FINAL REPORT

THE MOLESTERS

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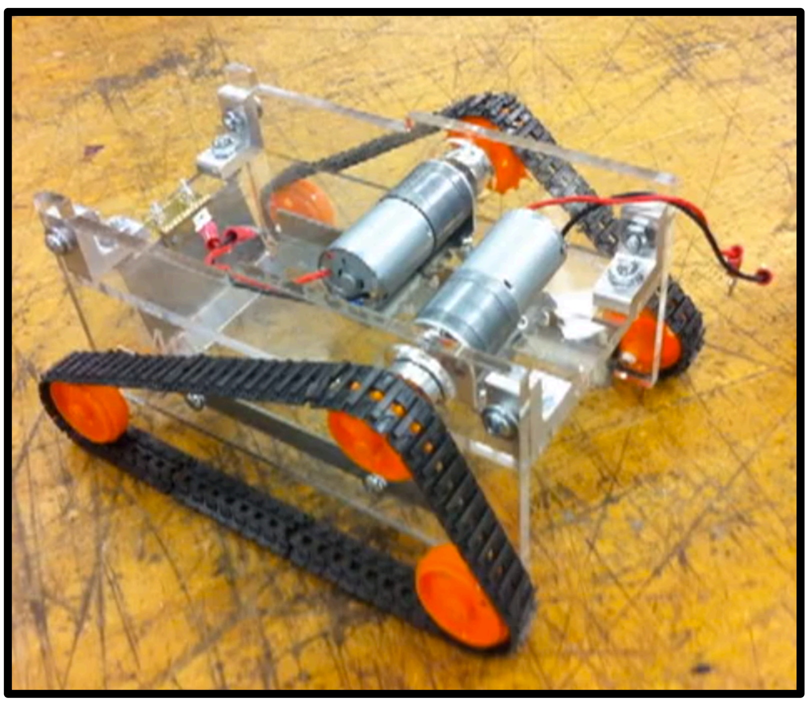
ME 250 Section 007, Group 29



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1. ABSTRACT

This report discusses the key developments made in our final robot design as well as components of our design process, including but not limited to strategy selection, vehicular requirements and concepts, a detailed analysis and solid model of our vehicle, product manufacturing and results from prototype testing. As indicated later in this report, the steps taken during this step-by-step design process served for the purposes of implementing a simple and clever robot design to maximize score and ultimately win the balltower competition.

2. INTRODUCTION

The purpose of this design was to create a remote-controlled machine, meeting certain size and weight requirements, that could collect and deposit as many balls as possible. Teams would have to assure that their machine was made to adapt to the conditions of the playing field by choosing a machine design that complemented their chosen game strategy. Each team's machine would ultimately undergo a seeding round as well as a single-elimination tournament to determine the overall champion of the competition. The winner of each round will be determined by the weight of all balls accumulated by that team at the end of the 90-second time limit.

3. VEHICLE DESIGN

3.1 Strategy Selection

The ultimate strategy our team chose was to traverse the incline, collect a high-scoring combination of red balls, deposit them into our goal, and then with time permitting, implement a robust defense strategy. Depending on the circumstances, our defense strategy would include blocking the opponent's vehicle or manipulating the arena to interfere with their intended strategy. Based on our chosen strategy, we decided on 4 different concepts to satisfy our strategy:

a. Employment of a basic-ball collecting chassis along with a hinged mechanical side arm to collect red balls. This arm would ride the shelf as the machine follows parallel to the incline. This design would eliminate any chance of our vehicle falling over the edge of the arena, however, the design itself is much more complicated and would add more drag to the machine as it tries to turn and maneuver around the playing field and could be very prone to breaking.

b. A split robot over the hinge design uses two separate bodies powered by a motor each. The bodies would be connected by a hinge mechanism, which allows one half of the entire car to ride along the shelf collecting the red balls. This design, similar to the one mentioned above, also eliminates any chance of our vehicle falling over the edge, however, it is also very complicated to design. Also, if our chassis is hinged down the middle of the vehicle, it will be difficult to store balls properly.

c. A permanently tilted chassis that grips the incline would sit above the flat playing field, with the body tilted at the angle between the shelf and the incline. The car would remain stiff while it traverses across the incline to the red balls on the ledge. This design will eliminate the chances of it falling over the edge of the arena and will be a much more solidified design than the hinged design, without a similar concept. The tilted chassis, however, will also be slightly more complicated to design and retain balls and will also not be as aesthetically appealing.

d. A compact body that simply rides the shelf of the playing arena. This smaller design would allow for easier steering and traversing up the incline and would be much easier to mount the shelf and drive in order to collect the red balls on the ledge. Although this design is small and may not be able to retain as many balls as intended, this compact design is very simple concept and fairly easy to manufacture.

Our final strategy was selected according to concept simplicity – a high priority. According to the Pugh chart (see Figure 1), our first and last strategy concepts had the same scores, however, we ended up choosing the compact chassis design because it was simpler than a machine with a mechanical side arm. This strategy can be countered if the opposing team decided to collect the red balls first or if they prevented us from climbing up the incline. Since this design is fairly small, we could use our swift maneuvering abilities as well as our speed to advance with our strategy before our opposing team.

3.2 Vehicle Requirements

Listed below are the functional requirements of our concept and a brief discussion of their importance in executing the strategy:

3.21 Ball Retention

The machine's ability to both capture and retain balls is one of the most critical functional requirements of our design because it is central to our scoring capability. If our machine is not able to collect balls, it would not render useful under the game's intended purposes.

3.22 Steering

Steering is critical to the vehicle's functionality because it ensures being able to climb and traverse the incline and maneuver through the field, so without it our design would render useless.

3.23 Defense

Defense is central to our strategy because we need a backup strategy as well as defensive capabilities in the case of an aggressive opponent. It is therefore important that our vehicle has both defensive capabilities and modules that can assist with a backup strategy in addition to the main strategy. The main defensive capability is the ironic possibility of falling into the hole, preventing the opponent from sabotaging our goal. Our ball retention module can easily acquire field balls if the vehicle malfunctions and cannot acquire ledge balls.

3.24 Cost

Cost is a functional requirement of our vehicle because it will restrain us from being able to manufacture certain parts of our design should we need to purchase any other materials that are not provided for us. This could ultimately be the deciding factor in what particular modules of our design we can and cannot have.

3.25 Manufacturability

As mentioned previously, our final design strategy was decided based on manufacturing simplicity. Due to time and monetary constraints, it is important that our design be as simple as possible. This way, we leave room for error, should we decide on alternate design modules or manufacturing plans during our design process.

3.3 Concept Design

We were able to compare our preliminary design concepts to each of our vehicle functional requirements that we believed to be the most critical in creating a successful machine. The Pugh chart in Figure 1 indicates the scoring of our design concepts with respect to the weight and importance of each of our functional requirements. As shown, the compact chassis and the mechanical sidearm concept scored the highest and proved to satisfy the most requirements. However, we decided that the compact chassis was the most feasible and simplest design that would prove to work just as efficiently, if not more so, than the mechanical sidearm design concept. Unlike the other concepts we initially had, the compact chassis was the simplest in terms of manufacturability, steering and ball retention. Although it was the most prone to falling over the edge of the arena, we figured that the time we would have devoted to making a more complicated design that would stay clear of falling over the edge, we would use to focus on steering our vehicle to create a full-proof strategy with smooth steering and control.

Figure 1

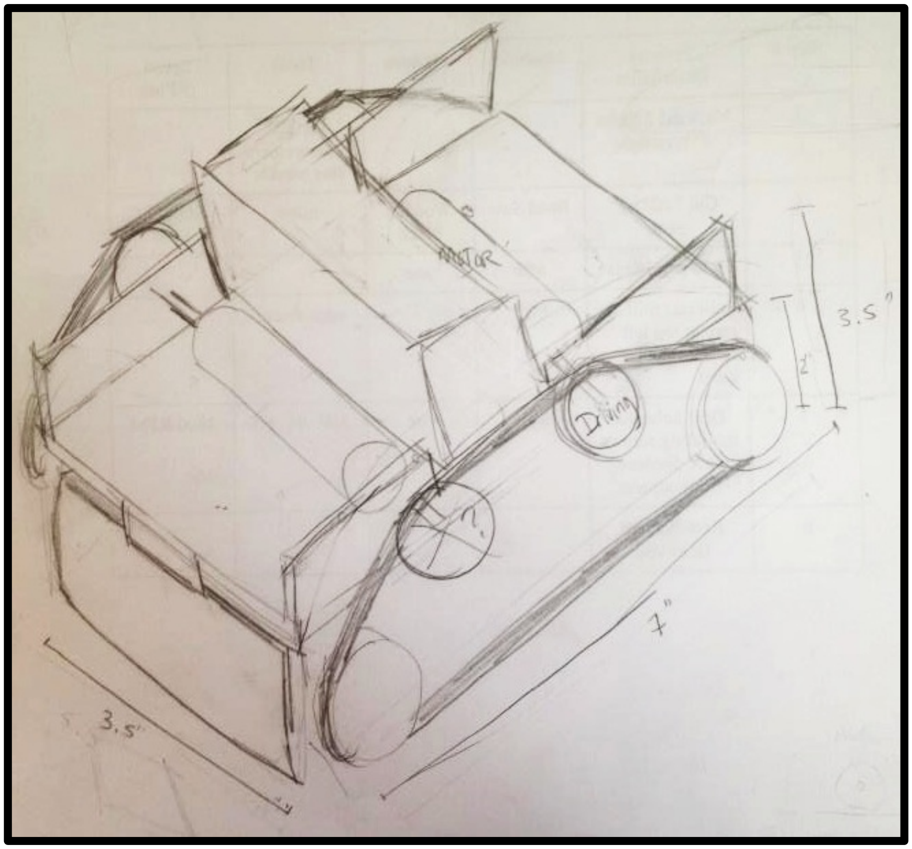
Pugh Chart

Requirements	Weight	Mechanical Sidearm	Hinged Chassis	Permanently Tilted Chassis	Compact Chassis
Ball Retention	4	0	0	-1	-1
Steering	3	0	-1	1	1
Defense	1	0	-1	-1	-1
Cost	2	0	-1	1	1
Manufacturability	2	0	-1	-1	0
Total		**0**	**-8**	**-2**	**0**

The three most important modules of our final design concept include our drivetrain, flaps and inner angled panels. With this particular design, we decided that steering was our main focus because with such a compact vehicle, it is important for us to be able to maneuver our machine carefully on the arena preventing it from falling into our goal or over the edge of the incline. Thus, our entire drivetrain, including our treads and motor, is crucial for proper installment. We also decided that our flaps along with our inner angled panels were two other important modules of our design concept because we need to ensure that with such a small design, our front and rear door flaps as well as our inner angled panels do not take up too much of the interior storage area of our robot, but also keep balls from slipping underneath our vehicle as we traverse up and across the incline and ledge.

Figure 2

Conceptual Sketch



3.4 Detailed Design

3.41 Analysis Model

The vehicle is designed to climb the incline, so we must inspect the physics of this strategy in order to arrive at a reasonable estimation for the required torque and ultimately determine which motor/gearbox to use. From SolidWorks we found the mass of the vehicle to be 2 kilograms and we estimated the coefficient of static friction between the wheels and the table to be 0.7. Given these estimations, free body diagram and Newtonian equations in Figure 3, we arrived at a 10.97 Newton force on each wheel. Multiplied by the wheel radius, we arrived at an estimated stall torque of 0.418 Nm.

After reviewing the torque-speed curves of each motor/gearbox, we found two arrangements that satisfied our high torque requirement: the 80-1 planetary gearbox ratio and the metal motor. Initially, we chose the 80-1 gear ratio of the planetary gearbox but later opted to use an arrangement of metal motors for several reasons:

a. The metal gearbox requires no assembly and therefore saves time and reduces the possibility of faulty assembly
b. The metal motor supplies a higher speed at the above calculated torque
c. The metal gearboxes are smaller and permit our overall design to be more compact and simple

Because we changed our mind on the 80-1 planetary ratio and ultimately chose the metal motor, the torque-speed calculations do not apply to our vehicle and are now useless. It was also decided at a later point to use acrylic paneling versus sheet metal, which greatly reduced the mass of the vehicle. Reduced mass means reduced force on the wheel, which means lower torque. Furthermore, we also rejected the plan to use wheels and we used treads instead. While the tread sprocket's radius is similar to that of the wheel, the application of friction now becomes more complicated with a tread system. Because the values of mass and friction have changed, we see that the free body diagram analysis does not apply to our updated vehicle and is therefore useless.

Determining the total time of executing our strategy required us to split the strategy into movement on the incline and flat-ground movement.

For incline movement, we assumed the angular wheel velocity to be 0.5426 m/s, which corresponds to our stall torque (0.418 Nm) and the distance (measured through Solidworks) to be 3.429 meters. Using v = rt, we found the time of the incline movement to be 11.97 seconds.

For flat ground movement, we assumed 20% of the stall torque, which corresponds to an angular velocity of 0.233 m/s. Again, applying v=rt and using a Solidworks-calculated distance of 2.794 meters, we found the flat-ground time to be 12.6 seconds.

Adding an estimated 22 seconds of time to turn, we arrived at an aggregate execution time for our strategy to be 46.6 seconds.

These calculations are precise, but again, our final concept has different dimensions and different motors than those discussed in Milestone 5. This means that our turning radius and speeds have changed, so this time analysis does not apply to our current vehicle and is therefore useless.

Figure 3

Free Body Diagram Analysis

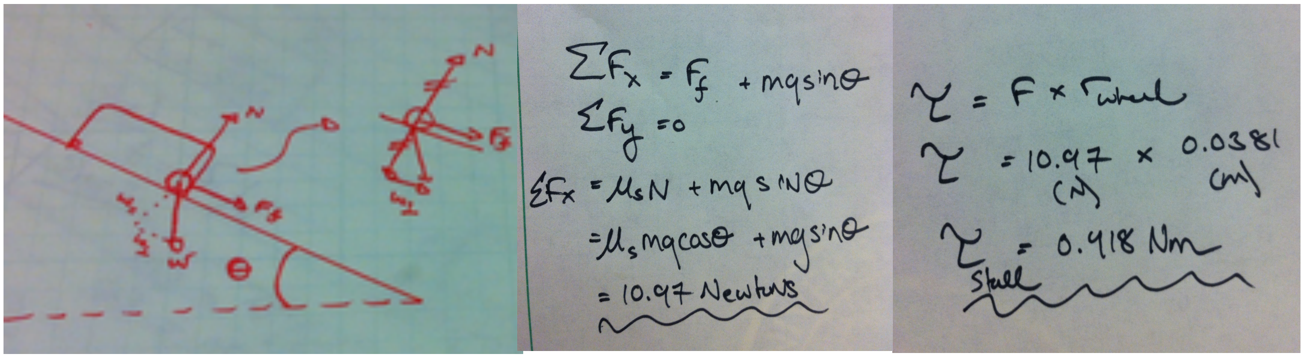


Figure 4

Torque-Speed Analysis

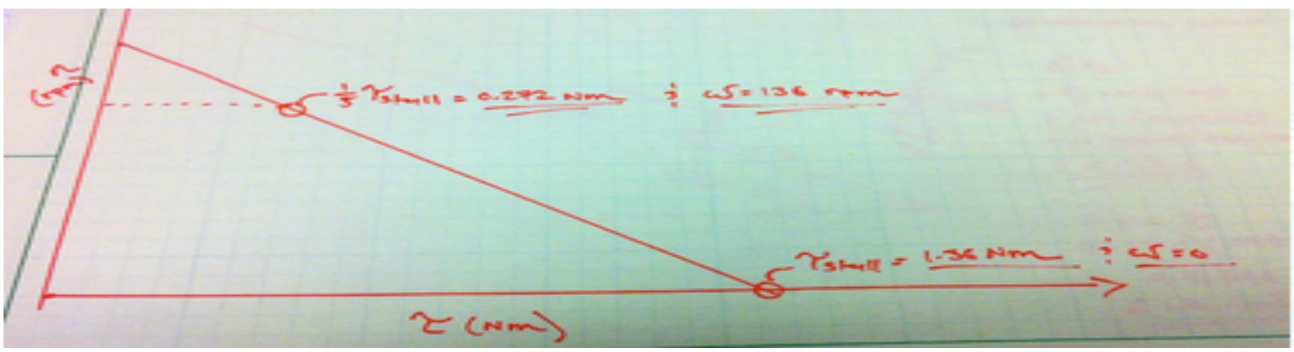


Figure 5

Time Analysis

Flat Ground (using T/5):

$$\sum distances = 135\ inches, 3.429\ meters$$

$$\rightarrow Time = \frac{3.429\ meters}{0.272\ \frac{meters}{second}} = T_{flat} = 12.6\ seconds$$

Incline (using incline load torque):

$$\sum distances = 110\ inches, 2.794\ meters$$

$$\rightarrow Time = \frac{2.794\ meters}{0.233\ \frac{meters}{second}} = T_{flat} = 11.97\ seconds$$

3.42 Solid Model

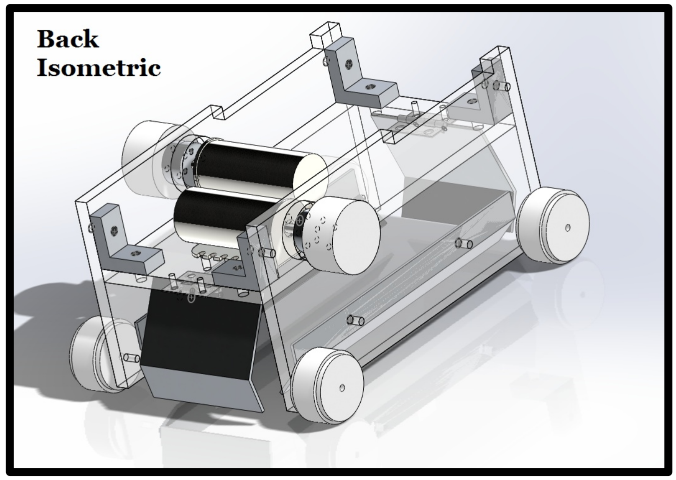


Figure 6

Back Isometric View

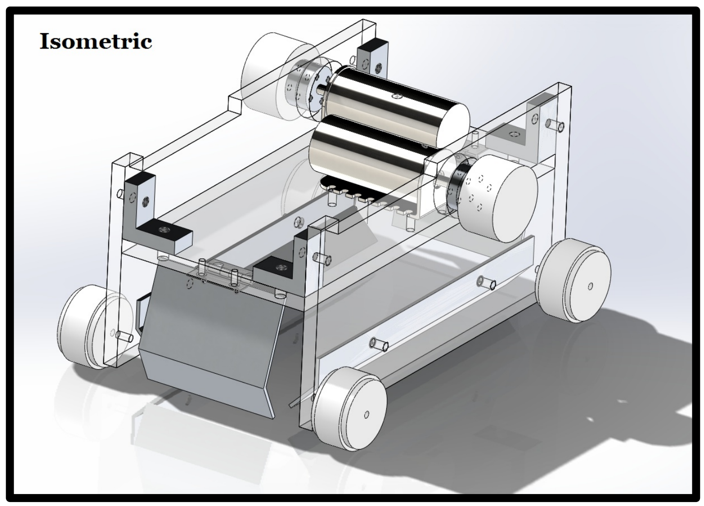


Figure 7

Isometric View

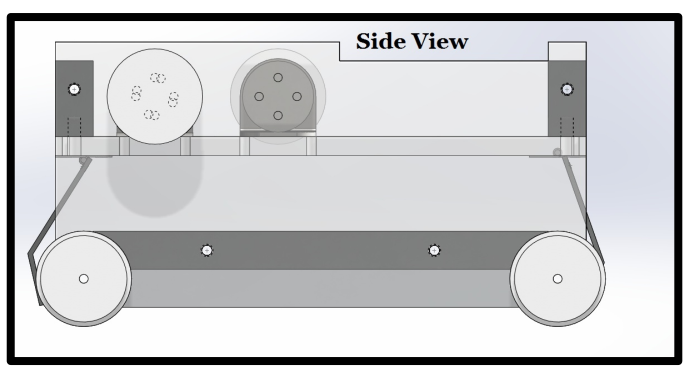


Figure 8

Side View

Our solid model was worked on and completed after our design review. Using feedback from Connor and Professor Umbriac, we were able to choose our final design and refine it slowly as we learned more about the specific parts that we would be using. Because our design changed drastically after the design review, our hand sketch closely mimicked our solid model. All of the dimensioning was done specifically for our new strategy, and no large changes needed to be made for our solid model design.

4 PRODUCT MANUFACTURING

See Appendix C for manufacturing plans.

4.42 Manufacturing Resource Description

In manufacturing our prototype, we used almost every machine in the shop. We used the laser cutter to form the two side panels and the middle panel from the acrylic in our kit. The band saw was used to make rough cuts of the L-brackets from the aluminum stock. The mill was used to trim them down with precision and the drill press was used to manufacture the holes in the L-brackets (we used the mill for drilling the holes in the acrylic due to the precision of edge finding). The sheet metal and the 90º angle stock was cut using the shear and the ends were bent using the brake.

5. BILL OF MATERIALS (BOM)

List of all parts or materials purchased and used from the kit to manufacture the prototype, below:

Figure 9

Bill of Materials

#	Description	Use	Dimensions	Availability	Quantity	Supplier	Part #	Price ($)	Other details
1	Metal motor	Power	See CAD	Kit	2	Pololu	1576	N/A	
2	Mounting bracket	Motor	See CAD	Purchase	2	Poll	1569	$7.45/each	
3	Mounting hubs	Motor	See CAD	Purchase	2	Pololu	1081	$6.95/each	
4	Track, tread, & wheel set	Treads	See CAD	Purchase	2	Pololu	70100	$7.50/each	
5	Aluminum plate	Flaps/angled panels	12"x18"x 1/16"	Kit	1	Alro	Quote	N/A	
6	Acrylic	Body	12"x18"x ¼"	Kit	1	Alro	Quote	N/A	
7	Aluminum 90° angle stock	L-mounts	1"x1"x18', ¼" thick	Kit	1	Alro	Quote	N/A	
8	Hinge	Flaps	See CAD	Kit	2	McMaster	1603A3	N/A	
9	Various screws	Mating	#2, #4, #8	Shop	8, 8, 8	N/A	Quote	N/A	
10	Velcro	Control box	24"x1"x"0.188"	Kit	1	McMaster	94985K816	N/A	may be replaced with different adhesive mechanism

6. PROTOTYPE TESTING

6.1. Preliminary Test Results

During preliminary testing it was discovered that the alignment of the treads was a prevalent problem; they kept falling off on one side of the machine, which was something that our model prediction never accounted for. The motor shafts were also bending because they weren't mounted properly. The free wheel axles were also bending within the acrylic, damaging it in the process. The acrylic panels suffered from impact fracturing whenever the axles were removed or replaced. The holes drilled into the motor mounts were discovered to have been dimensioned incorrectly. The screws connecting the hinges to the flaps interfered with the swing trajectory of said flaps. Lastly, some of the wheels and sprocket caps from the tread kit were loose and had to be either replaced or fixed as best as possible..

6.2. Redesign Based on Preliminary Tests

The holes in the motor mounts were first re-dimensioned and then drilled. The screws that attached the freely swinging halves of the hinges to the flaps had to be positioned so that the heads were facing towards the inside of the machine, in order to allow the flaps to swing through their full trajectory. The screws we initially used were the same thread size as the screws that connected the L-brackets to the side panels and middle panel, but we discovered that the heads of the screws collided with the top of the middle panel, preventing the hinge from swinging as far as it needed to. To remedy this, we bought miniscule metric screws with flat heads, and installing the flaps with these allowed the hinges the necessary full-arc movement. The worst wheels and sprocket caps were replaced. Our initial solution to the problem with the treads was to tighten them so that they could not separate from the wheels and sprockets. However, this caused the wheel shafts to drastically bend and move within and damage the acrylic, thus forcing us to drill another hole for one of the shafts. After we did this and refitted the shaft, the treads appeared to stay on the machine, and so we were able to proceed to and complete the seeding round without any problems arising.

6.3 Discussion of Competition Results

Ultimately, we were not able to completely safeguard against the problem with the treads, and during the competition the treads on one side of our machine snapped off, resulting in a score of zero points for the entire competition. The expected score analysis, which accounted for other issues (not the treads), gave a hypothetical score of 165 from collecting 3 red balls. During the seeding round we were able to score with 2. During said seeding round, the treads were seemingly well attached, and we had no problems that stemmed from them. This is the reason for the huge discrepancy between the expected/seed results and the actual tournament results.

7. DISCUSSION AND RECOMMENDATIONS

7.1. Project summary

Our design certainly wasn't perfect. We didn't, for instance, predict that the shafts would damages the acrylic housing them to the point of loosening them considerably. Having the knowledge that we currently possess, we would focus more on stabilizing the treads and ensuring that they remain on the machine. When we initially decided to use the treads, we didn't consider them to be a potential problem; we focused more on the issues that arose concerning the incline and the shelf upon which the red balls were situated. The treads also (rather inconveniently) fit perfectly into the cavity between the incline and the shelf, and once they fell into the cavity it was impossible to drive the machine out. Because the shelf was only six inches in width and our machine was more than five inches in width, we were not left with much room to operate, and thus it was very difficult to maneuver the machine on the shelf without one side becoming entrapped within the cavity. We were therefore forced to adjust our playing strategy. Previously, we had planned to ascend the incline to the shelf on the side on which we started and, after making a ninety-degree turn, travel along the shelf to its end, collecting the red balls as we did so. However, we deemed it safer to simply ascend the incline to the shelf without turning, collecting the ball situated there before descending the incline. Utilizing this method would limit us to collecting one ball at a time, which would take a greater amount of time per ball, but would also eliminate the risk concerning the cavity.

Despite the imperfections, our overall machine design was nevertheless solid. Were it not for the treads splitting apart, our machine would have performed admirably in the competition. Before the machine was due, however, we were considering adding an entirely new component to it that would have theoretically allowed it to perform even more efficiently. Since the treads were falling off of the wheels, two additional acrylic panels could be placed on either side of the machine, close enough to keep the treads from escaping but far enough so that their movement would not be hindered. These panels would be initially level with the side panels of the frame and would be attached to a rack-and-pinion setup, which would be powered by a double gearbox (using one of the two available shafts for each side). These motorized panels could then be lowered (and later lifted) past the treads of the machine into the aforementioned cavity, thus limiting the machine to moving only forwards and backwards. In this way, we would not have had to worry about either the treads becoming trapped or the entire machine falling off the edge of the table. Unfortunately, there was simply not enough time to bring this idea to fruition, and so we were left to simply adjust the shafts and treads as best we could.

In judging the project as a whole, two factors must be considered: the design of the machine itself, and the strategy the machine was to undertake in order to obtain the greatest amount of points possible. The strategy to pursue the red balls on the shelf was the first step decided upon, and none of us have since doubted that this was the correct action to take. Difficult to obtain, but yielding a wealth of points far greater than any other option, the elusive red balls would provide an easy win for anyone who was able to collect all eight of them. The concept behind our machine was also the most effective: a small, compact body that was to climb the incline and travel along the shelf, collecting as many red balls as possible before descending and depositing them into our goal. It is in the details of the design that improvements could have been made. Considering first the massive headache we endured from the bending of the shafts, it may have been a wiser alternative to build the frame of the machine entirely out of aluminum as opposed to acrylic, so that the shafts could be securely housed. There would be no worry of the shafts loosening or breaking through aluminum. Consequently, the problem with the treads could have been avoided entirely; they could be tightened over the wheels and sprockets without the added force causing the shafts to bend. The main problem would then have been to design a way for the machine to travel safely along the shelf without becoming trapped in the cavity or falling off the table, which could be solved by the aforementioned motorized panel system.

7.2. Future project idea

Any future class project should also be a balltower competition, except all the balls should be located at the top of a huge incline and the student are required to build hover-cars in order to reach them.

8. REFERENCES

The only resources used in writing this report were previous Milestone assignments.

9. ACKNOWLEDGEMENTS

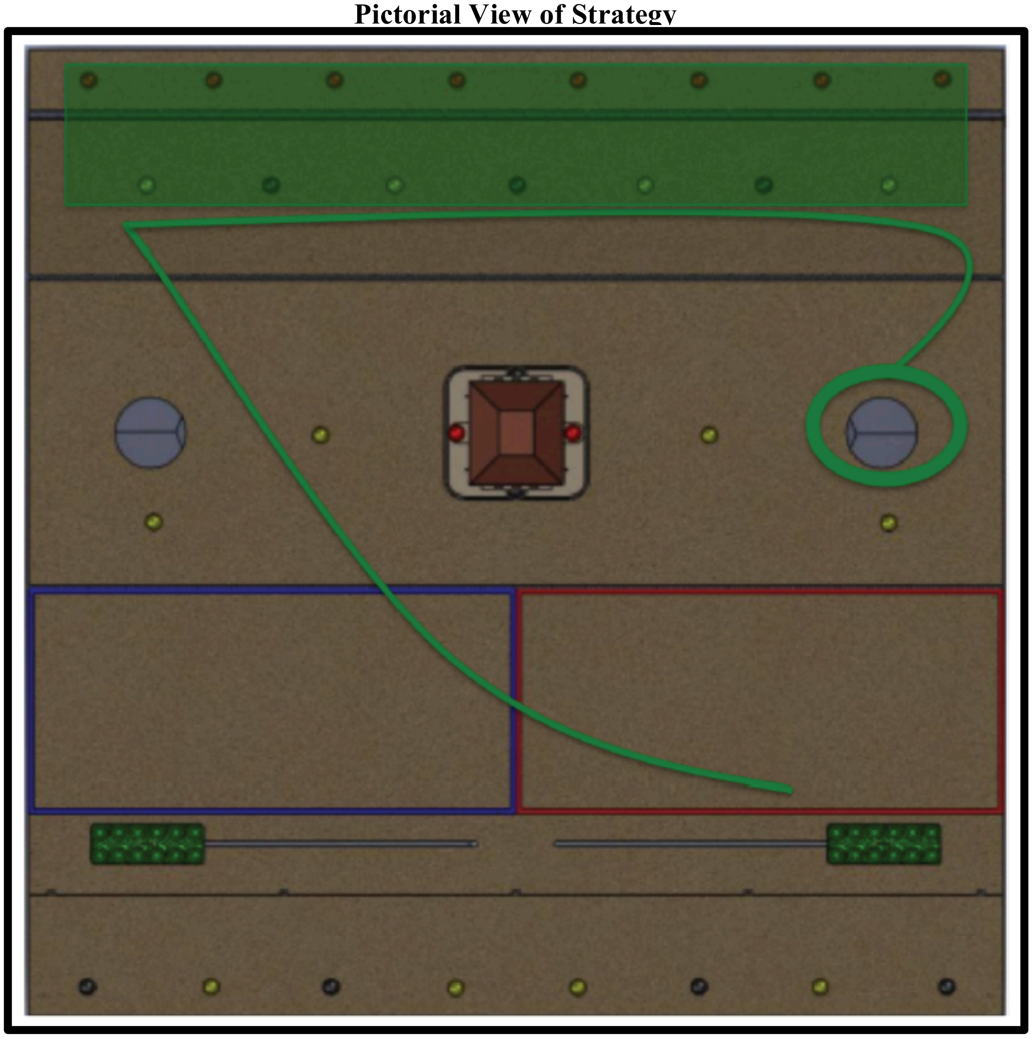
Connor Moelmann coached us through our frustrations and always reminded us to build a simple vehicle. He encouraged us to think outside the box and offered his clever ideas. Many thanks to him. Bob, Mark and Tony helped us master the resources in the machine shop. Many thanks to them. We would also like to thank Mike Umbriac for his help.

APPENDICES

A. STRATEGIES

Figure A1

Pictorial View of Strategy



B. CONCEPT SKETCHES

Figure B1

Concept Sketch 1

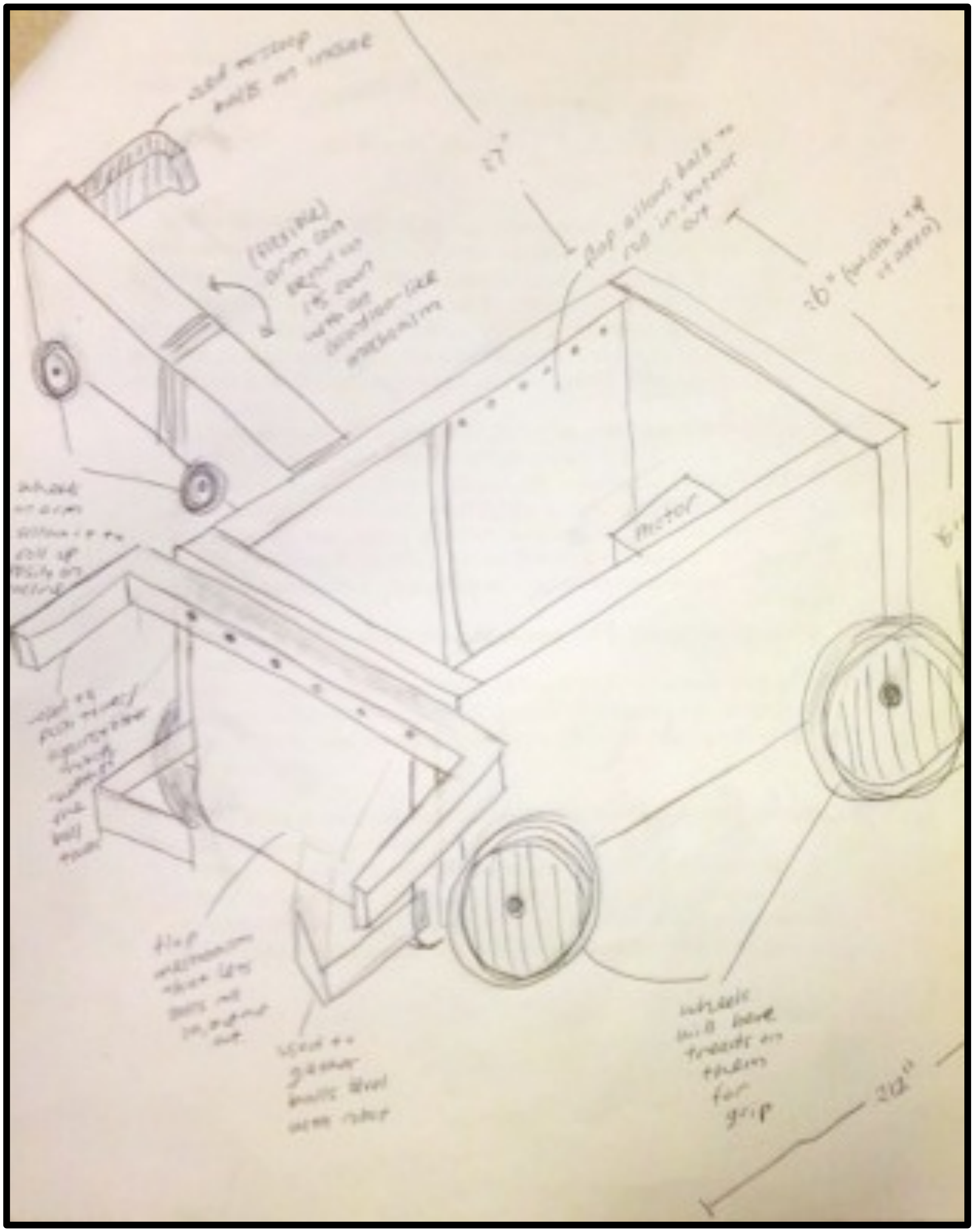


Figure B2

Concept Sketch 2

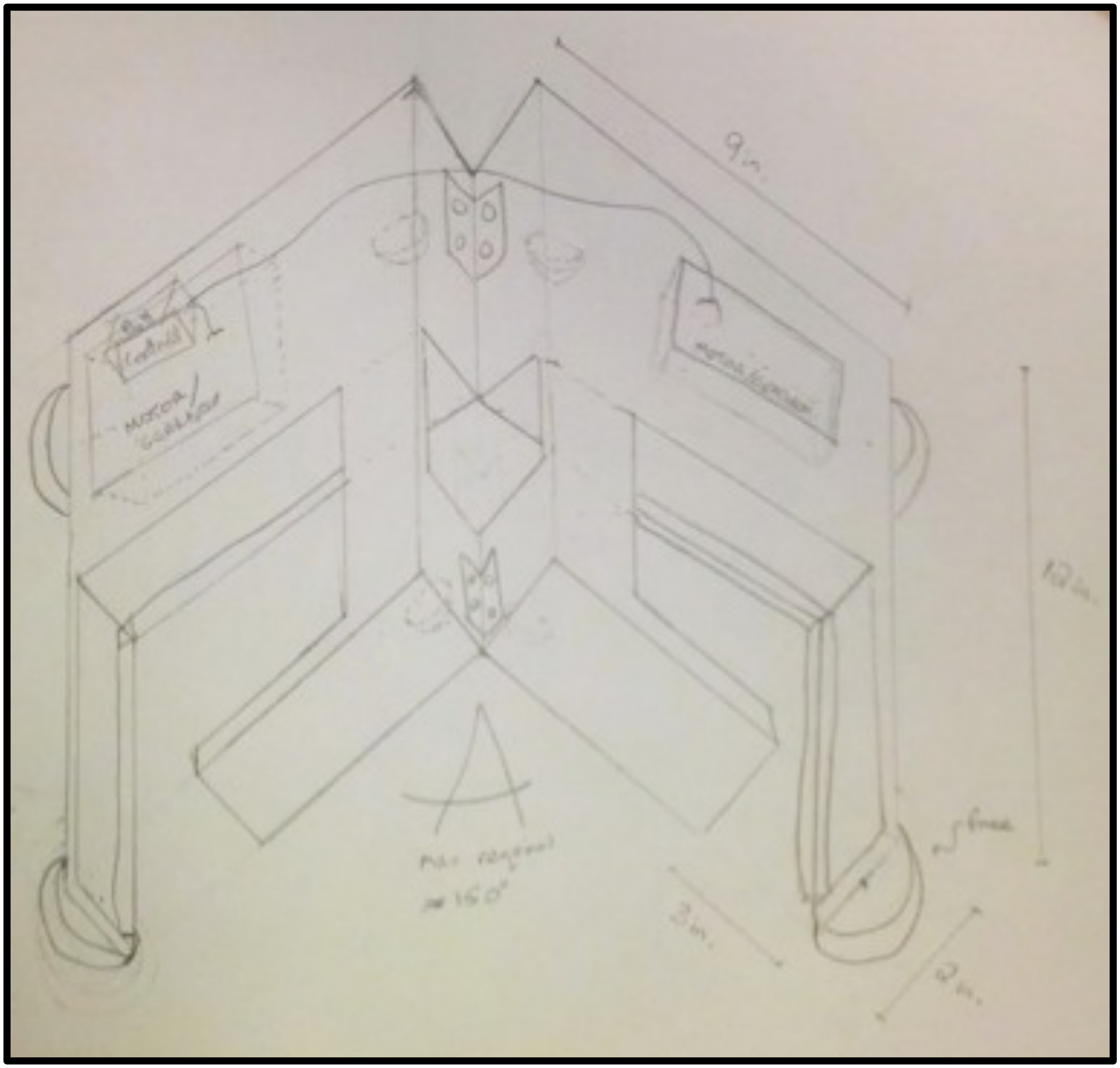


Figure B3

Concept Sketch 3

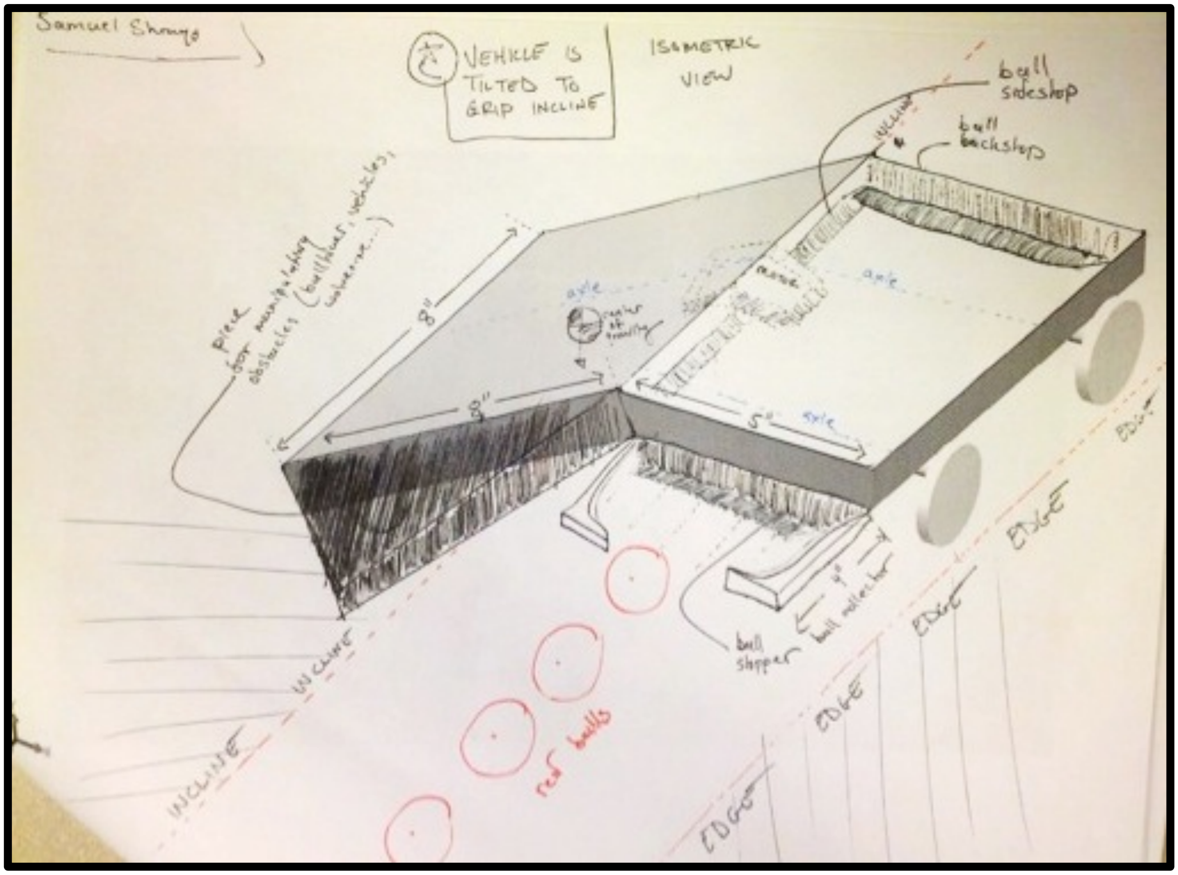
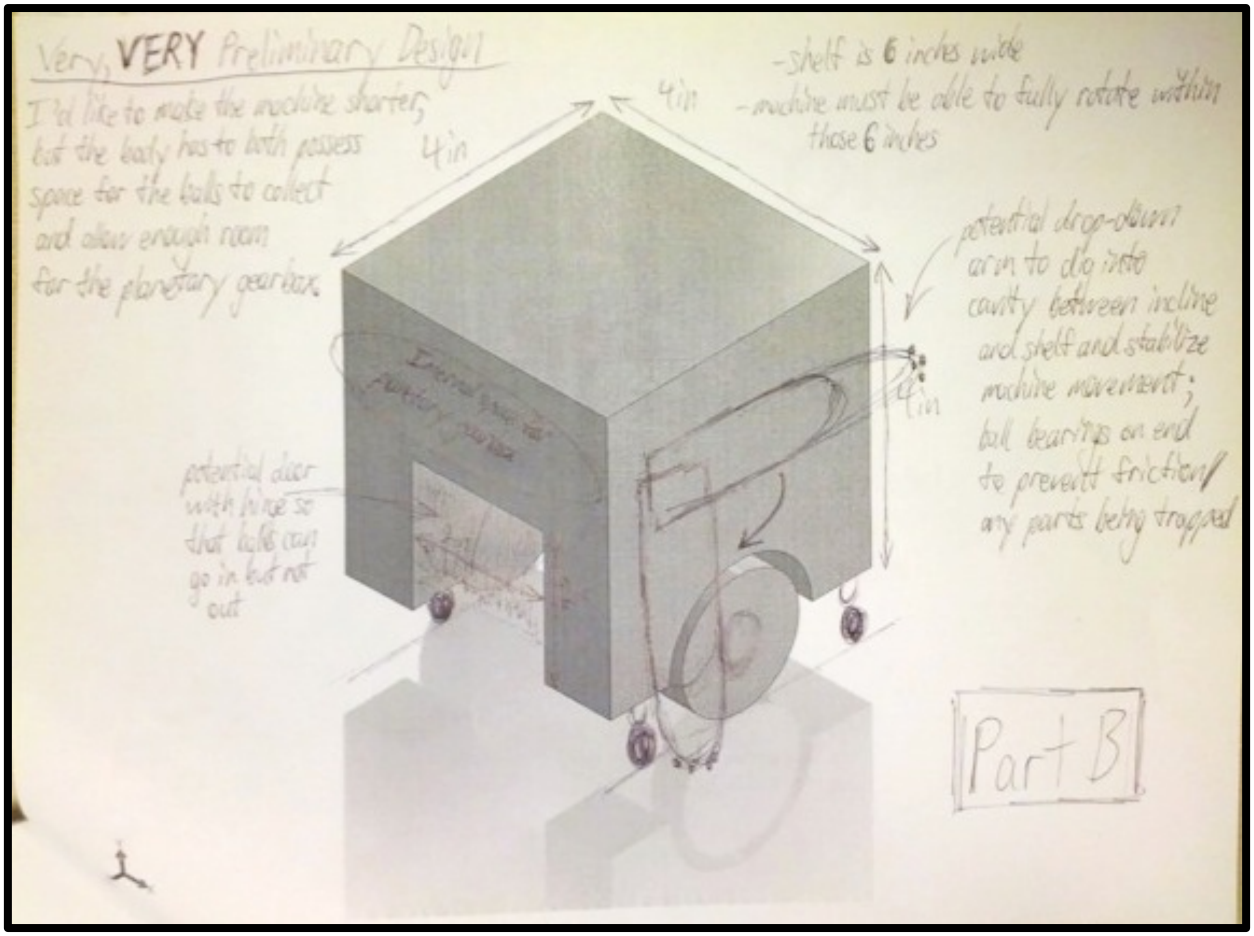


Figure B4

Concept Sketch 4

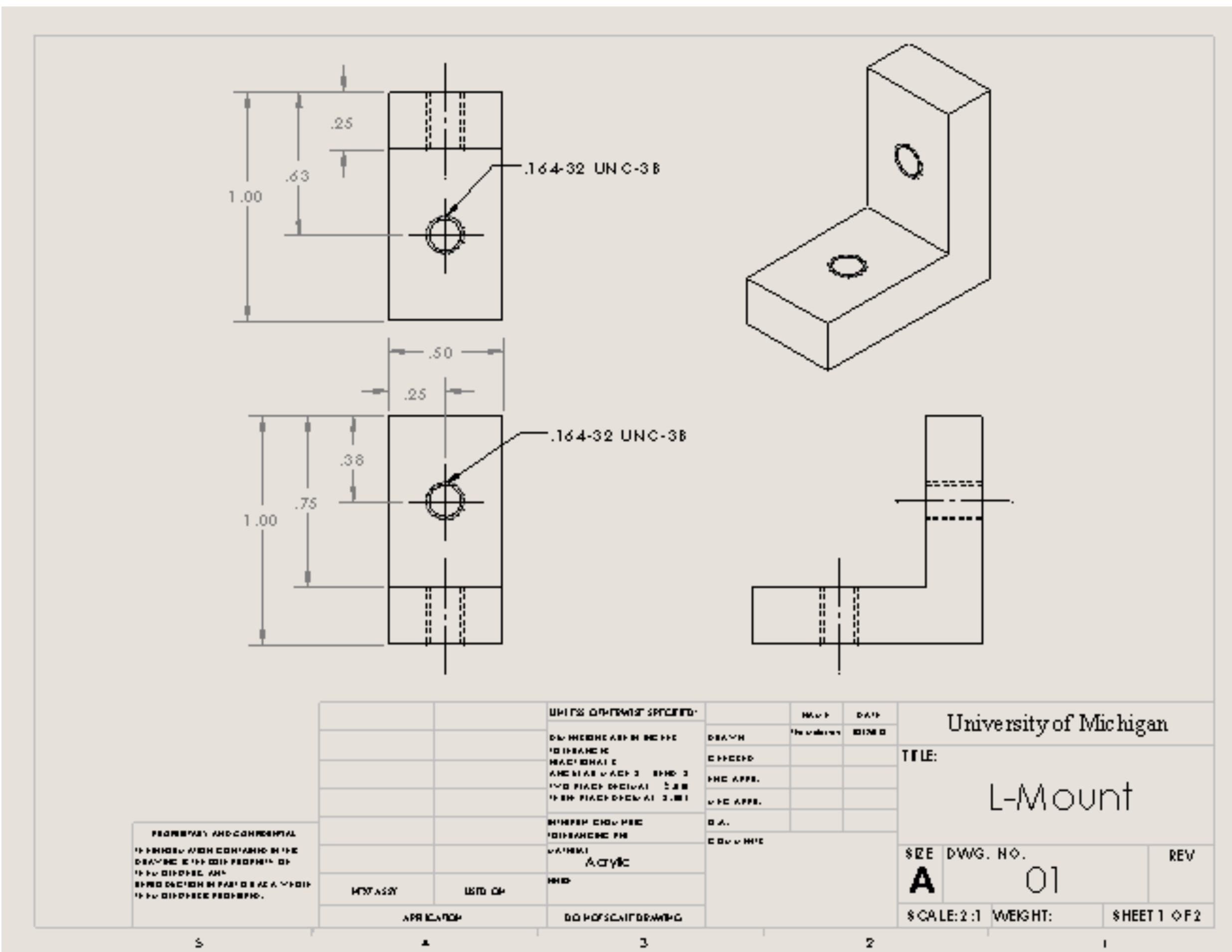


C. DIMENSIONED DRAWINGS AND MANUFACTURING PLANS

C.1. Dimensioned Drawing(s) of Individual Parts

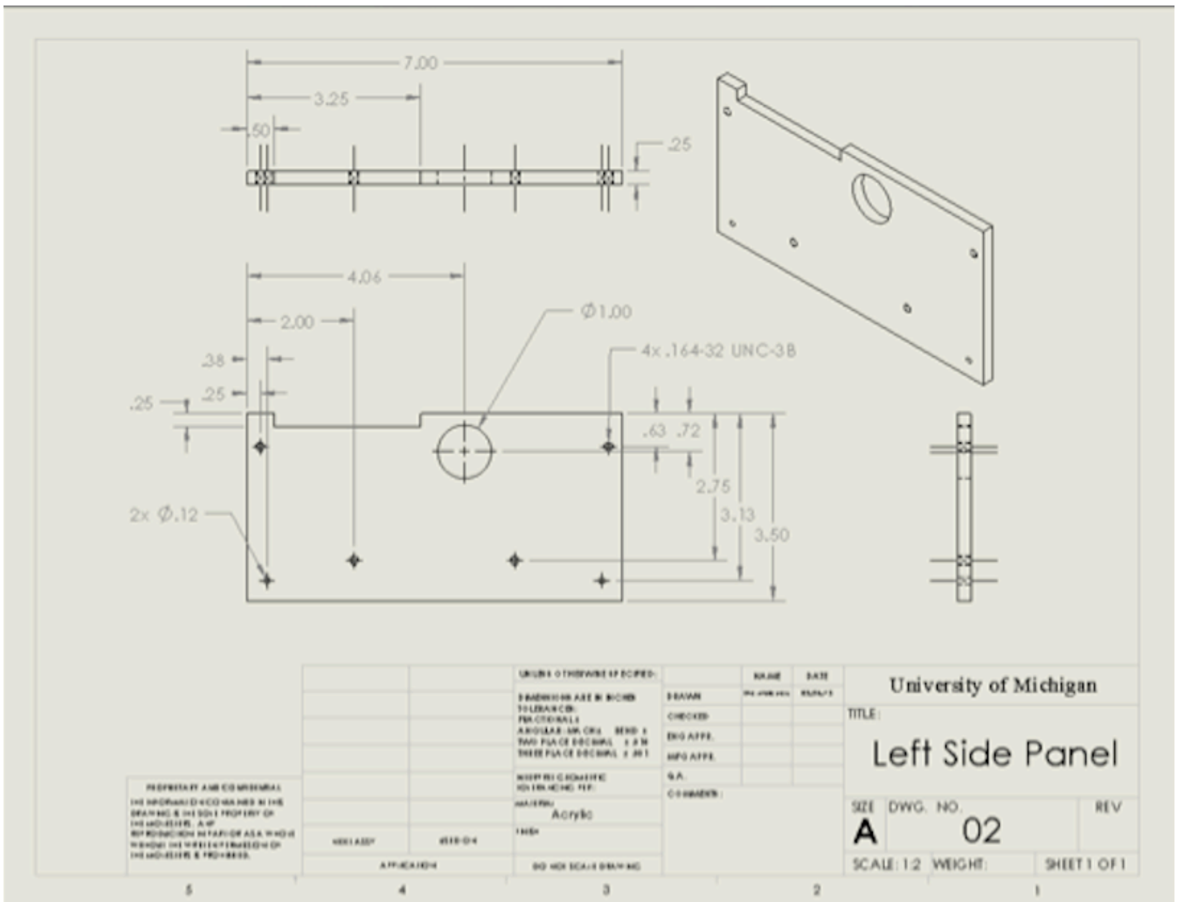
Part Number: ME250-01
Part Name: L-Mount
Team Name: Molesters
Raw Material Stock: Alro 3/8" Aluminum Rod

Figure C1
L-Mount Drawing



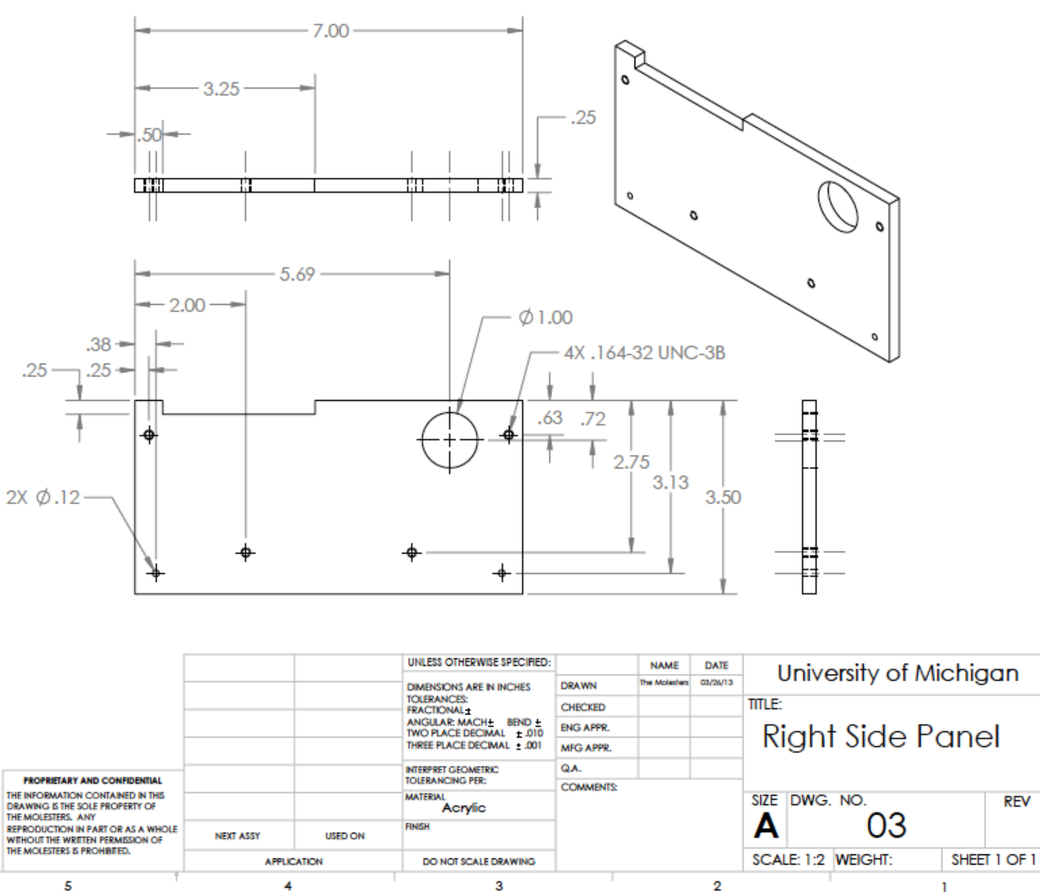
Part Number: ME250-02
Part Name: Body Left Panel
Raw Material Stock: Alro ¼” Acrylic Plate

Figure C2
Left Side Panel Drawing



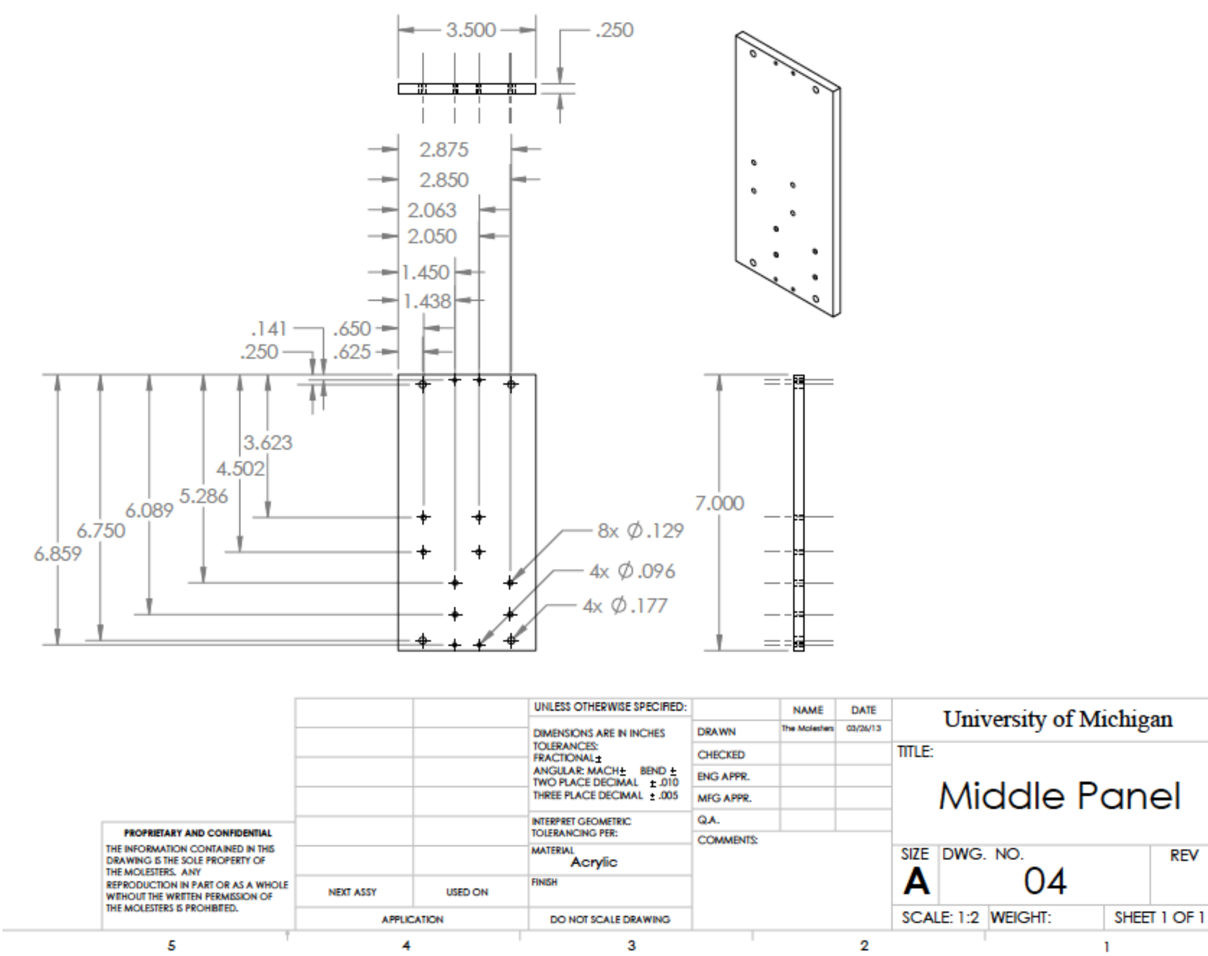
Part Number: ME250-03
Part Name: Body Right Panel
Raw Material Stock: Alro ¼" Acrylic Plate

Figure C3
Right Side Panel Drawing



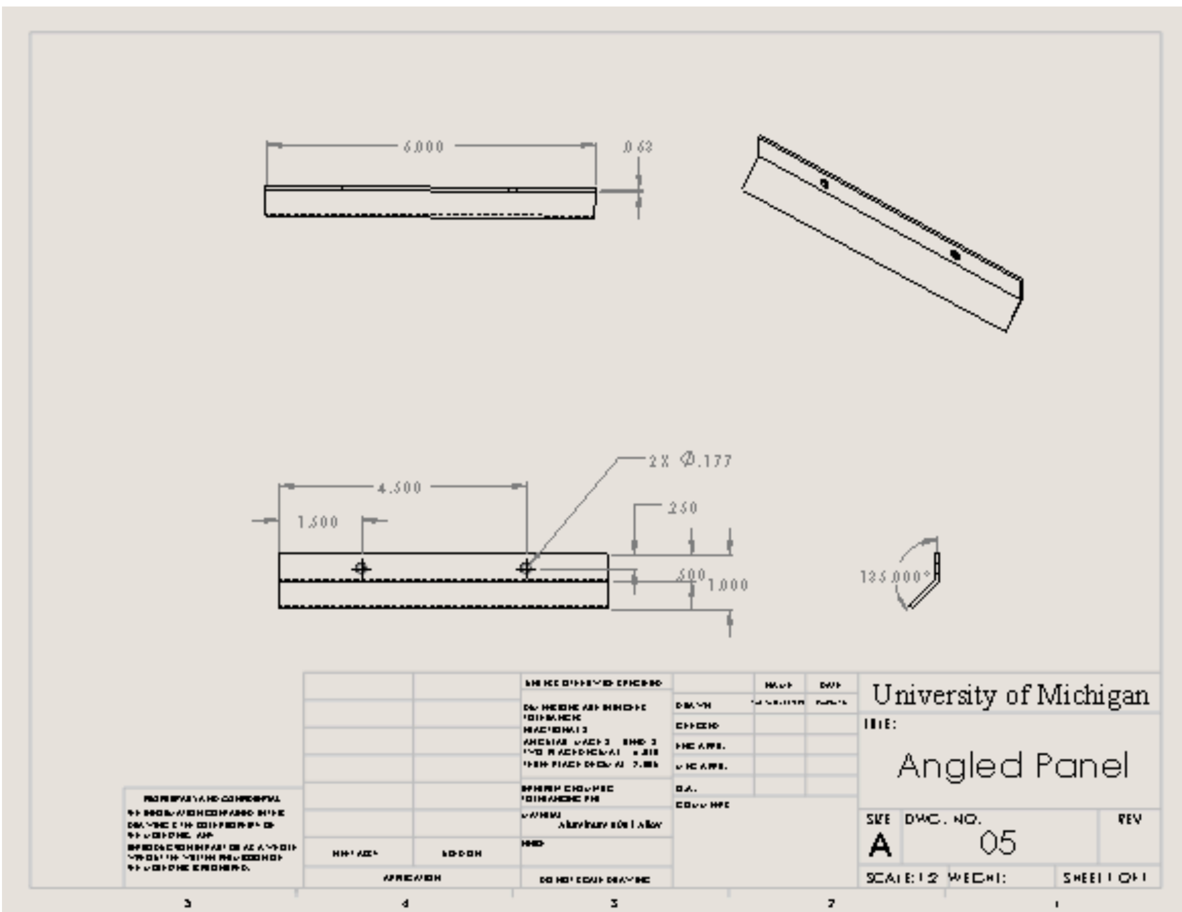
Part Number: ME250-04
Part Name: Body Middle Panel
Raw Material Stock: Alro ¼" Acrylic Plate

Figure C4
Middle Panel Drawing



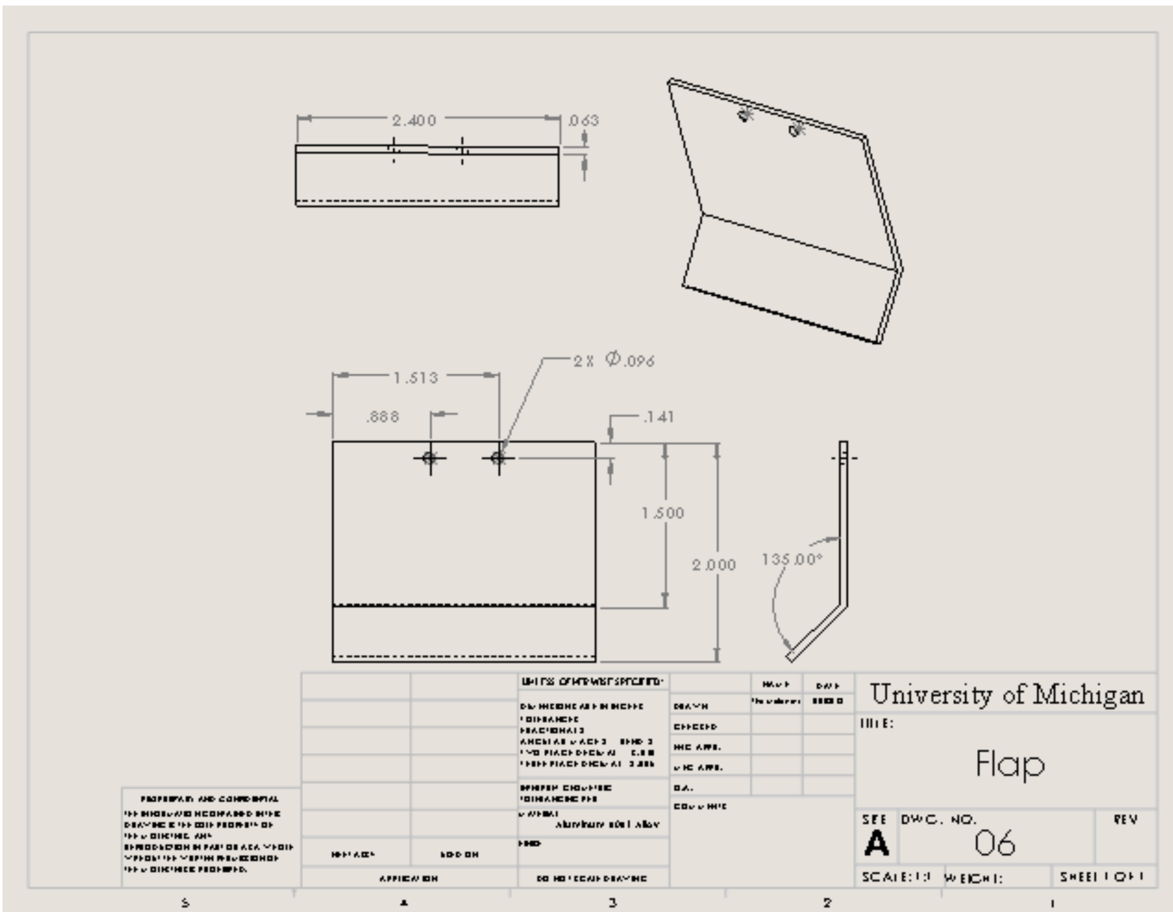
Part Number: ME250-05
Part Name: Angled Panel
Raw Material Stock: Alro 1/16" Aluminum Plate

Figure C5
Angled Panel



Part Number: ME250-06
Part Name: Flap
Raw Material Stock: Alro 1/16" Aluminum Plate

Figure C6
Flap Drawing



C.2. Manufacturing plans

Part Number: ME250-01
Part Name: L-Mount
Raw Material Stock: Alro 3/8" Aluminum Rod

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Cut out pieces of the rod, slightly larger than its desired size.	Band Saw		Wooden block	
2	Place part securely in vise, and ensure enough of it remains accessible for the endmill	Mill	Vise		
3	Install collet and endmill in spindle; tighten drawbar	Mill	Spindle	Collet, Endmill	
4	Ensure spindle range lever is in "Hi" position; turn spindle switch to hi range and set speed to 1000 RPM	Mill			1000
5	Lower spindle/raise table as necessary	Mill	Spindle Table		
6	Machine minimum amount off of exposed side in order to provide a fully machined surface	Mill		Endmill	
7	Remove part from vise and break all machined surfaces with file	Mill	Vise	File	
8	Place part back into vise and repeat steps	Mill	Vise	Endmill	

	5-6 for all sides of the part			File	
9	Machine part to length in multiple passes (taking part in/out of vise and using calipers to measure), leaving at least .01 inches by the conclusion of this step	Mill	Vise	Endmill Calipers	
10	Machine final .01 inches off all sides; use calipers for measurement	Mill		Endmill Calipers	
11	Remove part from vise and break all edges with file	Mill	Vise	File	
12	Use height gauge to mark part to remove .75” x .75” area of material	Mill		Height Gauge	
13	Return part to vise and use endmill to remove selected area; measure progress with calipers	Mill	Vise	Endmill Calipers	
14	Remove part from vise and break all edges with file	Mill	Vise	File	
15	Remove collet and install drill chuck; return part to vise so that the bottom portion is parallel with the device and the top portion is	Mill	Vise	Collet, Drill Chuck	

	perpendicular to it				
16	Install edge finder and set velocity to 1000 RPM	Mill		Edge Finder	1000
17	Find datum lines for X and Y (if bottom-left corner is zero, then X=.25 and Y=.375); move to hole location; install centerdrill and set velocity to 1600 RPM	Mill		Edge Finder Center Drill	1600
18	Centerdrill and then drill through part with #8 drill bit; lubricate as necessary	Mill		Center Drill #8 drill bit	
19	Remove part from vise and turn it ninety degrees so that the new position appears identical to the previous one; place back in vise	Mill	Vise		
20	Repeat steps 15-17 to create an identical hole in the current side	Mill	Vise	Edge Finder Center Drill #8 drill bit	1000 (Edge Finder); 1600 (Center Drill)
21	Remove all equipment and clean up	Mill			
22	Tap the four, 0.164” diameter holes with a size 29 tap drill.			#29 tap drill	
23	Remove any burrs if necessary			file	

24	Remove all equipment and clean up	Mill			

Part Number: ME250-02
Part Name: Body Left Panel
Raw Material Stock: Alro ¼" Acrylic Plate

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Ensuring the acrylic plate is no more than 0.25 inches thick and no larger than 32" x 18", place the acrylic plate in the laser cutter and cut out desired pattern.	Laser Cutter			
2	Place part in vise	Mill	Vise		
3	Install edge finder and set velocity to 1000 RPM	Mill		Edge Finder	1000
4	Find datum lines for X and Y of the 1" hole (if bottom-left corner is zero, then X=4.06 and Y=2.78); move to hole location; install centerdrill and set velocity to 1600 RPM	Mill	Vise	Center Drill	1600
5	Centerdrill and then drill through part with drill bit; lubricate as necessary	Mill		Center Drill drill bit	
6	Repeat steps 4-6 for the two .12" holes; assuming bottom-left corner is zero: [Hole 1: X=.38, Y=.37] [Hole 2: X=6.62,	Mill		Edge Finder Center Drill #32 drill bit	1000 (Edge Finder); 1600 (Center Drill)

	Y=.37]				
7	Repeat steps 4-6 for the remaining four holes; assuming the bottom-left corner is zero: [Hole 1: X=.25, Y=2.87] [Hole 2: X=6.75, Y=2.87] [Hole 3: X=2, Y=.75] [Hole 4: X=5, Y=.75]	Mill		Edge Finder Center Drill #8 drill bit	1000 (Edge Finder); 1600 (Center Drill)
8	Remove all equipment and clean up	Mill			
9	Tap the four, 0.164" diameter holes with a size 29 tap drill.			#29 tap drill	
10	Remove any burrs if necessary			file	
11	Remove all equipment and clean up	Mill			

Part Number: ME250-03
Part Name: Body Right Panel
Raw Material Stock: Alro ¼" Acrylic Plate

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Ensuring the acrylic plate is no more than 0.25 inches thick and no larger than 32" x 18", place the acrylic plate in the laser cutter and cut out desired pattern.	Laser Cutter			
2	Place part in vise	Mill	Vise		
3	Install edge finder and set velocity to 1000 RPM	Mill		Edge Finder	1000
4	Find datum lines for X and Y of the 1" hole (if bottom-left corner is zero, then X=5.69 and Y=2.78); move to hole location; install centerdrill and set velocity to 1600 RPM	Mill	Vise	Center Drill	1600
5	Centerdrill and then drill through part with drill bit; lubricate as necessary	Mill		Center Drill drill bit	
6	Repeat steps 4-6 for the two .12" holes; assuming bottom-left corner is zero: [Hole 1: X=.38, Y=.37] [Hole 2: X=6.62,	Mill		Edge Finder Center Drill #32 drill bit	1000 (Edge Finder); 1600 (Center Drill)

	Y=.37]				
7	Repeat steps 4-6 for the remaining four holes; assuming the bottom-left corner is zero: [Hole 1: X=.25, Y=2.87] [Hole 2: X=6.75, Y=2.87] [Hole 3: X=2, Y=.75] [Hole 4: X=5, Y=.75]	Mill		Edge Finder Center Drill #8 drill bit	1000 (Edge Finder); 1600 (Center Drill)
8	Remove all equipment and clean up	Mill			
9	Tap the four, 0.164" diameter holes with a size 29 tap drill.			#29 tap drill	
10	Remove any burrs if necessary			file	
11	Remove all equipment and clean up	Mill			

Part Number: ME250-04
Part Name: Body Middle Panel
Raw Material Stock: Alro ¼" Acrylic Plate

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Ensuring the acrylic plate is no more than 0.25 inches thick and no larger than 32" x 18", place the acrylic plate in the laser cutter and cut out desired pattern.	Laser Cutter			
2	Use the height gage to mark the holes on the middle panel			Height Gage, Marker	
3	Center punch the location of the holes.			Center Punch	
4	Secure the panel into a mount to prep for drilling.		Vise	1.5" Parallels	
5	Center drill each of the marked holes.	Drill Press	Vise	Center Drill drill bit, oil	
6	Drill through each of the holes using their corresponding drill bit size.	Drill Press	Vise	#16, #30, #41 drill bits, oil	
7	Remove all equipment and clean up.	Drill Press			
8	Remove any burrs if necessary			File	

Part Number: ME250-05
Part Name: Angled Panel
Raw Material Stock: Alro 1/16” Aluminum Plate

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Cut the desired size of the aluminum plate (6”x1.2”).	Band Saw		Push block	~300
2	Use the height gage to mark the holes on the piece of the cut-out aluminum and the line indicated where the bending of the material will take place.			Height Gage, Marker	
3	Center punch the location of the holes.			Center Punch	
4	Secure the panel into a mount to prep for drilling.	Dill Press	Vise	1.5” Parallels	
5	Center drill each of the marked holes.	Drill Press	Vise	Center Drill drill bit, oil	
6	Drill through each of the holes using their corresponding drill bit size.	Drill Press	Vise	#16 drill bit, oil	
7	Remove all equipment and clean up.	Drill Press			
8	Bend the material the desired angle (45^o).	Press Brake			
9	Remove any burrs if necessary			File	

Part Number: ME250-06
Part Name: Flap
Raw Material Stock: Alro 1/16" Aluminum Plate

Step #	Process Description	Machines	Fixtures	Tools	Speed (RPM)
1	Cut the desired size of the aluminum plate (2.4"x2.2").	Band Saw		Push block	~300
2	Use the height gage to mark the holes on the piece of the cut-out aluminum and the line indicated where the bending of the material will take place.			Height Gage, Marker	
3	Center punch the location of the holes.			Center Punch	
4	Secure the panel into a mount to prep for drilling.	Dill Press	Vise	1.5" Parallels	
5	Center drill each of the marked holes.	Drill Press	Vise	Center Drill drill bit, oil	
6	Drill through each of the holes using their corresponding drill bit size.	Drill Press	Vise	#41 drill bit, oil	
7	Remove all equipment and clean up.	Drill Press			
8	Bend the material the desired angle (45^o).	Press Brake			
9	Remove any burrs if necessary			File	

D. PURCHASED AND TRADED ITEMS

D.1 Purchased items

Tamiya 70100 Track and Wheel Set
Pololu.com, #106
Quantity: 2
Unit Price: $7.99
Total Price: $15.98
-Main part of most critical module. Used for primary geartrain to allow climbing of incline.

Pololu Universal Aluminum Mounting Hub for 3mm Shaft Pair, 4-40 Holes
Pololu.com, #1078
Quantity: 2
Unit Price: $5.95
Total Price: $11.90
-Used to couple 4mm D motor output shaft to 3mm hexagonal sprocket shaft.

Pololu Universal Aluminum Mounting Hub for 4mm Shaft Pair, 4-40 Holes
Pololu.com, #1081
Quantity: 2
Unit Price: $6.95
Total Price: $13.90
-Used to couple 4mm D motor output shaft to 3mm hexagonal sprocket shaft.

M2 Screws
Quantity: 4
Unit Price: $0.29
Total Price: $1.16
-Used to assemble hinged front and back panels to final assembly.

D.2. Traded items

We received extra ¼" Acrylic stock from the GSI's in the lab, we were able to trade in our planetary gearbox for it.