Hockey Puck Passer

A Baccalaureate thesis submitted to the
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Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

This is a group senior design project for the 2018 graduating Mechanical Engineering Technology class. I was one of the three group members and the other two team members were Connor Uhl and Steven Baltes. The project name is "Hockey Puck Passer" and it is designed to be fit the following criteria: solo use, portable, shoot up to 60 mph, cheaper then competitor, and passes the pucks at a random index between each pass. The specification that sets this product from the rest is the random indexing, all current competitors are unidirectional.

Although this is a group project, I was specifically in charge of the 4-bar linkage system. This is the system that would feed the pucks into the flywheel. Some things that had to be done to complete this were: selection of the idea of feeder, hopper ideas (holds the pucks), calculations, design, and assembly. I also constructed the whole poster for the presentation at the Tec Expo. As a group we tested and found solutions for the issues that arose.

Some recommendations or changes I would do differently would be increasing the motor torque. After some quick changes like vibrations in the pins holding the linkages and the height of the crank on the rob of the motor, the main problem was that the system could only work with 15 pucks instead of the desired 24. With a higher torque motor the system would work as desired with no other component failures

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Fundamental hockey skills such as receiving passes, is impossible to practice by yourself, thus we are designing an economical and portable hockey puck passer that provides a variety of passes.

BACKGROUND

In today's hockey world it is nearly impossible to practice your passing and receiving skills by yourself. All of the current products on the market either limit pass types (in the air, different angles, etc) or are unreasonably priced.

RESEARCH

SCOPE OF THE PROBLEM

Currently hockey teams rely on one another player to pass and practice shooting on goalies. Without the help of either a skilled coach or a teammate, practicing these skills are impossible. The current solution is far too expensive for the average Joe trying to gain better stick skills. In today's market, there are currently no machines that can directionally pass pucks, they only pass in one direction limiting the skills to be practiced. We are going to address this problem by designing our product to pass pucks in three different directions, which will not only allow players to practice their stick skills but also help them work on their footwork.

CURRENT STATE OF THE ART

One of the most basic forms of the hockey puck passer on the market today is a product called the "Hockey Shot Passing Kit Pro." This standard device is also used to practice passing and receiving pucks. The way that it works is the player passes the puck into the device and a durable bungee cord fires the puck back to the player. There are several pros and cons to this product.[1] The list of pros includes that the product is cheap and portable costing $179.95, it is easily assembled, easily stored and can be used by players of all skill levels. The cons of this machine include the length of the shooting pad limits the distance of passes to practice, all passes return straight to the player with little to no variety, there are no elevation changes, speed is

[1] For more info see Item 1 from Work Cited

limited based on the players' passing strength, if you miss the target you end up chasing your puck and this product cannot be used on ice (where hockey is typically played). This is a highly rated product based on the products functionality. The biggest issues the customer reviews have displayed are that the product takes much longer to ship then promised and the customer service is terrible, whether dealing with product return, not showing up, or just general questions.[2]

XPuck Passer Pro Automated Hockey Passing Machine is a device used by hockey players at any skill level and any age to practice their passing and shooting skills. It is a portable and compact machine that shoots pucks to an individual for them to catch and shoot or simply practice one timers. The passing machine can hold up to 18 pucks and shoot them at a desired rate between 2-16 seconds up to 40 mph.[3] It has the ability to be used on the ice or a dry surface such as a driveway. This machine is simply controlled by buttons for both the speed and interval of the passes. The device is constructed with steel and a powder coated finish for durability. The external puck loading mechanism assembles and disassembles without tooling.

This machine does a good job at making this solo practice possible. With the variable speed and time between shots allows the user to catch harder passes. The interval setting permits the user to work on their hand eye coordination by catching, shooting, and preparing for the following pass. One of the cons of this machine its inability to change the direction of the pass. All passes out of this machine are straight and predictable. Once the user becomes used to these passes it will be hard for them to further improve their skill set. Another downfall is its price, at $1700 it is no longer appealing to the average hockey player and is typically only purchased by organizations (semi-pro, NHL teams).

From the research our team has put together, the Boni Pro puck shooting machine is the top of the line. It shoots at a variety of different speeds (5-85 mph), and can shoot a puck from ice level up to the corner of the net. The machine is very expensive costing about $6000 for a brand new standard machine, adding options or customizing will add to the cost. This limits their target customer to larger organizations and not the everyday player who wants to practice. Another con of this machine is its enormity. The product weighs in at 245 pounds, so once it is placed there is

[2] For more reviews see Item 4
[3] For more about the XPuck Passer Pro visit Item 5

not much movement or variety around the rink.[4] From the forums, we found that those who could afford the machine were happy with the product, but most threads were about how the machine was far too expensive to buy and out of reach for the common consumer.[5]

END USER

We are designing our product for the everyday hockey player looking to improve their footwork and stick skills (Ages 5+). Unlike the products in today's market, we are looking to make our machine affordable and compact for easy storage. Our machine will only need one person to move, setup, turn on, practice and store away allowing anyone to play anytime. Our machine will also be able to utilize multiple surfaces. The target customer will be able to use this product on the ice or in the neighborhood cul-de-sac. We are also targeting to sell to ice rinks, who could then rent to their own customers. The machine will be powered with the standard 110 volt AC outlet for use in many different locations.

CONCLUSIONS AND SUMMARY OF RESEARCH

Through the design process our group will maintain a level head on both the customer's needs and our own budget. Our machine will include the capability of changing puck speeds of a range from about 5-60 mph. One of the key features of our product that is currently not available on the market, is the ability to pass the puck in several directions, keeping the player alert and on their toes. Keeping the construction of our machine inexpensive and lightweight will be difficult, however our team will maintain a focus of using a simple designs and components to reduce cost. Designing our product for use on multiple surfaces allows us to engage a larger target customer base. From our research, we have gained both a focus and knowledge to be able to move onto our next phase of our design.

CUSTOMER FEATURES

From our surveys we found that people were most interested in finding an affordable machine that can shoot pucks at a variety of speeds and directions, and also that the machine is

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[4] See Item 3 from Work Cited for more info. on Boni Products
[5] For more threads and reviews see Item 2

portable. Another feature that seemed to be very popular through our survey was being able to use this machine on multiple surfaces. After taking customer input, we came up with the following Customer Requirements and Engineering Characteristics that we included in our Quality Function Deployment. After evaluating the QFD, our three features that were weighted with the most importance came out to be the traversing speed (shooting directionally), the number of persons to operate, and the cost.

Survey for a Hockey Puck Shooting Machine					
	Not Important	**Somewhat Important**	**Important**	**Very Important**	**Necessity**
Shoots pucks in a range of speeds	1	2	3	4	5
Cord length	1	2	3	4	5
Durability	1	2	3	4	5
Shoots pucks in multiple directions	1	2	3	4	5
Fires pucks smoothly	1	2	3	4	5
Shoots pucks on different surfaces	1	2	3	4	5
Plugs into wall socket easily	1	2	3	4	5
Loads pucks easily	1	2	3	4	5
Transports easily	1	2	3	4	5
Low cost	1	2	3	4	5
Additional Comments					

Table 1: Survey and results

PRODUCT OBJECTIVES

Using the QFD, research, and surveys our team will deduce the most important customer features. The features with the highest weighted importance will determine the amount of time we spend on each feature.

QUALITY FUNCTION DEPLOYMENT

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Friction force (lbf)	speed of puck (miles per hour)	weight (pounds)	size/volume (cubic inches)	number of pucks to load	110 VAC	cord length (ft)	number of persons to operate	traversing speed(mph)	operating temperature range (°F)	puck shooting height (ft)	number of wheels	time inbetween puck shots (seconds)	Cost		get the puck outta here	boni puck pro	hockey shot passing kit pro	x passer pro
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▼	▲	X	▲	▼	X	▲	X	X	X	▼					
1	9	20.0	0.2	shoots pucks directionally	▲	Ο		Ο					Θ		Ο			Θ		5	0	0	0
2	9	15.0	0.2	shoot in a range of speeds	▲	Ο				Θ		Ο	Ο				Θ	▲		4	5	1	3
3	9	5.0	0.1	needs one person to operate			Θ	Θ	Ο		▲	Θ			▲	Θ	▲	▲		5	0	5	5
4	9	10.0	0.1	durable			Θ	Ο						Θ		▲		Θ		3	5	4	5
5	9	15.0	0.2	fires pucks smoothly	Θ	Ο						Ο	Ο		Ο		Ο			4	5	2	4
6	9	10.0	0.1	shoots pucks on different surfaces	Ο	Θ					Ο	▲	Ο	Θ		▲				4	0	2	5
7	9	5.0	0.1	plugs into wall socket easily						Θ	Ο	▲								5	5	0	5
8	9	5.0	0.1	cord is long enough						▲	Θ	▲								5	5	0	5
9	9	5.0	0.1	loads pucks easily	▲				Θ			Θ					▲			4	5	0	2
10	9	10.0	0.1	transports easily	▲		Θ	Θ				Θ				Θ				4	2	5	4
				Target or Limit Value	0.5	5 to 60	50	27,000	40	110v	30	1	2	0-100	0 to 4	4	5 to 16	900 to 1200					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	7	6	8	5	0	0	5	9	7	5	0	4	8					
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	3	9	9	9					
				Weight / Importance	215.0	240.0	225.0	225.0	60.0	185.0	95.0	290.0	300.0	180.0	110.0	155.0	190.0	290.0					
				Relative Weight	7.8	8.7	8.2	8.2	2.2	6.7	3.4	10.5	10.9	6.5	4.0	5.6	6.9	10.5					

Table 2: QFD

1. Shoots pucks at different range of speeds (5-60 mph)
2. Shoot pucks in a variety of directions
3. Portable
4. Needs one person to operate
5. Economically Priced
6. Shoots pucks into air
7. Holds 30 pucks
8. Can be used on multiple surfaces

DESIGN

Design Alternatives
Concept #1

- Single Vertical wheel
- System suspended above the ice by a vertical shaft
- Indexing done above the system

Concept #2

- Twin motorized horizontal wheel
- Uses gravity to load buck into mechanism

Concept #3

- Frame mounted motor for indexing
- Single Vertical wheel
- 4 bar linkage Crank Slider
- Frame mounted motor for indexing

Final Concept

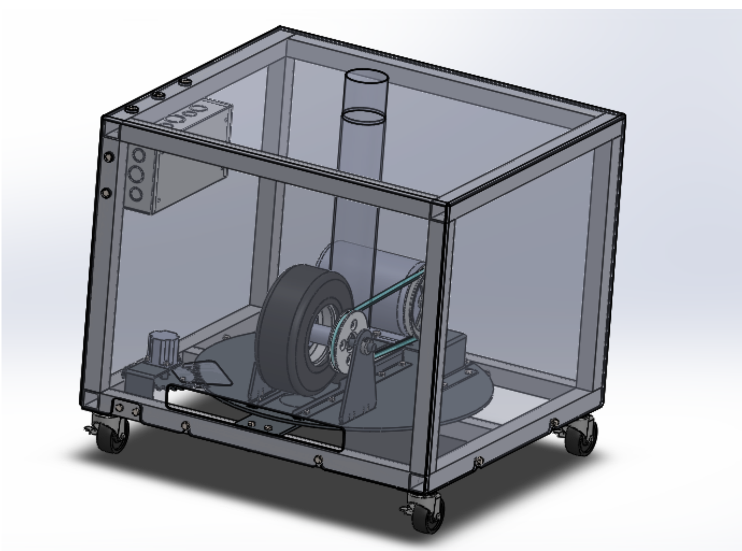


Figure 1: Final Concept

- Single Vertical wheel
- Crank Slider
- Frame mounted motor for indexing

Four-bar Linkage

This system is used to load the pucks into the wheel that will project the puck up to 60 mpg. It will load the pucks at 6-pucks per minute (repeating),is light weight, and small. This system includes the hopper, four bar linkage the repeatedly loads the pucks, and the motor and motor bracket holding the motor. The system holds the pucks in the center of the turn table to keep everything align when the system rotates. There are two guiderails that restricts the piston to only push the piston in a linear motion towards the spinning wheel. Like stated before this keeps the system aligned with the spinning wheel while the turntable rotates. The four-bar linkage was used to repeatedly rotate a crack bar that would translate the rotating driveshaft to the piston in the linear motion. Once at full stroked the puck is pushed under the spinning wheel and when the piston is retracted it allows the next puck to fall into place to be pushed under the wheel.

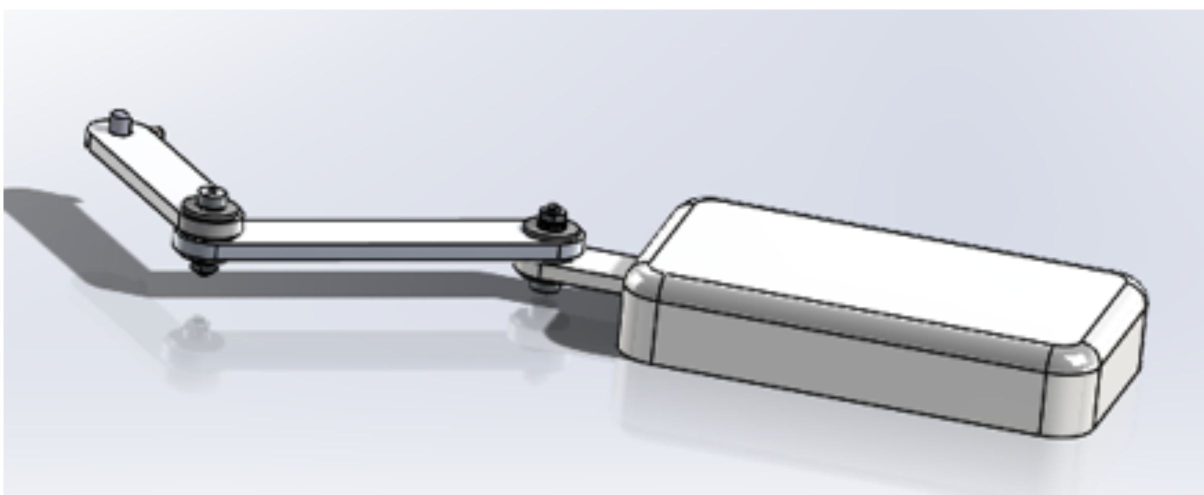


Figure2: 4-Bar Linkage System

When making the four-bar linkage, I had to take in consideration that the puck was 3" in diameter. This meant that the cracker had to be more then 1.5" because it had to be able to push the puck then retract a minimum of 3" and since it is a crank just has to be 1.5". Next was the piston which was 1” in height and 3” wide due to the puck being 1” tall and 3” wide. The length was determined so that when the slider pushes the puck forward it is going to have pucks in the hopper resting on it. The crank was made out of 11 gauge 5052 aluminum because it was thick enough for the set bolt to connect to the driveshaft. The other linkage was also made from 11 gauge to make the manufacturing of the part easier. The bracket was made from 16 gauge aluminum 5052 because it is light weight, available from Connor’s , and is within the safety factor. The piston was 3-d printed out of nylon because it was lightweight, available from Connor’s work, and within the safety factor. The motor was chosen because it was small, cheap, and was had enough torque that was calculated. Below shows calculations and stress analysis of parts.

Motor Calculations:

- $T= I*\alpha$
- T= 0.0028 Nm

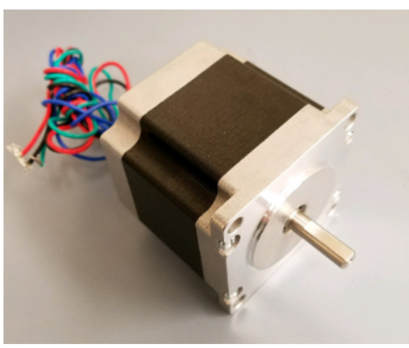


Figure 3: Selected Motor

The picture above is Nema 23 stepper motor with a holding torque of 1.26 Nm. This torque is well over the required torque but it was the cheapest motor found.

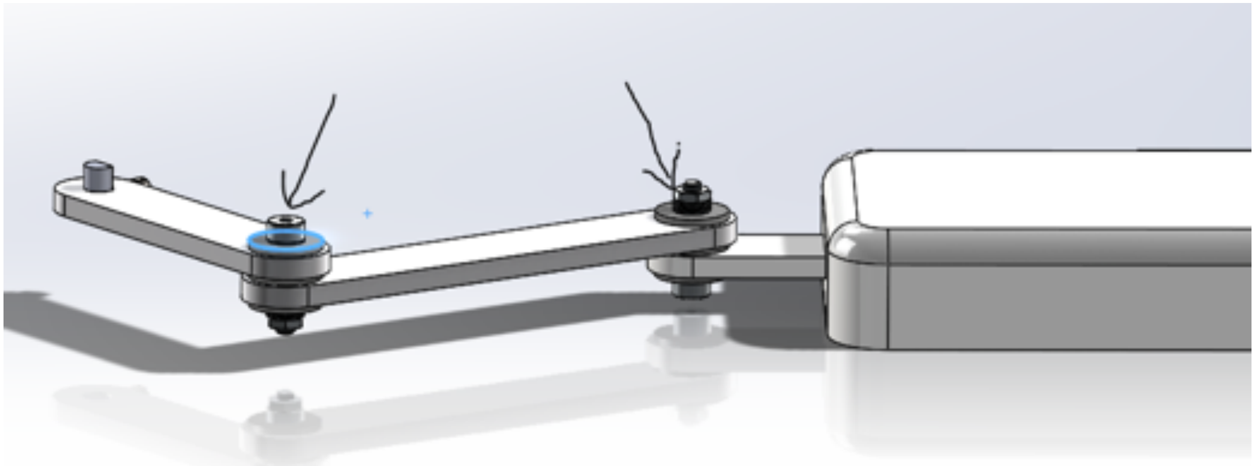


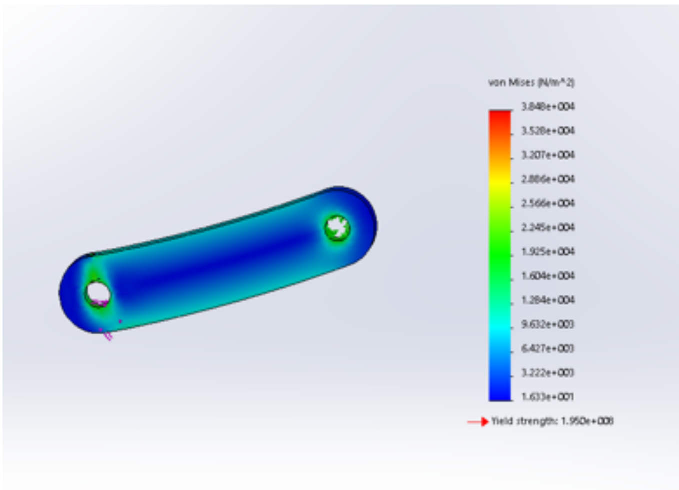
Table 4: Positions of Pin

The picture above shows the locations of the 2 pins holing the 4-bar linkage together. The pins have a yield strength of 450 MPa. Below shows that the calculated shear stress is well below the accepted yield strength.

$\tau = F/A\_s$

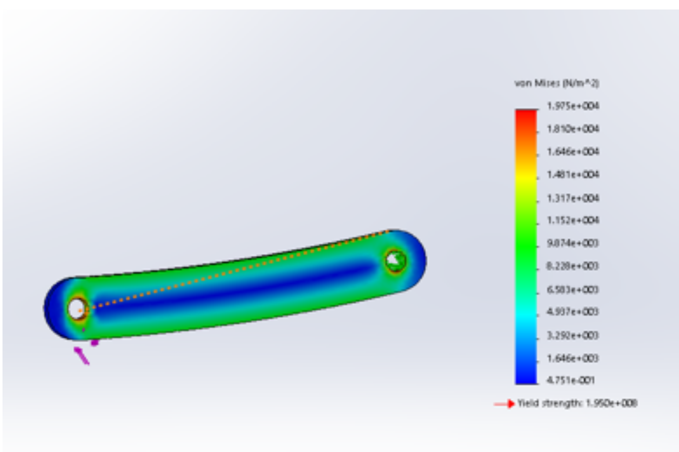
τ=255 Pa

Below are the stress analysis of the linkages, brackets, and piston.



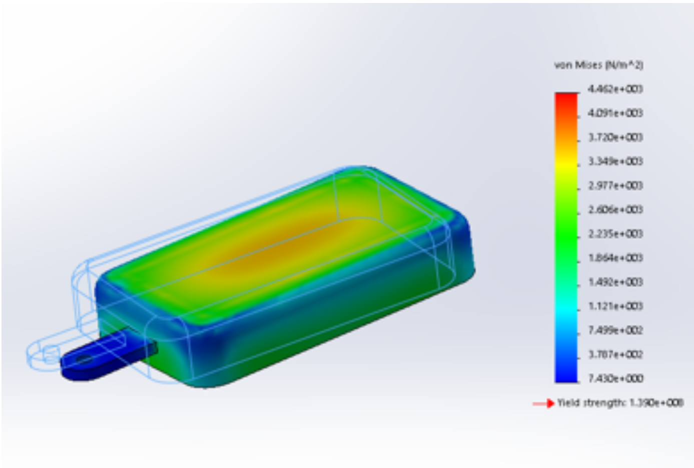
Safety factor of 5761

Figure 5: FEA of the Crank



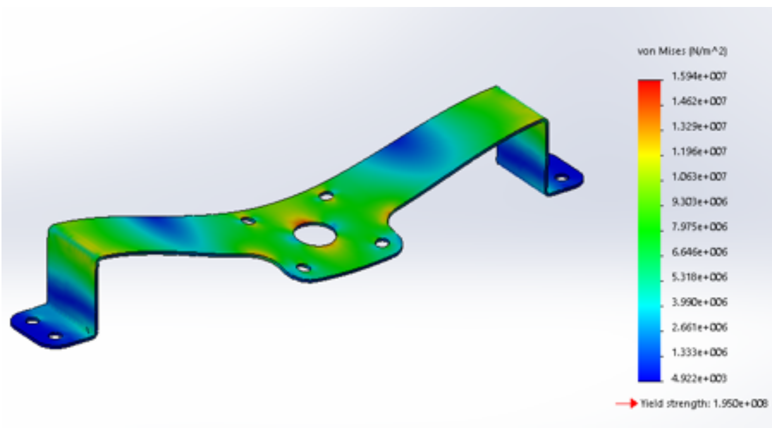
Safety factor of 9873

Figure 6: FEA of the Rocker



Safety factor of 31,151

Figure 7: FEA of piston



Safety factor of 12.23

Figure 8: FEA of the Motor Mount

Bill of Materials				
REF #	Part Name	Part Description	Quantity	DRAWINGS/MFG PROCESSES
1	2835T14	CASTER WHEELS W/ BREAKS	4	-
2	29T DRIVING SPUR GEAR	SPUR GEAR, 29 TEETH	1	APPENDIX A
3	303405	WASHER, M4, SS	4	-
4	303406	WASHER, M6, SS	28	-
5	303407	WASHER, M8, SS	35	-
6	303642	SHCS, M3 X 12, SS	4	-
7	309476	HHCS, M5 X 16, SS	10	-
8	309479	HHCS, M6 X 12, SS	4	-
9	309480	HHCS, M6 X 16, SS	18	-
10	309489	HHCS, M8 X 25, SS	4	-
11	309996	NUT, JAM, M4, SS	4	-
12	309997	NUT, HEX THIN, M6, SS	18	-
13	309998	NUT, JAM, M8, SS	8	-
14	311017	NUT, M6, HEX, SS	4	-
15	311018	NUT, M8, HEX, SS	23	-
16	352355	NUT, M5, HEX, SS	2	-
17	394446	HHCS, M8 X 16, SS	4	-
18	428318	SHCS, M4 X 6, SS	4	-
19	428336	WASHER, M3, SS	6	-
20	428337	NUT, M3, HEX, SS	6	-
21	458967	HHCS, M8 X 55, SS	20	-
22	479862	HHCS, M3 X 6, SS	1	-
23	6245K48	SPOKED DRIVE PULLEY, 5.75" PD	1	-
24	6274K32	WHEEL PULLEY, 4.8" PD	1	APPENDIX A
25	636805	HHCS, M3 X 25, SS	2	-

Table 3: BOM

Bill of Materials				
26	6435K15	CLAMPING SHAFT COLLAR, 5/8" ID	4	-
27	75065K15	ENCLOSURE, 12" L X 6" W X 4" D	1	-
28	Cover HPP	LEXAN PANEL COVER FOR FRAME	1	APPENDIX B
29	Fly Wheel Assembly	WHEEL, TIRE, HUB ASSEMBLY	1	-
30	Frame Assembly	WELDED 1.5" SQUARE TUBING	1	APPENDIX C
31	Gear Block	TAPPED MOUNTING BLOCK	1	APPENDIX D
32	Gear Cover	COVER FOR RIGIDITY	2	APPENDIX D
33	Gear Motor Bracket	L BRACKET	1	APPENDIX E
34	Hockey Puck	NHL APPROVED HOCKEY PUCK	24	-
35	Hopper HPP	PUCK LOADING HOPPER	1	-
36	Large Motor Bracket	BRACKET FOR PULLEY SYSTEM MOTOR	1	APPENDIX E
37	Motor Bracket	BRACKET FOR PISTON DRIVEN SYSTEM	1	APPENDIX F
38	Nema 23 Stepper Motor	STEPPER MOTOR, 200 STEPS	2	-
39	Plate HPP	ROTATING PLATE W/ GEAR TEETH	1	APPENDIX F
40	Pulley Mounting Plate	MOUNTS SHAFT	1	APPENDIX G
41	Pulley Mounting Plate OPP. Side	MOUNTS SHAFT	1	APPENDIX G
42	Pulley Shaft 0.625 OD	SHAFT, 5/8" OD	1	APPENDIX H
43	Pusher Piston Assembly	DRIVES PUCK INTO FLYWHEEL	1	APPENDIX I
44	Sample Pulley Motor	PULLEY SYSTEM MOTOR	1	-
45	Shaft Key HPP	SQUARE KEY	1	-
46	Shaft Support Plate	SUPPORTS ROTATING PLATE	1	APPENDIX H
47	Side Guide HPP	STANDARD L BRACKET GUIDE	1	APPENDIX J
48	Side Guide Opp Side	STANDARD L BRACKET GUIDE	1	APPENDIX J
49	Turntable	TURNTABLE, HOLDS 200 LBS	1	-
50	Washer ISO 7092 8-SS	WASHER, M8	8	-

Table 4: BOM Continued

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Here is our preliminary budget estimation for the predicted total cost of the project.

Preliminary Budget Estimation	
Manufacturing Costs	725
Purchased Parts Cost	475
Total	1200

Table 5: Budget

Below is an analysis of our budget based on manufactured parts and purchased parts.

Part Description	Raw Cost	Manufacturing Time	Manufacturing Cost/hr	Total
Gear Motor Bracket	9.61	0.25	25	15.86
Main Motor Bracket	50.98	0.5	25	63.48
Piston Motor Bracket	10.54	0.5	25	23.04
Rotating Plate	78.45	0.5	25	90.95
Gear	21.12	0.5	25	33.62
Side Guides	8.41	0.5	25	20.91
Linkages	2.51	0.25	25	8.76
Piston Pusher Head	28.14	2.5	25	90.64
Gear Covers	2.65	0.25	25	8.9
Lexan Cover	72.18	0.5	25	84.68
Shaft Support	15.97	0.25	25	22.22
Shaft	8.15	0.5	25	20.65
Frame	112.46	1.5	25	149.96
Fasteners	26.45	0	25	26.45
Cross Member	27.85	0.5	25	40.35
Total Manufacturing Costs				700.47

Table 6: Manufacturing Budge

Part Description	Quantity	Total Cost
Pulley Motor	1	109.29
Nema Motor	2	57.25
Spoke Pulley	1	17.77
Drive Pulley	1	30
Fly Wheel Assembly	1	86.76
Wheels	4	24.99
PVC Hopper	1	10
Electrical Enclosure	1	26.82
V-Belt	1	8.62
Collars	4	8.45
Turntable	1	2.18
PLC Equipment	1	400
Total Purchased Parts Cost		782.13

Table 7: Purchased Budget

SCHEDULE, PROPOSED /ACTUAL

Proposed Initial Schedule through January 2018.

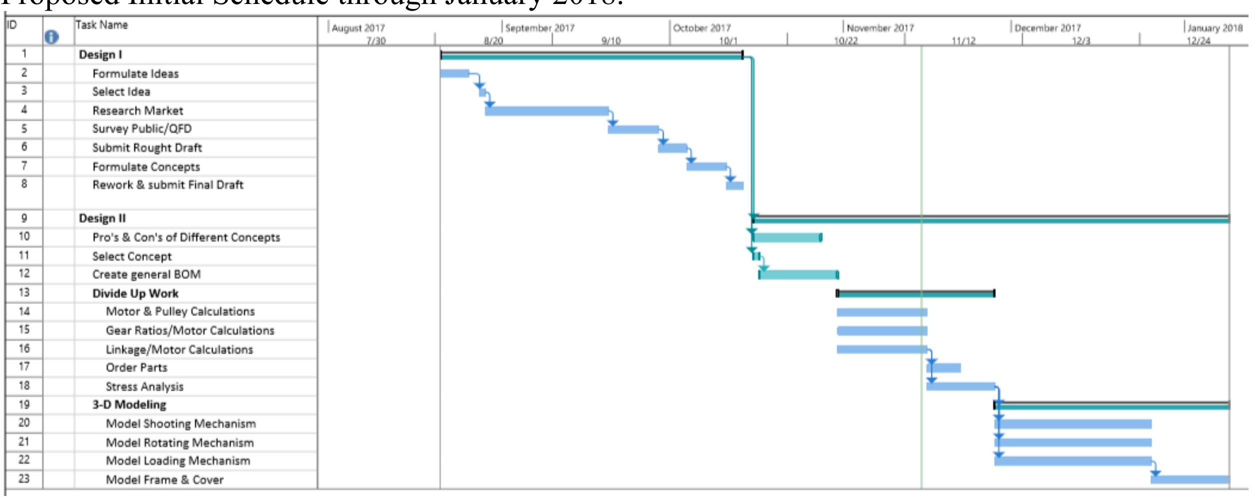


Figure 9:Actual Schedule

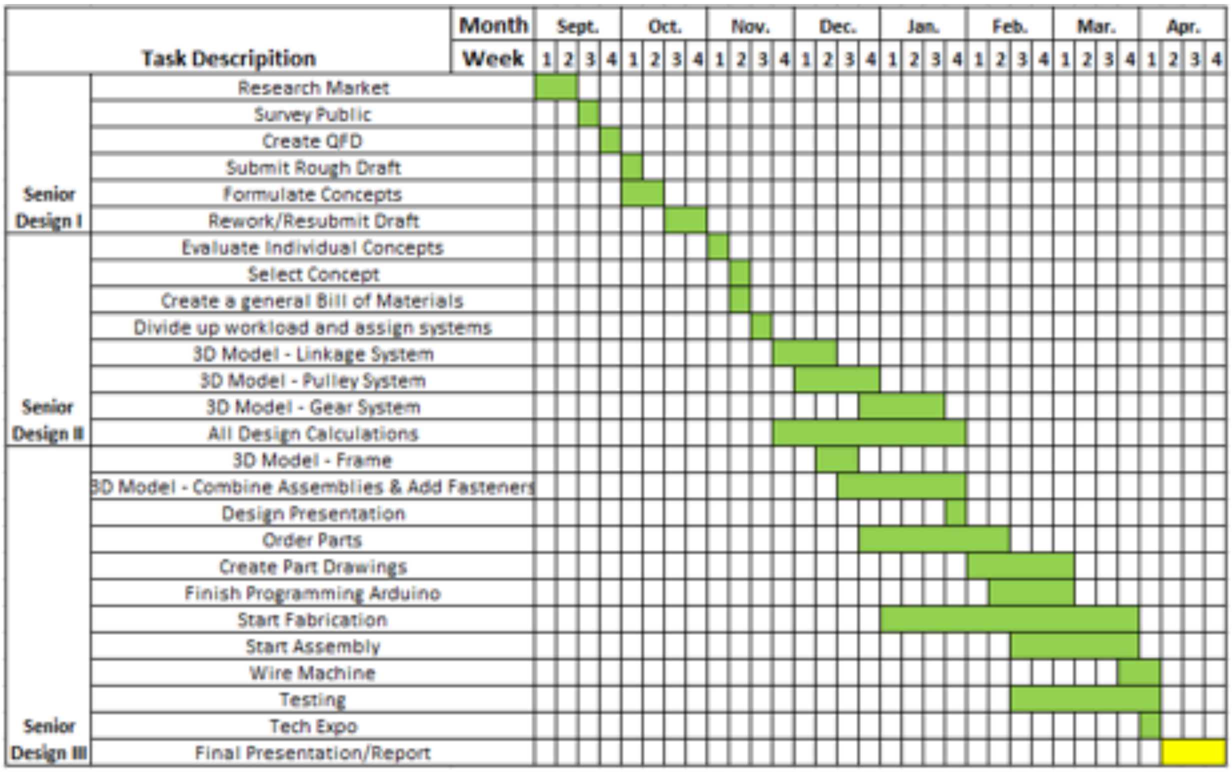


Table 8: Schedule

MANUFACTURING

The 4-bar linkage was constructed from 2 links, the piston, and the motor bracket. The links were constructed from 11-gauge aluminum 5052 and the motor bracket was 16-gauge aluminum 5052. The piston is 3-d printed with black nylon material.

The links and motor mount were cut out with the Trumpf 5030 which lasers them out of sheet metal. The motor mount was then bent on the brake press, Trumpf Trubend. The drawings of the links and motor mount are in Appendix I. The drawings for the motor mount are in Appendix F. Below is a picture of the completed product.

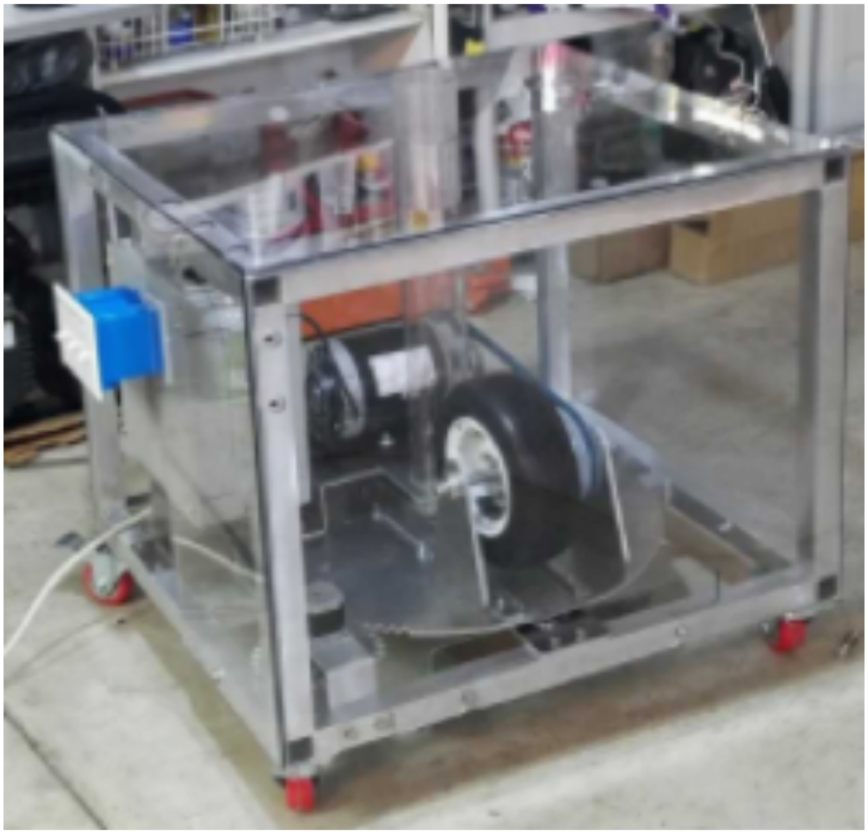


Figure 10: Real Picture of Hockey Puck Passer

TESTING

While testing the 4-bar linkage there were a few issues with the system. The table below shows the six different issues and the solutions.

Issues	**Solution**
Friction - piston sliding on plate	Wheels under the piston
Crank and Rod vibrating free	Bushings and cotter pins used
Height of the piston attachment point	Changed height of crank and rod
Hopper ID too large	Puck loader (a ribbon)
Piston would jam on incoming puck	Placed 3M insulation near the bottom
Motor did not provide enough torque	Needs new motor with more torque

Table 9: Testing Issues

When facing the issues with the piston having too much frictional force from the pucks, we knew that adding wheels would reduce the friction and it successfully did so. To make this change we redesigned the piston and 3-d printed a new piston with mounts for the wheels. These wheels are for sliding doors so they are able to handle the weight and repeating usage.

The height of the piston attachment point wasn't lined up correctly. This was fixed simply by relocating the set screw on the rod of the motor. Another simple fix was adding bushings and cotter pins where the linkages were secured. The vibrations were loud and causing the pins to fall out but the bushings and cotter pins secured everything with the vibrations.

There was an issue while loading the pucks. If the user loads the pucks one at a time, the puck could flip its orientation and not lad flat, which would cause a jam. This was because the I.D of the hopper was too large allowing the puck to move and this would be fixed by getting a tighter I.D restricting the pucks from landing on its side. The easy fix for us though was using a ribbon to lower the pucks in and then removing the ribbon.

When there are more than 8 pucks the weight is too much for the piston too freely move. To help with the load, adding a 3M insulation at the bottom pinching the bottom puck, dissipating the load. While the piston moved is would wiggle the puck free allowing it to still be able to drop.

The last issue was possibly this biggest issue. After testing and analyzing, it was apparent that there was not enough torque from the motor of the system. With a higher torque motor, we could work with all 24 pucks like designed for, instead of the 15 pucks we can shoot now due to the jamming let previously stated.

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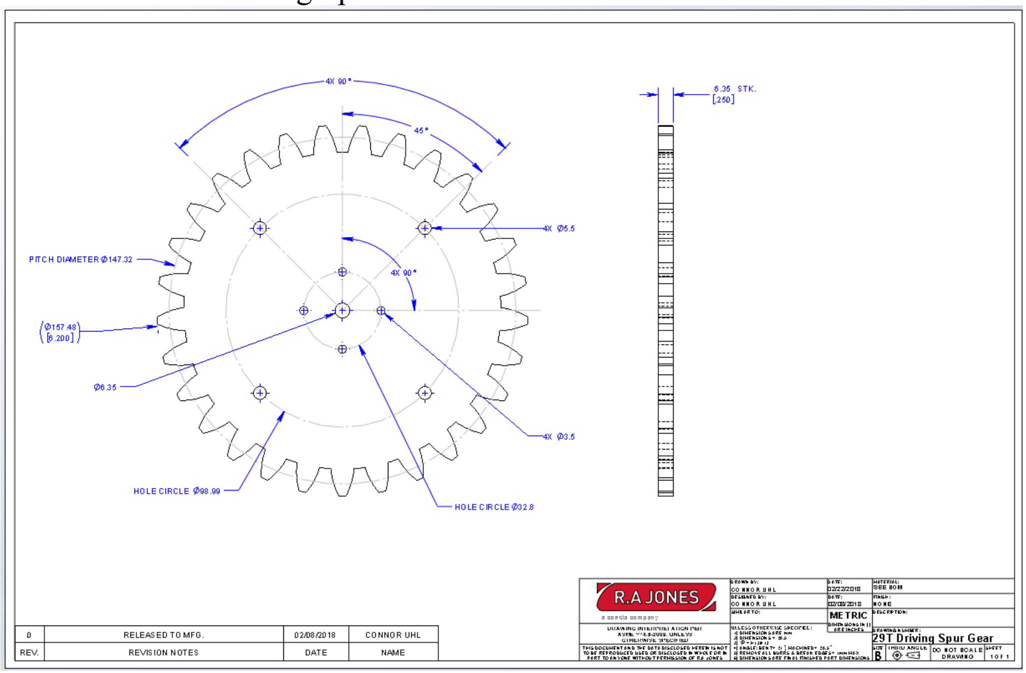
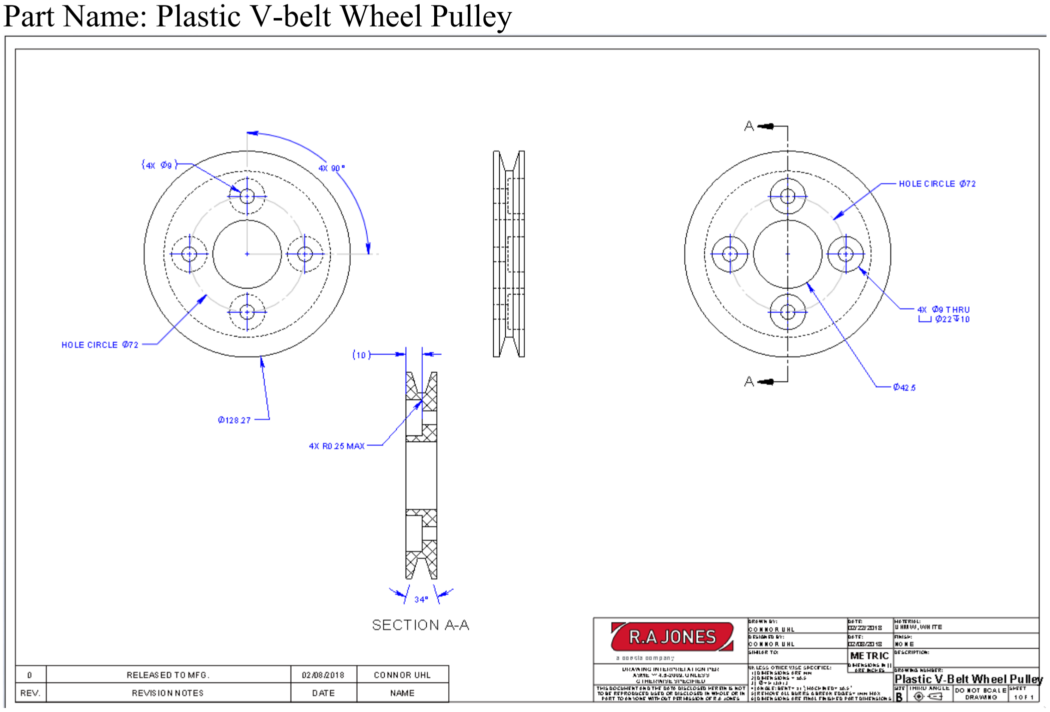
APPENDIX A

Part Name: 29T Driving Spur Gear



Manufacturing Processes: Cut 0.25” Aluminum 5052 on laser and deburred teeth.

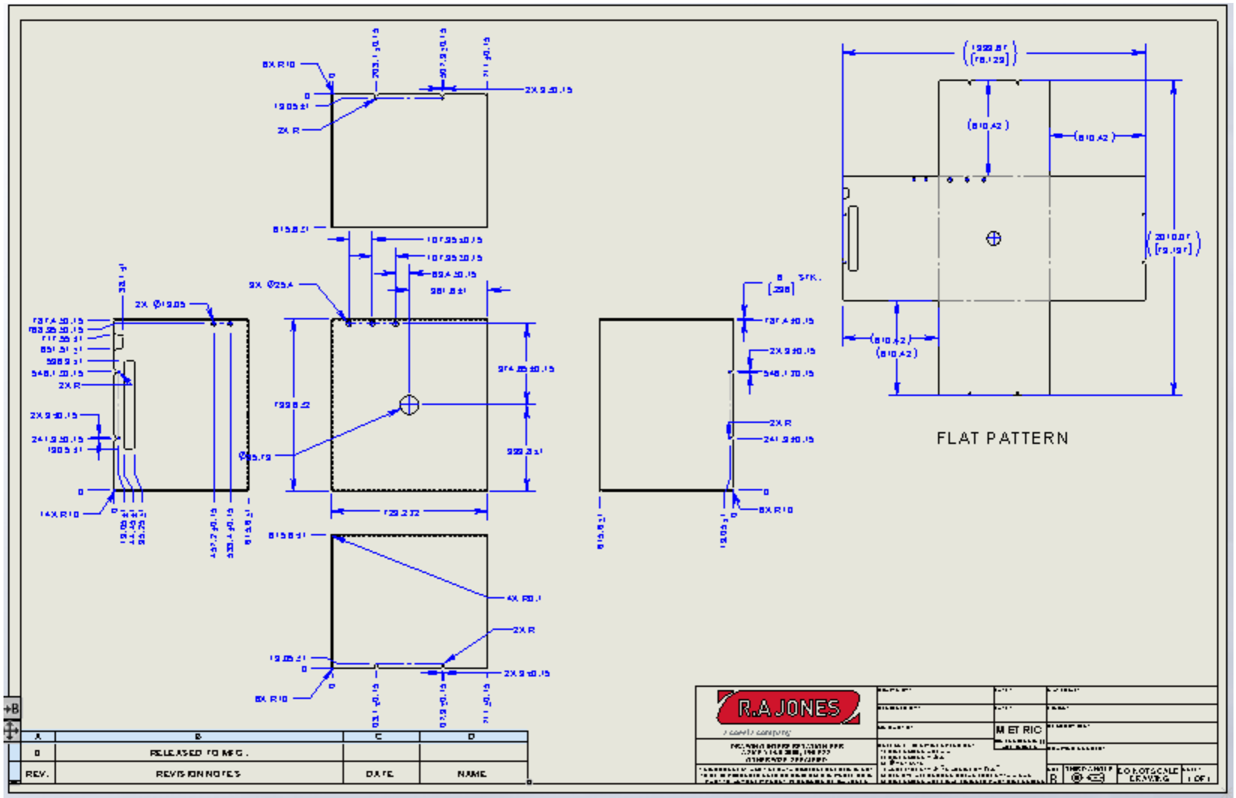
Part Name: Plastic V-belt Wheel Pulley



Manufacturing Processes: Counterbored on horizontal lathe.

APPENDIX B

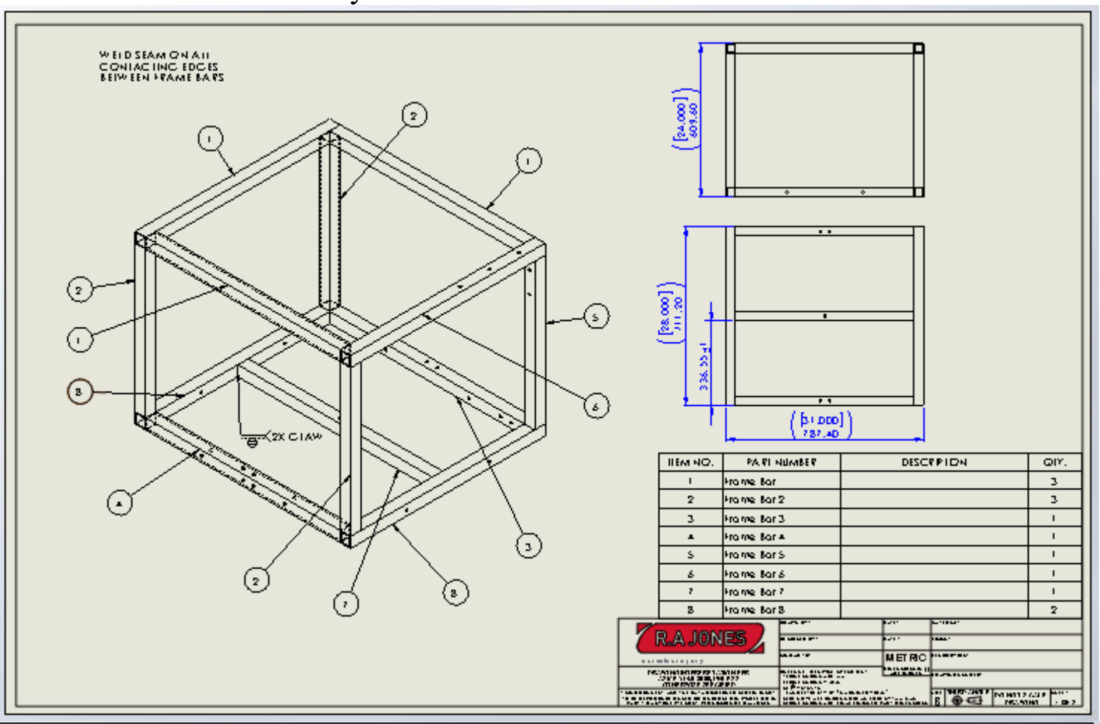
Part Name: Cover HPP

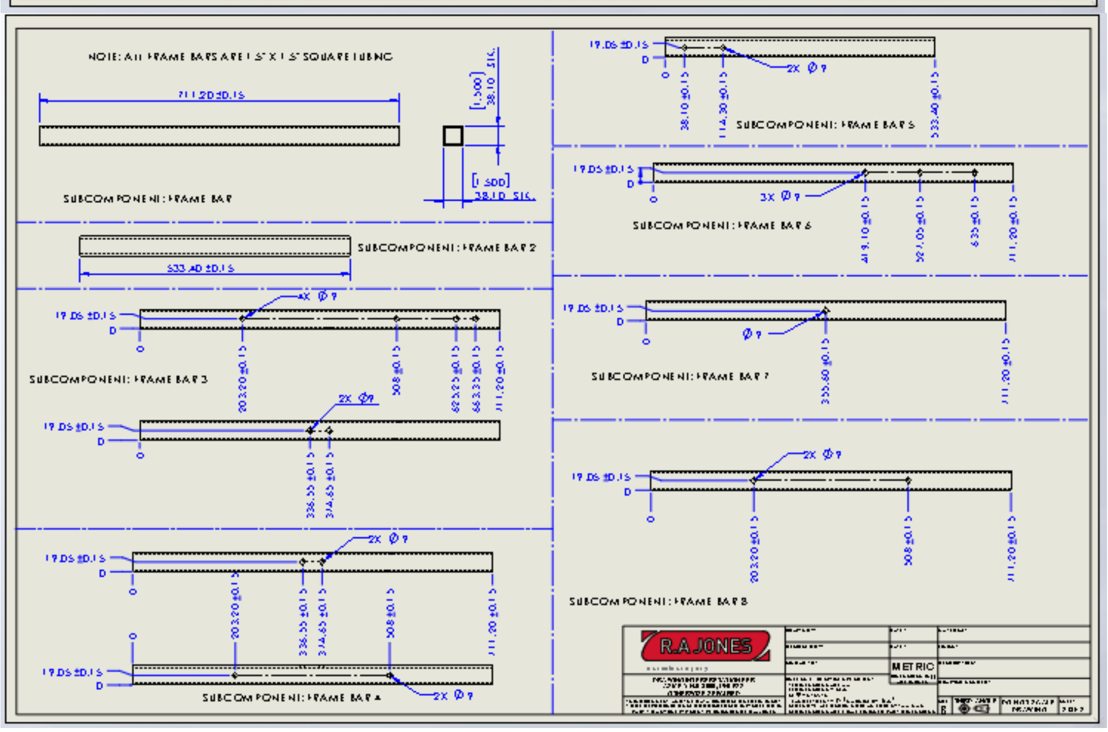


Manufacturing Processes: Cut out of Lexan on a router and then bent on a press brake.

APPENDIX C

Part Name: Frame Assembly

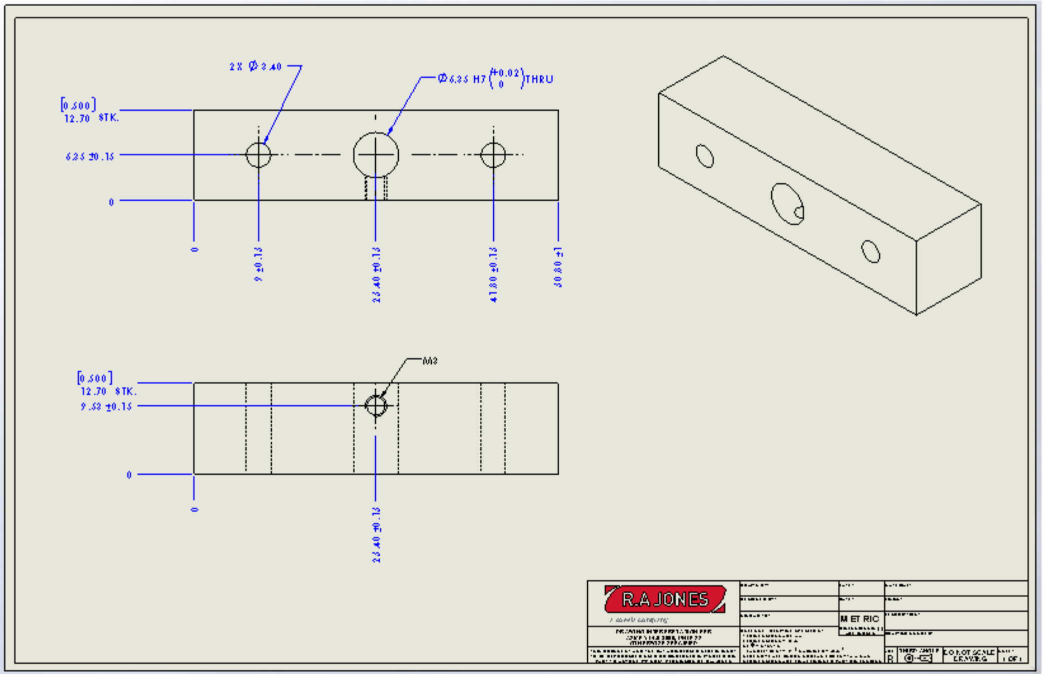




Manufacturing Processes: Aluminum 5052 1.5” x 1.5” square tubing cut on a saw and then welded using Gas Tungsten Arc Welding, and then ground down for finished look.

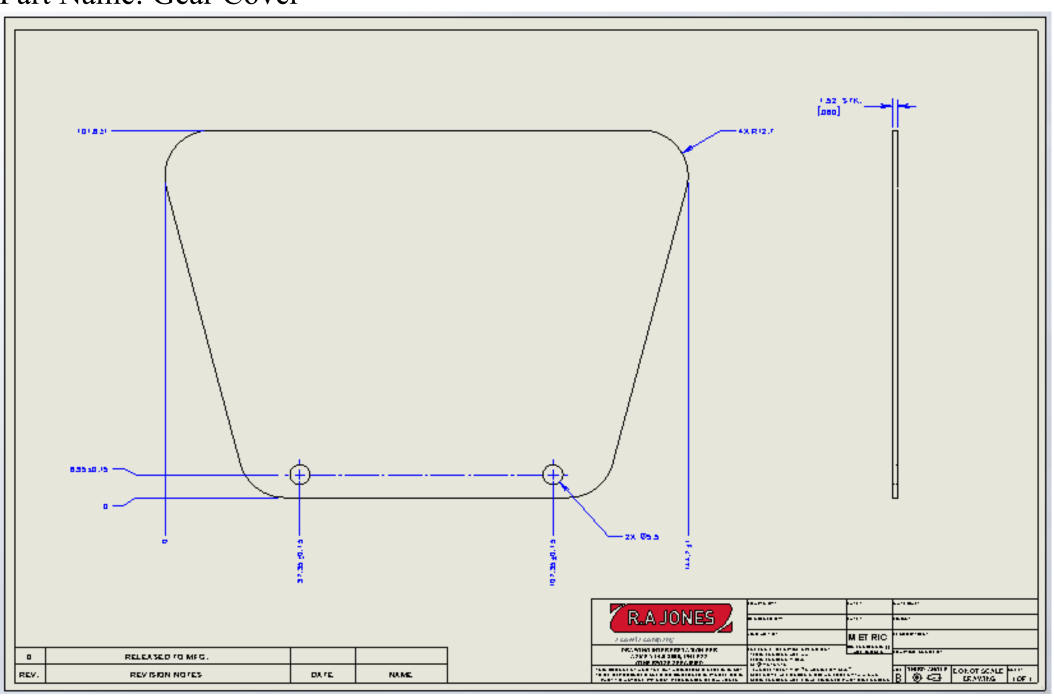
APPENDIX D

Part Name: Gear Block



Manufacturing Processes: Aluminum 5052 cut bar stock and tapped and drilled.

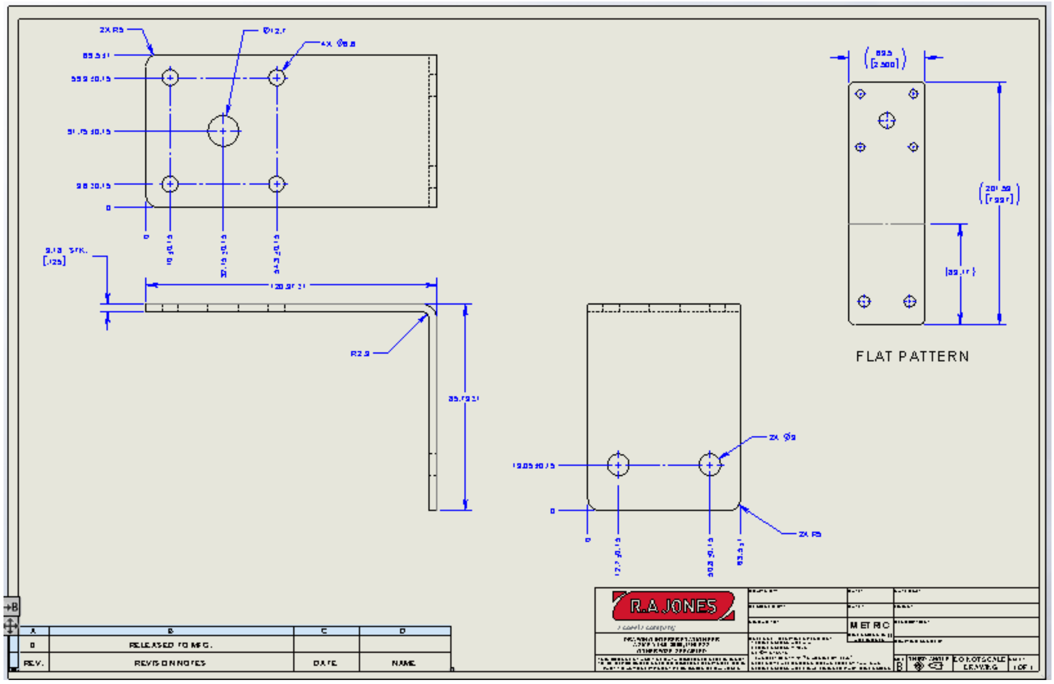
Part Name: Gear Cover



Manufacturing Processes: Cut 16 Gauge Aluminum 5052 using a laser.

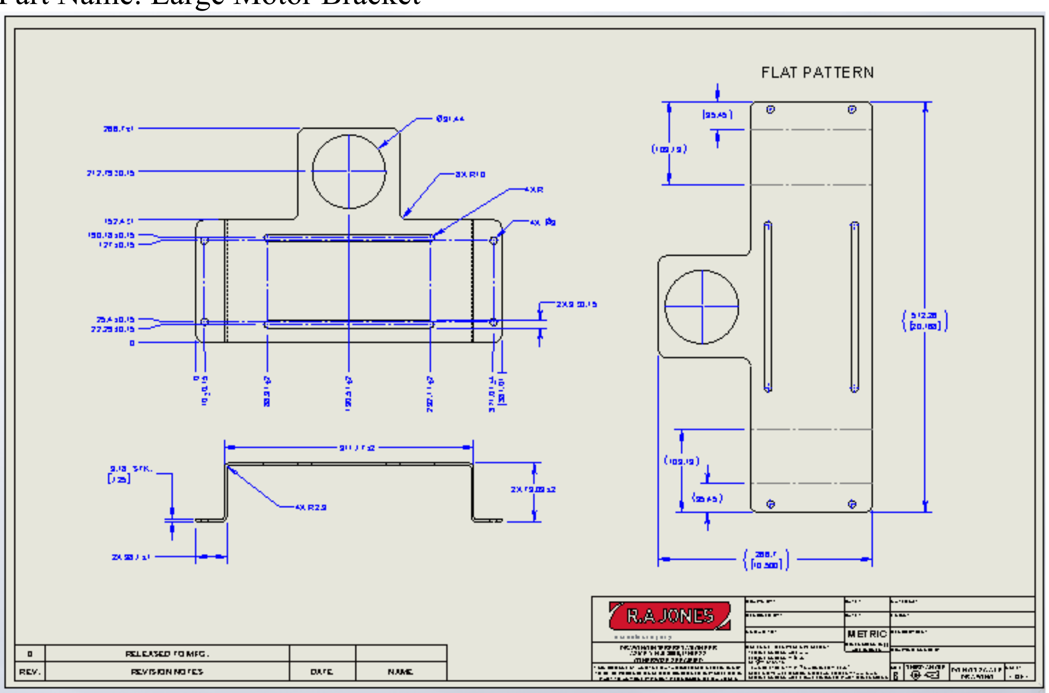
APPENDIX E

Part Name: Gear Motor Bracket



Manufacturing Processes: Cut 11 Gauge Aluminum 5052 using a laser and bent on press brake.

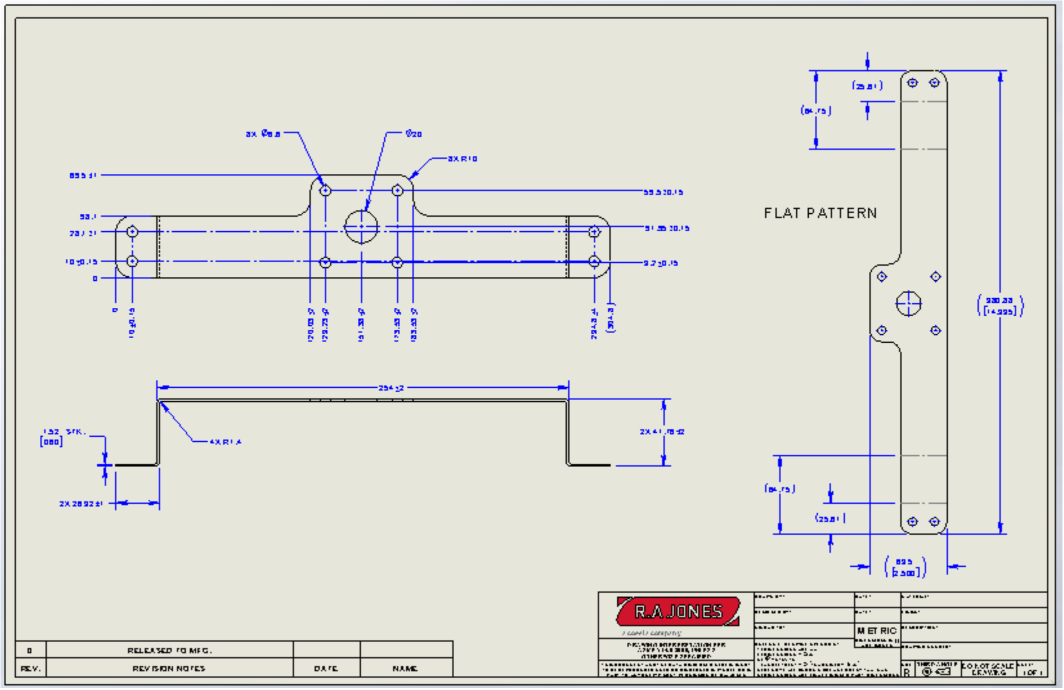
Part Name: Large Motor Bracket



Manufacturing Processes: Cut 11 Gauge Aluminum 5052 using a laser and bent on press brake.

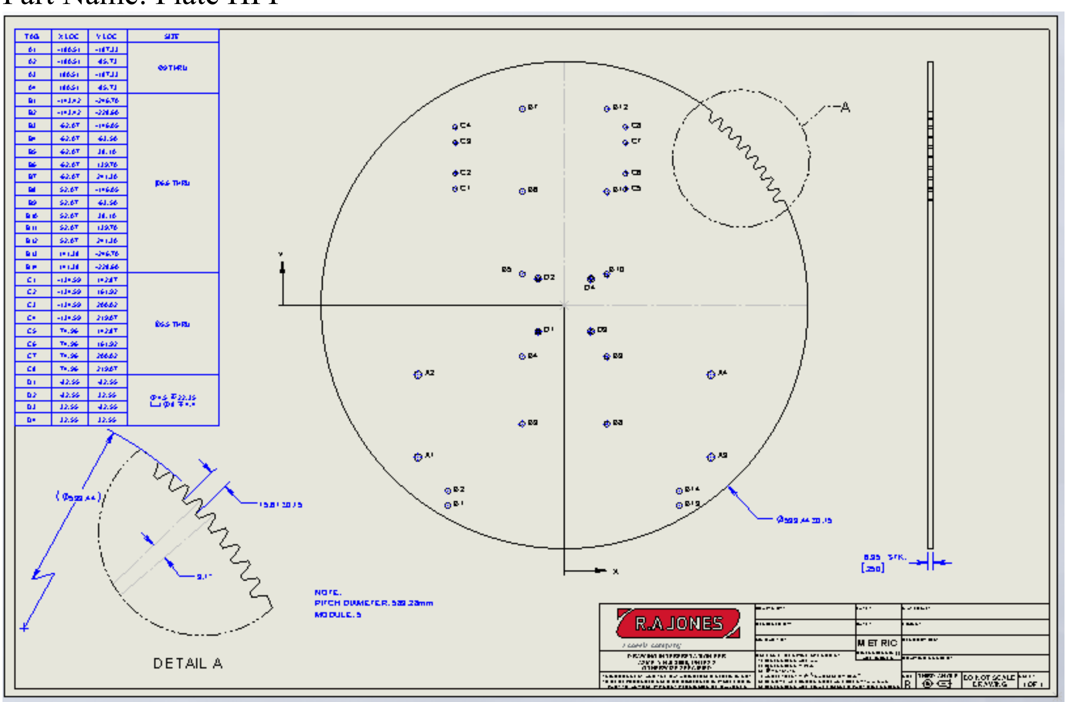
APPENDIX F

Part Name: Motor Bracket



Manufacturing Processes: Cut 16 Gauge Aluminum 5052 using a laser and then bent using press brake.

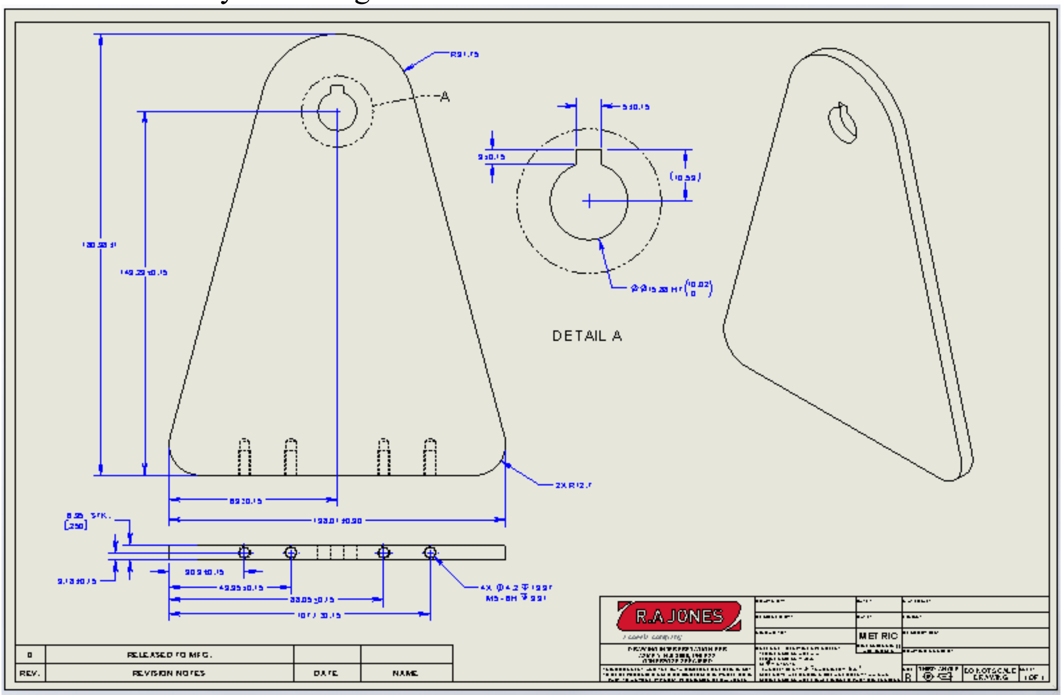
Part Name: Plate HPP



Manufacturing Processes: Cut 0.25" Aluminum 5052 using laser then counterbored using mill.

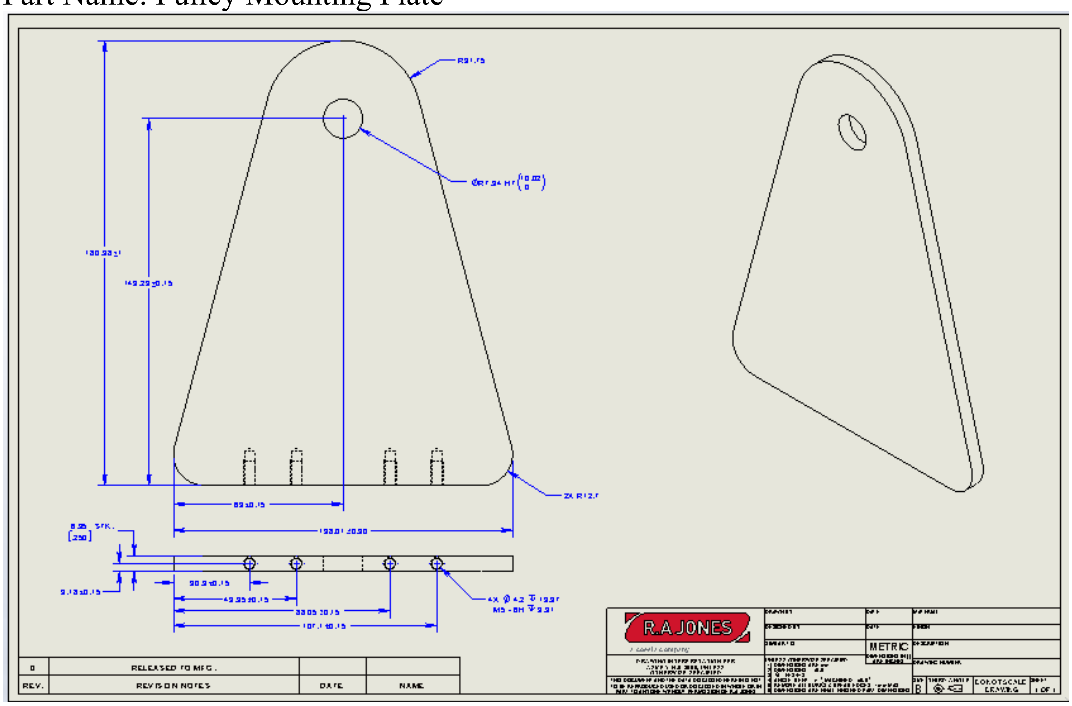
APPENDIX G

Part Name: Pulley Mounting Plate OPP. Side



Manufacturing Processes: Cut 0.25” Aluminum 5052 using laser, tapped using Toyoda, and broached keyway.

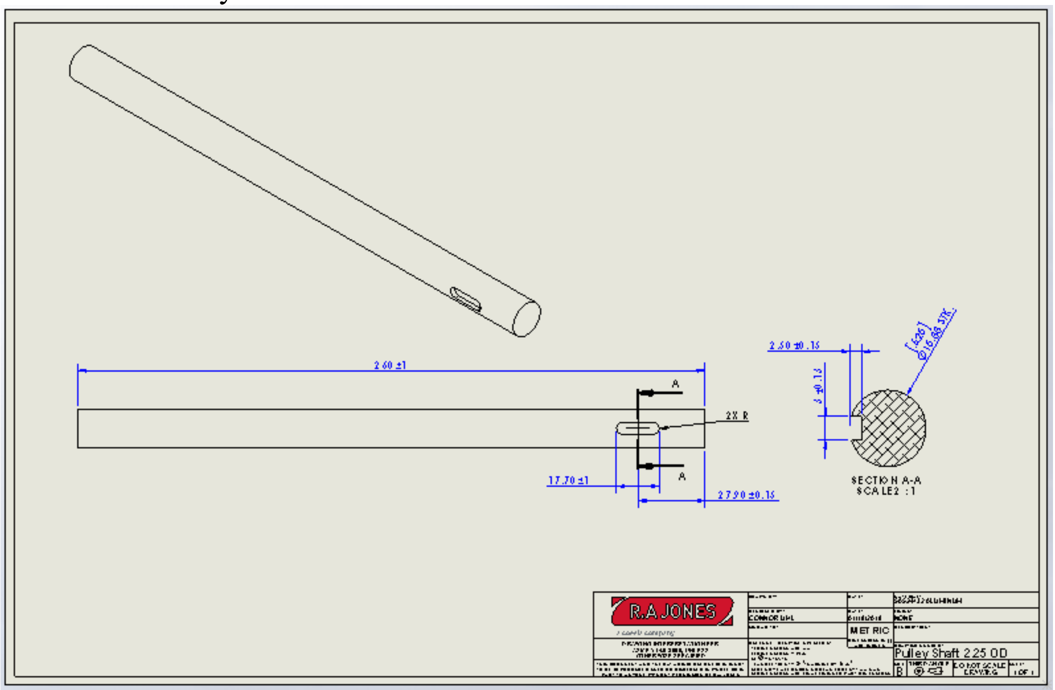
Part Name: Pulley Mounting Plate



Manufacturing Processes: Cut 0.25” Aluminum 5052 using laser and tapped using Toyoda.

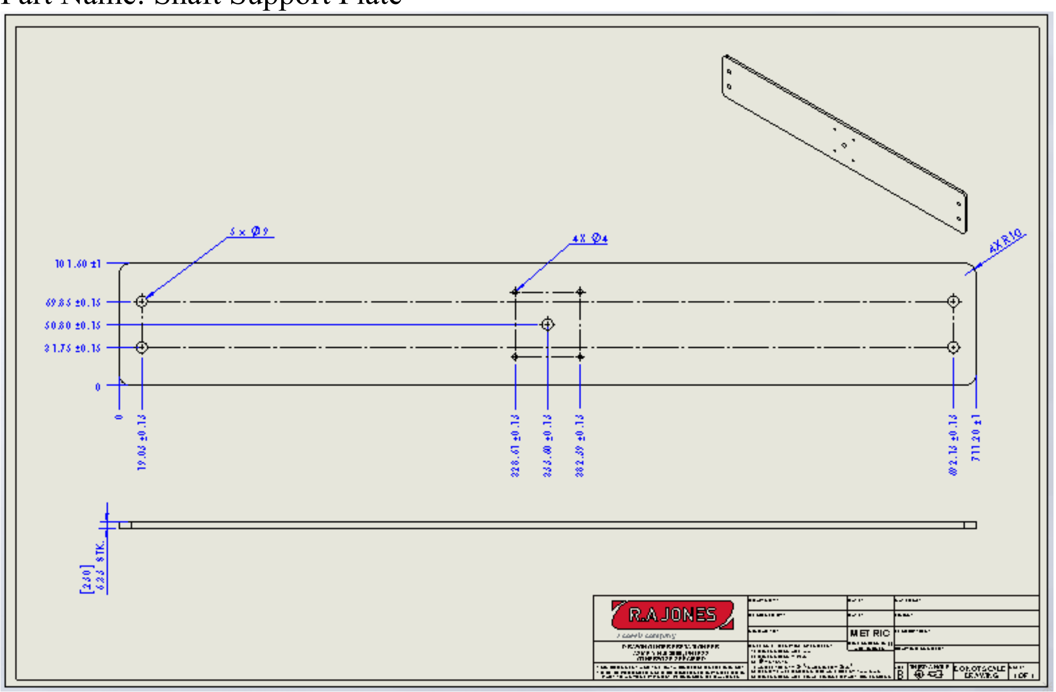
APPENDIX H

Part Name: Pulley Shaft 0.625 OD



Manufacturing Processes: Cut to length using a saw and milled the keyway.

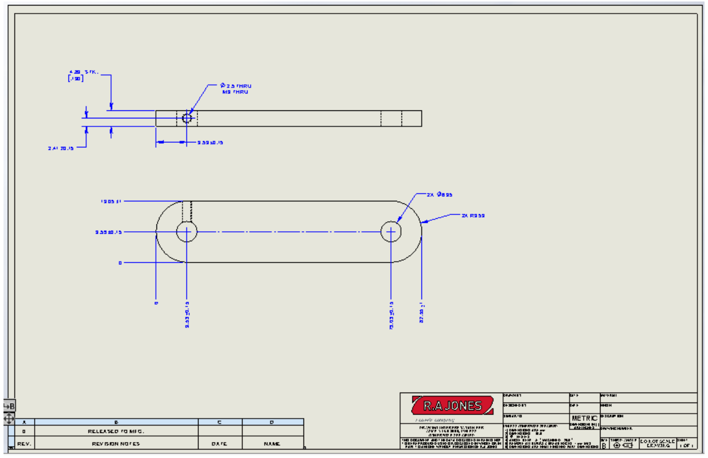
Part Name: Shaft Support Plate



Manufacturing Processes: Cut 0.25" Aluminum 5052 using laser.

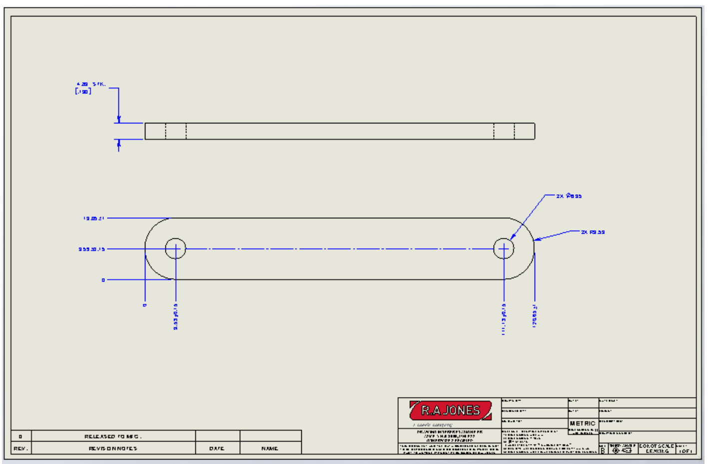
APPENDIX I

Part Name: Link - 2.5 inch



Manufacturing Processes: Cut 11 Gauge Aluminum 5052 using laser & tapped using Toyoda.

Part Name: Link - 4 inch



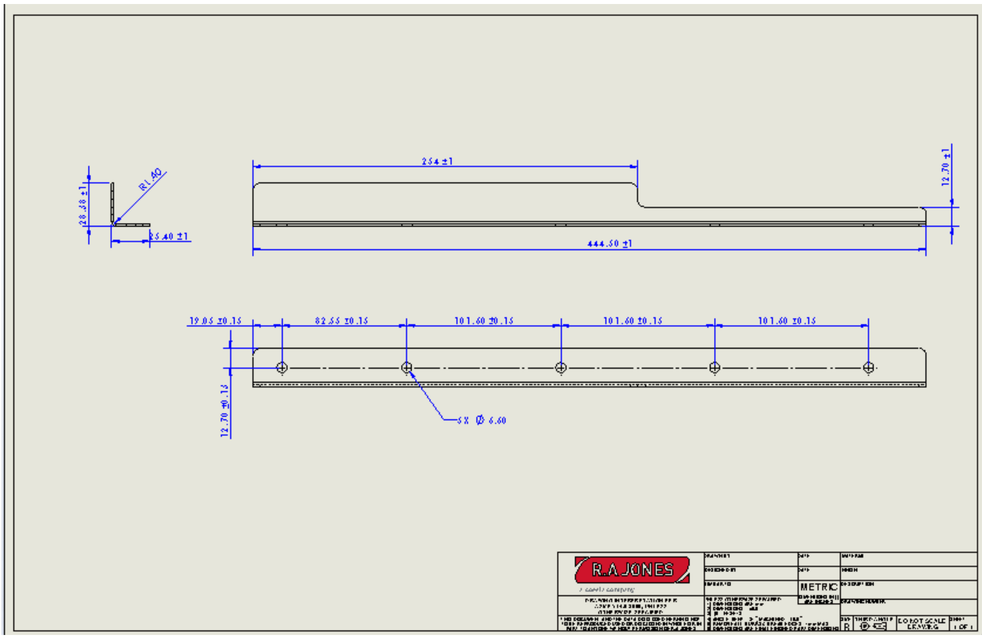
Manufacturing Processes: Cut 11 Gauge Aluminum 5052 using laser.

Part Name: Pusher Head Piston

Manufacturing Processes: Printed using Nylon in 3D Printer.

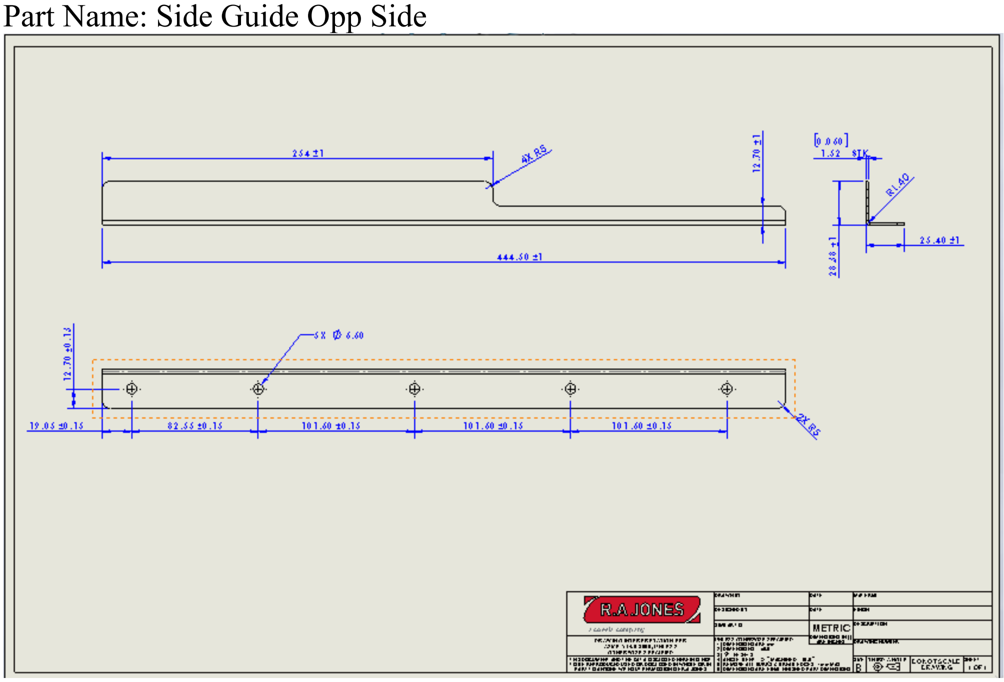
APPENDIX J

Part Name: Side Guide HPP



Manufacturing Processes: Cut 16 Gauge Aluminum 5052 using laser and then bent on press brake.

Part Name: Side Guide Opp Side



Manufacturing Processes: Cut 16 Gauge Aluminum 5052 using laser and then bent on press brake.