Cardiovascular Conditioning Machine For Sled Hockey Athletes

A Baccalaureate thesis submitted to the
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Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

In order to fulfill his requirement for the Cincinnatus Scholarship, Michael Bennett joined the Cincinnati Icebreakers sled hockey team as a volunteer. For three years, Michael has been on the ice coaching and assisting the players. One of the adults responsible for the management of the team has an affiliate strength and conditioning program, Iron Core, that consists of University of Cincinnati students who train the Icebreakers players. The nature of sled hockey is that it is very accessible to disabled athletes, typically those without use of their legs. The conception of this project started when Michael overheard that one of the players, pursuing a Paralympic career, was in need of a conditioning implement.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

It has been brought to our group's attention that there was a lack of accommodated fitness equipment provided to a paraplegic hockey team called the Ice Breakers. A project is needed to design, prototype, and test a new fitness equipment machine to aid them in their training.

RESEARCH

BACKGROUND AND SCOPE OF THE PROBLEM

The Cincinnati Ice Breakers is a sled hockey team based in northern Cincinnati. Sled hockey is a sport where the athletes are seated in a in a molded plastic "bucket" with two ice hockey skate blades underneath. The player is responsible for using his/her arms to propel themselves forward using two short hockey sticks that have ice picks on the butt-ends. Traditional ice hockey athletes require large leg muscles to propel themselves forward on the ice, while sled hockey athletes must use arm and back muscles. These smaller muscles tire out more quickly due to extracting less oxygen from the blood, compared to larger muscles (1). Sled hockey "shifts" (the amount a time a player is on the ice) are significantly longer than traditional ice hockey shifts, resulting in a very high amount of fatigue for the players. The University of Cincinnati holds adaptive strength and conditioning sessions weekly with physical therapy students assisting the players. Most of the sessions are very effective at strengthening the players, but it is difficult to maintain a high standard of steady state cardiovascular conditioning without adaptive equipment for that purpose. Adaptive equipment does exist for those who find themselves in wheelchairs, but they are mainly used for strength building over cardiovascular endurance (2). Cardiovascular endurance is essential to game performance because the greater the endurance, the longer the player can perform at their maximum level before fatigue. If players are fatiguing quickly and the teams is short on subs, this can have a great effect on their chances of securing a victory.

To improve athletic performance, both strength - the ability to exert force against an external resistance (3) - and aerobic endurance (conditioning) are essential. Aerobic endurance is best measured by an athlete's maximum oxygen consumption, or VO2max (3). Aerobic endurance training is typically accomplished in high-intensity interval training (HIIT), or low intensity extended duration training (steady-state cardiorespiratory conditioning). Since the athletes use their upper body and core muscles to move themselves on the ice. Traditional methods of strength training, with minor accommodations for the athlete's comfort, can still be used to train the muscle groups used for that motion. Traditional cardiovascular training methods for hockey like bike, treadmill, and skate training (4) cannot be used due to the limitations of the athlete. A deficiency arises and a new method for cardiovascular training is needed for a well-rounded training program.

Two of the current training mechanisms or implements on the market that utilize arm muscles are: the SkiErg (made by Concept 2, no patent exists), and the arm crank ergometer (made by various manufacturers). The arm crank ergometer was actually found to be an effective way to measure a person's maximum oxygen consumption (5), but the SkiErg is determined to be the most ideal machine for training sled hockey conditioning due to its larger range of motion and involvement of shoulder extension. Shoulder extension is a key movement involved in the "skating" motion that the athletes use to propel themselves on the ice. Unfortunately, the SkiErg requires the athlete to be standing on his/her feet. Even if a SkiErg were acquired for the team, adaptations would have to be made.

Since there are currently no solutions to this problem all other machines are inadequate. Our group is trying to cover the gap of allowing more advanced physical training for these athletes to better improve their performance in game scenarios. Mainly our goal is to increase their cardio endurance. From previous surveys the players feel that the current exercises are giving them the proper strength training they need, but not giving them the endurance training they need to make it through the game efficiently**.**

CURRENT STATE OF THE ART

The machine requires a resistance mechanism that the athlete will exert force against. Three existing exercise implements were selected for their resistance mechanism to be researched. Note that these machines are unable to be used on their own for a sled hockey athlete, without adaptations.

> **Viscous Damper – Sunny Health & Fitness Rowing Machine (SF-RW1205)** (6)
> Sunny Health & Fitness designed a simple, affordable rowing machine that uses a single viscous damper to apply resistance. This damper provides resistance when it is extended, but compresses with minimal force. The extension resistance is adjustable in 12 different levels. A viscous damper allows for a resistance that most closely simulates on-ice skating, and allows for a wide range of adjustment, but the damper requires an external force to compress.
>
> **Resistance Pulley – Exer-Genie** (7)
> The Exer-Genie is a small device that offers adjustable resistance as a rope passes through it. This device is intended to be used to simulate a "truck pull" event in strongman competitions, and is also used as a speed trainer. This method is quite expensive, and would consume a good portion of the budget. There also is not an opposing force that will return the device to the starting position in between reps.
>
> **Resistance Bands – Westside Barbell Plyoswing** (8)
> The Plyoswing is similar to a leg press machine, but it has the ability to use resistance bands. Resistance bands are a very lightweight option for providing resistance. One characteristic of resistance bands is that the force provided is directly related to the length that they are stretched. The bands can be oriented in ways that apply variable resistance at different paths of the movement pattern. Bands will wear out quickly, however, and would change the resistance of the machine as they wear.

END USER

The primary user of this conditioning machine will be a sled hockey athlete with full use of his/her arms, but minimal to no use of his/her legs. Spinal disabilities are also common and have minimal impact on the player's athletic performance but have a large impact on the overall height of the player. For this application, our end users range from the ages of 10-22 years. This means that our machine needs to be able to fit the smallest player in that age range and the largest player in that age range.

These athletes are responsible for propelling themselves forward on the ice per the demands of the game or practice, usually for extended periods of time. After surveying the players on the team, we found that 8 out of 13 players said they could not finish an entire game. 9 out of 13 players reported feeling soreness in their arms, shoulders and/or core as well as feeling out of breath. 7 out of 13 players said that they would utilize this machine outside of the Iron Core training provided by UC. With this information in mind we could see there being a need for the machine to be portable in some fashion or another.

A secondary user of this conditioning machine could be a coach or volunteer. Their usage of the machine will differ slightly from the players being that the coaches and volunteers are not competing, but ultimately they will be the personnel responsible for transporting this machine to different location (their practice rink or UC facility) if desired by the players. These users require no accommodations to use the machine, but the machine will still be simulating the experience of skating in a sled bucket. This can create an opportunity for the coaches and volunteers to connect more with what the players are actually feeling during a game scenario, which can create a better player to coach bond.

CONCLUSIONS AND SUMMARY OF RESEARCH

An ideal exercise implement does not currently exist on the market for a paraplegic sled hockey athlete to achieve a sufficient level of cardiorespiratory conditioning. A machine that holds the players in place while they exercise may give the team a competitive advantage. Maintaining high performance late into the hockey game will allow the team to succeed in tournaments. The machine may also improve the general health and fitness of the players. Many of the players are limited in the activities they can do, so having an exercise implement will only add to their activities list. The goal of this project is not only to create a useful athletic tool, but to give sled hockey athletes another activity to look forward to.
Multiple resistance mechanisms may be used in conjunction to optimize the performance of the machine. For example, the viscous damper could be used as the primary resistance mechanism, but a resistance band could be added to assist in the compression of the damper to reset for the next repetition. This "reset" in between repetitions appears to be the most difficult portion in selection of the resistance mechanisms. A slow reset would hinder the effectiveness of the machine, as players may eventually progress to be faster than the machine itself.

QUALITY FUNCTION DEPLOYMENT

CUSTOMER FEATURES

Portable
Accommodating to different strength levels
Fits in storage room (where the team practices)
Multi-functional (can do different movement patterns)
Ease of use and convenience (time dedication to the machine)
Safety
Increases on-ice performance

ENGINEERING CHARACTERISTICS

Mass (lbm) – the frame of the product is where most of the mass can be reduced. Using hollow structures and making the machine as minimalistic as reasonably possible is how this would be accomplished.
Resistance range (lbf) – adjustable resistance mechanisms, or adjustments that vary the leverage on the resistance mechanism (such as a resistance band that can be placed on different pegs to change the user's leverage).
Product size (cubic ft) – making the product fold or telescope can reduce the overall size.
Setup time (min) – having fewer setup steps will reduce the setup time. The fewer fasteners and adjustment points on the machine, the lower the setup time will be.
Factor of safety (ratio) – increasing the cross-sectional area of the structure and also reducing moment arms will increase the factor of safety.

HOUSE OF QUALITY

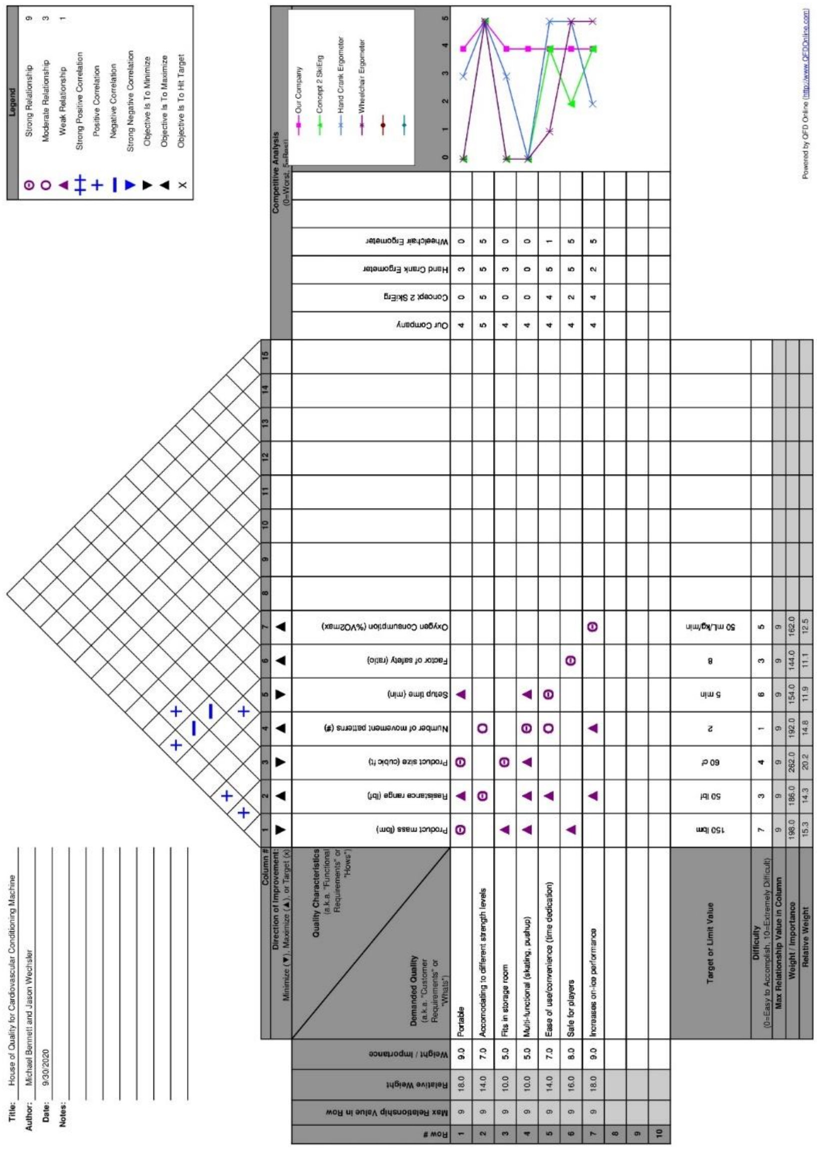

Table 1 – House of Quality

PRODUCT OBJECTIVES

18% Portable – unit must be able to be transported to different locations for the players to use.
14% Accommodating to different strength levels – novice players and advanced players should be able to use this machine.
10% Fits in storage room– the storage room has cubbies for the team to store equipment. Fitting in one of the cubbies will be very convenient for the team to use.
10% Multi-functional – the primary goal of the machine is to mimic a skating motion to achieve cardiorespiratory fitness. If other aspects of the game can be trained (such as a player pushing themselves up after their sled tips), the machine would be even more useful.
14% Ease of use and convenience – most players responded that they only had a half hour to dedicate to this machine. If the setup time is too long, the players will lose valuable time that could be spent training.
16% Safety – with the amount of force being applied by the players, the frame needs to have a high factor of safety to withstand dynamic loads and possible impacts.
18% Increases on-ice performance – the ultimate goal of this machine is to improve the team's performance by increasing their cardiorespiratory conditioning.

DESIGN

DESIGN ALTERNATIVES AND SELECTION

Below are three concepts of the resistance mechanism used in the workout machine. Only the basic structures to achieve a "proof of concept" are shown. These concepts are designed to be manufactured for testing purposes out of 2x4 pieces of wood.

Concept 1 – Viscous Damper

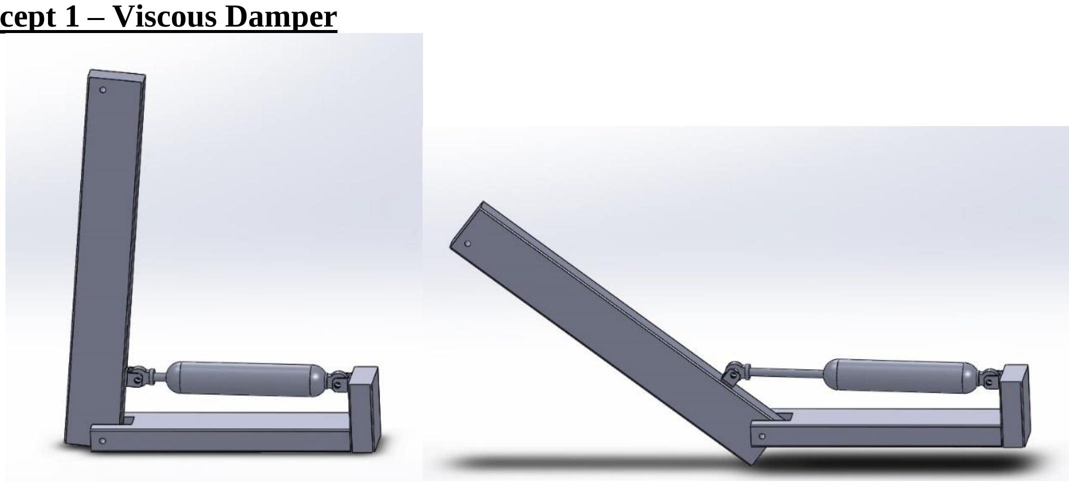

Figure 1 – Proof of Concept, Viscous Damper

The damper being used only applies resistance in extension; it can be compressed with minimal effort. The left image is the damper in compression. The right image is the damper in extension. The damper is adjustable, which will allow for multiple skill levels of players to use this. This concept is also very cost effective. The downside to this design is that it will not return between repetitions. The damper itself does not return after it is extended, so an additional force will need to be applied to reset the damper.

Concept 2 – Exer-Genie

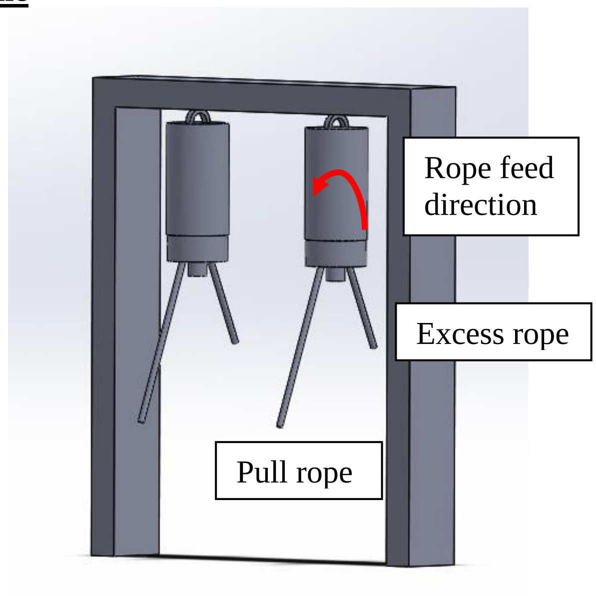

Figure 2 – Proof of Concept, Exer-Genie

The Exer-Genie is a truck pull simulator that uses a length of rope (120 feet or 200 feet available) that passes through the device. The resistance is nearly infinitely adjustable: it can be adjusted to nearly zero resistance, or it can be adjusted to a resistance beyond what an athlete is capable of training with. There is no return mechanism with this device. The athlete would have to grip the rope, make a skating motion, release his/her grip, take a grip higher up on the rope, and repeat the motion. This could be done for the entire length of the rope, but the device would have to be flipped over for the other end of the rope to be used. This method is also extremely expensive, each Exer-Genie is approximately $250, and two would be needed.

Concept 3 – Resistance Band

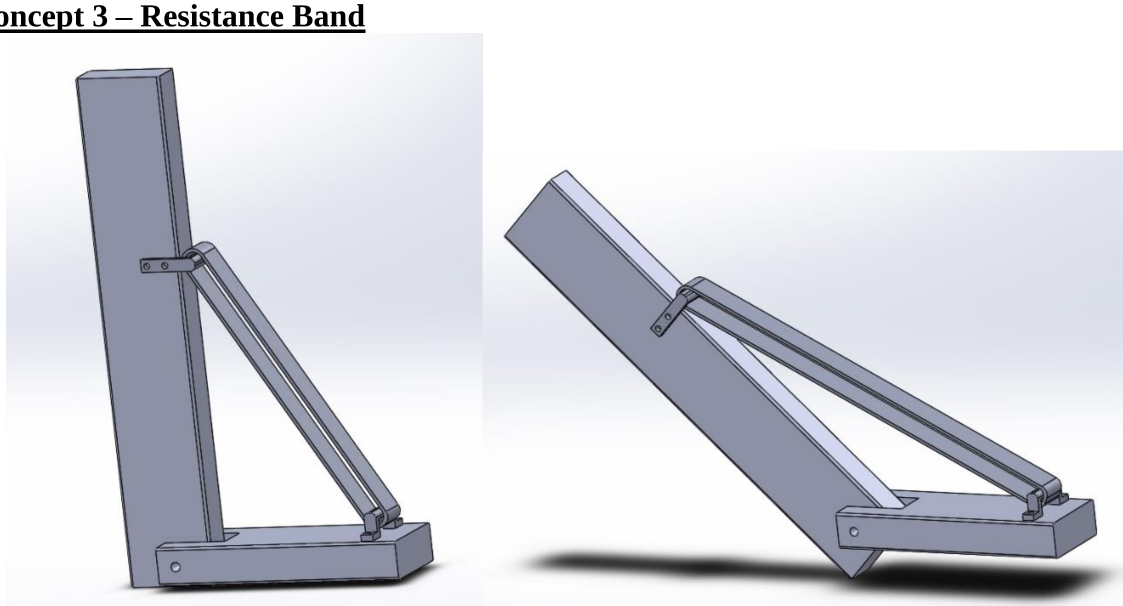

Figure 3 – Proof of Concept, Resistance Band

The resistance bands used here may be purchased from Rogue Fitness for under $20 per pair. Multiple tensions are available. The brackets may also be moved in order to accommodate different resistance levels (due to different leverage on the device). This concept is very cost effective and has a decent element of adjustability. The disadvantage of using resistance bands is the fact that the force is proportional to the distance stretched, so the resistance increases as the athlete gets farther into their skating stroke. In reality, the sled hockey athlete feels more resistance at the beginning of their skating stroke, and less resistance as they gain momentum and finish the stroke. Resistance bands can also be stretched from consistent use, and require frequent inspection to avoid the bands breaking during use.

Decision Matrix:

Criteria	Concept 1 Damper	Concept 2 Pulley	Concept 3 Band
Safety	10	9	3
Cost	9	1	10
Ease of Use	8	2	6
Resistance Range	8	10	6
Weight	6	5	10
Total	**41**	**27**	**35**

Table 2 – Resistance Mechanism Selection Criteria

The concepts were weighted based on relevant product objectives. The best concept is concept 1, viscous damper. The only downside of the viscous damper is that it requires an additional force in order for the machine to return in between repetitions. Thus, concept 3, resistance bands, was also selected to be used. A combination of concept 1 and concept 3 will provide the athletes with an effective resistance mechanism that satisfies all criteria. The only low rating was for the safety of the resistance bands. When the resistance band is used in conjunction with the damper, however, the machine is very safe. The viscous damper will be the primary resistance mechanism, while the band will serve to return the machine. If a resistance band breaks, it will not cause injury to the player. The combination of resistance bands and the viscous damper will allow a variety of different strength users to use our machine. The adjustment of the resistance setting should be very simple, and the design is safe. The viscous damper is very unlikely to fail, and the resistance band has minimal stress on it.

Engineering Calculations

List of equations

Bend stress

$$\sigma_b = \frac{MC}{I} = \frac{Moment * distance\ from\ centroid\ to\ edge}{Moment\ of\ Inertia\ of\ cross - section}$$

$$I_{square} = \frac{s^4}{12}; s = length\ of\ edge$$

$$I_{cylinder} = \frac{\pi D^4}{64}$$

$$M = F * d$$

Direct shear stress

$$\tau_d = \frac{F}{A}$$

Tensile stress

$$\sigma = \frac{F}{A}$$

Torsional stress

$$\tau = \frac{TC}{J}; J = polar\ moment\ of\ inertia\ (circular)$$

$$J_{square} = .14s^4$$

$$J_{square\ tube} = \frac{2t(s-t)^4}{(2s-2t)}$$

Loading Conditions
The majority of the components used in this device are loaded dynamically.

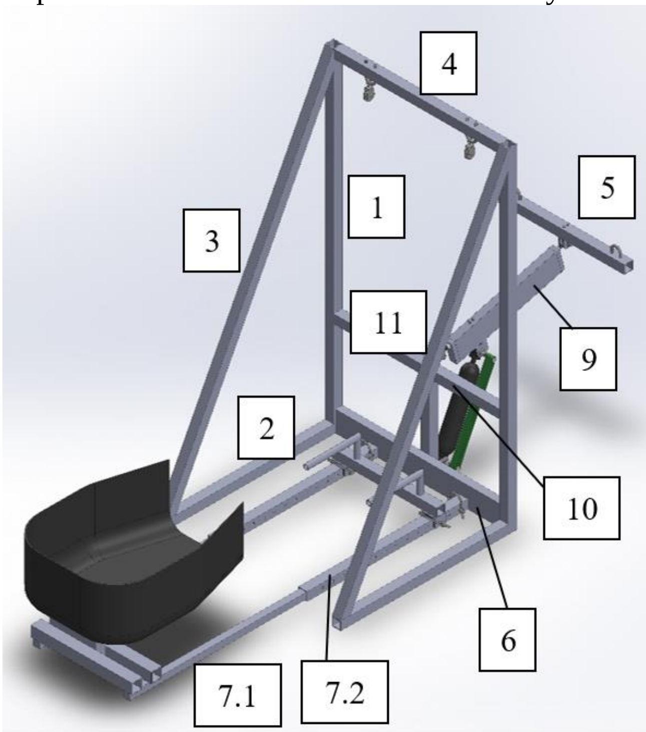

Figure 4 – Diagram of Beams

Assumptions:

F = 50lb_f, applied across two cables (25 lb_f each).

m_{player} = 150 lb_m

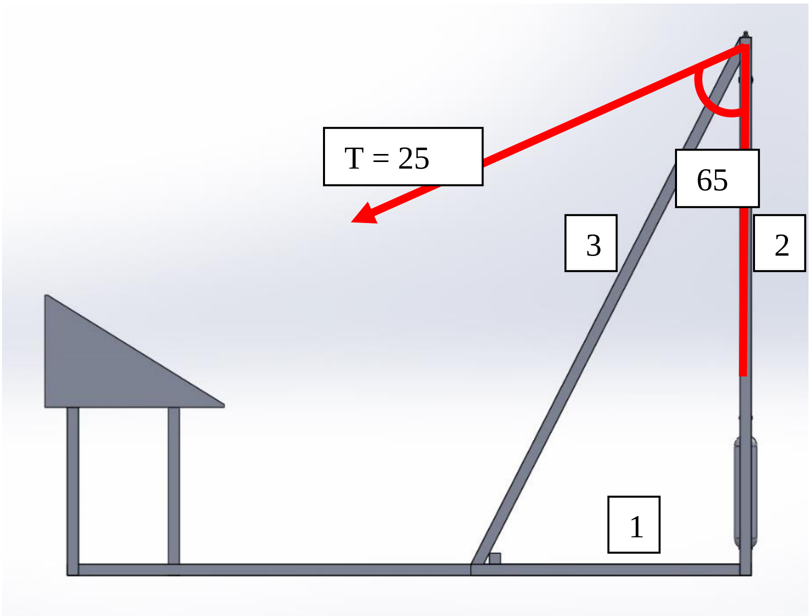

Figure 5 – Right Side View

The above image is the right side view. The cable path is shown in red. It is assumed that the angle of 65° will be maintained throughout the player's stroke.

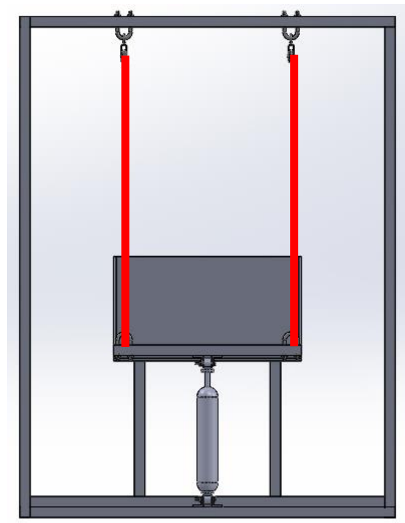

Figure 6 – Back View

The above image is the back view. The cable path is shown in red.

Below are the steps of calculating the stresses in each individual beam:

1. The reaction forces at the pulley were calculated based on the angle of the cable tension. The moment along the center axis of Beam 4 was calculated. These values are shown in the below free body diagram. The 2.68 inch measurement is the distance from the center of Beam 4 to the top of the pulley suspended from this beam.

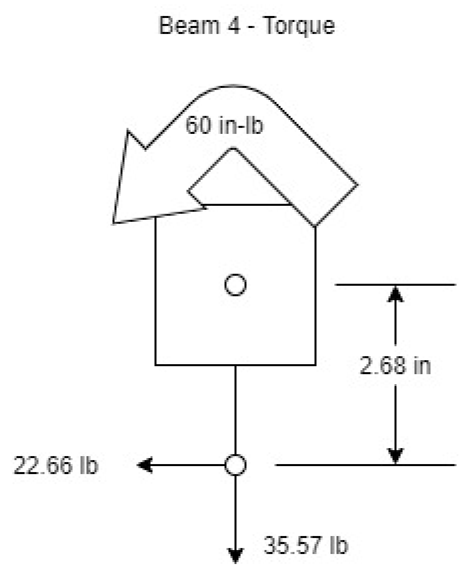

Figure 7 – Beam 4, Torque

2. The torsional stress on Beam 4 was determined to be 428 psi using the torsional stress formula.

$$J_{square\ tube} = \frac{2t(s-t)^4}{(2s-2t)} = \frac{2(.125)(1.25-.125)^4}{(2*1.25-2*.125)} = .178$$

$$\tau_4 = \frac{2TC}{J} = 2*\frac{60\ inlb*.625\ in}{.178*1.25in^4} = 337\ psi$$

3. Using the vertical force (17.8 lb_f) on each pulley, a free body diagram of Beam 4 was constructed to calculate the bend moment.

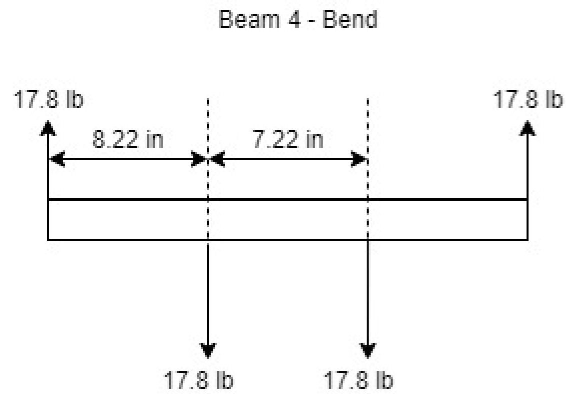

Figure 8 – Beam 4, Bend

4. The bend moment on Beam 4 was determined to be 146 inlb by creating a shear diagram and then a bending moment diagram. The bend stress on Beam 4 was determined to be 760 psi using the bend stress formula.

$$M = 17.8\ lb * 8.22\ in = 146\ inlb$$

$$I_{square\ tube} = \frac{H^4}{12} - \frac{h^4}{12} = \frac{1.25^4}{12} - \frac{1^4}{12} = .12\ in^4$$

$$\sigma_b = \frac{MC}{I} = \frac{146\ inlb * .625\ in}{.12\ in^4} = 760\ psi$$

5. The reaction forces on Beam 5 were determined from the cable tension. These forces are shown on the free body diagram below.

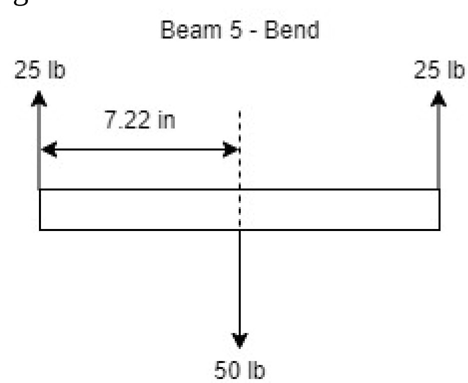

Figure 9 – Beam 5, Bend

6. The bend moment on Beam 5 was determined to be 180.5 inlb, and the bend stress was determined to be 940 psi.

$$M = 25\ lb * 7.22\ in = 180.5\ inlb$$

$$\sigma_b = \frac{MC}{I} = \frac{180.5\ inlb * .625\ in}{.12\ in^4} = 940\ psi$$

7. The moment about Beam 9 was summed up to determine F_d, the force from the damper, using the 50 lb applied force from cable tension on Beam 5. The forces in the 'Y' direction were summed to determine F_y, the reaction force on the pin joint.

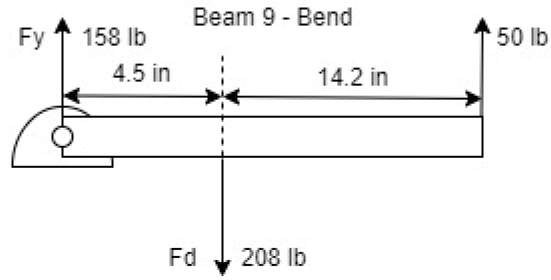

Figure 10 – Beam 9, Bend

8. The bend moment on Beam 9 was determined to be 711 inlb, and the bend stress was determined to be 1123 psi. Beam 9 is made of 1 x 3 inch rectangular tubing due to the high bend moment that it is exposed to.

$$I_{x,1x3} = \frac{bH^3}{12} - \frac{bh^3}{12} = \frac{1(3)^3}{12} - \frac{.75(2.75)^3}{12} = .95$$
$$M = 158\ lb * 4.5\ in = 711\ inlb$$
$$\sigma_b = \frac{MC}{I} = \frac{711(1.5)}{.95} = 1123\ psi$$

9. The reaction forces at Beam 6 were determined from the upward force of the damper. The reaction forces take place at the joints between Beam 6 and both Beam 7's.

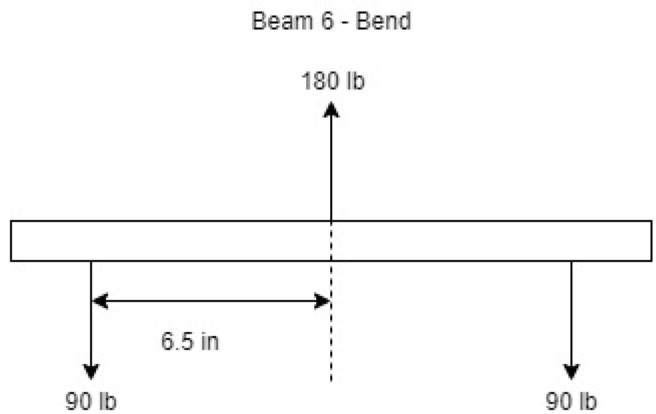

Figure 11 – Beam 6, Bend

10. The bend moment on Beam 6 was determined to be 585 inlb, and the bend stress was determined to be 923 psi. Beam 6 is also being made of 1 x 3 inch rectangular tubing.

$$M = 90\ lb * 6.5\ in = 585\ inlb$$
$$\sigma_b = \frac{MC}{I} = \frac{585\ inlb * 1.5\ in}{.95\ in^4} = 923\ psi$$

11. Beam 10 experiences tensile stress due to the upward force that Beam 9 exerts on it.

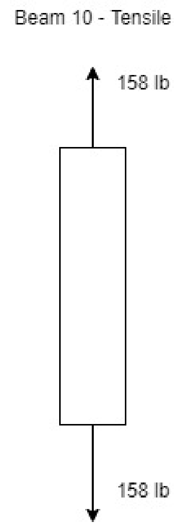

Figure 12 – Beam 10, Tensile

12. Beam 10 is subjected to 281 psi of stress.

$$A = 1.25^2 - 1^2 = .5625\ in^2$$

$$\sigma = \frac{F}{A} = \frac{158\ lb}{.5625\ in^2} = 281\ psi$$

13. Beams 7.1 and 7.2 both experience the horizontal component of the cable tension. Note that bend moment is not being calculated because the weight of the player exceeds the weight of the vertical force they exert on the cable tension.

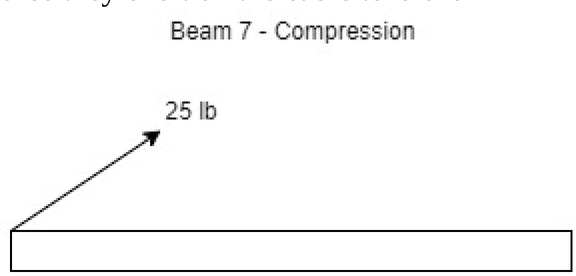

Figure 13 – Beam 7, Compression

14. Beam 7.1 experiences 24 psi of stress. 7.1 is made out of 1” square bar, machined down to 0.97 in.

$$\sigma = \frac{F}{A} = \frac{25lb * \cos 25°}{(.97in)^2} = 24\ psi$$

15. Beam 7.2 experiences 40 psi of stress.

$$\sigma = \frac{F}{A} = \frac{25lb * \cos 25°}{.5625\ in^2} = 40\ psi$$

16. The fastener holding the damper is referred to as a “shank”. This part functions like a screw to secure the damper but also holds the resistance band in place and supplies grease to the rubber of the damper. It experiences shear stress from the damper force, band force, and bracket. The highest stress is along the wall of the part between the grease port and the minor diameter of the threads.

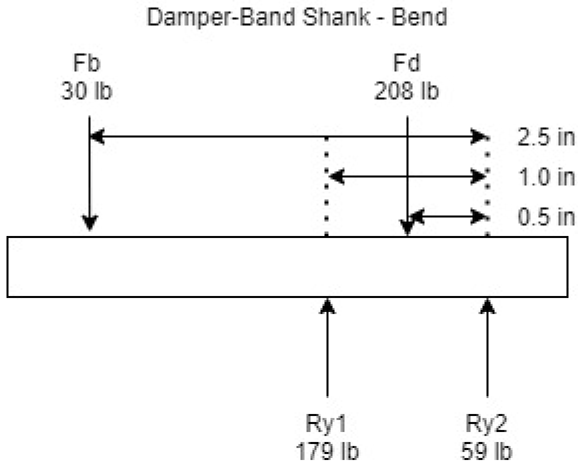

Figure 14 – Damper-Band Shank, Bend

17. The shank is subjected to 11.8 ksi of stress.

$$I = \frac{\pi(D-d)^4}{64} = \frac{\pi(.297-.125)^4}{64} = 3.7 * 10^{-4}\ in^4$$

$$M = 208\ lb * 0.5\ in = 104\ inlb$$

$$\sigma_b = \frac{MC}{I} = \frac{104\ inlb * .1485\ in}{3.7 * 10^{-4} in^4} = 11.8\ ksi$$

Material Selection Below is a chart of the stress in each component:

	Stress (psi)		
Beam	**Bend/Shear**	**Tensile**	**Torsional**
1	-	16	-
2	-	24	-
3	-	15	-
4	760	-	337
5	940	-	-
6	923	-	-
7_1	-	16	-
7_2	-	16	-
9	1123	-	-
10	-	281	-
11	-	-	-
Shank	11800	-	-

Table 3 – Stress Chart

The material selected for the chassis was 6061-T6 Aluminum. This was chosen for its high strength, low density, and affordability.

The material selected for the damper band shanks was 1144 alloy steel. This was chosen for its high strength and machinability.

Factors of Safety

The highest stress is on the shank, in shear, of 11.8 ksi. 1144 steel's yield stress is 100,000 psi. This gives us a Factor of Safety of 8.47. For dynamically loaded shear stress, the recommended factor of safety is at least 8. All of the aluminum pieces are well below the design stress. Beam 9 has the highest stress of any aluminum pieces, with a safety factor of 35.6.

$$\tau_d = \frac{s_{ys}}{2N}; N = 4;\ \tau_d = \frac{s_{ys}}{8}$$

	6061-T6 Al	1144 Steel
Ultimate strength (psi)	45,000	108,000
Yield strength (psi)	40,000	100,000
Modulus of elasticity (psi)	1.00E+07	
% elongation	17%	6.5%
Shear ultimate (psi)	30,000	
Shear yield (psi)	20,000	
Density (lbm/in3)	0.1	

Table 4 – Material Properties

MANUFACTURING DRAWINGS

All manufacturing drawings can be found in Appendix A.

Bill of Material

Parent Assembly Bill of Material:

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Beam 1	2	1.25 X 1.25 x .12 Square Tube
2	Beam 2	2	1.25 X 1.25 x .12 Square Tube
3	Beam 3	2	1.25 X 1.25 x .12 Square Tube
4	Beam 4	1	1.25 X 1.25 x .12 Square Tube
5	Beam 5	1	1.25 X 1.25 x .12 Square Tube
6	Pulley	2	Pulley 3/16 Wire Rope
7	Beam 6	1	3.0 X 1.0 x .12 Rectangular Tube
8	Beam 7_1	2	1.0 Square Bar
9	Beam 7_2	2	1.25 X 1.25 x .12 Square Tube
10	Beam 9	1	3.0 x 1.0 x .12 Rectangular Tube
11	Beam 10	1	1.25 X 1.25 x .12 Square Tube
12	Beam 11	1	1.25 X 1.25 x .12 Square Tube
13	Damper	1	Resistance Damper - Sunny Health and Fitness
14	Seat Assy	1	Subassembly
15	Footrest Assy	1	Subassembly
16	Bushing Bracket	2	Bracket to Mount Heim Joint
17	Damper Bracket	2	Bracket to Mount Resistance Damper
18	Damper-Band Shank Assy	2	Round Bar 1144 Steel
19	8880T85	4	U-Bolt 5/16-18
20	2458K141	2	Heim Joint 3/8-24
21	98416A215	2	Pin 5/16 x 1-3/8
22	98416A217	2	Pin 5/16 x 2-1/8
23	Misc. Hardware		
24	Resisance Band	1	30 lb 7/8" W x 12" L

Table 5 – Parent BOM

Footrest Bill of Material:

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Footrest Mount	2	Mounting Bracket - C Channel
2	Footrest Bushing	2	Bracket Bushing - 3D Print PLA
3	Footrest Beam	1	Cross Beam - 1.25 X 1.25 x .12 Square Tube
4	Footrest Beam2	2	Vertical Beam - .75 x .12 Round Tube
5	Footrest Beam3	2	Horizontal Beam - .75 x .12 Round Tube

Table 6 – Footrest BOM

Seat Assembly Bill of Material:

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Seat Plate	1	1/4" Thick Aluminum Plate
2	Bucket	1	IceBreakers to Supply
3	Seat Tube Inner	1	1.0 Square Bar
4	Seat Tube Outer	1	1.25 X 1.25 x .12 Square Tube
5	Seat Tube Mount	2	1.25 X 1.25 x .12 Square Tube
6	98416A215	1	Pin 5/16 x 1-3/8
7	91306A379	4	BHCS 1/4-20 x .75
8	90866A029	4	Wing Nut 1/4-20

Table 7 – Seat BOM

BUILD AND TEST

DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED

To complete this project, it was necessary to employ several different manufacturing processes to stay within the tolerances we specified for it. Some of these processes include cutting, machining, and welding.

Cutting:

Cutting was employed as a manufacturing process by utilizing a CNC bandsaw. The bandsaw was sought out as a viable method for cutting our tubing and bars to length. From co-op experience, I had found that leaving thirty thousandths of an inch on either end of the piece being cut is a valid method to ensure the piece is not cut under size and can be machined to ensure a flat, square face on either end of the work piece. The CNC bandsaws I utilized can hold tolerances as tight as ten thousandths of an inch. With our chosen tolerance being three times that number, we concluded that the CNC bandsaw would be a viable option to cut our material.

Milling/Turning:

Milling was employed as a manufacturing process by utilizing VMC (vertical machining center) CNC (computer numerical control) milling machine to mill pieces and by utilizing a lathe to turn pieces. The tubing and bars were faced and milled square on the ends in the VMC CNC machines. The VMC CNC machines were also utilized to perform drilling operations that are called out on the manufacturing drawings.

When performing the facing operations, a two-inch face mill was employed as the width of the cutter was greater than the width of our parts so subsequent radial cuts were not required. However, subsequent axial cuts were used to achieve the proper tolerances called out on the manufacturing drawings. Roughing cuts tended to be around twenty-five thousandths of an inch while finishing cuts were no greater than five thousandths of an inch. Along with this, the feed rate was decreased, and the RPM was increased by a factor of 20% to achieve a nice surface finish.

When performing the milling operations, an extended length half-inch endmill was employed. Most of the tubing had a greater width than the length of most standard half-inch endmills, so the extended length endmill was required. Each piece of tubing and bar had the ends milled flat and square where they were cut by the bandsaw. This method ensured that all pieces would fit together flush and at the proper angles required.

When performing the drilling operations, standard high speed steel drills at the sizes specified on the manufacturing drawings were employed. Since our material was aluminum, no special purpose drills were needed such as carbide or cobalt. If the material were harder and solid bar was selected over tubing, one might employ a carbide drill to reduce overall diameter gain due to concentrated heat during drilling. This carbide drill would reduce cycle times in this situation.

When performing the turning operations, standard high speed steel parting tools and carbide insert cutters were employed. Threading and drilling operations were also performed on the lathe. The threading operations used dies where the die handles were held in place with the lathe tailstock. The drilling operations used stationary drills while the work piece turned and was feed in at the appropriate feed rate through use of the tailstock. All turning was performed between centers so that the tailstock would hold the workpiece in place, reducing warped parts

Welding:
Welding was a method utilized to secure almost all non-moving parts of this machine. Some other components, such as the bucket and other various hardware, were secured using fasteners. Specifically, TIG welding was the selected method of welding for its ability to penetrate the base metal and provide clean welds with little to no surface blemishes such as porosity. The welding machine, which was of the brand Lincoln, was set to AC, allowed eight to ten seconds of excess gas, and was in the higher current range. The method of setting the welder to AC was used because that is the recommended current setting by the welding industry to weld aluminum. The strategy to allow excess gas to flow over the welds provided a shield from oxygen. Oxygen can penetrate hot welds as they cool which creates porosity weakening the welds. The strategy to use the higher current range was largely due to the fact that aluminum, when extruded from a foundry, tends to develop a layer of oxide on its outer surface. This oxide layer drastically increases the amount of heat needed to melt the metal, so a higher current range was used to ensure base metal penetration. Aside from the strategies pertaining to the welding machine, a few other manual strategies such as cleaning to work piece, beveling mating edges, and fixturing were used. It is vitally important to clean your work piece before you weld it. Cleaning the work piece by surface grinding can help remove the oxide layer and can help remove impurities that are embedded into the surface of the part such as coolant or other metals. Beveling the edges of mating parts was a strategy used to ensure base metal penetration. Since aluminum can dissipate heat due to its high heat transfer coefficient, starting deeper into the section one wishes to weld ensures that the base metal and the filler metal have ample area to fuse together. Fixturing, such as toggle clamps and other table clamps, was used to position the work pieces in the orientation desired.

In summary, the described manufacturing processes above achieved the outcome our team desired with minor errors. Aluminum is welded at higher current leaving more heat in the work piece which can cause the pieces to warp towards the area of the hot welds. This phenomena happened in a few pieces, but did not cause a critical error where mating pieces were not joinable. Methods to combat this include fixturing and welding different areas to allow the welds time to cool.

Manufacturing photos can be found in Appendix B.

TEST PROCEDURE AND CRITERIA

Our goal for this machine was to increase "on ice performance" by increasing the cardiovascular conditioning of the athletes. With greater cardiovascular conditioning, the heart can pump more oxygenated blood to the muscles in need.

Originally, we planned to use ourselves as testing subjects, but a player has volunteered themselves to be our test subject. Our criteria consists of recorded feelings from the test subject after each trial in the unit of RPE (rating of perceived exertion). RPE is determined by the player and is measured on a scale of 1-10, with 10 being a maximal effort. RPE ratings for aerobic movements tend to correlate with percentage of resting heart rate. In theory, over a week of testing, we would like to see a decrease in RPE between the beginning and end of the test weeks. We would also like the player to feel that their muscles are fatiguing less rapidly as the testing continues over its duration.

The testing procedure is as follows: 1.) Assist user into machine, 2.) Allow player to use the machine for three, five minute periods with equal amounts of rest, 3.) Player rates their exertion on a scale of 1-10, 4.) Assist player out of machine.

TEST RESULTS AND FINDINGS

Currently there are no formal test results to report. All testing so far has been informal, simply using the machine and making notes. The current concerns with the machine are as follows:

1. The chassis is not completely level due to the filler material from the welds. We plan to add dampening feet to the bottom of the chassis.
2. The resistance can be adjusted to a wide range, but the overall range needs to be lower. It is sufficient for most players, but we would like for there to be more adjustment on the lower end, less on the top end.
3. The selected resistance bands were too light. We had to use a stiffer resistance band that was not purchased for the project. The damper did not return quickly enough because of this.
4. Adjusting the machine is harder than expected. We plan to loosen some tolerances to make the sliding fits work better. The "male" square bar has a sharp 90° edge that slides into a square tube with an internal radius. If that square bar is chamfered, it will prevent the machine from binding.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

The initial purchased components list is shown below:

Part Description	*Part Number*	*Source*	*QTY*	*U/M*	*Price/Unit*	*Total*
Pulley	3213T57	McMaster-Carr	2	EA	$14.24	$28.48
HHCS 1/4-20 x 1.75	91247A548	McMaster-Carr	3	EA	$0.13	$0.38
Nut hex 1/4-20	95462A029	McMaster-Carr	3	EA	$0.05	$0.15
Wire rope	30645T169	McMaster-Carr	25	FT	$1.60	$40.00
U bolt	8880T85	McMaster-Carr	4	EA	$1.28	$5.12
Heim Joint	2458K141	McMaster-Carr	2	EA	$5.89	$11.78
1" square 6061 Al 144"	1116	Metal Supermarkets	4	EA	$56.59	$226.36
1x2 flat 6061 Al 40"	1142	Metal Supermarkets	1	EA	$72.00	$72.00
Damper		Sunny Health and Fitness	1	EA	$25.00	$25.00
2"x.188" square A500 tubing	10343	Metal Supermarkets	1	EA	$29.53	$29.53
1.25" Dia. Bar Stock 1018	1097	Metal Supermarkets	1	EA	$40.75	$40.75
1"x6"x24" A36 steel plate	12880	Metal Supermarkets	1	EA	$87.97	$87.97
18-8 Stainless Steel Pan Head Phillips Screw	91772A632	McMaster-Carr	1	EA	$7.75	$7.75
High-Strength Steel Serrated Flange Locknut	95922A120	McMaster-Carr	1	EA	$9.59	$9.59
Mounted Steel Ball Bearing with Cast Iron Housing	7728T74	McMaster-Carr	2	EA	$161.12	$322.24
16" X 16" X 1/2" A36 steel plate	15688	Metal Supermarkets	1	EA	$219.87	$219.87
.5" Dia. 4340 alloy steel bar stock	25262	Metal Supermarkets	1	EA	$6.37	$6.37
Light Duty Dry-Running Nylon Sleeve Bearing	6389K451	McMaster-Carr	2	EA	$16.77	$33.54

Table 8 – Initial Purchase List

The grand total of this list is $1167, and an initial budget was set to $1500 to cover any extra material cost or possible outsourcing of manufacturing.

The list of actual purchases made is shown below:

Materials Cost			
Date	From	Buyer	Price
4/3/20	Sunny Health and Fitness	Michael	$25
11/20/20	HTP America Welding	Michael	$15
1/26/21	Online Metals	Jason	$325
2/14/21	McMaster-Carr	Michael	$80
2/20/21	Online Metals	Michael	$55
3/2/21	HTP America Welding	Michael	$45
3/4/21	Online Metals	Michael	$40
3/24/21	Amazon	Jason	$25
4/5/21	McMaster-Carr	Michael	$80
4/8/21	Home Depot	Michael	$40
4/14/21	Home Depot	Michael	$25
4/19/21	McMaster-Carr	Michael	$15

Table 9 – Actual Purchase Orders

The grand total of this list is $770. Michael also supplied miscellaneous hardware from his own supply, at a negligible cost.

Other costs are shown below:

R&D Costs			
Date	From	Buyer	Price
1/25/21	Wright Brothers Gas	Michael	$140

Table 10 – Research and Development Cost

A cylinder of argon gas was purchased when we planned to do our own welding at home rather than use the provided lab space due to uncertainty. When the lab was made available, this argon is no longer needed.

The total spending ($910) is well under the initial budget of $1500.

Budget was reduced by taking the following actions:

- The seat design was changed to be a vertically adjusted mount with a lighter plate. The original seat design was quite expensive with the use of a heavy steel plate and expensive bearings.
- The chassis was changed from square steel bar (solid), to square aluminum bar (solid), to hollow aluminum tubing. Not only did the hollow tubing give an advantageous moment of inertia, it reduced the overall weight of the project by an estimated 25% (aluminum compared between 1” square bar and 1.25” 1/8” wall square tubing).

SCHEDULE, PROPOSED /ACTUAL

Our schedule concludes with donating the machine to the team and is the same conclusion for the proposed schedule and the actual schedule. Due to various obstacles that presented themselves, we did not finish and donate the project within the time frame we had initially projected. We were capable of finishing the project with just enough time to submit it functioning for tech expo, but we still need to perform testing on the machine to ensure its performance and safety is adequate.

Below is our projected schedule:

Projected Schedule	
Task	**Date To Complete**
Finalize Design	1/15/2021
Order Materials	1/16/2021
Manufacturing	3/1/2021
Welding and Assembly	3/23/2021
Testing Completion	4/13/2021
Donate to Team	4/27/2021

Table 11 – Projected Schedule

Below is our actual schedule:

Actual Schedule	
Task	**Date To Complete**
Finalize Design	1/15/2021
Order Materials	1/28/2021
Manufacturing	3/23/2021
Welding and Assembly	4/13/2021
Testing Completion	5/25/2021
Donate to Team	5/30/2021

Table 12 – Actual Schedule

SUSTAINABILITY AND MATERIAL USAGE

All of our project used new raw materials except for the brackets. The brackets were manufactured from steel stock from the scrap bin. Due to the high factors of safety, the chassis may have been able to be made from recycled aluminum. For ease of manufacturing, safety, and availability, new aluminum extrusions were purchased.

In terms of longevity, our machine is crafted almost entirely of aluminum which has great corrosion resistance compared to steel. This was desired to ensure longevity of the welds that hold the machine together as well as the general structural integrity of the pieces that make up the machine. If we were to have used steel, a protective coat would have been applied to the machine after fabrication and assembly which would have increase budget and time to complete the project. The sustainability of the machine is also adequate due to the low general maintenance that we designed into the machine. Moving parts need to be greased in order to accurately simulate the motions the machine was designed for. With this in mind, we designed the machine to have limited moving parts that required greasing having just two pieces that will need periodic greasing. The greasing maintenance was made easier by designing a grease port into the required pieces so the use of a grease gun can cover what is needed requiring minimal effort from the parties involved with maintenance.

Materials were used diligently, and some excess was ordered to cover mistakes if any arose. No pieces needed to be remanufactured due to mistakes, so excess material was used to practice welding techniques and test them for structural integrity. Currently, under twenty dollars of excess material remains.

CONCLUSIONS

The overall goal of this machine is to safely increase the on-ice performance of the hockey players while satisfying the other goals for the team's convenient usage. This machine is conveniently portable, easy to use, and accommodating to a wide variety of players. The main goal of the Cincinnati Icebreakers is to provide an athletic outlet for disabled players that may otherwise be excluded from sports. Providing the team a workout machine, to supplement the IronCore strength and conditioning, immerses the players into athletics more than they otherwise would be.

A manufacturing schedule was set and loosely followed. As soon UC's machine shop was open, our team was using it two or three days a week to machine the parts. The plan was to start assembling the chassis sooner, but instead we continued until all of the machining was complete. A better plan would have been to machine all of the chassis pieces and start welding the chassis while the other group member continued to machine the remainder of the pieces. This machine did not undergo any testing before the video was submitted, and it functioned properly because of a well-executed machining plan. Despite the poor scheduling, the design and machining allowed this prototype to function on the first try.

Before the team receives their donation, this workout machine will receive a few updates to improve functionality and user-friendliness. Testing yielded slight leveling issues in the chassis assembly, and an inconsistent damper return. Polymer dampening pads will be added to the bottom of the chassis so that it sits level on the floor and is quieter during use. A stiffer resistance band was ordered, and the damper band shank was redesigned to accommodate this larger band. Some of the tolerances are tight, so holes where a through-pin goes will be drilled larger to make for easier assembly. The leverage beam (Beam 9), where the damper mounts, may need new holes drilled to account for the extra force from the resistance band. The holes will move the damper mount closer to the fulcrum, which will reduce the resistance that the player feels.

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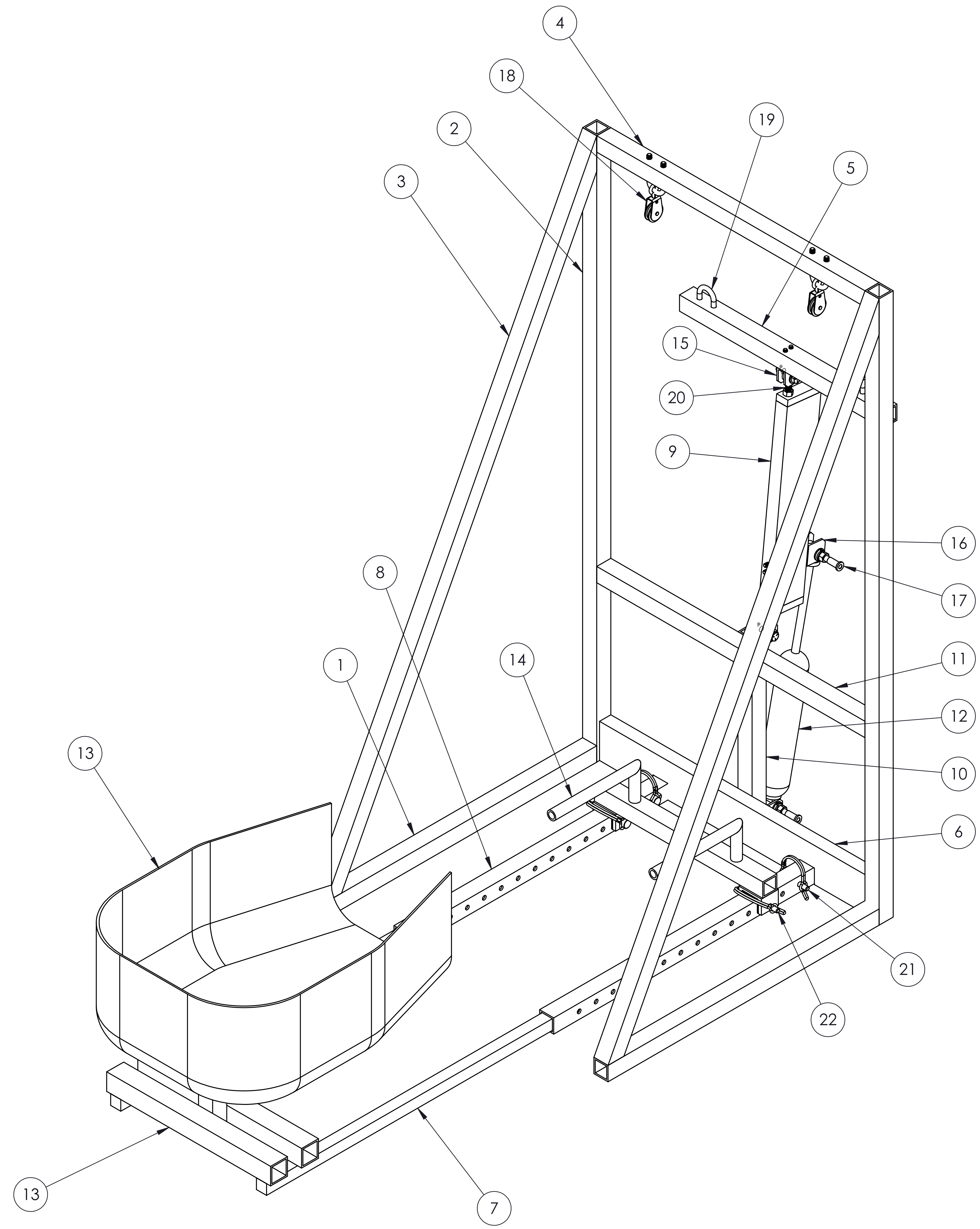
APPENDIX A

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Beam 1	2	1.25 X 1.25 x .12 Square Tube
2	Beam 2	2	1.25 X 1.25 x .12 Square Tube
3	Beam 3	2	1.25 X 1.25 x .12 Square Tube
4	Beam 4	1	1.25 X 1.25 x .12 Square Tube
5	Beam 5	1	1.25 X 1.25 x .12 Square Tube
6	Beam 6	1	3.0 X 1.0 x .12 Rectangular Tube
7	Beam 7_1	2	1.0 Square Bar
8	Beam 7_2	2	1.25 X 1.25 x .12 Square Tube
9	Beam 9	1	3.0 x 1.0 x .12 Rectangular Tube
10	Beam 10	1	1.25 X 1.25 x .12 Square Tube
11	Beam 11	1	1.25 X 1.25 x .12 Square Tube
12	Damper	1	Resistance Damper - Sunny Health and Fitness
13	Seat Assy	1	
14	Footrest Assy	1	
15	Bushing Bracket	2	Bracket to Mount Heim Joint
16	Damper Bracket	2	Bracket to Mount Resistance Damper
17	Damper-Band Shank Assy	2	
18	Pulley	2	Pulley 3/16 Wire Rope
19	8880T85	4	U-Bolt 5/16-18
20	2458K141	2	Heim Joint 3/8-24
21	98416A215	2	Pin 5/16 x 1-3/8
22	98416A217	2	Pin 5/16 x 2-1/8
23	Misc. Hardware		



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FINISH		
USED ON:		

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https://grabcad.com/michael.bennett-22

TITLE:
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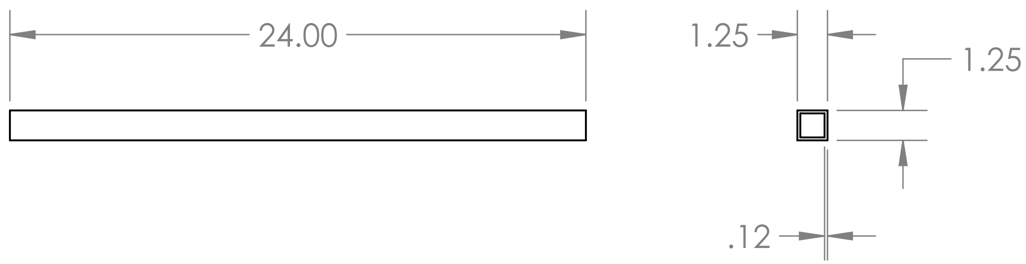
B B



A A

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		CLEAN AND DEBURR			
		MATERIAL 6061 Al			
		FINISH			
USED ON:					

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
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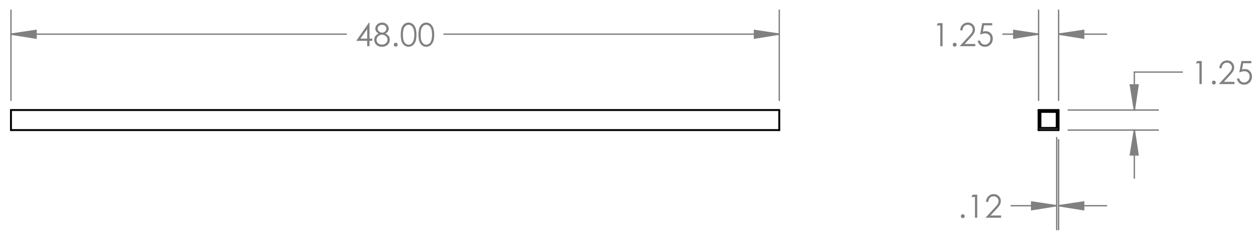

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MACH ± .125
.X ± .030
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.XXX ± .005

CLEAN AND DEBURR

MATERIAL
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FINISH

USED ON:

	NAME	DATE
DRAWN	MWB	26JAN21

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https://grabcad.com/michael.bennett-22

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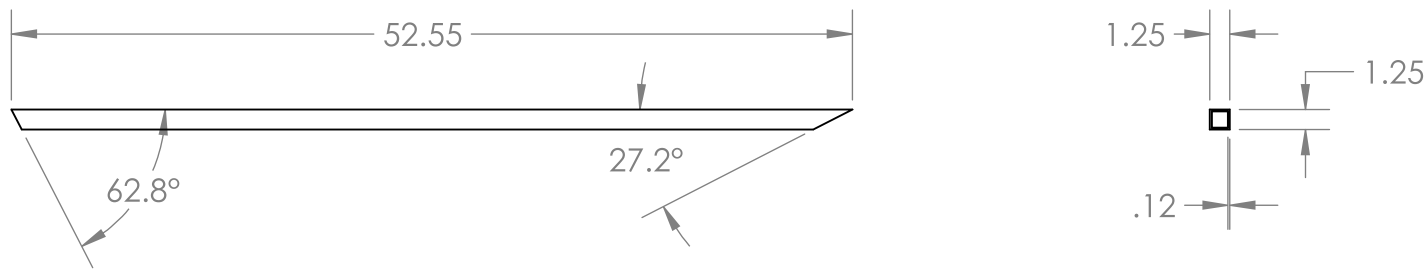

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MACH ± .125
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.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 Al

FINISH

USED ON:

	NAME	DATE
DRAWN	MWB	26JAN21

GrabCAD:
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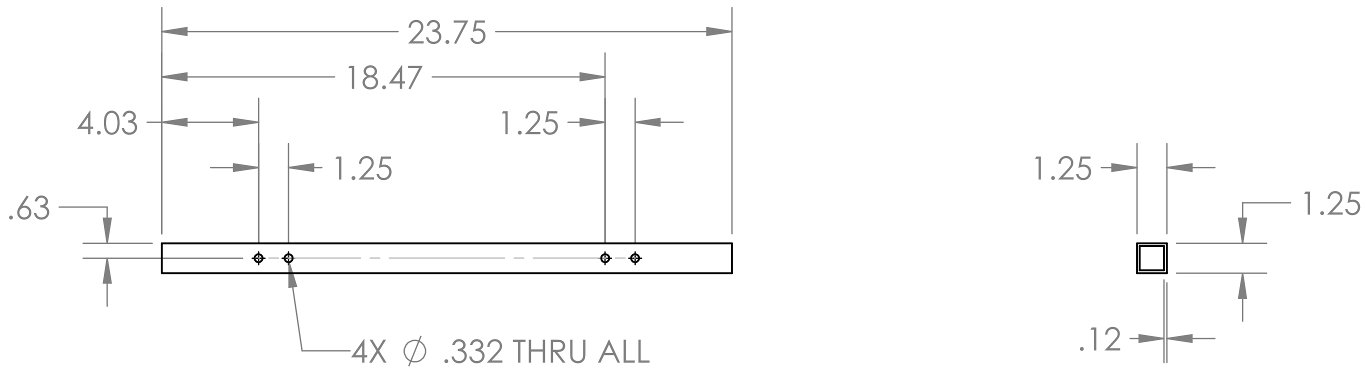

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TOLERANCES:
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MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 Al

FINISH

USED ON:

	NAME	DATE
DRAWN	MWB	26JAN21

GrabCAD:
https://grabcad.com/michael.bennett-22

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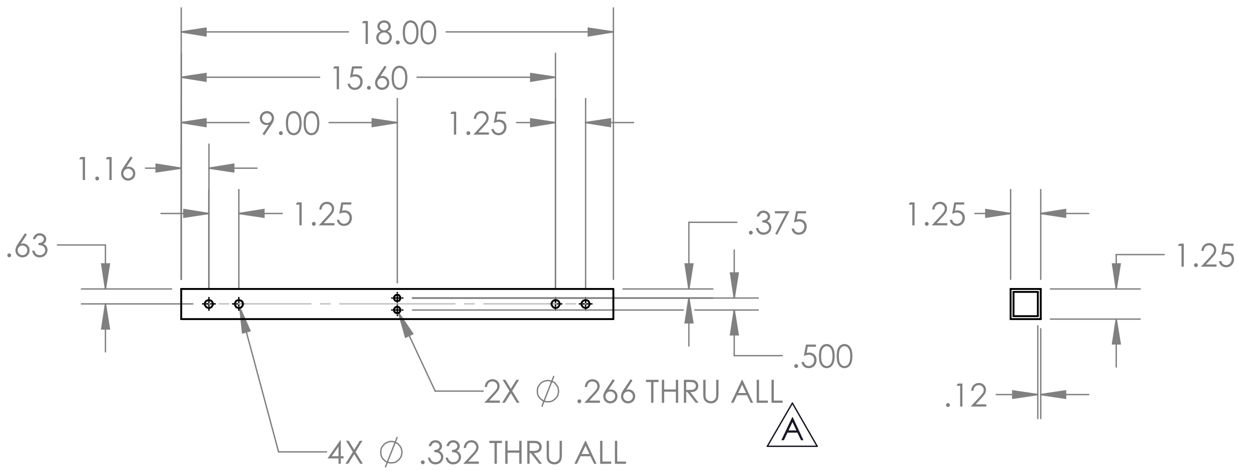

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MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL: 6061 Al

FINISH:

USED ON:

	NAME	DATE
DRAWN	MWB	26JAN21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
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REV: A

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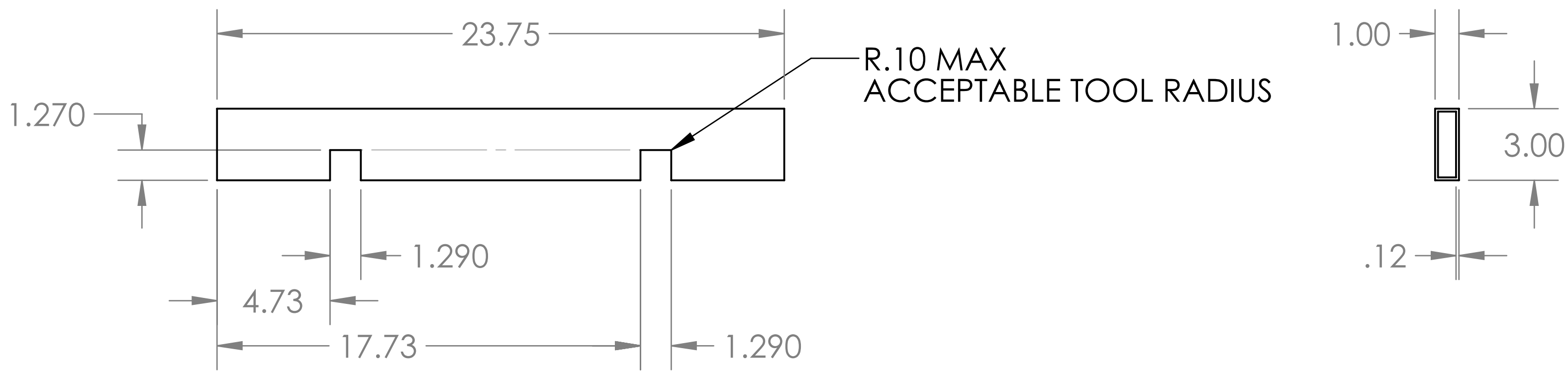

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DRAWN	MWB	26JAN21

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TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 Al

FINISH

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REV

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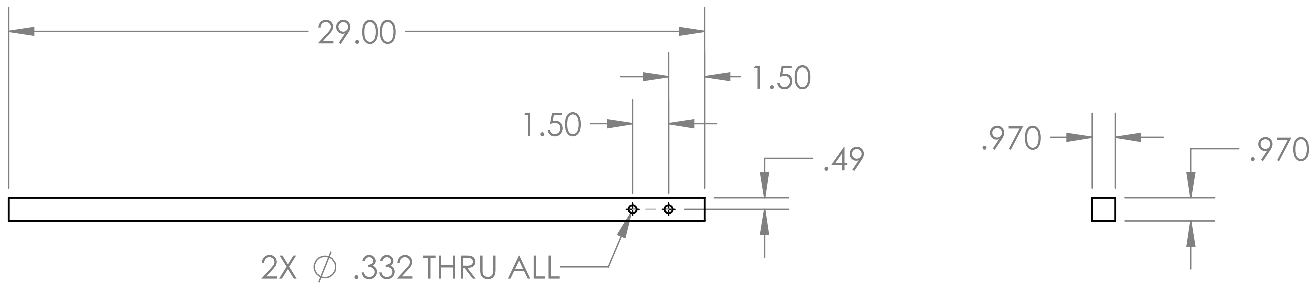

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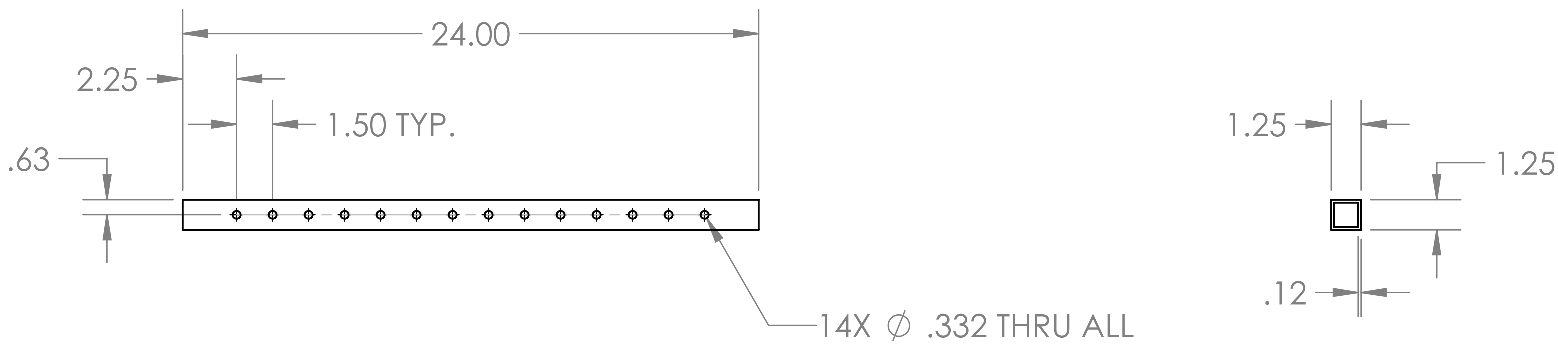

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UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

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MACH ± .125
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CLEAN AND DEBURR

MATERIAL
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FINISH

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DRAWN	MWB	26JAN21

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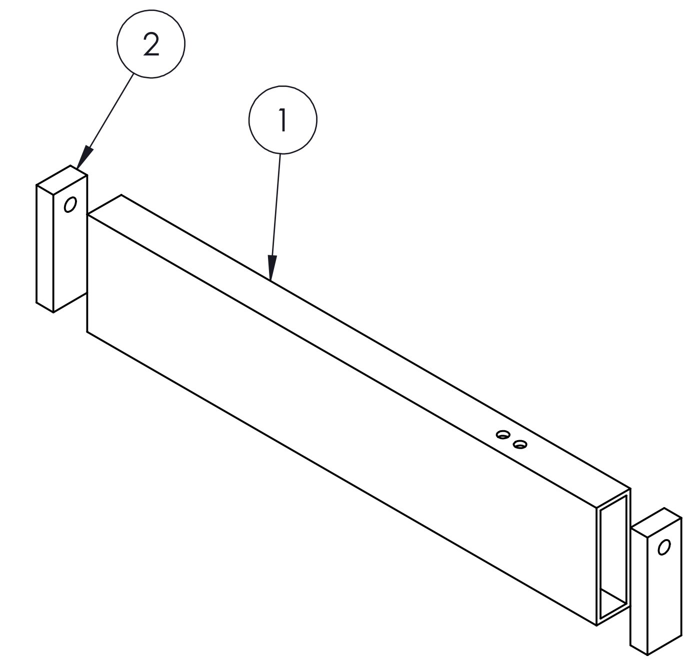
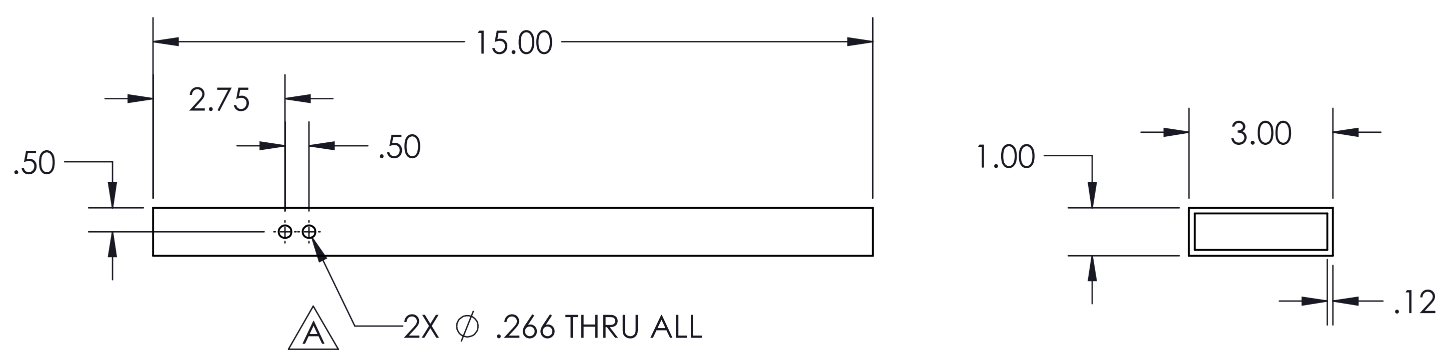
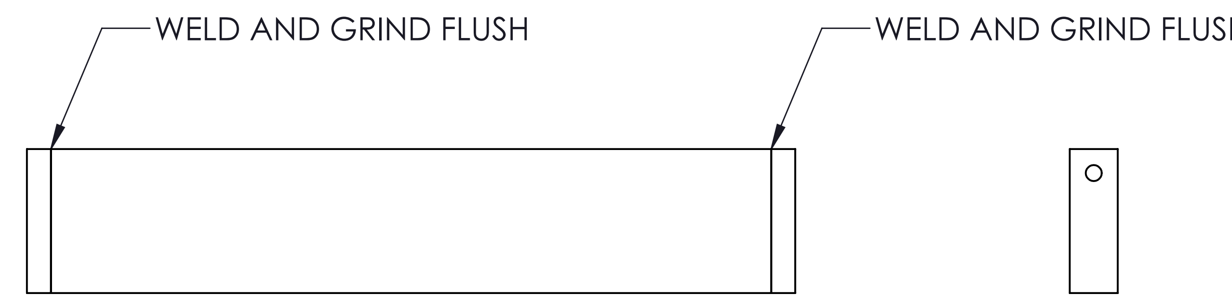
2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Beam 9-tube	3.0 x 1.0 x .12 Rectangular Tube	1
2	Beam 9-plate	1.0 x .25 Flat Bar	2

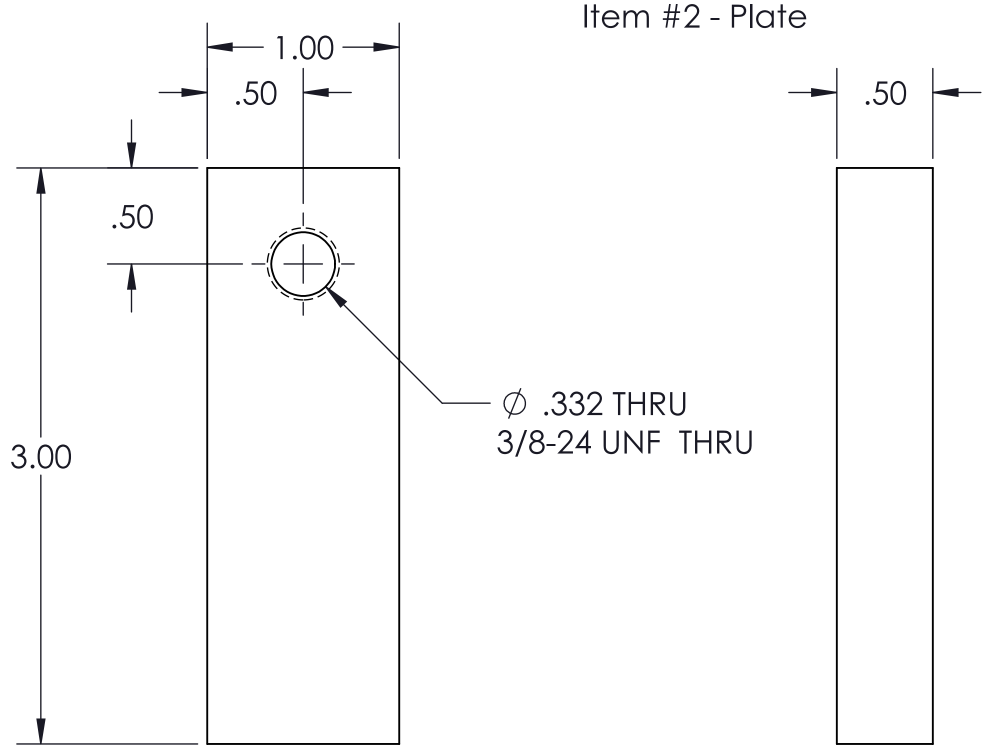


Item #1 - Tube





Item #2 - Plate



A Added holes MWB 01MAR21

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL 6061 Al

FINISH

USED ON:

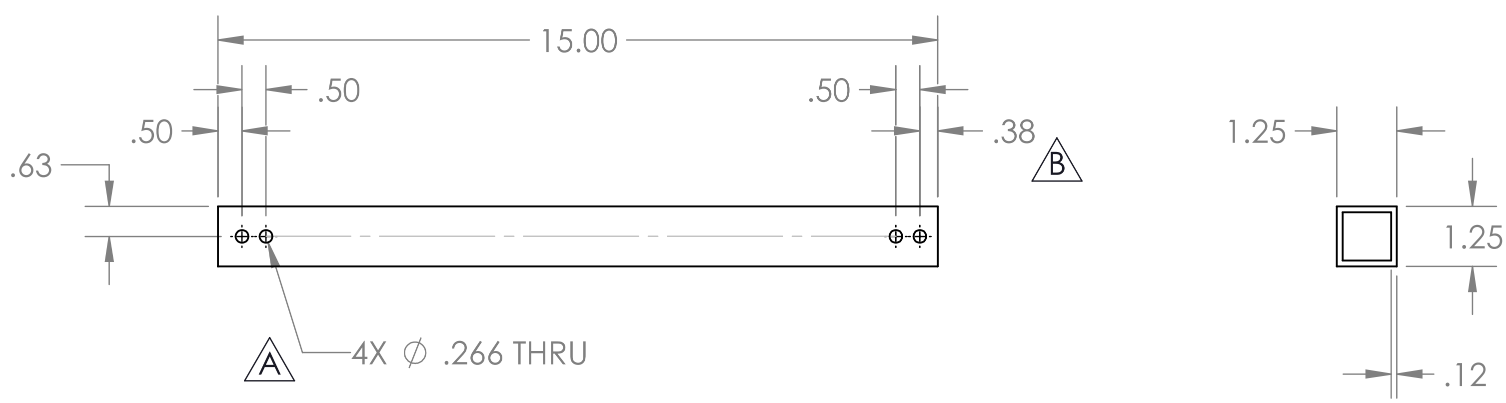
	NAME	DATE
DRAWN	MWB	26JAN21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
3.0 x 1.0 x .125 Rect. Tube

SIZE B | DWG. NO. Beam 9 | REV A

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



A	Added holes MWB 01MAR21
B	Was 0.5 inches MWB 04MAR21

USED ON:

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 Al

FINISH

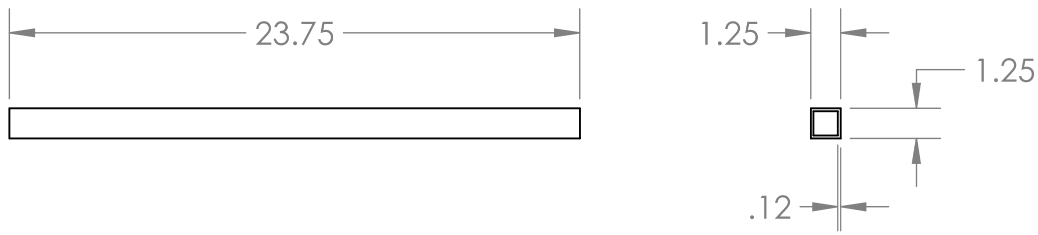
	NAME	DATE
DRAWN	MWB	26JAN21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
1.25 X 1.25 x .12 Square Tube

SIZE **A** | DWG. NO. Beam 10 | REV B

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



		UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES. TOLERANCES: ANGULAR ± .5 DEG MACH ± .125 .X ± .030 .XX ± .010 .XXX ± .005 CLEAN AND DEBURR		NAME	DATE
			DRAWN	MWB	26JAN21
		MATERIAL 6061 Al	COPYRIGHT STATEMENT: This work is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-sa/4.0/ or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.		
		FINISH			
USED ON:					

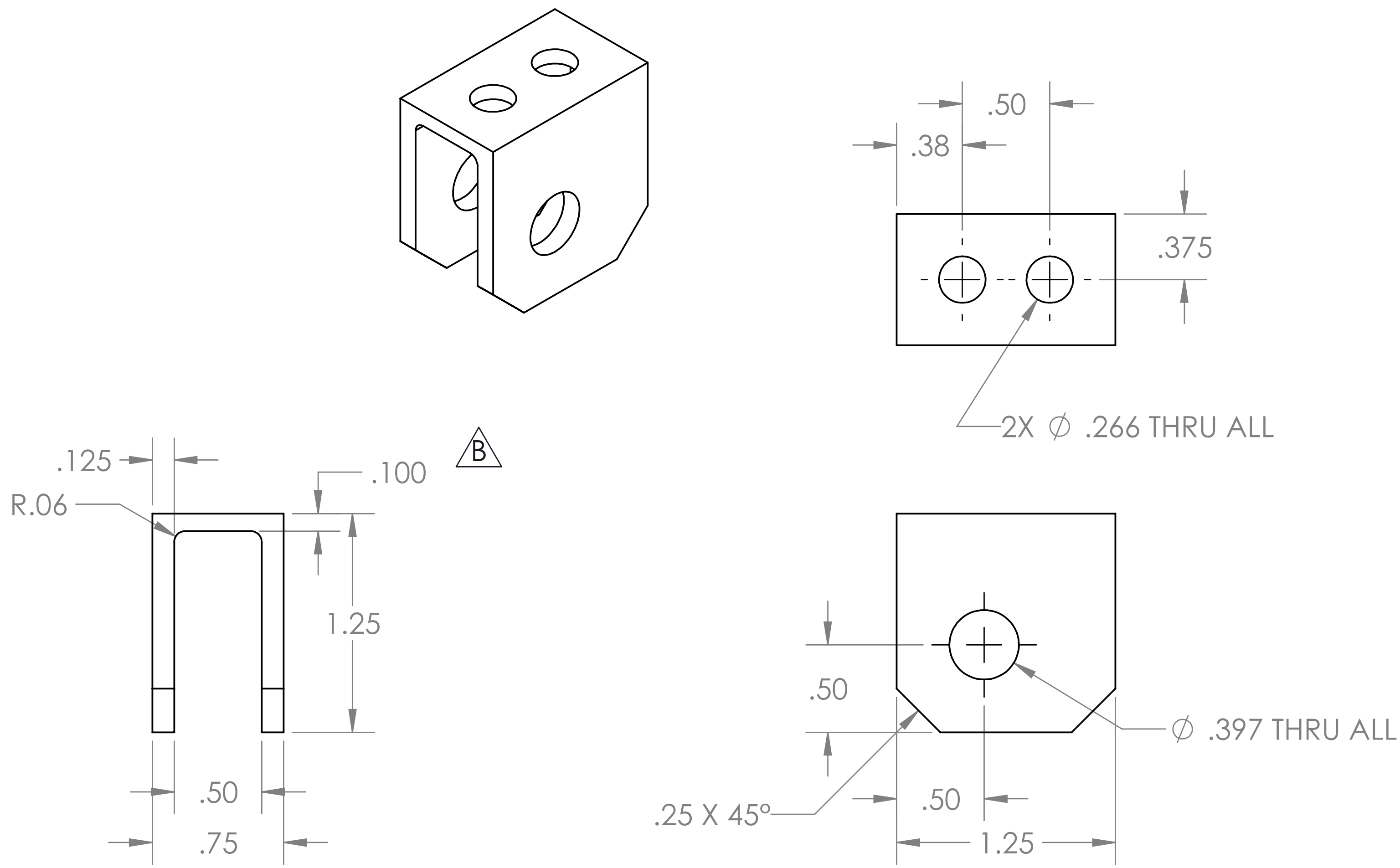
GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
1.25 X 1.25 x .12 Square Tube

SIZE	DWG. NO.	REV
A	Beam 11	

SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

2			1	



REV	DESCRIPTION
A	Was sheet metal 04APR21 MWB
B	Was .125 12APR21 MWB

USED ON:

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
Low Carbon Steel

FINISH

	NAME	DATE
DRAWN	MWB	22FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

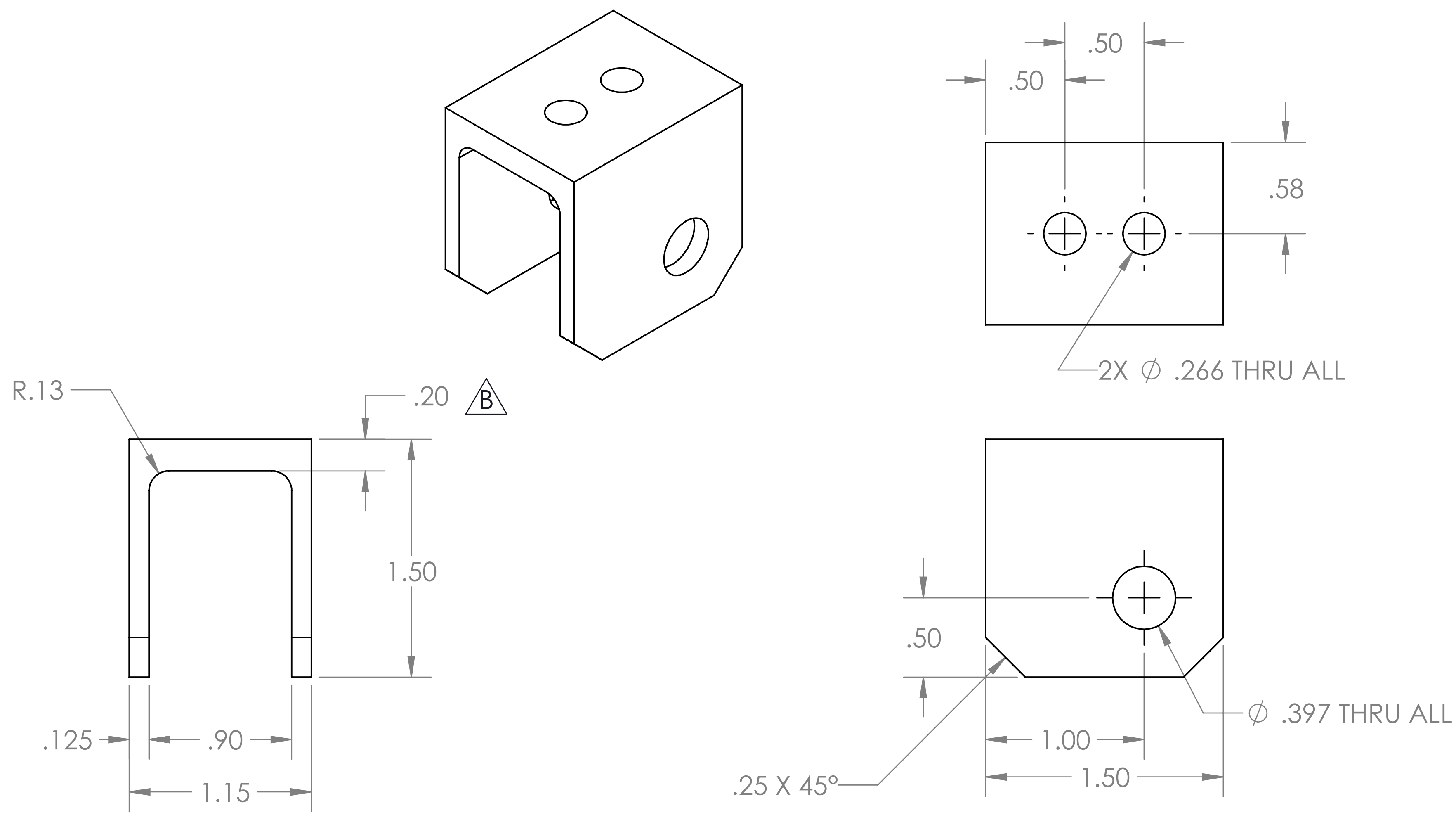
TITLE:
Bushing Bracket

SIZE	DWG. NO.	REV
A	B. Bracket	B

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

A	Was sheet metal 04APR21 MWB
B	Was .125 12APR21 MWB

USED ON:

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
Low Carbon Steel

FINISH
None

	NAME	DATE
DRAWN	MWB	22FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

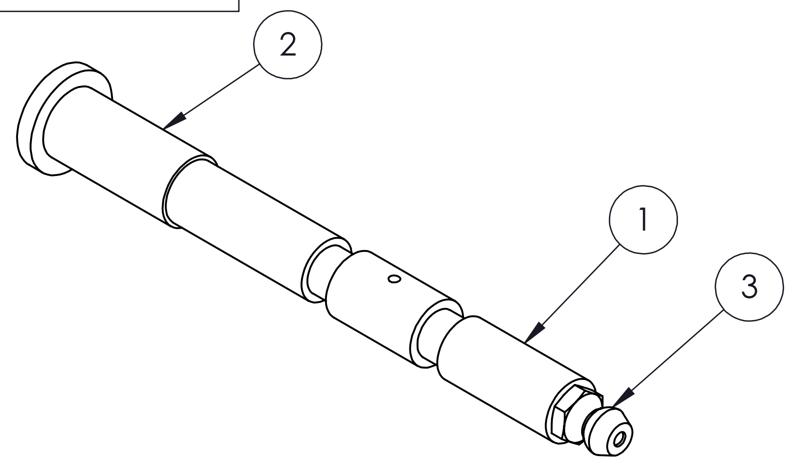
TITLE:
Damper Bracket

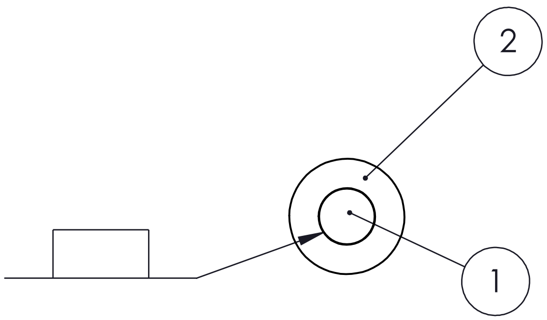
SIZE A | DWG. NO. D. Bracket | REV B

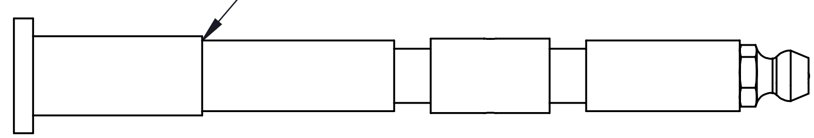
SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

2 1

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Damper-Band Shank	1	Shank to Secure Bands to Shock Mounts
2	Damper-Band Shank Band Mount	1	Mount for Resistance Band
3	Grease Fitting	1	Grease Fitting 1/4-28







UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
See Parts List

FINISH

USED ON:

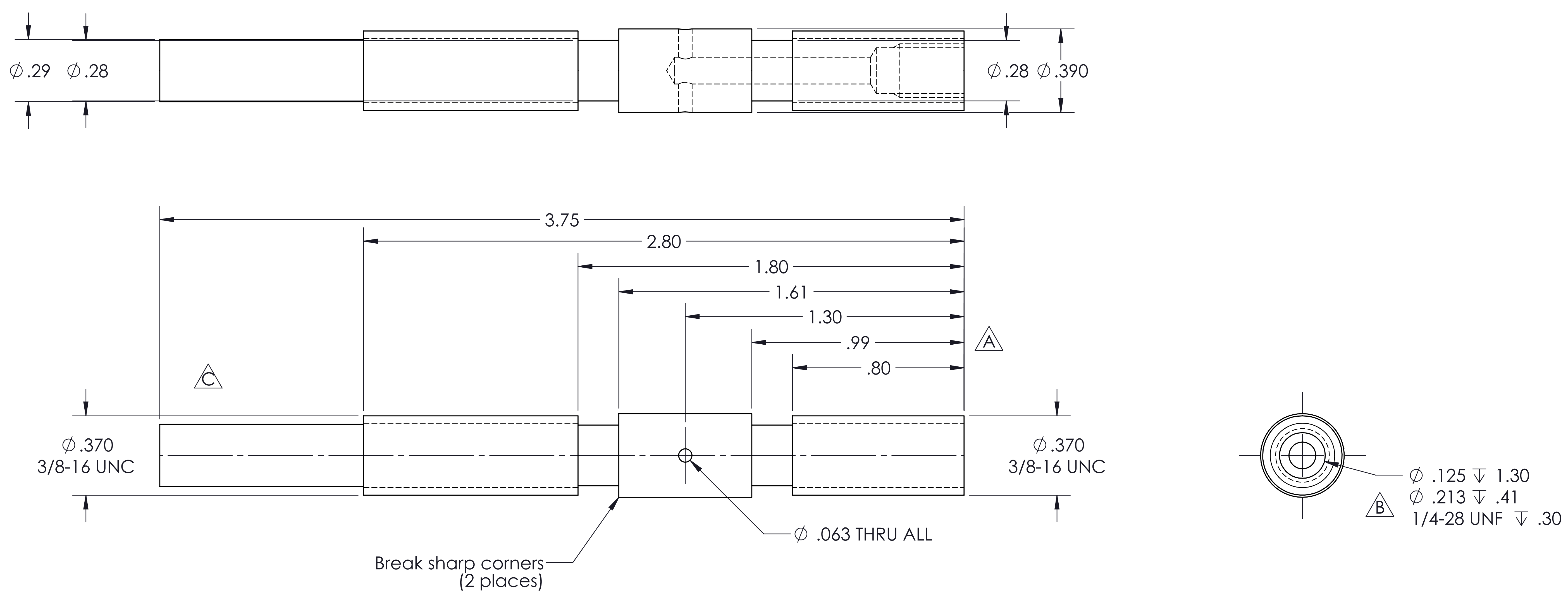
	NAME	DATE
DRAWN	MWB	19APR21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
Damper-Band Shank Assy

SIZE **A** DWG. NO. Shank Assy REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



A Increased thread relief MWB 01MAR21

B Added 1/8" hole MWB 01MAR21

C Added Item #3 Band Mount; Separate DWGs; MWB 17APR21

USED ON:

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
1144 Steel Round Bar

FINISH
None

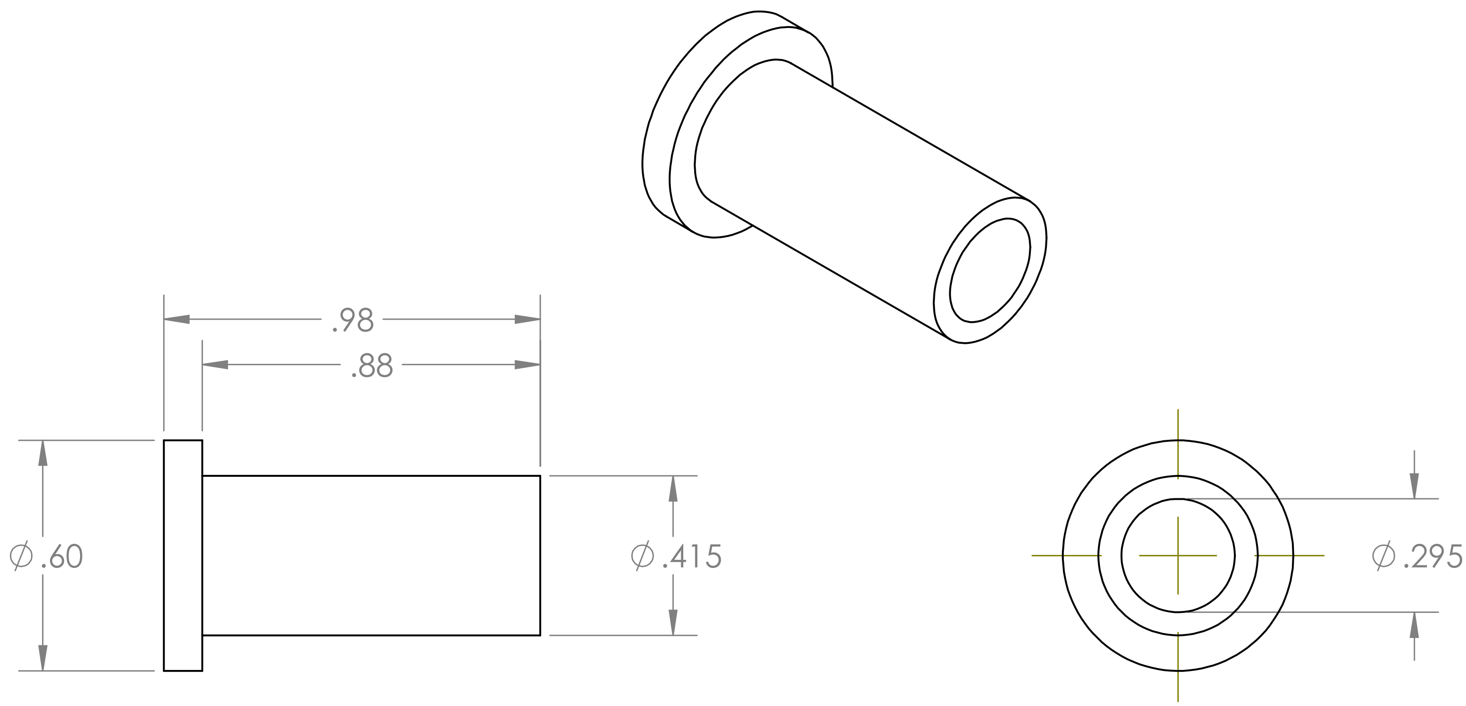
	NAME	DATE
DRAWN	MWB	20FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
Damper-Band Shank

SIZE B | DWG. NO. Shank | REV C

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



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

	NAME	DATE
DRAWN	MWB	17APR21

MATERIAL
1144 Round Steel

FINISH
None

USED ON:

GrabCAD:
https://grabcad.com/michael.bennett-22

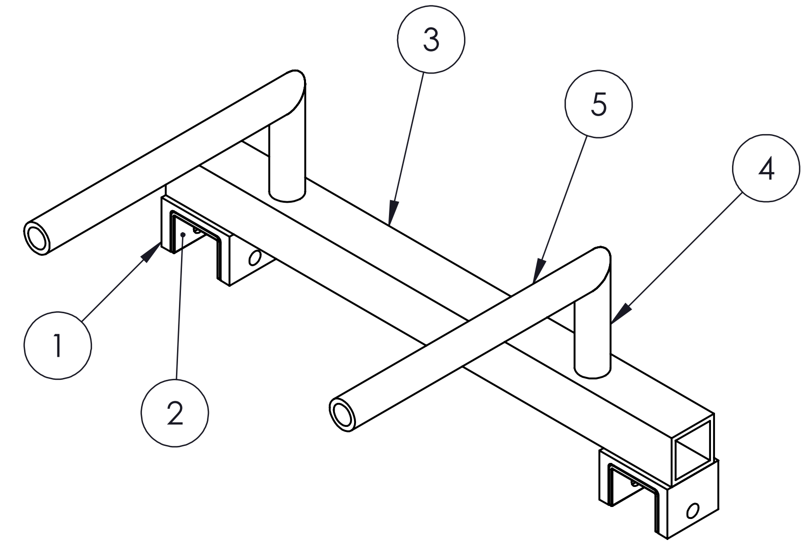
TITLE:

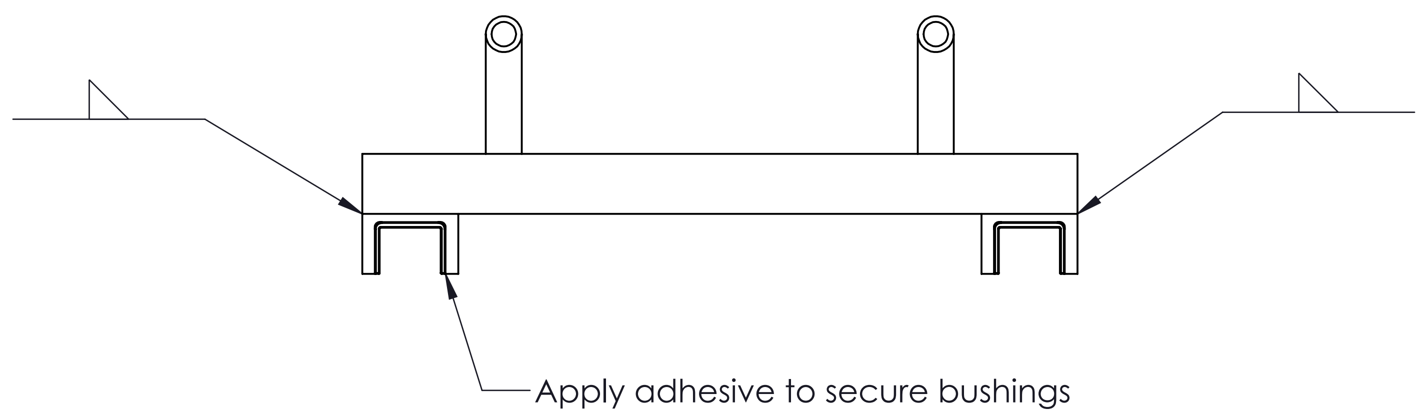
Band Mount Damper Shank

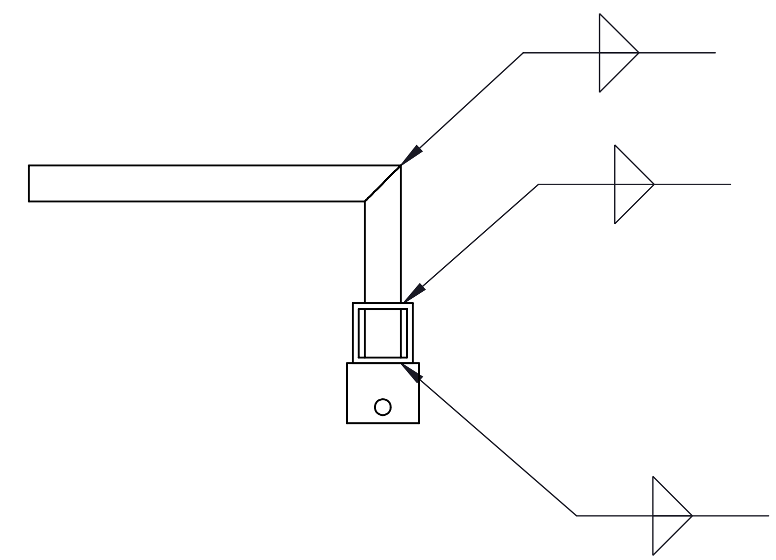
SIZE	DWG. NO.	REV
A	Band Mnt	

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

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Footrest Mount	2	Mounting Bracket - C Channel
2	Footrest Bushing	2	Bracket Bushing - 3D Print PLA
3	Footrest Beam	1	Cross Beam - 1.25 X 1.25 x .12 Square Tube
4	Footrest Beam2	2	Vertical Beam - .75 x .12 Round Tube
5	Footrest Beam3	2	Horizontal Beam - .75 x .12 Round Tube







UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL See Parts List

FINISH

USED ON:

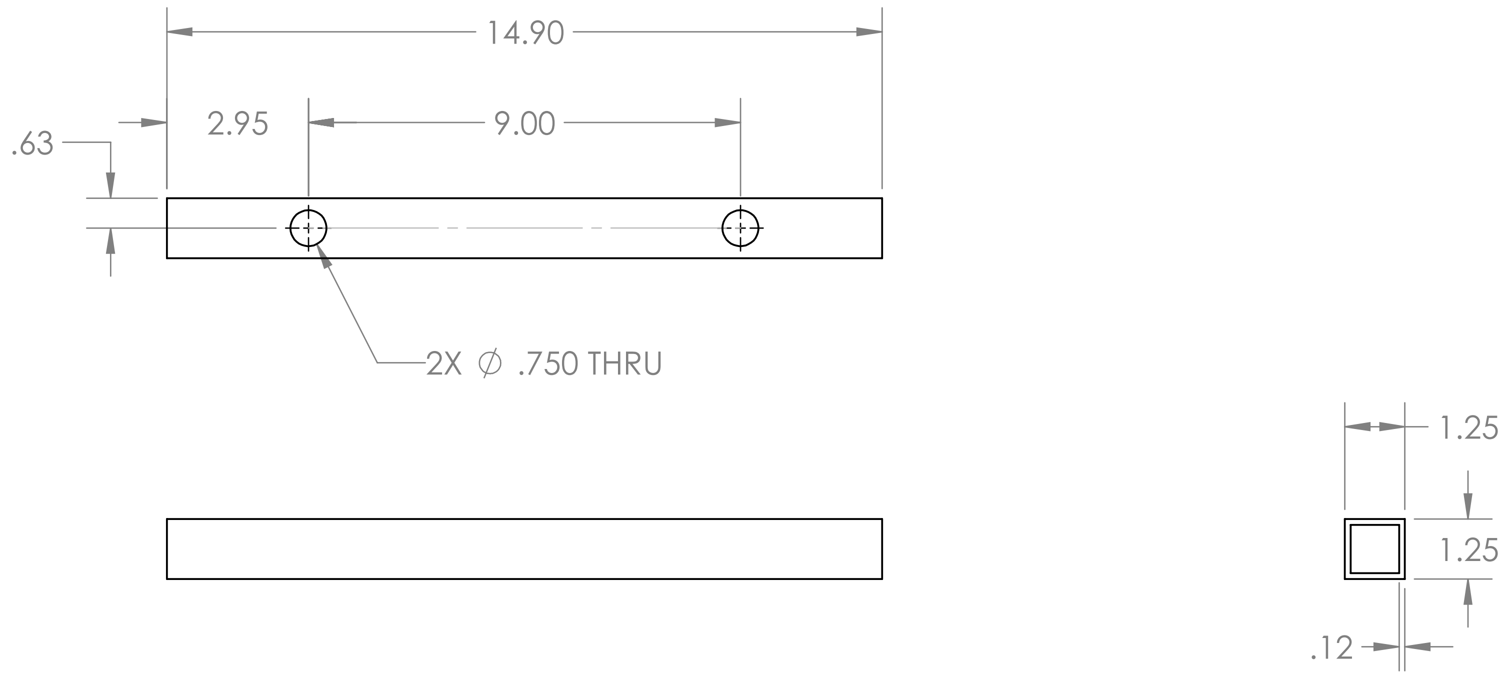
	NAME	DATE
DRAWN	MWB	19APR21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
Footrest Assy

SIZE B | DWG. NO. Footrest | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 T6 Alum

FINISH

USED ON:

	NAME	DATE
DRAWN	MWB	06APR21

GrabCAD:
https://grabcad.com/michael.bennett-22

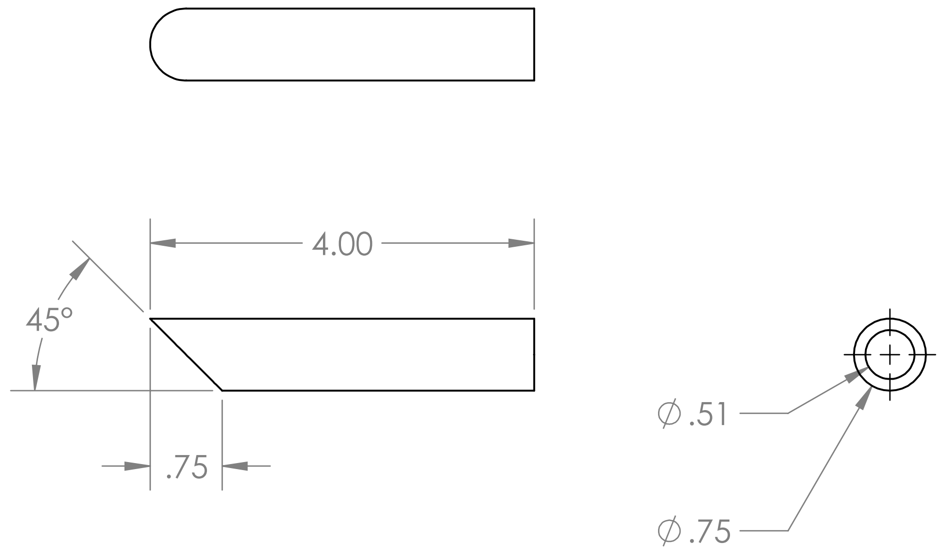
TITLE:
1.25 X 1.25 x .12 Square Tube

SIZE A

DWG. NO. Footrest Beam

REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.		NAME	DATE
	DRAWN	MWB	05APR21

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 T6 Al

FINISH

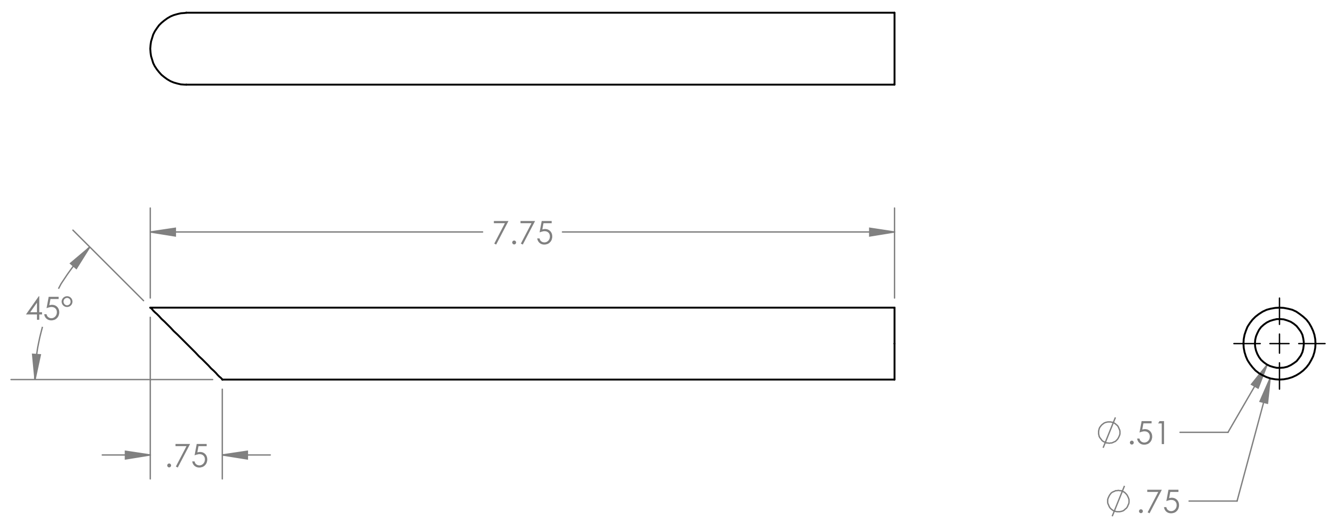
USED ON:

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
.75 x .12 Round Tube

SIZE	DWG. NO.	REV
A	Footrest Beam2	

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL: 6061 T6 Al

FINISH:

USED ON:

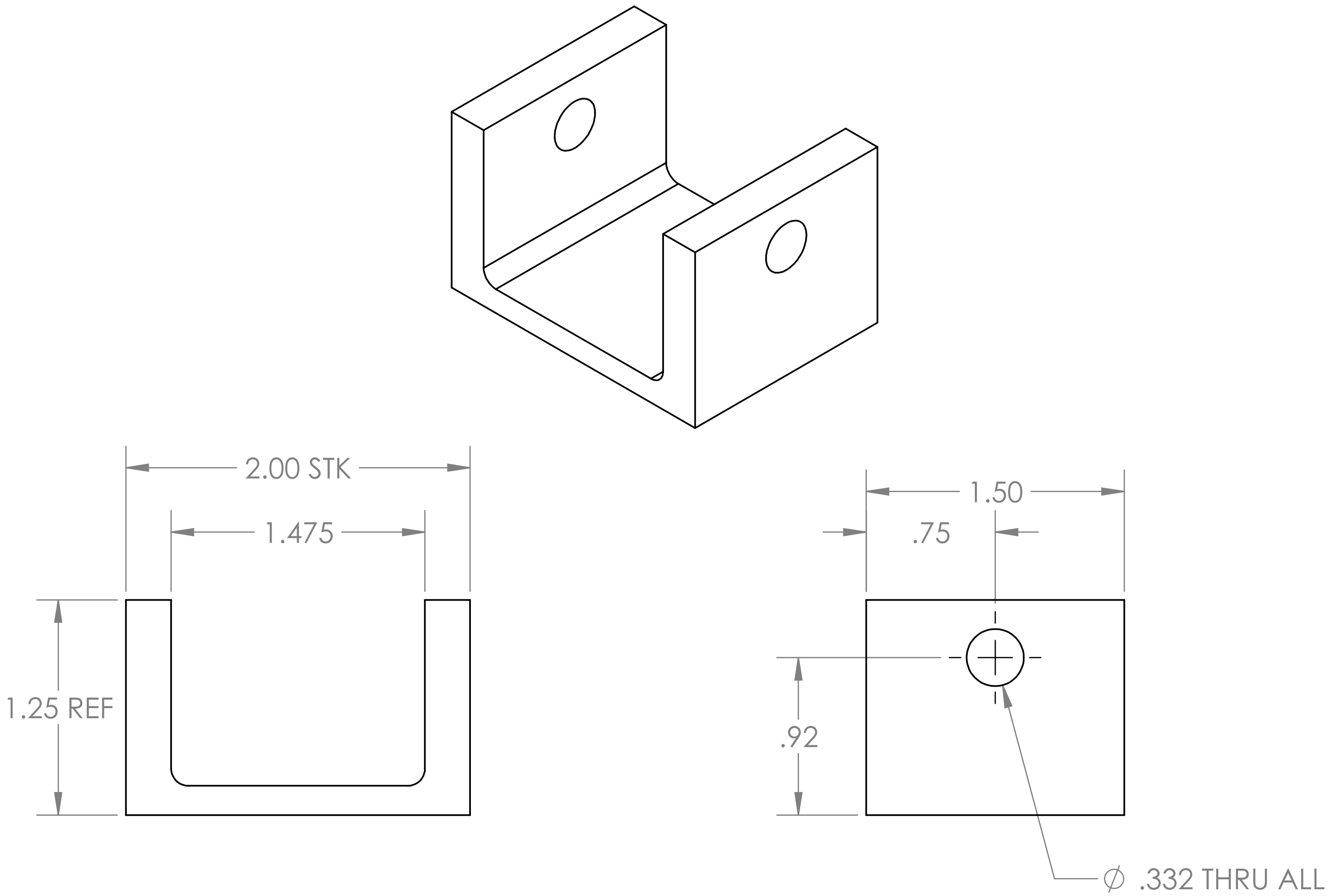
	NAME	DATE
DRAWN	MWB	05APR21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
.75 x .12 Round Tube

SIZE: A
DWG. NO.: Footrest Beam3
REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 T6 Al

FINISH
None

USED ON:

	NAME	DATE
DRAWN	MWB	05APR21

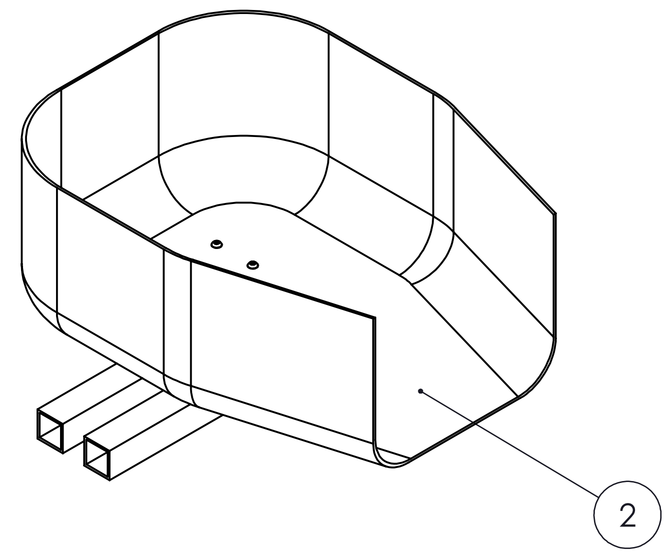
GrabCAD:
https://grabcad.com/michael.bennett-22

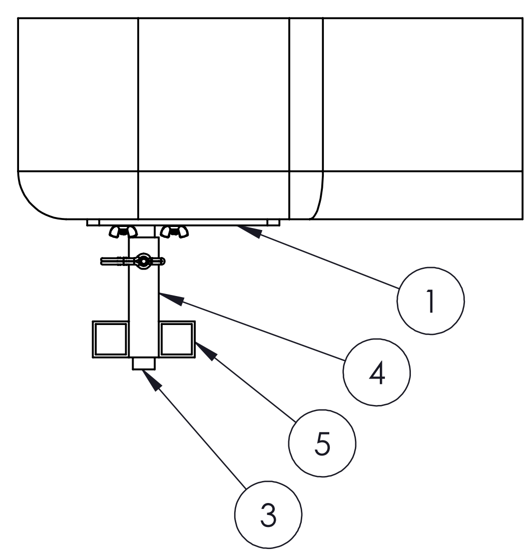
TITLE:
Footrest Mount

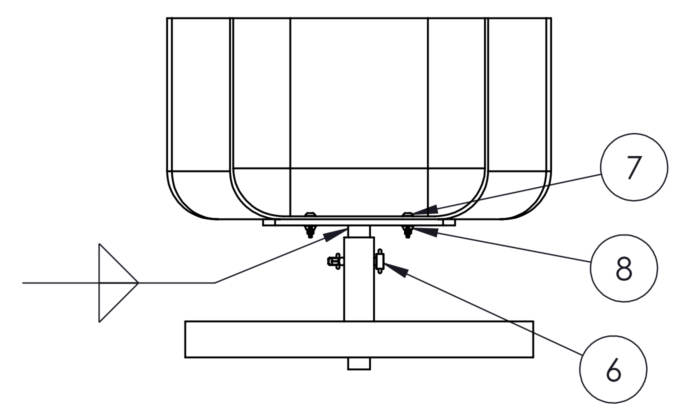
SIZE **A** DWG. NO. Foot Mount REV

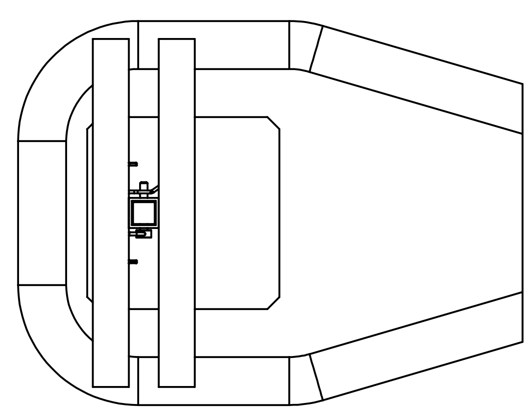
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

ITEM	PART NUMBER	QTY.	DESCRIPTION
1	Seat Plate	1	1/4" Thick Aluminum Plate
2	Bucket	1	IceBreakers to Supply
3	Seat Tube Inner	1	1.0 Square Bar
4	Seat Tube Outer	1	1.25 X 1.25 x .12 Square Tube
5	Seat Tube Mount	2	1.25 X 1.25 x .12 Square Tube
6	98416A215	1	Pin 5/16 x 1-3/8
7	91306A379	4	BHCS 1/4-20 x .75
8	90866A029	4	Wing Nut 1/4-20









UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL: See Parts List

FINISH

USED ON:

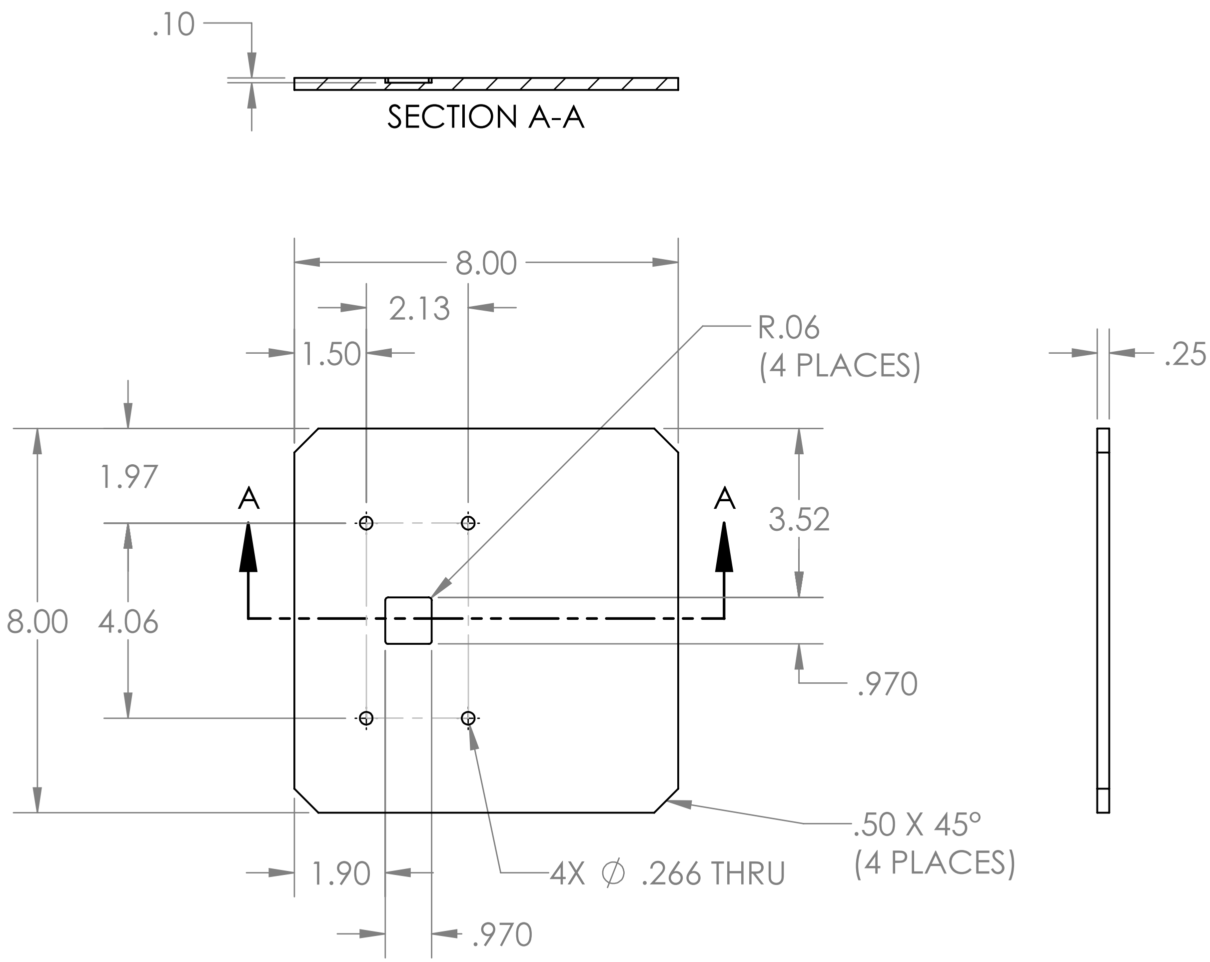
	NAME	DATE
DRAWN	MWB	01APR19

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE: Seat Assy

SIZE: B | DWG. NO. Seat Assy | REV

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1



A	Was #10 holes MWB 05APR21	

USED ON:

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061-T6 Alum

FINISH
None

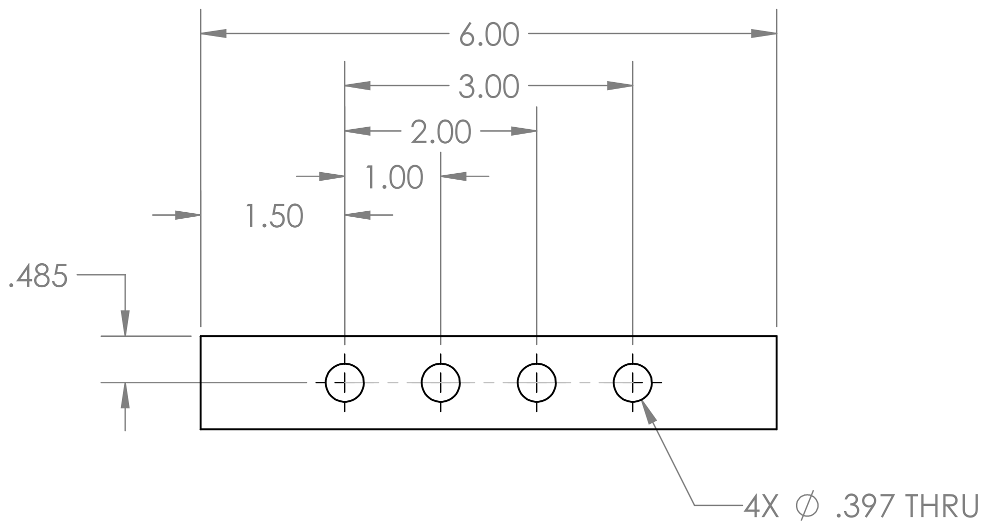
	NAME	DATE
DRAWN	MWB	23FEB21

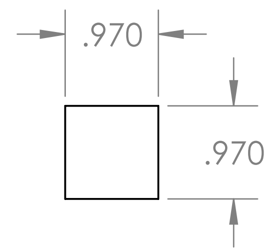
GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
1/4" Thick Aluminum Plate

SIZE	DWG. NO.	REV
A	Seat Plate	A

SCALE: 1:4 WEIGHT: SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 Al Sq Bar

FINISH
Machine all sides

USED ON:

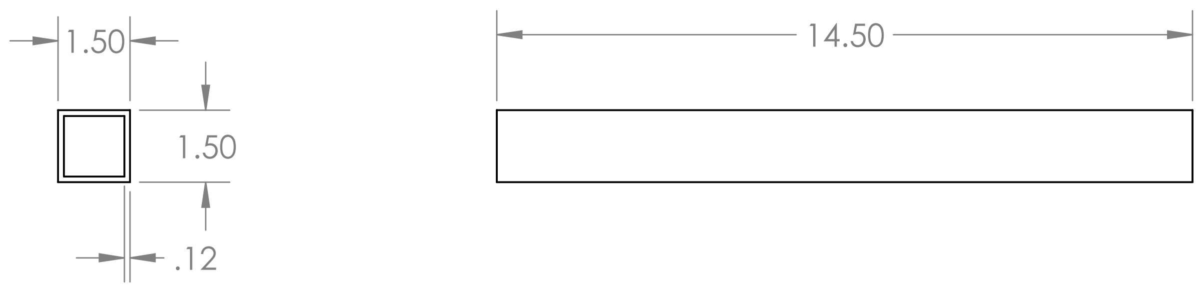
	NAME	DATE
DRAWN	MWB	23FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:
Seat Tube Inner

SIZE A | DWG. NO. Seat-Inner | REV

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



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL: 6061 Al Sq Tube

FINISH: None

USED ON:

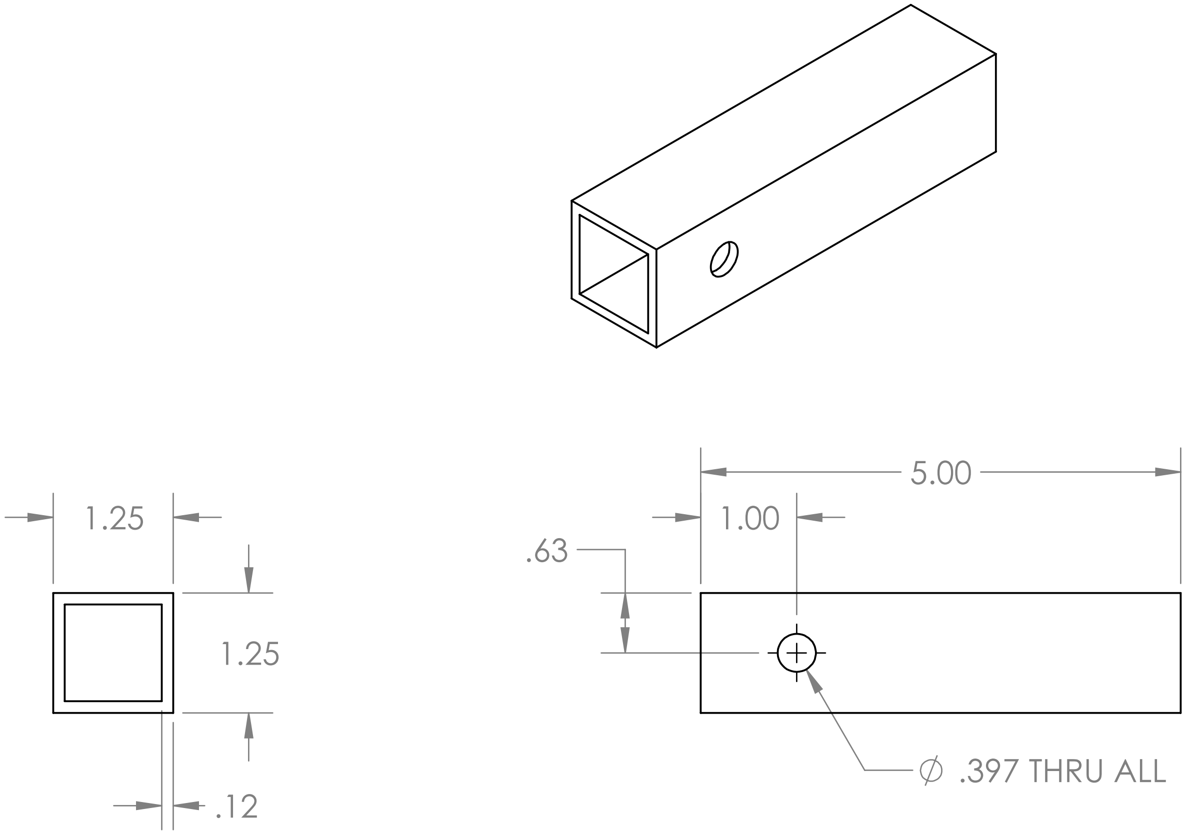
	NAME	DATE
DRAWN	MWB	23FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:

SIZE: A
DWG. NO.: Seat Tube Mount
REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
ANGULAR ± .5 DEG
MACH ± .125
.X ± .030
.XX ± .010
.XXX ± .005

CLEAN AND DEBURR

MATERIAL

FINISH

USED ON:

	NAME	DATE
DRAWN	MWB	22FEB21

GrabCAD:
https://grabcad.com/michael.bennett-22

TITLE:

SIZE A | DWG. NO. Seat Tube Outer | REV

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

APPENDIX B

LIST OF FIGURES

Figure 1 – Final Build

Figure 2 – Final Build

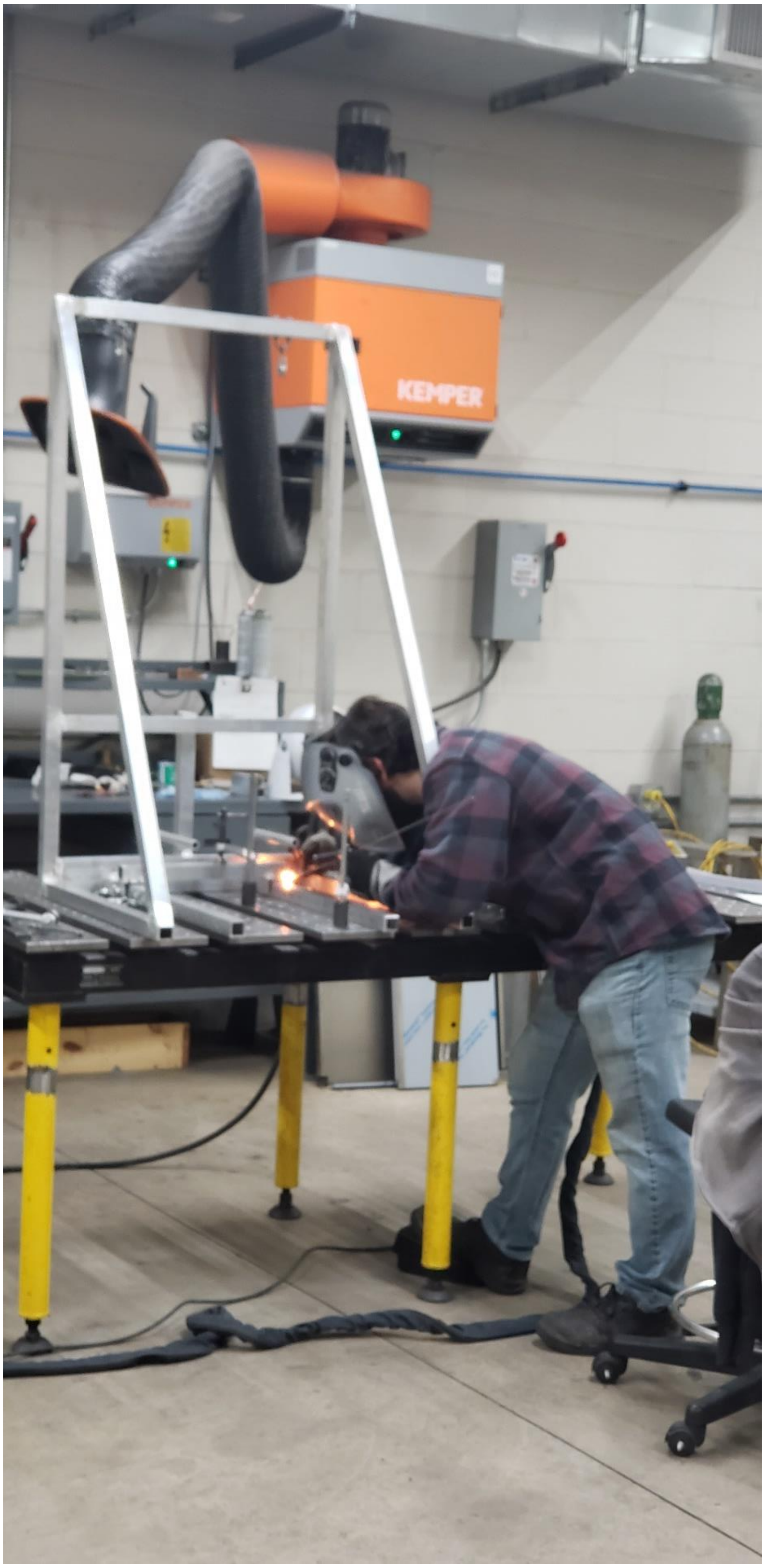


Figure 3 – Jason Welding Chassis

Figure 4 – Crimpers for Steel Cable

Figure 5 – Beam 9 End Caps

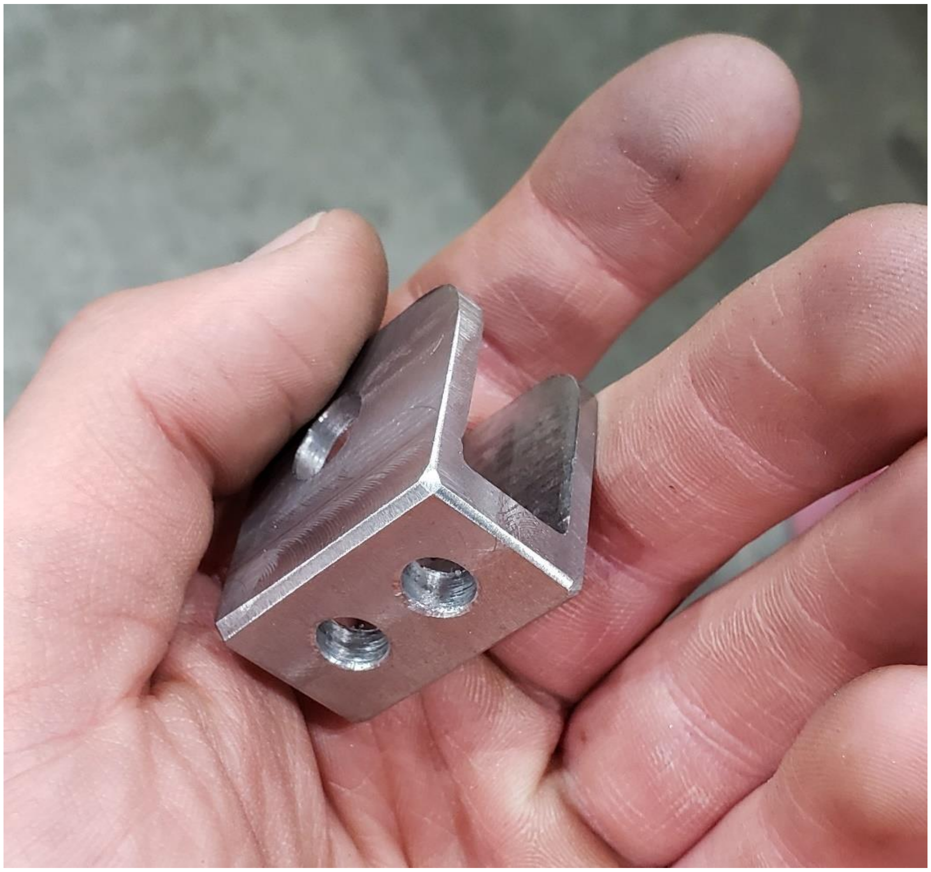


Figure 6 – Bushing Bracket

Figure 7 – Machining of Bushing and Damper Brackets

Figure 8 – Proto Trak Vertical Mill

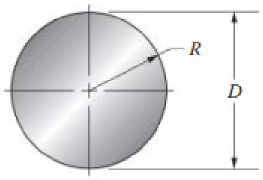
Figure 9 – Turning Damper-Band Shanks on Clausing Lathe

Figure 10 – Completed Turning Operation on Damper-Band Shanks


Figure 11 – Test Fit of Damper, Bracket, and Shank

APPENDIX C

Circle



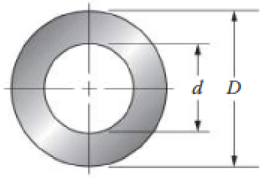
$$A = \frac{\pi D^2}{4} = \pi R^2 \qquad r = \frac{D}{4} = \frac{R}{2}$$

$$I = \frac{\pi D^4}{64} \qquad J = \frac{\pi D^4}{32}$$

$$S = \frac{\pi D^3}{32} \qquad Z_p = \frac{\pi D^3}{16}$$

Circumference $= \pi D = 2\pi R$

Hollow circle (tube)

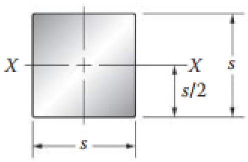


$$A = \frac{\pi(D^2 - d^2)}{4} \qquad r = \frac{\sqrt{D^2 + d^2}}{4}$$

$$I = \frac{\pi(D^4 - d^4)}{64} \qquad J = \frac{\pi(D^4 - d^4)}{32}$$

$$S = \frac{\pi(D^4 - d^4)}{32D} \qquad Z_p = \frac{\pi(D^4 - d^4)}{16D}$$

Square

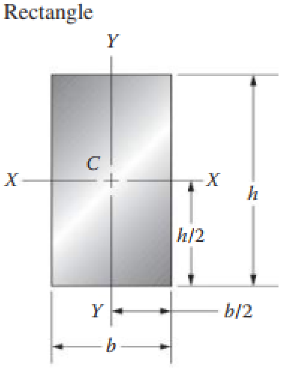


$$A = s^2$$

$$I_x = \frac{s^4}{12} \qquad r_x = \frac{s}{\sqrt{12}}$$

$$S_x = \frac{s^3}{6}$$

Rectangle



$$A = bh$$

$$I_x = \frac{bh^3}{12} \qquad S_x = \frac{bh^2}{6} \qquad r_x = \frac{h}{\sqrt{12}}$$

$$I_y = \frac{hb^3}{12} \qquad S_y = \frac{bh^2}{6} \qquad r_y = \frac{b}{\sqrt{12}}$$

Figure 1 – Moment of Inertia Chart (9)

A–17 Design stress guidelines.

Direct normal stresses

A. General machine and structural design

Manner of loading	Ductile materials (% elongation >5%)	Brittle materials (% elongation <5%)
Static loads	$\sigma_d = s_y/2$	$\sigma_d = s_u/6$
Repeated loads	$\sigma_d = s_u/8$	$\sigma_d = s_u/10$
Impact or shock	$\sigma_d = s_u/12$	$\sigma_d = s_u/15$

B. Static loads on steel members of building-like structures

AISC code $\quad \sigma_d = s_y/1.67 = 0.60\, s_y$ or $\sigma_d = s_u/2.00 = 0.50\, s_u$ (whichever is lower)

C. Static loads on aluminum members of building-like structures

Aluminum Association $\quad \sigma_d = s_y/1.65 = 0.61\, s_y$ or $\sigma_d = s_u/1.95 = 0.51\, s_u$ (whichever is lower)

Design bending stresses

A. General machine and structural design

Manner of loading	Ductile materials (% elongation >5%)	Brittle materials (% elongation <5%)
Static loads	$\sigma_d = s_y/2$	$\sigma_d = s_u/6$
Repeated loads	$\sigma_d = s_u/8$	$\sigma_d = s_u/10$
Impact or shock	$\sigma_d = s_u/12$	$\sigma_d = s_u/15$

B. AISC specifications: Structural steel, static loads on building-like structures

$$\sigma_d = s_y/1.5 = 0.66\, s_y$$

C. Aluminum Association specifications: Aluminum, static loads on building-like structures

$$\sigma_d = s_y/1.65 = 0.61\, s_y \text{ or } \sigma_d = s_u/1.95 = 0.51\, s_u \quad \text{(whichever is lower)}$$

Design shear stresses for beams in bending

A. Rolled structural steel beam shapes: Allowable web shear stress (AISC)

$$\tau_d = 0.40\, s_y$$

B. General ductile materials carrying static loads: Based on yield strength of the material in shear with design factor

$$\tau_d = s_{ys}/N = 0.5\, s_y/N = s_y/2N$$

Design shear stresses—for direct shear and for torsional shear stresses

Based on maximum shear stress theory of failure:

$$\tau_d = s_{ys}/N = 0.5\, s_y/N = s_y/2N$$

Manner of loading	Design factor	Design shear stress
Static loads	Use $N = 2$	$\tau_d = s_y/4$
Repeated loads	Use $N = 4$	$\tau_d = s_y/8$
Shock or impact	Use $N = 6$	$\tau_d = s_y/12$

Estimates for the ultimate strength in shear

Formula	Material
$s_{us} = 0.65\, s_u$	Aluminum alloys
$s_{us} = 0.82\, s_u$	Steel—plain carbon and alloy
$s_{us} = 0.90\, s_u$	Malleable iron and copper alloys
$s_{us} = 1.30\, s_u$	Gray cast iron

Figure 2 – Design Stress Guidelines (9)

A–14 Typical properties of aluminum alloys.[a]

Alloy and temper	Ultimate strength, s_u		Yield strength, s_y		Percent elongation	Shear strength, s_{us}	
	ksi	MPa	ksi	MPa		ksi	MPa
Alloys in wrought form							
1100-H12	16	110	15	103	25	10	69
1100-H18	24	165	22	152	15	13	90
2014–0	27	186	14	97	18	18	124
2014-T4	62	427	42	290	20	38	262
2014-T6	70	483	60	414	13	42	290
3003-0	16	110	6	41	40	11	76
3003-H12	19	131	18	124	20	12	83
3003-H18	29	200	27	186	10	16	110
5154-0	35	241	17	117	27	22	152
5154-H32	39	269	30	207	15	22	152
5154-H38	48	331	39	269	10	28	193
6061-0	18	124	8	55	30	12	83
6061-T4	35	241	21	145	25	24	165
6061-T6	45	310	40	276	17	30	207
7075-0	33	228	15	103	16	22	152
7075-T6	83	572	73	503	11	48	331
Casting alloys—permanent mold castings							
204.0-T4	48	331	29	200	8	—	—
206.0-T6	65	445	59	405	6	—	—
356.0-T6	41	283	30	207	10	—	—

[a]Modulus of elasticity E varies for different aluminum alloys:
For most alloys, including 1100, 3003, 6061, 6063, $E = 10 \times 10^6$ psi (69.0 GPa).
For alloy 2014, $E = 10.6 \times 10^6$ psi (73.1 GPa).
For alloy 5154, $E = 10.2 \times 10^6$ psi (70.3 GPa).
For alloy 7075, $E = 10.4 \times 10^6$ psi (71.7 GPa).
Density of most aluminum alloys is approximately 0.10 $lb_m/in.^3$ (2770 kg/m^3).

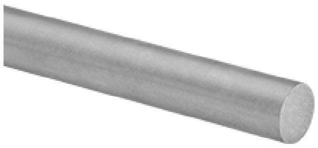
Figure 3 – Aluminum Alloy Properties (9)

McMASTER-CARR

Find

Easy-to-Machine 1144 Carbon Steel Rod

High-Strength, 5/8" Diameter



Length, ft.
1
3
6

Each

ADD TO ORDER

6628K324

1 each ordered on April 19
0419MBENNETT.

Select a CAD file type | Download

Material	1144 Carbon Steel
Shape	Rod and Disc
Shape Type	Rods
Diameter	5/8"
Diameter Tolerance	-0.003" to 0"
Tolerance Rating	Undersized
Yield Strength	100,000 psi
Fabrication	Cold Drawn
Heat Treatment	Stress Relieved
Hardness	Rockwell C25
Hardness Rating	Hard
Maximum Hardness After Heat Treatment	Not Rated
Heat Treatable	Yes
Certificate	Material Certificate with Traceable Lot Number
Appearance	Plain
Temperature Range	Not Rated
Specifications Met	ASTM A108, ASTM A29, ASTM A311
Straightness Tolerance	Not Rated
Coefficient of Thermal Expansion	7.4×10^{-6}
Elongation	6.5%

Figure 4 – 1144 Alloy Steel Properties (10)