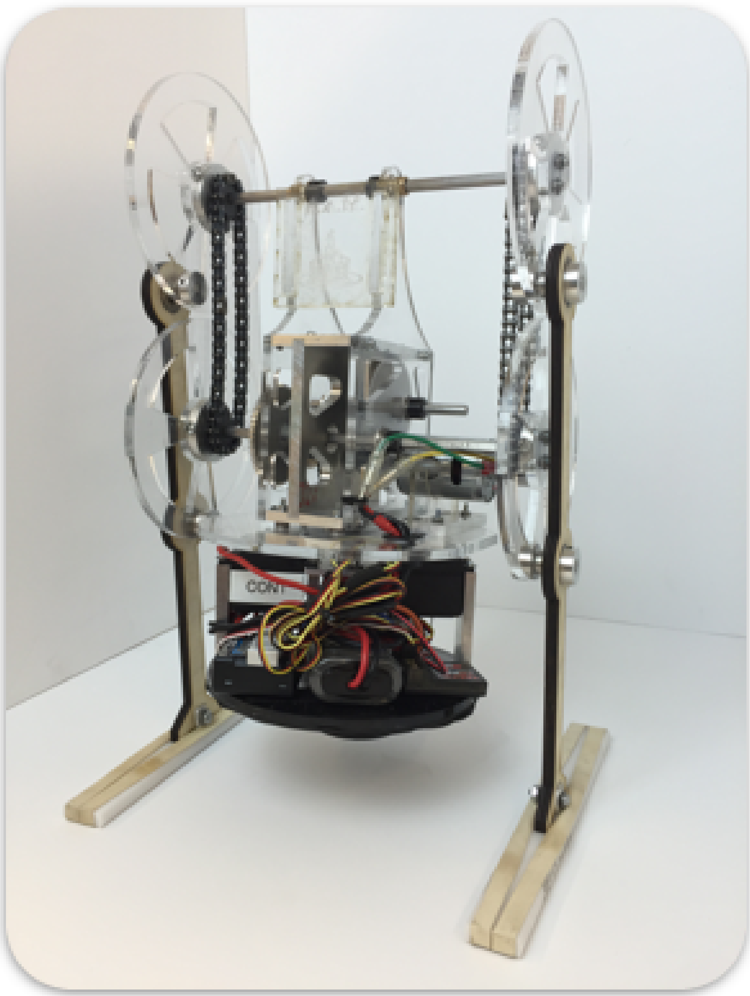
ENGS 76
Machine Engineering
Final Report



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Problem Definition

Course Objective

*"*Teams of 3-4 students design and fabricate joystick-controlled machines to navigate an obstacle course."

Project Specifications

The obstacles and the available materials provide design requirements for the machine, as detailed below:

Obstacle/Material	Necessary Specifications
Maze	● Turning: Can turn 90˚ in two directions ● Size (Hard): Fits within a 10" square, including when turning ● Size (Easy): Fits within a 11" square, including when turning
Teeter-Totter	● Slope: Can walk up and down a 27˚ incline ● Robustness: Does not fall when the teeter-totter changes incline ● Arm (Hard): Can pull down the teeter totter from a height of 16.25"
Peg Forest	● Height (Hard): Vertical clearance of 3" ● Height (Easy): Vertical clearance of 1.5" ● Width (Alternative): Can fit between the pegs on some route through the obstacle
Battery	Strength: Can lift or drag the 390 g battery
Course Size	Speed: Absolute minimum of 13 ft/min (based on a 12 x 20 course and a five minute time limit)
No wheels	Do not use wheels for forward motion
Plywood obstacles cannot be damaged	Contact with the ground cannot damage the atrium floor or the plywood obstacles
Step	Can step onto the ¼" plywood obstacles

Final Specifications

Due to time and design constraints, our strategy was to complete a single lap doing the hard maze. It obeys project specifications above, excluding the teeter totter and peg forest. Subassembly specifications are as follows:

Gearbox

Torque	Must provide enough torque to lift the vehicle: 1.11 Nm
Gear ratio	129.6:1

Size	3.73 x 2.32 x 4.03 in

Legs

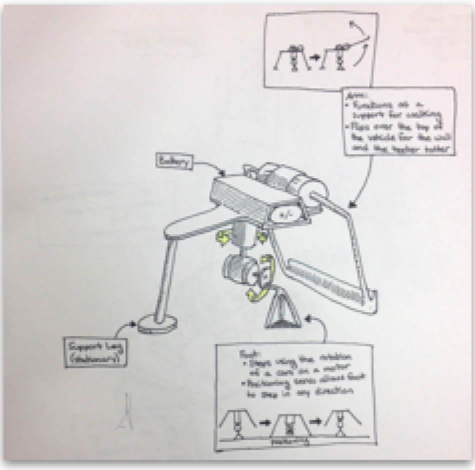
Length	● 5.3" from foot to first hole, 5.3" from first hole to second hole ● Link wheels have 4.5" lift--see leg length calculations ● Allows chassis to hit the ground, the feet do not hit link wheels
Stable	Feet should be irrotational in all directions when attached to the legs
Synchronous	Legs must be linked together to run simultaneously. Gears are being used by the gearbox: use a chain and sprocket system.
Feet	Contain the center of mass during movement: 8"
Robust	● Materials do not break during use ● Leg rods, ¼" plywood: Allows some bending and is lighter than aluminum. ● Feet, acetyl: Less brittle than acrylic, heavier than wood to help keep legs straight, not as heavy as aluminum ● Wheel links, acrylic: Fast prototyping, light

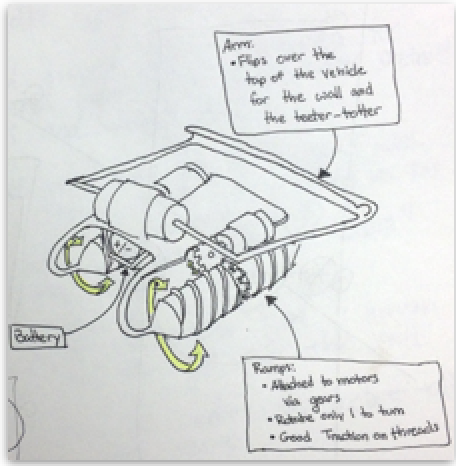
Chassis

Does not hit the feet	● Has to be narrower than the legs ● Cannot hinder walking motion
Wires are contained	● Do not tangle with the legs or other moving parts ● Allow chassis to turn at least 90 degrees ● Must wire two servos on the same channel
Compact	● Fits within the maze, diameter <10" ● Make center of mass as low as possible
Robust	● Does not deform under estimated total weight of 1.5 kg ● Servos must provide over .64 Nm of torque to rotate the top plate

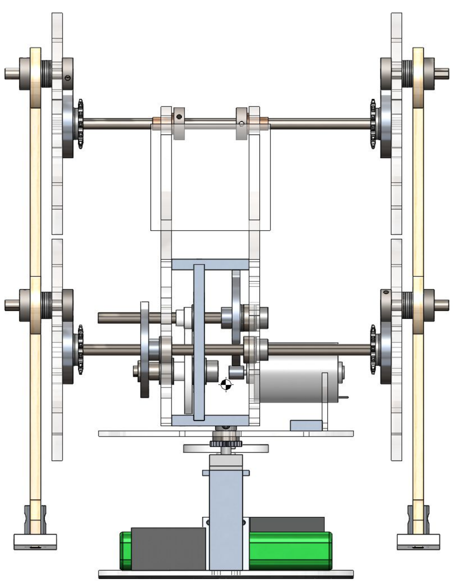
Alternative Design Concepts and Selected Design

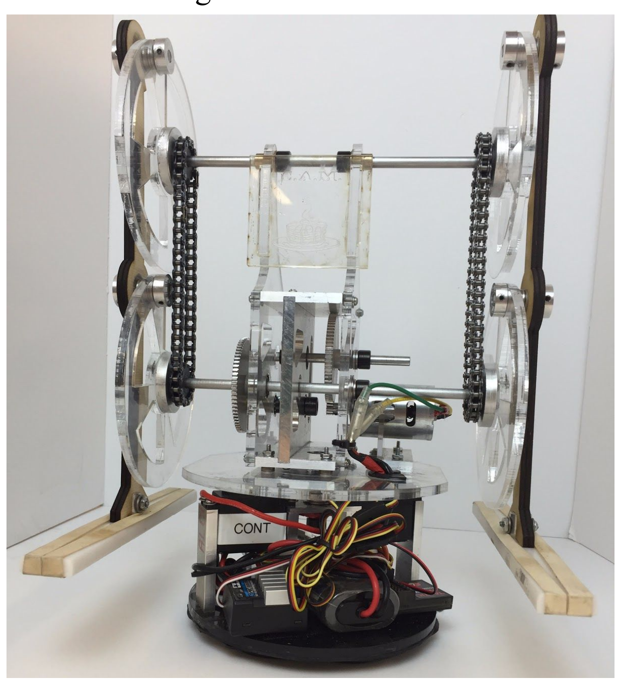
Before choosing the concept that would evolve into our final design, we discussed the pros and cons of four options. These were walking with two legs, walking with four legs, "the ramps"/ "the corkscrew" (a 1960's Russian vehicle), and the tripod. Walking using legs is fairly self explanatory. The ramping concept was based on the idea that two threaded cylinders rotate, and the helical structure digs into the ground to pull the vehicle forward. While we liked this idea, we were skeptical about it's functionality on hard tile, so we decided not to use it. We moved forward with the tripod concept (see the image below). The movement mechanism is simple: there is a inner foot, surrounded by an outer support structure. The foot is attached to a wheel that lifts the foot as it rotates. When the foot is fully extended, it lifts the entire outer frame and moves it forward a specified step size. The inner foot structure is attached to a vertical axle that also rotates, allowing point turning. This turning concept remained throughout design iteration.

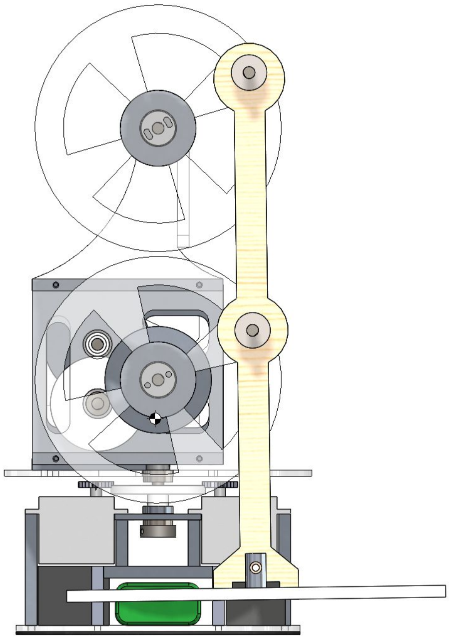


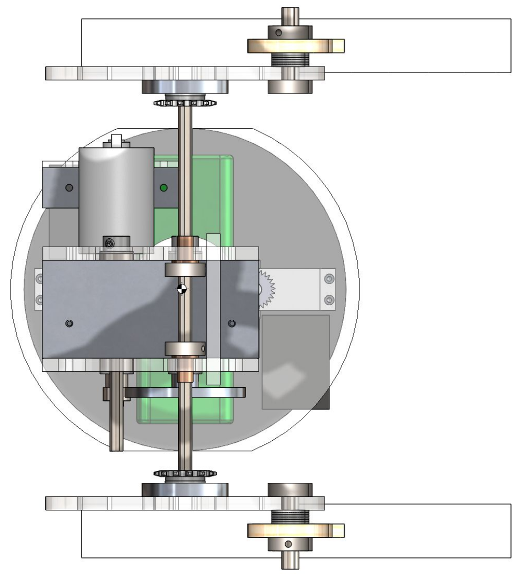


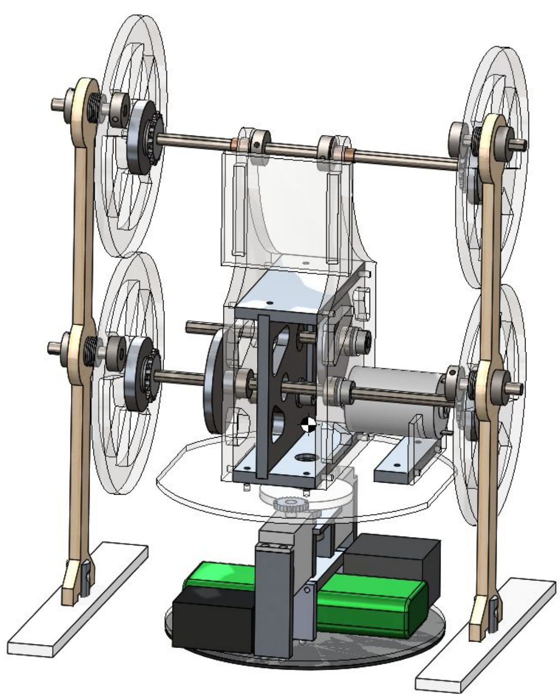
We moved forward with this design for three reasons: it was simple, appeared easy to control, and was fairly robust. These three parameters were the deciding factors because, with the accelerated timeline of this project, we wanted something that wouldn't be too complicated to machine and build quickly, as well as something that didn't break apart after just a few runs. The ease of control was a consideration for the sake of the person driving the vehicle during competition. Here are some final images of our chosen design:

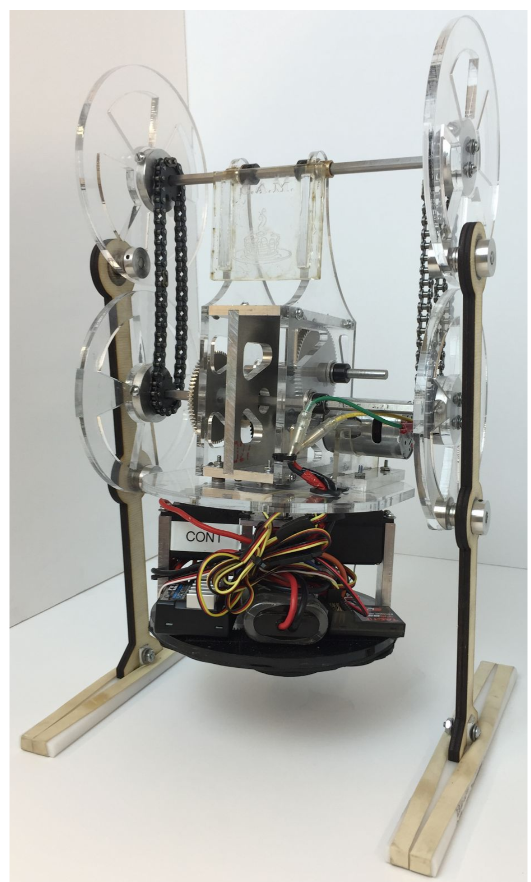








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Analysis

Torque Calculations

To estimate torque needed, we first estimated the approximate mass of the vehicle by weighing parts we thought we would include, and multiplying by the acceleration of gravity and 3" (lift needed). Subsequent calculations used weight estimations from SolidWorks (1.5kg). The first estimate was 1.9 to 6.3 kgm, depending on stock material used and arm length.The second estimate was 11.31 kgcm, based on 1.5kg and a 0.076m lift

Leg Length Calculations

The first set of legs designed did not allow the chassis to reach the ground. Instead we found that the chassis at its lowest point, was 1" off of the ground. We determined that if the legs were shortened enough to let the chassis touch the ground, the feet would hit the wheels. To maintain 3" of lift, the wheels could not be made smaller. We therefore made the wheels larger (5.25" in diameter) which allowed a higher lift, and the leg length to be decreased by 1.5". This was later changed to a length of 5.3" between holes.

Gearbox Calculations

To design our gear box, we used the torque specifications discussed above, as well as the motor information we gathered from homework. We used the calculated torque value, and compared it to the amount of torque we got with a 16.2 gear ratio gearbox. We used that comparison to determine a ballpark number for the gear ratio we would need, then looked at the gear combinations possible. We ultimately decided on a three mesh gearbox with a gear ratio of 129.6 to 1, using two 72 teeth gears, two 16 teeth gears, one 64 teeth gear, and one 10 teeth gear. The pitch diameters, and length between shafts was calculated accordingly.

SolidWorks

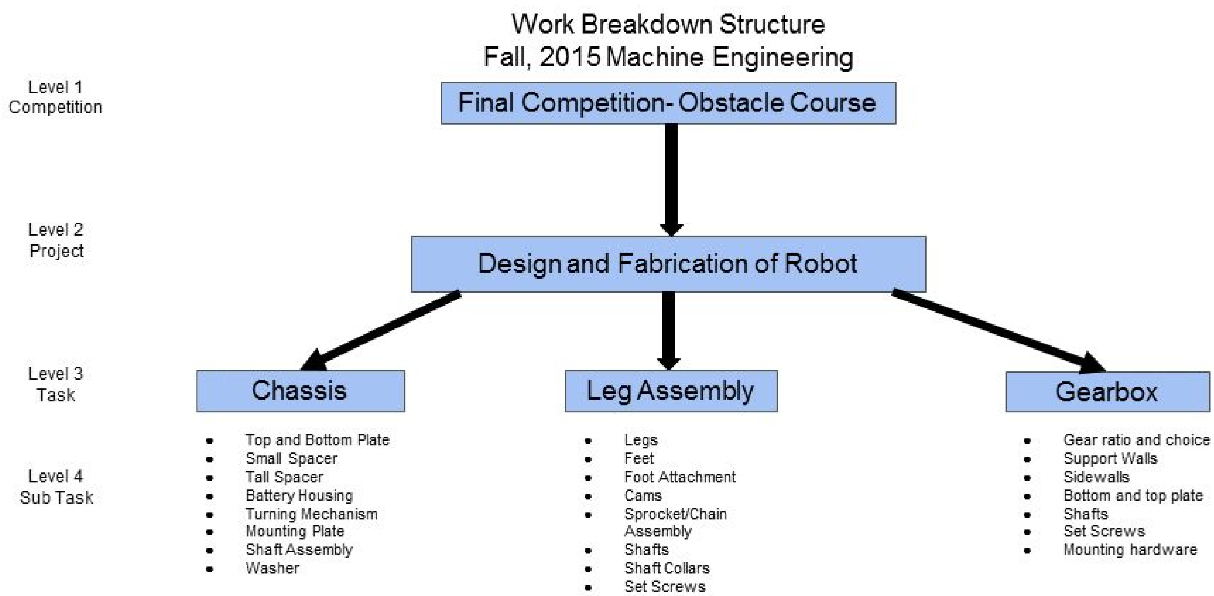
We used SolidWorks to visually inspect how the various components fit together, making adjustments to part size through iterative problem solving. SolidWorks was also used to find the center of mass of the vehicle.

Design Details

The current mass of the device is 2,657.7 grams. Compared to our previous calculation, which was 1500 grams, we're off by about 1000 grams, but that can be taken into account when you consider the extra material and parts added (most of which were made out of aluminum). The original weight also didn't take into account our decision to change to using the drive motor and include a gear box. Our finalized drawings and bill of materials can be found in the Appendices I and II.

Implementation

Our manufacturing plan was simple, as summarized in project report 3. This diagram summarizes how we broke up the project and manufacturing the necessary components:

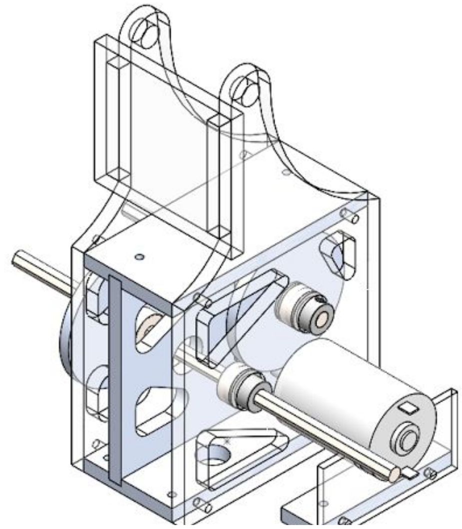


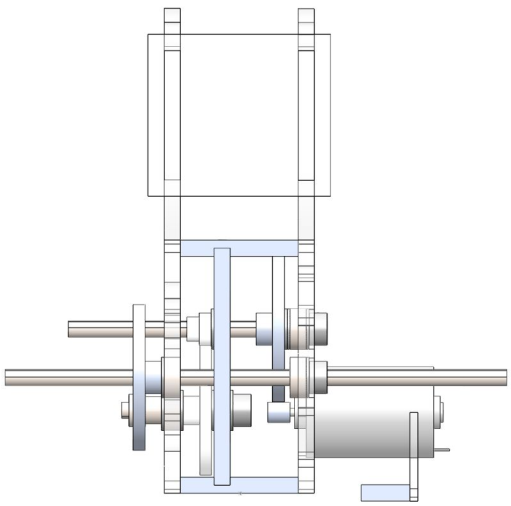
Callan fabricated the gearbox, Anna fabricated the leg assembly, and Margaux fabricated the chassis. When it came to "on the fly" modifications such as wiring and padding the bottom of the chassis, we all contributed. Every part was fabricated in the machine shop using the CNC mills, lathes, drill press, and laser cutter. We discovered assembly design problems after testing our prototypes. Many of these were easily resolved by adding materials and tightening connections, e.g. tightening the vertical axle, controlling the connecting wires using zip ties, adding washers for spacing, and adding rubber to the bottom surfaces to improve traction. Issues with individual parts are discussed below. This entire processes could have been improved by better organizing our files on Thayer FS and better communicating the difficulties of each design iteration.

A few positive choices really stood out. The robot was able to reliably walk, and was also robust enough fall down and not break. We are really proud that the gearbox came together so nicely, and the foot attachment part held together in every foot assembly we made with super glue, epoxy, and more. We are proud of our group dynamics, abilities to communicate, the fun we have as we work, and our problem solving abilities. Ultimately we managed to rebuild our whole robot an hour before the competition, coming up with some great last minute solutions.

Gearbox

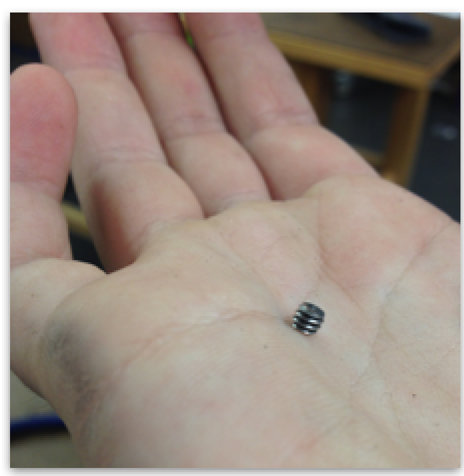
The eight parts made for the gearbox were sidewall 1, sidewall 2, sidewall 3, the top plate, the base plate, the motor support wall, the motor support wall base, and the sidewall support. The motor support wall and the sidewall support were the easiest to fabricate, as they could be cut out of ⅛ inch and ¼ inch acrylic respectively using the laser cutter. Sidewall 1 and sidewall 3 were also made out of acrylic, but because their holes were for ball bearings, they needed to be more precise than was capable with the laser cutter. The profile was cut out using the laser cutter, but the bearing and motor holes were milled, and any clearance holes for screws were drilled using the appropriate drill bit.



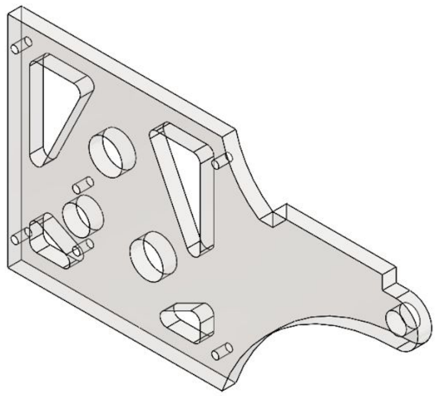
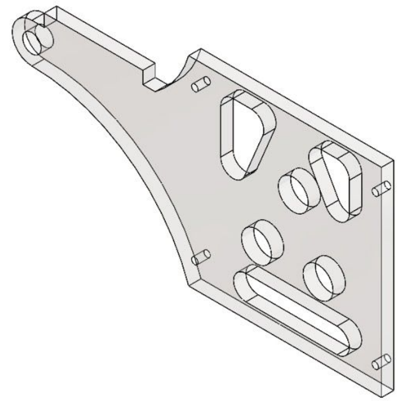


For the aluminum pieces (sidewall 2, the top plate, the base plate, and the motor support wall base), we used the mill to square up the metal and bring it down to size. For most of the parts, the holes were easy enough to locate and drill by hand. However, the milled circle pocket in the base plate, as well as all the bearing holes and pockets in sidewall 2 were too complicated to do by hand, so we used a DXF program to mill out those pockets.

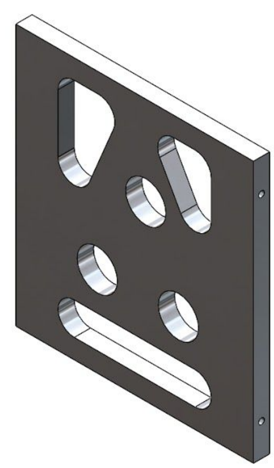
We encountered several manufacturing difficulties during the process of making these parts. The most problematic issue was discovering that the .64 reamer was not quite accurate enough to press-fit the bearings into the bearing holes. This meant we had to mill out each hole using DXF pockets. We also discovered, that because of the laser cutter's width, it's not possible to laser cut some holes and mill out others while maintaining the distance needed between the center of each hole. There was also an issue with the slot cut in the top plate. When trying to construct the gear box the first time, we discovered that the inner slot had not been cut exactly parallel, and the gearbox wasn't square, requiring the top plate be remade. Additionally, we had issues with set screws slipping in the plastic gears, leading to the decision to drill through the shaft and use screws as pins as opposed to set screws. This process was also used on one metal



gear because the torque on the shaft caused the set screw to shear. However the torque was so large, it also sheared the metal screw, so we ultimately ended up using a hardened set screw to keep the gear in place.

Most of the parts in the gearbox stayed the same with the exception of sidewall 1 and sidewall 3 (pictured above). Sidewalls 1 and 3 changed multiple times, mostly because, with every change of the legs the length of the protruding arm on the sidewalls changed. The first iteration of changes lengthened the protruding arm. We also chose to cut them out of 1/4 inch acrylic instead of 1/8 inch because we were concerned the acrylic couldn't withstand the pressure the upper axle was creating. The second iteration of changes came because we realized we needed to put bushings in the holes for the upper axle for added support. We also were having issues with the protruding arm breaking off, so we made the sides more sloping to take away the stress angle. We also took Professor Diamond's advice and added a support wall between the two arms, so a joint was added to the arm, and the new piece (the sidewall support) was fabricated.

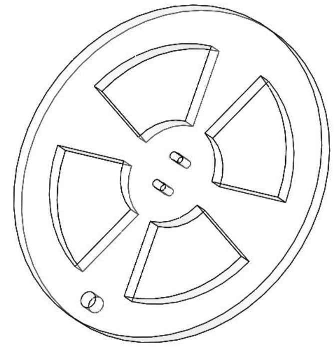


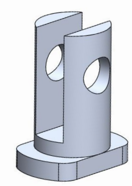
In terms of the gear box parts, there isn't much that could be done to optimize construction. Because of it's function, the parts needed to be precise and needed to come together cleanly, which means they cannot be simplified. We could forgo cutting out the pockets that were meant to help with reducing weight, but because we had to mill the bearing holes already, adding this small step was not overly inhibitive.

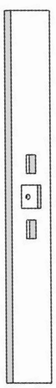
Leg Assembly

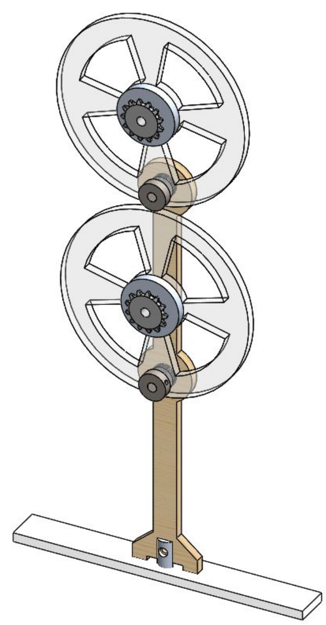
The legs underwent many iterations before reaching the final design. To increase the speed of prototyping, many components were first cut out of acrylic instead of the planned material (which was originally aluminum). This is a breakdown of the fabrication plan for each manufactured component.

The leg rod was made out of ¼” acrylic, later changed to ¼” plywood which was cut on the laser cutter. Iterations improved its attachment to the foot, idealized leg length, and decreased the likelihood of snapping. The link wheels were made out of ¼” acrylic, cut on the laser cutter. One of the link wheels in each leg assembly was cut with slots for adjusting the sprocket attachment, while the other was cut with simple holes that would fix the position of sprocket attachment. The foot attachment was made out of a ½” aluminum rod and was made on the lathe and mill. Initially the pieces were cut exactly to size on the lathe, making it difficult for them to be stabilized to cut them on the mill. They were remade, and milled appropriately. One of them had an attachment hole drilled slightly off center,requiring that the head of the original attachment screw be filed so that it would fit. The shaft collar was fabricated out of ¾” aluminum rod, with the center hole drilled on the lathe, and the tapped hole drilled on the mill (set screw size was changed once to prevent slipping). The foot was made out of ¼”aluminum, then acrylic, then acetyl. Acrylic and wood models were cut on the laser cutter, and the aluminum, acetyl, and acrylic were milled (to create pockets). Programming the mills to cut the original pocket (two lines connected by rounded ends) proved somewhat tricky because the mill would overcut when the program started or ended on the end of a line. Some trial and error was necessary before the program was functional, and subsequent pockets were changed to circles or a round rectangle, which are easier to program.The sprocket collar was made from ¼” aluminum, cut to size and bored on the lathe, with a 8-32 hole drilled and tapped on a mill..The chain and axles were cut to size in the shop.





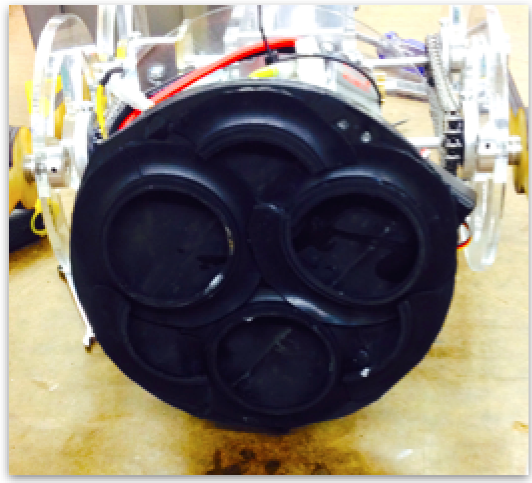




Leg assembly was particularly tricky. Many of the above modifications were made to improve attachments, and resulted in an improved design, but there were two problems never satisfactorily resolved: chain tensioning and alignment. Chain tensioning is discussed below (in performance). Aligning the legs straight relative to each other was difficult, largely because of the adjustment slots added to ensure that they could be made straight despite machining errors. This was because a) the slot screws would become loose despite lock washers and lose the position, and b) they had to be repositioned every time the legs were reattached.

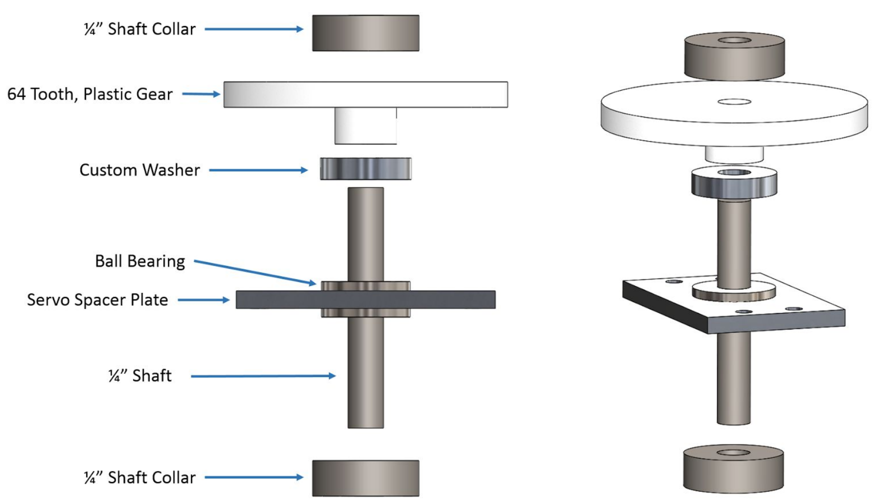
Chassis

The fabrication of the chassis used laser cutting and milling. The top and base plates were laser cut out of ¼" acrylic, while the rest of the pieces were milled out of aluminum and bolted together. After we assembled the robot for the first time we realized the short support wall needed a notch added to it to make room for the servo wires. This was an easy fix on the hand mill. We also added counterbores to the top and bottom plates to let the screws lie flat with the surface. We added the neoprene and tire padding to try and reduce the stress on the bottom plate during walking (see below).



The RC components were contained using velcro, and the wires were contained with zip ties. Unfortunately the zip ties limited our movement. One other issue we ran into was that the hardware in the chassis would vibrate out of its sockets over time, so we added lock washers to every 4-40 screw.

The mechanism to hold the top and bottom plates together was a solid ¼" shaft locked in place with two shaft collars. Here is a picture of the complete shaft assembly in the chassis that lets the robot turn on a single axis:



First the shaft was inserted into the ball bearing pressed into the servo spacer plate. The 64 tooth, plastic gear was aligned with the gears on the servos using a fabricated washer. Then a ball bearing in the center of the top plate was put over the shaft. The shaft was held in place by shaft collars on the top and the bottom. This held the chassis together and allowed the robot to turn on a dime.

Performance

Demonstration

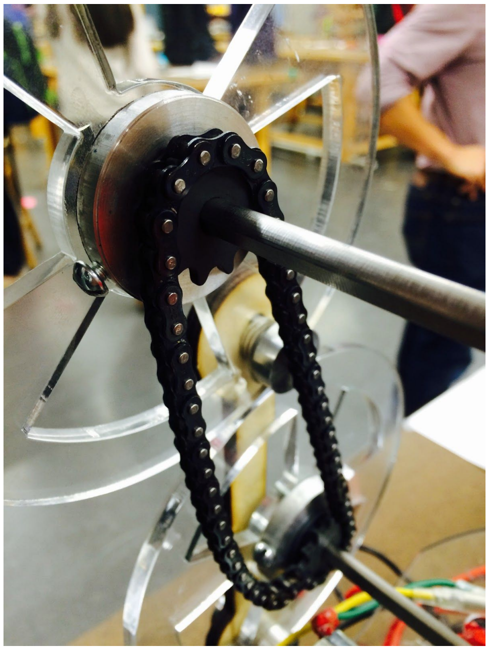
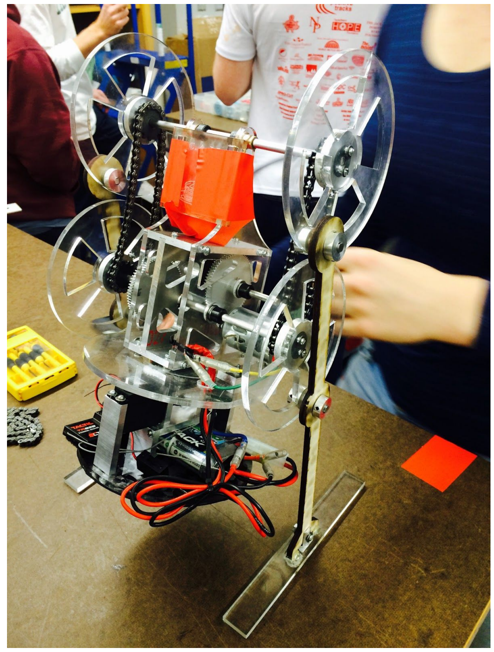
The machine performed as expected during the demonstration. It completed a single lap of the course, going through the hard maze and bypassing the other obstacles. While it generally functioned as predicted, there were a few difficulties. Firstly, the vehicle fell over three times getting on and off of the obstacles (something that could have been remedied with more practice running the machine). The vehicle was not as fast as expected, partially because of these falls, and partially because it wobbled when a certain speed was reached, limiting the rate at which it could complete the obstacles.

Controls

Our machine only had four directions to go: forward, backward, left, and right, meaning that in theory its movement was very simple. The turning itself was touchier than expected, but that was just a function of the sensitivity of the servos and not of the actual construction of the vehicle. While the controls were easy to understand it certainly took practice to drive our robot well.

Notable Issues

Chain tensioning was never satisfactorily resolved, though we experimented with sprockets and zip ties to improve the condition--when the chain did slip, the machine was still able to walk in one direction. In practice, this led to the chain occasionally jumping, misaligning the legs and stalling the machine. This did not happen during the demonstration. Additionally, the center of mass in the direction parallel to the legs was imperfect, as predicted in SolidWorks, because the drive shaft needed to be centered. This did not appear to be a major impediment, but may have contributed to the tensioning problem, or explain why the machine was still able to walk in one direction when the chain slipped. Here are two photos of the robot and chain after the chain had jumped:

The turning mechanism also had limitations. The wires connecting the motor to the power could catch while the bottom plate was spinning, either because they were at the end of their rope, or because they got tangled. This would stall out the turning, and required the driver to take time to unwind the wires, effectively resetting the turning mechanism.

The last issue was tipping. There were several factors contributing to this. First, the center of mass was just high enough that it affected the vehicle's stability, even on flat ground. Second, every time the chassis came into contact with the ground, there was a sizable impact because of the mass of the vehicle, which caused bouncing instead of a clean landing. Third, at top speed the vehicle seemed to find resonant frequency in the rocking motion it used to move forward, and the longer it walked, the more it rocked, until it finally fell over of its own accord. Because it's so compounded, solving this problem would probably require a more in-depth analysis, and potentially a more extreme design change.

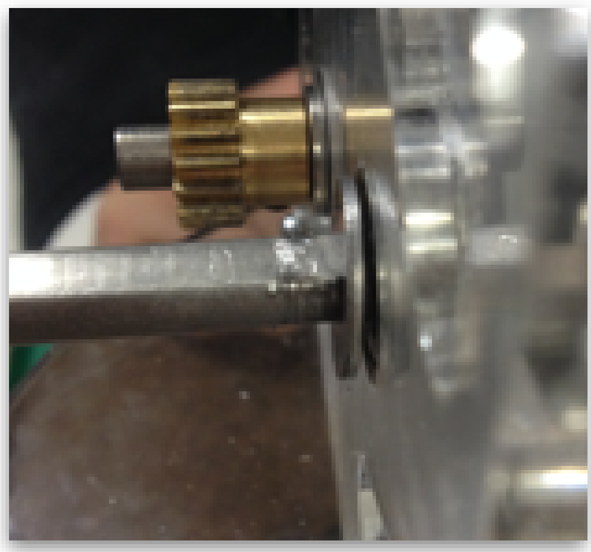
Future Considerations

In the future, the vehicle could be improved to handle more of the obstacles. Adding stilts or changing the center of mass would allow the vehicle to navigate the peg forest, while an external support system (for instance, a rod that prevents the vehicle from falling over backwards) or lowering the center of mass during the the lifting motion could allow the robot to do the teeter-totter. If the legs could be linked to rotate over the robot, it may be possible to use them as an arm to get over the wall--we certainly have enough torque from the gear box. This might entail adding servos to help articulate the legs. Lastly, it would be really cool if we could paint the robot and have it play "Eye of the Tiger" during competition, and possibly shoot confetti.

Comparison to Previous Analysis

Analysis was primarily based on hand calculations with a little help from SolidWorks to acquire mass information. Our analysis used large factors of safety, so it underpredicted our vehicle's performance. We had more torque and speed from the drive motor than expected. Another piece of analysis that went wrong was the ability to do the peg forest. We thought we made our machine wide enough to pass through the hard way, but we could never find a place to rest our base that would keep the robot upright. Because we could not complete the peg forest we shortened the legs to help stabilize the robot. Our turning radius for the maze was as expected, because we designed our robot especially for the maze and made sure we could turn within the 10" wide channels. Our gearbox worked as planned, was extremely reliable, and provided more than enough torque and speed.

Potential Improvements to Analysis



There was a combination of bad assumptions and missing analysis that could've improved the vehicle's performance. Most of our invalid assumptions related to the hardware involved in building the robot. We never considered that this aspect of building might not function exactly how we assumed it would. As a result we had issues with screws falling out, set screws shearing, wires being stripped, and a general loosening of assemblies while we walked. There were also a few complications with kit parts not being exactly as expected from the description. For example, the driveshafts were not actually hardened, causing them to deform under the pressure of the set screws (see above).

This could've been avoided by taking some time to consider the role hardware plays, and by doing a materials analysis on hardware in high stress locations on the robot. Increased materials analysis would have improved performance and expedited building by preventing breakages and iteration. Taking the time to do the material strength analysis could have greatly reduced or eliminated that process, and would have given us a better idea of the force path moving through our vehicle. This deeper understanding of the walking mechanism could have helped us pinpoint problem areas much more specifically.

As mentioned above, one of the other big issues we had was the wobble that happened when the robot walked. This was problematic for two reasons. One, it caused tipping and falling. Two, because our rate of travel calculation didn't take it into account, we moved much slower than we expected. We could have mitigated this by doing a motion study in SolidWorks which may have alerted us to this issue before building, and given us the time to make some design modifications to reduce or remove the wobble before competition, which would've sped up our moment and removed the falling issue.

Conclusion

We are proud of the work we have done and the robot we created. Our design process was detailed, explorative, lengthy, and collaborative. From this process we fabricated a working machine that met our expectations in some areas and blew us away in others. Thank you for this learning experience and adding the challenge of "no wheels," as it pushed us to be creative and "think outside the box." Without this challenge we would never have ended up building a robot that looks like a stack of pancakes and moves like a gorilla.

APPENDIX I: Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	The Lazy Flapjack	Robot	1
1.1	Chassis	Base structure of robot	1
1.1.a	¼" Acrylic Base		1
1.1.b	¼" Acrylic Top		1
1.1.c	Battery		1
1.1.d	Continuous Rotation Servo		2
1.1.e	Plastic 32p, 64t, .1875 acetal gear		1
1.1.f	1/4" Ball Bearing		2
1.1.g	Servo Gear		2
1.1.j	¼ " Steel Shaft		1
	¼" Shaft Collar		2
1.1.k	Aluminum Servo Plate		1
1.1.l	Tall Aluminum Servo Spacer		2
1.1.m	Short Aluminum Servo Spacer		2
1.1.n	Aluminum Battery Housing Top		1
1.1.o	Aluminum Battery Housing Sidewall		2
	Red Servo Gear Spacer		1
	Wire Extension		2
	Y-Split Cable		1
1.1.r	4-40 x ½ " RHMS		24
1.1.s	4-40 Lock Washer		16

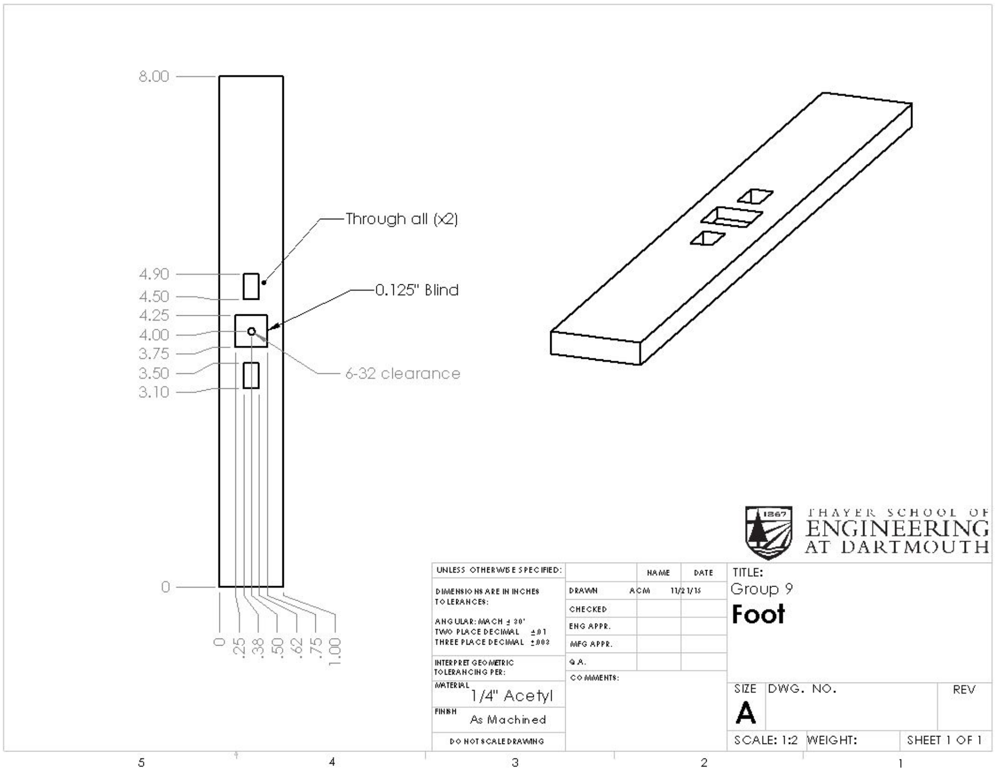
1.1.t	Battery Heat Sink		1
1.1.u	Tactic Receiver		1
1.1.v	Velcro		1
1.1.w	Neoprene Padding		1
1.1.x	RC Car Tire		2
1.1.y	Nylon Cable Ties, Small		2
	Super Glue Packets		3
1.2	Gearbox		1
1.2.a	Base Plate		1
1.2.b	Sidewall 1		1
1.2.c	Sidewall 2		1
1.2.d	Sidewall 3		1
1.2.e	Ball bearings		6
1.2.f	Axle 1		1
1.2.g	Axle 2		1
1.2.h	Axle 3		1
1.2.i	Gear (10, metal)		1
1.2.j	Gear (16, metal)		1
1.2.k	Gear (16, plastic)		1
1.2.l	Gear (64, metal)		1
1.2.m	Gear (72, metal)		2
1.2.n	1/4" washers		22
1.2.o	1/4" shaft collars		3
1.2.p	Mabuchi motor		1
1.2.r	Top plate		1

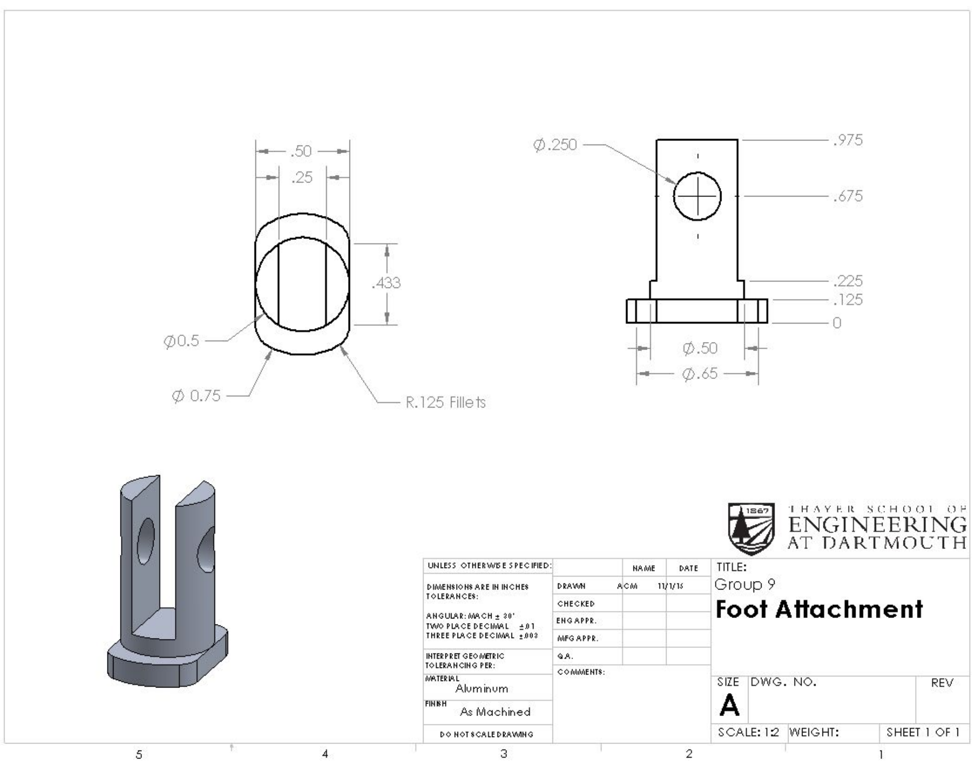
1.2.s	Motor support wall		1
1.2.t	Motor support wall base		1
	Sidewall support wall		1
1.2.u	RHMS 4-40 x 1/2”		8
1.2.v	RHMS 4-40 x 1/4”		6
1.2.w	RHMS 4-40 x 3/4”		6
1.2.x	Hex Nuts 4-40		6
1.2.y	ISO m3x0.5		2
1.2.z	lockwashers 4-40		14
1.2.aa	Set screws 3/32 x 1/8"		4
1.2.ab	Set screws 4-40 x 1/4”		2
1.2.ac	Set screws 1/16"		2
1.3	Leg Assembly		2
1.3.a	Top Link Wheel	Linkage	1
	Bottom Link Wheel		1
1.3.b	6-32 Screw, ½”		1
	6-32 Washer		2
	6-32 Nut		1
	¼” Steel Shaft, 1 ⅜”		2
1.3.c	¼ " Shaft Collar		4
	Sprocket Collar		2
	8-32 Set Screw		2
1.3.d	¼ " Washer		8
	4-40 Washer		6
	4-40 Lock Washer		4

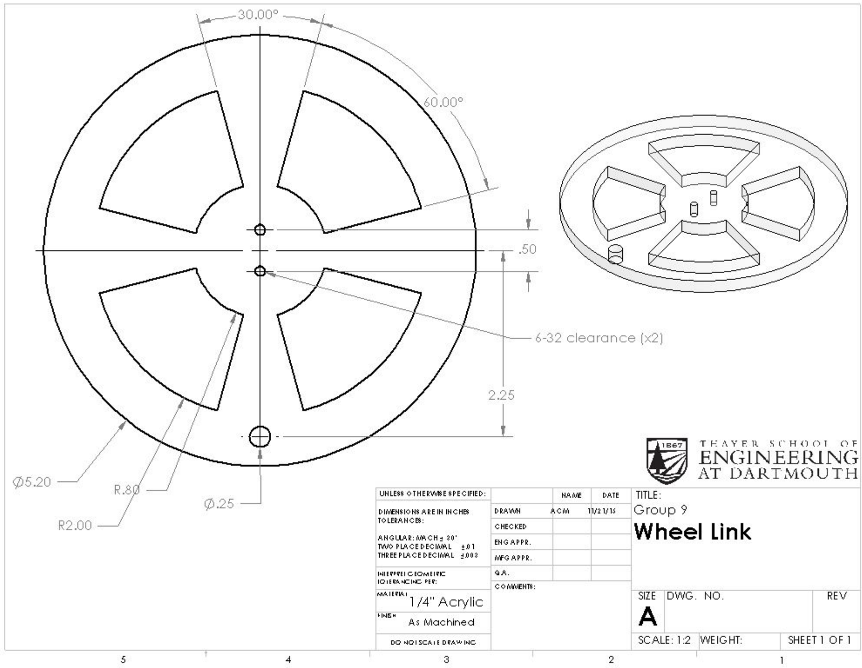
1.3.e	Leg Plate	Length of the leg	1
1.3.g	Foot Grip	Attaches the foot to the leg rod	1
1.3.h	Foot Base	Main part of the foot	1
1.3.k	13t Sprocket		2
	11t Sprocket		2
1.3.l	4-40 Screw, 0.5"		8
1.3.m	4-40 Set Screw, 0.25"		8
1.3.n	6-32 Screw, 0.75"		2
1.3.o	4-40 Lock Washer		2
1.3.p	Chain, 24"		1
	Rubber Band		2
1.4	Assembly Hardware		1
	4-40 Screw, .25”	Attach Gearbox to Top Plate of chassis	4
	4-40 Hex Nut		4
	4-40 Lock Washer		4
	4-40 Washer		16
	¼” Bushing	Hold top drive shaft in acrylic plate	2
	¼” Shaft Collar	Hold top drive shaft in place	2
Raw Materials			
	1/8" Acrylic		52 sq. in.
	1/4" Acrylic		67 sq. in.
	1/8" Aluminum Plate		2.5 sq. in.

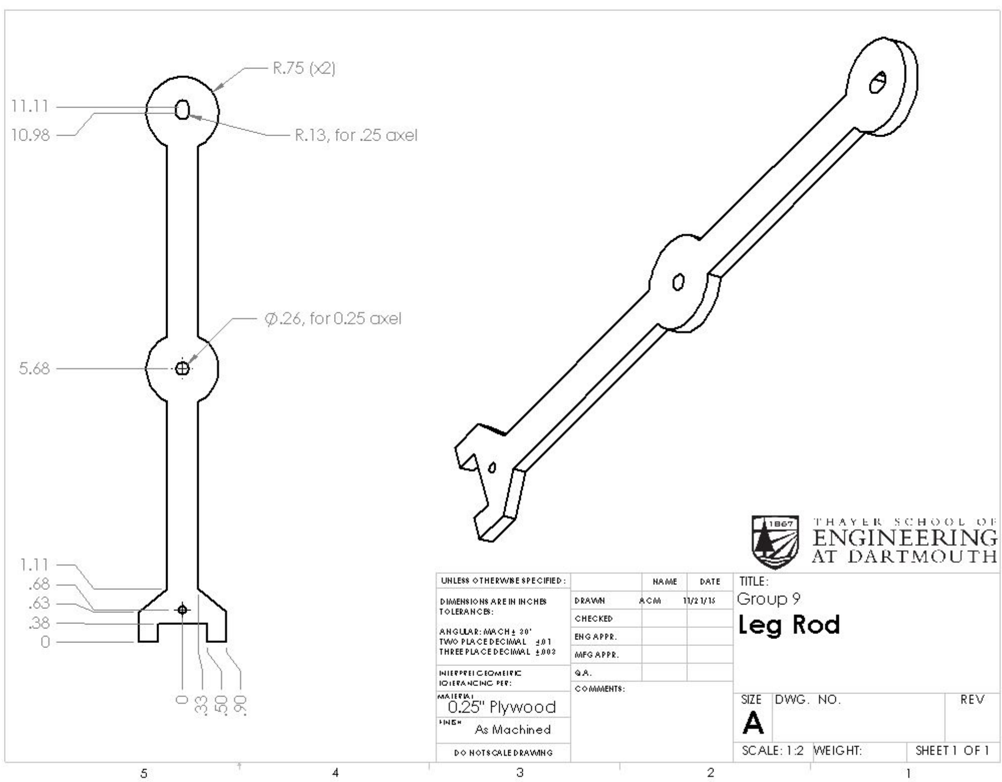
	1/4" Aluminum Plate		50 sq. in.
	Hardened Steel Rod		22 in.
	3/4" Aluminum Rod		9 in

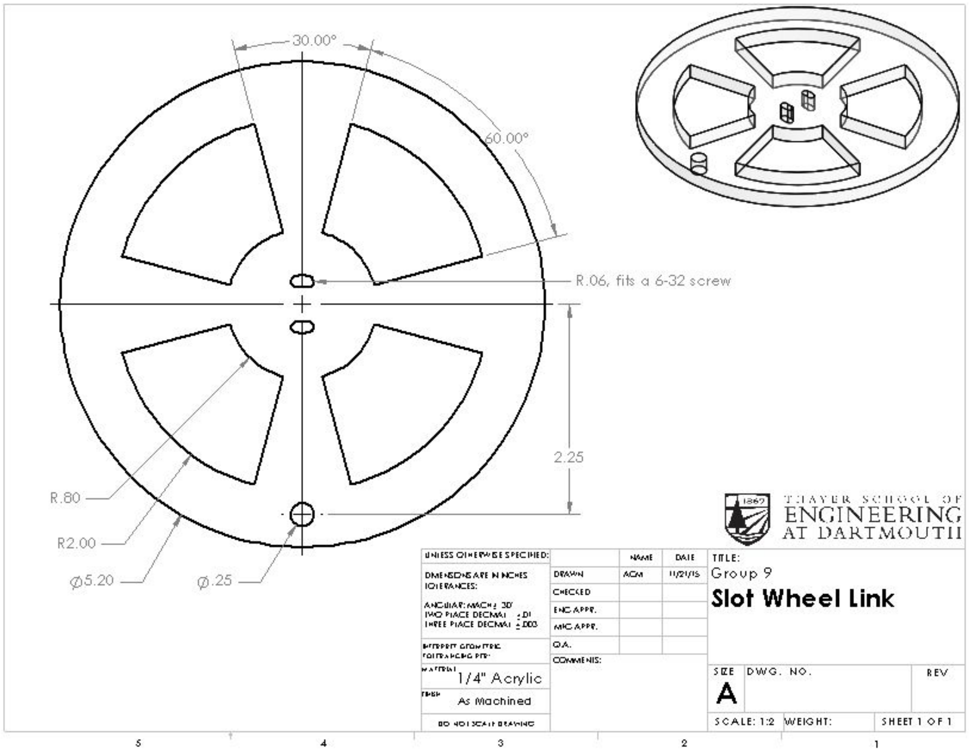
APPENDIX II: Final Drawings

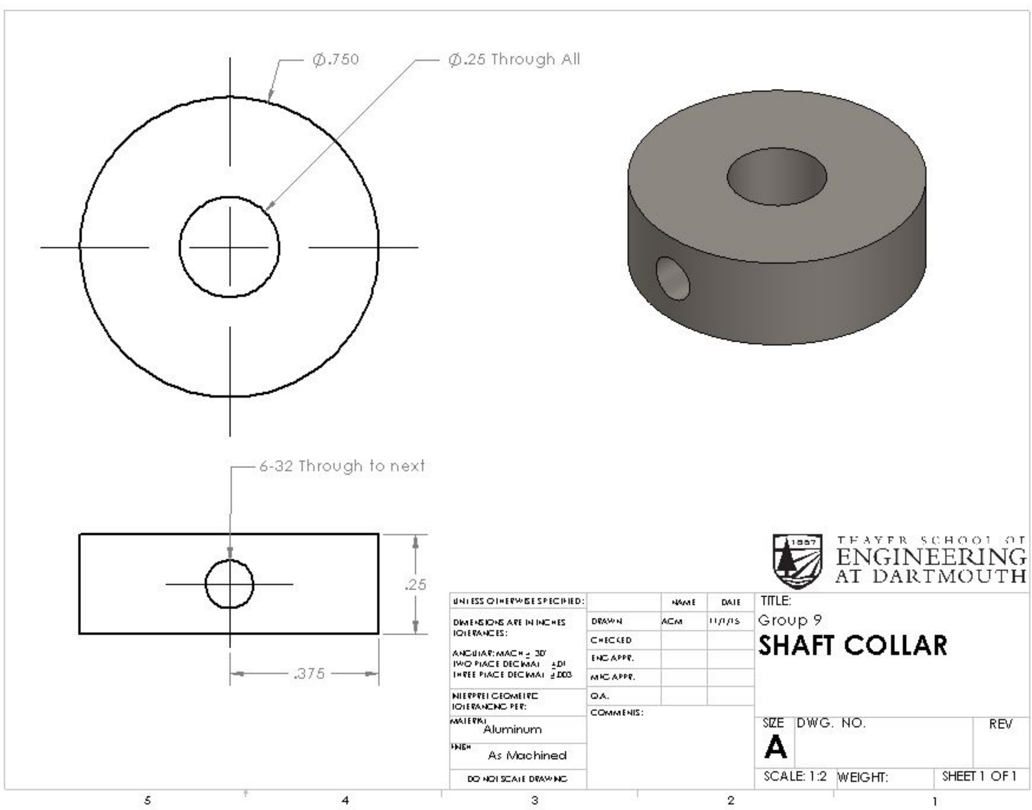


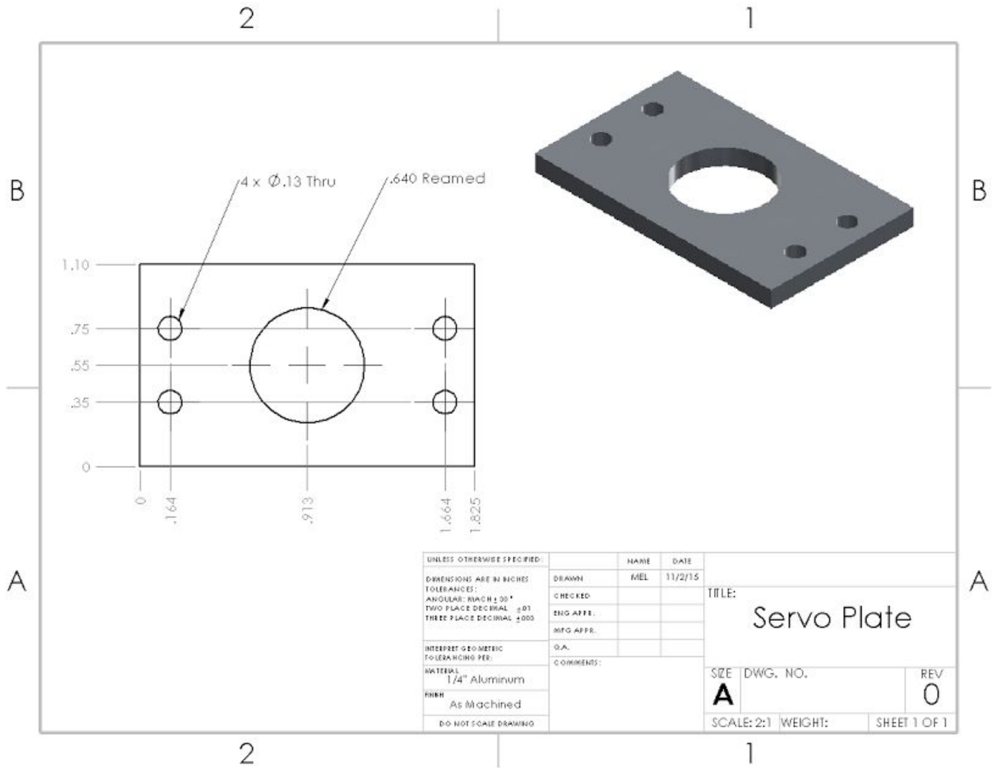


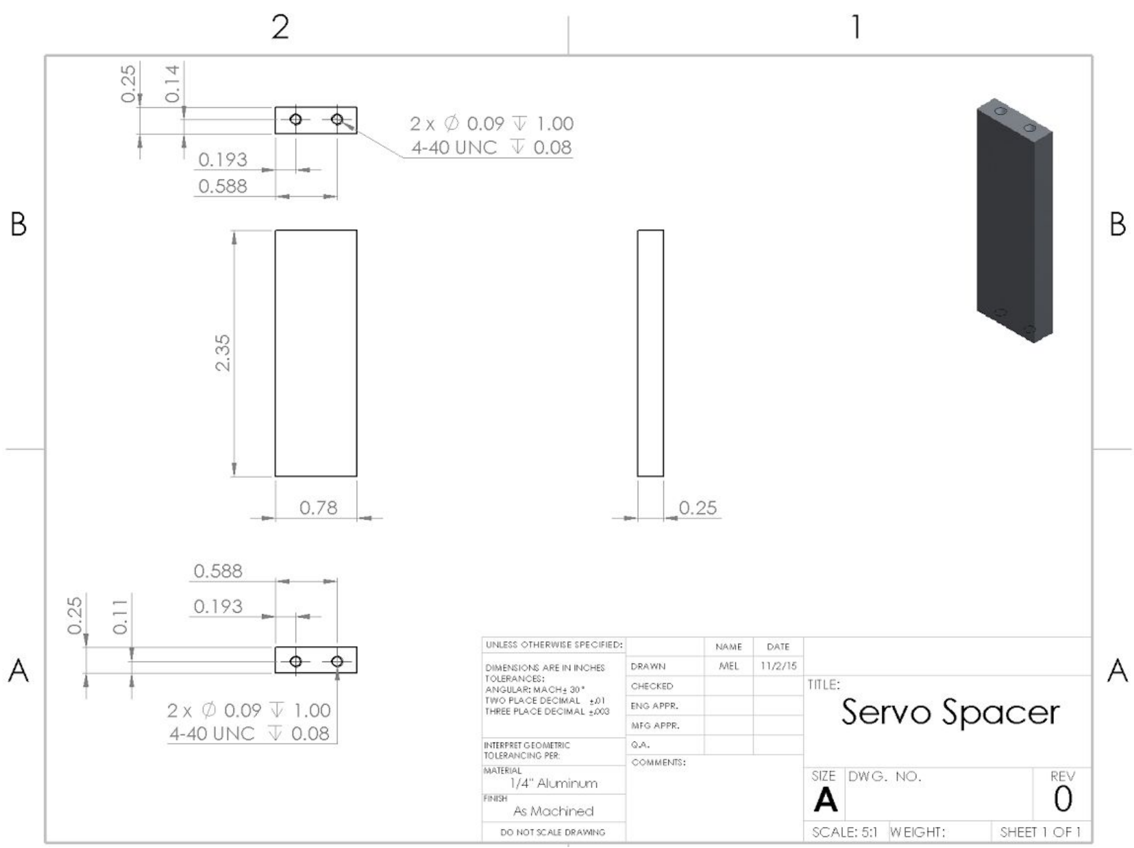

30.00°
60.00°
.50
6-32 clearance (x2)
2.25
Ø5.20
R.80
Ø.25
R2.00
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 1/4" Acrylic
FINISH As Machined
DO NOT SCALE DRAWING
NAME DATE
DRAWN ACM 11/21/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Group 9
Wheel Link
SIZE A DWG. NO. REV
SCALE: 1:2 WEIGHT: SHEET 1 OF 1
5
4
3
2
1

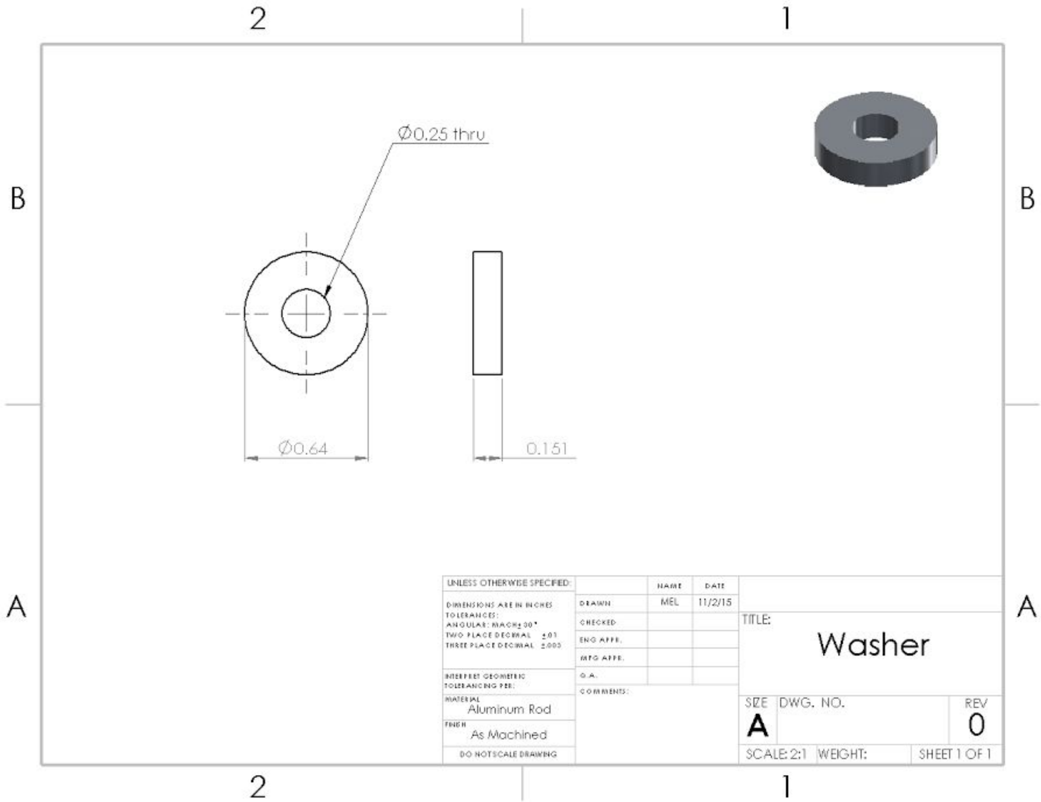

R.75 (x2)
11.11
10.98
R.13, for .25 axel
Ø.26, for 0.25 axel
5.68
1.11
.68
.63
.38
0
0
.33
.50
.90
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 0.25" Plywood
FINISH As Machined
DO NOT SCALE DRAWING
NAME DATE
DRAWN ACM 11/21/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Group 9
Leg Rod
SIZE A DWG. NO. REV
SCALE: 1:2 WEIGHT: SHEET 1 OF 1
5
4
3
2
1

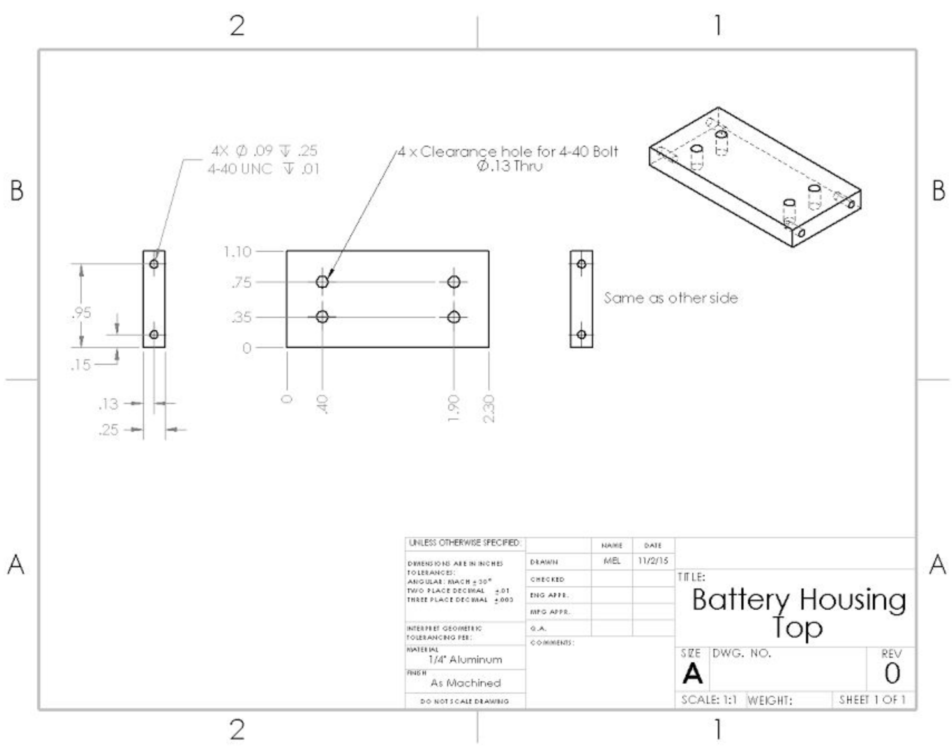

30.00°
60.00°
R.06, fits a 6-32 screw
2.25
R.80
R2.00
∅5.20
∅.25
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ACM
TITLE:
Group 9
Slot Wheel Link
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
1/4" Acrylic
As Machined
SIZE
DWG. NO.
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

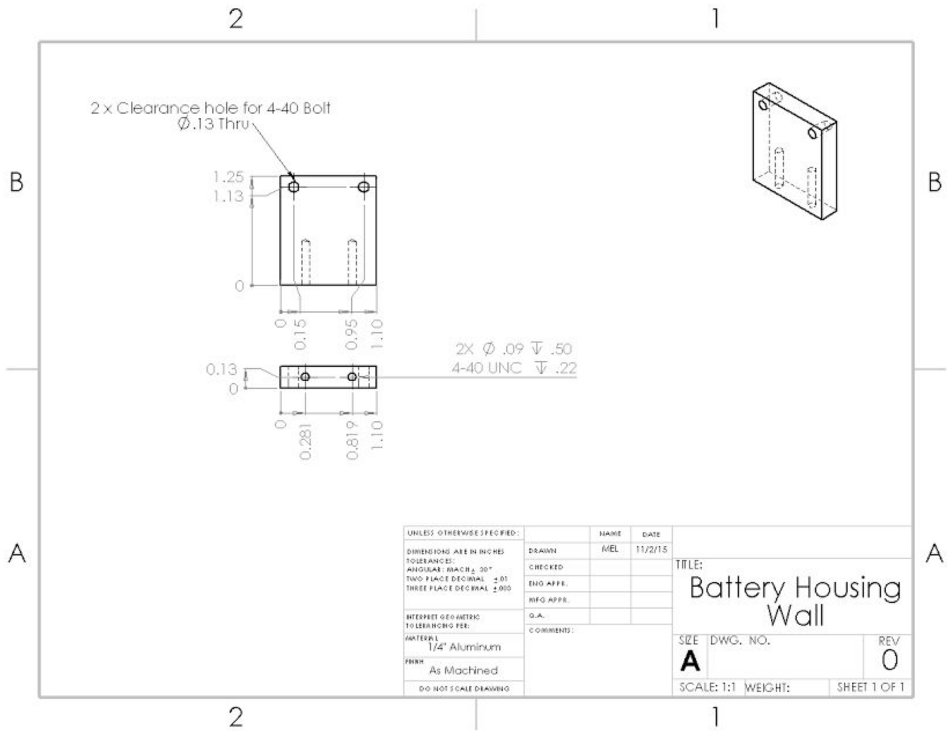

∅.750
∅.25 Through All
6-32 Through to next
.25
.375
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ACM
TITLE:
Group 9
SHAFT COLLAR
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Aluminum
As Machined
SIZE
DWG. NO.
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

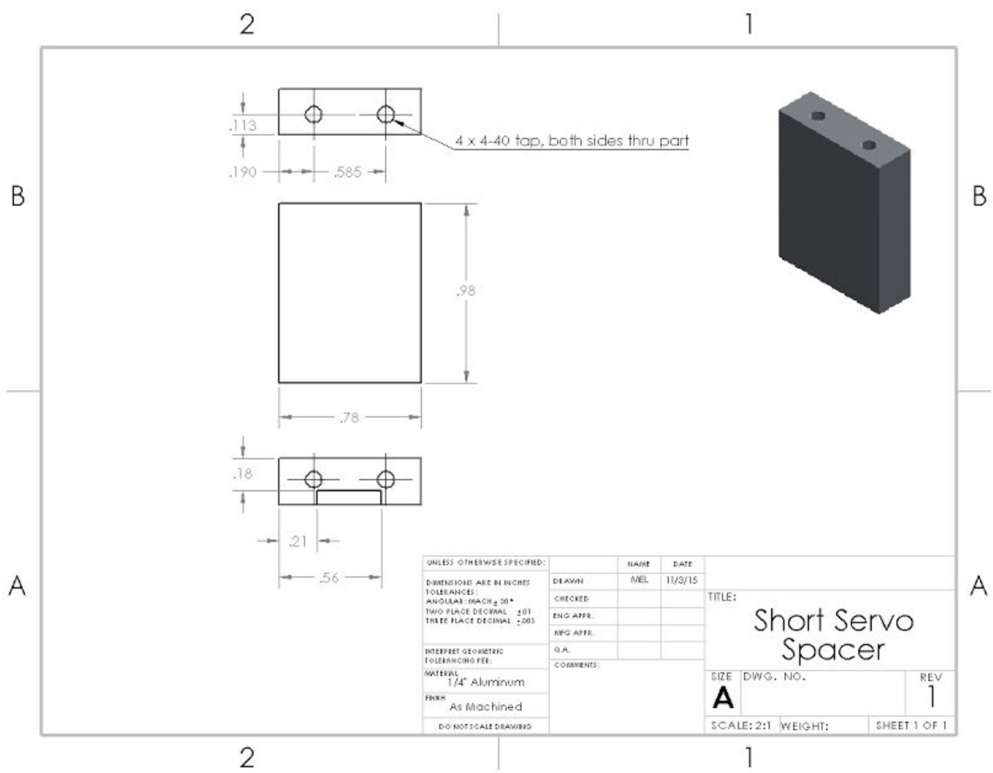

4 x Ø.13 Thru
.640 Reamed
1.10
.75
.55
.35
0
0
.164
.913
1.664
1.825
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
MEL
11/2/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
1/4" Aluminum
FINISH
As Machined
DO NOT SCALE DRAWING
TITLE:
Servo Plate
SIZE
A
DWG. NO.
REV
0
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

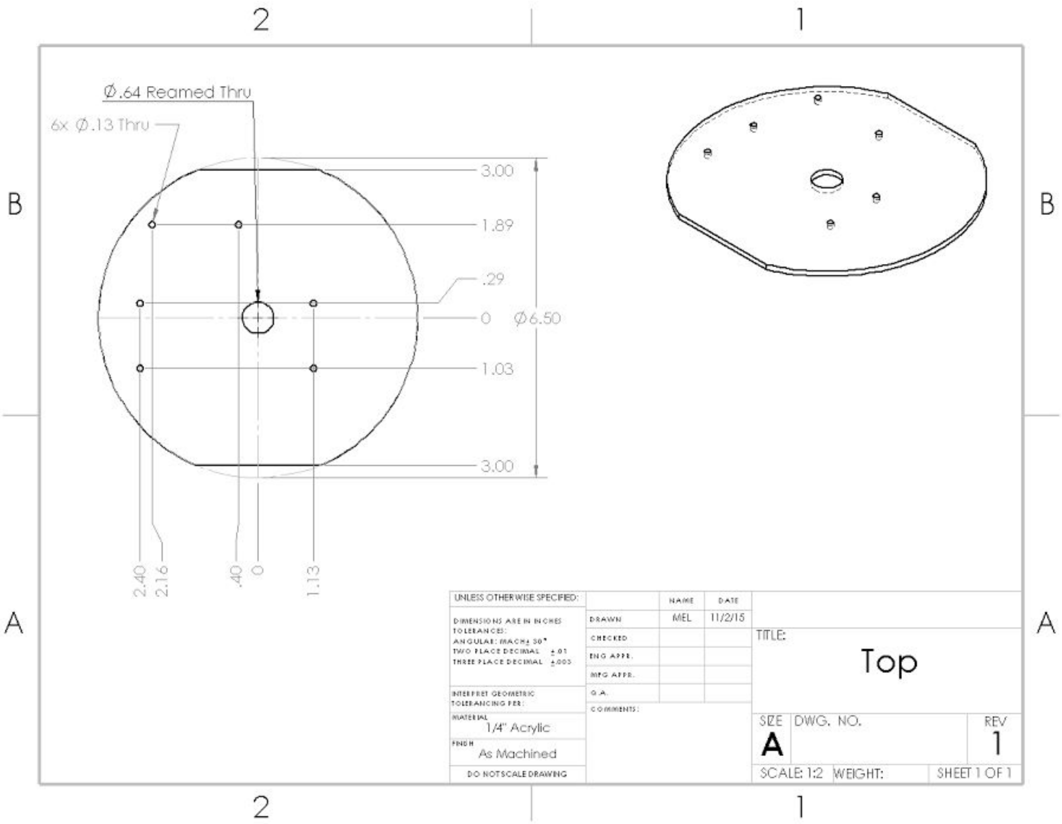

0.25
0.14
0.193
0.588
2 x Ø 0.09 ↧ 1.00
4-40 UNC ↧ 0.08
2.35
0.78
0.25
0.588
0.193
0.25
0.11
2 x Ø 0.09 ↧ 1.00
4-40 UNC ↧ 0.08
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC TOLERANCING PER:
NAME
DATE
DRAWN
MEL
11/2/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
1/4" Aluminum
FINISH
As Machined
DO NOT SCALE DRAWING
TITLE:
Servo Spacer
SIZE
A
DWG. NO.
REV
0
SCALE: 5:1
WEIGHT:
SHEET 1 OF 1


Ø0.25 thru
Ø0.64
0.151
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±30°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum Rod
FINISH
As Machined
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MEL
11/2/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Washer
SIZE
A
DWG. NO.
REV
0
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

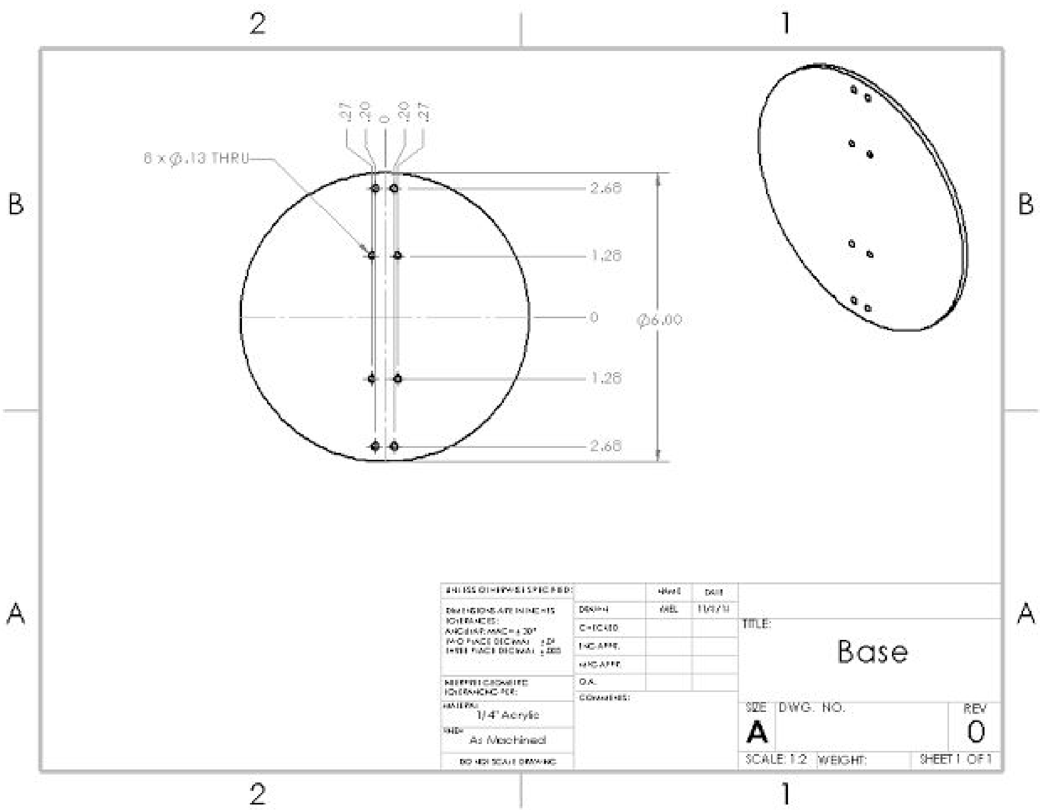

4X Ø .09 ↧ .25
4-40 UNC ↧ .01
4 x Clearance hole for 4-40 Bolt
Ø.13 Thru
Same as other side
1.10
.75
.35
0
.95
.15
.13
.25
0
.40
1.90
2.30
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±30°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/4" Aluminum
FINISH
As Machined
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MEL
11/2/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Battery Housing Top
SIZE
A
DWG. NO.
REV
0
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


2 x Clearance hole for 4-40 Bolt
Ø.13 Thru
2X Ø .09 ↧ .50
4-40 UNC ↧ .22
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 1/4" Aluminum
FINISH As Machined
DO NOT SCALE DRAWING
DRAWN MEL 11/2/15
TITLE: Battery Housing Wall
SIZE A
REV 0
SCALE: 1:1
SHEET 1 OF 1

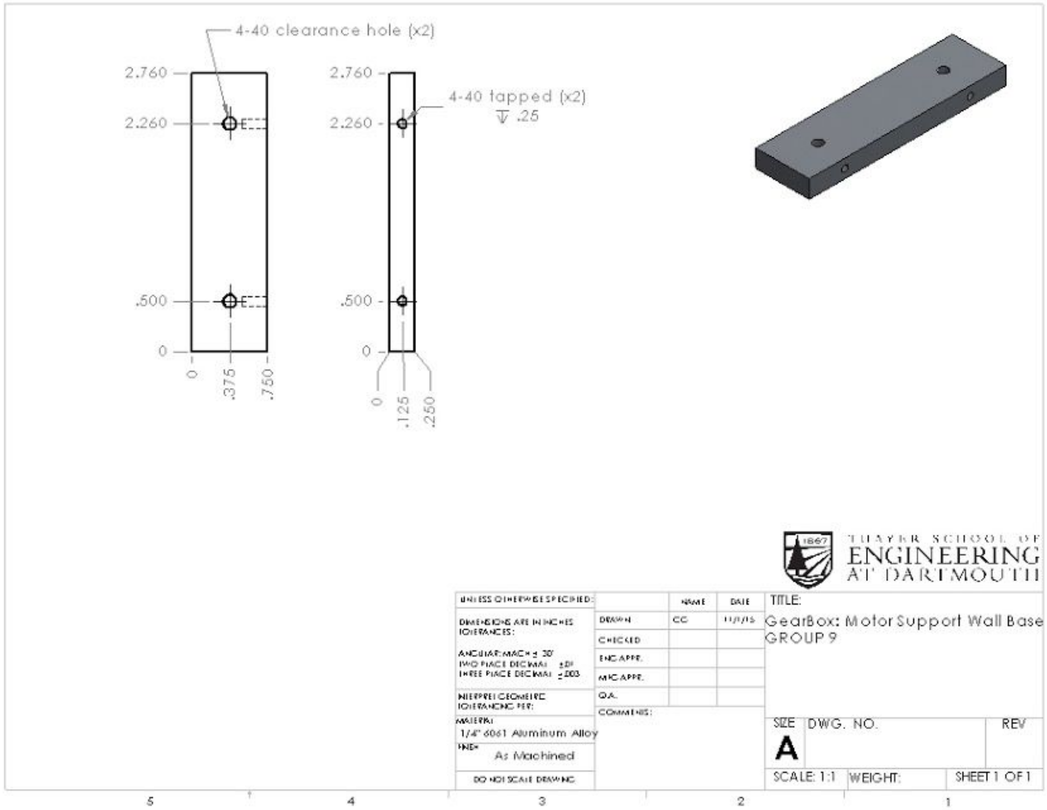

4 x 4-40 tap, both sides thru part
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 1/4" Aluminum
FINISH As Machined
DO NOT SCALE DRAWING
DRAWN MEL 11/3/15
TITLE: Short Servo Spacer
SIZE A
REV 1
SCALE: 2:1
SHEET 1 OF 1

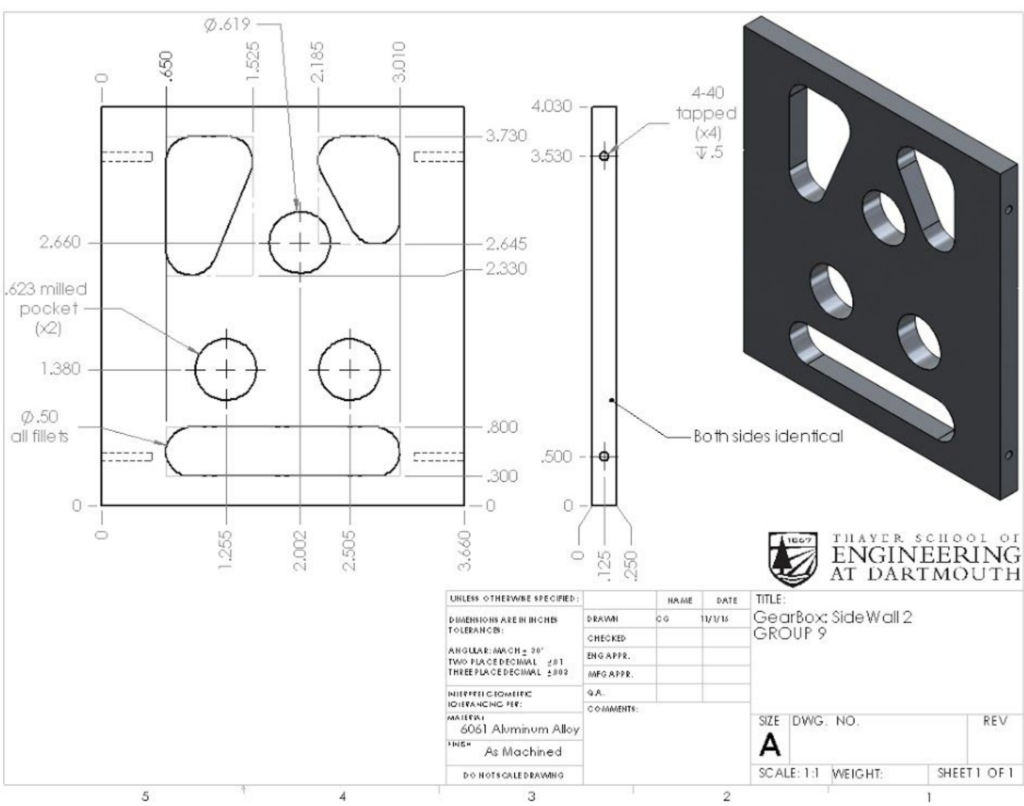


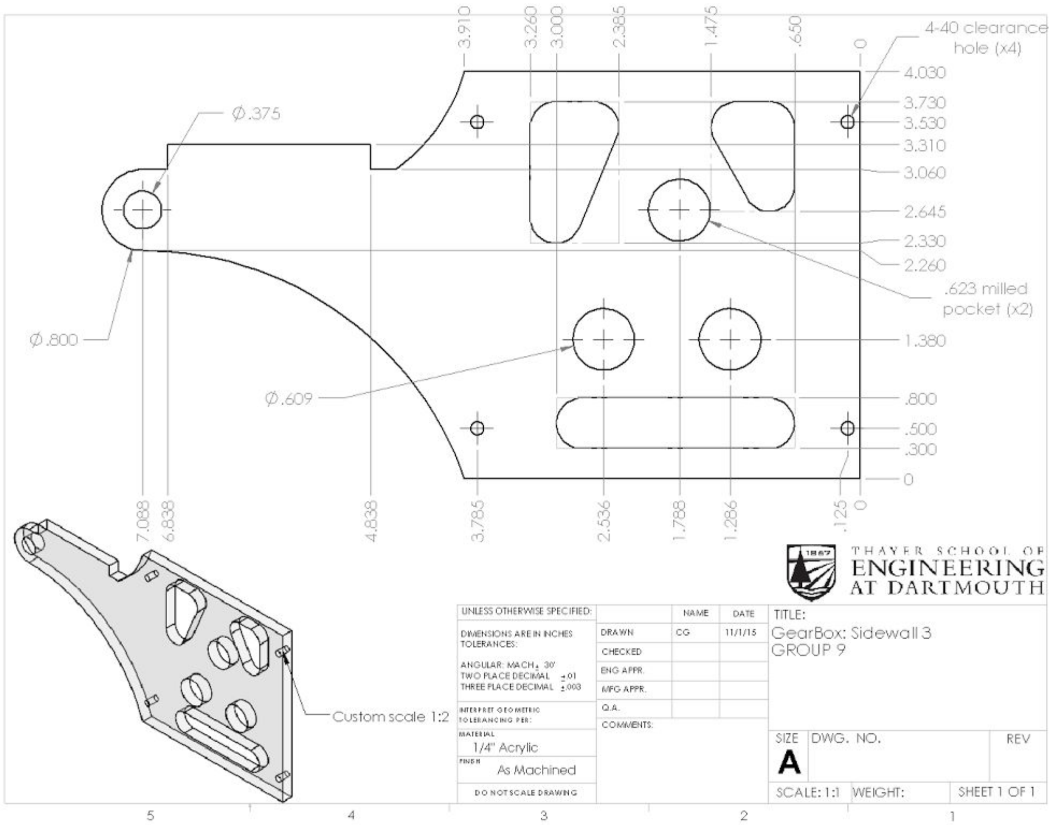
Ø.64 Reamed Thru
6x Ø.13 Thru
3.00
1.89
.29
0
Ø6.50
1.03
3.00
2.40
2.16
.40
0
1.13
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH± 30°
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
1/4" Acrylic
FINISH
As Machined
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MEL
11/2/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Top
SIZE
DWG. NO.
REV
A
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

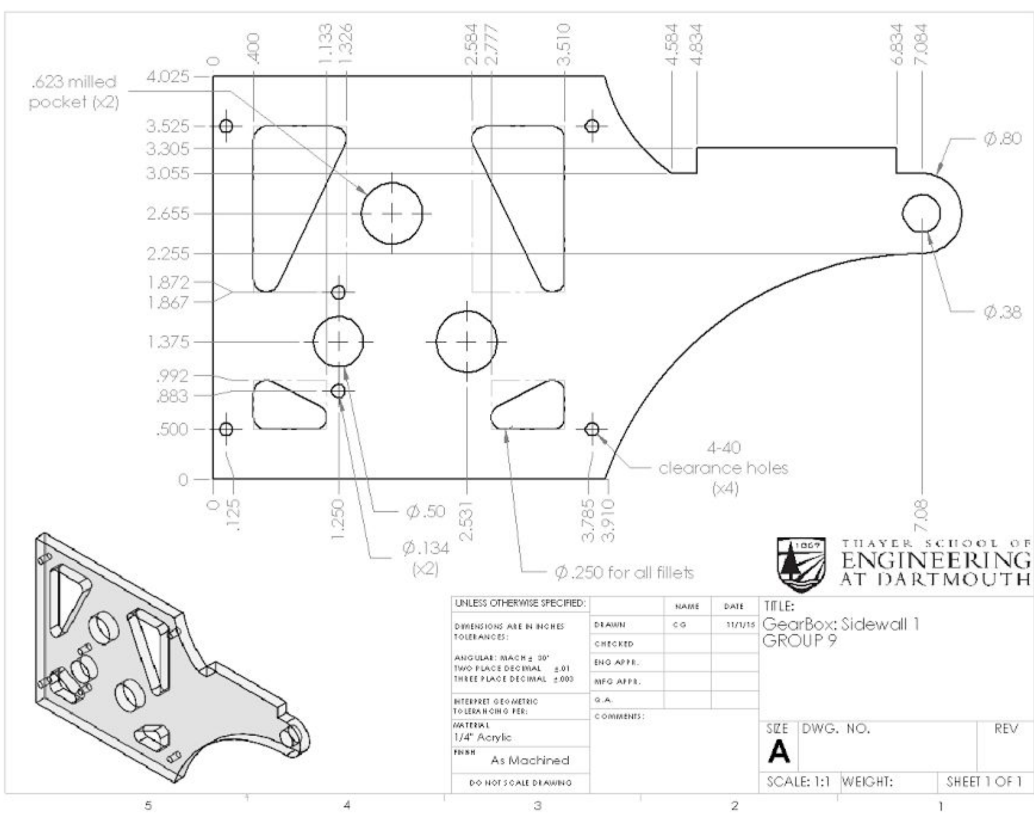


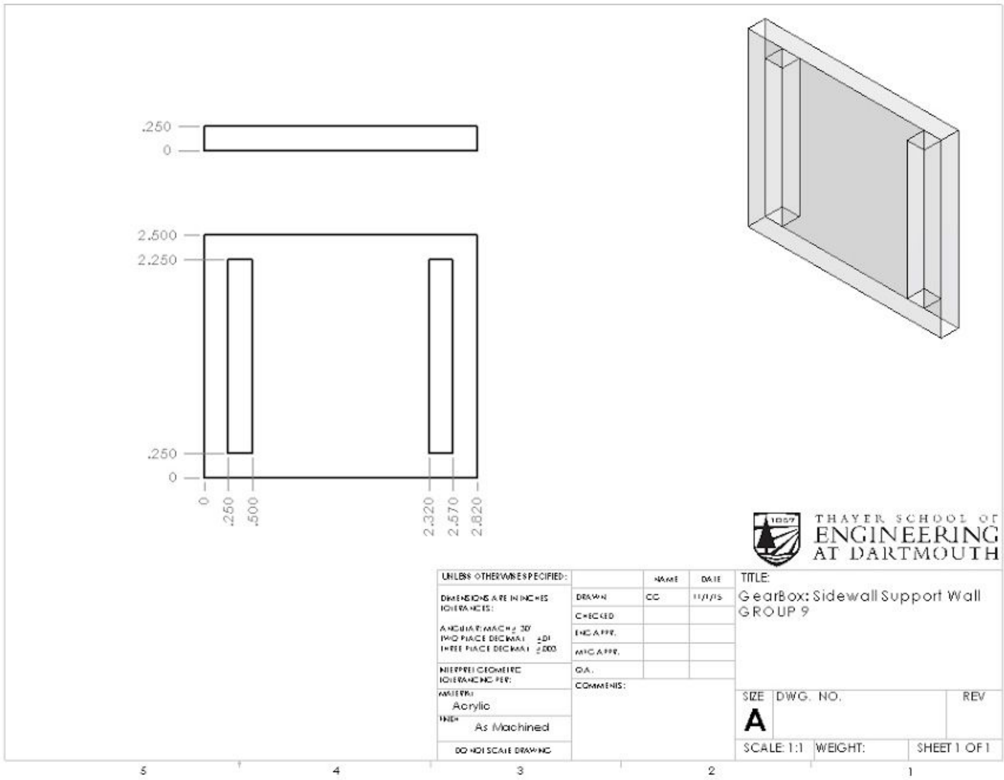
.27
.20
0
.20
.27
8 x Ø.13 THRU
2.68
1.26
0
Ø6.00
1.26
2.68
NAME
DATE
DRAWN
MEL
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
1/4" Acrylic
FINISH
As Machined
TITLE:
Base
SIZE
DWG. NO.
REV
A
0
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

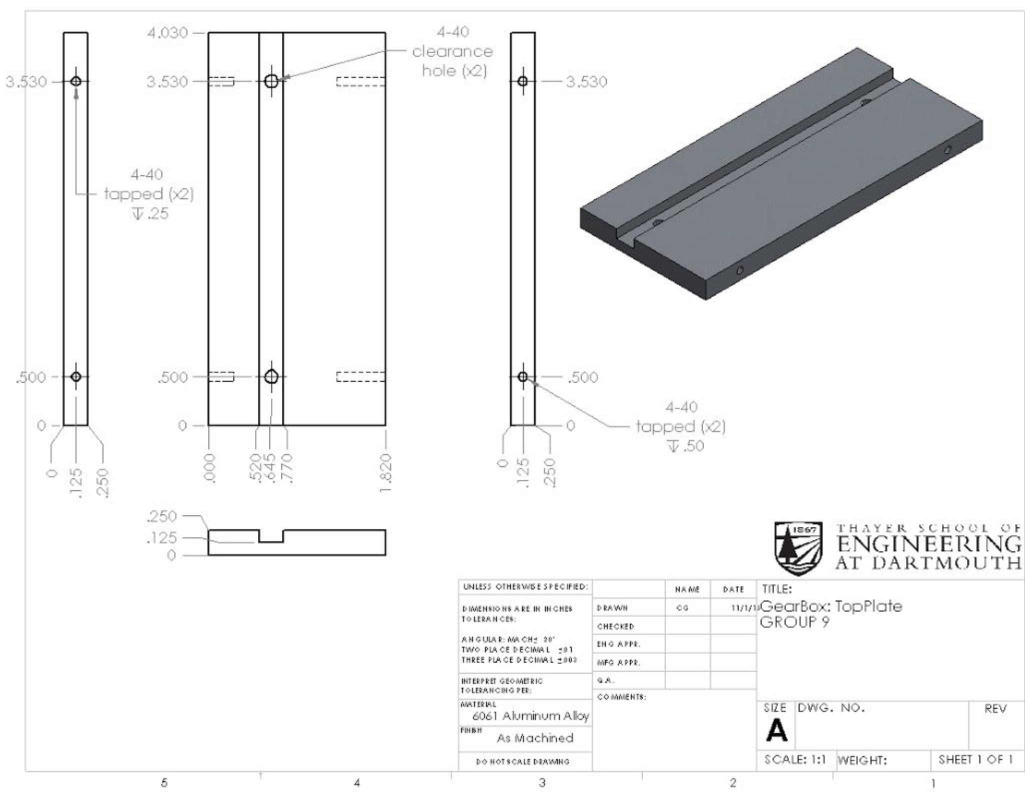

4-40 clearance hole (x2)
4-40 tapped (x2)
∇ .25
2.760
2.260
.500
0
.375
.750
.125
.250
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
TITLE:
GearBox: Motor Support Wall Base
GROUP 9
MATERIAL
1/4" 6061 Aluminum Alloy
FINISH
As Machined
DO NOT SCALE DRAWING
SIZE DWG. NO. REV
A
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

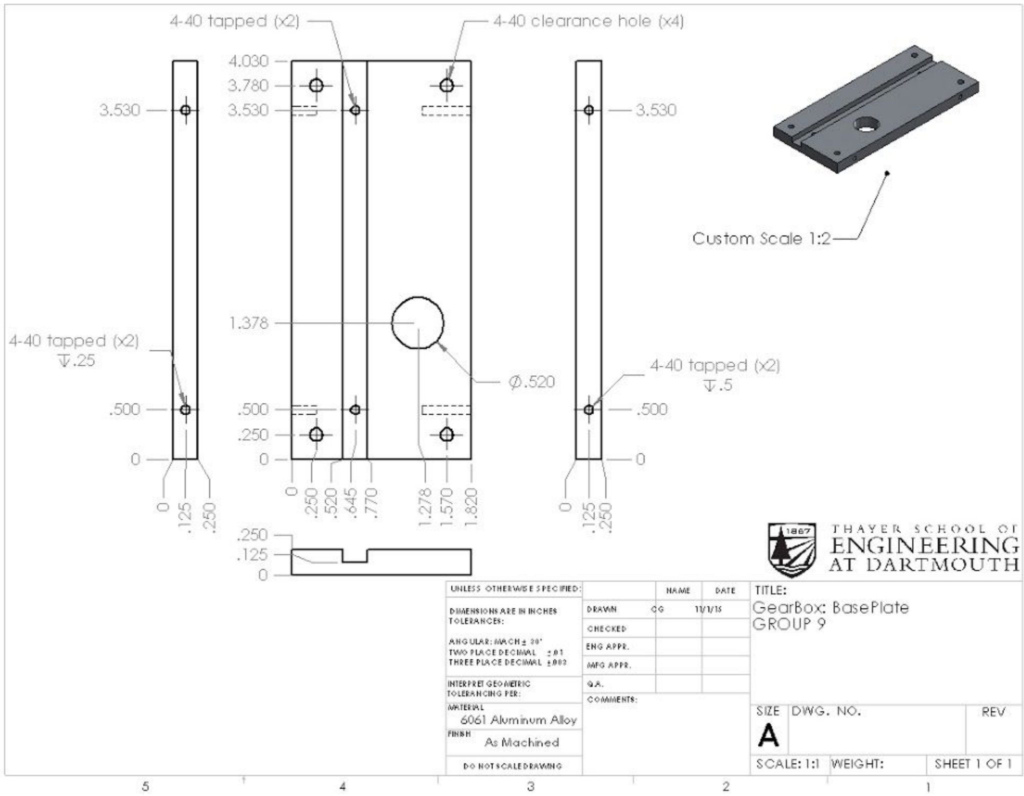

Ø.619
0
.650
1.525
2.185
3.010
4-40
tapped
(x4)
∇.5
4.030
3.730
3.530
2.660
2.645
2.330
.623 milled
pocket
(x2)
1.380
Ø.50
all fillets
.800
.500
.300
Both sides identical
0
1.255
2.002
2.505
3.660
.125
.250
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
TITLE:
GearBox: Side Wall 2
GROUP 9
MATERIAL
6061 Aluminum Alloy
FINISH
As Machined
DO NOT SCALE DRAWING
SIZE DWG. NO. REV
A
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

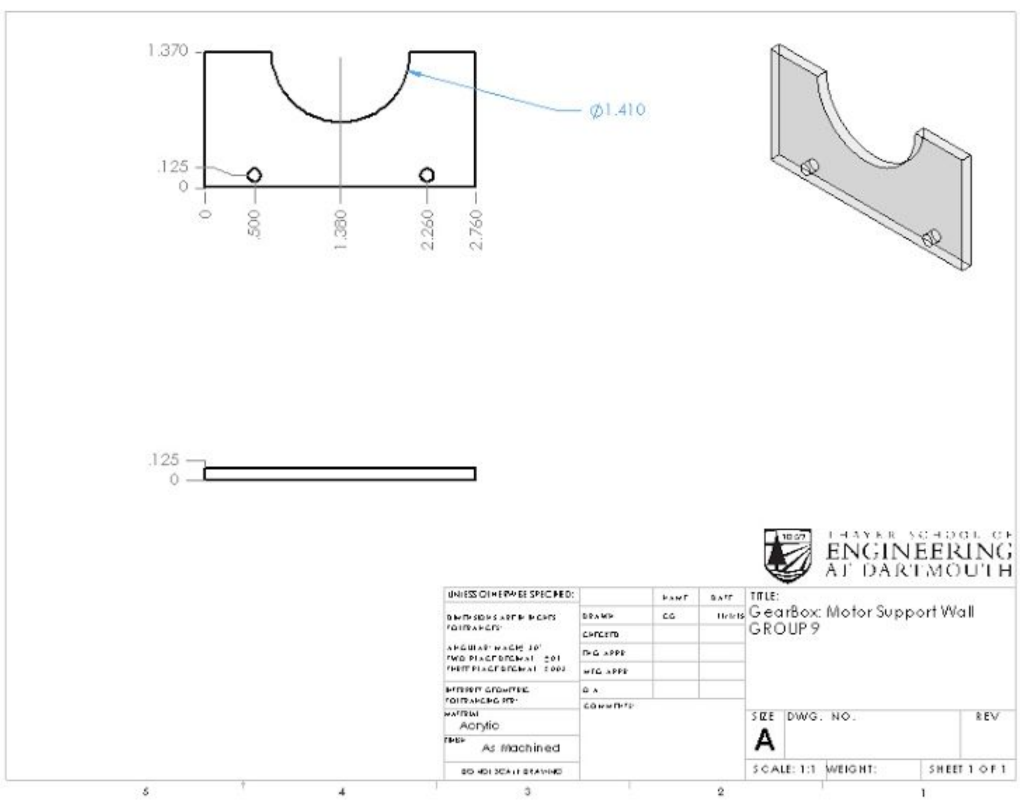

4-40 clearance hole (x4)
Ø.375
Ø.800
Ø.609
.623 milled pocket (x2)
Custom scale 1:2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
MATERIAL
1/4" Acrylic
FINISH
As Machined
DO NOT SCALE DRAWING
DRAWN CG 11/1/15
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
TITLE:
GearBox: Sidewall 3
GROUP 9
SIZE A
SCALE: 1:1
SHEET 1 OF 1


.623 milled pocket (x2)
Ø.80
Ø.38
Ø.50
Ø.134 (x2)
Ø.250 for all fillets
4-40 clearance holes (x4)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.003
MATERIAL
1/4" Acrylic
FINISH
As Machined
DO NOT SCALE DRAWING
DRAWN CG 11/1/15
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
TITLE:
GearBox: Sidewall 1
GROUP 9
SIZE A
SCALE: 1:1
SHEET 1 OF 1


THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CG
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Acrylic
FINISH
As Machined
DO NOT SCALE DRAWING
TITLE:
GearBox: Sidewall Support Wall
GROUP 9
SIZE
DWG. NO.
REV
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


4-40 clearance hole (x2)
4-40 tapped (x2) ⩛ .25
4-40 tapped (x2) ⩛ .50
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
DRAWN
CG
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061 Aluminum Alloy
FINISH
As Machined
DO NOT SCALE DRAWING
TITLE:
GearBox: TopPlate
GROUP 9
SIZE
DWG. NO.
REV
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


4-40 tapped (x2)
4-40 clearance hole (x4)
4.030
3.780
3.530
1.378
Ø.520
4-40 tapped (x2)
↧.25
4-40 tapped (x2)
↧.5
.500
.250
0
.125
1.278
1.570
1.820
.520
.645
.770
Custom Scale 1:2
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum Alloy
FINISH
As Machined
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CG
11/1/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
GearBox: BasePlate
GROUP 9
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


1.370
Ø1.410
.125
0
.500
1.380
2.260
2.760
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH
UNLESS OTHERWISE SPECIFIED:
MATERIAL
Acrylic
FINISH
As Machined
DRAWN
CG
TITLE:
GearBox: Motor Support Wall
GROUP 9
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1