Hockey Puck Passer

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Bachelor of Science

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by

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ABSTRACT

The purpose of this project is to manufacture a hockey puck shooting machine that will be used by one person and pass pucks to the user in random directions. This machine is targeted toward club and professional teams that will have access to an ice rink. Comparing it to other leading designs such as the “Boni Pro” we also wanted our machine to be easy to transport and less expensive. This project was completed by three team members, which include Connor Uhl, Steven Baltes, and Edward Brandon. From these factors we were able to start setting specifications we wanted to achieve. The machine will be made from lightweight construction and will be less than 3 cubic feet with lockable wheels. This machine will include three different automated systems. The first system is a fly wheel mechanism with pulleys and an AC motor. This system will be designed by Steven and will utilize the use of pulleys to step up the AC motor to 2060 rpm in order to shoot the puck up to 60 mph. The second system is a 4 – bar crank slider that will be design by Eddie. This mechanism will be be a 4 bar linkage that uses a programmable stepper motor to to feed the hockey pucks. The pucks will be gravity loaded and the piston will retract far enough for one puck at a time to fall and then be pushed forward into the fly wheel to project the puck. The last system is an indexing system that will be designed by Connor. This system will involve a gear and pinion gear to index the entire system. The purpose of this is to be able to rotate the giant central plate between 0-15 degrees so that the puck can be projected outward at different angles to the player receiving the passes. This system will also use a stepper motor which will be programmed to set the angle of the gear before firing the pucks. The central plate will ride on a turntable bearing for ease of rotation. All three systems will be wired to switches for ease of use for the user. With all systems implemented, the machine will be able to shoot 24 pucks, up to 60 mph, at a variety of different angles to keep the user on their toes.

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					

Figure 1- SurveyFigure 1

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")	1 Friction force (lbf)	2 speed of puck (miles per hour)	3 weight (pounds)	4 size/volume (cubic inches)	5 number of pucks to load	6 110 VAC	7 cord length (ft)	8 number of persons to operate	9 traversing speed(mph)	10 operating temperature range (°F)	11 puck shooting height (ft)	12 number of wheels	13 time inbetween puck shots (seconds)	14 Cost	15	get the puck outta here	boni puck pro	hockey shot passing kit pro	x passer pro
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▼	▲	X	▲	▼	X	▲	X	X	X	▼					
1	9	20.0	0.2	shoots pucks directionally	▲	O		O					Θ		O			Θ		5	0	0	0
2	9	15.0	0.2	shoot in a range of speeds	▲	O				Θ		O	O				Θ	▲		4	5	1	3
3	9	5.0	0.1	needs one person to operate			Θ	Θ	O		▲	Θ			▲	Θ	▲	▲		5	0	5	5
4	9	10.0	0.1	durable			Θ	O						Θ		▲		Θ		3	5	4	5
5	9	15.0	0.2	fires pucks smoothly	Θ	O						O	O		O		O			4	5	2	4
6	9	10.0	0.1	shoots pucks on different surfaces	O	Θ					O	▲	O	Θ		▲				4	0	2	5
7	9	5.0	0.1	plugs into wall socket easily						Θ	O	▲								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					

Figure 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

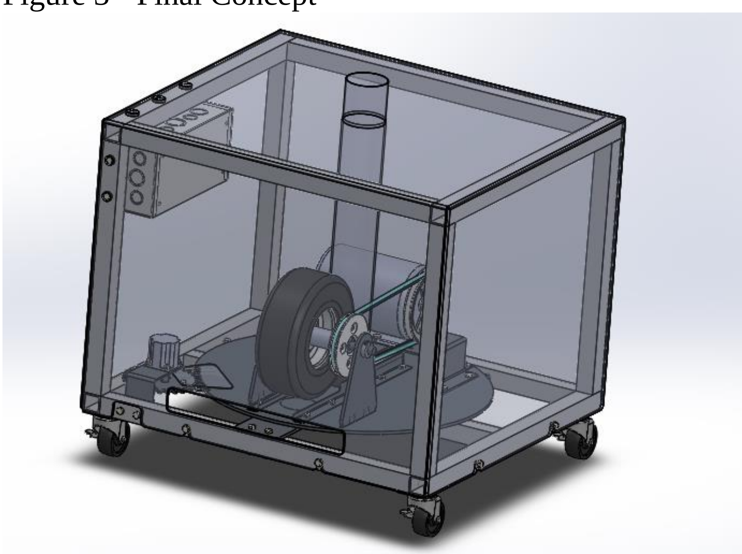
Concept #2

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

Concept #3

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

Figure 3 - Final Concept



- Single Vertical wheel
- 4 – Bar Crank Slider
- Frame mounted motor for indexing

Rotational System

The Rotational system was the last system that was needed to be designed because all the other components mount directly to the main circular gear plate. One of the most important engineering characteristics of our machine was the capability to rotate because there are no other hockey passing machines on the market that have the ability to shoot passes at different angles. The first step in designing this central plate was to determine the size. In order to pick the size and thickness I had to consider some other parameters that had already been set (frame size under 3 cubic feet & weight under 125 pounds). Next was to determine how much weight was being mounted on this plate and where it was distributed. After considering the factors above I was able to determine that a thickness of 0.25 inches was a sufficient value in order to mount all the parts, keep the part as light as possible, and still have the ease of manufacturing.

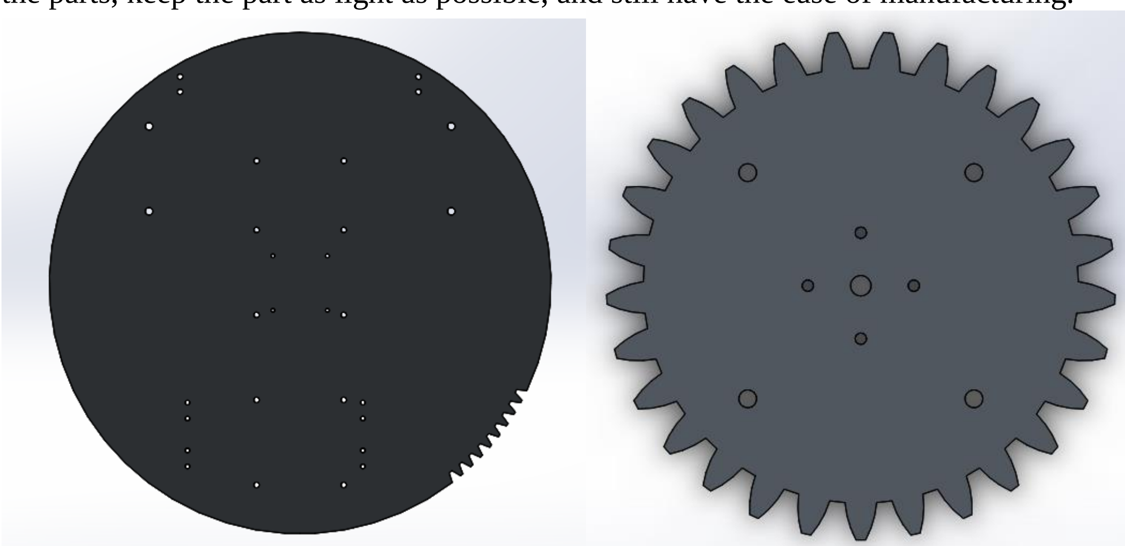


Figure 7 -Rotating Plate & 29 Tooth Gear

Next step was to determine how to make the system rotate back and forth effortlessly and we decided to use a gear system. A gear system made the most sense for this application because you can manipulate gear ratios to significantly reduce the torque applied back to your motor. I then designed the gear based on the already designed plate. I matched the thickness of 0.25" on the gear in order to ensure the teeth would remain engaged. The next decision was to figure out how the plate will spin and how/where the gear will be mounted. After doing some research online, I decided to mount the plate on a turntable purchased from McMaster Carr to increase stability and allow ease of rotation while also keeping the price low instead of investing in a large bearing. By mounting the gear and motor directly to the frame with slotted holes I was able to allow the required backlash on the motor to keep the gears from binding up. The last step was to pick the motor based off the torque and required speed. Below you can find the calculations used to select a sufficient motor for this application.

Motor Calculations:

- $Required\ Torque = I\alpha = 0.195\ Nm$
- $Required\ Power = \frac{Tn}{63000} = 0.00164\ hp = 1.22\ Watts$

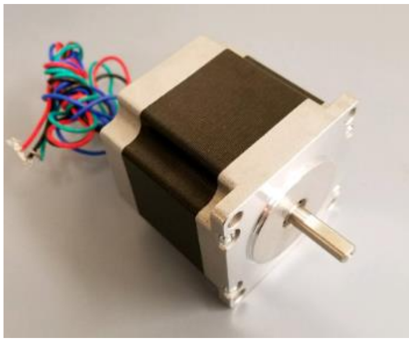


Figure 8 - Nema 23 Stepper Motor

The above motor was selected based on the required torque, speed and power needed to rotate the disk back and forth. It is a Nema 23 stepper motor with a holding torque of 1.26 Nm and 7.9 watts of power. The motor also has 200 steps per revolution which translates to an accuracy of 1.8 degrees of rotation per step. This final bit of information helped me finalize the design of the plate and gear by determining the required teeth and correct gear ratio. By predetermining the speed, distance, and user range with a hockey stick, I was able to determine a suitable amount of rotation needed for the system with the simple geometry below.

$\theta = \tan^{-1}\left(\frac{8}{30}\right) = 14.93\ or\ 15\ degrees$

$$Gear\ Ratio = \left(\frac{116\ teeth}{29\ teeth}\right) = \left(\frac{4}{1}\right)$$

$$Center\ Distance = \frac{d_1 + d_2}{2} = 368.3mm\ (14.5")$$

$$P_d = \frac{N_p}{D_p} = \frac{N_g}{D_g} = 0.197$$

$$Rec. Backlash\ (Table\ 8-5\ in\ Machine\ Elements\ of\ Mechanical\ Design) = 0.4124mm$$

$$Contact\ Ratio - m_f\ = [(\sqrt{(R_{op}^2} - R_{bp}^2) + \sqrt{(R_{oG}^2} - R_{bG}^2) - Csin\Phi)]/(pcos\Phi) = 1.74$$
$$> 1.2\ (Inustry\ Standard)$$

$$Force\ on\ Teeth -\ F_t = \frac{2T}{D_p} = 0.078\ N$$

$$Separating\ Force - F_n = F_t cos\Phi = 0.028\ N$$

$$Max\ Force - F_r = \frac{F_t}{cos\Phi} = 0.083\ N$$

$$Surface\ Speed - V_m = \frac{\pi D_p n}{1000} = 0.00994\frac{m}{min}$$

$$Dynamic\ Bending\ Force - F_s = \frac{S_n Y b}{P_d} = 1.657\ N$$
$$Force\ Transmitted - F_d = \frac{600 + V_m}{600} F_t = 0.078\ N$$
Safety Factor of Gears – 1.25 < N < 1.5 – Medium Shock, frequent starts N = 1.3
$$\frac{F_s}{N} > F_d - \rightarrow 1.27 > 0.078$$
I used the calculations above to make sure that the gears would properly engage each other as well as handle the stress of the torque from the motor exceeding industry standards to operate smoothly and safely. There are many different types of gears so it rereading our past textbook, Machine Elements of Mechanical Design I was able to decide that a spur gear design would work most effectively for this application. By basing the calculations above on the material that we selected (5052-H32 Aluminum) I knew that the gears would hold up for regular use with little maintenance other than keeping them slightly lubricated.

$$Bolt\ Torque = KDP = 0.905\ Nm$$
$$Td = \frac{sys}{2N} = FA$$
$$A = \pi r^2$$
$$D = 2r$$

- Bolt used M3, calculated Diameter= 0.48mm, Safety factor = 6.2
- Bolt used M4, calculated Diameter = 0.81 mm, Safety factor = 4.9
- Bolt used M6, calculated Diameter = 0.64 mm, Safety factor = 9.4
- Bolt used M8, calculated Diameter = 0.59mm, Safety factor = 13.4

All bolts used in mounting these parts are A2-70 Stainless Steel. The safety factors above are sufficient to make sure the parts are properly and safely mounted to avoid bolts wiggling loose and causing a dangerous situation.

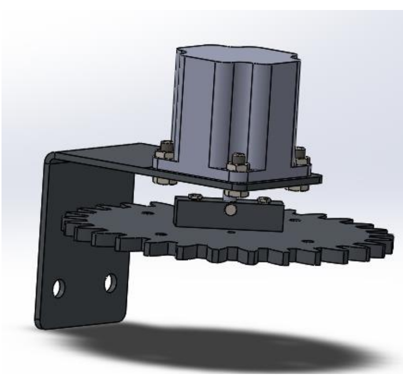


Figure 9 - Gear Mounting Configuration

Above you will see the mounting configuration to attach the motor to the gear and mount the system to the edge of the frame. By adding a tapped block to the top of the gear we can now drive a bolt into the flat surface of the shaft locking it in place and allowing the gear and motor shaft to rotate at the same rate as one.

Below you can find all of the Finite Element Analysis performed using Solidworks on the components undergoing stresses for this system.

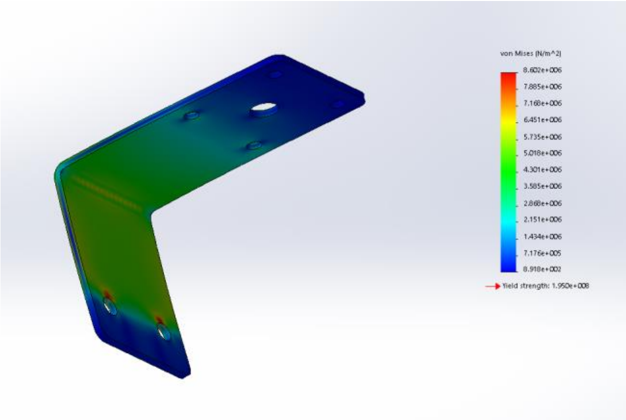


Figure 10 - FEA Gear Motor Bracket

$$Safety\ Factor = \frac{195000000}{8602000} = 22.7$$

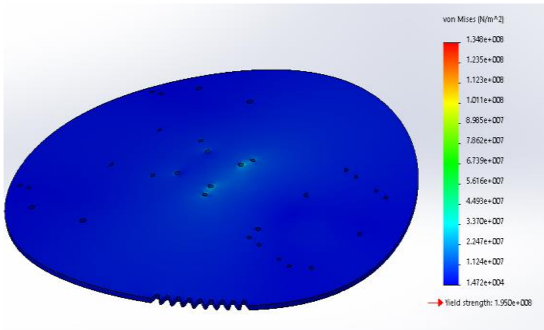


Figure 11 - FEA Rotating Gear Plate

$$Safety\ Factor = \frac{195000000}{134800000} = 1.45$$

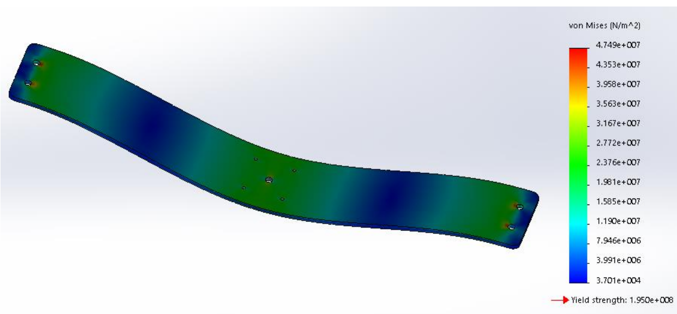
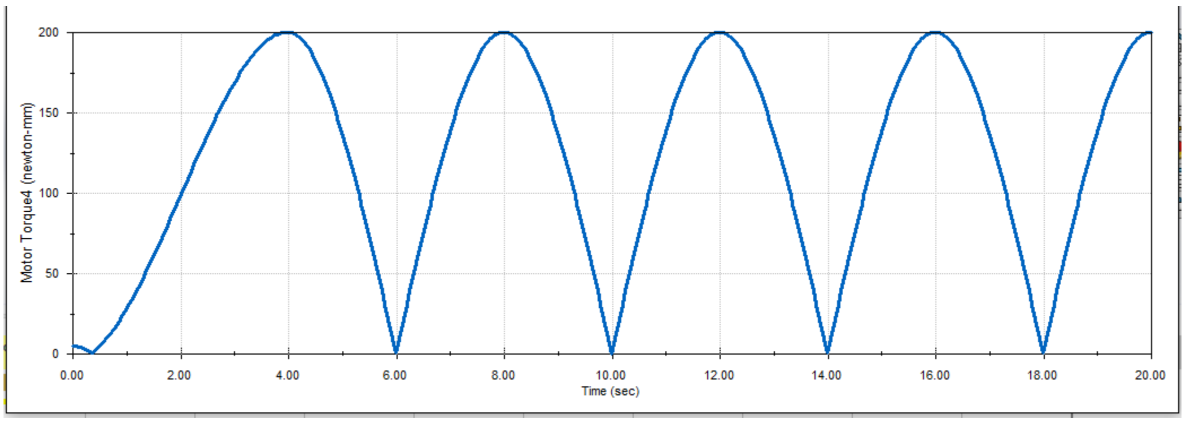


Figure 12 - FEA Supporting Cross Member

$$Safety\ Factor = \frac{195000000}{47490000} = 4.1$$

Some of the safety factors above may appear high for their particular applications but although they could handle the stress they were under, by changing the part to a thinner material, the deflection became greater than 1mm. To keep deflection to a minimum we decided to bump up the material thickness to ensure the systems would remain at their critical heights that were initially designed. Another reason to justify these safety factors is to compensate for the vibrations of all other acting systems.

Using Solidworks Motion Analysis I was able to depict the following graph to show the torque back on the motor as it cycles back and forth.



Graph 1 - Motor Torque vs Time

As seen in the above graph, the torque back on the motor reaches its highest point when changing direction. Every 4 seconds the gear rotates 60 degrees which subsequently rotates the plate gear 15 degrees in the opposite direction and then instantaneously switches back direction based on the code written in the programmable logic controller. Each time it switches direction the torque reaches its highest point until the next 4 second interval.

One of the major reasons the parts were designed as they were was for ease of manufacturing. My company, R.A Jones was kind enough to manufacture many of these parts for me. My company does a lot of sheet metal working so it was a no brainer to utilize the high powered precise laser that we have in house. By keeping nearly all the parts to four different thicknesses of metal sheets, keeping them all to one material (5052-H32 Aluminum), and minimizing machining processes we were able to significantly make the manufacturing process easier, while also reducing time to manufacture the parts.

Table 1 - Bill of Materials

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	-

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	-

MANUFACTURING AND ASSEMBLY

The manufacturing of all parts took place at R.A Jones.(Refer to the appendix for drawings) Using a variety of machines which will be mentioned later, we were able to obtain 30 different/unique fabricated parts to perfection. The help from Jones is really what helped make this project manageable. Not only having all the parts made, but having the costs covered really saved us time and resources in order to focus on testing and getting the machine to operate. All of the machines used in the manufacturing of parts are listed as follows, a Trumpf laser, a Trumpf press brake, a lathe, a 3-D Printer (Fortus 360md), a router, a horizontal maching center (Toyoda), a weld booth and tapping/deburring station.

For simplicity of design and ease of manufacturing, 16 of the 20 parts (not including frame) were all burned on a Trumpf laser. By designing these 16 parts to only three different thicknesses, Jones was able to manufacture all the parts we needed in three different runs of the laser. After the laser all parts move to the tapping and deburring station. To save Jones own employees time, I deburred and tapped all parts to finish the parts or get them ready for the next machine.

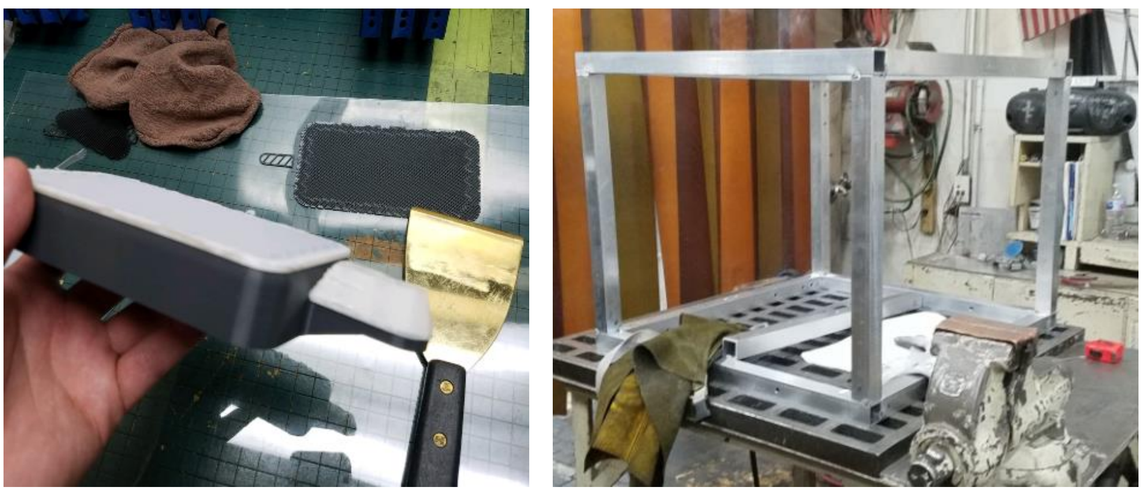


Figure 13 - Manufacturing Processes – 3-D printed piston (left) & frame tack welded in preparation for final welding (right)

The parts in need of bending would then be taken to the press brake and would be bent according to the flat patterns on the drawings. As seen above the frame was welded using gas tungsten arc welding in a booth by one of our expert welders. He first tacked the frame pieces in place to make sure it was assembled correctly, and then welded a fillet on each joint to give the frame extra rigidity. The picture above on the left is revision 1 of our 3-D printed piston. The pistons purpose was to push the hockey puck into the fly wheel. It was made of grey nylon and took about 2.5 hours to manufacture. Afterwards the tool seen in the picture was used to break away the extra supporting plastic while the part was being made. It then soaks in the tank until later dried off and ready for use.

The remaining parts were completed on the router, the Toyoda, and the lathe. We used 6mm Lexan, which is a durable and bendable see-through plastic for the cover of our machine. This allows the user to see the functionality of the machine as it runs. The shaft happened to be a stock size but was then put onto the Toyoda to be mill out a keyway to ensure the shaft would remain fixed in the uprights. Lastly, a lathe was used to turn down a step in our hopper. The hopper was made of polycarbonate. It’s dimensions are 2 feet long, with a 3.5 inch O.D. and 3.25 inch I.D. In order to secure the hopper once the cover was placed on, we had it turned down $1/16^{th}$ of an inch which was just big enough of a step to hold it in place.

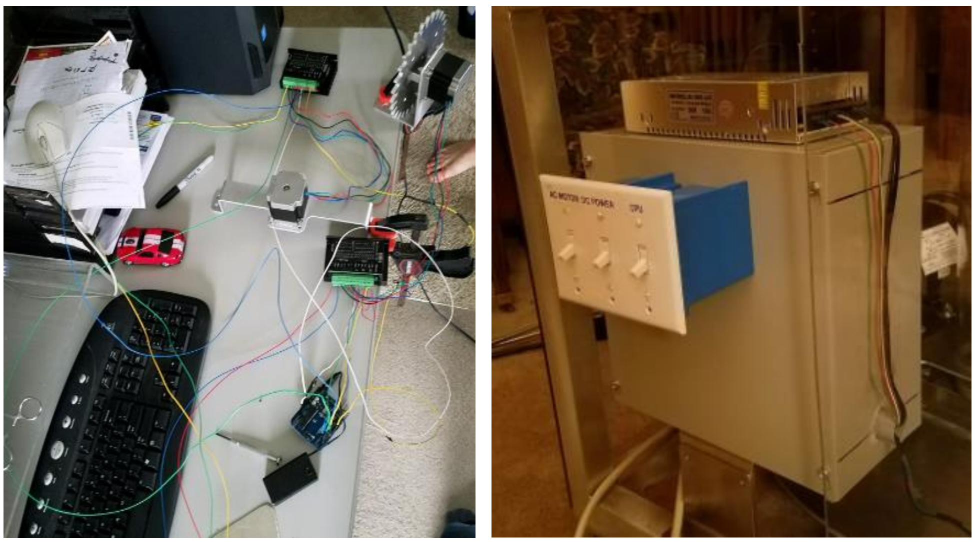


Figure 14 - Electrical Wiring

Assembling the majority of the machine was very straightforward. A2-70 Steel bolts, nuts, and washers were used to assemble all parts onto the frame and plate. Standard tooling such as socket wrenches were used to tighten down the bolts securely and safely. The key to assembling the entire machine successfully was to assemble it in the correct order.

Having three mechanical engineers made wiring the motor drivers, programmer, and switches to power everything was a fun but challenging new task for us to tackle. Pictured above on the left is all the wiring used to go from the programmer (Arduino) and motors to the drivers. Above on the right is the electrical enclosure we managed to organize the drivers, programmer, and wires in. Situated on top of the enclosure is our power supply which was strategically placed to allow its’ fan to be put to use and keep it cool. Overall assembly of every part took about 3 days in total.

Figure 15 - Final Product

TESTING

Testing of the machine was perhaps the trickiest and most fun part of the entire project. The first testing we did was to make sure we could write a code to communicate and tell our two stepper motors what to do. We used an Arduino Uno for our programmer (pictured below).

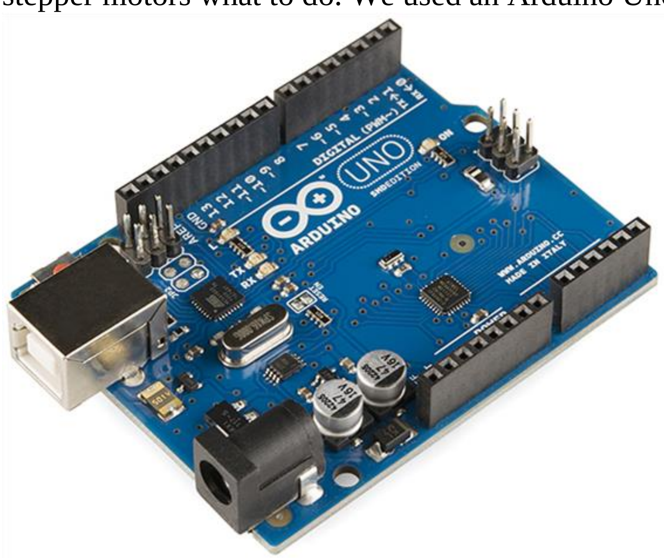


Figure 16 - Arduino Uno

We used two Adafruit V2.3 shields to interpret the code from the Arduino and relay it to our motors. We tested the motors with no loads and the program appeared to be working flawlessly. Once we mounted our motors to their respective brackets and introduced a load is where we ran into some trouble. The Adafruit shields were only capable of 12V and 3 Amps. We bought a 12V, 3 amp power supply and ended up frying half of the shield. Here is where we bought a new power supply and two new drivers which would supply more than enough power to our motors to achieve their peak torque levels. Once we rewired and reprogrammed the new drivers, the motors were capable of handling the torque with a load. For a sample from the code we used see Appendix L.

The next issue we ran into with testing was the balancing of the plate. The center of gravity was not in the middle of the plate, and therefore the plate remained unbalanced. When the plate would rotate the teeth in the plate and the teeth in the gear would not remain fully engaged. To solve this issue we purchased two transfer ball bearings and mounted them in the front and back side of the plate. This was the key to stabilizing the plate. Through testing we determined that the go kart wheel we purchased was very out of round. This was causing extreme vibrations through the whole plate and frame. To deal with this, we decided to balance the wheel ourselves. Once the tire was balanced and in combination with the transfer balls, the vibrations and noise level of the whole machine was significantly reduced.

Friction between the plate and the edge of the puck was our next issue. Although the puck was able to slide very freely on the plate, when the wheel would grab ahold of the puck it wanted to pinch and drag the front edge along the plate which caused an extreme amount of friction. In order to account for this friction we tried several crafty methods. We tried placing down different Teflon surfaces under the wheel, which worked, but the puck eventually ripped up the material. Next we tried putting parchment paper under each puck. This was a surprisingly effective solution, but the downside was extra load time and having to clean up paper trash after each puck was fired. The final key to our success was using a non-residue spray silicon lubricant. By applying the lubricant to the "runway" for the puck it created a near frictionless surface and allowed the pucks to be fired at full rate of the spinning wheel.

The final issue we ran into while testing was the full load of the pucks being too much weight on the piston retracting and extending forward. Through several trials we decided to make a type of sleeve inside the hopper. There was a ¼" of play for the pucks to bounce around side to side in the hopper. We decided to put 3M double sided tape at the bottom of the hopper. By applying two layers we were able to reduce the I.D. of the hopper much closer to the O.D. of the hockey puck (about 3 inches). Now with the load of multiple pucks, the very bottom puck was sort of trapped in the sleeve. When the piston would travel forward and backward now it would wiggle just the bottom puck free relieving much of the prior stress on the piston and allow it to fall to the plate.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

See APPENDIX K for more details

Table 2 - Preliminary Budget Estimation

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

Table 3 - Manufacturing Costs

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
Enclosure Bracket	10.41	1	25	35.41
Piston Pusher Head Rev 2	28.14	2.5	25	90.64
Estimated Total Manufacturing Costs				826.52

Table 4 - Purchasing Costs

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	32.64
Electrical Enclosure	1	26.82
V-Belt	1	8.62
Collars	4	8.45
Turntable	1	2.18
Electrical Equipment	1	321.2
Hardware	1	138.66
Total Estimated Cost		864.63

SCHEDULE, PROPOSED /ACTUAL

Figure 17 - Initial Schedule

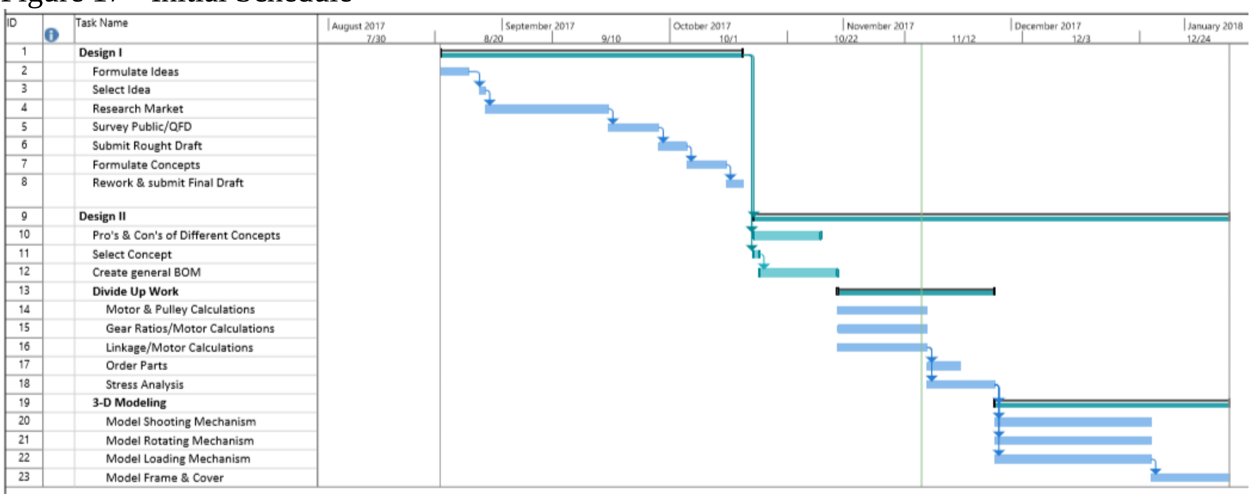
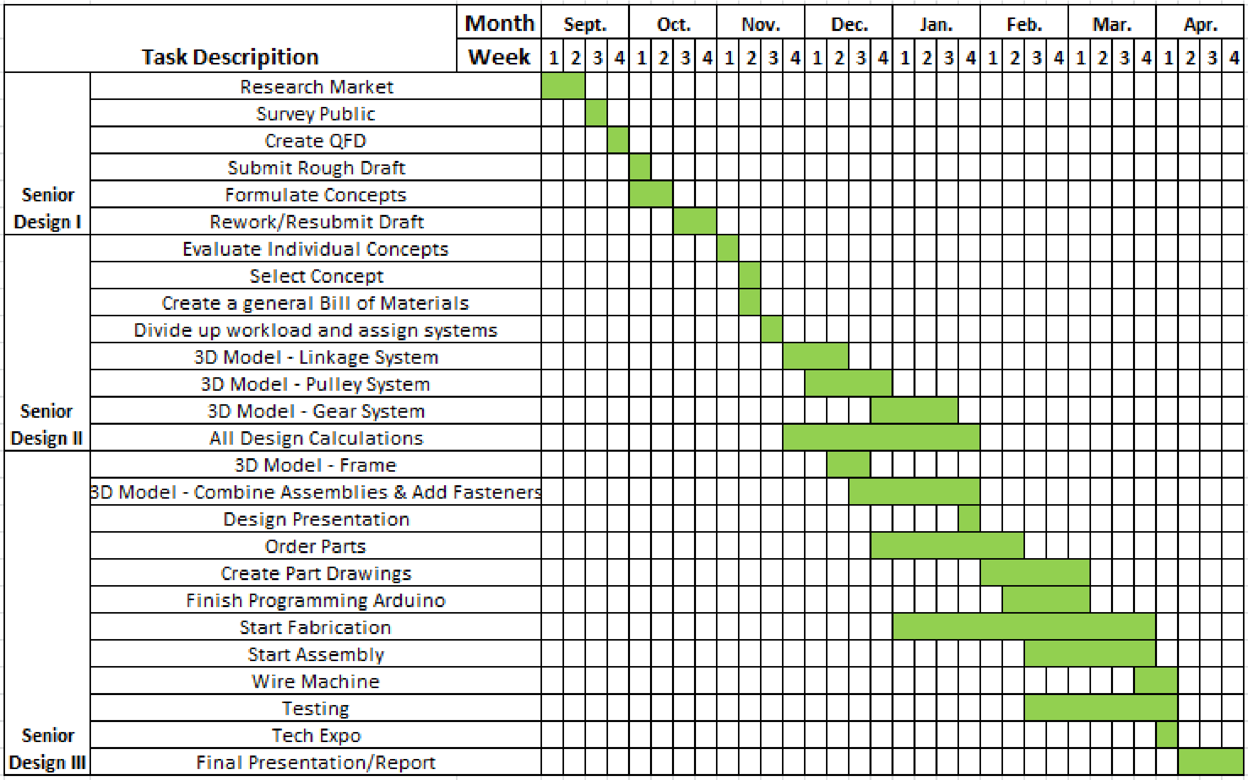


Figure 18 - Actual Schedule



PLAN TO FINISH

The main objective of the plan to finish this project is to be able to actually take the machine on the ice and measure the velocity of the pucks. We were unable to get ice time or rent a speed radar gun to this testing but this is the only true way to determine if we achieved what we set out to do. In the complete second overhaul of this machine there are several design changes we would have made. The first change would be to find a more powerful and higher torque stepper motor for the 4-bar crank slider. We were only able to shoot 15 pucks at peak torque with the current motor. Finding a higher torque motor would solve the issue of jamming we were experiencing. The next part to be redesigned would be the plate teeth and gear teeth. We would add a significant amount more teeth to both and make the teeth much finer. This would allow us to have much finer adjustment of the angle that the puck is shooting out at. Although we were able to achieve the back and forth angle of 15 degrees, we ideally would like to shoot randomly and a smaller degree of angle. We would like to redesign the system to shoot pucks without any lubricant at all. In order to do this we would add either an idler wheel or some conveyor rollers underneath the wheel to eliminate the heavy amount of friction we experienced. Lastly, we would design to compact the design as much as possible to reduce material costs.

Overall I had a very enjoyable experience working from the start to the finish of this project. It was very rewarding to see parts designed and then created and then assembled. Although we ran into some rough patches during testing having the machine become operational was very satisfying. The machine was able to shoot 15 pucks, at 2 different maxed out angles, and at an unknown (fast) velocity. Our efforts were enough to help us achieve 1st place of 26 teams at the 2018 MET Tech Expo.

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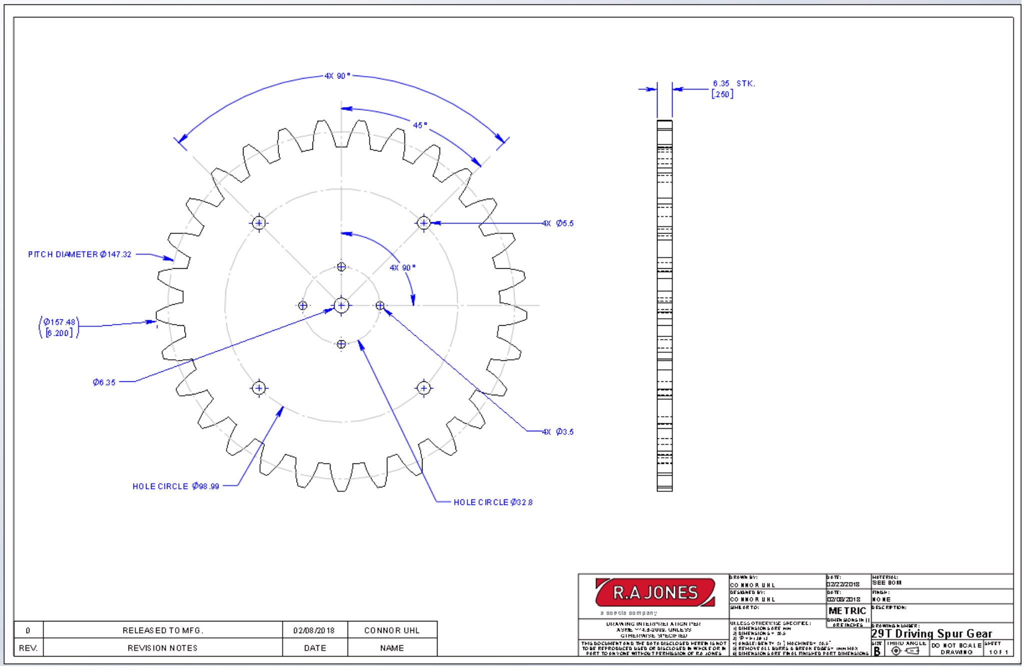
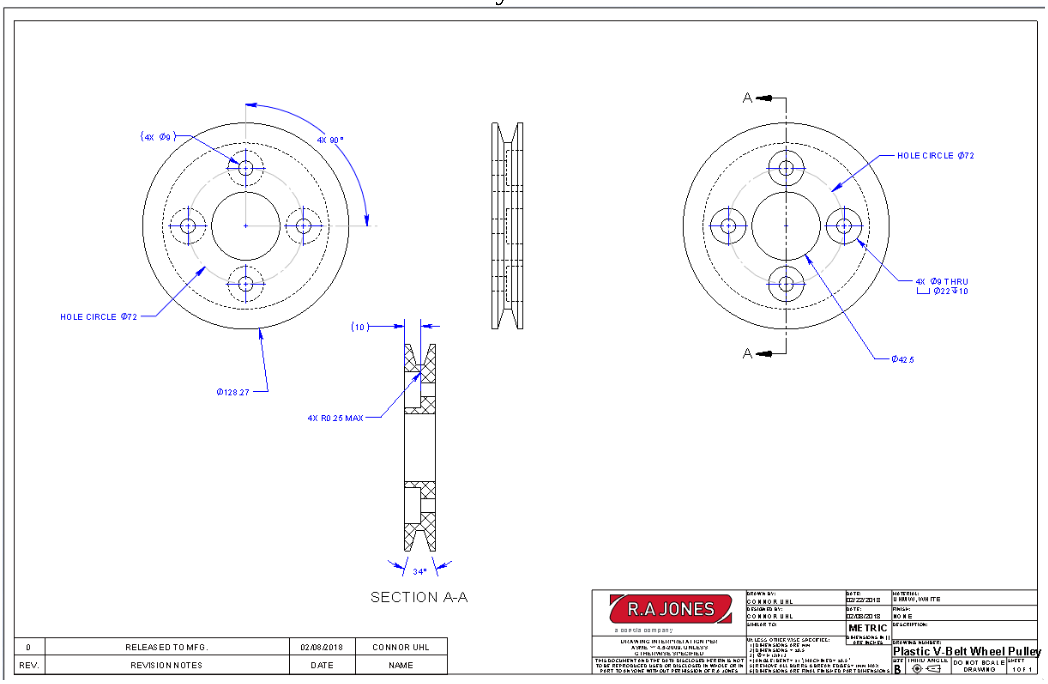
APPENDIX A

Part Name: 29T Driving Spur Gear



Manufacturing Processes: Cut 0.25” 5052-H32 Aluminum on laser and deburred teeth.

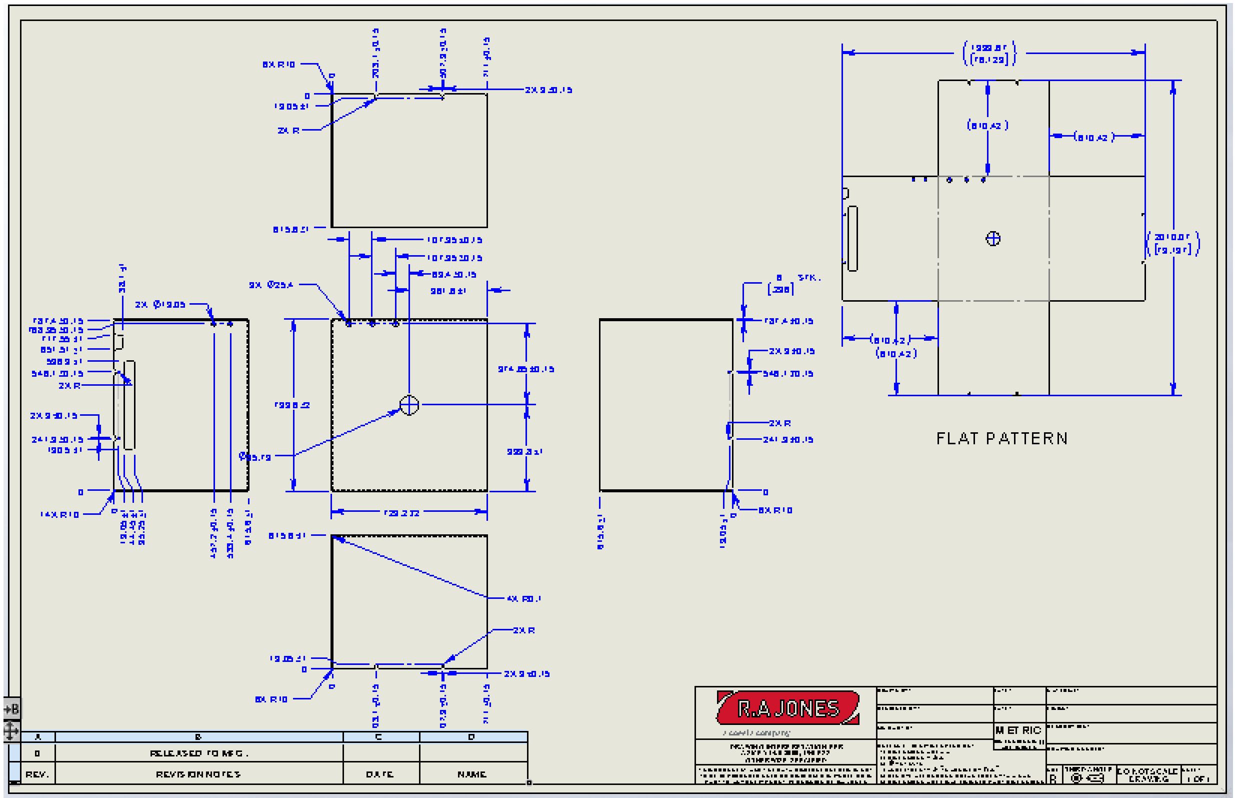
Part Name: Plastic V-belt Wheel Pulley



Manufacturing Processes: Counterbored on horizontal lathe.

APPENDIX B

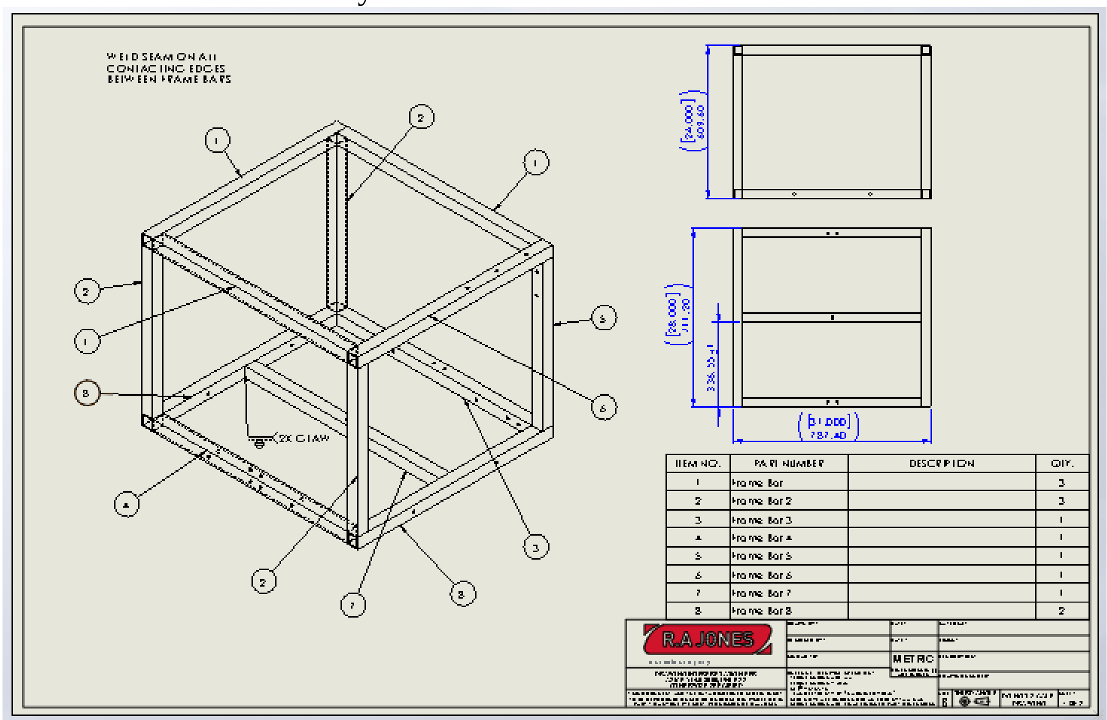
Part Name: Cover HPP

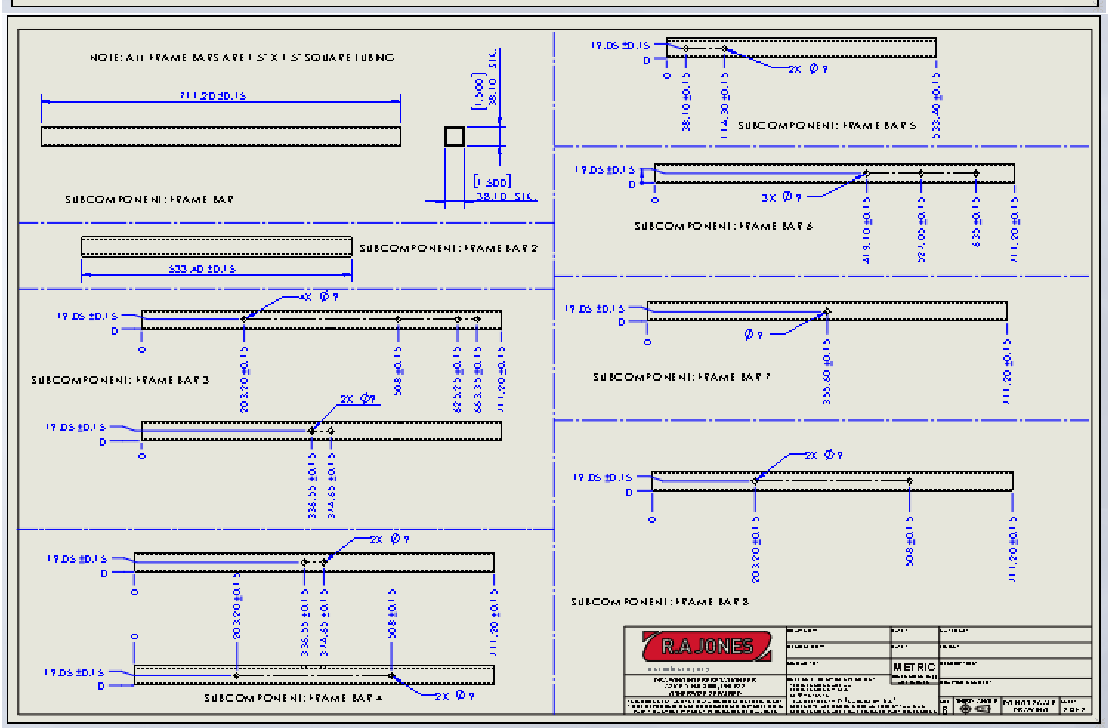


Manufacturing Processes: Cut out of Lexan on a router and then bent on a press brake.

APPENDIX C

Part Name: Frame Assembly

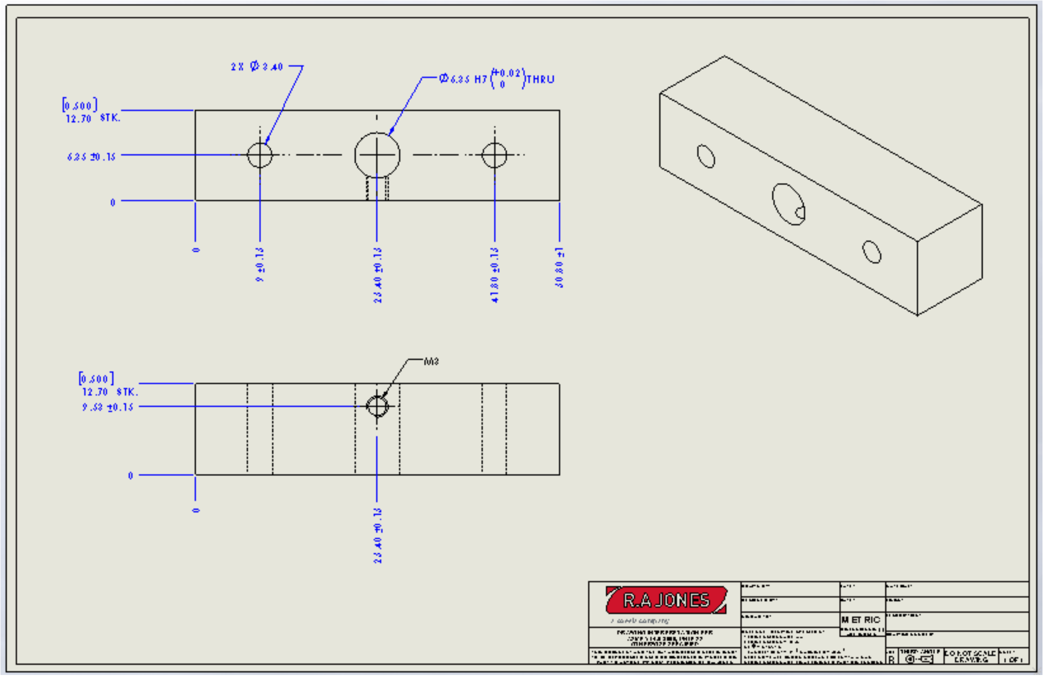




Manufacturing Processes: 5052-H32 Aluminum 1.5” x 1.5” square tubing cut on a saw and then welded using Gas Tungsten Arc Welding, and then ground down for finished look.

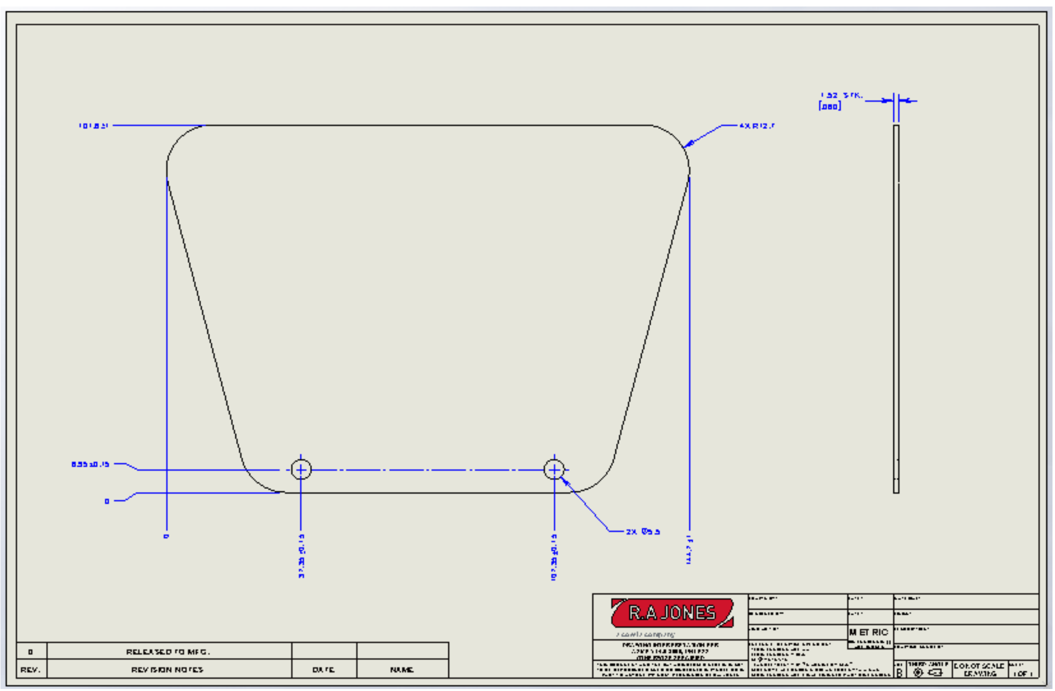
APPENDIX D

Part Name: Gear Block



Manufacturing Processes: 5052-H32 Aluminum cut bar stock and tapped and drilled.

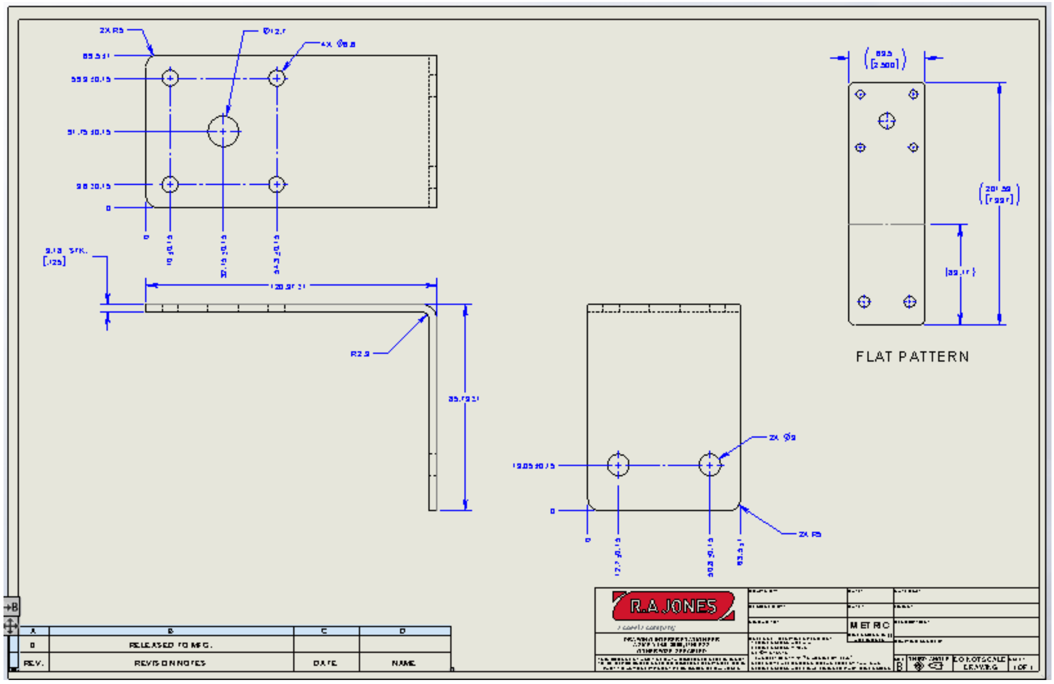
Part Name: Gear Cover



Manufacturing Processes: Cut 16 Gauge 5052-H32 Aluminum using a laser.

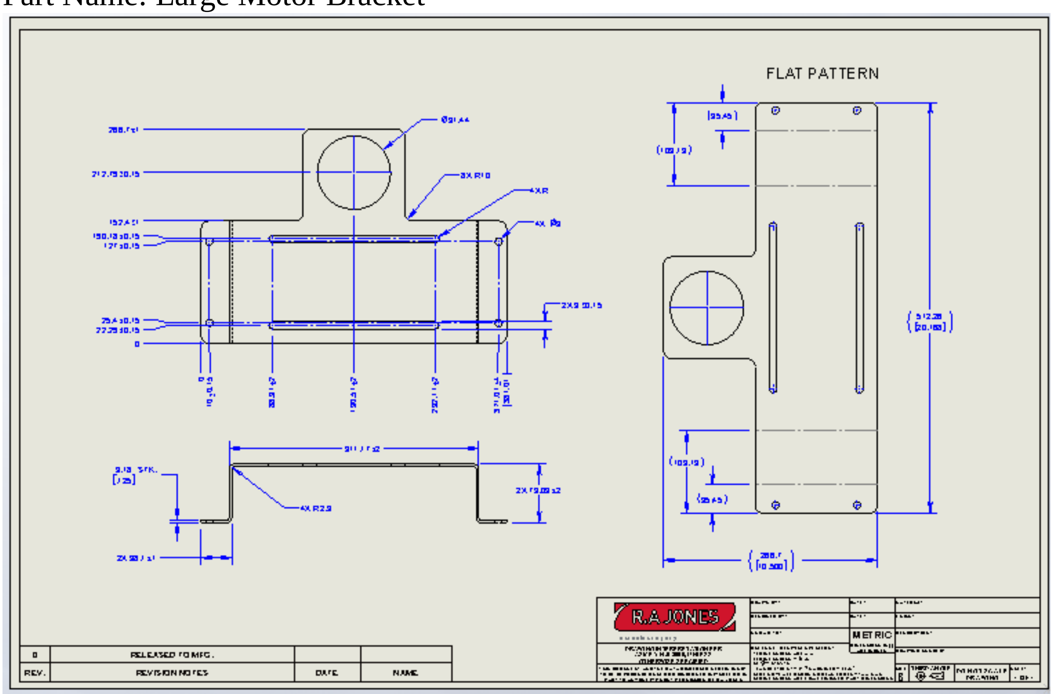
APPENDIX E

Part Name: Gear Motor Bracket



Manufacturing Processes: Cut 11 Gauge 5052-H32 Aluminum using a laser and bent on press brake.

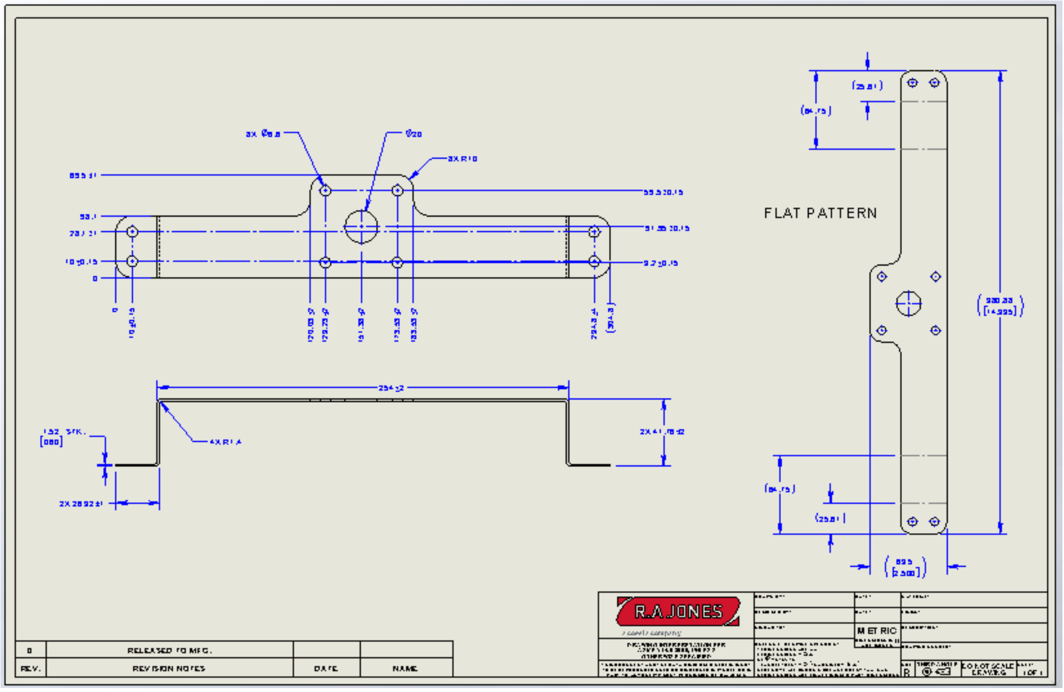
Part Name: Large Motor Bracket



Manufacturing Processes: Cut 11 Gauge 5052-H32 Aluminum using a laser and bent on press brake.

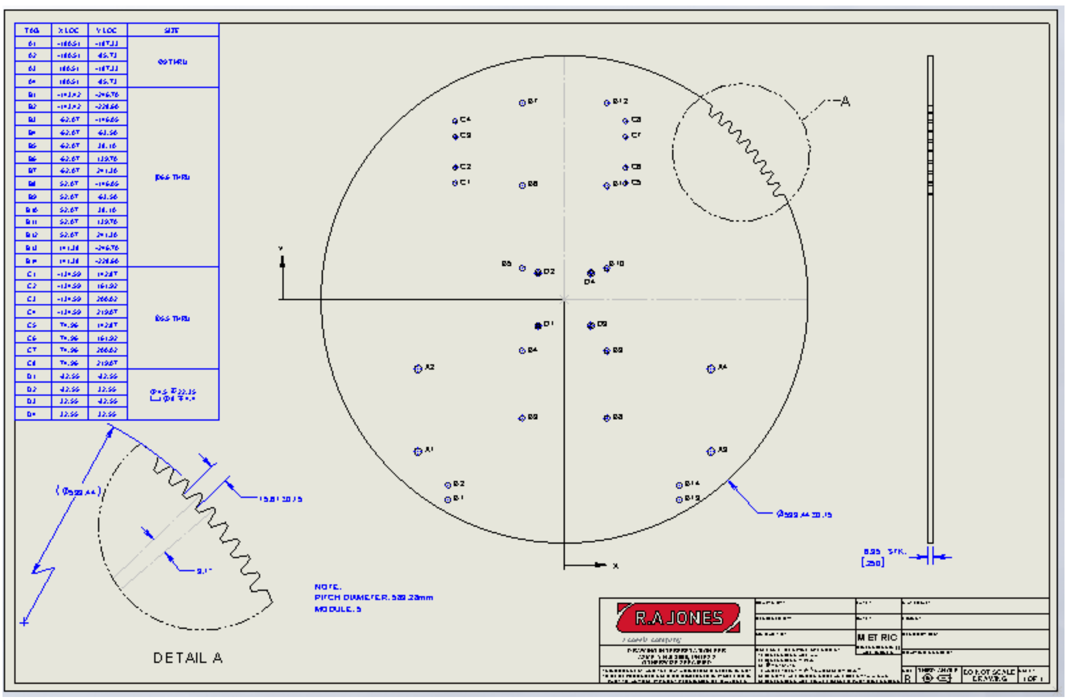
APPENDIX F

Part Name: Motor Bracket



Manufacturing Processes: Cut 16 Gauge 5052-H32 Aluminum using a laser and then bent using press brake.

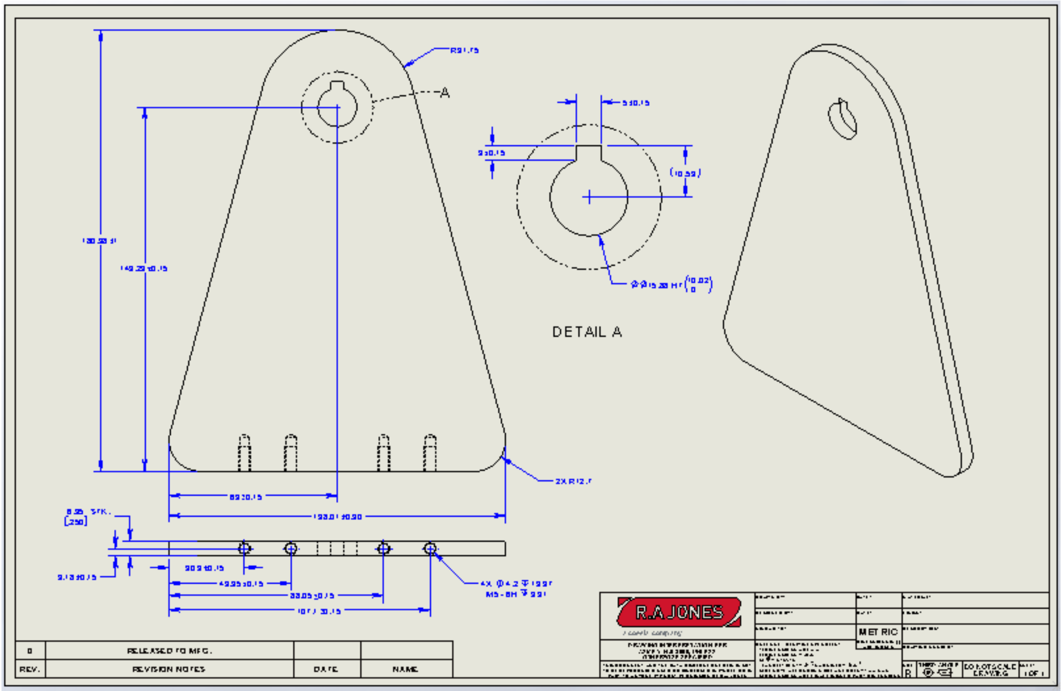
Part Name: Plate HPP



Manufacturing Processes:Cut 0.25” 5052-H32 Aluminum using laser & counterbored using mill.

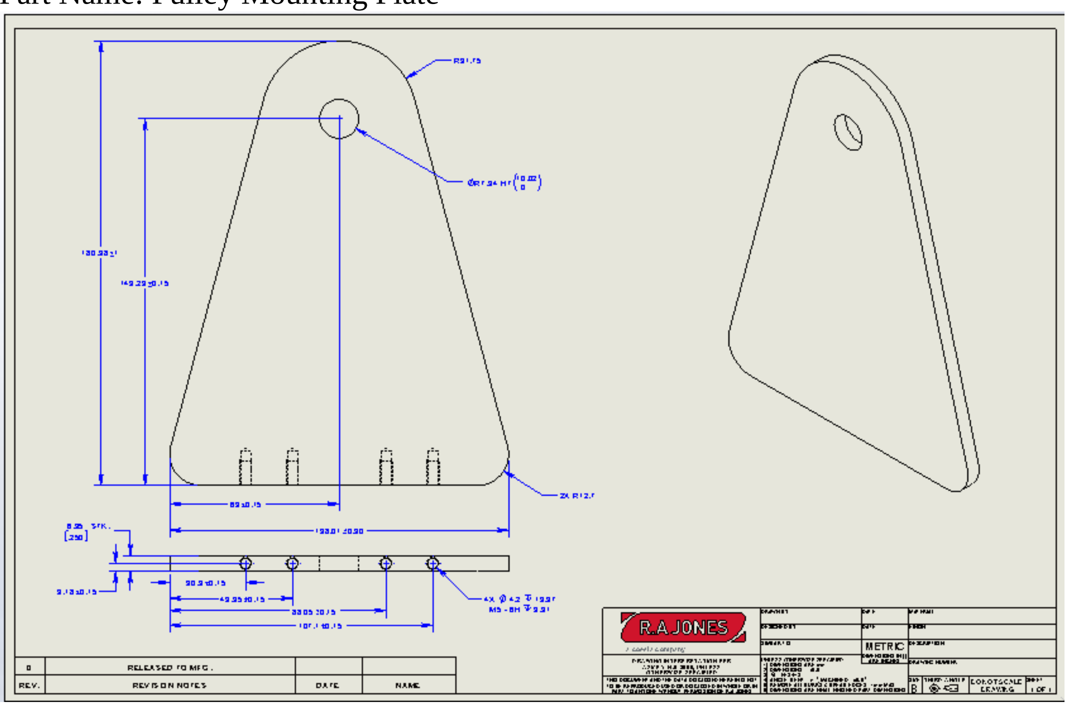
APPENDIX G

Part Name: Pulley Mounting Plate OPP. Side



Manufacturing Processes: Cut 0.25” 5052-H32 Aluminum using laser, tapped using Toyoda, and broached keyway.

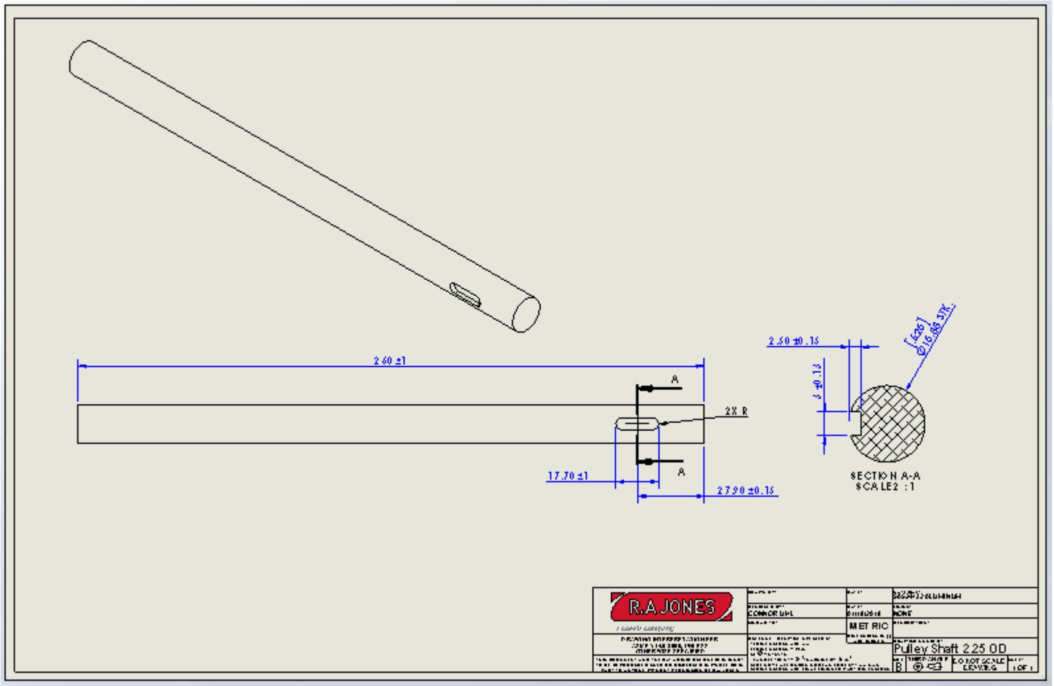
Part Name: Pulley Mounting Plate



Manufacturing Processes: Cut 0.25” 5052-H32 Aluminum using laser and tapped using Toyoda.

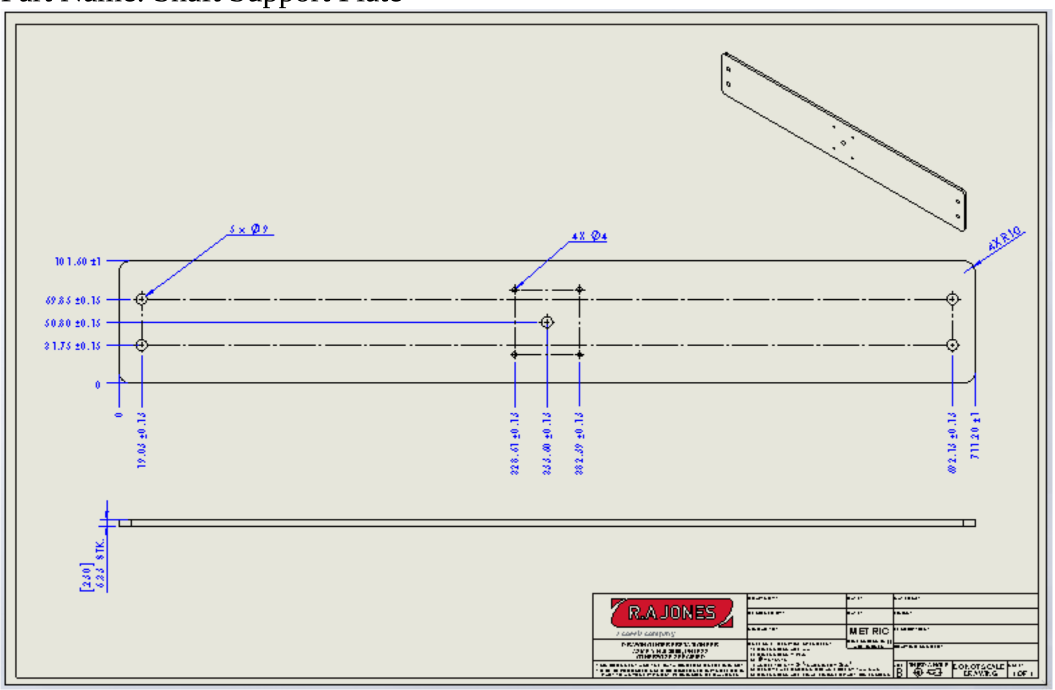
APPENDIX H

Part Name: Pulley Shaft 0.625 OD



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

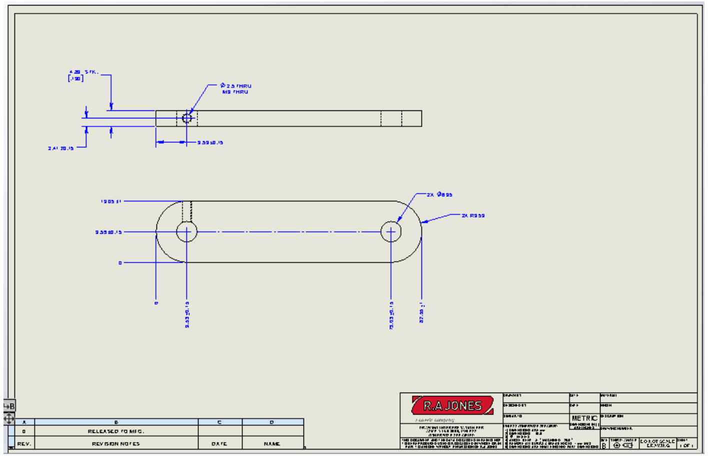
Part Name: Shaft Support Plate



Manufacturing Processes: Cut 0.25” 5052-H32 Aluminum using laser.

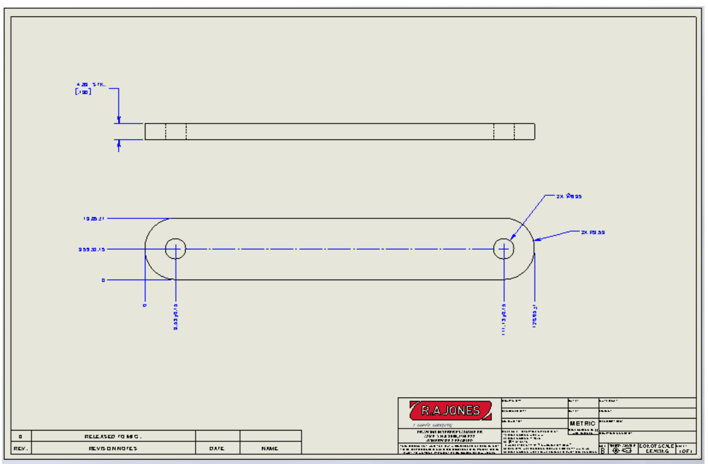
APPENDIX I

Part Name: Link - 2.5 inch



Manufacturing Processes: Cut 11 Gauge Alu5052-H32 Aluminum minum 5052 using laser & tapped using Toyoda.

Part Name: Link - 4 inch



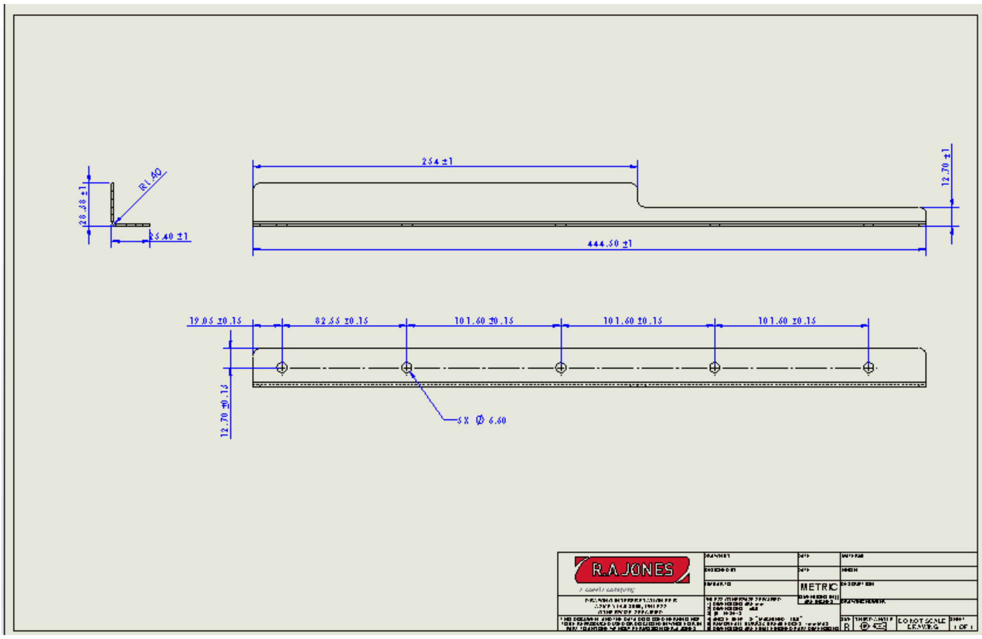
Manufacturing Processes: Cut 11 Gauge 5052-H32 Aluminum using laser.

Part Name: Pusher Head Piston

Manufacturing Processes: Printed using Nylon in 3D Printer.

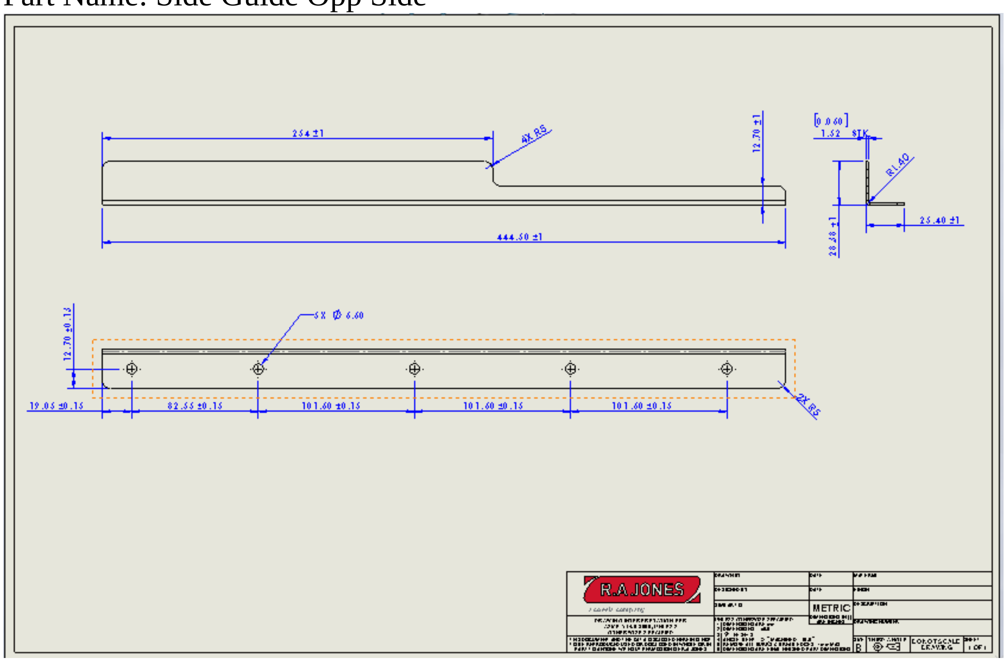
APPENDIX J

Part Name: Side Guide HPP



Manufacturing Processes: Cut 16 Gauge 5052-H32 Aluminum using laser and then bent on press brake.

Part Name: Side Guide Opp Side



Manufacturing Processes: Cut 16 Gauge 5052-H32 Aluminum using laser and then bent on press brake.

APPENDIX K

Budget Analysis:

Manufacturing Costs	~~826.52~~
Purchased Parts Cost	864.63
Total	864.63

Estimated Budget	1200
Estimated Savings	335.37

R.A Jones handled the manufacturing costs; therefore the total budget will be $864.63 which saved us $335.37 from our initial budget estimation.