Team 1: Gear Pong

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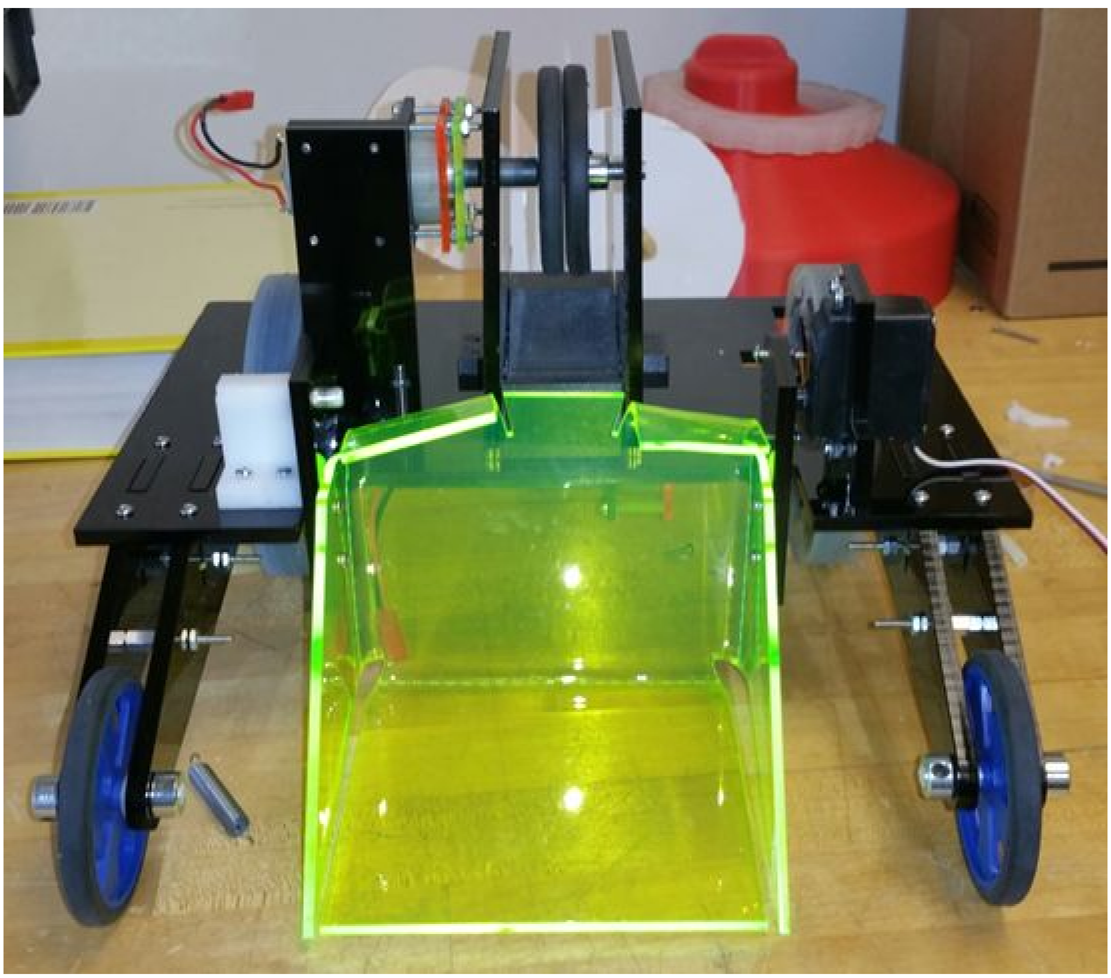
ES51
May 3, 2017

Picture of Final Design:
PewPew 3000



Abstract

Our team set out to build a robot that could traverse the Turf Wars competition arena and score as many points as possible in three minutes. Our main goal in designing our robot was to minimize trips up the ramp and to score as possible balls at a time as possible. This led to our final design, inspired by a baseball pitching machine, which scoops up balls and feeds them into a spinning flywheel that launches the balls into the 5-point hole. The final design utilized a two-wheel drive propulsion system with two additional, smaller front wheels for stability. Ultimately, our robot conquered the course, using its shooting wheel to pitch balls into the top hole successfully. The final competition saw Gear Pong place 2nd out of 10 teams in a double-elimination tournament for which we were seeded 2nd place with 100 points scored in three minutes.

Concept Development

To accomplish our goal of a winning robot, a large variety of factors had to be taken into account. Limited time and a set competition board were firm guidelines starting off, yet more specific requirements would guide our thinking the rest of the way. First of all, the team was limited to either two screwdriver motors and two Servos or three motors and one Servo, a guiding factor when discussing possible design configurations. An additional major design constraint was the allowed size of the robot. It was required to fit inside a 12 × 12 × 12 inch cube, preventing many simpler designs for achieving our goal of scoring in the top hole. Beyond these predominant restrictions, the materials available to build the robot were limited to only what was in our box and anything found in the ES51 Clubhouse. A list of given materials can be found in Appendix F.

The criteria we used in evaluating our potential designs were based largely on speed, maneuverability, balls per trip, and potential to score in the highest hole. We aimed to minimize trips up and down the ramp, which ultimately increases our speeds and number of rounds of our chosen technique. Also, limiting height, size overall, and weight were priorities, since a smaller vehicle would have increased speed and maneuverability. Lastly, a low center of gravity would increase stability and help the robot climb up the steep ramps. Our Pugh matrix helped us decide on our design going forward early on in the project. It specifically rated three different designs on speed, maneuverability, ball capacity, reliability, simplicity, and hoop height. The three designs considered were a Bulldozer (Appendix A), Claw and Arm system (Appendix B), and finally our Pitching Machine (Appendix C).

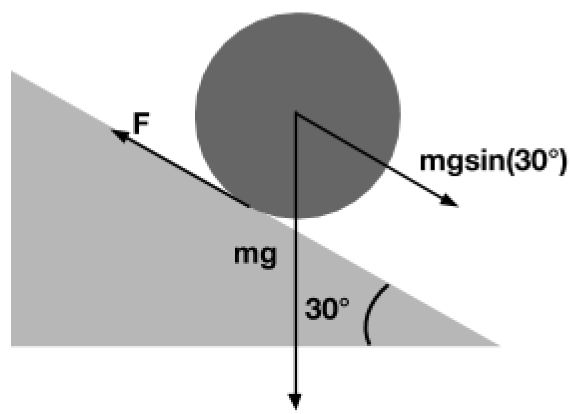
Pugh Matrix			
	Bulldozer	**Claw and Arm**	**Pitching Machine**
Speed	0	-1	1
Maneuverability	0	-1	1
Ball Capacity	-1	1	0
Reliability	1	-1	0
Simplicity	1	0	-1
Hoop Height	-1	0	1
Total	**0**	**-2**	**+2**
Rank	**2nd**	**3rd**	**1st**

(Figure 4 – Pugh Matrix from Design Review 1)

Analysis

Drivetrain Torque Calculations

How heavy can PewPew be while still able to climb the ramp?



Givens:

Gear Ratio of Gearbox = 243 : 1

$r_{wheel} = 2.25 \text{ in} = 57 \text{ mm}$

$\tau_{stall} = 0.0063 \text{ N} \cdot \text{m}$

Calculations:

$\tau_{max\ power} = \frac{\tau_{stall}}{2} = 0.0032 \text{ N} \cdot \text{m}$

$\tau_{output} = 243 \cdot \tau_{max\ power} = 0.77 \text{ N} \cdot \text{m}$

$F_{wheel} = \frac{\tau_{output}}{r_{wheel}} = \frac{0.77}{0.057} \text{ N} = 13.5 \text{ N}$ per gearbox

$F = 2 \cdot F_{wheel} = 27 \text{ N}$

$F = mg \sin(30°)$

$27 \text{ N} = m \cdot 9.8 \text{ m/s}^2 \cdot \sin(30°)$

$m = 5.5 \text{ kg}$

Conclusion:
With a safety factor of 1.5, the PewPew 3000 needs to weigh under 3.7 kg to climb the 30 degree ramp.

Shooter Wheel Calculations

Could we make a mechanism that can shoot a ball into a hole from the turf?

Givens:
The motor is rated for 13518 RPM, or and 0.012 $N \cdot m$ at maximum efficiency and 3.6 V.
The minimized gearbox has a gear ratio of 9:1.
The wheel radius is 1.3125 in, or 0.033 m.
A ping pong ball has a mass of 0.003 kg.

Calculations:
$\omega_{out} = \frac{1}{9} \cdot \omega_{in} = 1502\,\mathrm{RPM} = 157$ rad/s
$\tau_{out} = 9 \cdot \tau_{in} = 0.11\,\mathrm{N \cdot m}$
$v_{edge} = \omega r = 157\,\mathrm{rad/s} \cdot 0.033\,\mathrm{m} = 5.2$ m/s
$F_{edge} = \frac{\tau}{r} = 3.3$ N
$a = \frac{F}{m} = 1100\ \mathrm{m/s^2}$
$\Delta x = \frac{v^2}{2a} = 0.012$ m

Conclusion:
The wheel will spin with a surface velocity of around 5.2 m/s. To accelerate to that speed, the ball will need to travel 1.2 cm in contact with the wheel. With a safety factor of 1.5, we could reliably achieve 3.5 m/s, which gives a projectile around 0.4 m of vertical travel with a 45-degree launch angle. The shooter design is feasible.

Designing the Shooter

When we decided on designing a shooter mechanism to fire the ping pong balls in the hole, it was very unclear how the shooter would actually be implemented. Initial thoughts and inspirations led us to consider a two wheel pitching machine design, with one wheel on top and one on the bottom, driven by the same motor and a belt system. However, simple foam core prototypes showed the two wheel design would make our robot much taller than desired, raising our center of mass and decreasing our stability. We then decided to quickly test a prototype shooter with only one wheel firing against a flat surface. Preliminary tests showed that this redesign was very feasible and we would simply have to decide on a surface to use for the other side.

To accurately and consistently shoot, we designed a chute with side supports that only allowed one ball at a time to go through the shooter. As we could not find any good sources for single-flywheel ball launcher design, we made an educated guess for a chute with a circular profile that would give around of an inch of contact distance with the ball, keep the ball equidistant from the wheel center and the chute. This first 3D-printed chute performed the best, even with three more attempted redesigns and new chutes. For the flywheel itself, we used two servo wheels side-by-side in order to minimize the axial deflection and maximize contact area. Our initial estimates for appropriate spacing between the flywheel edge and chute based on the average diameter of a ping-pong ball resulted in insufficient force normal to the trajectory of the ball. To correct this we added three rubber bands to the shooter wheels, which increased contact time and frictional forces, created higher exit velocities. We found it necessary to use fishing line to secure the rubber bands in place on the wheels as well, since the outer edge of the wheel experienced something in the realm of 80g of centripetal acceleration. Overall, we were very impressed with the final design of our shooter and its consistency, as we were very uncertain of its feasibility in early rounds of design.

Conclusion:
Our shooter was able to consistently and accurately score balls in the top hole, although it was unfortunately necessary to go slightly up the ramp to aim because we could not find a chute design with a high enough launch angle.

Final Solution and Competition

The final design for the robot worked almost as well as expected. At max efficiency, we are able to fire 9 balls in rapid succession for 45 points in the span of less than 10 seconds. To score, we drive our robot into the pit, scoop between 5 and 9 balls using our heat-bent scooper, and then drive part-way up the steep ramp (30°) in order to fire into the 5-point. hole. In the competition, we placed 2nd overall. Our first round went incredibly well, with us scoring 270 points within three minutes, a team record. We also set a new record for the amount of balls we carried, 11 or 12, due to the large amount of balls on the field. However, as the competition progressed, scoring became much more difficult, We use our eyes as our aiming mechanism, so at times, it was difficult to aim properly. Also, we had to deal with opponent robots ramming into us and knocking us out of alignment, making proper aiming almost impossible to do. However, after a loss against Team No Doubt, we were able to climb up the Loser's Bracket and compete in a rematch. Luckily, we were able to secure victory the second time and proceed into the finals where we faced Team Rough Cut. During our rounds, we used our small robot to our advantage. With its speed, we were able to block Team Rough Cut from descending from their ramp for some time. We were able to narrowly secure the victory for the first round, but, unfortunately, we lost the second time with a difference of 4 balls in the 5-point hole. Barring the unexpected events that affected our robot such as wire disconnections and a faulty radio receiver, the PewPew 3000 performed as expected, and we are proud to have made it so far.

In terms of the criteria we set as a team, our robot performed very well. It was one of if not the fastest robot of the ten teams, so we were able to outmaneuver teams and impede movement if necessary. In terms of maneuverability, we were agile enough to turn on a dime, and we had incredible acceleration, but it was a bit difficult to control because of how powerful it is. Ball capacity was not as high as our other designs would have been per trip, but because of how fast it is, it was not too much of a problem. The maximum amount of balls PewPew could hold hold and fire reliably is 9. Even with its low ball capacity, the PewPew 3000 is proved to be a reliable design. It was durable, agile, fast, and very easy to score with. Durability was the biggest benefit. The acrylic we were provided with is surprisingly sturdy, so when unexpected things happened throughout the process (robot flipped over, one of us dropped it, the scooper getting caught on the field, etc), the robot stayed in one piece. Also, our robot weighed 2400 g, making us the lightest robot in the competition.

We are still unsatisfied with a few aspects of PewPew's performance and design. The idea behind the robot was to be able to score without needing to use the ramp as we waste time aiming in the competition. We were unable to design a proper ramp that would fire the balls high and far enough to score in the five-point hole without using the ramp. Through multiple firing tests, we were able to determine a few plausible causes for our problem:

1) When the balls feed into the wheel, they hit prematurely, causing them to bounce vertically while feeding through the ramp instead of rolling through.

2) We don't think the ramp was long enough and didn't have enough of an upward curve because the ball would shoot linearly.

3) The ramp and wheel did not provide an even time and length of contact with the ball, affecting its trajectory.

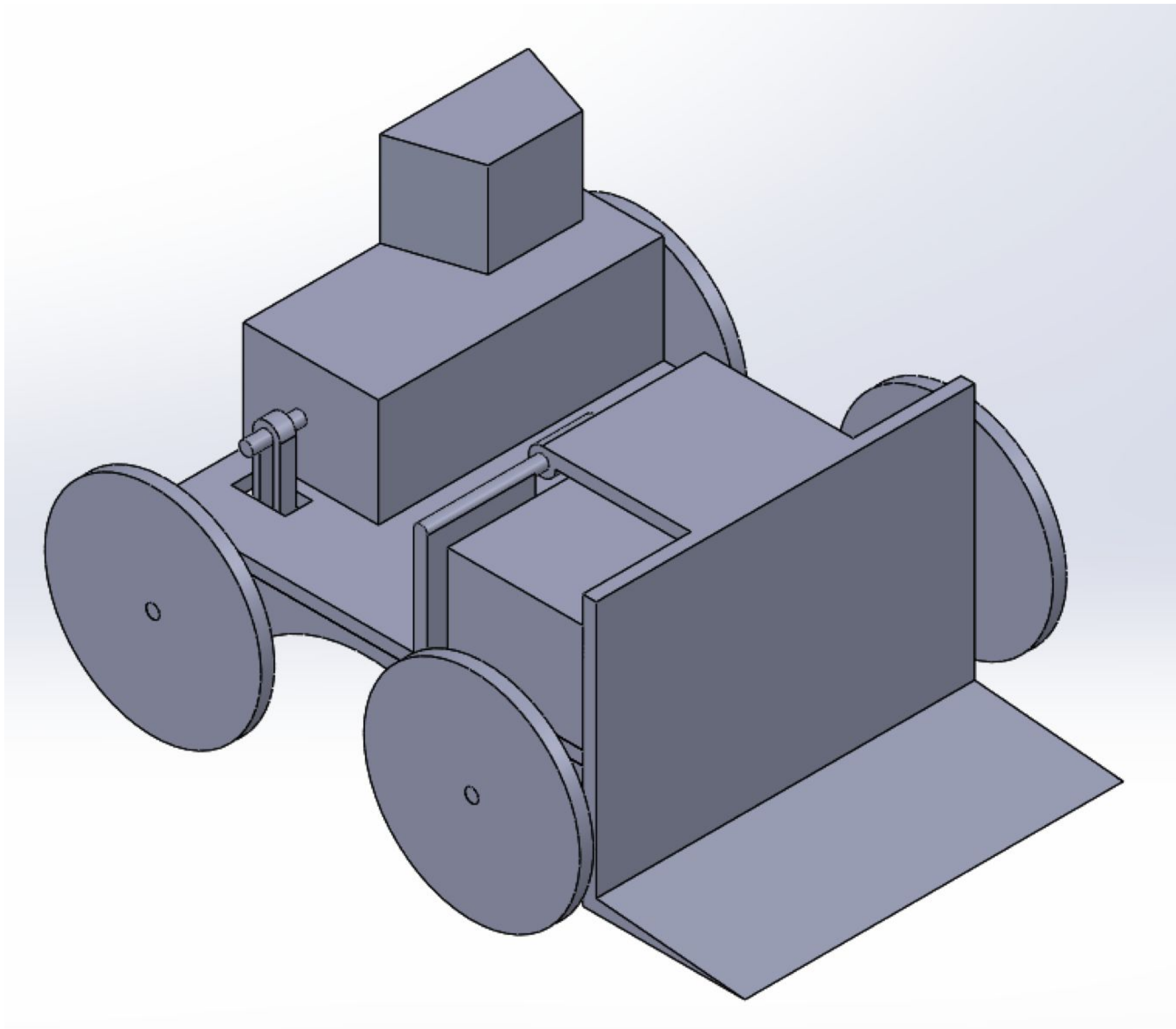
Even with numerous ramp reprints, we were not able to design a ramp that allowed us to shoot from the ball pit. Our robot's speed and lightweight are large advantages for us in the event of needing to tie the opposing team, but we are disadvantaged in that we have to use the ramp to score and that we have a much smaller ball capacity than other teams. If we had had more time, we would have focused on making the ideal ramp we wanted as well as making a ball storage system that could have stored a much larger amount of balls to where we could fire an incredible amount of balls with only one full run.

Final Design Specifications

Final Design Specifications	
Mass	2400 g
Length	11.83 in
Width	11.41 in
Height	7.72 in
Undercarriage Clearance	1.44 in
Turning Radius	0
Drivetrain Gear Ratio	243:1
Shooter Gear Ratio	9:1
Ball Carrying Capacity	12 balls
Average # Balls Scored in 3 minutes	33 balls
Highest Score	270 points

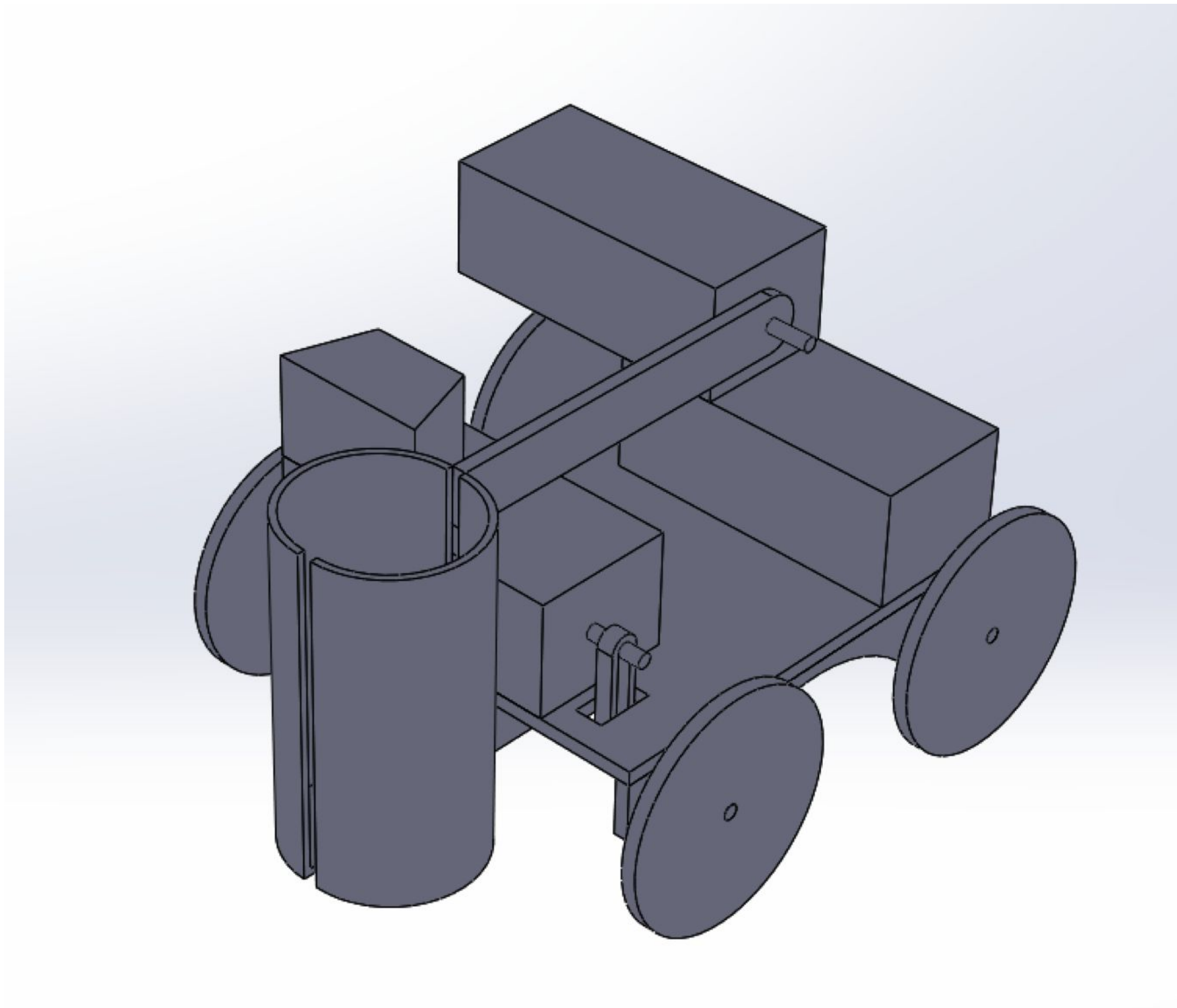
APPENDIX A

Early Bulldozer Design



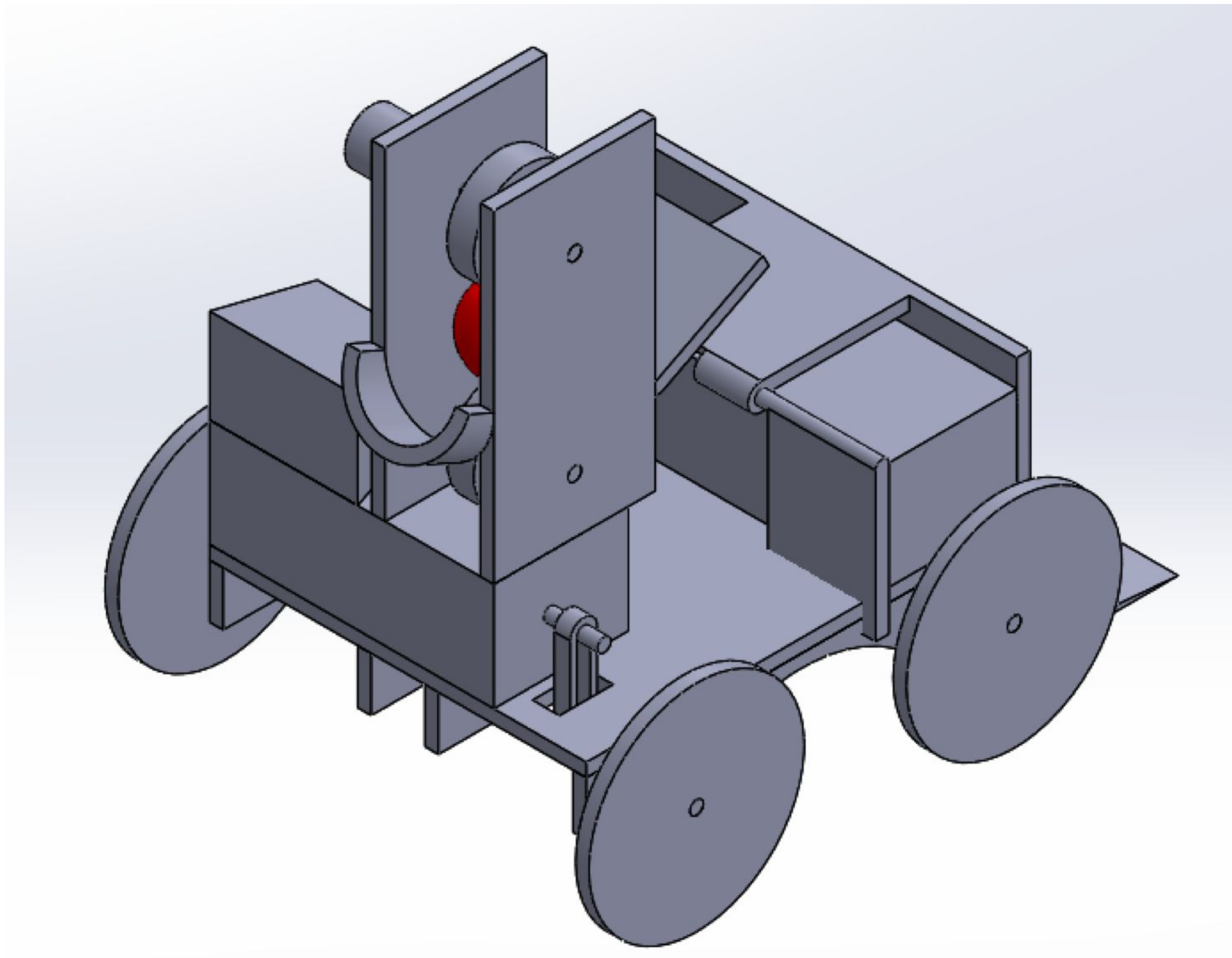
APPENDIX B

Early Claw and Arm Design



APPENDIX C

Early Pitching Machine Design



APPENDIX D

Bill of Materials			
ID. NO	PART NAME/NUMBER	Description	QTY.
1	Base Plate	Laser cut ¼” acrylic. Chassis of robot.	1
2	3D Printed Motor Mount	Holds DC Motors (ID No. 3) and allows them to be attached to other parts	3
3	DC Motor	4.8 V DC Motor for drivetrain and shooter mechanism	3
4	91801A135	M2.5 Flat Head Machine Screw, 6mm Length	6
5	94639A662		8
6	91772A115	4-40 Pan Head Machine Screw, 1” length	22
7	Lasercut Front Plate	⅛” laser-cut acrylic. Secures planetary gearbox to DC Motor (ID No. 3)	3
8	White Planetary Gear	Plastic ring gear for use in drivetrain planetary gearboxes. Holds two stages of planetary gears.	2
9	Metal Gear-Shaft Interface	Metal Circle with 6 Notches (from Drill Gearbox)	3
10	Hex Drive Shaft	From Drill Gearbox	3
11	91772A110	4-40 Pan Head Machine Screw, ½” Length	20
12	Delrin Support	For use in drivetrain. CNC milling and drill press	2
13	Hex to Round Axle	¼” steel hex rod turned, faced, and cut on lathe for use in drivetrain.	2
14	Lengthened Round Rod	Rear wheel axle in drivetrain.	2
15	95606A120	Nylon Washer ¼” ID	2
16	97431A300	E-Clip ¼” ID	2
17	gear, 16t, 32module	Drivetrain gear	2
18	gear, 48t, 32module	Drivetrain gear	2
19	Double Shaft Mount	Made from aluminum angle stock using bandsaw and drill press	2

20	Rear Wheel Threaded	Laser cut acrylic with tapped holes. Attaches to Rear Wheel Unthreaded (ID No. 23)	2
21	Rear Wheel Hub	Laser cut acrylic with tapped holes and hole for spring pin. Fixes rear wheels to axle (ID No. 14).	2
22	Silicone Tire	Mold-cast EcoFlex 00-50. Cast around and through wheels.	2
23	Rear Wheel Unthreaded	Laser cut acrylic. Attaches to Rear Wheel Threaded (ID No. 20)	2
24	91772A113	4-40 Pan Head Machine Screw, ¾" Length	8
25	Plastic Sleeve Bearing	Nylon Flange Bushing OD ⅜"	2
26	91771A112	4-40 Pan Head Machine Screw, ⅝" Length	6
27	91772A108	4-40 Pan Head Machine Screw, ⅜" Length	10
28	Servo Mount	Laser cut acrylic	1
29	Parallax 900-00008	Continuous rotation servo for moving scooper	1
30	Servo Adapter	Plastic x-shape in servo kit that allows parts to be attached to and moved by the servo motor	1
31	Scooper	Heat-bent laser-cut ⅛" acrylic	1
32	Scooper Attachment	Laser-cut ¼" acrylic. Attaches Scooper (ID No. 31) to Servo Adapter (ID No. 30)	1
33	Scooper Attachment Delrin Side	Laser-cut ¼" acrylic. Attaches Scooper (IDNo. 33) to the shaft in the Delrin Scooper Mount (ID No.34)	1
34	Delrin Scooper Mount	CNC milled Delrin with drilled hole. Holds the shaft about which the Scooper (ID No. 31) rotates.	1
35	Shooter Side Plate Motor Side	Laser-cut ¼" acrylic. Mounted to Base Plate (ID No. 1). Holds the shooter wheel shaft on the motor side of the mechanism.	1
36	Shooter Side Plate End Side	Laser-cut ¼" acrylic. Mounted to Base Plate (ID No. 1). Holds the shooter wheel shaft on the non-driven end of the shaft	1

37	Shooter Hex to Round	¼” steel hex rod turned on lathe for use in shooter mechanism.	1
38	Shooter Wheel	Plastic servo wheels broached to accept hex rods for use in shooter mechanism	2
39	Minimized White Planetary Gear	Plastic ring gear for use in shooter planetary gearbox. Holds on stage of planetary gears.	1
40	Shooter Motor Base Mount	Laser-cut ¼” acrylic. Attaches 3D Printed Motor Mount (ID No. 2) in shooter mechanism to Base Plate (ID No. 1)	1
41	Chute	ABS 3D-printed on Stratasys machine. Directs balls in shooter mechanism.	1
42	91841A005	4-40 Hex Nut	28
43	90107A005	No.4 Flat Washer	16
44	Lasercut Front Plate 2	Laser-cut ⅛” acrylic. Used in shooter mechanism to secure the Hex Drive Shaft (ID No. 10)	1
45	9414T6	Set Screw Shaft Collar	5
46	Front Leg	Laser-cut ¼” acrylic. Attaches Front Wheels (ID No. 50) to Base Plate (ID. No 1)	4
47	91115A164	4-40 hex standoff, ½” length, ¼” diameter.	4
48	Front Wheel Axle	Aluminum rod 1.5” length, ¼” diameter	2
49	Scooper Shaft	Aluminum rod 1.5” length, ¼” diameter	1
50	Front Wheel	Plastic servo wheel with ¼” hole drilled in center	2
51	91772A119	4-40 Pan Head Machine Screw, 1.5” Length	4

APPENDIX E

Time-Labor Report (Person hours)	
Conceptual Development	15
SolidWorks	50
Driving Practice	2
Report Writing	10
Milling	2.5
Drilling	9 + Jack
Turning	4 + Jack
Assembly	21
Repair and Redesign	15

APPENDIX F

Team Gear Pong's Turf Wars Kit Inventory	
Quantity in Kit	**Item Description**
2	Al Round Rod 1/4"OD x 24"L
2	Steel Hex Rod 1/4" x 1' L
2	Al Box Extrusion 1" x 1" x 18"L - 1/8 " T
2	Al Flat Rod 3/8" x 1/4" T x 24"L
1	Al Flat Rod 3/8" x 3/32" T x 24"L
1	Al Angle Iron 1" x "1 x 1/8"T x 18"L
1	Delrin Rod 1"OD x 6"L
1	Delrin Rod 0.5"OD x 6"L
2	Delrin Block 1.5" x 4" x 1"
*	Larger Delrin Available by Request
3	Acrylic Sheet 12" x 24" x 1/4" (Black)
1	Acrylic Sheet 12" x 24" x 1/8" (Fluorescent Green)
Radio	
3	Vex Robotics Motor Controllers
1	4-ch, 2.4 GHz Radio Controller Transmitter
1	6-ch, 2.4 GHz Radio Receiver
1	4.8 V, 2000 mAh battery
Misc.	
1	Large tote box for storage

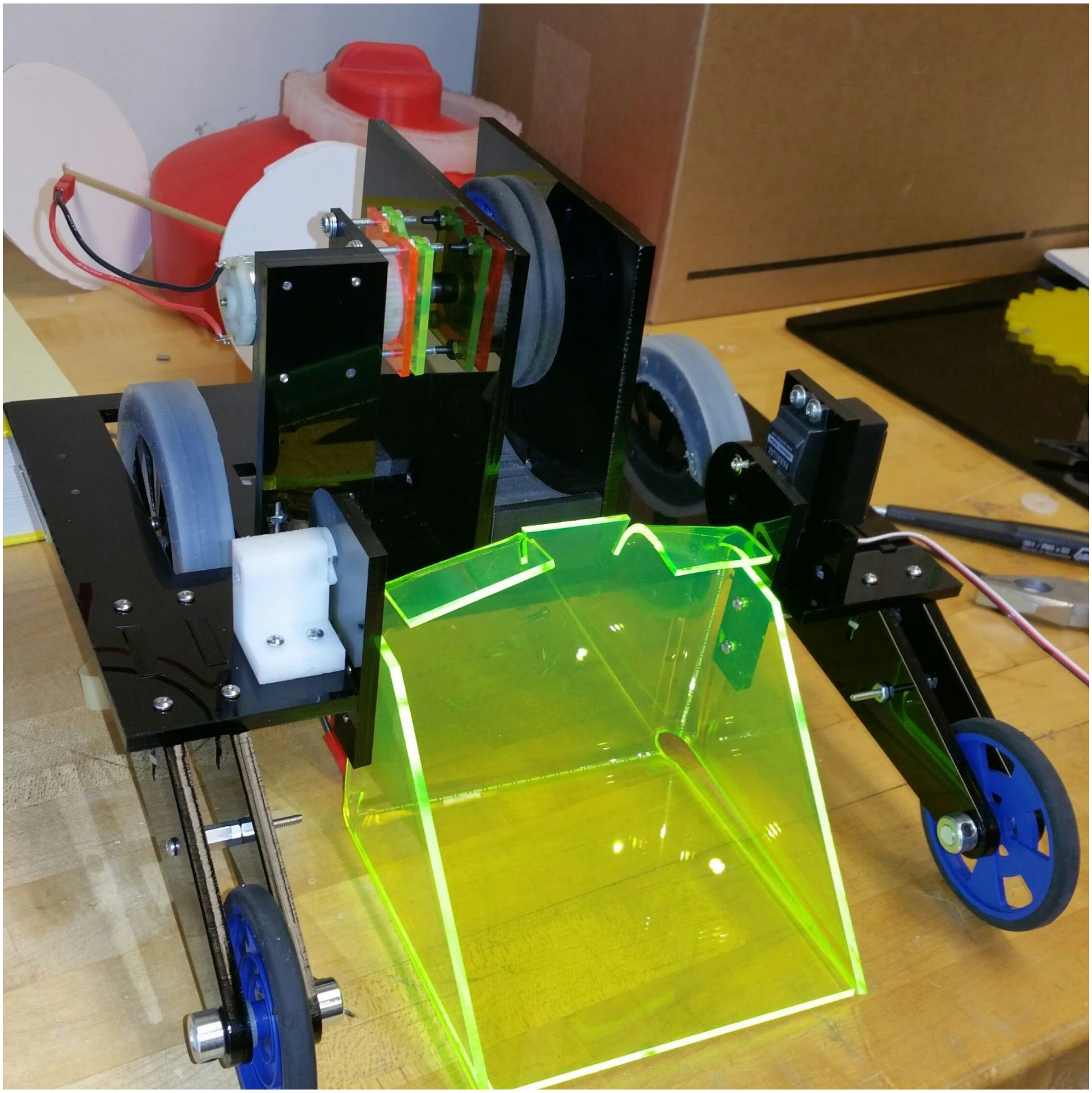
(From Turf Wars website, 2017)

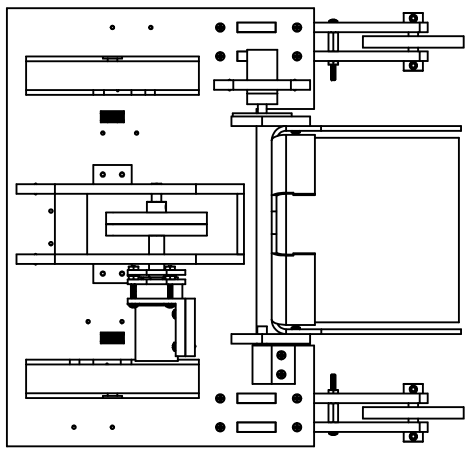
APPENDIX G

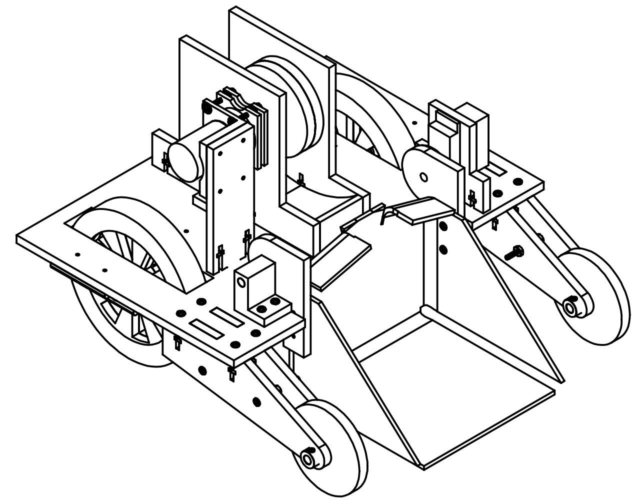
Gear Pong vs. Rough Cut (Championship Round)

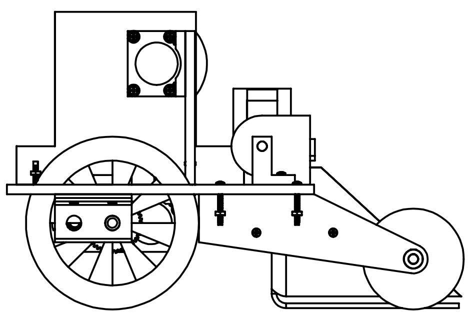
APPENDIX H

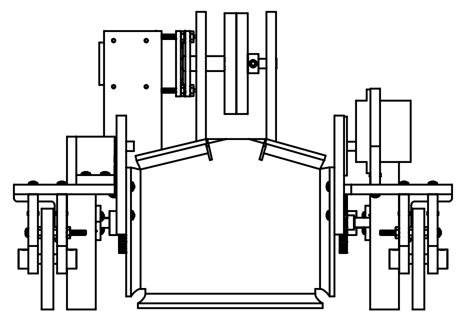
PewPew 3000 Final Design











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APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

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DO NOT SCALE DRAWING

	NAME	DATE
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

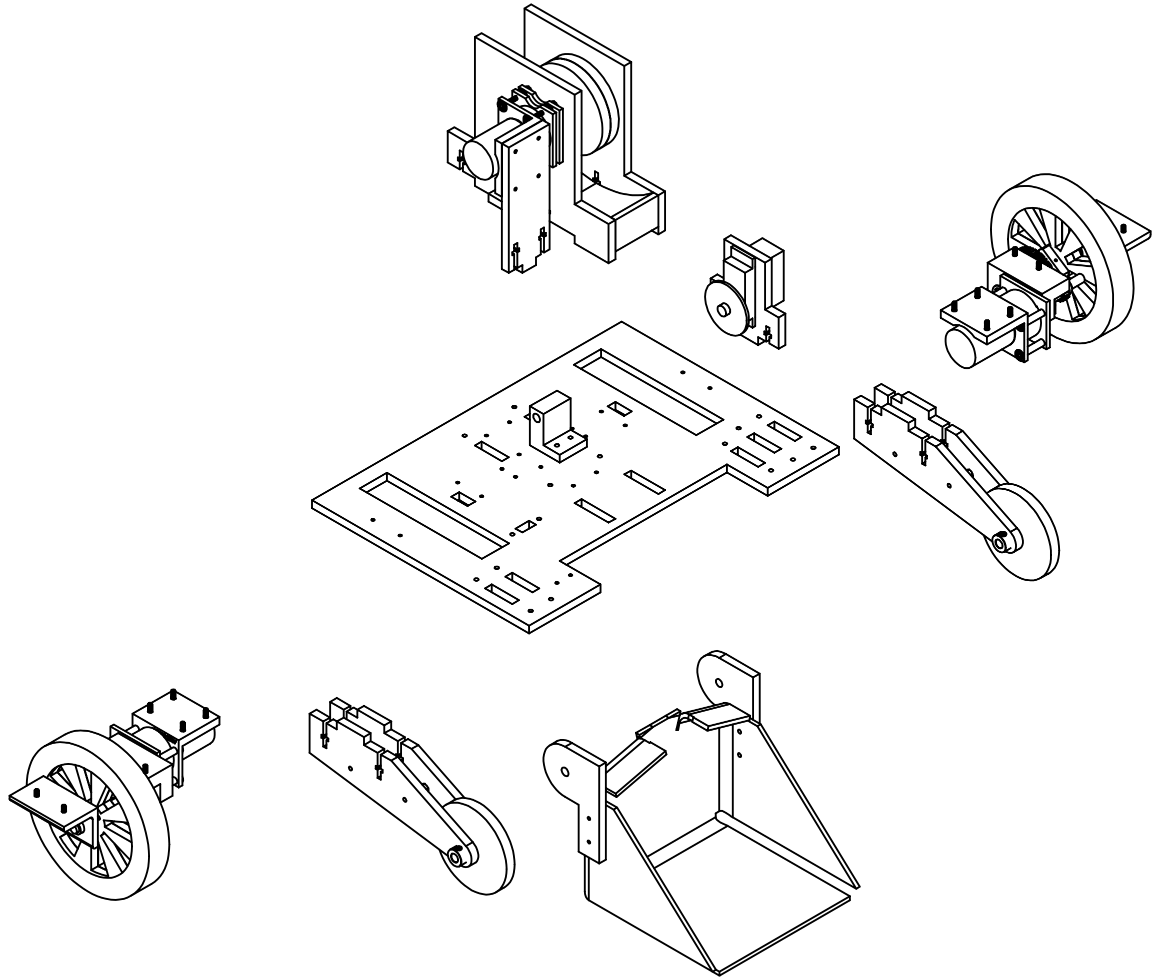
ES51 Team 1: Gear Pong

TITLE:

PewPew3000

SIZE **A** | DWG. NO. PewPew 3000 Full Assembly | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1



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ES51 Team 1: Gear Pong

TITLE:

PewPew300 Exploded View

SIZE	DWG. NO.	REV
A	PewPew3000	

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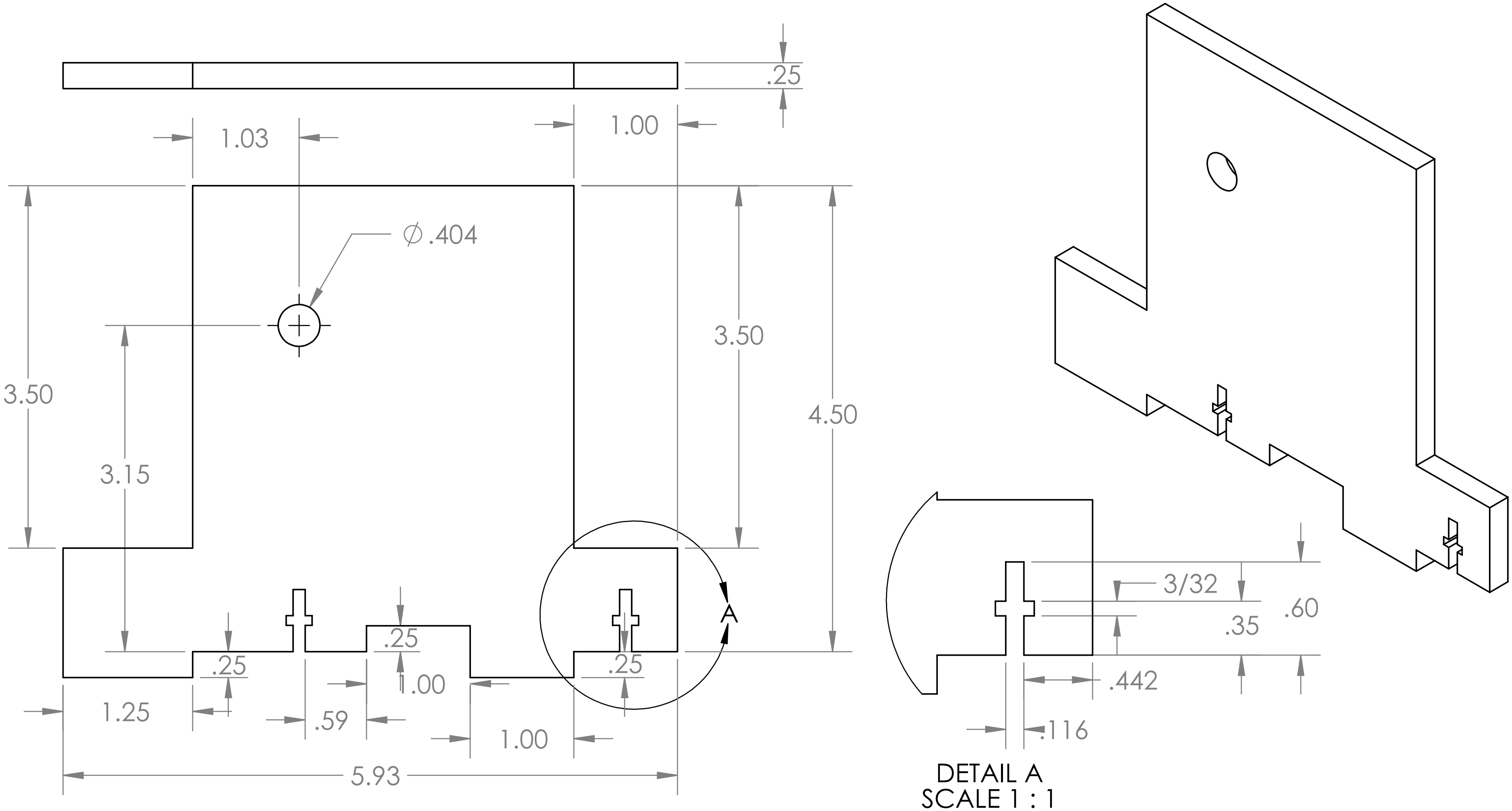

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DIMENSIONS ARE IN INCHES TOLERANCES: ONE PLACE DEMICAL: ±0.1 TWO PLACE DECIMAL: ±0.01 THREE PLACE DECIMAL: ±0.005	DRAWN			TITLE: Shooter Side Plate Motor Side
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	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Acrylic	COMMENTS:			SIZE **A** DWG. NO. **Side Plate** REV
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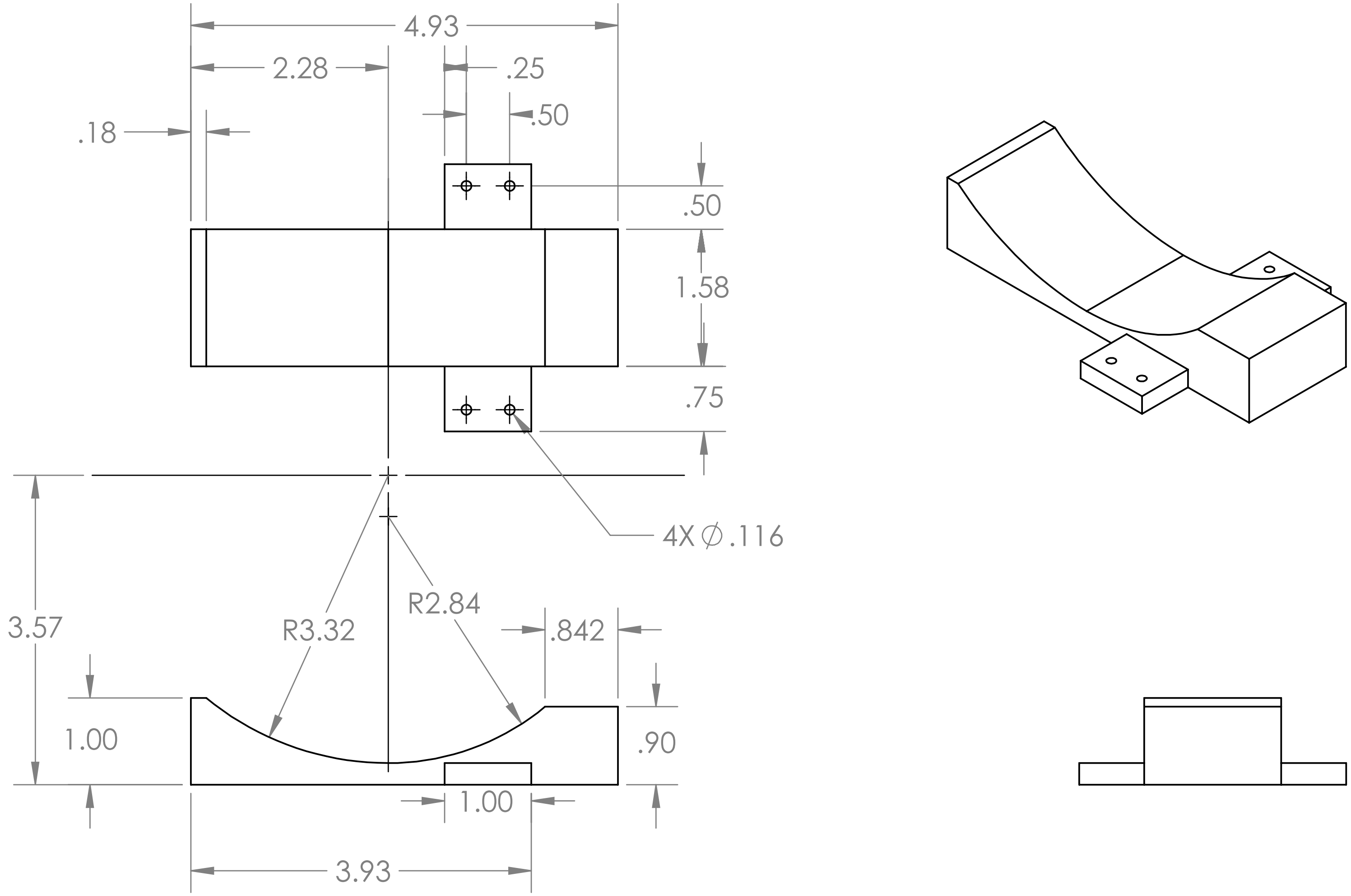

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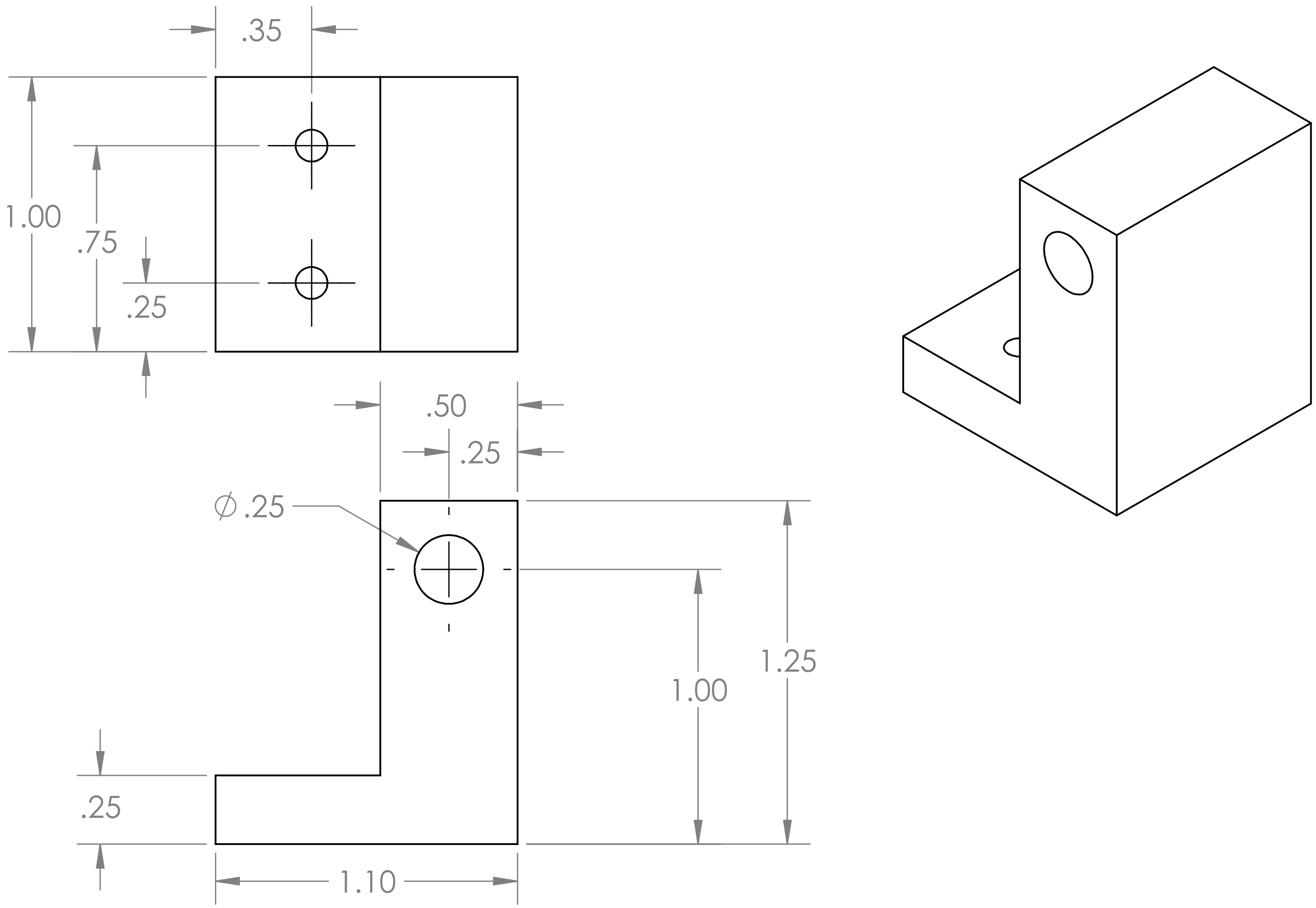
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL ABS Plastic	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

ES51 Team 1: Gear Pong

TITLE:

Shooter Chute

SIZE	DWG. NO.	REV
A	Chute	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



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INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Delrin	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

ES51 Team 1: Gear Pong

TITLE:

Scooper Mount Drawing

SIZE A | DWG. NO. Delrin Scooper Mount | REV

SCALE: 3:2 | WEIGHT: | SHEET 1 OF 1