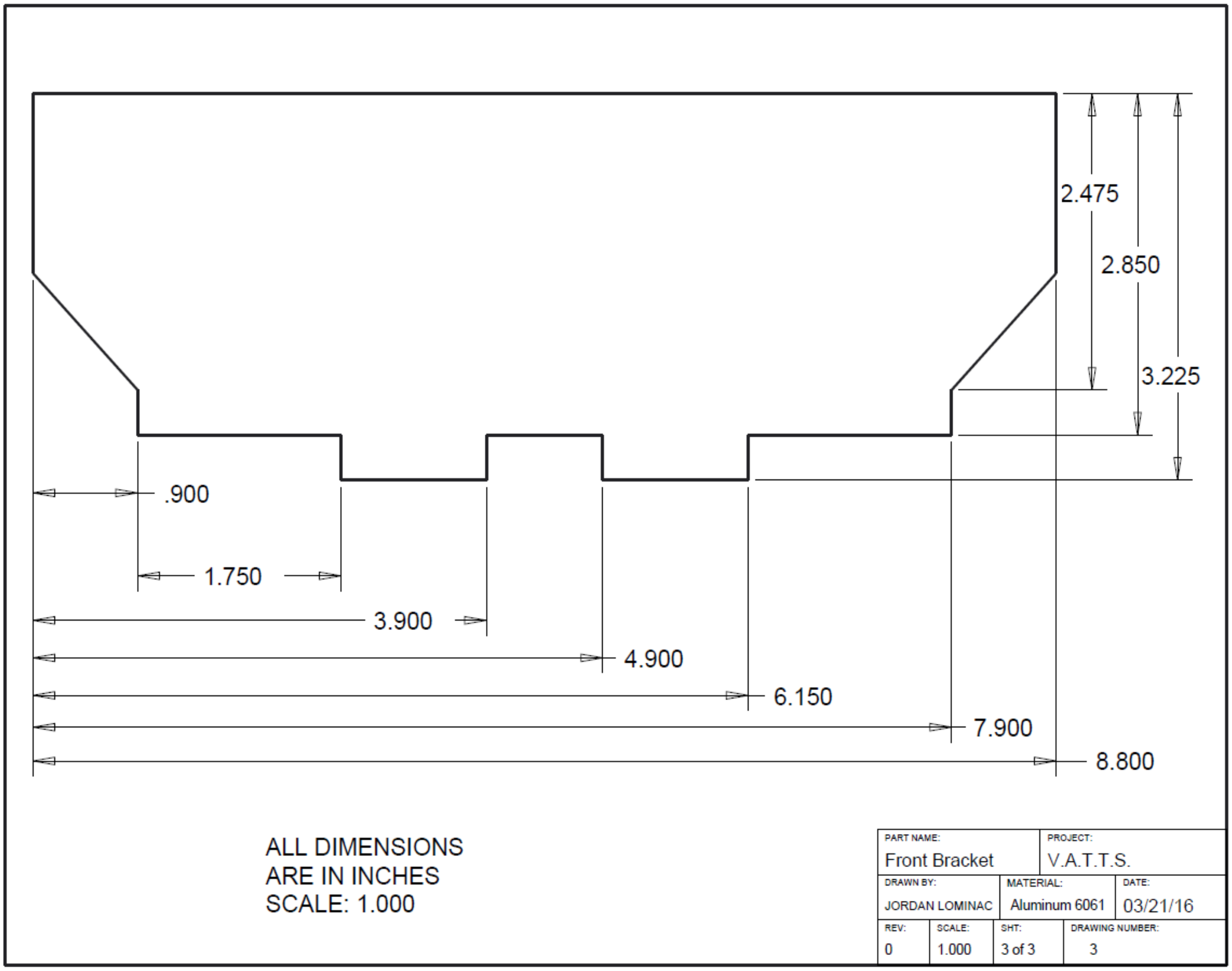
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1.750
3.900
4.900
6.150
7.900
8.800
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Front Bracket
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DRAWN BY:
JORDAN LOMINAC
MATERIAL:
Aluminum 6061
DATE:
03/21/16
REV:
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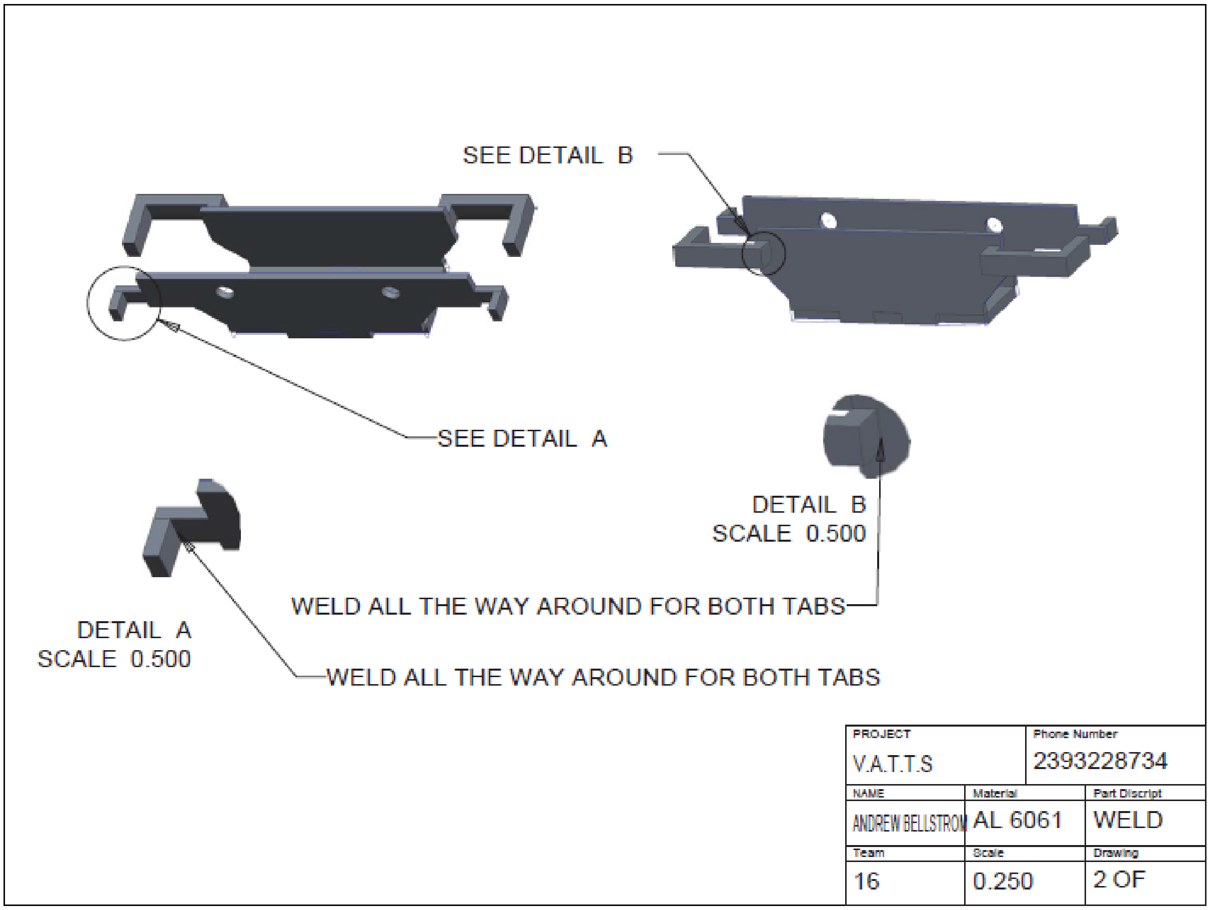
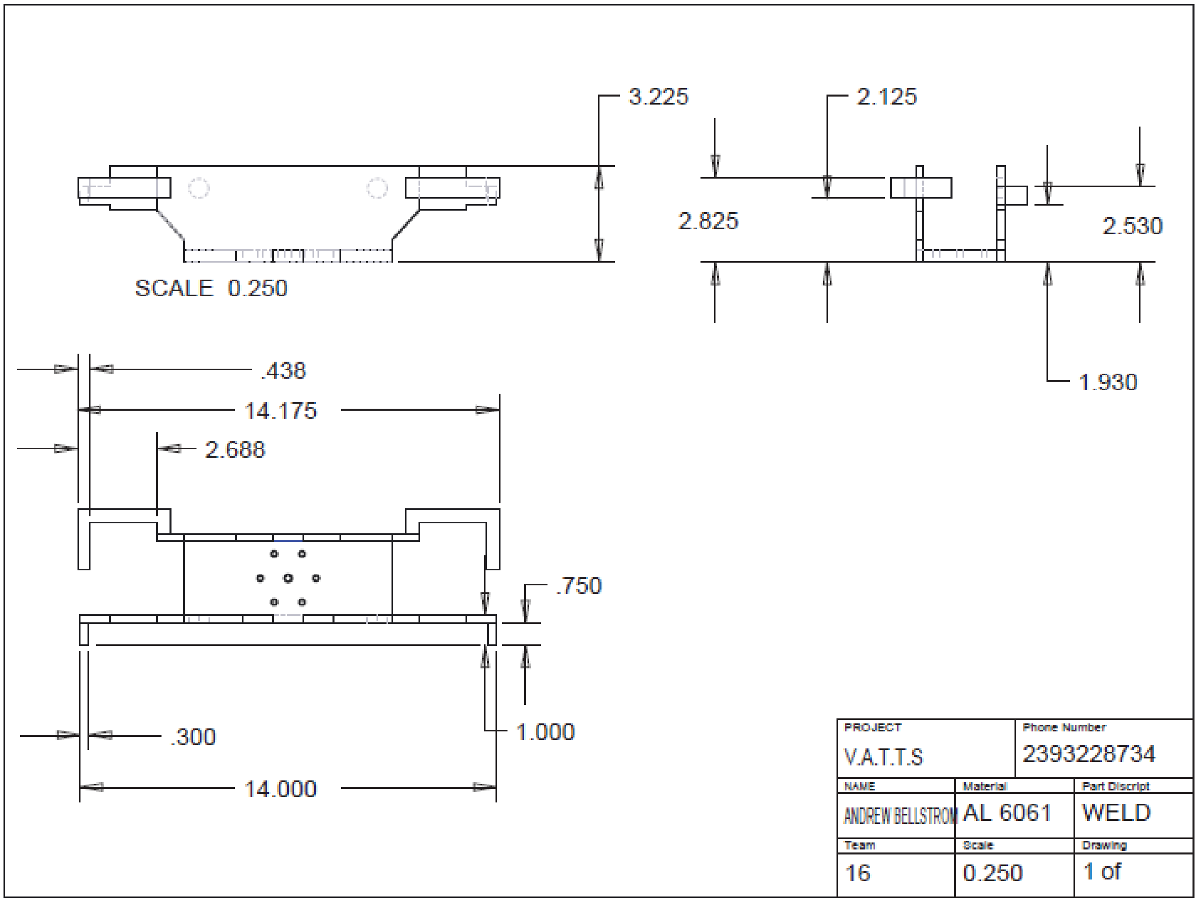
SCALE:
1.000
SHT:
3 of 3
DRAWING NUMBER:
3


SEE DETAIL B
SEE DETAIL A
DETAIL B
SCALE 0.500
DETAIL A
SCALE 0.500
WELD ALL THE WAY AROUND FOR BOTH TABS
WELD ALL THE WAY AROUND FOR BOTH TABS
PROJECT
V.A.T.T.S
Phone Number
2393228734
NAME
ANDREW BELLSTROM
Material
AL 6061
Part Discript
WELD
Team
16
Scale
0.250
Drawing
2 OF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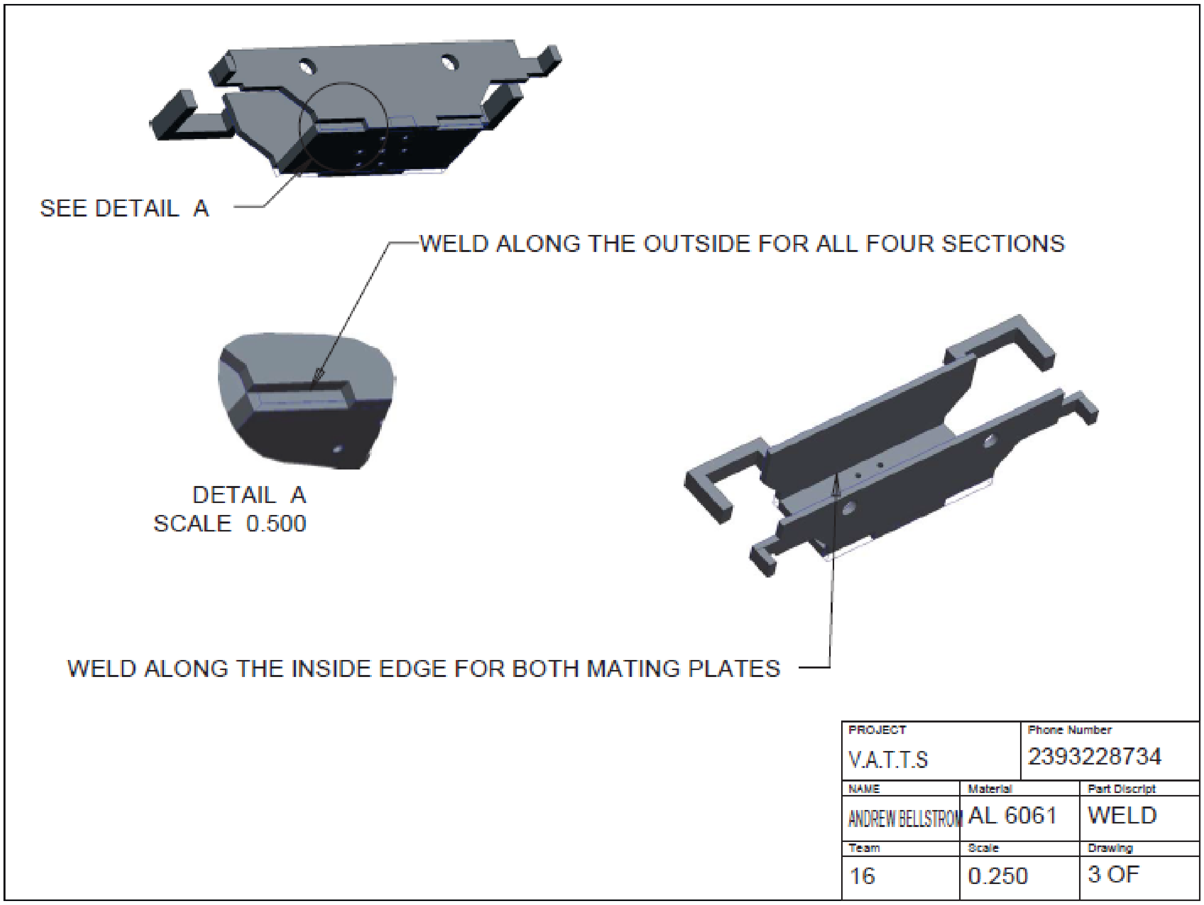
2.125
2.825
2.530
SCALE 0.250
1.930
.438
14.175
2.688
.750
.300
1.000
14.000
PROJECT
V.A.T.T.S
Phone Number
2393228734
NAME
ANDREW BELLSTROM
Material
AL 6061
Part Discript
WELD
Team
16
Scale
0.250
Drawing
1 of


SEE DETAIL A
WELD ALONG THE OUTSIDE FOR ALL FOUR SECTIONS
DETAIL A
SCALE 0.500
WELD ALONG THE INSIDE EDGE FOR BOTH MATING PLATES
PROJECT
V.A.T.T.S
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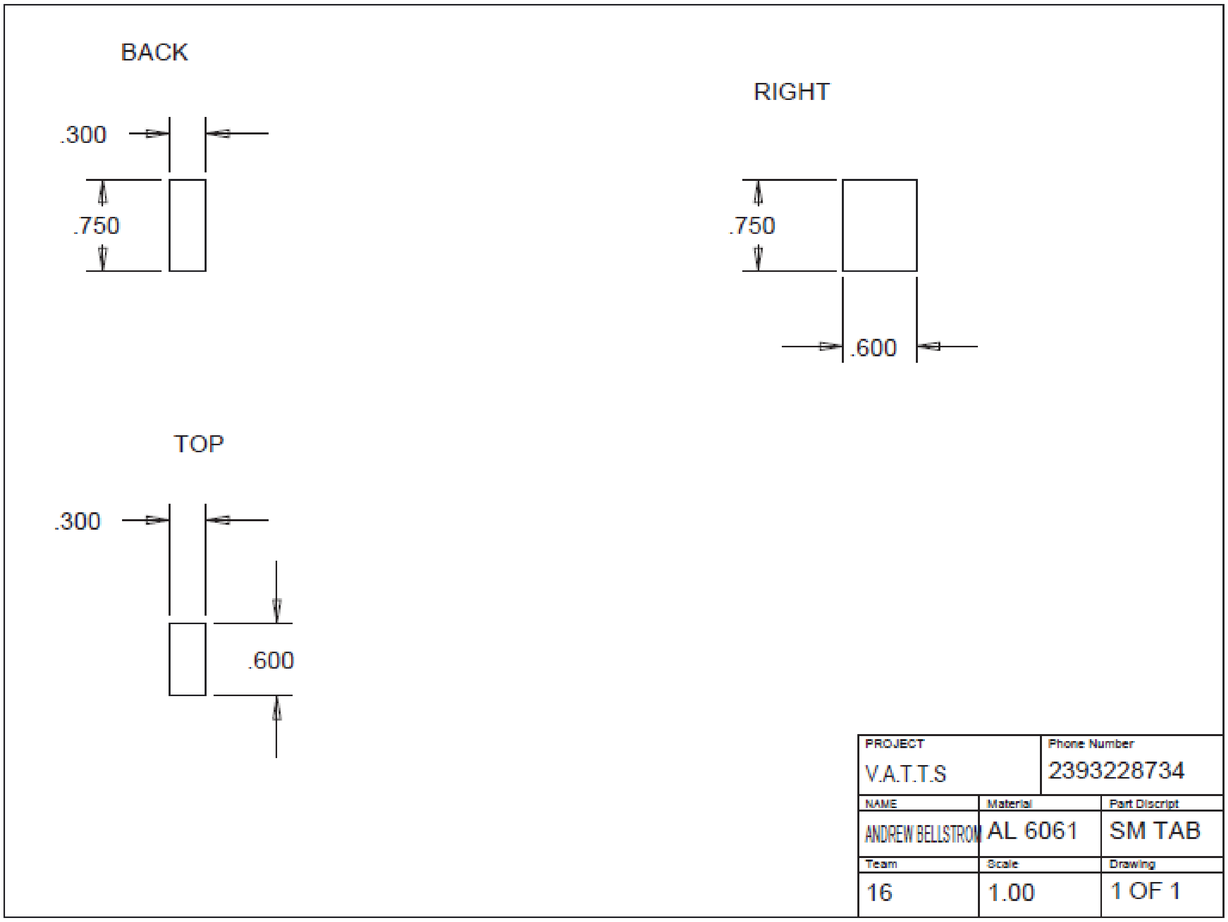
ANDREW BELLSTROM
Material
AL 6061
Part Discript
WELD
Team
16
Scale
0.250
Drawing
3 OF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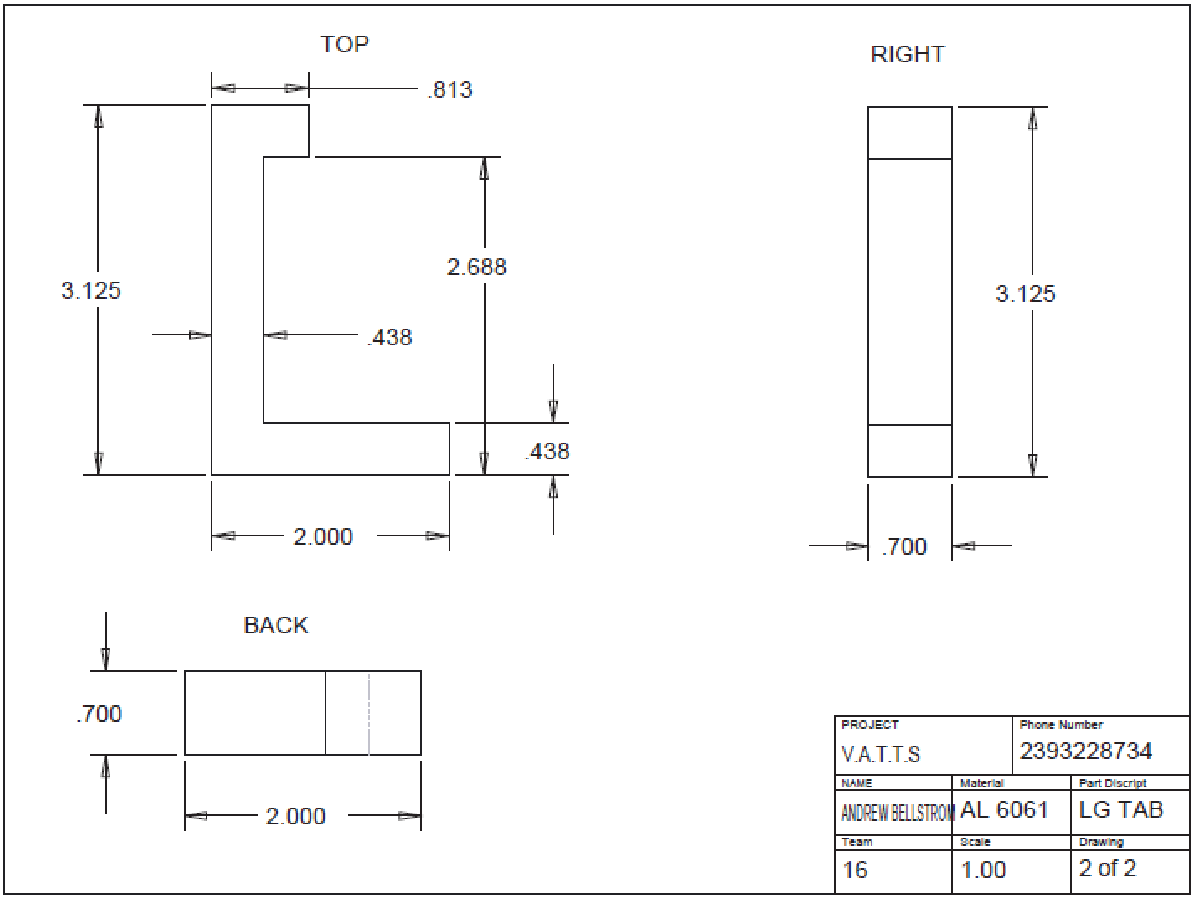
1 OF 1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2.000
RIGHT
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BACK
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2.000
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V.A.T.T.S
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NAME
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LG TAB
Team
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Scale
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Drawing
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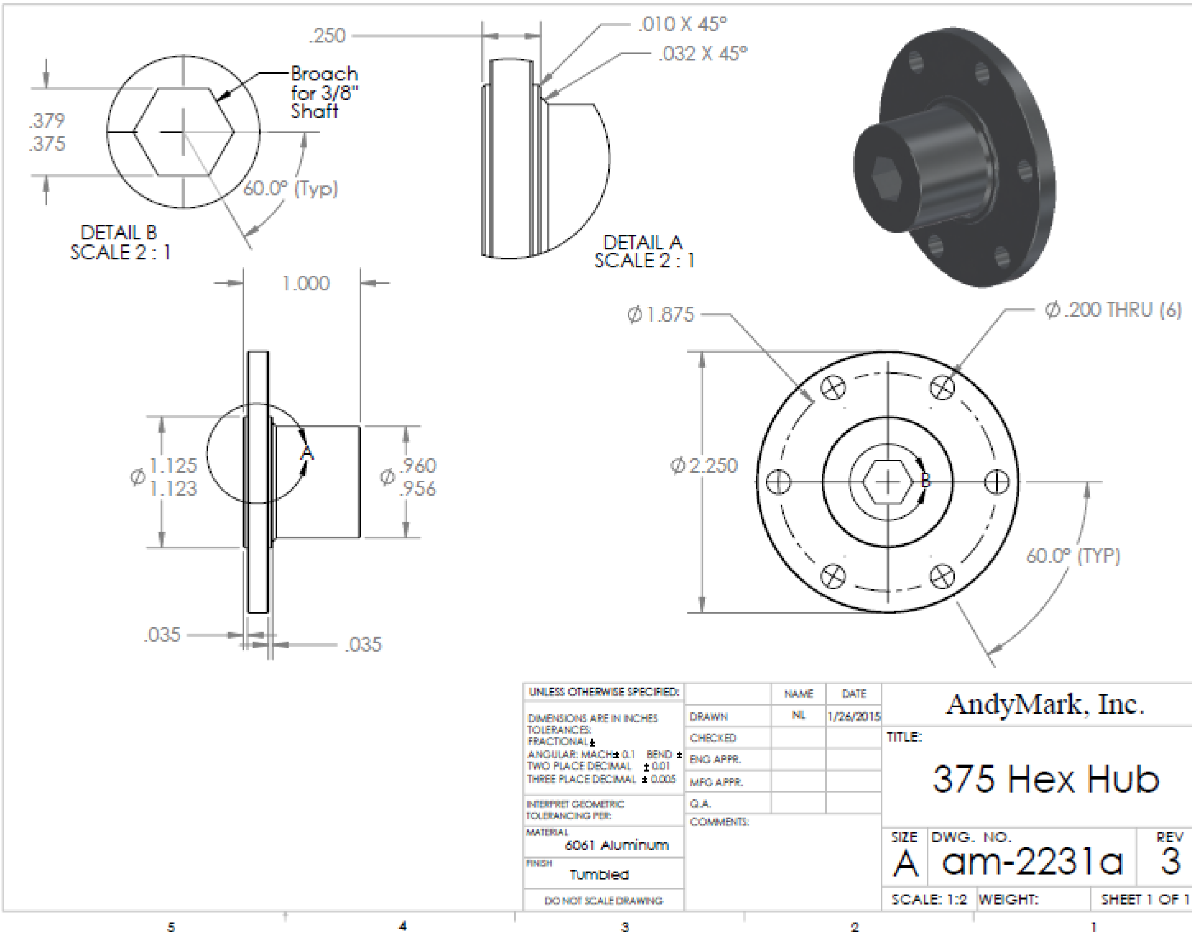

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Broach for 3/8" Shaft
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DETAIL A
SCALE 2 : 1
1.000
Ø 1.875
Ø .200 THRU (6)
Ø 1.125
1.123
A
Ø .960
.956
Ø 2.250
B
60.0° (TYP)
.035
.035
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± 0.1 BEND ±
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Tumbled
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
NL
1/26/2015
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AndyMark, Inc.
TITLE:
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SIZE
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DWG. NO.
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2
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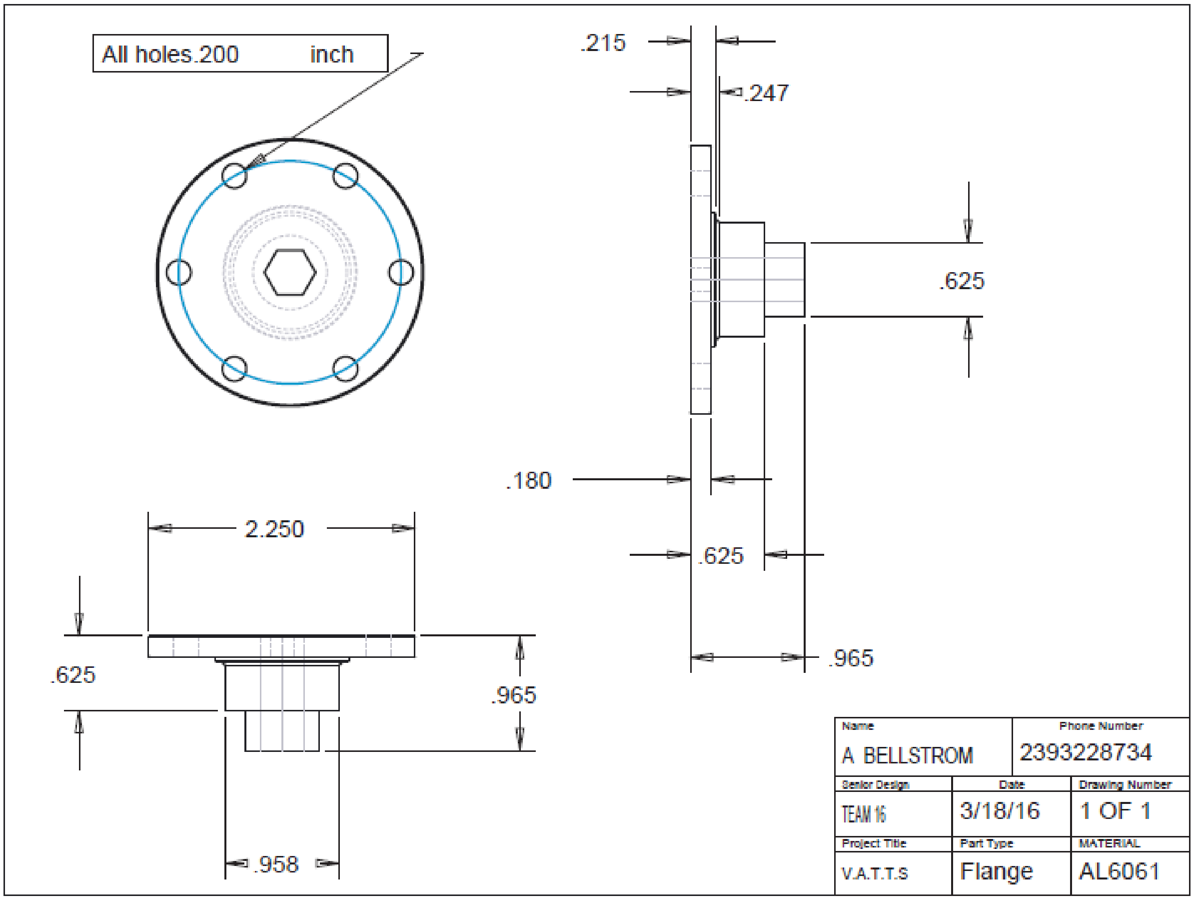
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2.250
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.958
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Phone Number
2393228734
Senior Design
TEAM 16
Date
3/18/16
Drawing Number
1 OF 1
Project Title
V.A.T.T.S
Part Type
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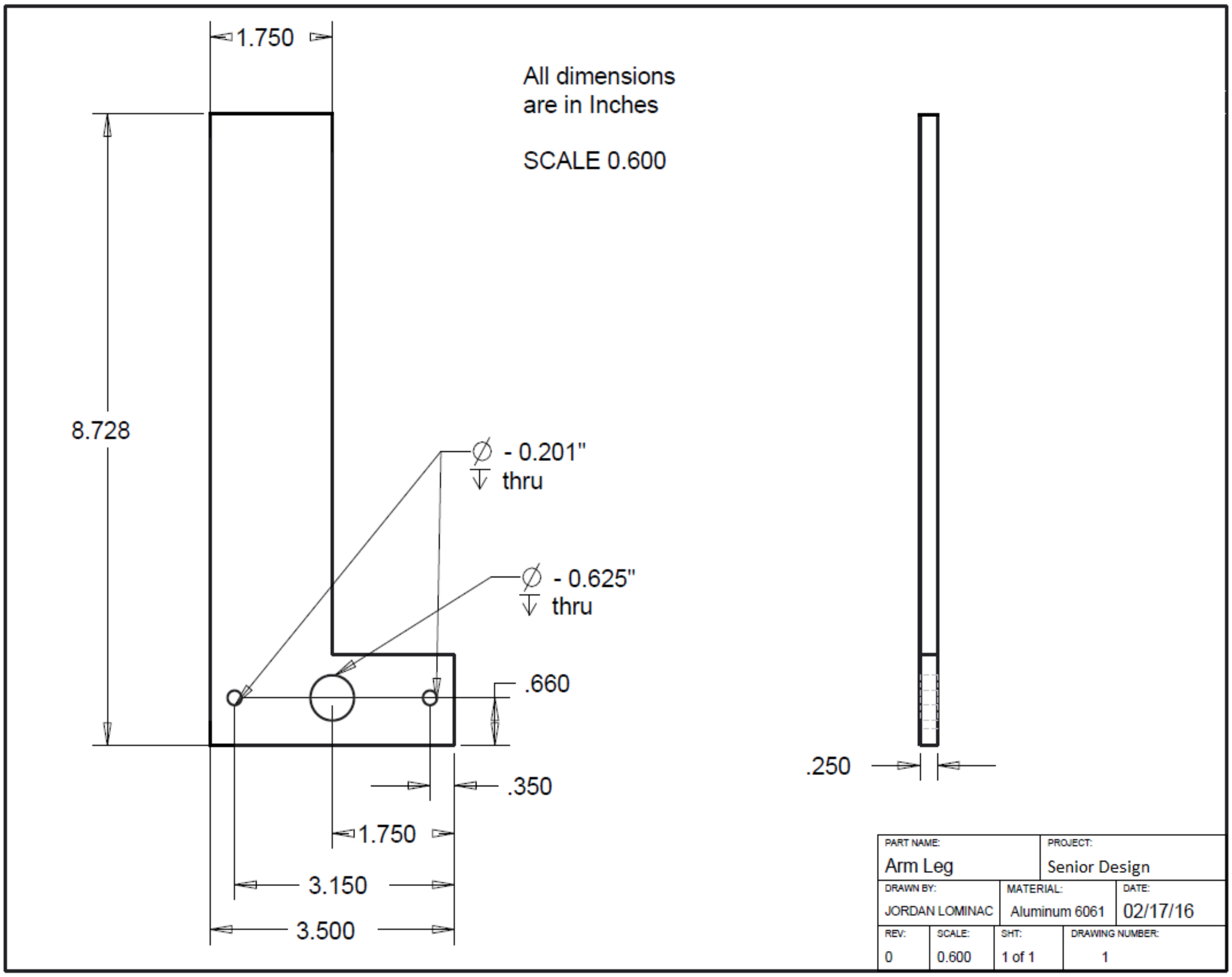
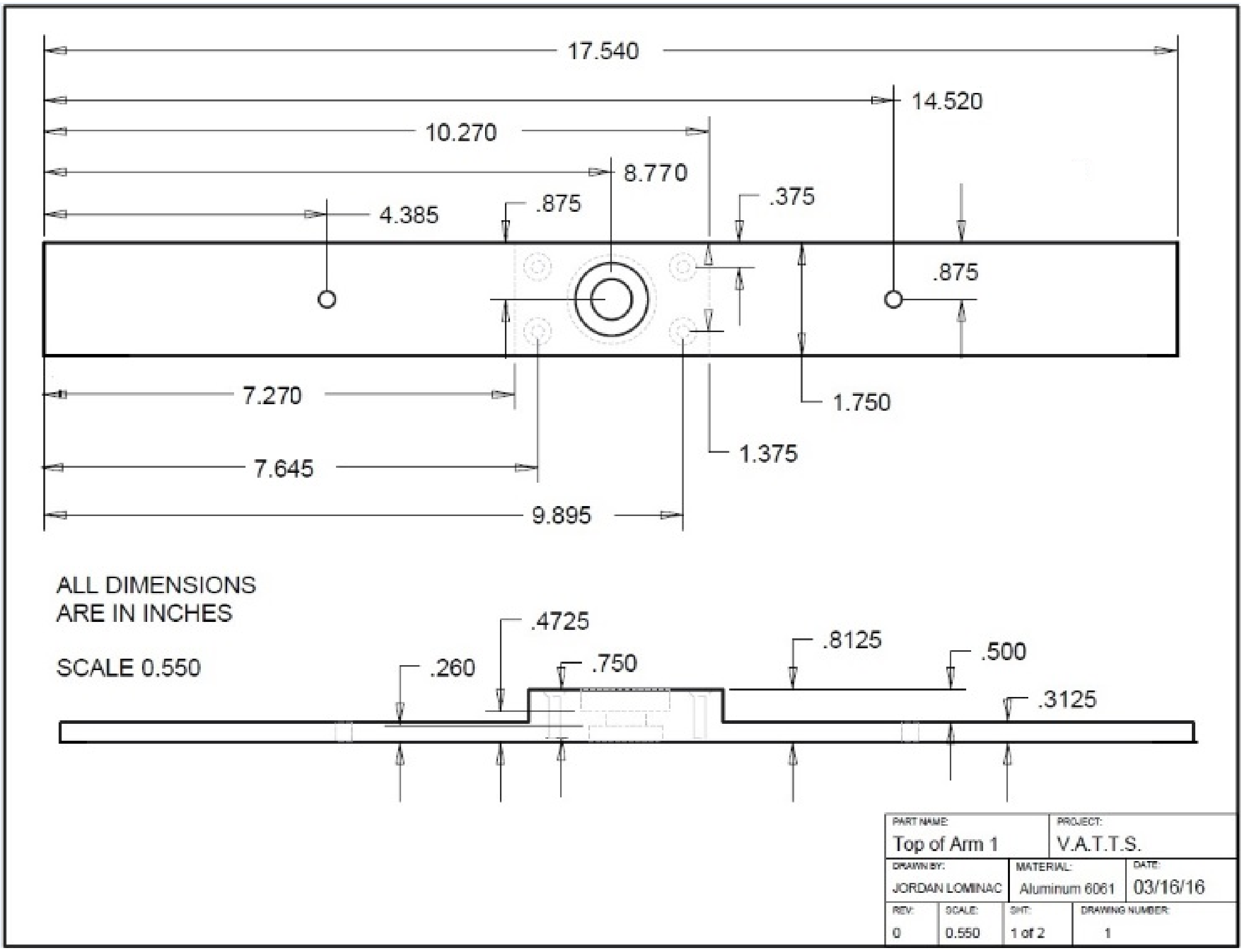
MATERIAL
AL6061

Appendix B (Arm Drawings and Components)

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8.770
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.875
.375
.875
7.270
1.750
1.375
7.645
9.895
ALL DIMENSIONS
ARE IN INCHES
SCALE 0.550
.4725
.260
.750
.8125
.500
.3125
PART NAME:
Top of Arm 1
PROJECT:
V.A.T.T.S.
DRAWN BY:
JORDAN LOMINAC
MATERIAL:
Aluminum 6061
DATE:
03/16/16
REV:
0
SCALE:
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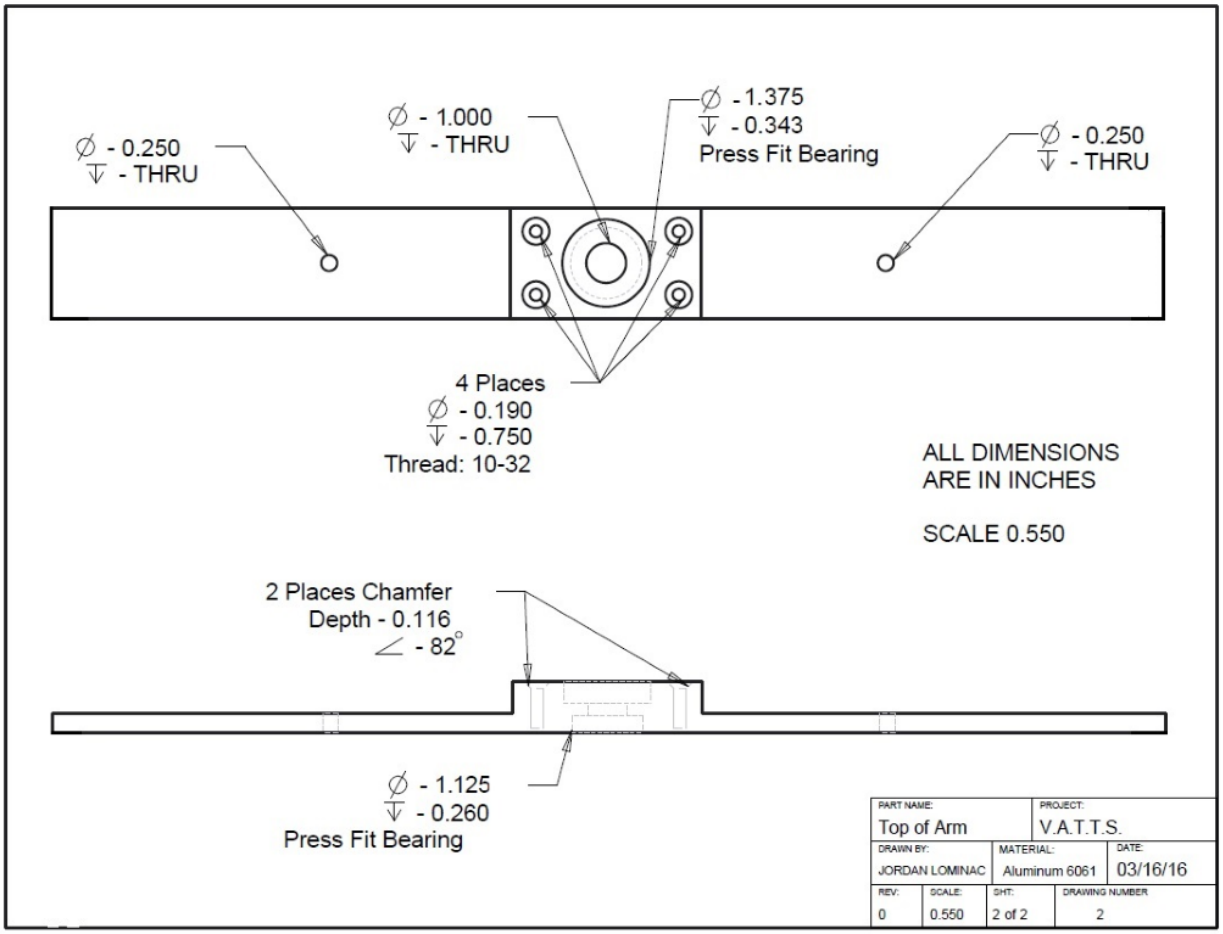
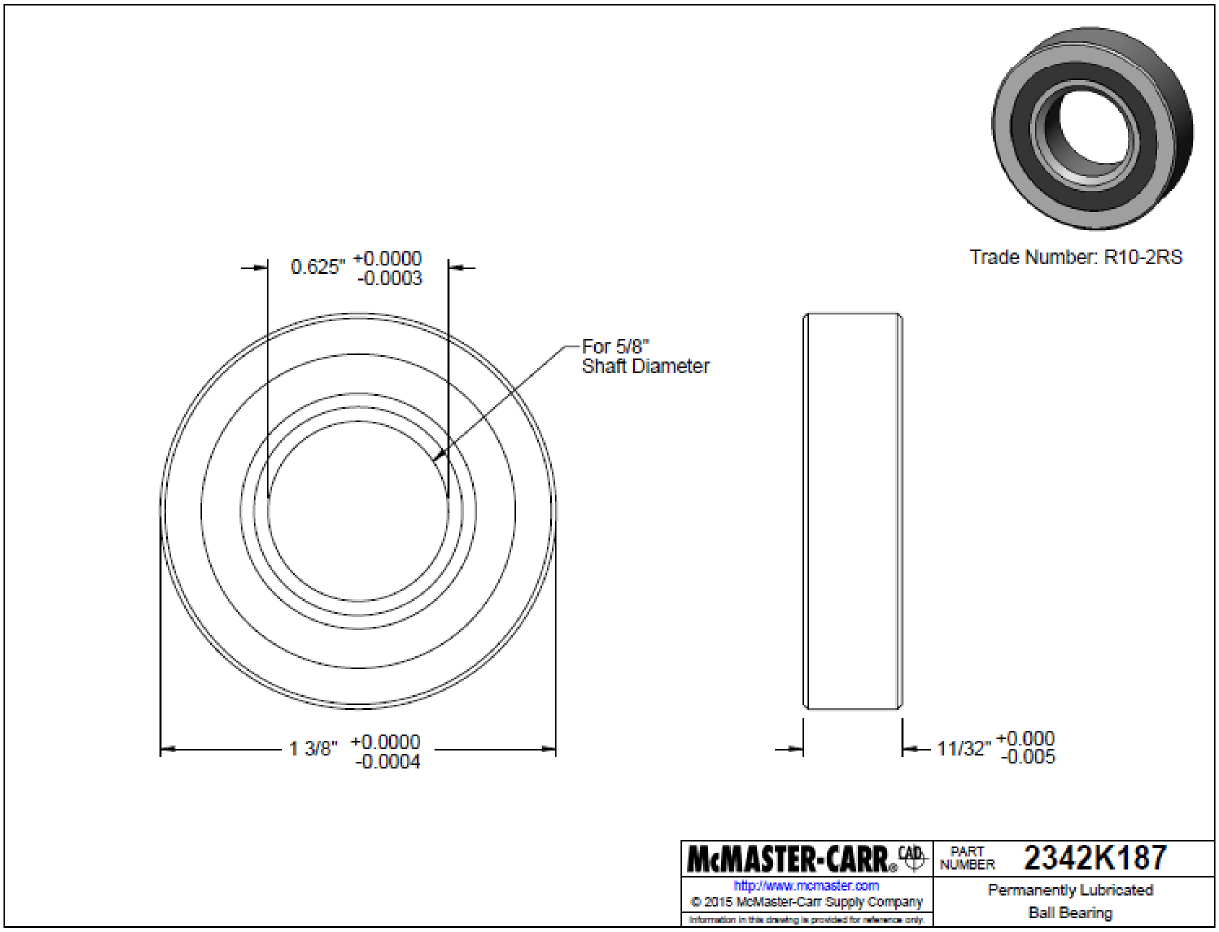
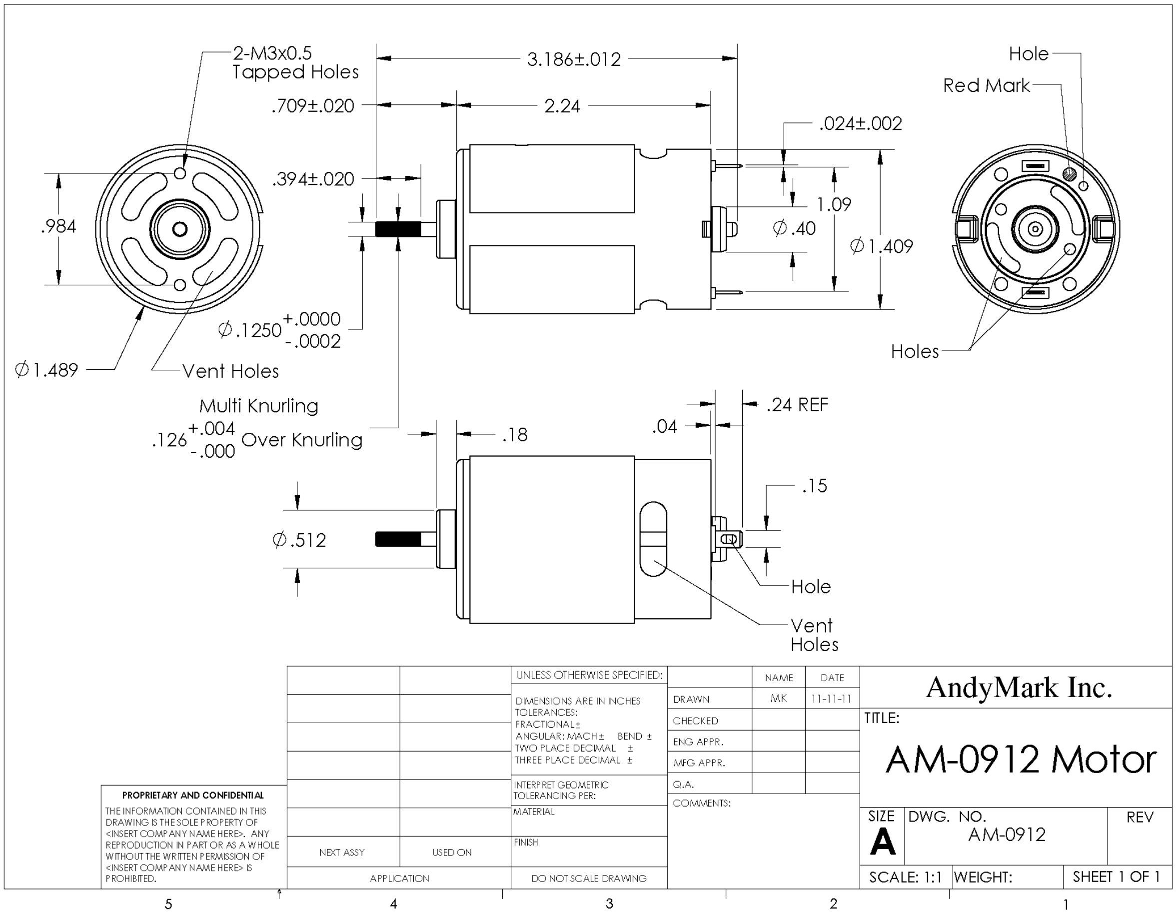
SHT:
1 of 2
DRAWING NUMBER:
1



∅ - 0.250
↧ - THRU
∅ - 1.000
↧ - THRU
∅ - 1.375
↧ - 0.343
Press Fit Bearing
∅ - 0.250
↧ - THRU
4 Places
∅ - 0.190
↧ - 0.750
Thread: 10-32
ALL DIMENSIONS
ARE IN INCHES
SCALE 0.550
2 Places Chamfer
Depth - 0.116
∠ - 82°
∅ - 1.125
↧ - 0.260
Press Fit Bearing
PART NAME: Top of Arm
PROJECT: V.A.T.T.S.
DRAWN BY: JORDAN LOMINAC
MATERIAL: Aluminum 6061
DATE: 03/16/16
REV: 0
SCALE: 0.550
SHT: 2 of 2
DRAWING NUMBER 2


Trade Number: R10-2RS
0.625" +0.0000 -0.0003
For 5/8" Shaft Diameter
1 3/8" +0.0000 -0.0004
11/32" +0.000 -0.005
McMASTER-CARR
PART NUMBER 2342K187
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Permanently Lubricated Ball Bearing

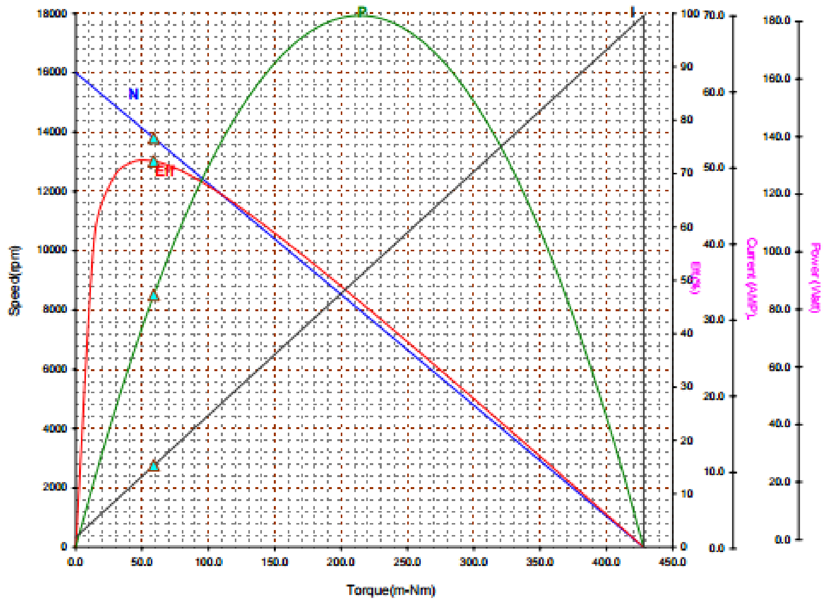
Appendix C (Turning Mechanism Components)



Chiaphua Components
Group of Companies

http://www.cclmotors.com

Project No : DB-30F-2005
Proposal No:
Winding : 0.00 - 0
Motor test reference no : (CCW)
Operator : JACKY
Date : 2011/11/10



Performance (In an ambient temperature of 25 -30 C)
Motor tested rapidly to prevent significant temperature rise.

At a constant voltage of	12.00	Volts
With a circuit resistance	0.000	Ohms

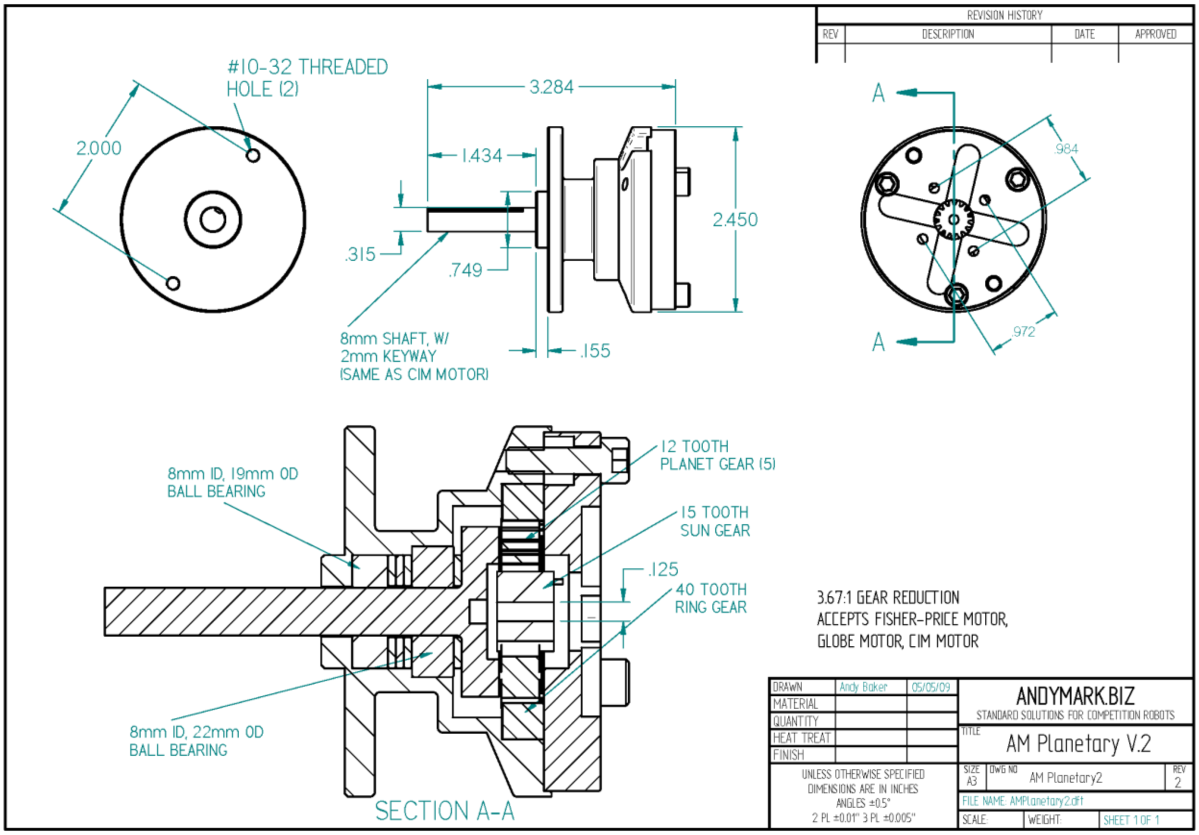
AT No Load		
Speed :	16000	Rpm
Current:	1.200	Amp
At stall (Extrapolated)		
Torque :	428.073	m-Nm
Current:	63.745	Amp
At maximum efficiency		
Efficiency :	72.50	%
Torque :	51.647	m-Nm
Speed :	14070	Rpm
Current :	8.746	Amp
Output :	76.095	Watts
At maximum power		
Torque :	214.036	m-Nm
Speed :	8000	Rpm
Current :	32.473	Amp
Output :	179.311	Watts

Characteristics		
Torque Constant :	6.844	m-Nm/Amp
E.M.F Constant :	6.844	mV/rad/sec
Dy. Resistance :	0.188	Ohms
Motor Regulation:	37.377	Rpm/m-Nm

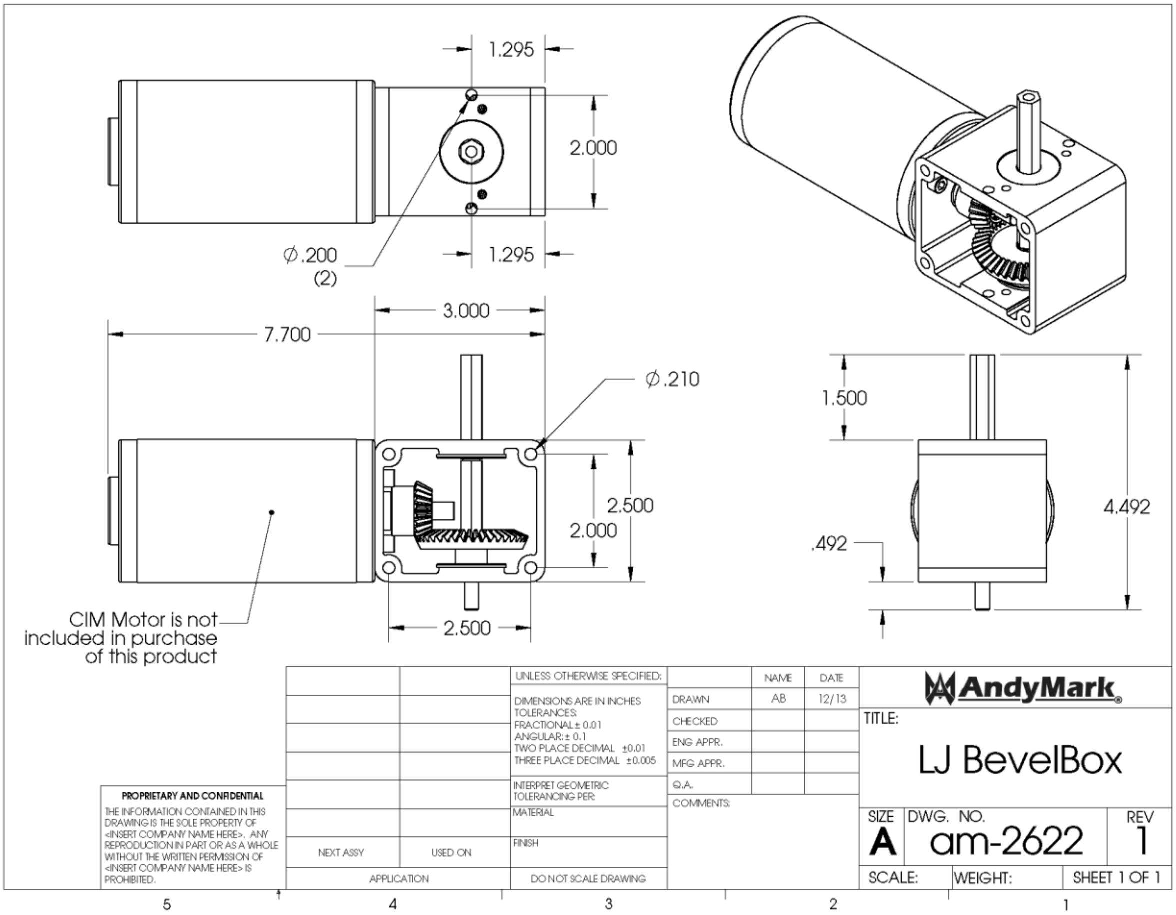
Calculation

At Torque Level:			At Fan:		
Torque:	58.860	m-Nm	Torque:		m-Nm
Speed:	13800	Rpm	Speed:		Rpm
Current:	9.800	Amp	Current:		Amp
Efficiency:	72.33	%	Efficiency:		%
Output:	85.061	Watts	Output:		Watts

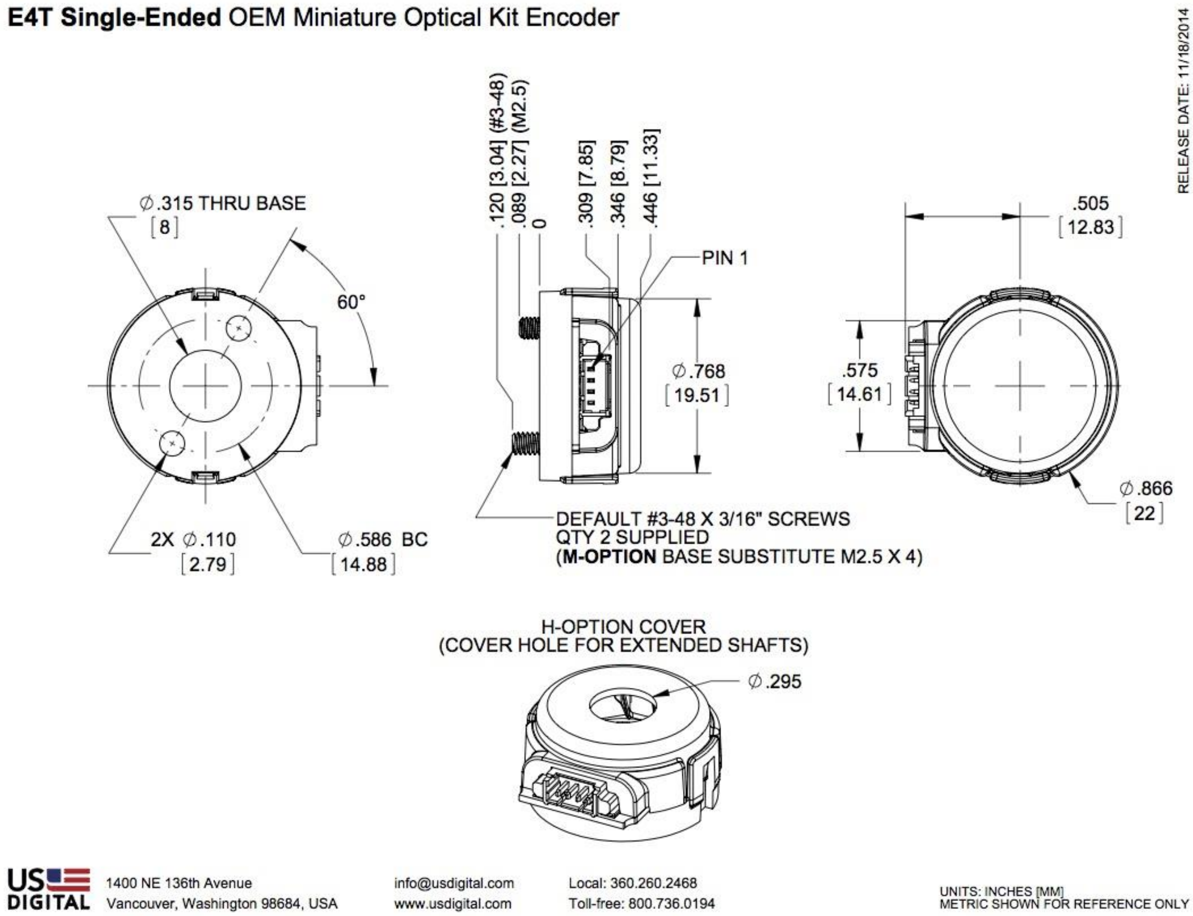
COMPUTER PRINT-OUT
NORMINAL MOTOR CURVE
Performance and characteristics are measured based on limited motor sample only

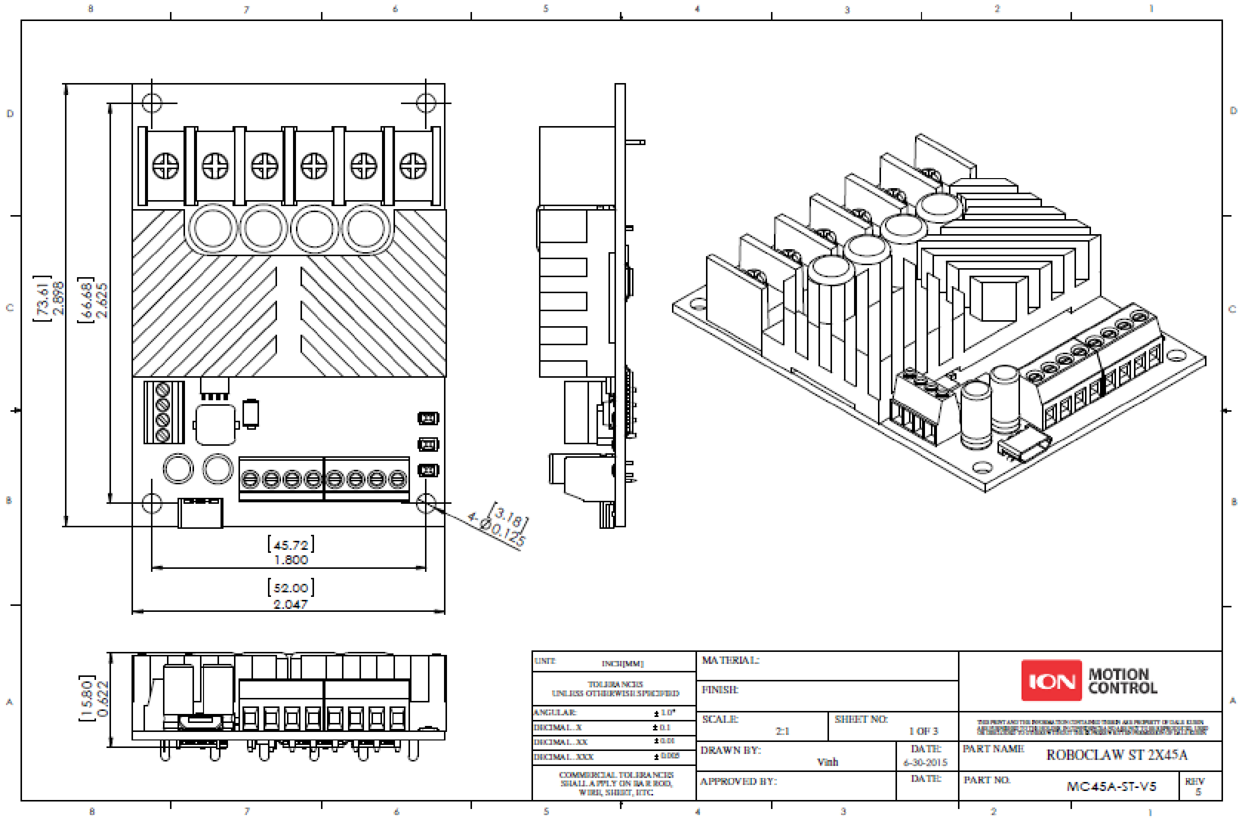


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
#10-32 THREADED HOLE (2)
2.000
3.284
1.434
.315
.749
2.450
8mm SHAFT, W/ 2mm KEYWAY (SAME AS CIM MOTOR)
.155
A
A
.984
.972
8mm ID, 19mm OD BALL BEARING
12 TOOTH PLANET GEAR (5)
15 TOOTH SUN GEAR
.125
40 TOOTH RING GEAR
3.67:1 GEAR REDUCTION
ACCEPTS FISHER-PRICE MOTOR, GLOBE MOTOR, CIM MOTOR
8mm ID, 22mm OD BALL BEARING
SECTION A-A
DRAWN
Andy Baker
05/05/09
MATERIAL
QUANTITY
HEAT TREAT
FINISH
ANDYMARK.BIZ
STANDARD SOLUTIONS FOR COMPETITION ROBOTS
TITLE
AM Planetary V.2
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES ANGLES ±0.5° 2 PL ±0.01" 3 PL ±0.005"
SIZE A3
DWG NO
AM Planetary2
REV 2
FILE NAME: AMPlanetary2.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

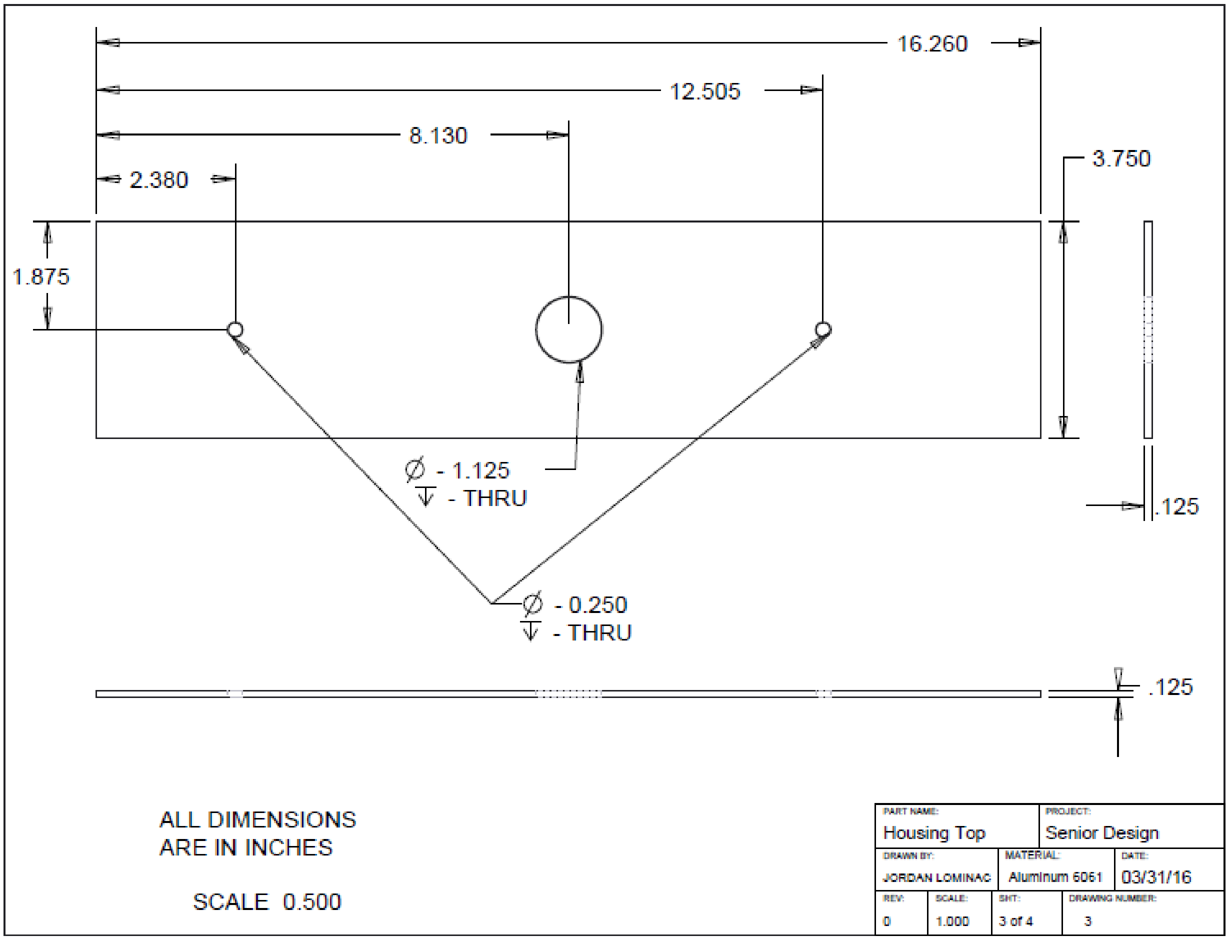


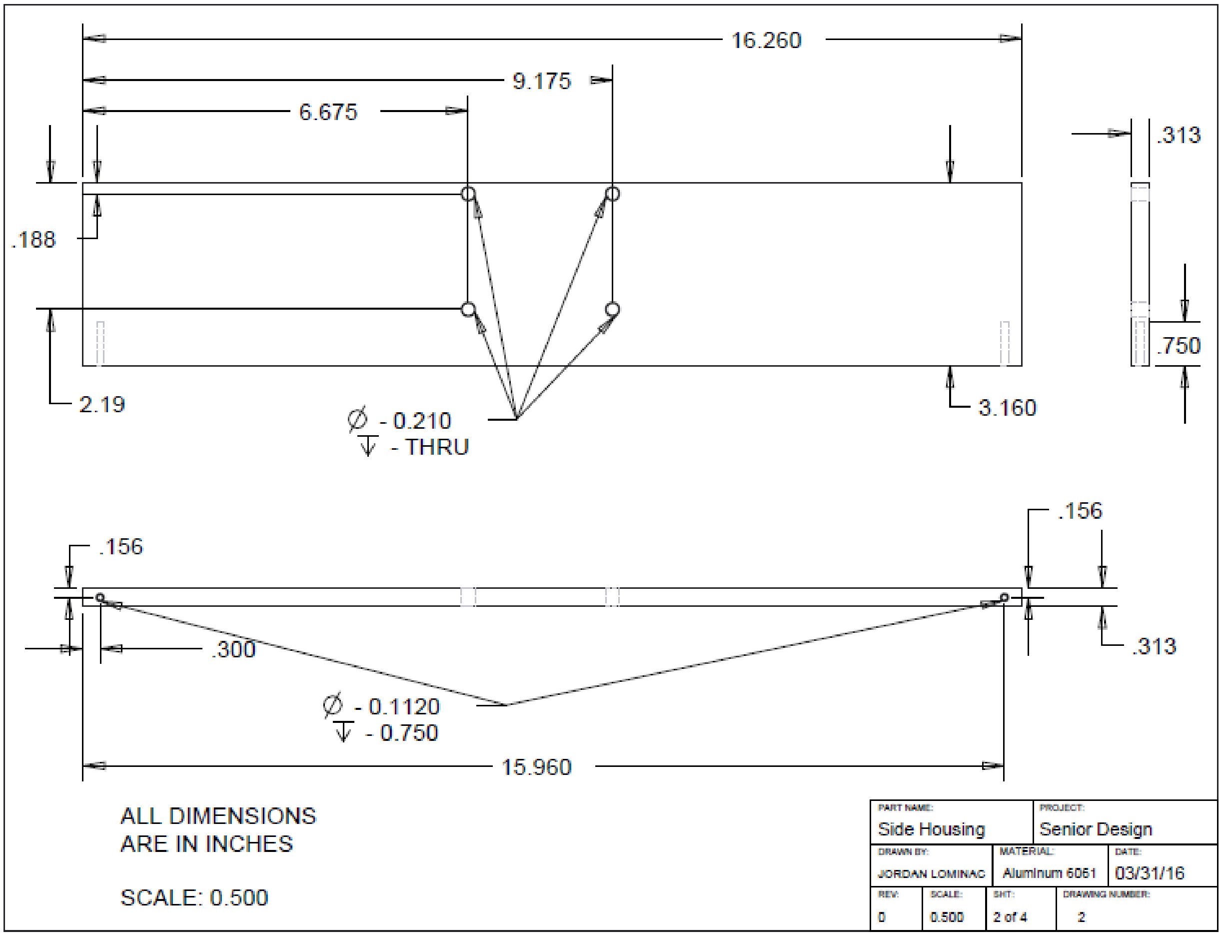
1.295
2.000
⌀.200
(2)
1.295
3.000
7.700
⌀.210
1.500
2.500
2.000
4.492
.492
2.500
CIM Motor is not included in purchase of this product
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.01
ANGULAR: ± 0.1
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
DRAWN
AB
12/13
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
AndyMark
TITLE:
LJ BevelBox
SIZE
A
DWG. NO.
am-2622
REV
1
SCALE:
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

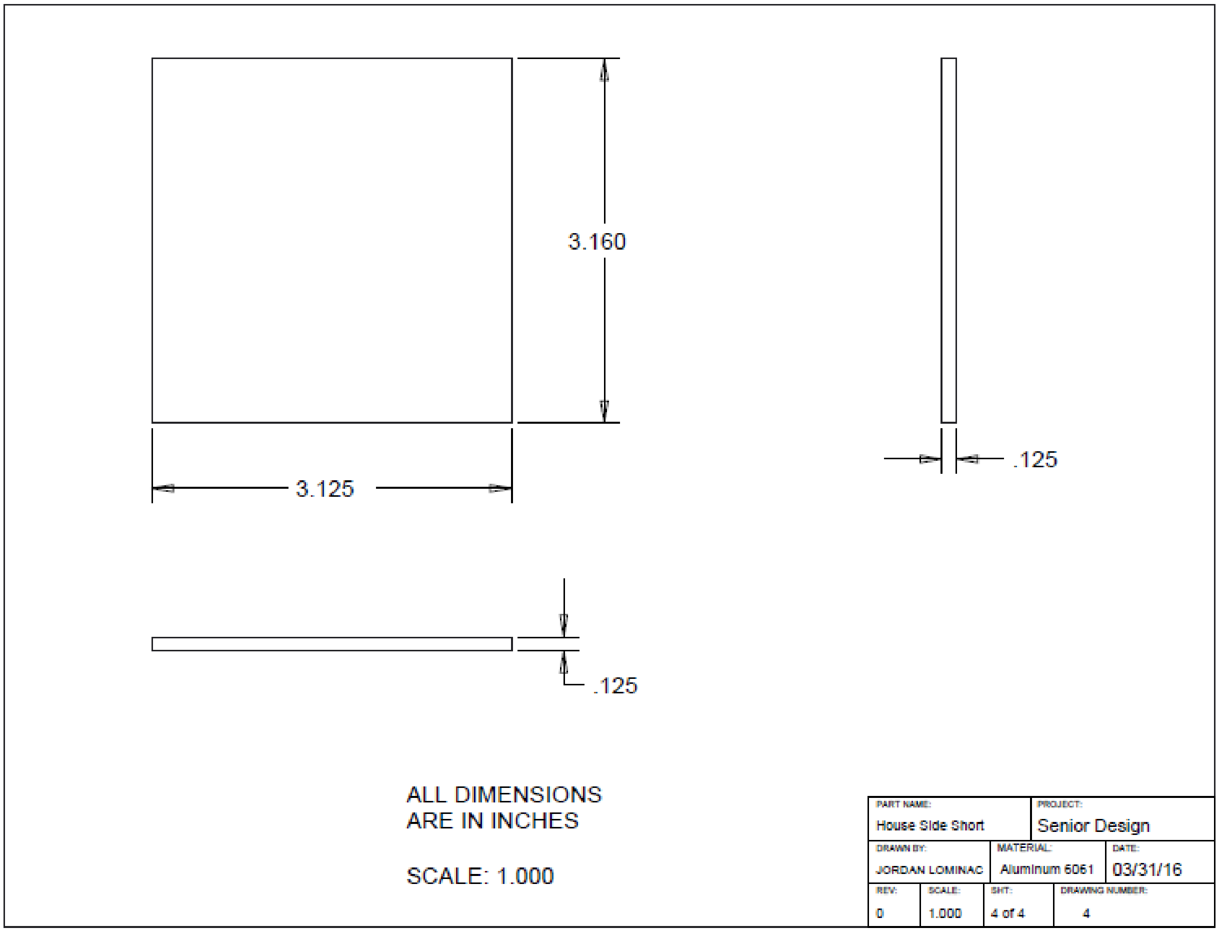

E4T Single-Ended OEM Miniature Optical Kit Encoder
RELEASE DATE: 11/18/2014
Ø.315 THRU BASE
[8]
60°
2X Ø.110
[2.79]
Ø.586 BC
[14.88]
.120 [3.04] (#3-48)
.089 [2.27] (M2.5)
0
.309 [7.85]
.346 [8.79]
.446 [11.33]
PIN 1
Ø.768
[19.51]
DEFAULT #3-48 X 3/16" SCREWS
QTY 2 SUPPLIED
(M-OPTION BASE SUBSTITUTE M2.5 X 4)
.505
[12.83]
.575
[14.61]
Ø.866
[22]
H-OPTION COVER
(COVER HOLE FOR EXTENDED SHAFTS)
Ø.295
US DIGITAL
1400 NE 136th Avenue
Vancouver, Washington 98684, USA
info@usdigital.com
www.usdigital.com
Local: 360.260.2468
Toll-free: 800.736.0194
UNITS: INCHES [MM]
METRIC SHOWN FOR REFERENCE ONLY

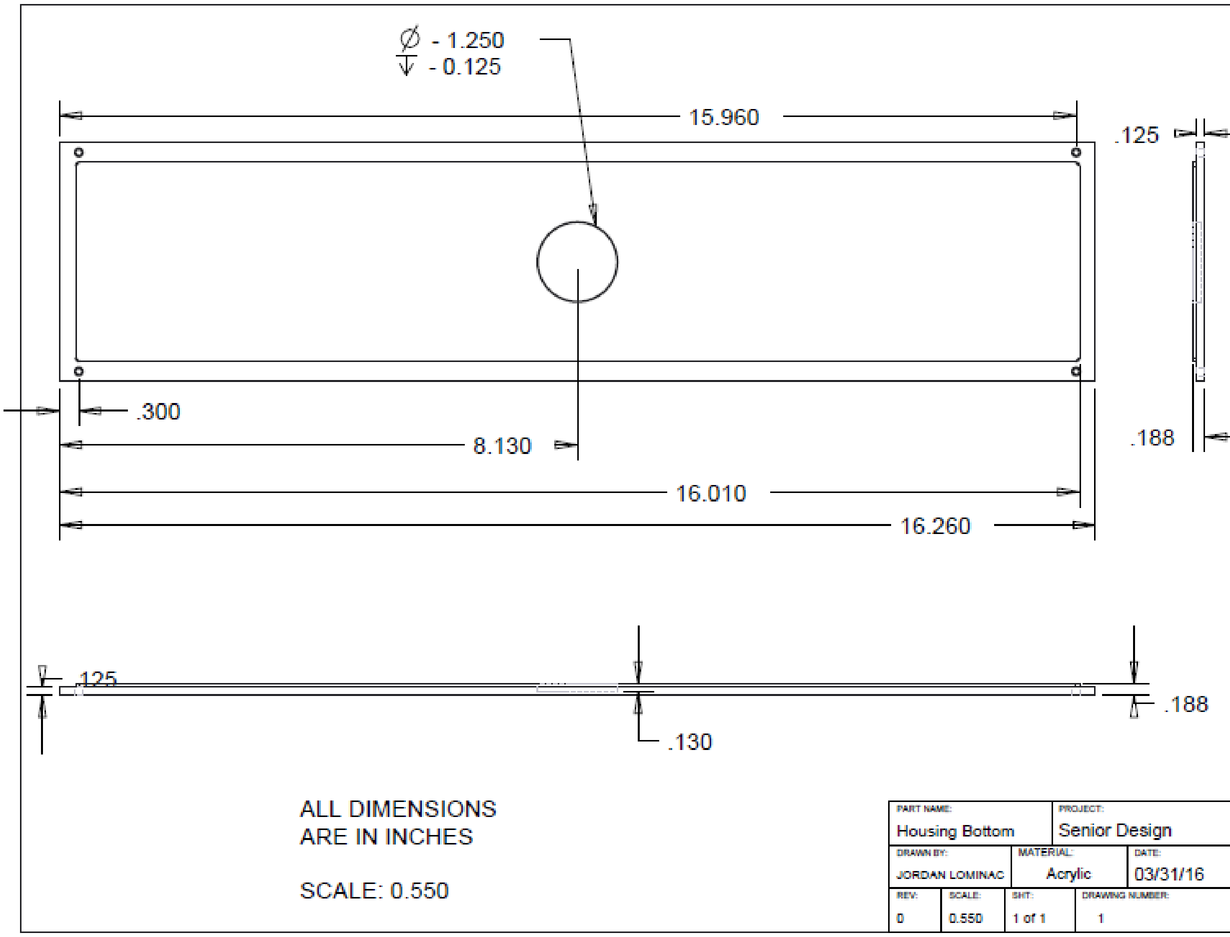

[73.61]
2.898
[66.68]
2.625
[45.72]
1.800
[52.00]
2.047
[3.18]
4-Ø0.125
[15.80]
0.622
UNIT: INCH[MM]
TOLERANCES
UNLESS OTHERWISE SPECIFIED
ANGULAR: ±1.0°
DECIMAL .X ±0.1
DECIMAL .XX ±0.01
DECIMAL .XXX ±0.005
COMMERCIAL TOLERANCES
SHALL APPLY ON BAR ROD,
WIRE, SHEET, ETC.
MATERIAL:
FINISH:
SCALE: 2:1
SHEET NO: 1 OF 3
DRAWN BY: Vinh
DATE: 6-30-2015
APPROVED BY:
DATE:
ION MOTION CONTROL
PART NAME ROBOCLAW ST 2X45A
PART NO. MC45A-ST-V5
REV 5

Appendix D (Enclosure Drawings)

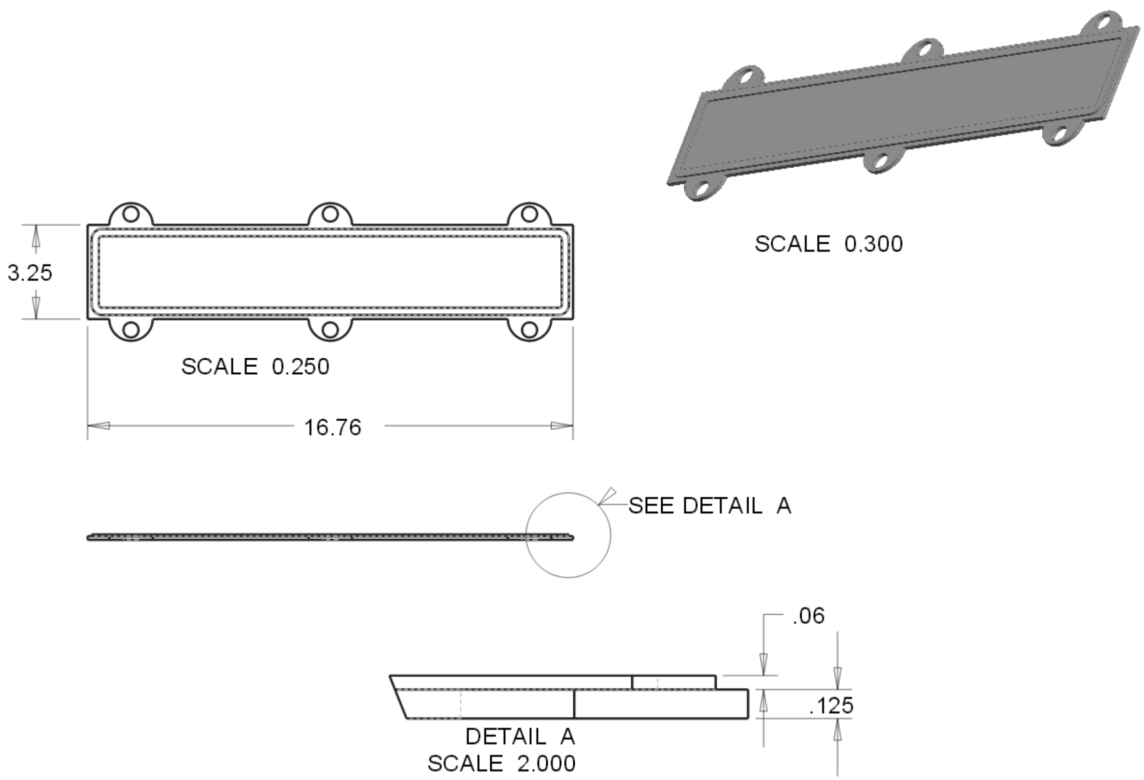


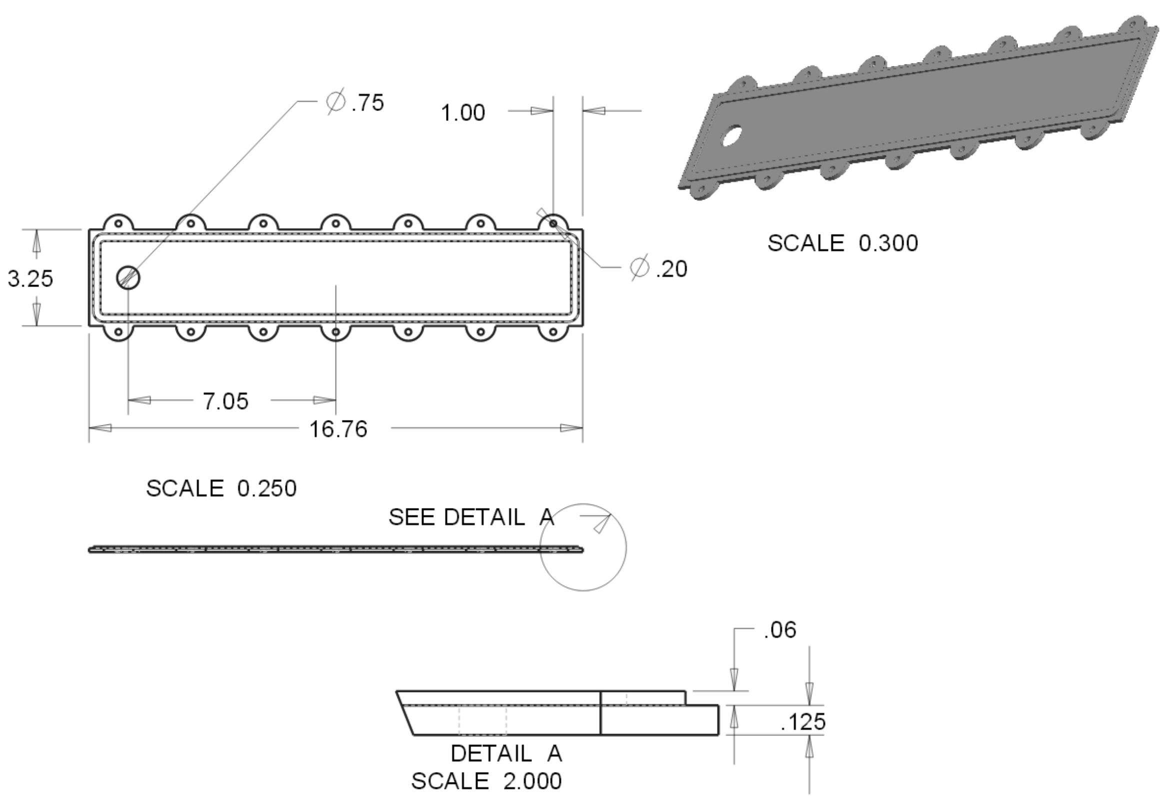

16.260
9.175
6.675
.313
.188
.750
2.19
3.160
∅ - 0.210
- THRU
.156
.156
.300
.313
∅ - 0.1120
- 0.750
15.960
ALL DIMENSIONS
ARE IN INCHES
SCALE: 0.500
PART NAME:
Side Housing
PROJECT:
Senior Design
DRAWN BY:
JORDAN LOMINAC
MATERIAL:
Aluminum 6061
DATE:
03/31/16
REV:
0
SCALE:
0.500
SHT:
2 of 4
DRAWING NUMBER:
2


3.160
3.125
.125
.125
ALL DIMENSIONS
ARE IN INCHES
SCALE: 1.000
PART NAME:
House Side Short
PROJECT:
Senior Design
DRAWN BY:
JORDAN LOMINAC
MATERIAL:
Aluminum 6061
DATE:
03/31/16
REV:
0
SCALE:
1.000
SHT:
4 of 4
DRAWING NUMBER:
4



∅ - 1.250
- 0.125
15.960
.125
.300
8.130
.188
16.010
16.260
.125
.188
.130
ALL DIMENSIONS ARE IN INCHES
SCALE: 0.550
PART NAME: Housing Bottom
PROJECT: Senior Design
DRAWN BY: JORDAN LOMINAC
MATERIAL: Acrylic
DATE: 03/31/16
REV: 0
SCALE: 0.550
SHT: 1 of 1
DRAWING NUMBER: 1


SCALE 0.300
3.25
SCALE 0.250
16.76
SEE DETAIL A
.06
.125
DETAIL A
SCALE 2.000


∅.75
1.00
SCALE 0.300
3.25
∅.20
7.05
16.76
SCALE 0.250
SEE DETAIL A
.06
.125
DETAIL A
SCALE 2.000

Appendix E (Arduino Code)

```
//*****************************************************************************
//******************** ~~~~~~ < V . A . T . T . S . > ~~~~~~ ******************
//*****************************************************************************
//Florida State University
//Mechanical Engineering Department
//Senior Design Team 16: Variable Angle Target Training System (V.A.T.T.S.)
//Sponsor: Lockheed Martin

//Team 16: Ashar Abdullah      (aa12t@my.fsu.edu)
//         Andrew Bellstrom    (ajb10k@my.fsu.edu)
//         Ryan D'Ambrosia     (rd11s@my.fsu.edu)
//         Jordan Lominac      (jll11f@my.fsu.edu)
//         Fernando Rodriguez  (fr12c@my.fsu.edu)

//Date last modified: 04/07/16

//Programmers: Ryan D'Ambrosia
//             Andrew Bellstrom
//             Ashar Abdullah

//*****************************************************************************
//***************************        PURPOSE     ******************************
//*****************************************************************************
//This code is intended for use with the mechanical prototype developed by Team 16.
//The code was run on an Arduino Uno R3, interfaced through packet serial
//communication with an IonMotion Roboclaw 2x45A motor controller/driver. The code
//uses Roboclaw builtin libraries to operate a 12V DC Brushed motor. The motor's
//stall current was determined to be ~63A. AWG12 wires were used to wire the
//12V, 30A power supply to the Roboclaw, and the Roboclaw to the motor. Pin headers
//were used for connection between the Roboclaw and the Arduino Uno. A cumulative
//gear ratio of ~100:1 from the motor to the output was designed.

//This code functions as a closed loop position control for the prototype system.
//An incremental quadrature encoder was used to track the position of the
//system's output shaft. This quadrature encoder had 1440 quadrature pulses per
//revolution (given in the spec. sheet). Due to the system
//design, the encoder could only be placed directly on the output shaft, meaning the
//ratio of encoder quadrature pulses to output revolutions was 1440 pulses per final
//output shaft revolution. In the future, it is suggested that an
//absolute encoder on the output shaft, or a second shaft directly attached to the
//turning motor be used, as this will ensure a reference position as home. Currently,
//the system must be zeroed to the home position manually on every power up. An
//absolute encoder, or higher speed/resolution potentiometer will alleviate this
//design flaw.

//The position control constants used in the below code were determined using
//IonMotion's application connected via USB. The PD control was "Auto-Tuned" to
//produce the desired response. *(Note: Due to the slack in the gearing, the PD gain
//values were lowered from the default, revieced values from the application
//to avoid system instability)*
//
//*****************************************************************************
```

```
//*****************************     OPERATION     ********************************
//********************************************************************************
//
//The user will input vaules into the Arduino Serial Monitor as characters, followed
//by hitting the "Enter" key. The Serial Monitor will print out the entered command's
//target position. The commands the user may input and corresponding target
//positions are as follows:
//
// 0 : Concealed                  (90 Degree Rotation from Default Position)
// 1 : Simple Hostile             (Default Position)
// 2 : Restricted Hostile Left    (-45 Degree Rotation from Default Position)
// 3 : Restricted Hostile Right   (45 Degree Rotation from Default Position)
// 4 : Simple Neutral             (180 Degree Rotation from Default Position)
// 5 : Restricted Neutral Left    (-135 Degree Rotation from Default Position)
// 6 : Restricted Neutral Right   (135 Degree Rotation from Default Position)
//
//A diagram for these positions may be found in the team's final report. The team
//defined the default position to be "Simple Hostile", as this is the standard
//target presentation without any system rotation.
//********************************************************************************
//********************************************************************************
//********************************************************************************

//Arduino Mega and Leonardo chips only support some pins for receiving data back from the
RoboClaw
//This is because only some pins of these boards support PCINT interrupts or are UART receivers.
//Mega: 0,10,11,12,13,14,15,17,19,50,51,52,53,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15
//Leonardo: 0,8,9,10,11

//Arduino Due currently does not support SoftwareSerial. Only hardware uarts can be used, pins
0/1, 14/15, 16/17 or 18/19.

//Note: Most Arduinos do not support higher baudrates rates than 115200.  Also the arduino
hardware uarts generate 57600 and 115200 with a
//relatively large error which can cause communications problems.

//See BareMinimum example for a list of library functions

//Includes required to use Roboclaw library
#include "BMSerial.h"
#include "RoboClaw.h"

//Roboclaw Address
//Current Code set to Mode 7 (Address 0x80), Option 3 (baud: 19200bps)
#define address 0x80          //Communications address for serial communication between
Arduino and Roboclaw

//Velocity PID coefficients
#define Kp 0.0                //Proportional Constant (Velocity)
#define Ki 0.0                //Integral Constant (Velocity)
#define Kd 0.0                //Derivative Constant (Velocity)
```

```
//Voltage and Current Limits
#define minbatvoltage 0.0       //Minimum Battery Voltage in 0.1V increments
#define maxbatvoltage 150.0     //Maximum Battery Voltage in 0.1V increments
#define maxcurrent 400.0        //Maximum Current written to motor in 0.1A increments

//Position PID coefficients
#define kp 4000.0               //Proportional Constant (Position)
#define ki 10.0                 //Integral Constant (Position)
#define kd 40000.0              //Derivative Constant (Position)
#define kiMax 0.0               //
#define deadzone 0              //Deadzone of the motor
#define minpos -540             //Minimum Encoder Position
#define maxpos 720              //Maximum Encoder Position
#define qpps 3064               //Encoder Quadrature Pulses Per Second (Determined from
IonMotion Application)

//Definte terminal for display. Use hardware serial pins 0 and 1 (Computer USB Port)
BMSerial terminal(0,1);

//Setup communcaitions with roboclaw. Use pins 10 and 11 with 10ms timeout
RoboClaw roboclaw(10,11,10000);

void setup() {
  //Open terminal and roboclaw serial ports
  terminal.begin(57600); //Serial monitor baud rate
  roboclaw.begin(19200); //baud rate between Arduino and Roboclaw works better at lower baud
than 38400bps

  //Setting Voltage and Current Limits
  roboclaw.SetMainVoltages(address,minbatvoltage,maxbatvoltage); //Limiting main battery
voltage into Roboclaw
  roboclaw.SetM1MaxCurrent(address,maxcurrent); //Limiting max current provided to motor

  //Set PID Coefficients
  roboclaw.SetM1VelocityPID(address,Kd,Kp,Ki,qpps); //Setting the defined velocity PID constants
  roboclaw.SetM1PositionPID(address,kp,ki,kd,kiMax,deadzone,minpos,maxpos); //Setting the
defined position PID constants
  roboclaw.SpeedAccelDeccelPositionM1(address,0,0,0,0,0); //Initiallize the position function
  roboclaw.ResetEncoders(address); //Reset and zero encoders on startup
}

void loop() {

if (Serial.available())
  {
    char ch = Serial.read(); //Reads User Input to Serial Monitor
  //displayspeed(); //Will Display Position in Encoder Ticks and Speed in Encoder Ticks per
Second. Helpful for troubleshooting.
      switch (ch) {

                  case '0':
                    concealed();
```

```
                    Serial.print("Concealed \n\n");
                    break;

                  case '1':
                    sh();
                    Serial.print("Simple Hostile \n\n");
                    break;

                  case '2':
                    rhl();
                    Serial.print("Restricted Hostile Left \n\n");
                    break;

                  case '3':
                    rhr();
                    Serial.print("Restricted Hostile Right \n\n");
                    break;

                  case '4':
                    sn();
                    Serial.print("Simple Neutral \n\n");
                    break;

                  case '5':
                    rnl();
                    Serial.print("Restricted Neutral Left \n\n");
                    break;

                  case '6':
                    rnr();
                    Serial.print("Restricted Neutral Right \n\n");
                    break;

                  default:
                    Serial.print("Invalid Command \n\n");
                  break;
                 }//End of Switch Case

  }//End of User Input from Serial Monitor

}//End of Loop

//*************************************************************************************
//**************************         FUNCTIONS          ****************************
//*************************************************************************************
//The values in these turning commands specify the speed, accelleration,
//decelleration, and final position. Acceleration is in quadrature pulses(qp) per
//second^2. Velocity is in qp/s. Position is in quadrature pulses. The value for
//accelleration, decelleration and speed were set to 1800000 in order to saturate
//the values in order to run at the fastest speed and accelleration to get to the
//desired position. The last value of "0" in all the functions is a flag and
//is simply a placeholder.
```

```
//****************************************************************************
void concealed(void)
{
  //Concealed (90 Degree Rotation from Starting Position 1)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,180000,1800000,360,0);
  delay(10);
}

void sh(void)
{
  //Simple Hostile (0 Degrees of Rotation: Starting Position)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,0,0);
  delay(10);
}

void rhl(void)
{
  //Restricted Hostile Left (45 Degree Rotation from Starting Position 1)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,180,0);
  delay(10);
}

void rhr(void)
{
  //Restricted Hostile Right (-45 Degree Rotation from Starting Position 1)
   roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,-180,0);
   delay(10);
}

void sn(void)
{
  //Simple Neutral (180 Degree Rotation from Starting Position 1)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,720,0);
  delay(10);
}

void rnl(void)
{
  //Restricted Neutral Left (-135 Degree Rotation from Starting Position 1)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,-540,0);
  delay(10);
}

void rnr(void)
{
  //Restricted Neutral Right (135 Degree Rotation from Starting Position 1)
  roboclaw.SpeedAccelDeccelPositionM1(address,1800000,1800000,1800000,540,0);
  delay(10);
}
//****************************************************************************

void displayspeed(void) //This function Displays Encoder Values (Position) and Speed of M1 and
```

```
M2 connected to Roboclaw
{
  uint8_t status1,status2,status3,status4;
  bool valid1,valid2,valid3,valid4;

  int32_t enc1= roboclaw.ReadEncM1(address, &status1, &valid1);
  int32_t enc2 = roboclaw.ReadEncM2(address, &status2, &valid2);
  int32_t speed1 = roboclaw.ReadSpeedM1(address, &status3, &valid3);
  int32_t speed2 = roboclaw.ReadSpeedM2(address, &status4, &valid4);
  terminal.print("Encoder1:");
  if(valid1){
    terminal.print(enc1,DEC);
    terminal.print(" ");
    terminal.print(status1,HEX);
    terminal.print(" ");
  }
  else{
  terminal.print("failed ");
  }
  terminal.print("Encoder2:");
  if(valid2){
    terminal.print(enc2,DEC);
    terminal.print(" ");
    terminal.print(status2,HEX);
    terminal.print(" ");
  }
  else{
  terminal.print("failed ");
  }
  terminal.print("Speed1:");
  if(valid3){
    terminal.print(speed1,DEC);
    terminal.print(" ");
  }
  else{
  terminal.print("failed ");
  }
  terminal.print("Speed2:");
  if(valid4){
    terminal.print(speed2,DEC);
    terminal.print(" ");
  }
  else{
  terminal.print("failed ");
  }
  terminal.println();
}
//*****************************************************************************************
//**********************          END OF FUNCTIONS          ***********************
//*****************************************************************************************
```

Appendix F (Purchase Forms)

Department of Mechanical Engineering

Purchase Order Request
Please Fill in All Information
INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date:	01/22/2016	**Requestor**	
Sponsor:	Lockheed Martin	**First Name:**	Fernando
Project Advisor:	Isler, Chris	**Last Name:**	Rodriguez
Team #	Team 16	**Email:**	fr12c@my.fsu.edu
Project:	V.A.T.T.S	**Phone:**	850-524-6212

Vender Information

Name:	Online Metals
Address:	1848 WestLake Ave N Suite A Seattle, WA 98109
Telephone:	(800) 704-2157
Fax:	(206) 285-7836
Contact Person:	

Item Description	Item Number	Qty*	Price	Total Cost
Aluminum 6061T651 Plate 0.3125" Cut to: 1.75" x 18"		1	12.92	12.92
Aluminum 6061T651 Plate 0.375" Cut to: 7.25" x 3.25"		1	8.01	8.01
Aluminum 6061T651Plate 0.25"Cut to: 4" x 15"		3	13.20	41.1
Aluminum 6061T651Plate 0.5"Cut to: 1" x 1"		6	0.45	8.7
Aluminum 6061T6Sheet PVC 1 side 0.125"Cut to: 16.25" x 5.25"		4	13.65	57.6
Aluminum 6061T6Sheet PVC 1 side0.125"Cut to: 5" x 3"		3	2.4	8.7
Aluminum 6061T651BarePlate 0.25"Cut to: 9" x 8"		1	15.84	15.84

SUB TOTAL: 152.87

Department of Mechanical Engineering
Purchase Order Request
Please Fill in All Information
INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date:	03/21/2016	**Requestor**	
Sponsor:	Lockheed Martin	**First Name:**	Fernando
Project Advisor:	Isler, Chris	**Last Name:**	Rodriguez
Team #	Team 16	**Email:**	fr12c@my.fsu.edu
Project:	V.A.T.T.S	**Phone:**	850-524-6212

Vender Information

Name:	Pololu
Address:	920 Pilot RD Las Vegas, NV 89119 USA
Telephone:	(702) 262-6648
Fax:	
Contact Person:	

Item Description	Item Number	Qty*	Price	Total Cost
Arduino Uno R3	#2191	1	29.95	29.95

SUB TOTAL: 29.95

Department of Mechanical Engineering
Purchase Order Request
Please Fill in All Information
INCOMPLETE REQUESTS WILL NOT BE PROCESSED

Date:	04/04/2016	**Requestor**	
Sponsor:	Lockheed Martin	**First Name:**	Fernando
Project Advisor:	Isler, Chris	**Last Name:**	Rodriguez
Team #	Team 16	**Email:**	fr12c@my.fsu.edu
Project:	V.A.T.T.S	**Phone:**	850-524-6212

Vender Information

Name:	MSC Industrial Supply
Address:	75 Maxess Road Melville, NY 11747 USA
Telephone:	1-800-645-7270
Fax:	
Contact Person:	

Item Description	Item Number	Qty*	Price	Total Cost
WorkSmart - 1/16 Inch Diameter Round Cord Stock. *13 length feet*	31959372	1	0.24	3.12
WorkSmart - 1/8 Inch Diameter Round Cord Stock *12 length feet*	31959398	1	0.57	6.84

SUB TOTAL: 9.96

Appendix G (Prototyping Images)


FIG 12
Arun Fabs