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ASME Student Design Challenge

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MEMS 411: Senior Design Final Report

ASME Design – Robot Pentathlon

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1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

The Olympic Summer Games test the abilities of people throughout the world in a wide variety of athletic challenges. The athlete that wins the Olympic decathlon or heptathlon is referred to as the world's greatest male or female athlete. The 2017 Student Design Competition challenges your technical design skills to create a robot that is fast, strong, and agile. Your team must build a remotely controlled device to compete against others in five different events – a robot pentathlon. Scores from each of the events will be combined to determine the overall champion. Our team will attempt to design a robot that will compete in two of the five events that still meets all the standards and rules of the competition. The two events that we are planning to compete in are the sprint and the throw. These two events, along with the device's foundation, will be competed in the fall. The hit, lift, and climb will be completed in the spring.

1.2 LIST OF TEAM MEMBERS

Team members include: James Mitchell, Ean Murnan, and Alexander Wirtz

2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM

A short design brief description that describes the problem. Include a description of the operational requirements. For example, if your project is to design a catapult, how far must it throw a mass? What is the maximum mass the catapult can throw?

This piece of equipment produced will be used to compete in the ASME Student Design Challenge Competition in which this robot will be tested on multiple capabilities. Various spatial and energy constraints are specified by ASME and general competition requirements are outlined. The objective of the competition is to complete five tasks – such as a pentathlete would – by using a remotely controlled device. The robot must complete a *sprint*, *throw*, *climb*, *lift*, and *hit*. For the purposes of this design project, our team will be creating a functional and remotely-responsive foundation along with the ability to complete (efficiently) two of the pentathlon tasks: the *sprint* and the *throw*.

This robotic device must fit within a sizing box of maximum size 50 cm x 50 cm x 50 cm in which the robot will be subjected to throughout the entire competition. The main source of energy from the device must be provided by rechargeable batteries. If any other source of energy is used, the state of that energy must be restored back to its original state by means of the battery power. For the *sprint* event, the robot must be able to travel 10 meters as fast as possible within a confided, straight area of 1 meter wide. The device must then touch a fixed wall 8 centimeters high and return to the start line to finish. Teams will be ranked based on completion time and will have only one attempt to complete the event. The *throw* event requires devices to throw a tennis ball as far as possible. Devices must be confined to a 1 m x 1 m space in which throwing distance is measured from the each of this measurement line. Teams are allowed to place the ball in the device during a one-minute preparation period. Teams will be ranked based on throwing distance and will have two attempts to throw the ball.

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

Due to the unusual circumstances of the design project, there are no readily available design competitors to this design project. There won't be any competitors to this design until the day of the competition as all universities are encouraged to participate. Therefore, it is irrelevant to state any old competition models as new technology will be introduced each year in the competition, along with the objectives of the completion changing from year to year. Any parallels to our project could be found by reviewing the ASME 2015 Design Competition competitors and viewing previous ideas used in that particular competition (a robotics design challenge). Please view the 2017 ASME Design Competition Rules and Guidelines for any additional concerns or information.

3 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS

3.1 OPERATIONAL REQUIREMENTS ALLOCATED AND DECOMPOSED TO DESIGN REQUIREMENTS

Design Constraints.docx

The main design constraints for our robot revolve around the ASME Robotic Competition. The rules of the competition constrain our robot's ability to move and perform which constrains the materials, concepts, and ideas that we can implement.

3.1.1 Customer Interview

Initial Interview: Professors at Washington University with knowledge of the ASME design challenge and requirements.

Customer: Prof. Mark Jakiela and Prof. Mary Malast

Interviewers: James Mitchell, Ean Murnan, Alexander Wirtz

Date of Interview: September 21, 2016

Would you want the robot to resemble reality or specified to the competition?

- Specified to ASME Challenge
- Robot can't have detachable parts
- Importance: 2

What type of throwing mechanism do you prefer?

- Trebuchet
- Needs to launch tennis ball as far as possible and return to original state
- Importance: 5

Would you prefer wireless or wired remote control?

- Malast - Wireless (Less cords and more advanced system); Jakela - Wired (Easier to debug and cheaper)
- To control the robot without physically touching the robot
- Importance: 4

Fig. 1 Customer Goals/Needs for ASME Design Challenge.

3.1.2 Identified Operational Requirements

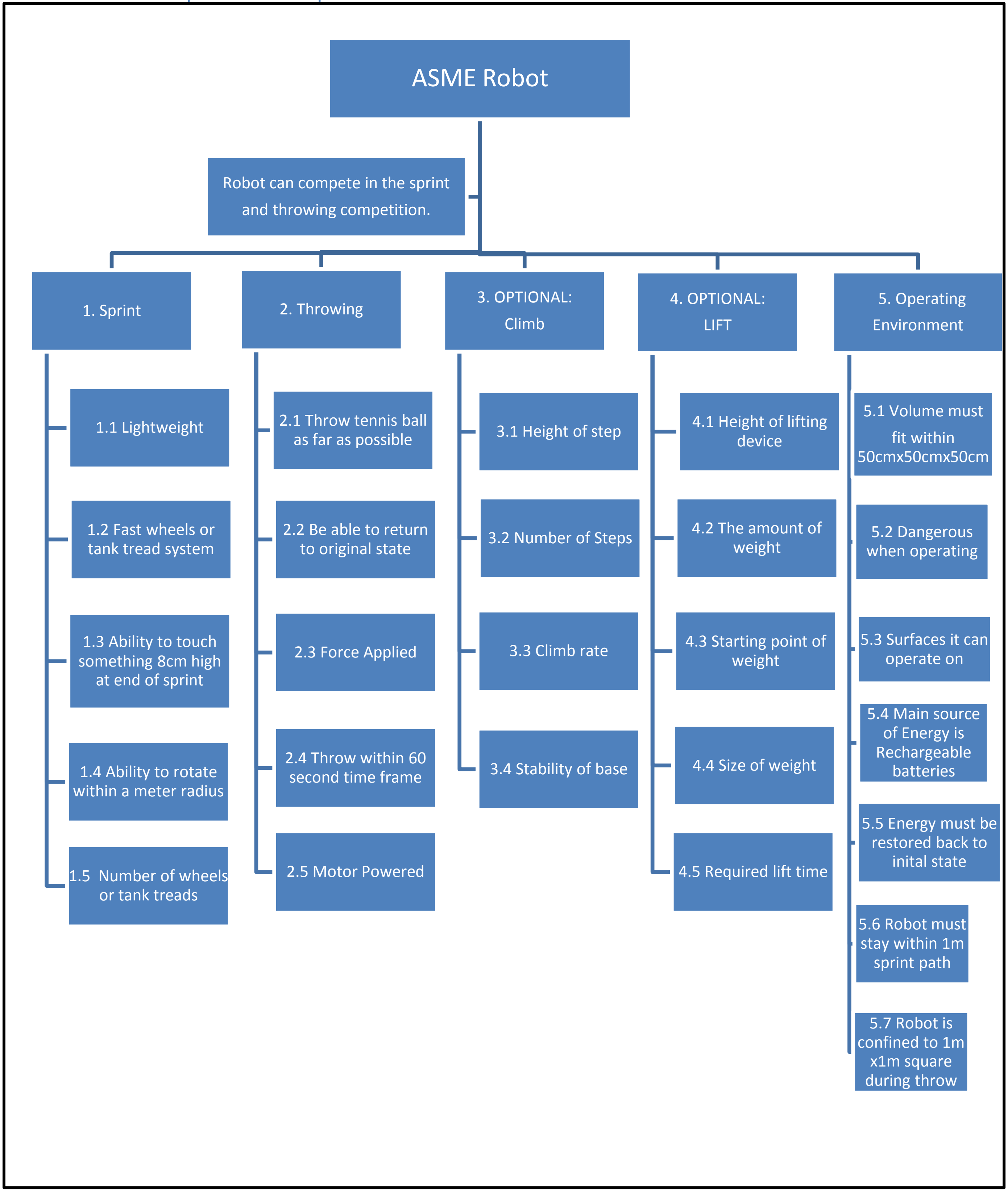

Fig. 2 **Operational Requirements for the ASME Design Challenge.**

3.1.3 Identified Design Requirements

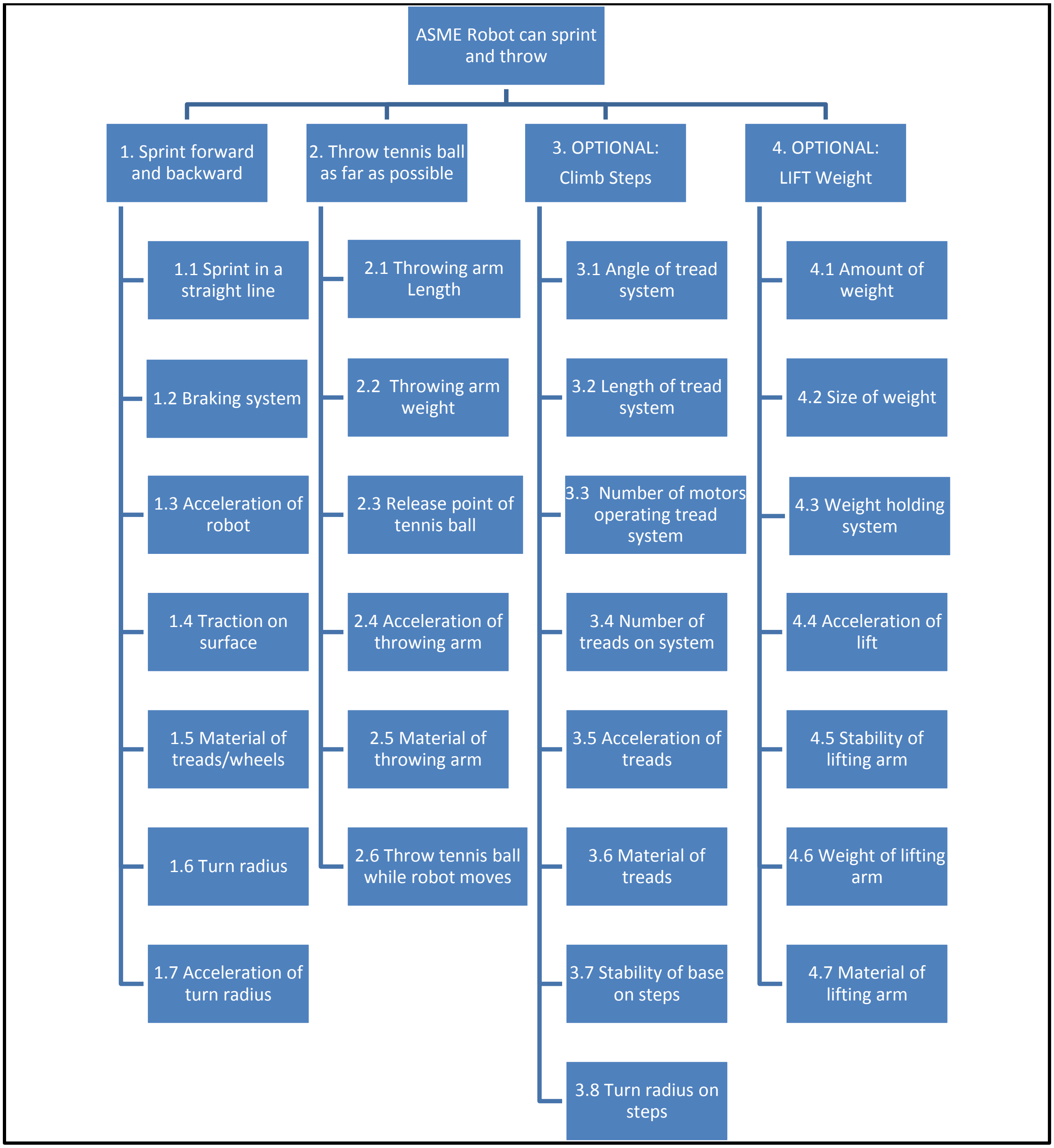

Fig. 3 Design Requirements for ASME Design Challenge.

3.2 FOUR CONCEPT DRAWINGS

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Fig. 4 Design Concept #1

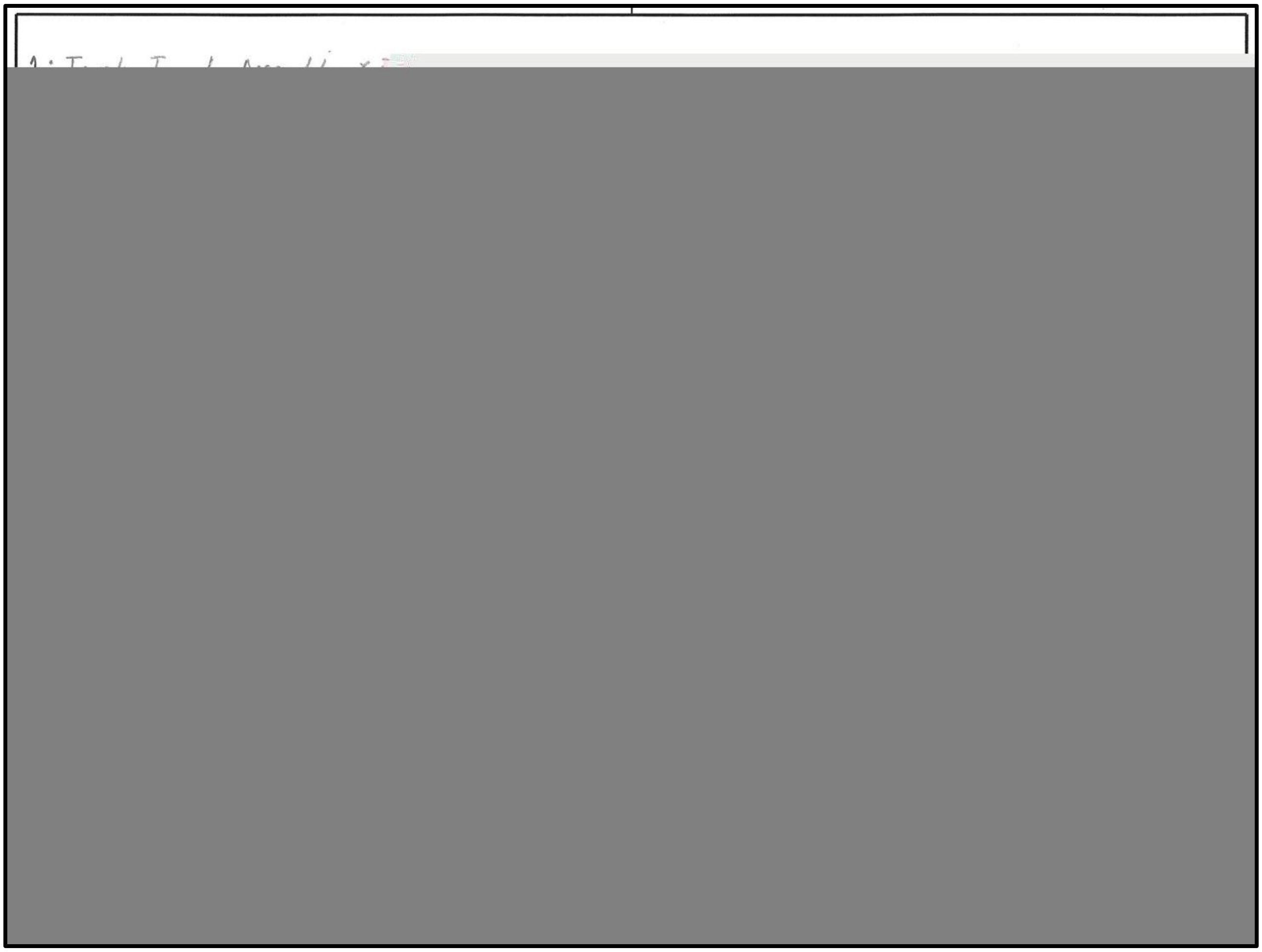

Fig. 5 **Design Concept #2**

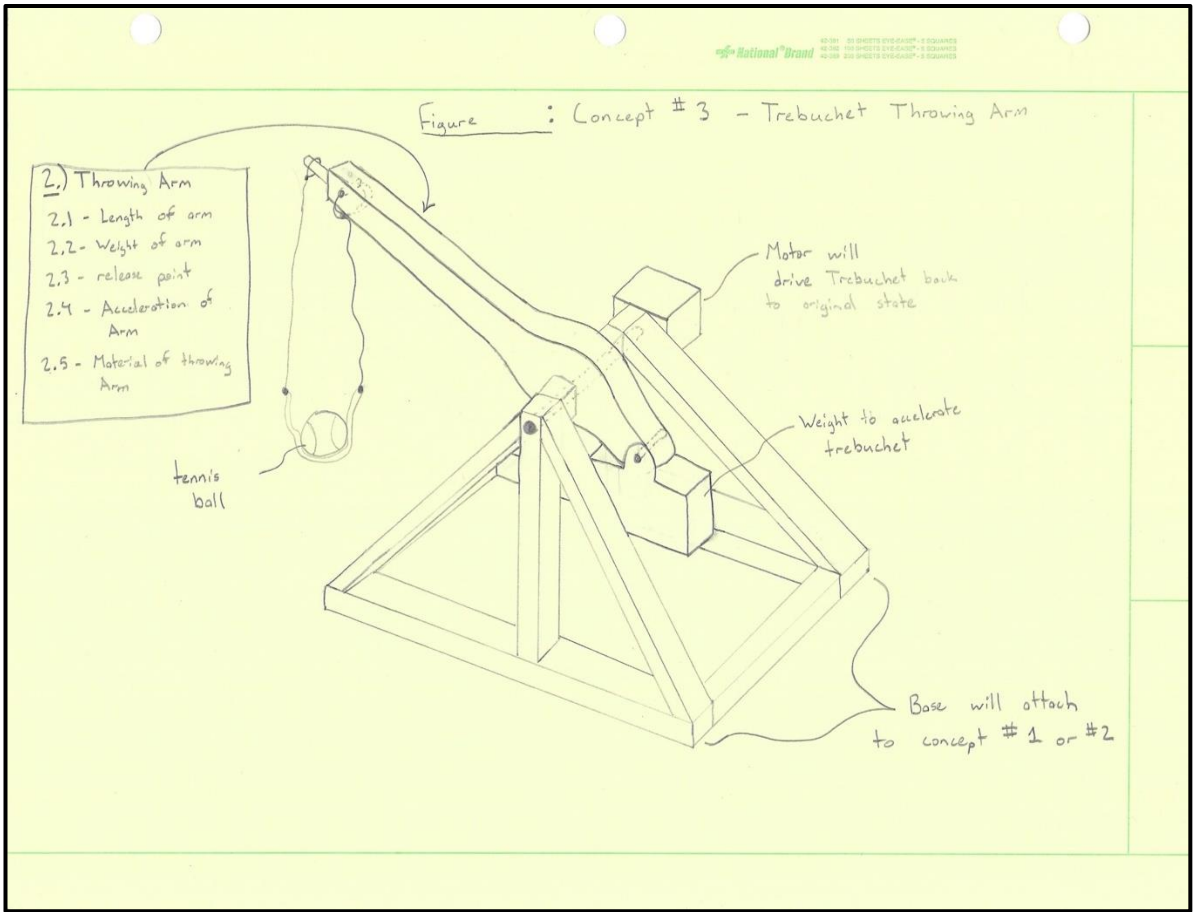

Fig. 6 **Design Concept #3**

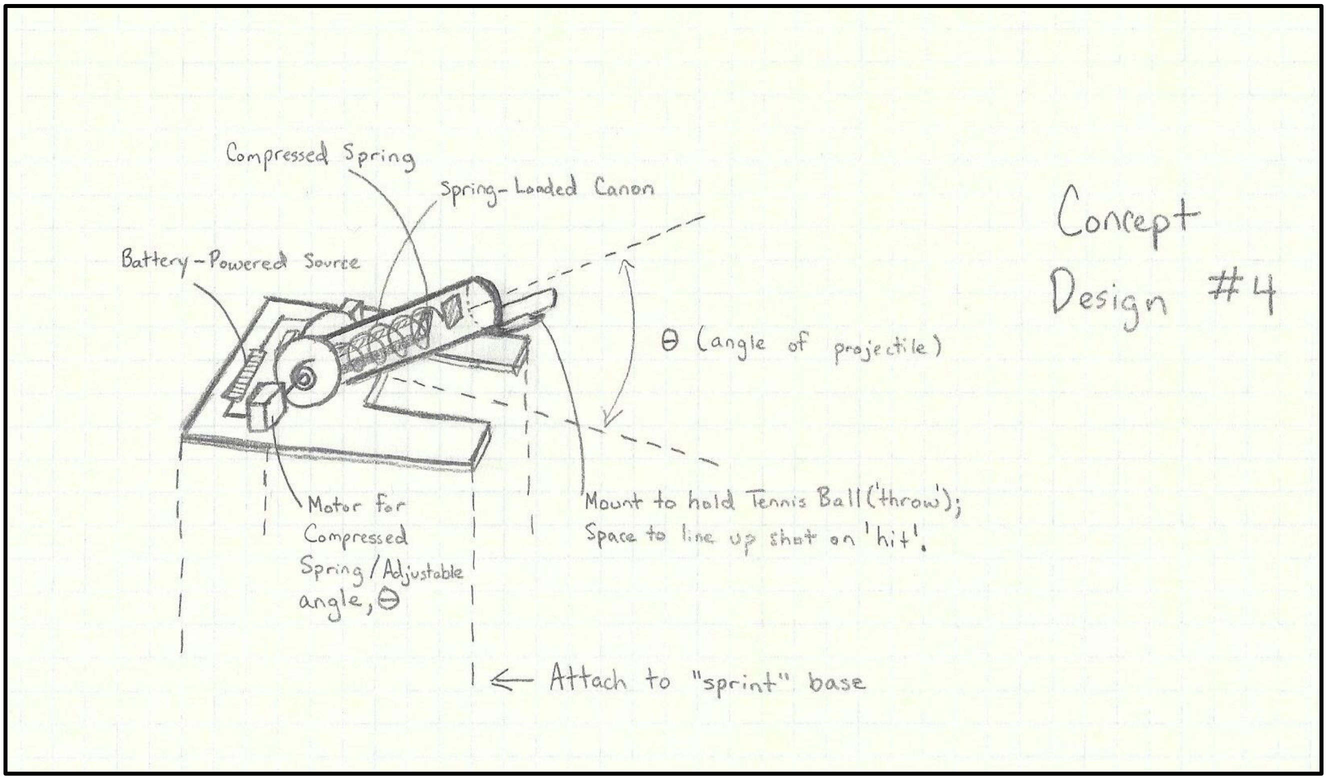

Fig. 7 **Design Concept #4**

3.3 CONCEPT SELECTION PROCESS

3.3.1 Preliminary Analysis of each Concept

DESIGN #1: Standard Wheels

This design incorporates a wheel based robot design. When working on this design, we mainly focused on doing well in the sprint event. The wheel design is focused on getting the best grip with the least amount of surface area touching the ground. The benefit of this design is that it would be very light. The lighter we can make it the faster we will be able to accelerate. With this design, we can gear up the system for the best acceleration. With the competition guidelines for the sprint event, short sprint distance and having to change directions, acceleration is key.

Also with this design we have a solid and open base to build off for the other events. This design does have some problems. If we would go with this design, then we would have to add a whole new system for the climbing event, if we choose to do the full competition. If we need to add another system to the robot it could make heavier, then that would defeat the purpose of making this base light. This design is very one-dimensional. This design mainly focuses on just for the sprint event, so then once we add the rest of the systems we probably wouldn't do very well on the sprint event.

DESIGN #2: Tank-Tread Wheels

Concept number 2 is the design for one the bases that our robot will use. This is critical because this will determine the entire mobility of our robot. This concept design utilizes the idea of tank treads as our form of mobility with an elevation change at 35 degrees from the ground. This concept idea has some design constraints that will have to be addressed such as the number of motors, the length of each tank tread, the optimal angle at which the tank tread elevates at, the number of treads, the material the tread is made out of, and the ability to control each motor in unison so the tread can easily move along the wheels. The number of motors that will be chosen depends not only on the length of each tread, but the number of wheels that each tread will have along its path. The current design is to have 3 wheels and motors total, therefore one in the middle and one at each end of the tread. The length of the tread is determined not only by our design constraint of 50cm total length in the x or y direction, but also by the stability of the base. Therefore, the tread that rest on the ground will be no less than 28cm in length and the elevated tread will take up the rest of the length needed to climb a step. The step is anywhere from 8 to 15cm high, therefore to cover all grounds the optimal angle would be 35 degrees from horizontal. The number of treads will help the amount of traction along with the material that the treads are made of, therefore the optimal material would be some type of rubber such as the same type of material a tire is made of. The main design constraint though would be getting all the motors to turn in sync so that the tread not only stays along the path of the wheels but also allows the robot to travel in a straight path.

If all the design constraints can be met as stated above, the tank treads base would prove to be very optimal in allowing our robot to not only sprint but also climb. This exceed the expectations of this project during the time frame of this class. The tank treads would allow the robot to turn in a very small radius unlike concept one with the wheels. We will move forward with a very similar design concept dealing with the tank treads to accomplish more than two events for the ASEM Robotic challenge.

DESIGN #3: Trebuchet

Concept number 3 deals with the challenge of throwing a tennis ball as far as possible while having the robot return to its original state after the toss. The concept consists of a trebuchet attached to the top of concept # 1 or concept # 2 that is already preloaded and ready to fire. We would activate a pin and a motor which would allow the trebuchet to release and would allow the motor to help accelerate the trebuchet to launch the tennis ball. There are a few concerns with this concept such as the weight of the arm, the material of the arm, the efficiency of the motor helping the trebuchet arm accelerate, and returning the trebuchet arm to its initial state. If the trebuchet arm is too heavy then it won’t accelerate enough by the time the tennis ball hits its release point, therefore not throwing the tennis ball very far. This would be due to the material that the arm is made of and how big the arm is. For instance, a steel arm will be sturdy and could handle the throwing force exerted on it, but it would not accelerate the tennis ball as fast due to its weight. Another factor is the motor and if it will be powerful enough to help accelerate the trebuchet arm, therefore adding more throwing force to the tennis ball. This all depends on the type of motor, size of the motor, and how much power the motor utilizes. The latter will be of most importance since the robot can only run off batteries and not a plug-in wall socket. Probably the most concerned issue with this design is returning the trebuchet back to its original state after we throw the tennis ball. We would rely on the motor to be able to produce enough torque to rotate the trebuchet back in place where it first had started. This shouldn't be too hard with the right amount of motors, but the main concern is the rope that connects to the end of the trebuchet arm that comes unattached after a throw. We would need to create some sort of design or re-latching system that could hook the rope back onto the end of the trebuchet after it throws the tennis ball. These concerns listed above fall into the category of design constraints that we further need to consider to completely come up with a working design for our ASME robot.

If we were to work out the design constraints listed above, the trebuchet would produce a great amount of force for the size constraints that our design falls under. It would utilize not only gravity but also one or two motors to help accelerate the tennis ball. The base of a trebuchet is known to be very sturdy with little concern of the robot tipping over during or after throw, and trebuchets have been around for so long that they can be easily optimized to our design constraints so the tennis ball exits at the optimal angle. The trebuchet is a very feasible idea for the throwing competition and we plan to go forward with a very similar concept of the trebuchet.

DESIGN #4: Spring-Loaded Canon

Concept 4 is the alternative option to the trebuchet for the throw event in the robot pentathlon. Similarly, the design will attach to either concept #1 or concept #2. This design incorporates a powerful spring to launch the tennis ball as far as possible. The tennis ball will be placed on a customized mount and the device will use motors to compressed the spring to a reasonable point. With remote capability of the device, we will release the spring to launch the tennis ball as far as possible.

The benefit with the spring-loaded canon is the ability to easily optimize the launch as the angle of the projectile can be customized and use in tandem with the calculated potential energy of the spring released. This design is also useful as the custom mount can be incorporated later into the hit event as the spring-loaded cannon will be able to reach all the way to mount and launch the ping-pong ball for the hit event as well. For the lift event, weight can be placed into the canon and raised to the maximum height to achieve the best score on that event as well.

In contrast, the design isn't ideal as a lot of energy will be required to compress a spring of considerable strength. Many motors will be need to compress the spring and adjust the angle of the canon which will add quite of bit of weight and cost to this design. The motors required might be out of the budget range of the design, and the power needed might be too much to load this tennis ball. Power must be distributed evenly if the device will last the entire competition.

3.3.2 Concept scoring

	Interpreted Need	Importance
1	Volume Constraint before each Event	5
2	Height of 8cm for the Spring Event	5
3	Drive Straight for Sprint Event	4
4	Device is Capable of Reverse	4
5	Device has Traction	3
6	Device is Reliable	5
7	Device is Battery Powered	5
8	Device is Wireless	3
9	Ability to Return to Original State	5
10	Device can Throw a Tennis Ball	5
11	Device has no detachable parts	5
12	Safety for Competitors in the area	5
13	Ability to Throw the Ball while moving	2
14	Ability to Throw the Ball Straight	3
15	Model uses Aluminum Parts	3
16	High Torque Motors within Budget	4
17	Device is Under 3lbs	2
18	Programing isn't complicated	3

Table 1 **User Needs and Importance Table**

Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	1,2	Square Dimention of Device	cm	20	50	40	0.667
2	1	Volume of material	cm^3	8000	125000	80000	0.615
3	2	Height of Device	cm	7	50	50	1.000
4	3, 4, 5, 13	Angle on the Drive Shafts	degrees	80	90	90	1.000
5	5	Surface Area of Treads/Wheels	cm^2	10	200	160	0.789
6	6, 7	Voltage	V	0	24	24	1.000
7	8	Connectivity	Binary	0	1	1	1.000
8	10	Projectile Distance	cm	0	3000	900	0.300
9	11, 13, 15, 17	Weight	kg	0.5	4.5	2.7	0.550
10	12	Number of Sharp Edge	Integer	1	40	5	0.103
11	14	Angle of Projectile off Center	degrees	0	90	0	0.000
12	16	Torque on Motor	Newton meter	0	10	6.5	0.650
13	18	Programming Features	Integer	1	10	3	0.222
						TOTAL	**7.896**

Table 2 Design Metrics Table for ASME Design Challenge.

3.3.3 Final summary

After some debate, we have decided to go with concept #2 and concept #3 combined into one. These concepts would create a robot with tank treads as its base of mobility and a trebuchet type of throwing mechanism to throw the tennis ball. The reasons for choosing these concept designs over concept #1 and concept #4 is because they create a more feasible design towards our performance goals. These performance goals rely on our robot's ability to sprint 10 meters forward, touch the 8 cm high wall, and sprint 10 meters back within 20 seconds, and our robot's ability to throw a tennis ball 10 feet. Another important performance goal that we believe will be achieved by these concepts is the weight of our robot which we would like it to be light for the sprint, but heavy enough to stay stable during the throw.

Concept #2 is the tank treads which will be the base of our robot, therefore this is how our robot will move around, turn, sprint, etc. We chose this design over the wheel's design because tank treads would allow our robot to sprint over any surface in case the sprint is in sand, gravel, etc. and it would allow us to move on further with the competition as our robot would be able to climb the steps required in another event in the competition. The wheels might be a little faster if the surface were flat and smooth, but the time difference to surface risk and multiply abilities isn't worth it. The tank treads will also allow us to stop very quickly with the amount of traction and surface area the treads have on the ground. This will allow us to acceleration longer during the sprint and stop faster close to the wall we need to touch at the end. If needed during this time as well, the tank treads will allow our robot to easily turn within a small radius so we can sprint back the 10 meters to the starting line. Overall the tank treads outweigh the wheel's design concept with a better fit to the performance goals dealing with sprint.

Concept #3 is the trebuchet which will be the main outline for the design to throw the tennis ball as far as possible. We chose this design over the spring-loaded cannon because the design constraints of the trebuchet would be easier met than the spring-loaded cannon. The spring-loaded cannon we believe has some major design issues that would we not be able to account for such as recompressing the spring after it releases. The amount of force and torque it would take to recompress the spring would be more than our motors could produce, therefore this idea would not be feasible. On the other hand, the trebuchet is very feasible with a few design changes from concept #3. The trebuchet will be easy to return to its original state if we use the throwing arm to create a large moment to pull it back into launch position which is the main concern with this throwing event. Another main perk with the trebuchet is that its design capability is so well known that we could easily optimize the angle or release of the tennis ball, the weight of the trebuchet arm, the length of the trebuchet arm, and possibly use the arm as a lifting device for the lifting event. This is not required, but we are setting ourselves up for the ability to create a robot that we could add more to it to compete in more events. The trebuchet also uses not only a motor to help accelerate the tennis ball, but it will utilize gravity as well to create a greater force on the tennis ball. Overall the trebuchet is a better design concept than the spring-loaded cannon because it is not only a more feasible design, but it will help us reach the performance goals we set for the ASME Robotic Competition.

The main design of our ASME Robotic robot will consist of concept #2 and concept #3, therefore the robot will have tank treads with a trebuchet on top of the treads. This design concept will not only allow our robot to complete the sprint in the fastest possible time on any surface that it needs to travel on, but it will also allow our robot to throw a tennis ball as far as possible using a driven motor and gravity. With both concept designs combined and optimized, our robot should be able meet and exceed the performance goals set.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

Performance Goals:

1) Device with volume of 50mm x 50mm x 50mm.
2) Throw event resulting in a 10-foot distance.
3) Sprint event resulting in 20-second time.
4) Entire device ranging from 5 – 6 lbs.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING

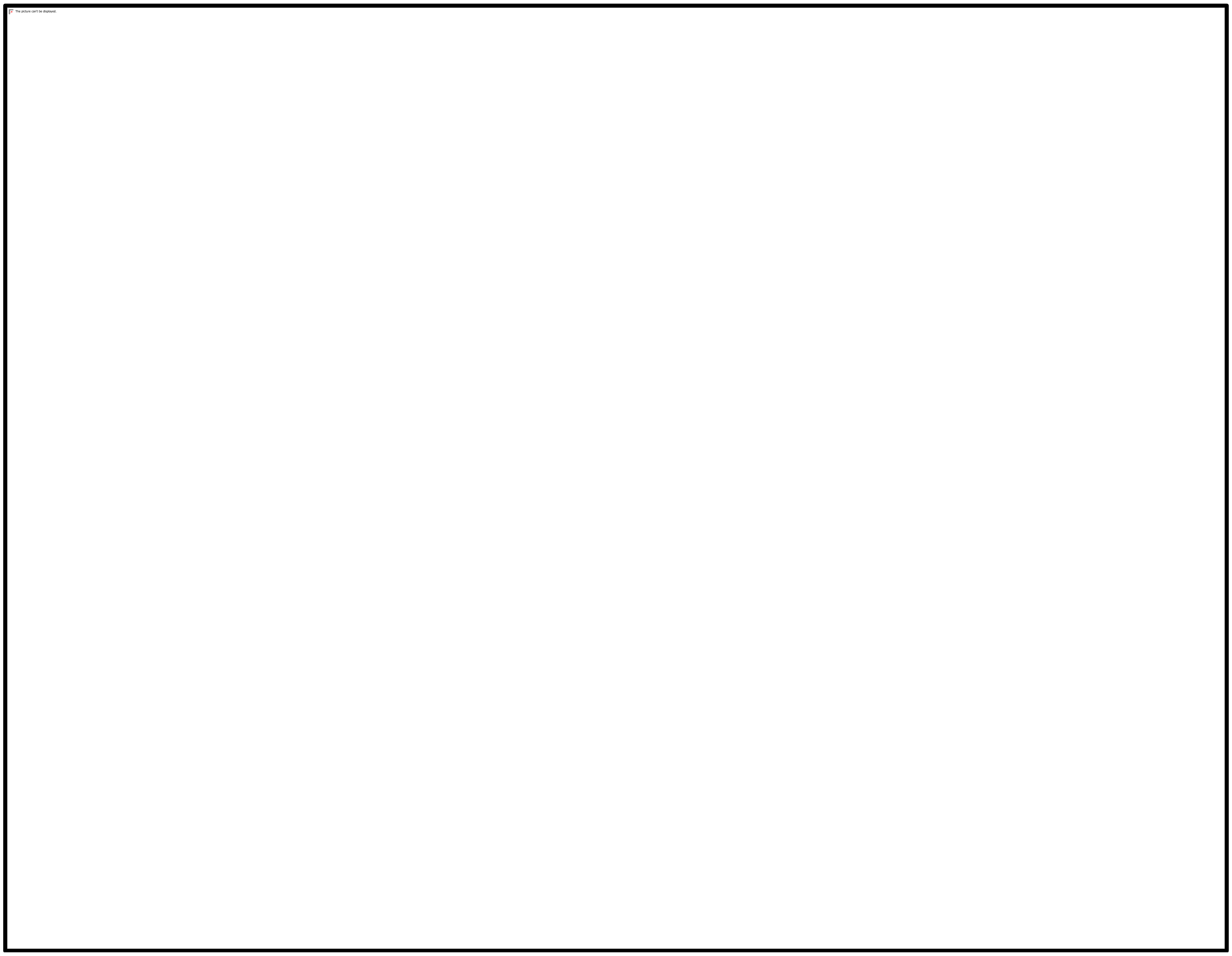

Fig. 8 Design Assembly: Embodiment Drawing.

4.2 PARTS LIST

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Tax ($0.00 if tax exemption applied)	Shipping	Quantity	Total price
1	Magnetic Motors	ASME Club	-	Silver	$0.00	$0.00	$0.00	15	$0.00
2	Tank Treads	ASME Club	-	Green	$0.00	$0.00	$0.00	2	$0.00
3	Arduino Uno	ASME Club	-	Blue	$0.00	$0.00	$0.00	4	$0.00
4	Wiring Kit	ASME Club	-	Black	$0.00	$0.00	$0.00	1	$0.00
5	Carboard box	Ean	-	Brown	$0.00	$0.00	$0.00	1	$0.00
6	Aluminum Plate 25x5 (6-pack)	VEX	276-2311	Gray	$24.99	$0.00	$24.11	1	$49.10
7	Aluminum Angle 2x2x35 (6-pack)	VEX	276-2304	Gray	$34.99	$0.00	$0.00	1	$34.99
9	Aluminum C-Channel 1x5x1x35	VEX	276-2290	Gray	$44.99	$0.00	$0.00	1	$44.99
10	Drive Shaft 12" (4-pack)	VEX	276-1149	Silver	$8.96	$0.00	$0.00	1	$8.96
11	Tank Tread Kit	VEX	276-2214	Green	$29.99	$0.00	$0.00	1	$29.99
12	Nut 8-32 Nylock (100-pack)	VEX	275-1027	Silver	$3.99	$0.00	$0.00	1	$3.99

13	Screw 8-32 x 0.375" (100-pack)	VEX	275-1003	Silver	$7.49	$0.00	$0.00	1	$7.49
14	Mini CIM Motor	VEX	217-3371	Silver	$24.99	$0.00	$0.00	1	$24.99
15	2-Wire Motor 393	VEX	276-2177	Green	$14.99	$0.00	$0.00	7	$104.93
16	Shaft Collar (16-pack)	VEX	276-1010	Black	$7.99	$0.00	$0.00	1	$7.99
17	Bearing Flat (10-pack)	VEX	276-1209	Black	$4.99	$0.00	$0.00	1	$4.99
18	Motor Controller 29	VEX	276-2193	Green	$9.99	$0.00	$0.00	7	$69.93
19	393 Motor Turbo Gear Set (4-pack)	VEX	276-3527	Green	$12.99	$0.00	$0.00	2	$25.98
20	Hobby King 2.4Ghz 6Ch Tx & Rx V2 (Mode 2)	KING	HKT6A M2	Orange	$29.99	$0.00	$9.13	1	$39.12
21	12 Volt Battery Holder	Amazon	a1311190 0ux0452	Black	$8.12	$0.00	$0.00	1	$8.12
22	Gorilla Tape	Walmart	5242786 0012	Black	$4.84	$0.00	$0.00	1	$4.84
23	25PC Set	Walmart	8234208 1790	Silver	$4.97	$0.00	$0.00	1	$4.97
24	Drill Set	Walmart	2887731 714	Silver	$5.88	$0.00	$0.00	1	$5.88
	TOTAL								$481.25

Table 3 **Parts List Table**

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

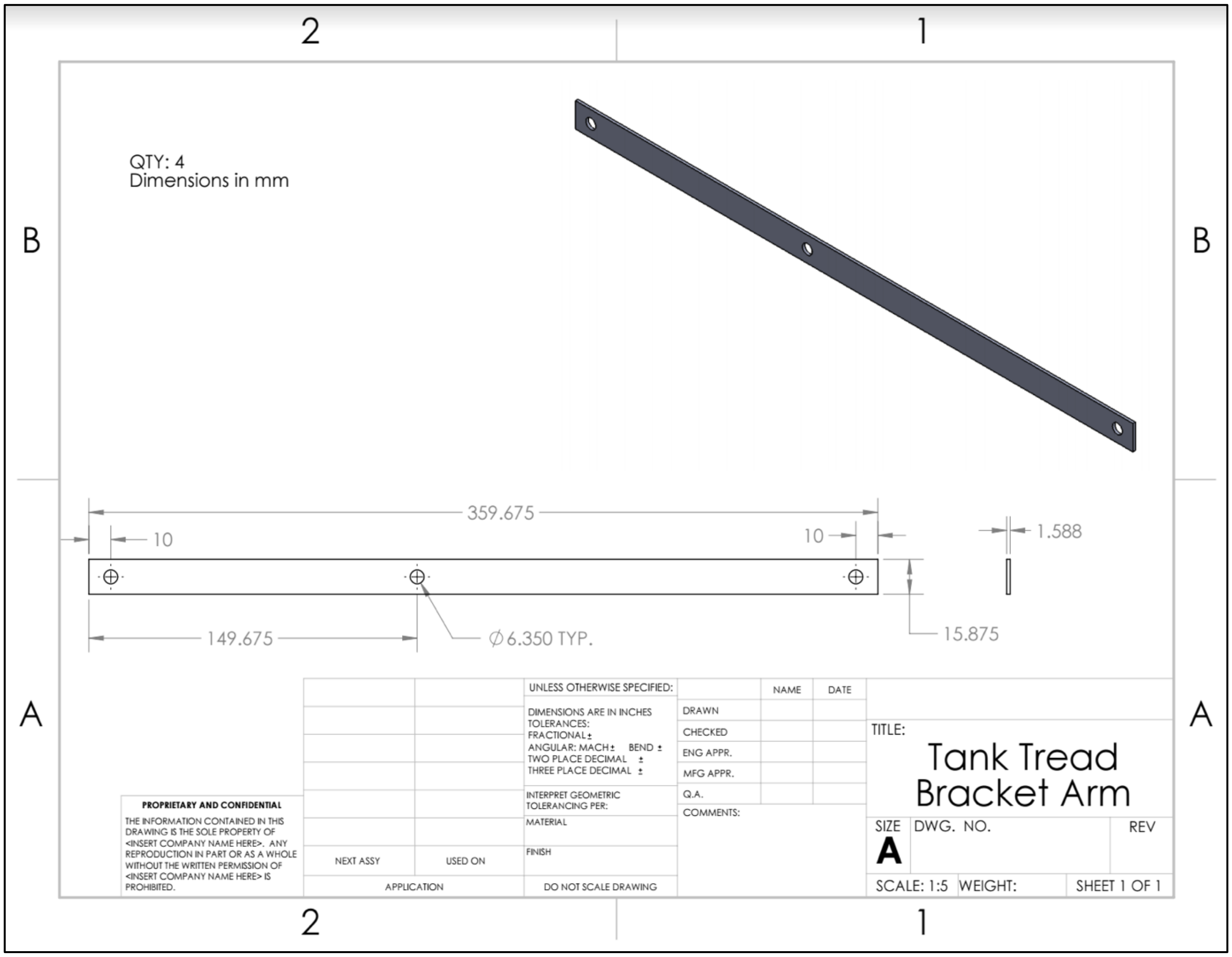

Fig. 9 Tank Tread Bracket Piece, 3D printed.

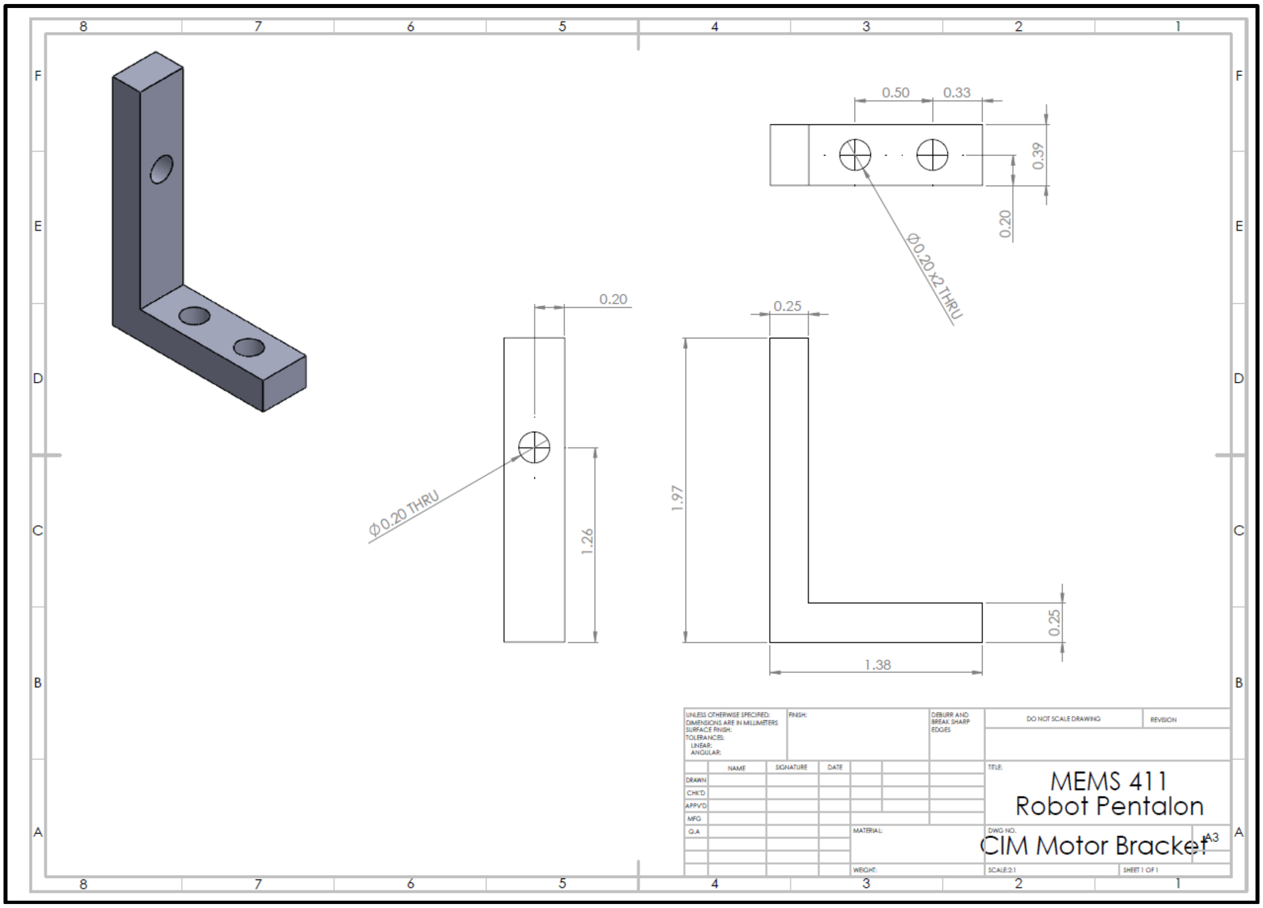

Fig. 10 **CIM Motor Bracket, 3D printed.**

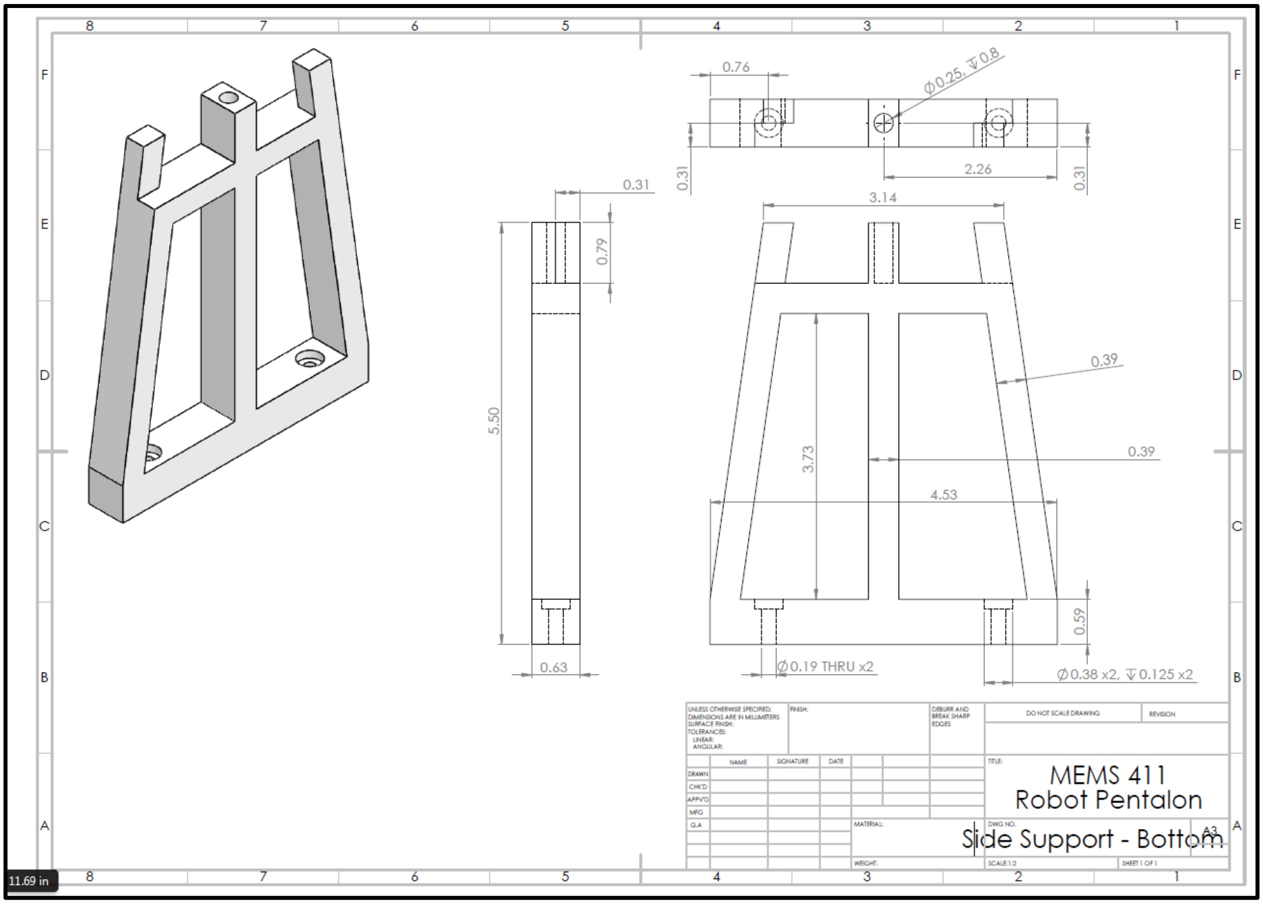

Fig. 11 Side Support Bottom Piece, 3D Printed.

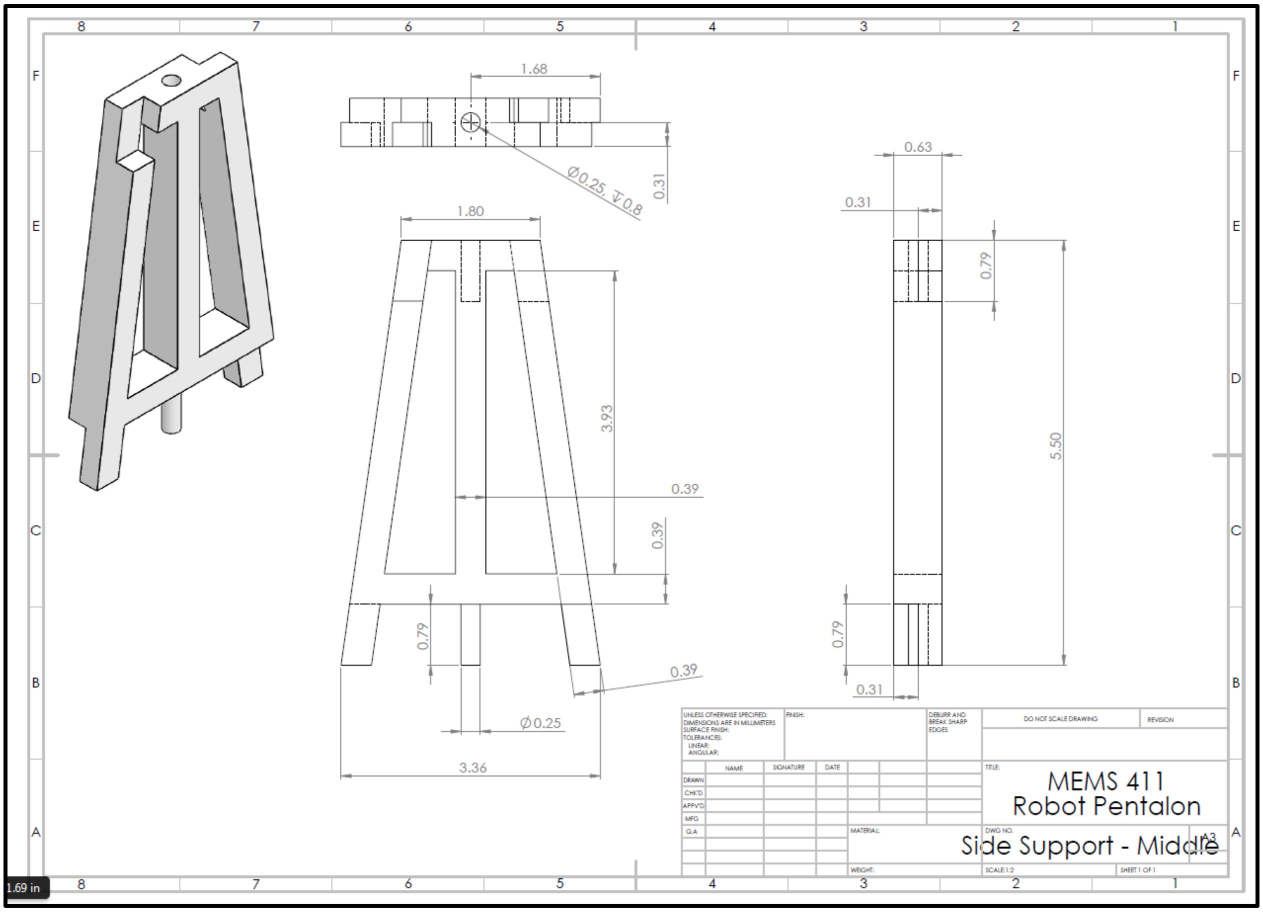

Fig. 12 **Side Support Middle Piece, 3D Printed.**

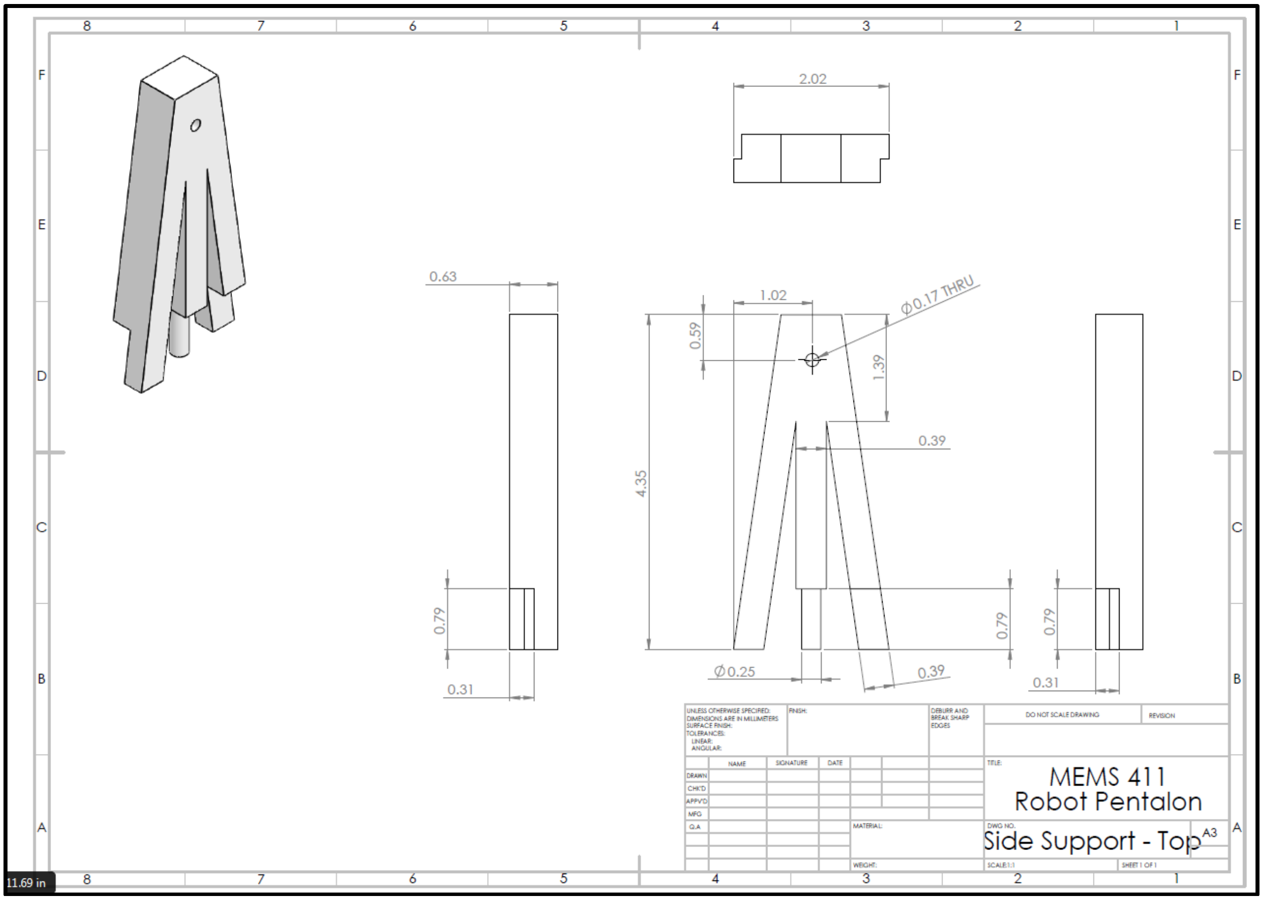

Fig. 13 **Side Support Top Piece, 3D Printed.**

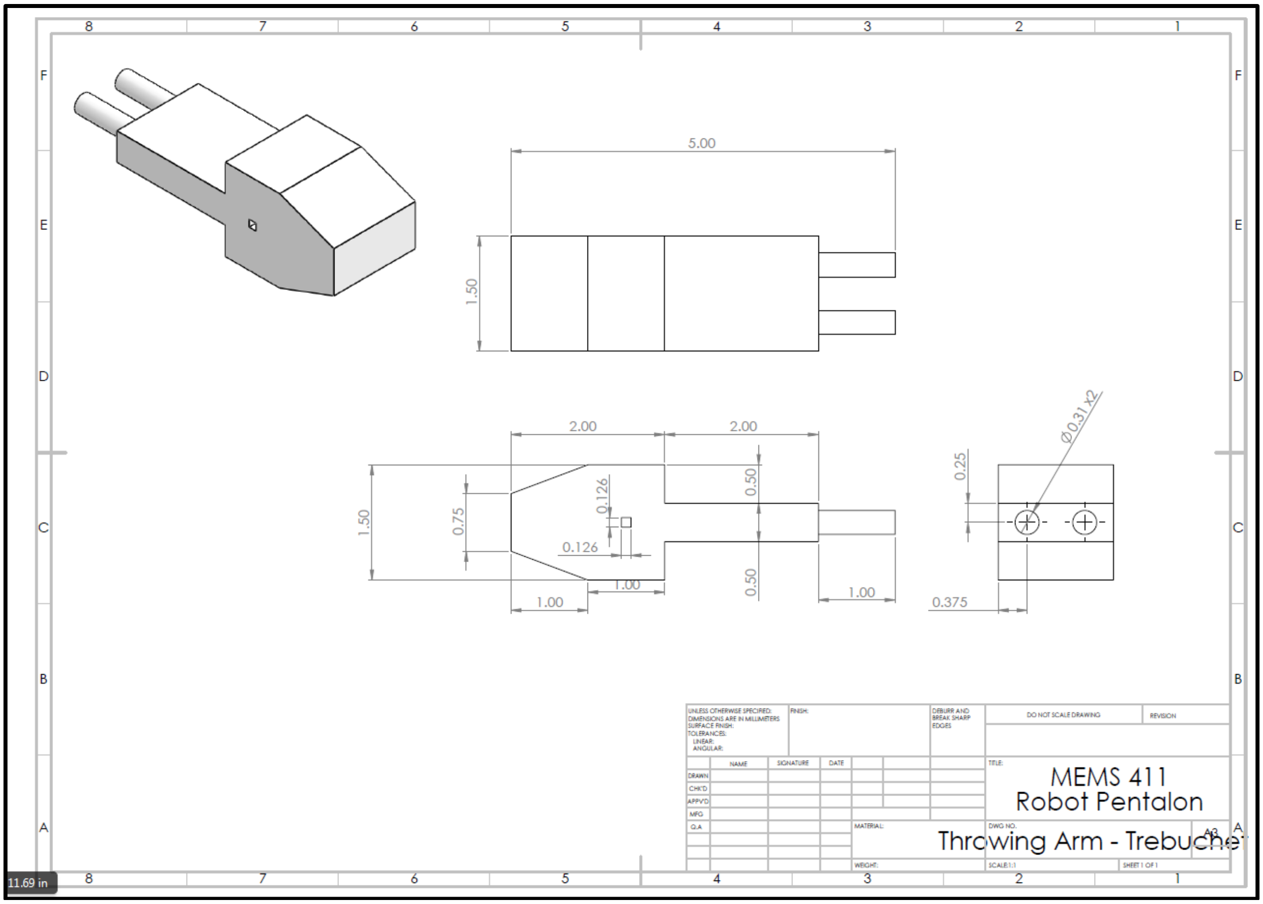

Fig. 14 **Throwing Arm Shaft Connection, 3D Printed.**

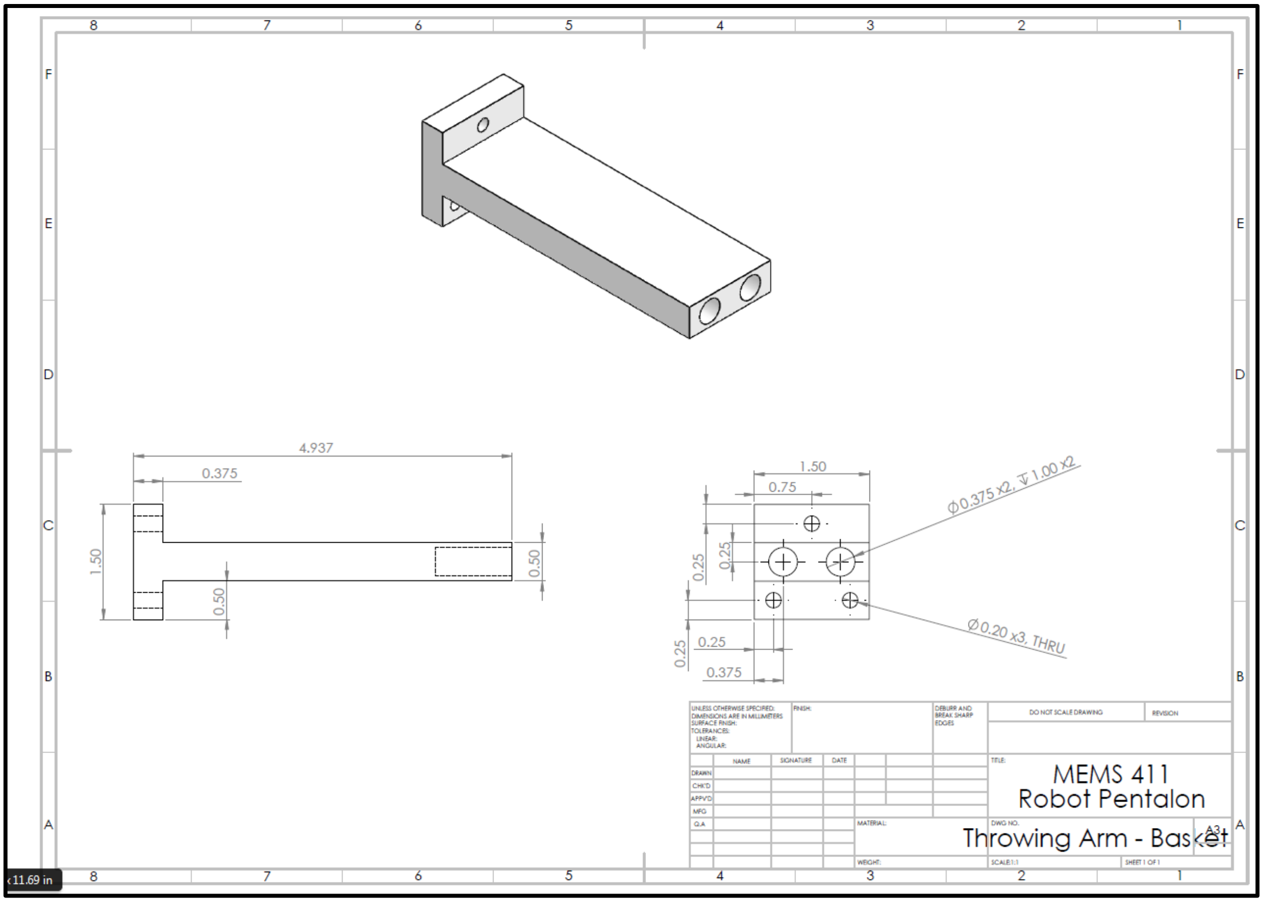

Fig. 15 Throwing Arm Basket Connection, 3D Printed.

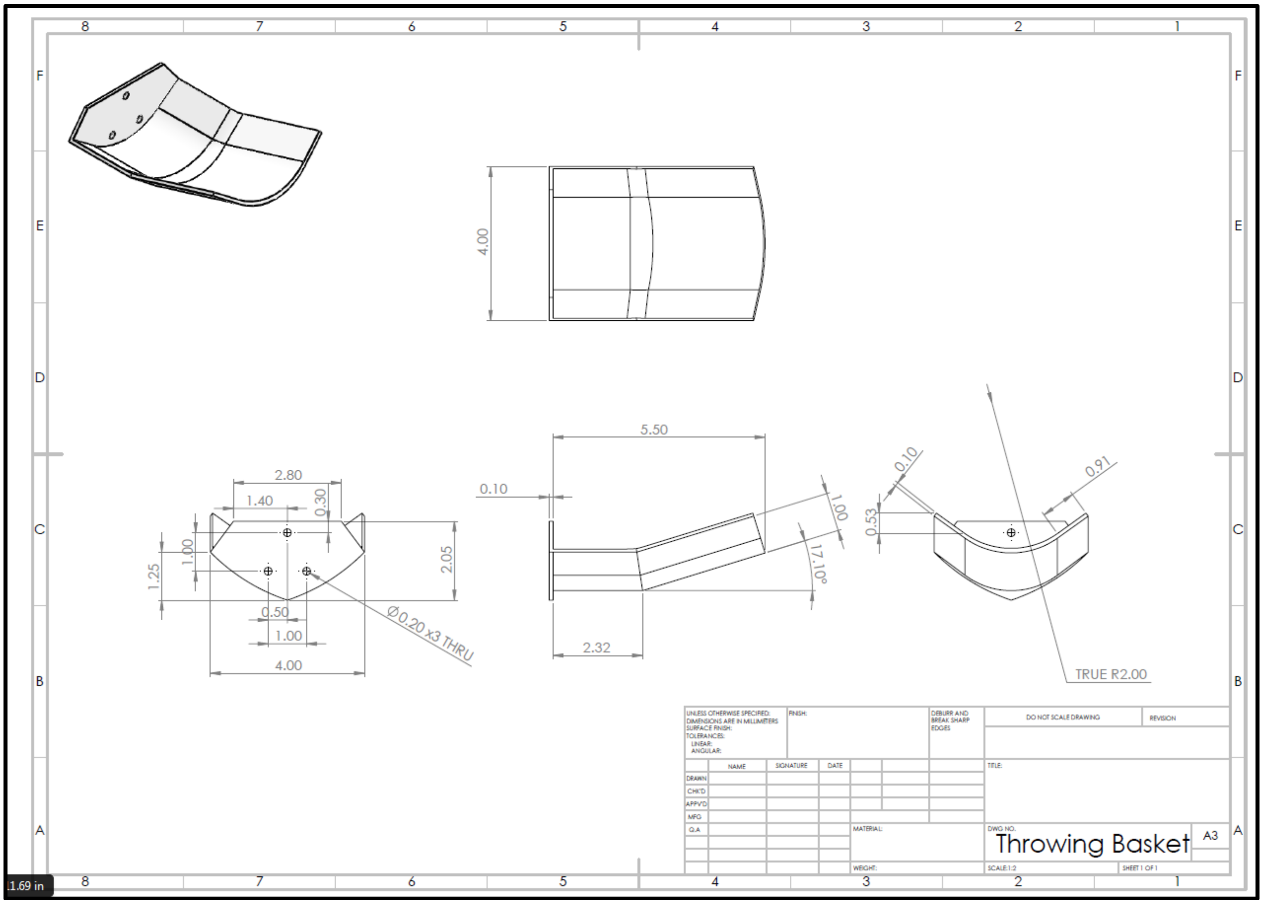

Fig. 16 **Throwing Basket, 3D Printed.**

4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART

2-Wire Motor 393:

The 2-Wire Motor 393 were chosen for our design project because they are small, cheap, easy to work with, vary in torque ratios, and can run off a small rechargeable battery. These are perfect for our robotic design because we needed something that would be lightweight, to keep the overall weight of the robot low, and small enough to power our tank treads. They can easily be wired using simple wiring kits and come in many torque ratios if we need high torque motors for climbing, etc. They are a better fit for our design than say a heavy motor with faster rpm.

Mini CIM Motor:

The Mini CIM Motor was chosen as the motor to provide the torque and acceleration to the trebuchet arm because this motor has a free speed of 5,840 rpm which we can use mechanically to throw the tennis ball farther than the 2-Wire Motor 393. Though this motor weighs quite a bit more, we only have one and not 6 like we need for our tank tread system. This motor can produce a torque up to 1.4 N/m which is more than enough to toss a tennis ball our goal distance of 10 ft.

Tank Treads/Tank Tread Kits:

Tank Treads were chosen for our design project because they allow our robot more degrees of freedom than wheels do. With tank treads, our robot will be able to not only sprint across any sort of terrain (sand, rocks, wood, etc.), but tank treads will allow our robot to also climb stairs which is a major advantage over wheels. Wheels would not be able to climb stairs and possibly might not even be able to sprint across rough surfaces. The tank treads add more surface area which will give our robot more traction for uneven surfaces.

Arduino Uno:

Arduino Uno was chosen for our design project because not only did we receive it for free from the ASME club, but the Uno is very useful when it comes to programming motors and other electronics. The Uno is very user-friendly and will allow us to program features on our robot such as how fast the motors spin, when they spin, when to release the trebuchet, etc. The Arduino will be the core to our robot because it will allow us to control the moveable features on our robot via a wireless receiver. An Arduino is lightweight and compact as well which keeps the overall weight of our robot down.

Wiring Kit:

The wiring kit was chosen for our design project because to create any sort of electronic robot one needs wires to connect motors, lights, etc. to the power source. This simple wire kit will also be easy to work with because the wires are fitted for the Arduino as a partner kit.

Hobby King 2.4Ghz 6Ch Tx & Rx V2 (Mode 2):

The wireless controller, which comes with a wireless receiver, has six channels that are programmable. Each channel will be used as a specific function for our robot. The controller will be able to control the movement of the robot tank treads, the motors to release and rotate the trebuchet, and other features dealing with the other events. The range on the controller will allow us to control our robot from a distance which will take out the hassle of cords attached to our controller and robot if we decided to go with a wired controller. The controller overall gives us a cleaner, less wired robot. The wireless receiver is partnered with the controller and therefore will provide little hassle when setting up. It is all very small and compatible with Arduinos; therefore, no unnecessary connections will be required to connect the receiver to the Arduino. This also keeps the overall weight of our robot low.

Cardboard Box:

The cardboard box is used for our design project based off the rules of the ASME challenge, where our robot and the control unit of our robot must fit within a 50x50x50 cm^3 box before the competition begins. Therefore, instead of spending money on a nice box, we plan to go pick up some free cardboard boxes from Walmart and create the regulation box for our robot

Aluminum Plate 25x5 (6-Pack):

The aluminum plate 25x5 (6-pack) was chosen for our design project because of the size, weight, and shape of the plates. To create a sturdy base that our robot will be built around, we went with specific robotic aluminum plates because not only is aluminum lighter than steel, but it was cheaper and still strong enough for the tasks that our robot will perform.

Aluminum Angle 2x2x35 (6-pack):

The aluminum angle 2x2x35 (6-pack) was chosen for our design project because we needed some angled structure pieces for the trebuchet that will be on top of the base of our robot. These angled pieces will be the structure that holds the trebuchet in place. These pieces give extra support to make sure that the trebuchet does not deform or break other structural pieces when it is launched.

Aluminum C-Channel 1x5x1x35 (6-pack):

The aluminum c-channel 1x5x1x35 (6-pack) was chosen for our design project because of the “C” style shape of each piece. This gives us an extra plane to work with when building the robot without having to make a separate connection to use that plane. For instance, the “C” channel piece could easily be used to hold the shafts for the motors or could be used to start the base structure for the trebuchet.

Drive Shaft 12” (4-pack):

The drive shaft 12” (4-pack) was chosen for our design project because we needed shafts to hold the free rotating tread wheels in place while the motors hold/drive the other tread wheels. These are basic, cheap, aluminum shafts that will be easy to work with and hold the wheels in place during motion.

Nut 8-32 Nylock:

The Nut 8-32 Nylock locks the screws in place for when we build the frame.

Screw 8-32 x 0.375”:

The Screws 8-32 hold our frame in place.

Shaft Collar:

The shaft collar is used to align and hold our rotating shafts in place while the tank treads move or the trebuchet arm rotates.

Bearing Flat:

Holds our motor shafts on the designated axis while they rotate. This reduces any unwanted wobble or off-rotation of the shaft at high rpms.

393 Motor Turbo Gear Set:

The 393 Motor turbo Gear Set will be attached to each 2-Wire Motor 393 which will produce an output speed of 140% faster than the motor would without the turbo gear set. This will allow our tank treads to rotate faster and therefore causing our robot to move faster.

Motor Controller 29:

The Motor Controllers are an important part to our robot because they allow use to remotely control the speed at which each motor rotates. It gives full control over the motor at varying speeds.

Tank Tread Bracket Arm:

This design was chosen to be an efficient way to keep the wheel on the longer tank treads rigid. This will be integrated on both sides of the longer tank tread such that the treads will be able to adjust and easily climb an incline of three steps. This bracket will also require simple milling to create out of sheet aluminum. This piece is required to hold all the motors on the same rotating axis as we change the angle of the treads for the climbing event.

Trebuchet Support:

The design was chosen as an average trebuchet model uses such supports. These trebuchet support happen to incorporate a small hole for the motor to be applied and two smaller holes for the supports to be attached to the lower base of the robot. This piece will be 3D printed into 3 pieces that will have an interlocking mechanism along with pins to ensure each piece is connected and can withstand the force of the throwing arm.

Trebuchet Throwing Arm:

The design chosen for the trebuchet throwing arm was a long, rigid, 3D printed piece that will be able to throw the tennis ball efficiently and with stand the torque created by the mini CIM motor. The throwing arm is simply connected at one end with a shaft and motor and at the other end will be a lacrosse type basket. The lacrosse type basket will initially hold the tennis ball and will be placed at the optimal angle so that the tennis ball is released at its optimum height.

4.5 GANTT CHART

MEMS 411 Gantt Chart.xlsx

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS RESULTS

5.1.1 Motivation

The before analysis is the most important thing to study at this time because the analysis will give us a complete understanding of how our robot will operate under the loads applied. The most important aspect of the analysis deals with the trebuchet arm and the supports holding the arm. This analysis will determine whether our motor can create enough torque to rotate the trebuchet arm fast enough, the deformations and stresses occurring on the trebuchet arm, whether the trebuchet supports will within stand the torque created by the trebuchet arm, and if there will be any interferences during the motion of the trebuchet arm. This will facilitate the type of material we use for the trebuchet arm and the trebuchet supports and any design changes to fix interferences. If during analysis anything fails, we must go back and either redesign the structure or choose a stronger material. Without analysis, time and money would be wasted.

5.1.2 Summary statement of analysis done

The engineering analysis done dealt with the weight of the MINI CIM Motor on one of the trebuchet supports and how the weight of this motor along with the max torque that it would apply on the trebuchet shaft arm would affect the trebuchet support. Therefore, the engineering analysis consisted of applying a torque to one of the trebuchet supports as shown in Fig. 17 and Fig. 18.

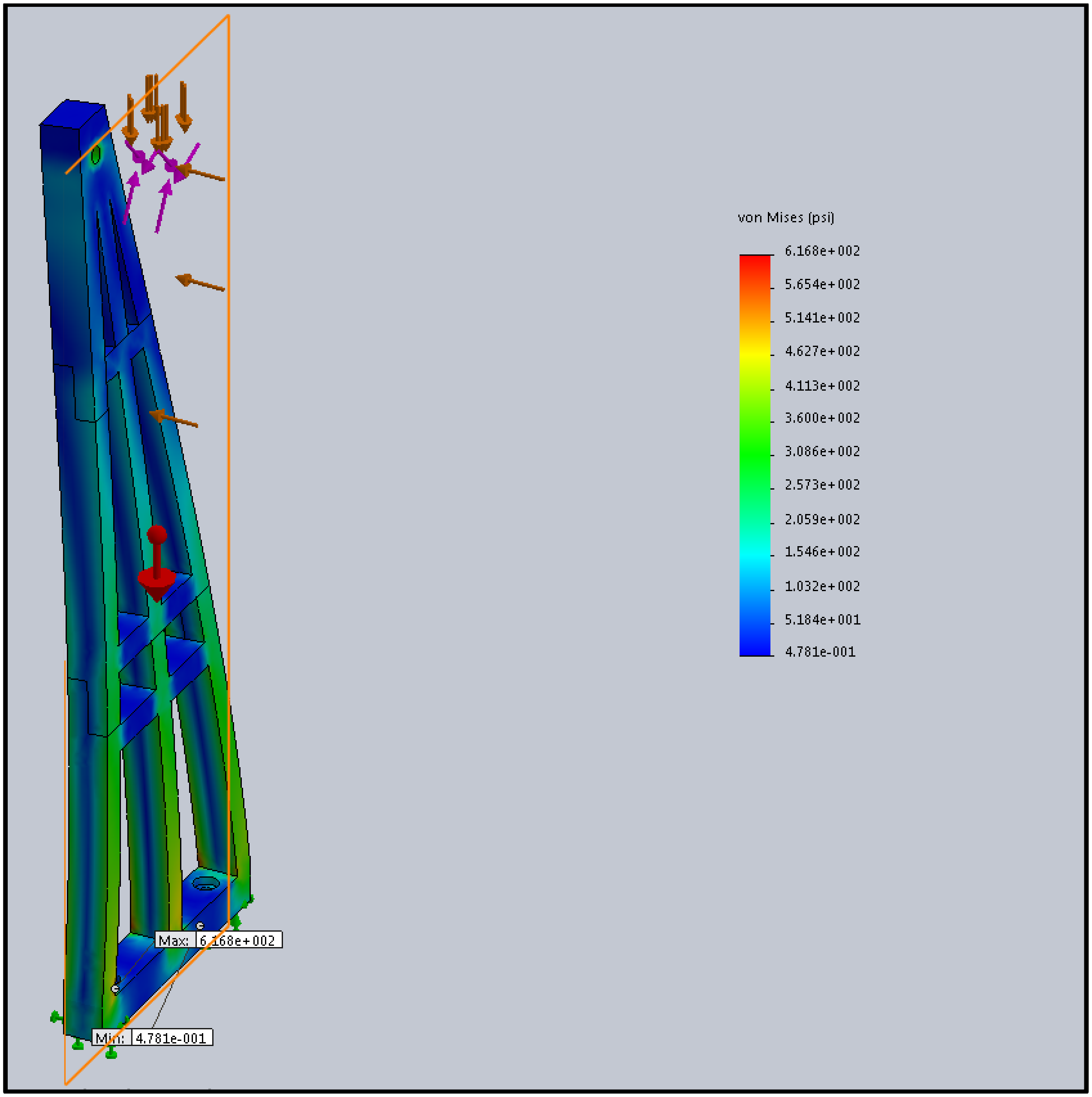

Fig. 17 **Trebuchet Arm Support "Before" MINI CIM Motor was moved. The MINI CIM Motor is not shown is analysis picture, but it is represented with the correct forces applied at the correct locations.**

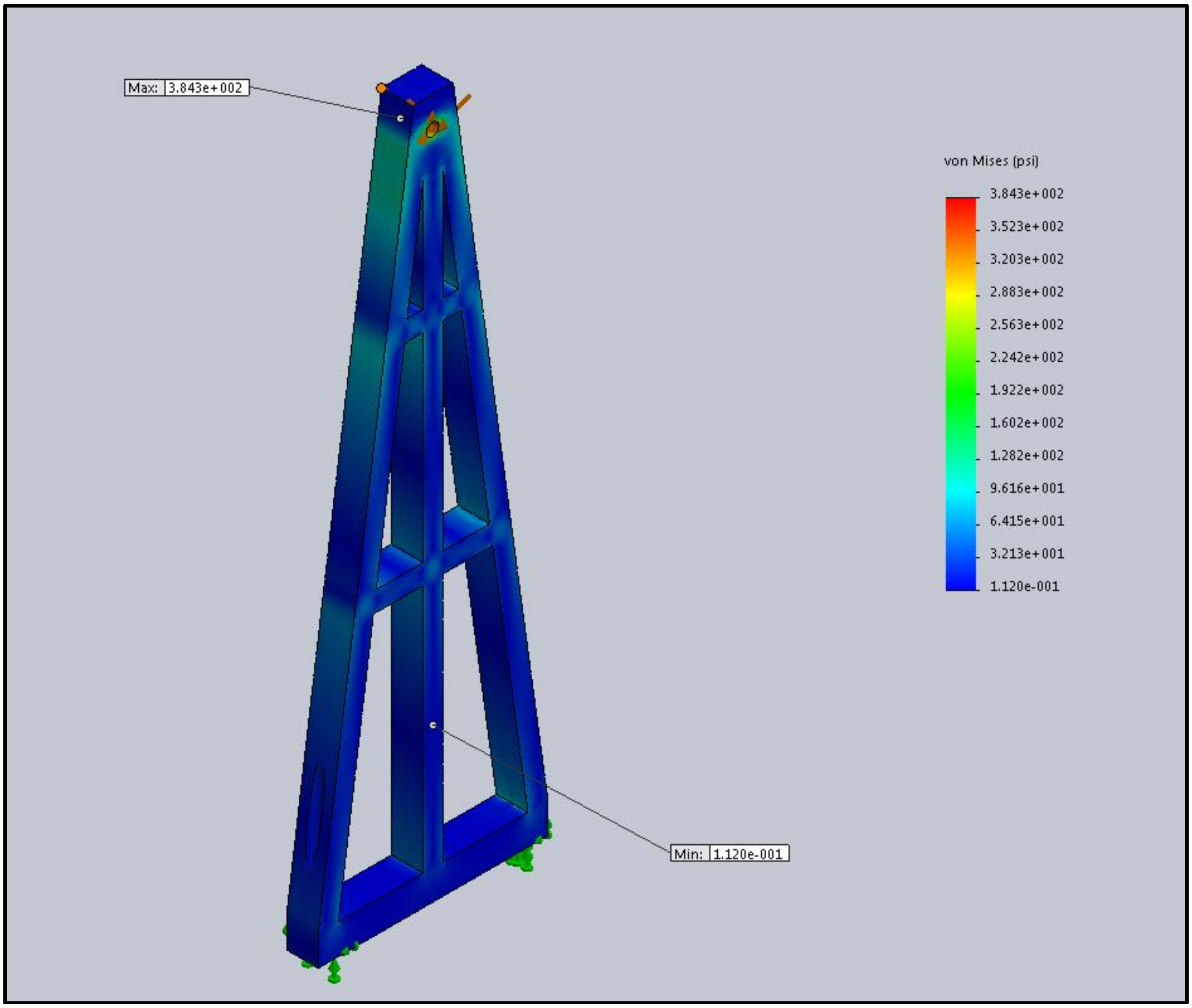

Fig. 18 **Trebuchet Arm Support "After" MINI CIM Motor was Moved. Support is Under 12.4 in-lbs of Torque.**

The relevant engineering equations that could be used to analyze this situation is shown in Eq. 1,

$$M = r \times F \tag{1}$$

where M is the moment applied to the trebuchet support, r is the distance from the fixed bottom of the support, and F is the force applied at the shaft hole at the top of the support.

5.1.3 Methodology

The analysis was done two different ways. The first way was 3D printing the trebuchet supports and then attempting to attach our Mini CIM Motor to one of the supports while also putting a small amount of torque on the supports. This experimental test displayed really how heavy our Mini CIM Motor was and that it would be wise of us to not attach it to our supports. The motor was so heavy that one support would be in compression and deform enough to cause more unnecessary friction on our drive shaft that held the trebuchet arm. When the trebuchet arm attempted to spin, that extra friction made a significant difference in the amount of torque it required to spin the shaft. Therefore, our team decided to take the Mini CIM Motor and move it to the bottom of the robot with chain and sprocket system to spin the trebuchet arm while decreasing the stress on the trebuchet support and decreasing the amount of friction in-between the drive shaft and the support so it was easier to spin. The second method we used was a simple SOLIDWORKS stress analysis on the supports with now just the stress of the torque being applied from the trebuchet throwing arm and tennis ball on the supports.

5.1.4 Results

The results of our engineering analysis study displayed that if we move the MINI CIM Motor from the trebuchet support arm to the bottom of the robot and add a chain/sprocket system that the stress applied to the trebuchet arm will not be of concern during the throwing event. As shown in Fig. 18, the max torque of 384 psi applied at the drive shaft does not deform or cause the trebuchet support to compress at all. This result make sense because our initial designs for the trebuchet support arm were made to hold the weight of the MINI CIM Motor and take the applied torque that the motor would produce on the throwing arm drive shaft.

5.1.5 Significance

The results of the analysis influenced the final prototype by changing the design of the trebuchet supports and where the motor that will drive the trebuchet arm will be placed. The problem that we ran into was that we wanted our trebuchet arm to be a specific length which was longer than the supports, therefore the arm would not rotate all the way around but instead hit the robot at about 210 degrees from axis. We fixed this by changing the height dimensions of the trebuchet supports to be slightly longer than the trebuchet arm. We then ran into the problem that our Mini CIM motor weighed about 2 lbs which put a lot of stress on one of the trebuchet supports but not the other. Therefore, we moved the motor from the trebuchet support to the base of the robot and added a type of pulley gear system from the motor to the shaft of the trebuchet arm. This reduced stress and unwanted torque in the trebuchet supports. The before and after results from the analysis and shown in Fig. 19 and Fig. 20.

Fig. 19 Design of Robot before the Engineering Analysis.

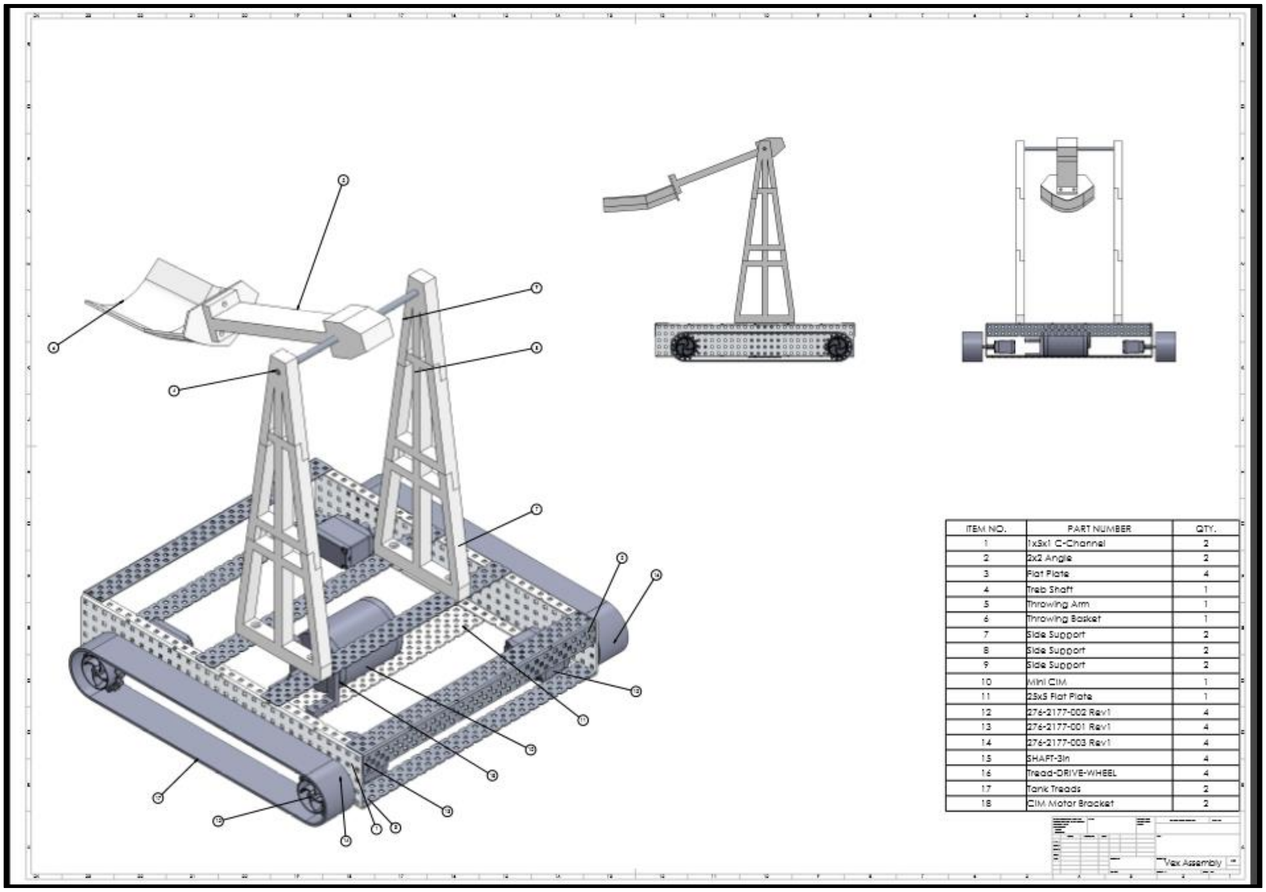

Fig. 20 Design of Robot after Engineering Analysis.

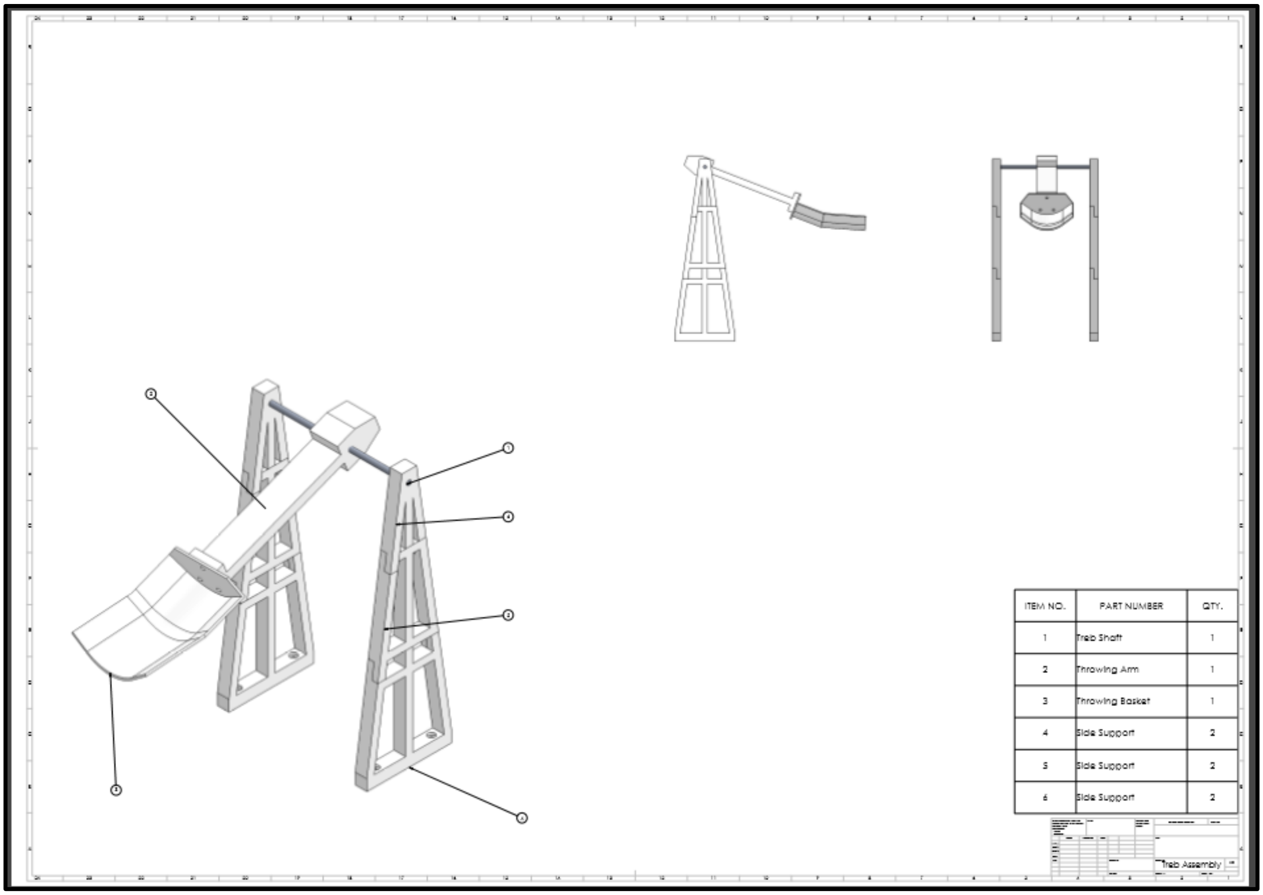

Fig. 21 After Engineering Analysis, Trebuchet assembly.

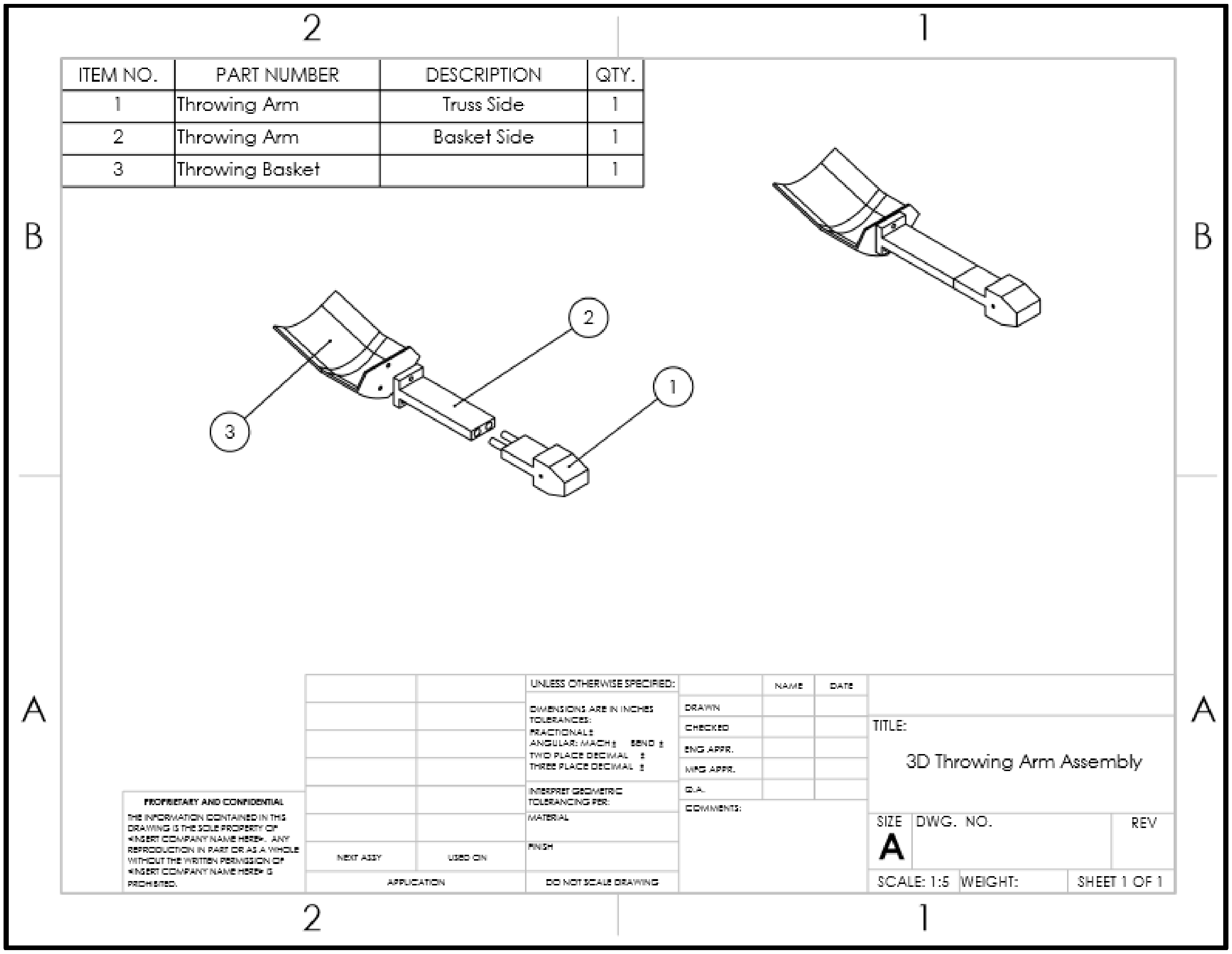

Fig. 22 After Engineering Analysis, Trebuchet Throwing Arm Assembly.

5.1.6 Summary of code and standards and their influence

In the analysis of our prototype, we did not encounter any codes or standards that would influence any revisions within our design at this time.

5.2 RISK ASSESSMENT

5.2.1 Risk Identification

Risk Assessment.xlsm

5.2.2 Risk Impact or Consequence Assessment

1. Path of Tennis Ball – This risk would not impact the cost, schedule, or technical performances of our robot, but this risk would potentially cause harm to anything within the tennis ball's path. The risk deals with potential harm to an individual. This probability

is low-medium because most people would be smart enough not to walk in front of our robot during the throwing test.

2. Part Ordering – This risk would impact the cost and schedule because if during the part ordering process, we receive defective parts, wrong parts, or unnecessary parts, our schedule would be pushed back and we could potentially lose money. If we have to turn around and return parts, this will reduce the amount of time we have to build our robot and if we order wrong parts with the chance we can't return them we end up losing overall budget to build our robot. This probability is medium because it is really out of our hands after we order the correct parts.
3. Defective Design – This risk deals with the safety, cost, schedule, and technical performances of our robot. If our robot design is defective in some way, this could cause some parts to break, potentially harming individuals around the robot. It would also cost us money because we would need to buy another part which would reduce the overall amount of time we have to build our robot. The probability of this occurring is low-medium because we have done our engineering analysis and have tested how our robot would react under specific actions.
4. Theft – This risk would be catastrophic because it would cost us everything and so much time. The probability of this occurring is low.
5. Material Failure – This risk is very similar to the defective design risk because it would deal with safety, cost, schedule, and performance of our robot. If we choose a material that cannot within stand the needed loads and stresses, there is a possibility that our robot will fail and potentially harm any individual around it. This will also cost us money because we will have to buy another part to replace the failed piece, which will cost us time as well. The probability of this occurring is medium especially after the engineering analysis which displays the amount of stress each material can handle.
6. Current too Large – This risk deals with cost and schedule of our robot. If the current is too large, we will fry the Arduino because it can only handle so much current. We would then need to obtain another Arduino. The probability of this occurring is high if we don't use precautions when wiring our robot.
7. Coding Issues – This risk deals with the schedule of our ability to test the robot. If the coding is not finished, then we cannot test the remote by remote control which is a major part of our project. It would push back the schedule on when we have a working prototype that can be operated by remote control. The probability of this occurring is medium-high because during coding some sort of coding errors arise, but with all of us having experience in coding we should be able to debug everything that comes up.

5.2.3 Risk Prioritization

Most critical to least critical rank of identified risks for our robot:

1. Current too Large
2. Coding Issues
3. Part Ordering

4. Path of Tennis Ball
5. Defective Design
6. Material Failure
7. Theft

6 WORKING PROTOTYPE

6.1 A PRELIMINARY DEMONSTRATION OF THE WORKING PROTOTYPE

https://www.youtube.com/watch?v=SeEZDBCRmas&feature=youtu.be

6.2 A FINAL DEMONSTRATION OF THE WORKING PROTOTYPE

https://www.youtube.com/watch?v=ViHCjWjg3ys

6.3 AT LEAST TWO DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE

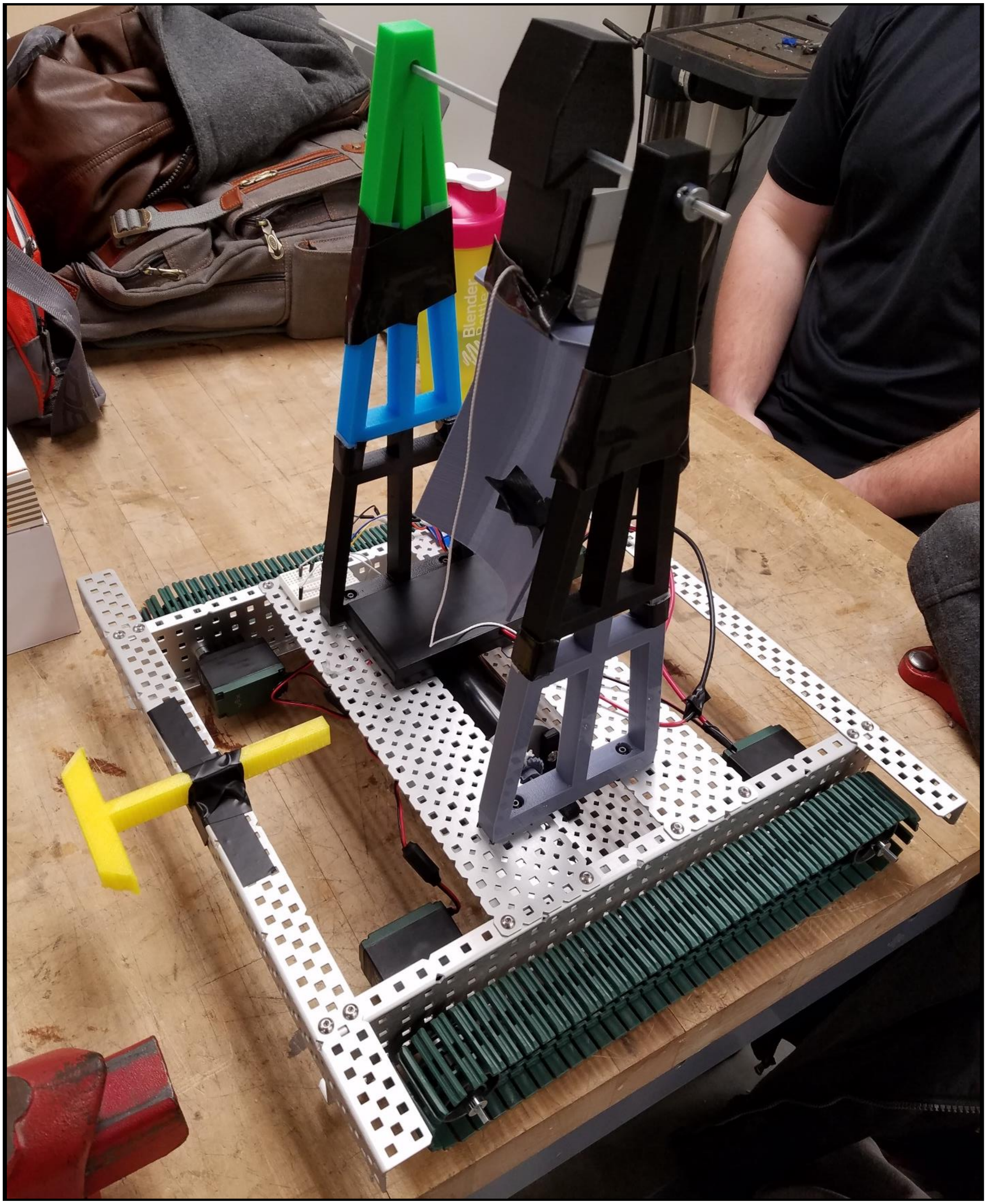

Fig. 23 This picture displays our working prototype before the demo with the trebuchet arm in the down position.

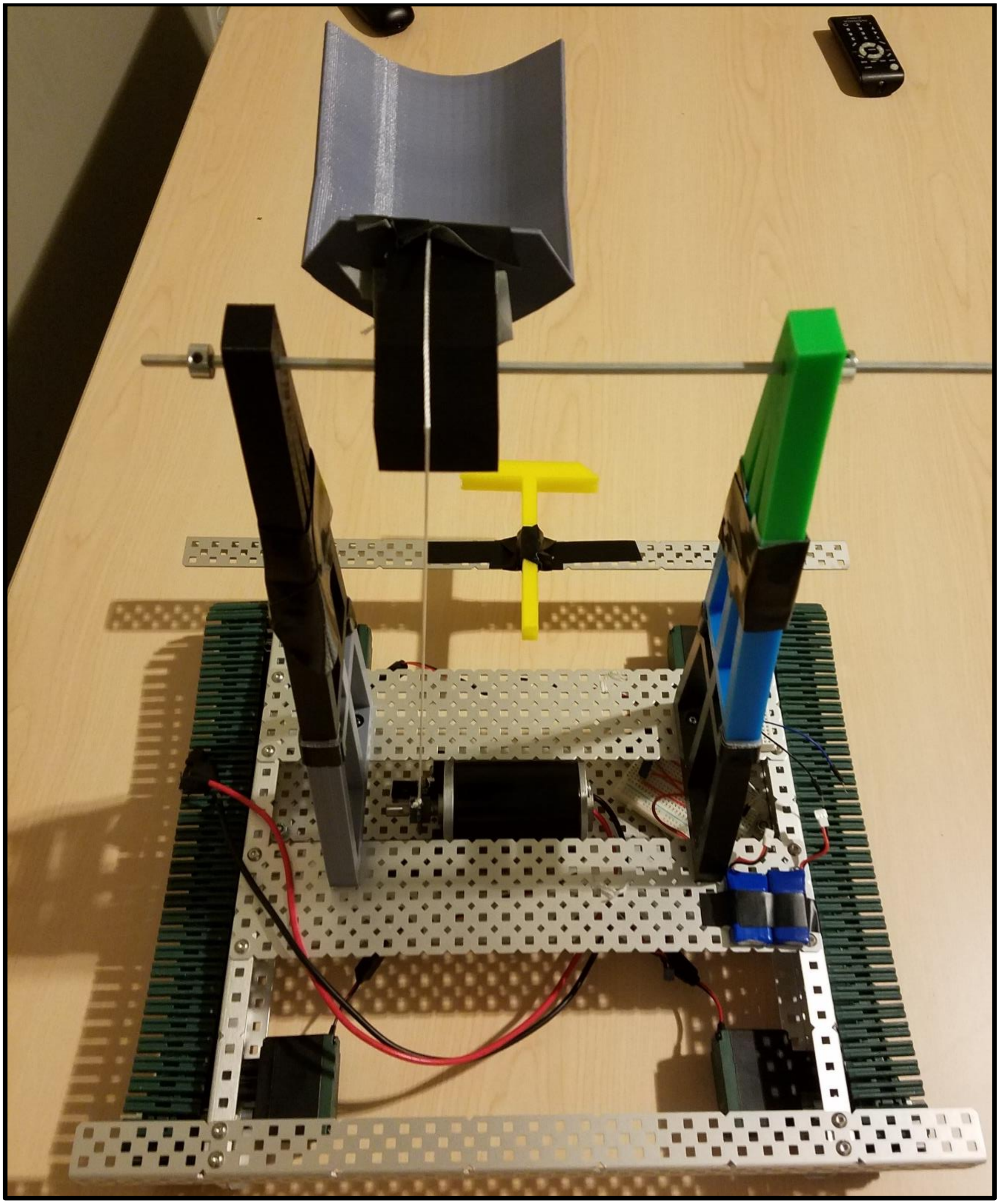

Fig. 24 **This picture displays our working prototype before the demo with the trebuchet arm in launch position.**

6.4 A SHORT VIDEOCLIP THAT SHOWS THE FINAL PROTOTYPE PERFORMING

6.5 AT LEAST 4 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

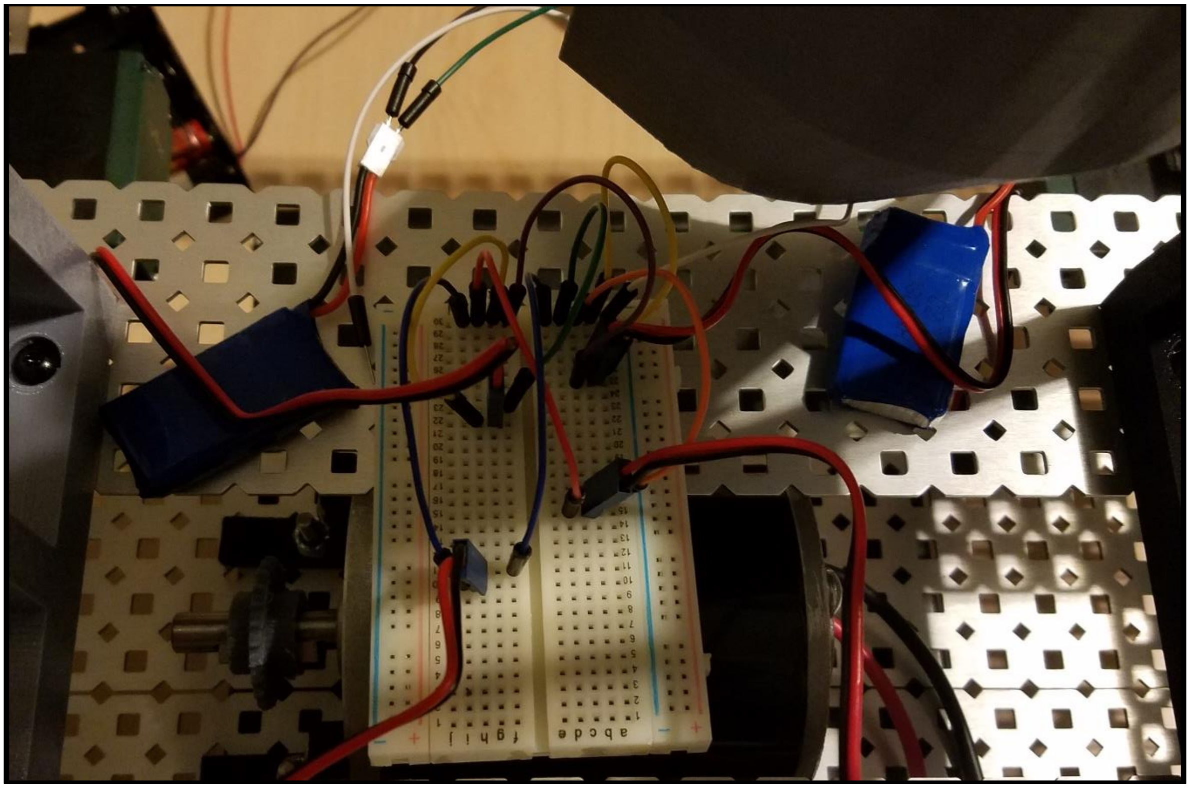

Fig. 25 **This picture displays the circuit we used during the prototype demo which has two 3V batteries connected in series. The power is then distributed to our four motors used for the tank treads to allow our robot to sprint. This circuit was used because during the learning process of setting up our wireless receiver to the wireless controller, the wireless receiver was fried and no longer useful.**

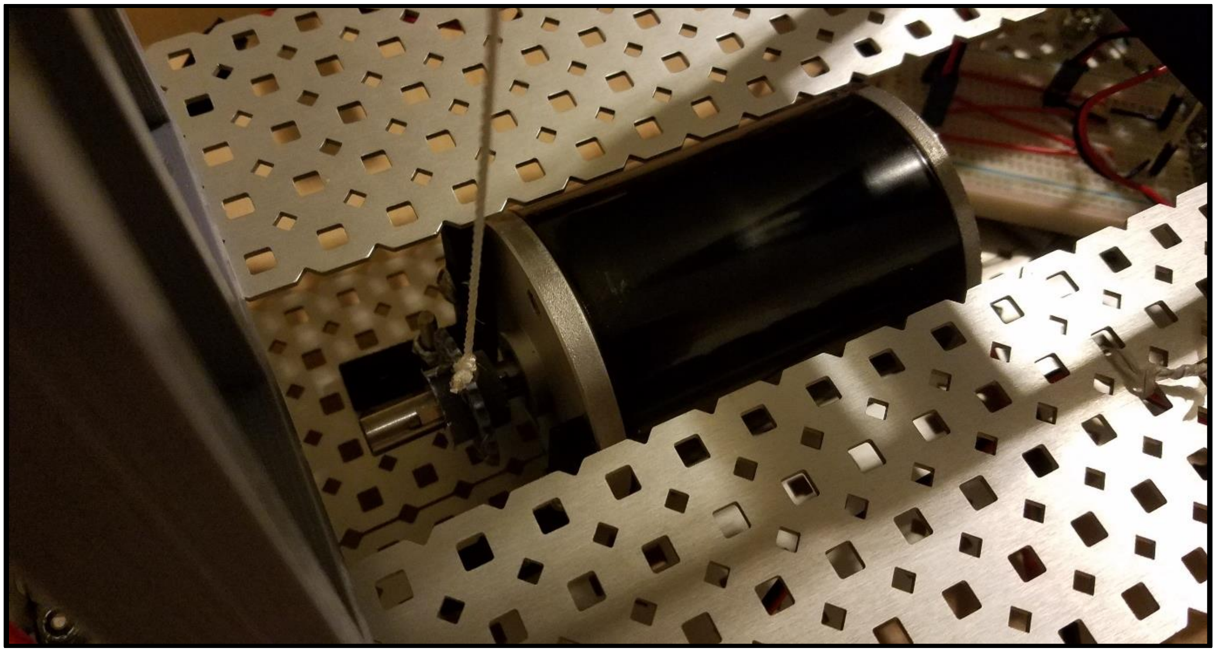

Fig. 26 **This picture displays the Mini CIM Motor that we use to throw the tennis ball. Since it weighs roughly 2lbs, we placed it at the bottom of our robot to lower the center of mass so there is no chance for tipping during the throw. Attached to the motor is a sprocket that at this time has a string tied to it, but currently now has a chain going around it to another sprocket connect to the trebuchet throwing arm.**

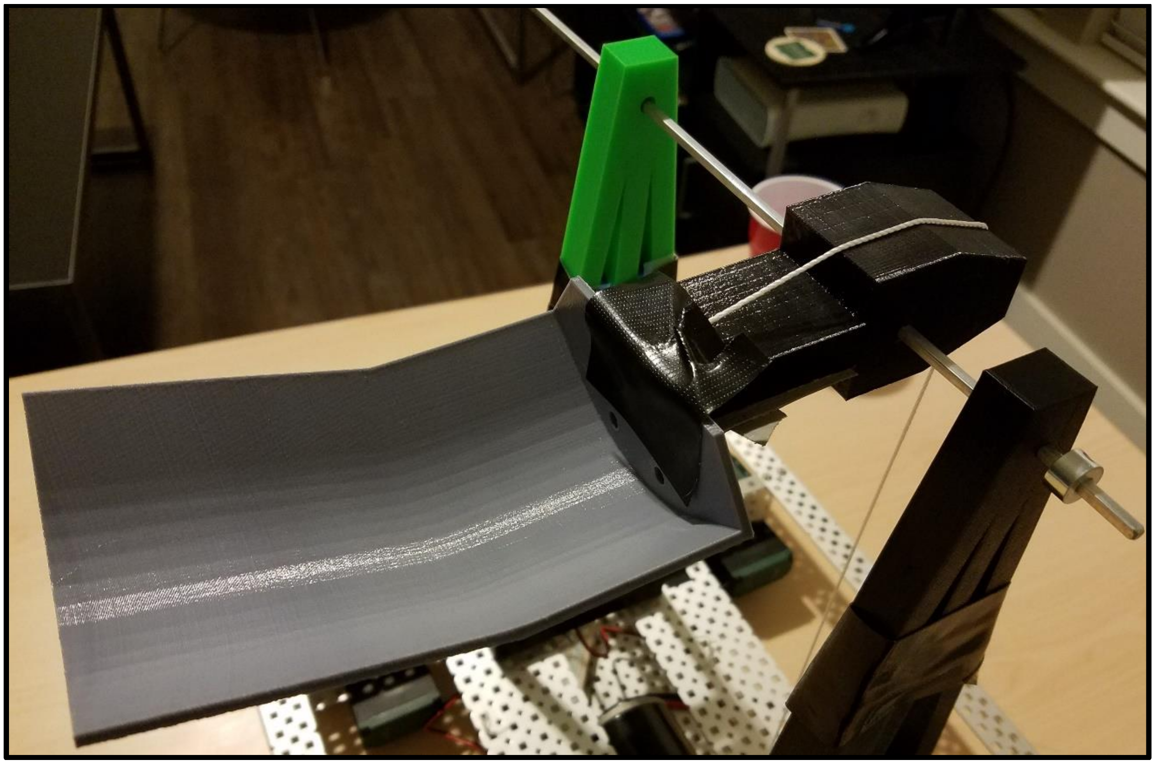

Fig. 27 **This picture displays the trebuchet throwing arm during prototype conditions. Without the chain to connect both sprockets, the string was used as a temporary replace to demonstrate that the trebuchet arm throws the tennis ball, but the arm had to be shortened for this to work. Therefore, the trebuchet arm is shorter in this picture than it will be during competition.**

Fig. 28 **This picture displays the connection between one of the four motors that power the tank treads and the tank treads. It is a square shaft that fits into the motor followed by a set of collars to keep the shaft from coming out of the motor. The square shaft has another female connection on the tank tread wheels fitting nice and secure.**

7 DESIGN DOCUMENTATION

7.1 FINAL DRAWINGS AND DOCUMENTATION

7.1.1 Engineering drawings

See Appendix A for the CAD model files.

7.1.2 Sourcing instructions

To source this robot one needs to head to Table 3 and order all the parts listed. One would then need to head to section 7.3 and model all the 3D printed parts in a modeling software such as SolidWorks. If one does not know how to use a modeling software or would rather save time, go to Appendix A where a link to all the SolidWorks model files will be located. One will then have to 3D print all these parts. Once one has received all ordered parts and has 3D printed all parts, go to Appendix A, 9.2, to assemble the robot. Electrical wiring is subject to change and has various sourcing methods, therefore it is not shown.

7.2 FINAL PRESENTATION

7.2.1 A live presentation in front of the entire class and the instructors

https://www.youtube.com/watch?v=s9ZBzidc3kk&index=3&list=PLpaIgTgYdmcLjSiXEt6mo26GsC4ohV1Fs

7.2.2 A link to a video clip

https://www.youtube.com/watch?v=SeEZDBCRmas&feature=youtu.be

7.3 TEARDOWN

Since we are competing in the ASME Robotic Competition in April, we will not be tearing down our project this semester. Currently we are holding onto all parts we have acquired.

Teardown Tasks Agreement.docx

8 DISCUSSION

8.1 FINAL PROTOTYPE METRICS AND QUANTITATIVE NEEDS EVALUATION

- The final prototype did not meet our design metrics that we set at the beginning of the project. For the sprint event, our robot sprinted 10m, touched an 8cm high wall, and sprinted back 10m finishing with a time of 20 seconds. Our design metric for the sprint was 20 seconds, therefore we met this requirement. For the throwing event, our robot threw the tennis ball 5ft. Our design metric for the throwing event was to throw the tennis ball 10ft, therefore we have not met this requirement yet. The sprint event did indeed meet the design metrics, but the throwing event fell short. Over the next few months, we will improve the design and performance of our robot before competition to exceed these requirements.

8.2 SIGNIFICANT PARTS SOURCING ISSUESS

- We did not encounter any significant part sourcing issues, any unreasonably long part delivery times, or any defective parts during our part ordering process. The issue we came across which was our own doing was the controller that we ordered was only able to wirelessly connect to its receiver. This is a bad thing because we ended up frying that receiver. Recommendations for future projects would be to ask someone more knowledgeable who was had experience with what you are trying to accomplish. They will be able to give one insight on what to buy, if it will work, the best products, etc.

8.3 DISCUSSISON OF OVERALL EXPERIENCE:

8.3.1 Was the project more or less difficult than you had expected?

- We believe the project was more difficult than expected in some areas and less difficult in others. For instance, it was very easy building our robot and attaching the tank treads because of the compatibility of the parts through VEX Robotics. All parts were designed and ordered to fit without question which made it easy for us to build. On the other hand, we didn't expect wiring and the electrical aspect of our robot to be that difficult. At first we struggled trying to get the wireless remote to work with our remote. The interface was not simple and not user friendly which consumed a lot of our time.

8.3.2 Does your final project result align with the project description?

- Our final project result we believe does align with the project description because the main goal of the project description was to build a robot that could sprint 10 meters, throw a tennis ball, and fit within a 50cm cubic box. The final design of our project could do these things tasks; therefore, it did align with the project description.

8.3.3 Did your team function well as a group?

- We believe our team functioned very well as a group. All three of us brought some sort of aspect to the group to help build this robot. We were all very flexible on when we needed/could meet to finish assignments, design reviews, etc.

8.3.4 Were your team member's skills complementary?

- As stated above, yes our skills were complementary. Whether it was working in SOLIDWORKS, building the robot, working with electrical components, or writing the report, we always complimented each other's skills which allowed our group to be very efficient.

8.3.5 Did your team share the workload equally?

- We believe for the most part our team shared the work load equally. We believe Ean Murnan probably put in the most work due to his amazing abilities in SOLIDWORKS which allowed us to create SOLIDWORK models without any issues which we appreciated a great deal.

8.3.6 Was any needed skill missing from the group?

- We would say the one skill that was missing was someone who knew electrical circuits and electrical components. All three of us have had some experience with circuits and

Arduinos, but none of us never have attempted to build a robot with them. This became very apparent when we attempted to make the robot wireless with a wireless receiver and controller (before the receiver was fried). We really didn't have any idea how to go about setting up the controller and how to make a specific action happen when a specific button is pressed. This was by far our team's biggest downfall during the project build.

8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

- We did not have to consult with our customer during the process because we did not have a customer. Since our project was the ASME Robotic challenge, the robot is a one-time use thing and therefore there was no need to have a customer.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

- As stated above, since we didn't have a customer our design brief did not shift very much. The times that our design brief did shift was during the engineering analysis and SOLIDWORK modeling of our robot when we would run into complications such as the trebuchet throwing arm dimensions, etc.

8.3.9 Has the project enhanced your design skills?

- We believe that this project has enhanced our design skills because of all the preparation, implementation, testing, and analysis during the whole process. Each step has given our team insight on how much work and preparation go into the designing aspect of a project. It has also given us an insight on how important aspects such as the engineering analysis are during the designing phase because that analysis might give you details or complications that you didn't even think of during the design process. It is a very good tool to check if the design you plan to move forward with is actually going to work when built.

8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?

- We would all agree that we would all feel way more comfortable accepting a design project assignment at a job after this design project. We think this is because of the steps we took during the design process and how detailed and specific each step was before we moved onto the next step. Along with that, we believe just the experience of going through such a design project has given us more confidence for future design projects.

8.3.11 Are there projects that you would attempt now that you would not attempt before?

- We believe that after all the struggle with electrical components, wireless receivers, Arduinos, and wiring that we would all attempt another project that relied on electrical components. Though we struggled and spent more time than we wanted on the electrical portion of this robot, the knowledge we gained from it would allow us to attempt more complicated electrical heavy projects we believe.

9 APPENDIX A - CAD MODELS

9.1 3D PRINTED SOLIDWORKS CAD MODEL FILES

https://drive.google.com/drive/folders/0B3BCU0c_oBX0MEdpblp5dDRuQXc?usp=sharing

9.2 ASSEMBLY SOLIDWORK CAD MODEL FILES

https://drive.google.com/drive/folders/0B8tFnY1-0mQcTGZ3ampaMXdzOWM?usp=sharing

10 APPENDIX B – SOLIDWORKS SIMULATION REPORT

SolidWorks
Simulation Report.doc

11 ANNOTATED BIBLIOGRAPHY

American Society of Mechanical Engineers, comp. Student Design Competition: The Robot Pentathlon: Citius, Altius, Ingenious: 2017 Challenge. Issue brief. N.p.: ASME, n.d. Print.

ASME-issued design competition brief and problem statement. Describes all design constraints and design objectives. Discusses the competition events and scoring parameters. Effectively functioned as our primary source for major design decisions.