Cardiovascular Conditioning Machine For Sled Hockey Athletes

A Baccalaureate thesis submitted to the
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College of Engineering and Applied Science
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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 was 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

Skiing, hockey, and sled hockey all use a similar motion called skating with minor variations from sport to sport. Skating for skiing and hockey require the use of the athlete's legs and arms, whereas in sled hockey the athlete is limited to the use of their arms. Skating can be described as a pushing motion performed by ones legs that uses the sharp, inside edge of the ski or skate to dig into the snow or ice and push off of that edge almost in a running motion. One continues that same pushing motion with both legs and propels themselves. In skiing, one can use their arms in combination with their ski poles to add another pushing force along with their legs. In hockey, the athletes use their arms for stability and added momentum. In sled hockey, the athlete cannot use their legs, so they propel themselves on the ice using a combination of a pole and hockey stick, one end having a hockey stick head and the other having a spike to penetrate the surface of the ice. There have been many devices made to mimic the skating motion used in skiing and hockey to train an athlete, but none specifically designed for sled hockey.

Cross-country Skiing Machine (6)

This is a machine designed to mimic the motions used in cross-country skiing. Those motions include the skating motion described above as well as incorporating the ability to sway side to side, which simulates the motion a skier uses to physically turn the ski. The benefit to this machine, in terms of training a sled hockey athlete, is its ability to train the skating motion performed by the arms. Some glaring and obvious setbacks to this machine are that it has not been designed to consider a paraplegic individual. Many adaptations would need to be made in order for this machine to accommodate someone who cannot use their legs, making this machine a poor choice for training a sled hockey athlete.

SkiErg

Another machine that is used to train the motions of skating when one skis is the Ski Ergometer or SkiErg (7). This machine has a more limited application, specifically that it only recreates the motion of skating performed by one's arms. Skating can be generally described as a pendulum motion of the arms that transfers the potential energy of one's arms at the top of their stroke, to kinetic energy as the arms reach the bottom of the stroke, then a pushing motion as the skier's poles penetrate the snow. The machine recreates the motion and the resistance felt by having two cables travel along a pulley that mimics the starting position of one's arms, having independent, variable resistances controlled at the base of the machine. This means that the user can move both arms in unison and/or move them iso-laterally. The sled-hockey athletes use the pendulum-like skating motion described above to propel themselves on the ice with their arms and no use of their legs, which is why the Ski Ergometer can be seen as a more suitable conditioning device for these athletes over the Cross-country Skiing Machine. A draw back to this machine again, is that it was not designed with a paraplegic individual in mind. This machine would require significantly less adaptations than the Cross-Country Skiing Machine but would still need at least add a place for the athlete to sit.

Arm Crank Ergometer

The Arm Crank Ergometer is another machine that can train similar muscle groups that are used when performing the skating motion used as a sled hockey athlete. The main difference is that the motion for this machine is linear instead of parabolic like the desired pendulum motion mentioned above. One big advantage to this machine is the fact that it is a great way to measure maximum oxygen consumption over a period of time (8). Another big advantage over the SkiErg or Cross-country Skiing Machine is that this machine is usually fashioned with a bench that is connected to the resistance lever that the user sits on to train on the machine. This is an advantage because very minor accommodations will need to be made to allow a paraplegic individual to use it. One could add some straps to secure their legs and maybe a vertical plate to rest the user's back against for comfort. The main drawback of this device is its limitation to only linear motion due to its design.

In terms of paraplegic adapted fitness equipment, there are few existing machines out there. Most, if not all, are based around the incorporation of a wheelchair to be used as a base rather than a seat for those machines that utilize one. Specifically, for cardiovascular training, there is a machine called the Wheelchair Ergometer. The Wheelchair Ergometer is a machine that uses a wheelchair as a base which is connected to resistance mechanisms that are usually controlled by an electronic panel (9). It seems, after performing research, that these devices are not sold commercially and are mainly used in a lab setting to collect data on their benefit to the rehabilitation or general health of paraplegic individuals. This device is great for increasing arm muscle endurance and lowering oxygen consumption but does not replicate the skating motion the players use therefore it could be training the incorrect muscle groups. A new type of machine is needed for these athletes to have a well-rounded fitness regimen.

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 feeling during a game scenario, which can create a better player to coach bond.

CONCLUSIONS AND SUMMARY OF RESEARCH

After performing research on the topics of sled hockey, athletic training programs, and fitness equipment adapted for paraplegic individuals our team has found that for our specific application there is not much existing in the open market, in terms of a fitness machine, to be purchased and used to train these individuals. Most fitness equipment that exists to train the specific motion used during the sled hockey games is geared towards able bodied individuals and is not designed specifically for the sport of sled hockey itself. Fitness equipment that has been made for paraplegic individuals, that is available on the market, is focused more on strength training. The cardio equipment made for paraplegic individuals is used in a lab setting, is not for commercial sale, and does not accurately replicate the skating motion used by the players. It can be said that no machine currently exists for the specific application of training sled hockey athletes to improve their cardiovascular conditioning while simulating an in-game experience.

QUALITY FUNCTION DEPLOYMENT

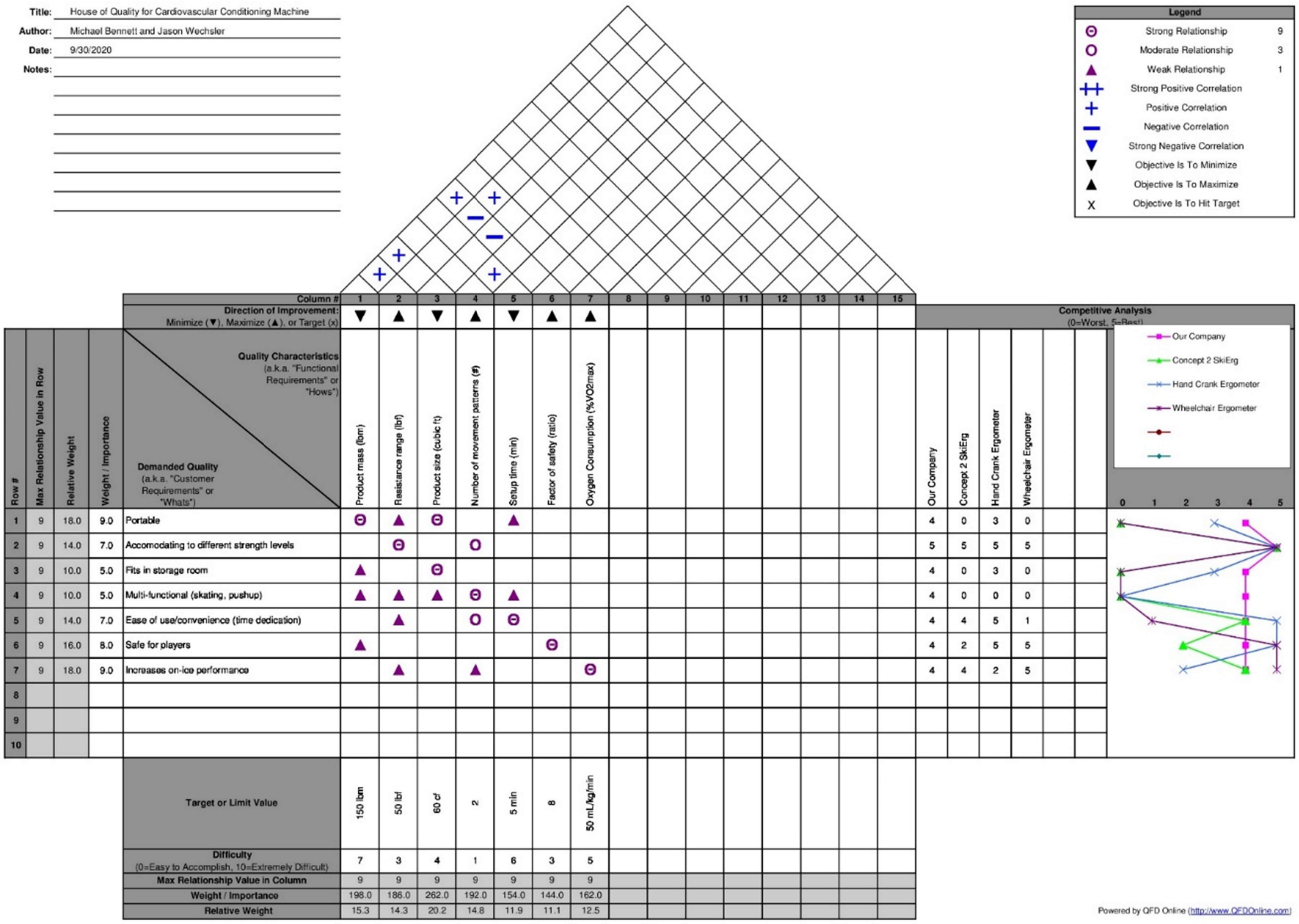
CUSTOMER FEATURES

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



Title: House of Quality for Cardiovascular Conditioning Machine
Author: Michael Bennett and Jason Wechsler
Date: 9/30/2020
Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Product mass (lbm)	Resistance range (lbf)	Product size (cubic ft)	Number of movement patterns (#)	Setup time (min)	Factor of safety (ratio)	Oxygen Consumption (%VO2max)									Our Company	Concept 2 SkiErg	Hand Crank Ergometer	Wheelchair Ergometer		
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▲	▼	▲	▲														
1	9	18.0	9.0	Portable	Θ	▲	Θ		▲											4	0	3	0		
2	9	14.0	7.0	Accomodating to different strength levels		Θ		O												5	5	5	5		
3	9	10.0	5.0	Fits in storage room	▲		Θ													4	0	3	0		
4	9	10.0	5.0	Multi-functional (skating, pushup)	▲	▲	▲	Θ	▲											4	0	0	0		
5	9	14.0	7.0	Ease of use/convenience (time dedication)		▲		O	Θ											4	4	5	1		
6	9	16.0	8.0	Safe for players	▲					Θ										4	2	5	5		
7	9	18.0	9.0	Increases on-ice performance		▲		▲			Θ									4	4	2	5		
8																									
9																									
10																									
				Target or Limit Value	150 lbm	50 lbf	60 cf	2	5 min	8	50 mL/kg/min														
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	3	4	1	6	3	5														
				Max Relationship Value in Column	9	9	9	9	9	9	9														
				Weight / Importance	198.0	186.0	262.0	192.0	154.0	144.0	162.0														
				Relative Weight	15.3	14.3	20.2	14.8	11.9	11.1	12.5														

Figure 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 – SEAT ASSEMBLY

Concept 1:

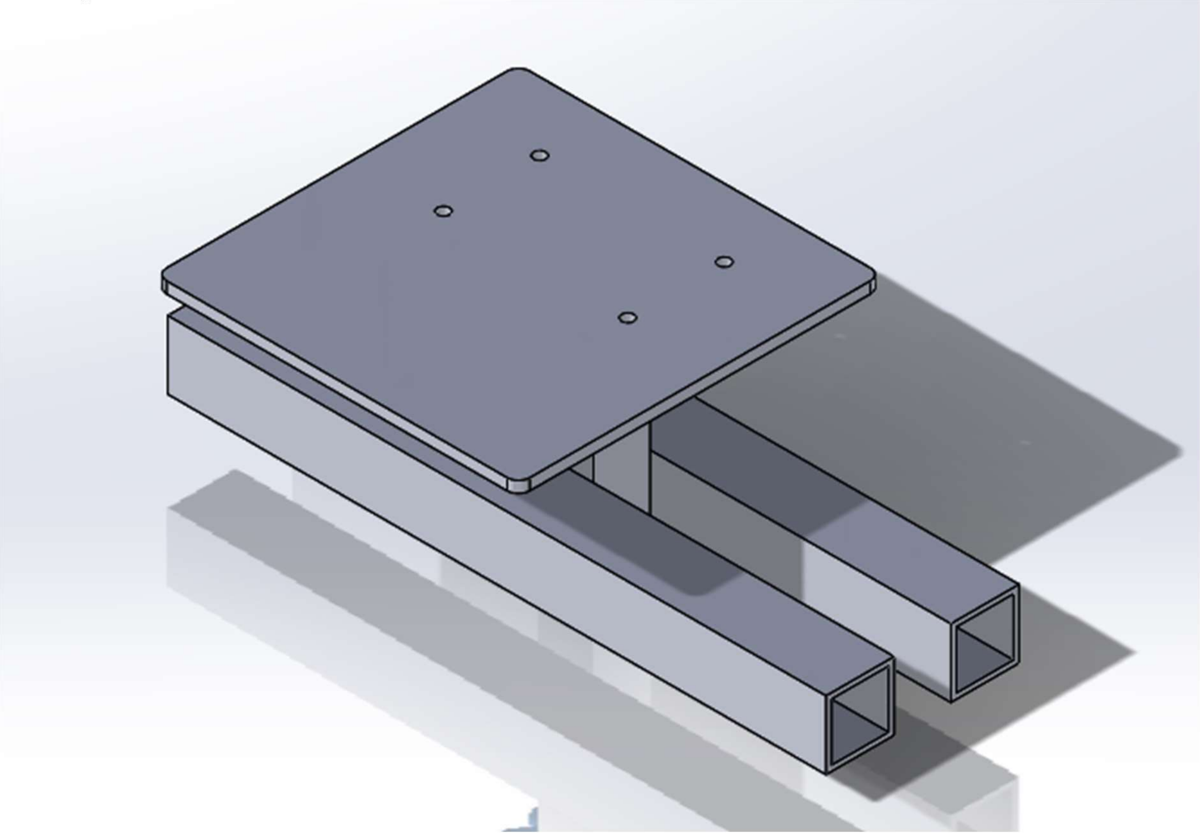


Figure 2. Isometric View of Seat Concept 1

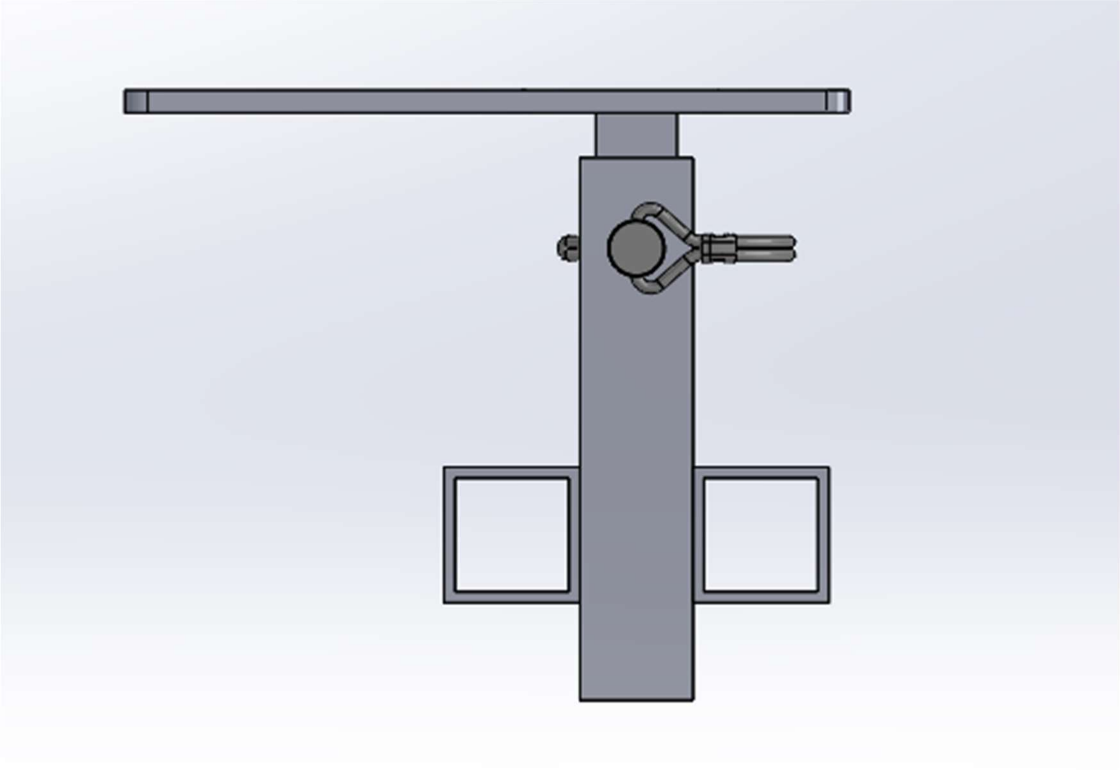


Figure 3. Side View of Seat Concept 1

Concept 1 is a height adjustable seat that consists of a plate, an inner tube, a locking pin, an outer tube, and two tube mounts. The plate is constructed of aluminum and has clearance holes to bolt the seat on. The inner tube is a piece of aluminum bar that is welded to the plate and has equally spaced holes used to adjust the height. The outer tube is constructed of square aluminum tubing with a singular through hole where a pin is inserted to lock the inner and outer tubes in place. The tube mounts are a pair of square aluminum tubing that provide stability for the outer tube. The outer tube is welded to the tube mounts and positioned so that the outer tube is in contact with the floor. This reduces the stress seen by the tube mounts and make the design safer. The tube mounts are welded into the base of the machine to ensure structural stability. Some advantages to this design are that it is adjustable, stable, and light weight. Some disadvantages to this design are that it has a telescoping section that manifests a pinching hazard to the person who adjusts the seat.

Concept 2:

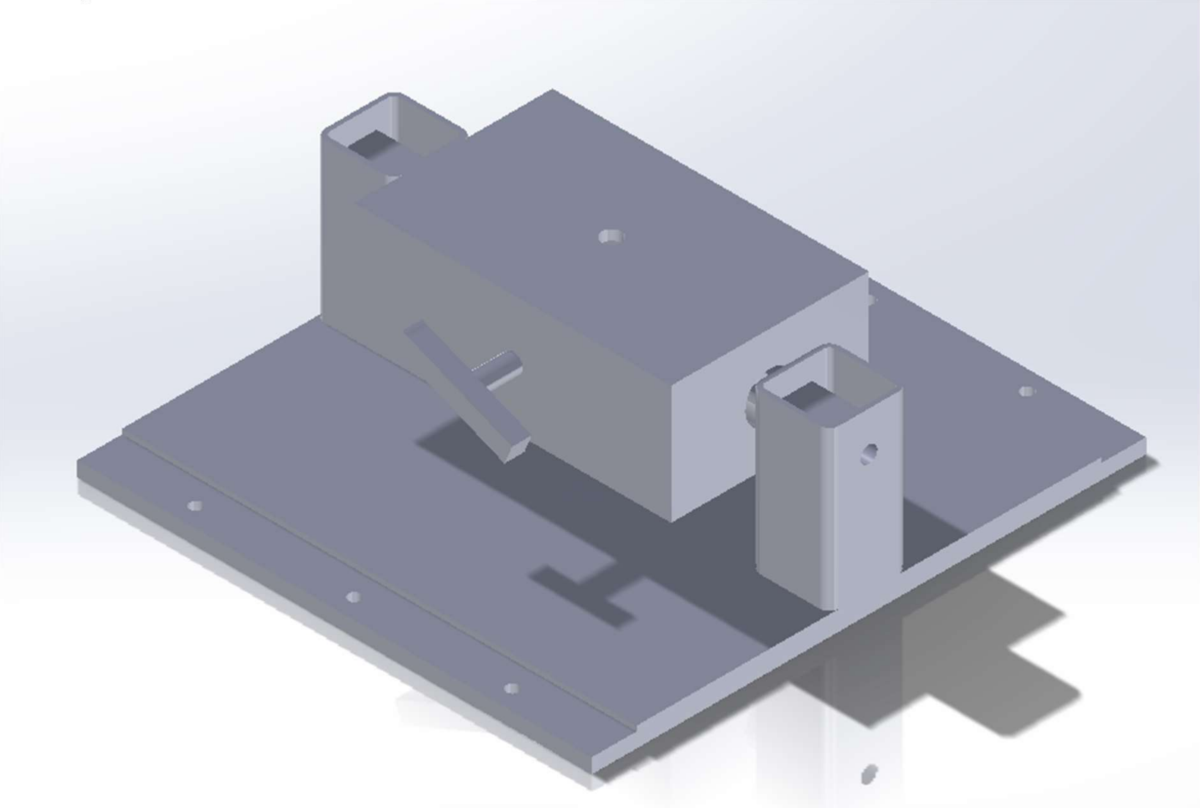


Figure 4. Isometric View of Seat Concept 2

Concept 2 was designed to add a new feature to the machine that would simulate another aspect of being on the ice. That feature being that the seat could rotate. The players sometimes fall over on the ice and must push themselves, while staying in the bucket, back into the upright position. With the ability for the seat to rotate the players could practice pushing themselves back to the upright position. This concept is constructed of a base plate, a pair of square tubing, a shaft, a casted bearing housing, a seat mount, and a locking pin. The base plate is constructed of structural steel with mounting holes to bolt into the main frame. The square tubing is also steel and has a square pocket at the top where the shaft seats and is welded to the base plate. The shaft is constructed of steel with each end milled square to be inserted into the matching pocket in the tubing and the shaft has a central hole used to lock the seat mount in place. The square ends prevent the shaft from rotating. The shaft will be secured from sliding by welding it to the tubing. The casted bearing housing is a McMaster-Carr part that consists of a cast iron housing that holds a set of two bearing that will allow the seat to rotate. The housing fastens to the seat mount with a pair of screws. The seat mount is constructed of 5 steel plates that are welded together with holes for the bearing housing to mount into, holes for the seat to mount to the seat mount, and a hole that aligns with the hole in the shaft that allows for a pin to lock the seat in place. Some advantages to this design are that it is structurally sound and provides an extra feature to the machine that will assist in on ice performance. Some drawbacks to this design are the cost being very high, it is heavy, and manifests numerous pinching or crushing hazards to the user of the machine.

Concept 3:

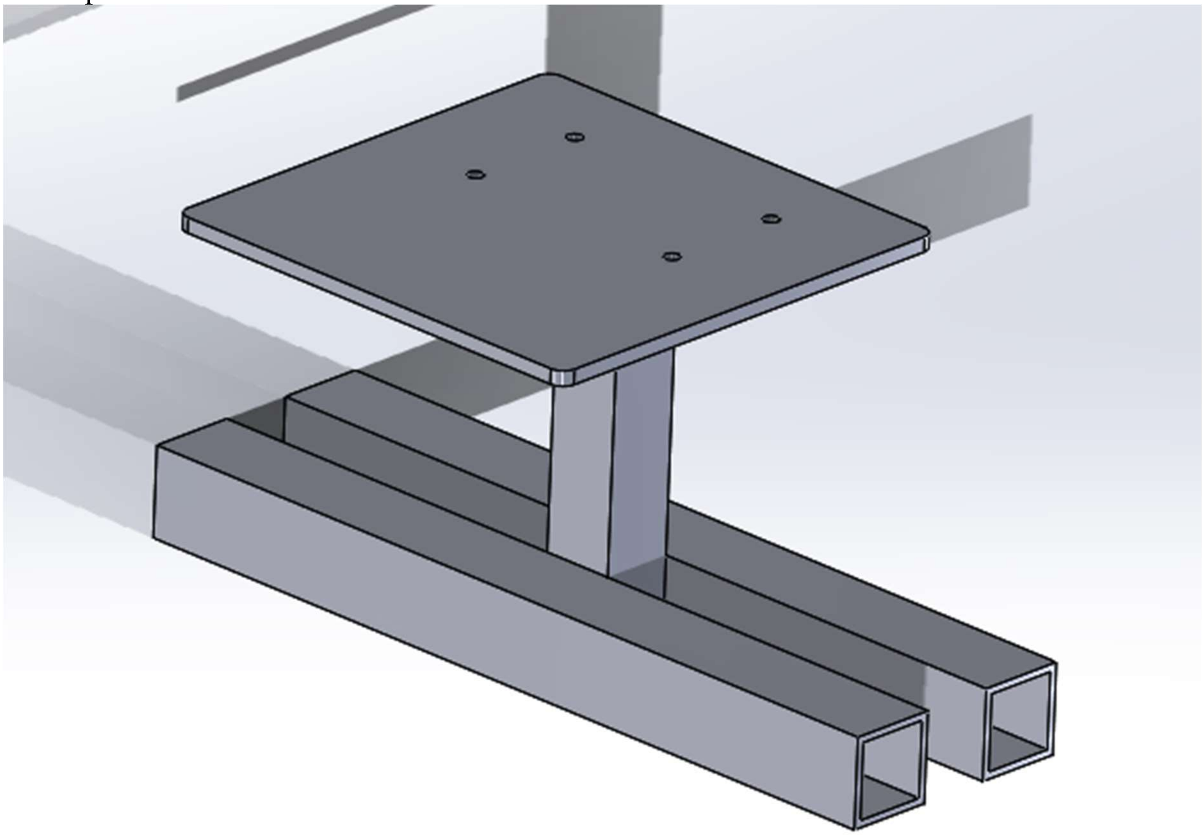


Figure 5. Isometric View of Seat Concept 3

Concept 3 is similar to concept 1 minus the seat inner tube and locking pin. The outer tube is a bit longer and is welded to the seat plate and the tube mounts. Some advantages to this design are that it is safe, light weight and simple to manufacture. This design can be seen as safer than concept 1 because there is not a pinching hazard caused by the adjustable seat. On the contrary, the biggest disadvantage to this design is that it is not adjustable which prohibits this design from being capable of accommodating any sized player.

DESIGN ALTERNATIVES AND SELECTION – FOOTREST ASSEMBLY

Concept 1:

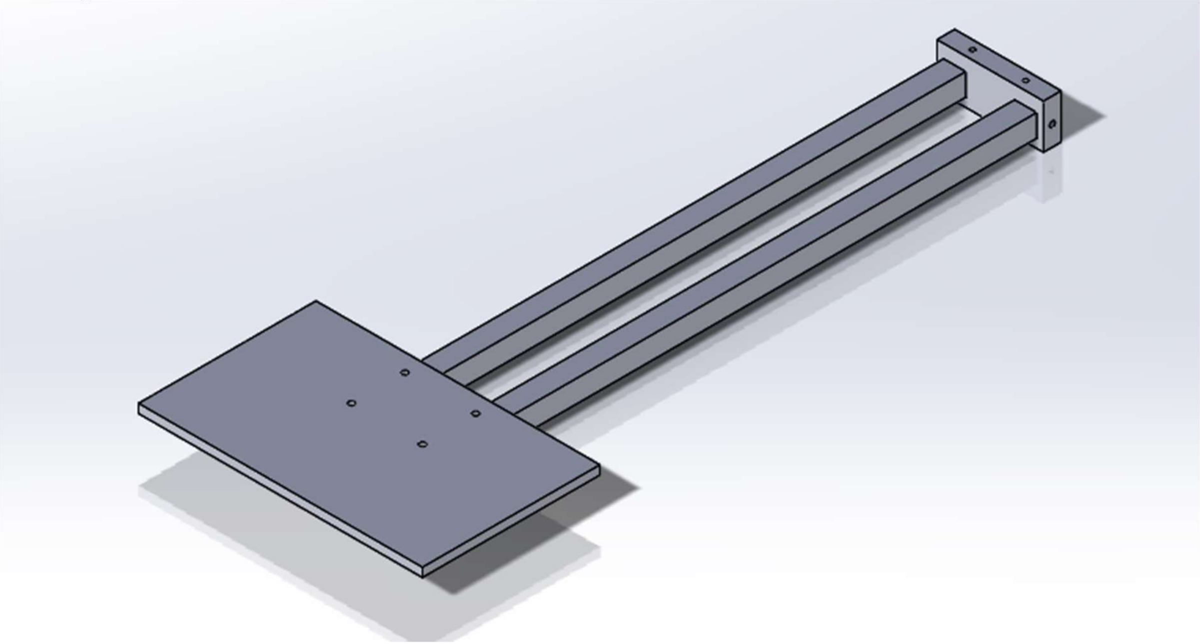


Figure 6. Isometric View of Footrest Concept 1

Concept 1 was designed to be a simple adjustable footrest that attached to the bottom of the seat. It is constructed of a block of aluminum that mounts to the seat with screws. The block of aluminum has two milled pockets where two pieces of aluminum tubing will insert. There is a hole on either side of the block where a set screw is used to lock the tubing in place. At the end of the tubing, a piece of wood is mounted and secured using screws and lock nuts. Some advantages to this design are it is light weight, adjustable, and inexpensive. Some draw backs to this design are in the structural aspect. A large moment will be created in the tubing when it is at full extension and will result in a bending stress. This could potentially cause deformation in the tubing or worse begin to strip the threading in the aluminum block in the holes that mount to the seat.

Concept 2:

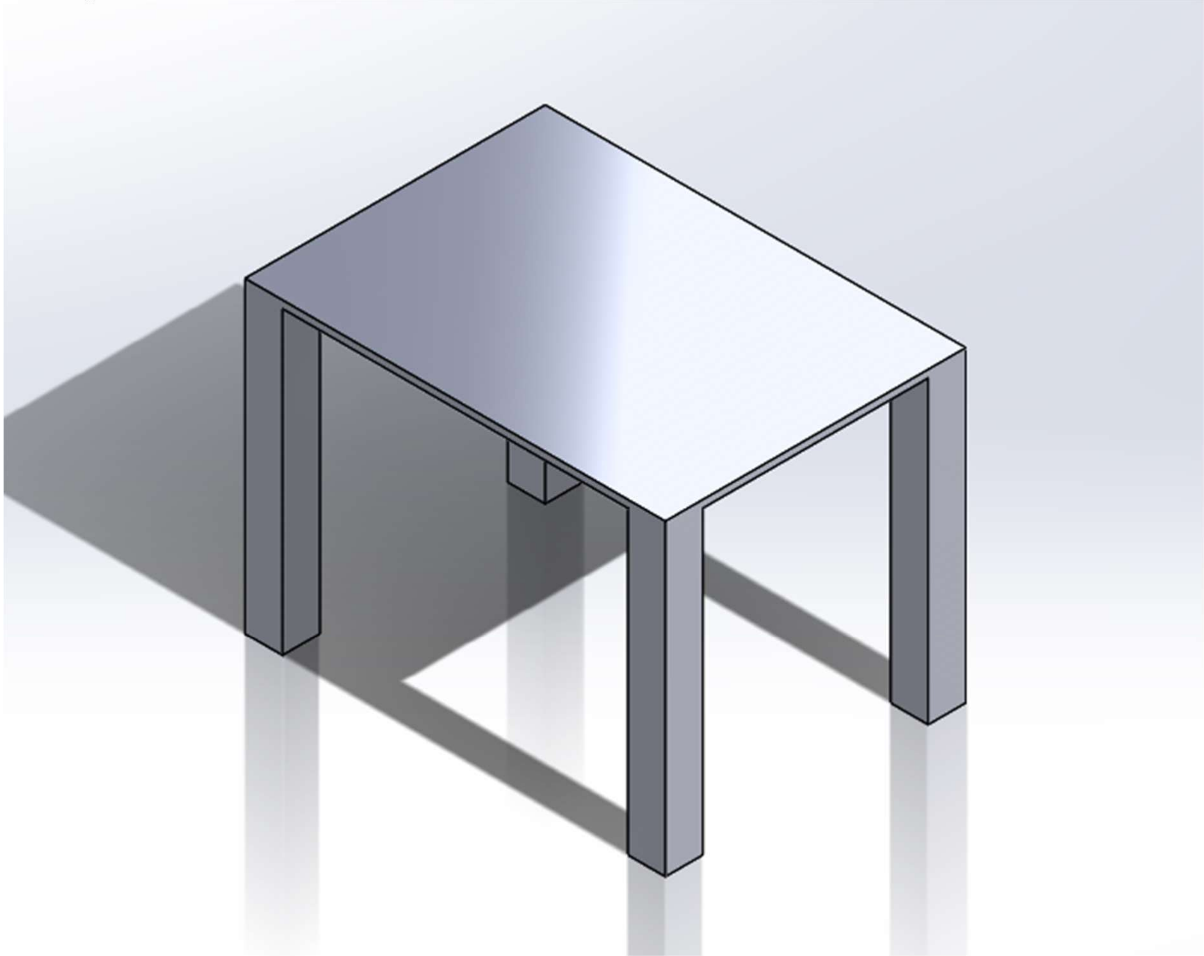


Figure 7. Isometric View of Footrest Concept 2

Concept 2 is a stool that the user places at a comfortable distance from the seat. It is constructed of four aluminum bars that fasten to a thinner aluminum plate with screws. Some advantages to this design are it is structurally sound, simple, and light weight. The biggest disadvantage to this design is that it is not adjustable in height but only in placement. This is an issue because we are trying to accommodate any sized player on this machine.

Concept 3:

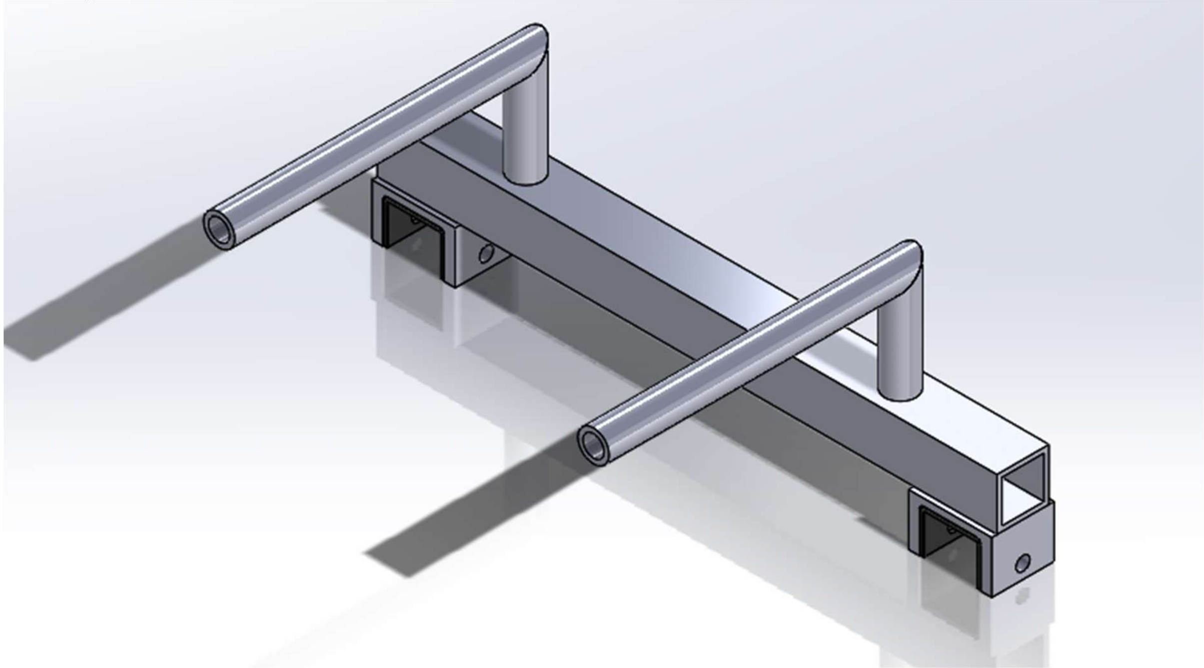


Figure 8. Isometric View of Footrest Concept 3

Concept 3 is more complex in construction but provides a more realistic "in game" feeling for the user as it was designed to replicate the footrest on the sleds. This concept consists of two pieces of aluminum channel with PLA that mimics the channels geometry, a piece of square aluminum tubing with holes on the top, two sets of round aluminum tubing, and a canvas cover that inserts over the tubing where the players feet will rest (canvas not pictured). The PLA provides a low friction mount for the footrest allowing it to be easily adjusted. There are through holes on each aluminum channel with PLA that allow for a pin to lock the footrest in place. The square aluminum tubing has holes that match the outside diameter of the round tubing. The shorter pieces of tubing are cut at a 45° angle on one end and are inserted into the holes in the square tubing as shown. The tubing is then welded into place. The longer pieces are also cut at a 45° angle on one end and are welded to the shorter pieces at the 90° joint. Then the piece of canvas is inserted over the round tubing and will hold the players feet. Some advantages to this design are it is adjustable, easy to use, light weight, and best replicates the feeling of being in the sled on the ice. The biggest disadvantage to this design is it is more complex to manufacture as it is a more complex design.

Summary of Concepts

Decision Matrix:

Seat Concept Selection Matrix			
Criteria	**Concept 1 - Seat with Adjustable Height**	Concept 2 - Seat with Fixed Height and Ability to Rotate	Concept 3 - Seat with Fixed Height
Safety	9	6	10
Cost	9	5	10
Weight	9	6	9
Ease of Use	9	6	10
Functionality	10	8	7
Total	**46**	31	46

10 = Best 1 = Worst

Table 1. Seat Concept Selection Matrix

From the seat selection matrix, you can see that both concepts 1 and 3 rank the same, but we chose concept 1 mainly based upon its large functionality rating. Safety is evaluated by how many moving parts exist that may cause a pinching hazard. Cost is simply how much it would cost in materials and manufacturing time. Weight is directly related to the amount of material needed for the design. Ease of use pertains to how quickly the user can set the seat up. Functionality is used to describe how well it accommodates different users and the ability for the height to be adjustable makes the machine available to a wider variety of players.

Footrest Concept Selection Matrix			
Criteria	Concept 1 - Adjustable Extension from Seat	Concept 2 - Stool	**Concept 3 - Adjustable Footrest on Base Beams**
Safety	6	10	8
Cost	8	10	8
Weight	8	9	10
Ease of Use	7	7	9
Functionality	9	8	10
Total	38	44	**45**

10 = Best 1 = Worst

Table 2. Footrest Concept Selection Matrix

From the Footrest Selection Matrix, you can see that concept 3 is the best option. The concepts were compared with safety, cost, weight, ease of use, and functionality in mind. Safety relates to the amount of moving parts and loading conditions from the user. Cost is evaluated as a value of 10 being the lowest costing option. Weight is evaluated as 10 being the lowest weight. Ease of use is evaluated as 10 being the easiest to set into the desired position with the least amount of assistance needed as some players cannot stand on their own. Functionality was evaluated as 10 being the best at accommodating different sized players. Concept 3 has good structural integrity, it was low cost, light weight, and most importantly gave us the best functionality.

ENGINEERING CALCULATIONS

List of equations

Shear Stress:

$$\tau = \frac{VQ}{Ib}$$

Tensile Stress

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

Torsional Stress

$$\tau = \frac{Tc}{J}$$

Torsional Stress

$$\tau = \frac{T}{Z_p}$$

Max Bending Stress:

$$\sigma_{max} = \frac{M}{S} * K_t$$

Max Bending Stress:

$$\sigma_{max} = \frac{6Mw}{(w^3 - d^3)t} * k_t$$

Design Shear Stress:

$$\tau_d = \frac{S_y}{2N}$$

Design Bending Stress:

$$\sigma_d = \frac{S_y}{N}$$

Loading Conditions - Seat Assembly

This machine will experience both static and dynamic loading conditions that will result in bending, tensile, and shear stresses across different members. Static loading conditions will be experienced from when the user is seated in the machine and when the user is at the end of their repetition. The dynamic loading conditions will arise in the moving parts when the player performs a stroke on the machine. Below we will analyze the different loading conditions applied to seat assembly and the footrest assembly.

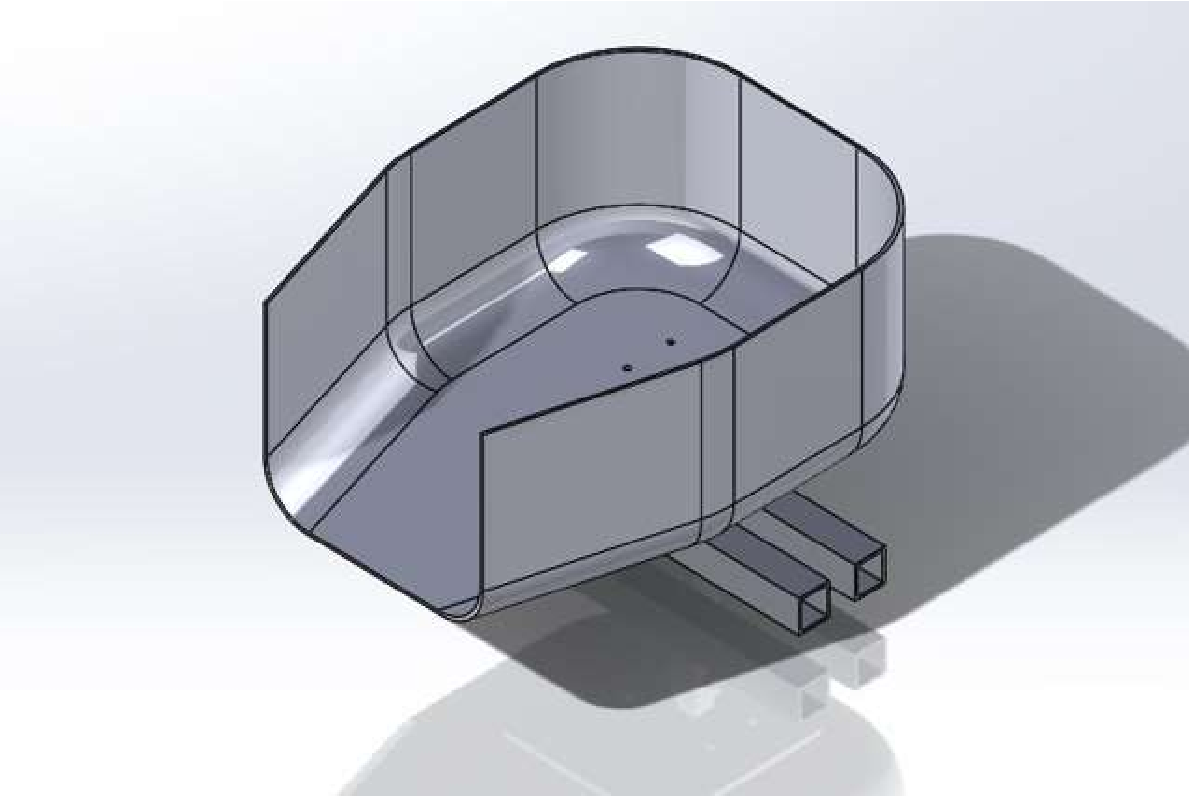


Figure 9. Isometric View of Seat Assembly

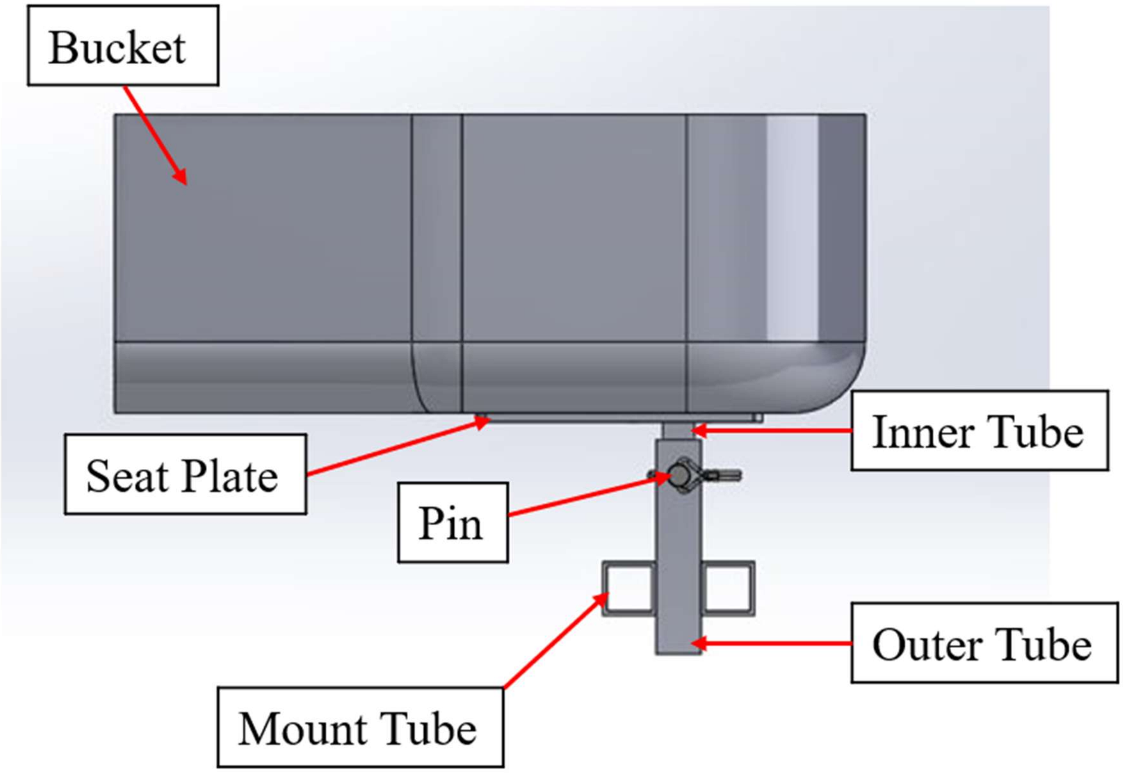


Figure 10. Labeled Side View of Seat Assembly

1. The plate is subjected to the forces shown below:

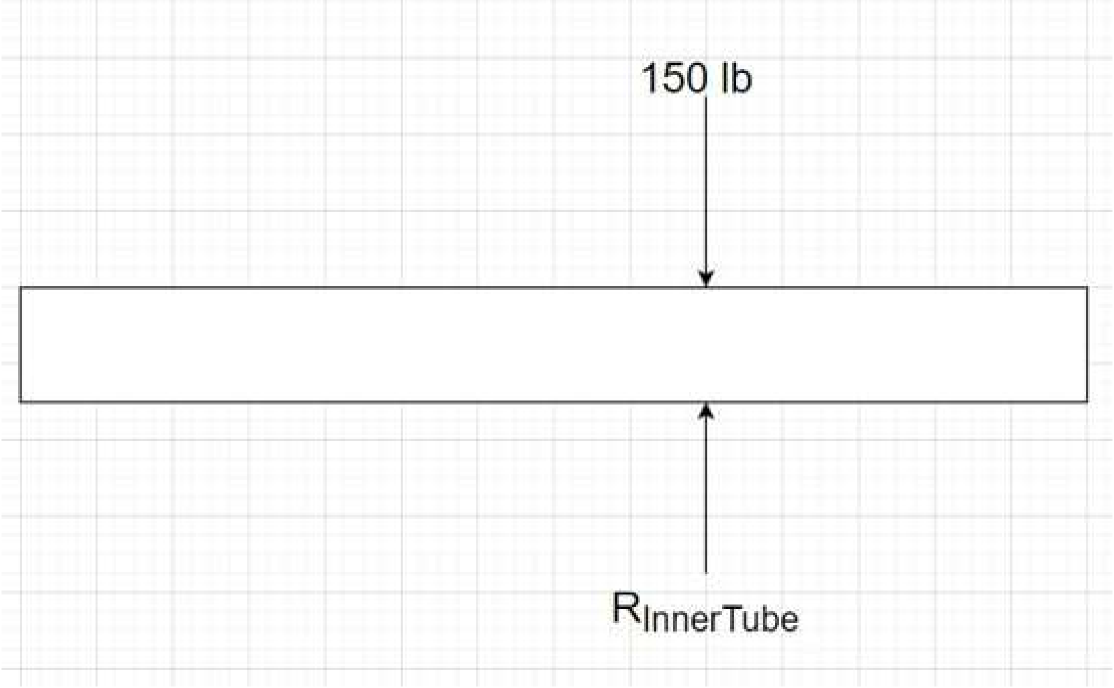


Figure 11. Free Body Diagram of Seat Plate

2. The plate is subjected to the static load of the player sitting on it and the reaction force of the inner tube. The plates material is Aluminum 6061-T6 with a yield strength of 40 ksi. A safety factor of 4 was chosen for repeated loads as the players will be getting in and out of the seat.

$$\sigma_{max} = \frac{F}{A} = \frac{150\ lb}{(.9in)^2} = 185\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Tensile\ Stress$

$F = Applied\ Force$

$A = Area$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the plate, therefore the material and safety factor are appropriate for this application.

3. The inner tube is subjected to the forces shown below:

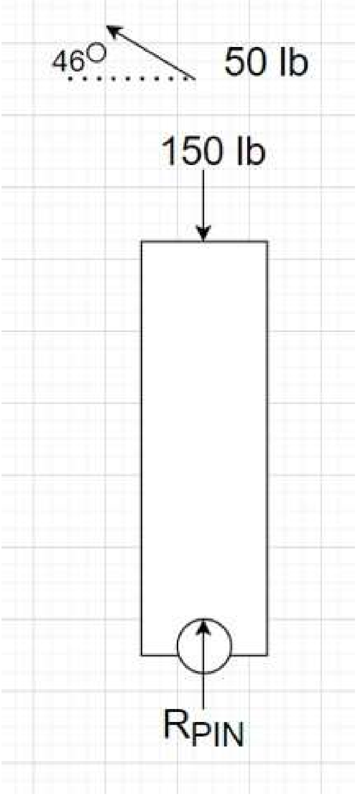


Figure 12. Free Body Diagram of Inner Tube

4. The inner tube is subjected to the static force of the player sitting in the seat which creates a static tensile loading condition. The inner tube is also subjected to a moment created by the player ending their stroke while using the machine which creates a dynamic loading condition. A safety factor of four was chosen for repeated loads considering the player will be getting in and out of the machine and performing multiple repetitions at a time.

   We will first consider the static loading of the player sitting in the equations shown below:

$$\sigma_{max} = \frac{F}{(w-2r)t} * k_t$$

$$\sigma_{max} = \frac{150\ lb}{(.9\ in - \ .397\ in).9} * 2.15 = 712.5\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Tensile\ Stress$

$F = Applied\ Force$

$w = Width\ of Plate\ With\ Hole$

$r = Radius\ of\ Hole\ in\ Plate$

$t = Thickness\ of\ Plate$

$k_t = Stress\ Concentration$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the inner tube, therefore the material and safety factor are appropriate for this application.

Next, we will consider the static repeated loading condition player ending their stroke in the equations shown below:

$$\sigma_{max} = \frac{6Mw}{(w^3 - d^3)t} * k_t$$

$$\sigma_{max} = \frac{6(851\ in - lb).9\ in}{((.9in)^3 - (.397in)^3).9\ in} * 1 = 7{,}662\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Bending\ Stress$

$M = Moment$

$w = Width\ of Plate\ With\ Hole$

$d = Diameter\ of\ Hole\ in\ Plate$

$t = Thickness\ of\ Plate$

$k_t = Stress\ Concentration$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the inner tube, therefore the material and safety factor are appropriate for this application.

5. The pin is subjected to the forces shown below:

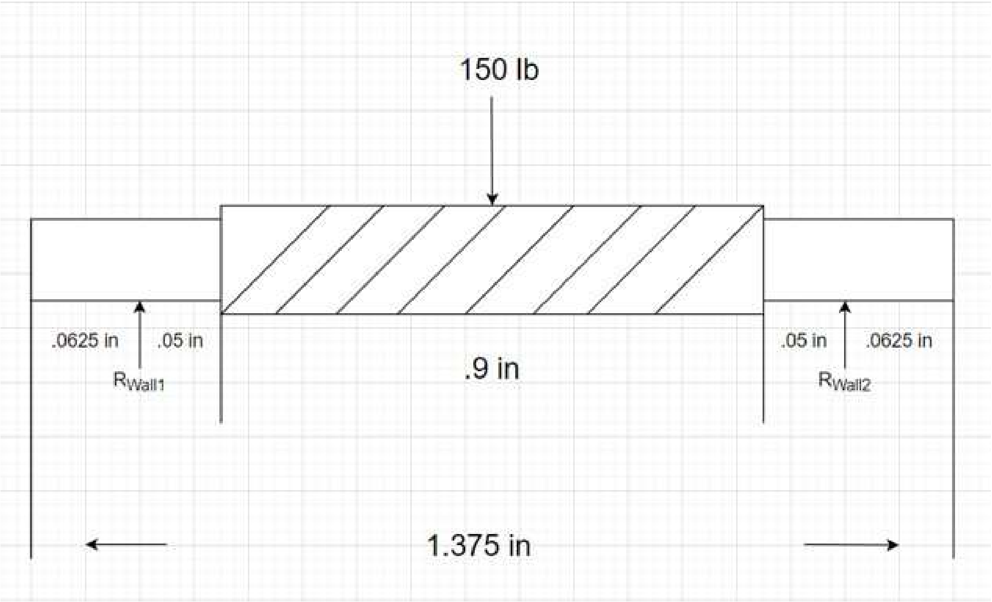


Figure 13. Free Body Diagram of Pin

6. The pin is subjected to static loading conditions which create bending and shear stresses across the pin. A safety factor of four was chosen for repeated loads as the players will be getting in and out of the seat.

   We will first consider the stress due to bending in the equations shown below:

$$\sigma_{max} = \frac{M}{\frac{\pi d^3}{32}}$$

$$\sigma_{max} = \frac{16.875\ in - lb}{\frac{\pi(.3125in)^3}{32}} = 5{,}632.5\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{60{,}000\ psi}{4} = 15{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Bending\ Stress$

$M = Moment$

$d = Diameter\ of\ Hole\ in\ Shaft$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 15 ksi is greater than the applied stress to the pin, therefore the material and safety factor are appropriate for this application.

Next, we will consider the stress due to shearing in the equations shown below:

$$\tau_{max} = \frac{4V}{3A}$$

$$\tau_{max} = \frac{4\ (75lb)}{3\pi(.156in)^2} = 1{,}304\ psi$$

$$\tau_d = \frac{S_{us}}{2N} = \frac{90{,}000\ psi}{8} = 11{,}250\ psi$$

Variables:

$\tau_{max} = Max\ Shear\ Stress$

$V = Shear\ Force$

$A = Shearing\ Area$

$\tau_d = Design\ Shear\ Stress$

$S_{us} = Ultimate\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 7.5 ksi is greater than the applied stress to the pin, therefore the material and safety factor are appropriate for this application.

7. The outer tube is subjected to the forces shown below:

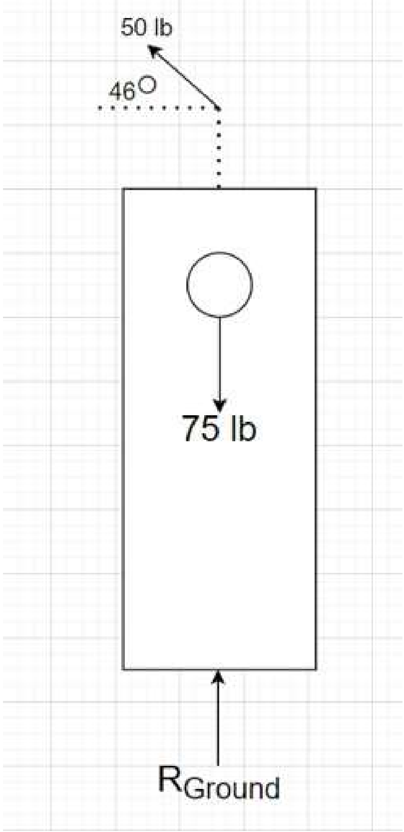


Figure 14. Free Body Diagram of Outer Tube

8. The outer tube is subjected to static loading from the pin resting on the walls of the tubing and a static repeated load from the player ending their stroke while using the machine. A safety factor of four was chosen for repeated loads considering the player will be getting in and out of the machine and performing multiple repetitions at a time.

   We will first consider the static stresses acting on the holes in the equations shown below:

$$\sigma_{max} = \frac{F}{(w-d)t} * k_t * 2\ walls$$

$$\sigma_{max} = \frac{75\ lb}{(1.25\ in - .397\ in).125} * 3.75 * 2 = 5{,}276\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Bending\ Stress$

$F = Applied\ Force$

$w = Width\ of Plate\ With\ Hole$

$d = Diameter\ of\ Hole\ in\ Plate$

$t = Thickness\ of\ Plate$

$k_t = Stress\ Concentration$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the tube walls, therefore the material and safety factor are appropriate for this application.

Next, we will consider the stress due to bending in the equations shown below:

$$\sigma_{max} = \frac{M}{S_{net}} * k_t = \frac{935\ in - lb}{\left(\frac{1.25in * (1.25in)^3}{6}\right) - \left(\frac{1in * (1in)^3}{6}\right)} * 1 = 5{,}881\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Bending\ Stress$

$S_{net} = Net\ Section\ Modulus$

$k_t = Stress\ Concentration$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the tube, therefore the material and safety factor are appropriate for this application.

9. The tube mount is subjected to the forces shown below:

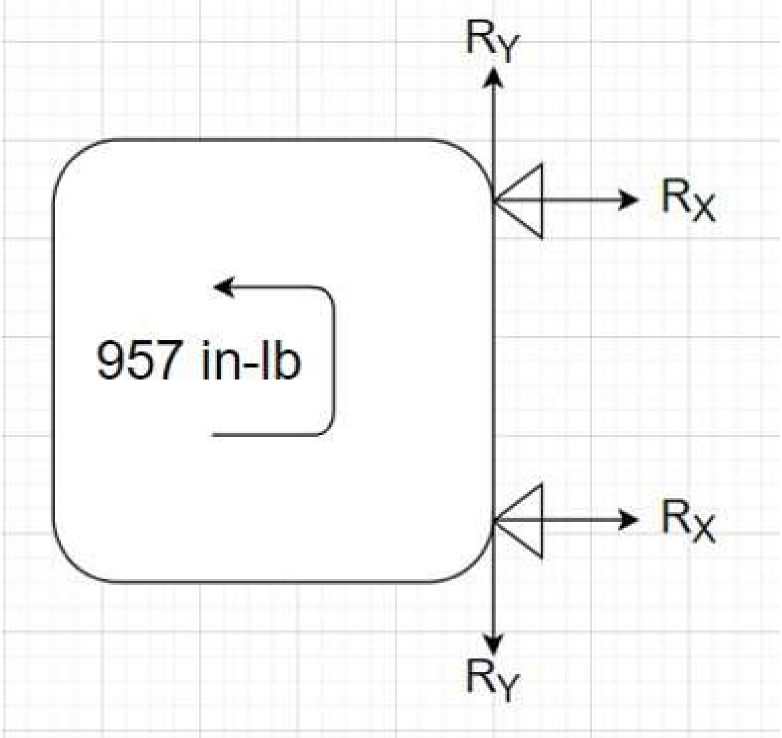


Figure 15. Free Body Diagram of Tube Mount

10. The tube mount is subjected to a static repeated load from the player ending their stroke while using the machine. A safety factor of four was chosen for repeated loads considering the player will be performing multiple repetitions at a time.

$$\tau_{max} = \frac{Tc}{J}$$

$$\tau_{max} = \frac{957in - lb * .625\ in}{\left(\frac{(1.25in)^4}{6}\right) - \left(\frac{(1in)^4}{6}\right)} = 2{,}492\ psi$$

$$\tau_d = \frac{S_{us}}{2N} = \frac{45{,}000\ psi}{8} = 5{,}625\ psi$$

Variables:

$\tau_{max} = Max\ Shear\ Stress$

$T = Applied\ Torque$

$c = Distance\ to\ Centroid$

$J = Polar\ Moment\ of\ Inertia$

$\tau_d = Design\ Shear\ Stress$

$S_{us} = Ultimate\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 4.5 ksi is greater than the applied stress to the tube, therefore the material and safety factor are appropriate for this application.

Loading Conditions - Footrest Assembly

The footrest assembly will encounter static repeated loading conditions from the user getting in and out of the machine which will create bending and shearing stresses within the individual members.

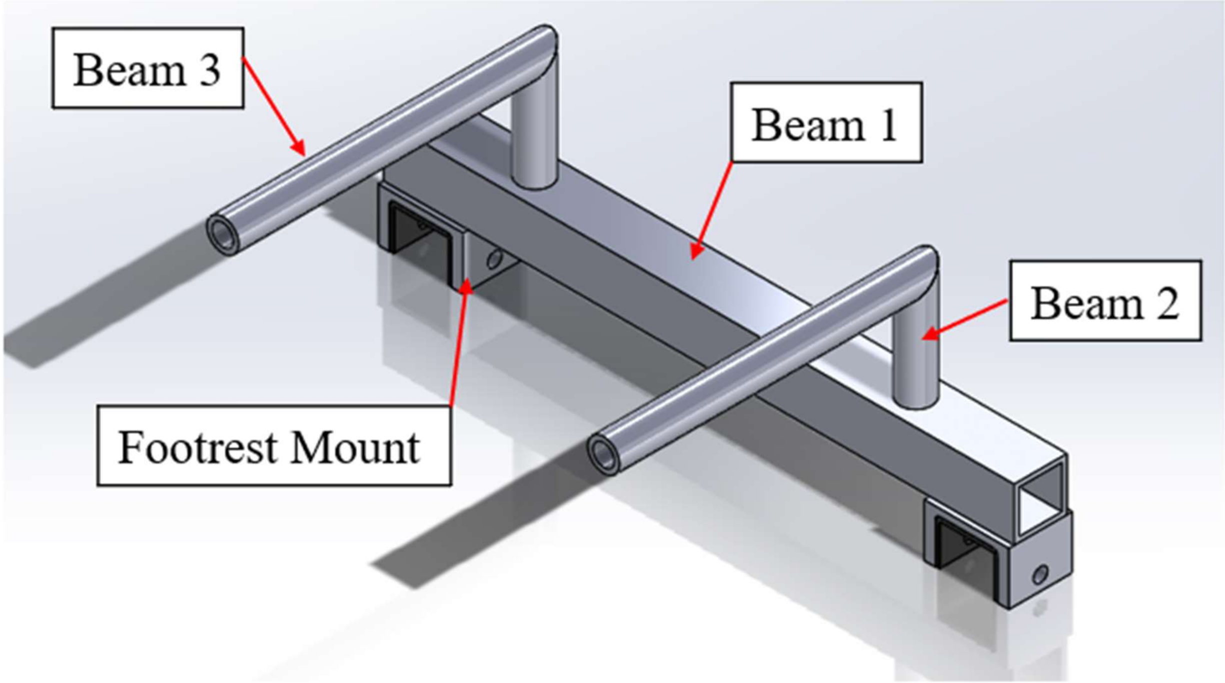


Figure 16. Labeled Isometric View of Footrest

11. Beam 3 is subjected to the forces shown below:

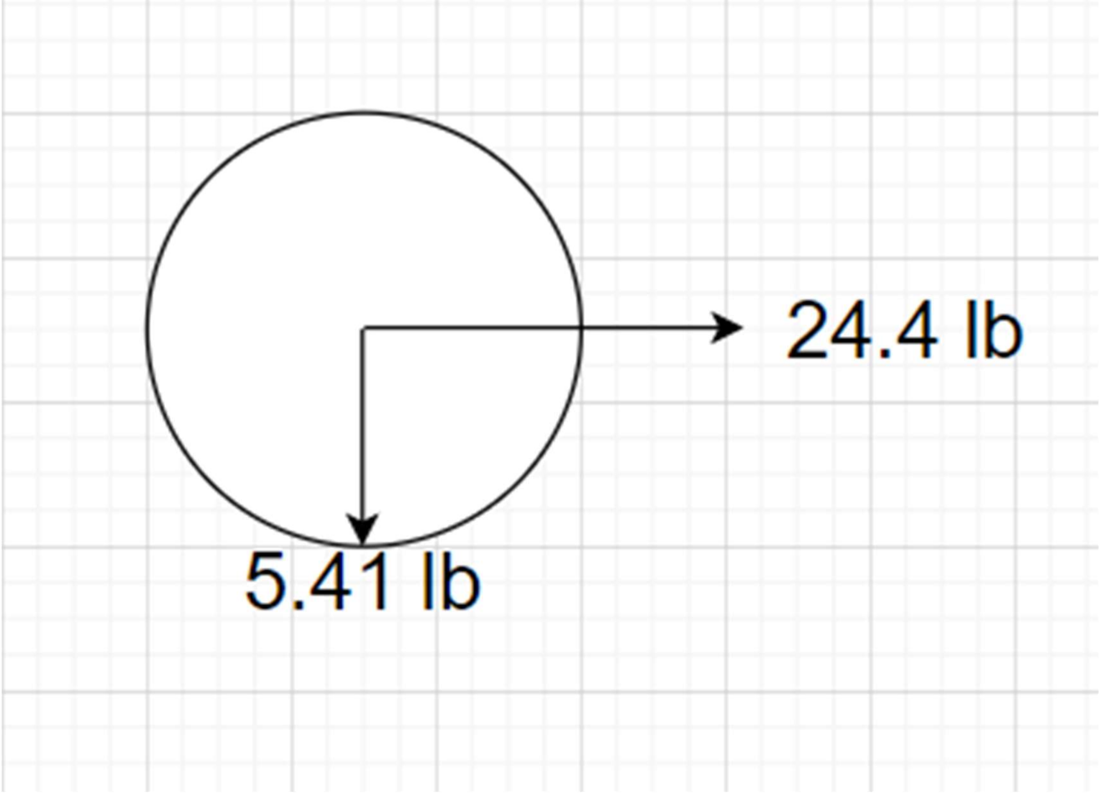


Figure 17. Free Body Diagram of Beam 3

12. Beam 3 is subjected to static repeated forces in both the X and Y direction which represents the weight of the players feet acting on the beam. A safety factor of 4 was chosen for repeated static loads.

    Loading in X:

$$\sigma x_{max} = \frac{M_x}{S_{net}}$$

$$\sigma x_{max} = \frac{190\ in - lb}{\left(\frac{\pi(.75in)^3}{32}\right) - \left(\frac{\pi * (.51in)^3}{32}\right)} = 6{,}662\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Loading in Y:

$$\sigma y_{max} = \frac{M_y}{S_{net}}$$

$$\sigma y_{max} = \frac{42\ in - lb}{\left(\frac{\pi(.75in)^3}{32}\right) - \left(\frac{\pi * (.51in)^3}{32}\right)} = 1{,}477\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma x_{max} = Max\ Bending\ Stress\ X - Direcion$

$\sigma y_{max} = Max\ Bending\ Stress\ Y - Direcion$

$M_x = Moment\ in\ X - Direction$

$M_y = Moment\ in\ Y - Direction$

$S_{net} = Net\ Section\ Modulus$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the tube, therefore the material and safety factor are appropriate for this application.

13. Beam 2 is subjected to the forces shown below:

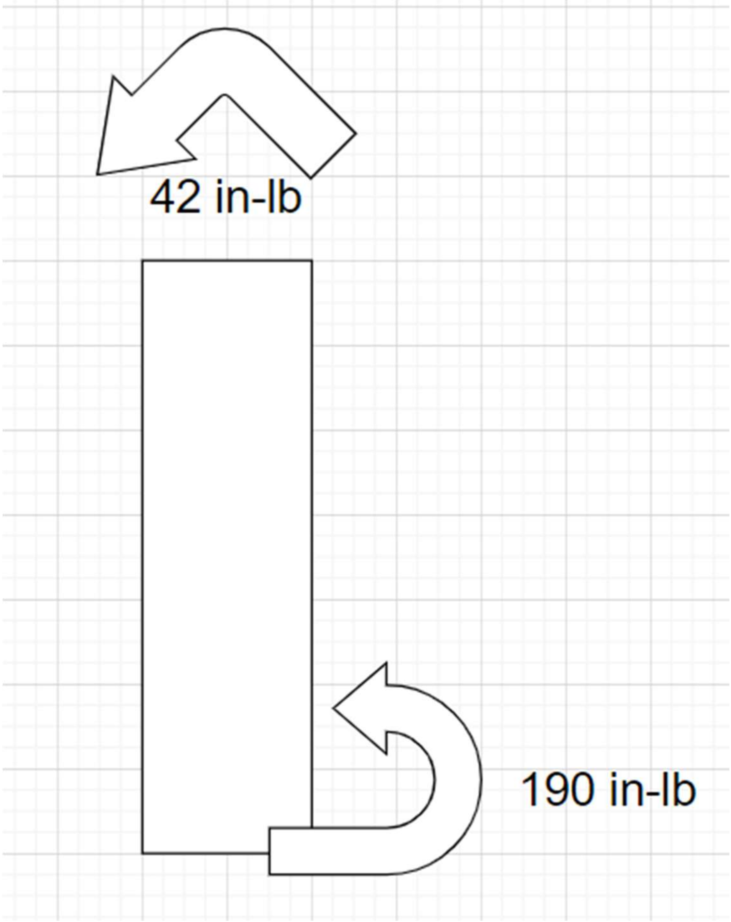


Figure 18. Free Body Diagram of Beam 2

14. Beam 2 is subjected to two moments from the X and Y components of the players feet resting on the footrest. These moments will create bending and shear and will be considered a repeated loading condition to simulate users getting in and out of the machine, therefore a safety factor of 4 was chosen for repeated static loads.

    First, we will consider the stresses due to bending:

$$\sigma_{max} = \frac{M}{S_{net}} = \frac{42\ in - lb}{\left(\frac{\pi(.75in)^3}{32}\right) - \left(\frac{\pi * (.51in)^3}{32}\right)} = 1{,}479\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Next, we will consider the stresses due to torsional shear:

$$\tau_{max} = \frac{T}{Z_{p\ net}} = \frac{190\ in - lb}{\left(\frac{\pi(.75in)^3}{16}\right) - \left(\frac{\pi * (.51in)^3}{16}\right)} = 3{,}345\ psi$$

$$\tau_d = \frac{S_{us}}{2N} = \frac{45{,}000\ psi}{8} = 5{,}625\ psi$$

Variables:

$\sigma_{max} = Max\ Bending\ Stress\ X - Direcion$

$M = Moment$

$S_{net} = Net\ Section\ Modulus$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

$\tau_{max} = Max\ Shear\ Stress$

$T = Applied\ Torque$

$Z_{p\ net} = Net\ Polar\ Modulus$

$\tau_d = Design\ Shear\ Stress$

$S_{us} = Ultimate\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 5,625 psi is greater than the applied stress to the tube, therefore the material and safety factor are appropriate for this application.

15. Beam 1 is subjected to the forces shown below:

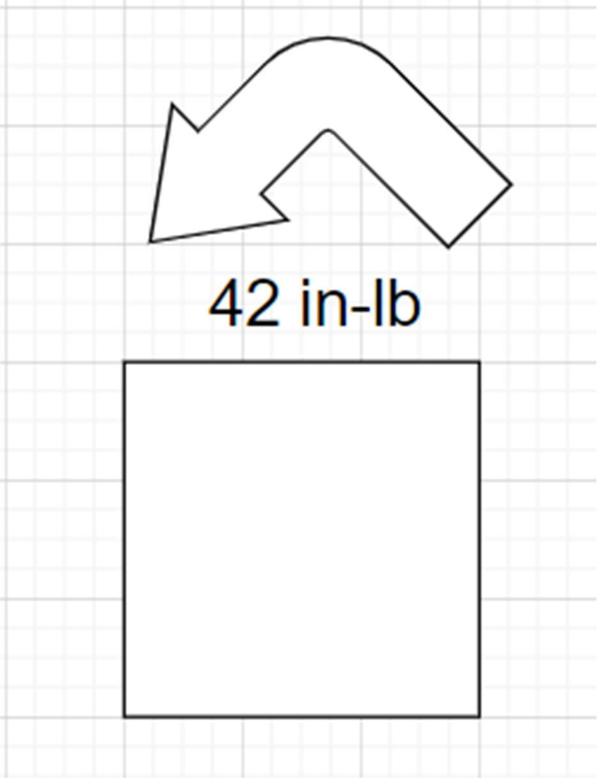


Figure 19. Free Body of Beam 1

16. Beam 1 is subjected to a singular moment created from the vertical weight of the users' feet resting on the footrest. There is a stress concentration factor of 1.25 due to the hole in the tubing wall where beam 2 is inserted. A safety factor of four was chosen because it will simulate the user getting in and out of the machine.

$$\tau_{max} = \frac{Tc}{J} * K_t$$

$$\tau_{max} = \frac{42\ in - lb * .625\ in}{\left(\frac{(1.25in)^4}{6}\right) - \left(\frac{(1in)^4}{6}\right)} * 1.25 = 137.5\ psi$$

$$\tau_d = \frac{S_{us}}{2N} = \frac{45{,}000\ psi}{8} = 5{,}625\ psi$$

Variables:

$\tau_{max} = Max\ Shear\ Stress$

$T = Applied\ Torque$

$c = Distance\ to\ Centroid$

$J = Polar\ Moment\ of\ Inertia$

$K_t = Stress\ Concentration$

$\tau_d = Design\ Shear\ Stress$

$S_{us} = Ultimate\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 5,625 psi is greater than the applied stress to the tube, therefore the material and safety factor are appropriate for this application.

17. The footrest mount is subjected to the forces shown below:

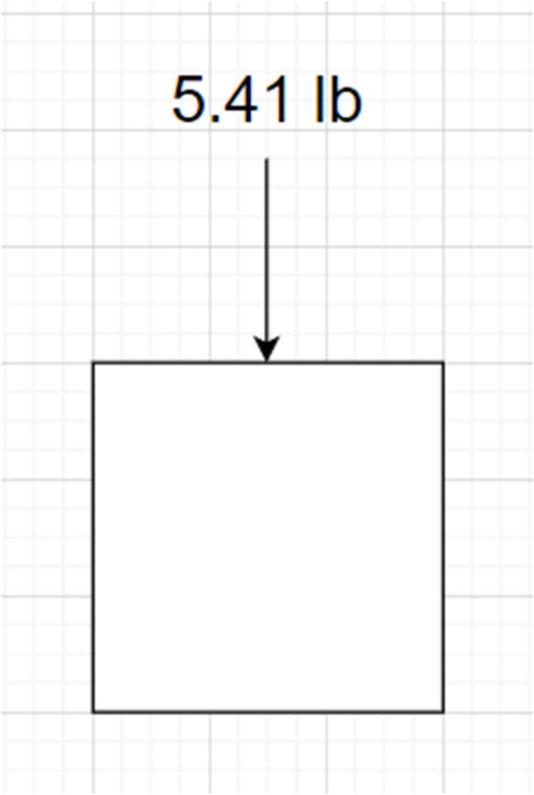


Figure 20. Free Body Diagram of Footrest Mount

18. The footrest mount is subjected to the vertical component of the user's feet resting on the footrest. A safety factor of four was chosen to represent the repeated loading of the user getting in and out of the machine.

$$\sigma_{max} = \frac{F}{A} = \frac{5.41\ lb}{(1.475\ in * 1.5\ in)} = 185\ psi$$

$$\sigma_d = \frac{S_y}{N} = \frac{40{,}000\ psi}{4} = 10{,}000\ psi$$

Variables:

$\sigma_{max} = Max\ Tensile\ Stress$

$F = Applied\ Force$

$A = Area$

$\sigma_d = Design\ Stress$

$S_y = Yield\ Strength$

$N = Factor\ of\ Safety$

Our chosen design stress of 10 ksi is greater than the applied stress to the footrest mount, therefore the material and safety factor are appropriate for this application.

Material Selection

The material for this application needs to be a ductile metal that also has a moderate yield and ultimate strength due to the repeated loading conditions of this device. We also desired the machine to be light weight due to our product objectives suggesting that our end user wants this machine to be portable. Our team settled on 6061-T6 Aluminum as the main material as it has all the characteristics listed above. Some components and hardware, like the pin in the seat assembly, are of different materials because they are common source products and reside in areas of greater stress.

Please reference Appendix B for materials data.

Factors of Safety

The factors of safety were chosen to represent the repeated use of the machine. From the Robert L. Mott "Strength and Materials" book, safety factors for repeated loads were analyzed. From analysis, I found that a safety factor of four was needed for static repeated loads and a safety factor of eight was needed for static repeated loads in shearing scenarios. In the table below, one will find the recorded properties of our selected material and listed safety factors.

MANUFACTURING DRAWINGS

Seat assembly components:

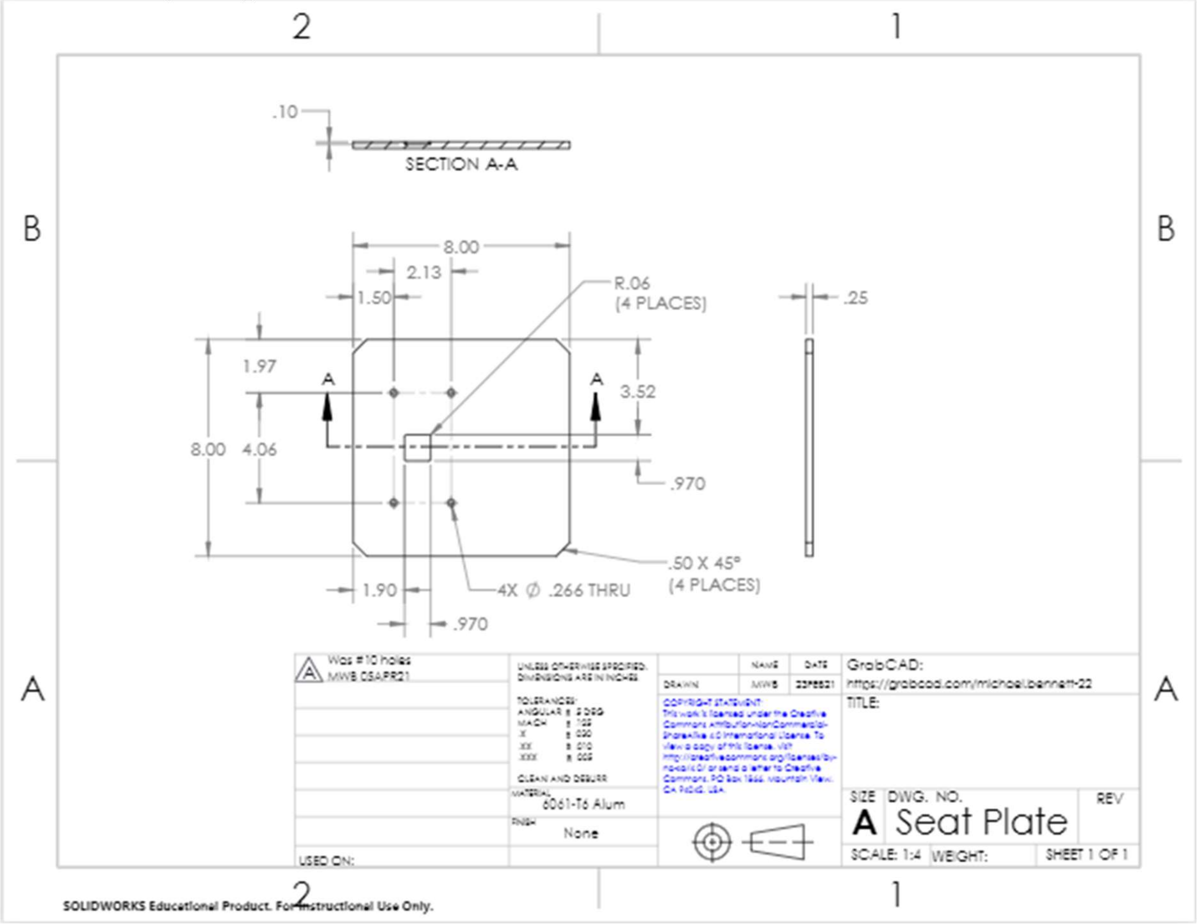


Figure 21. Seat Plate Drawing

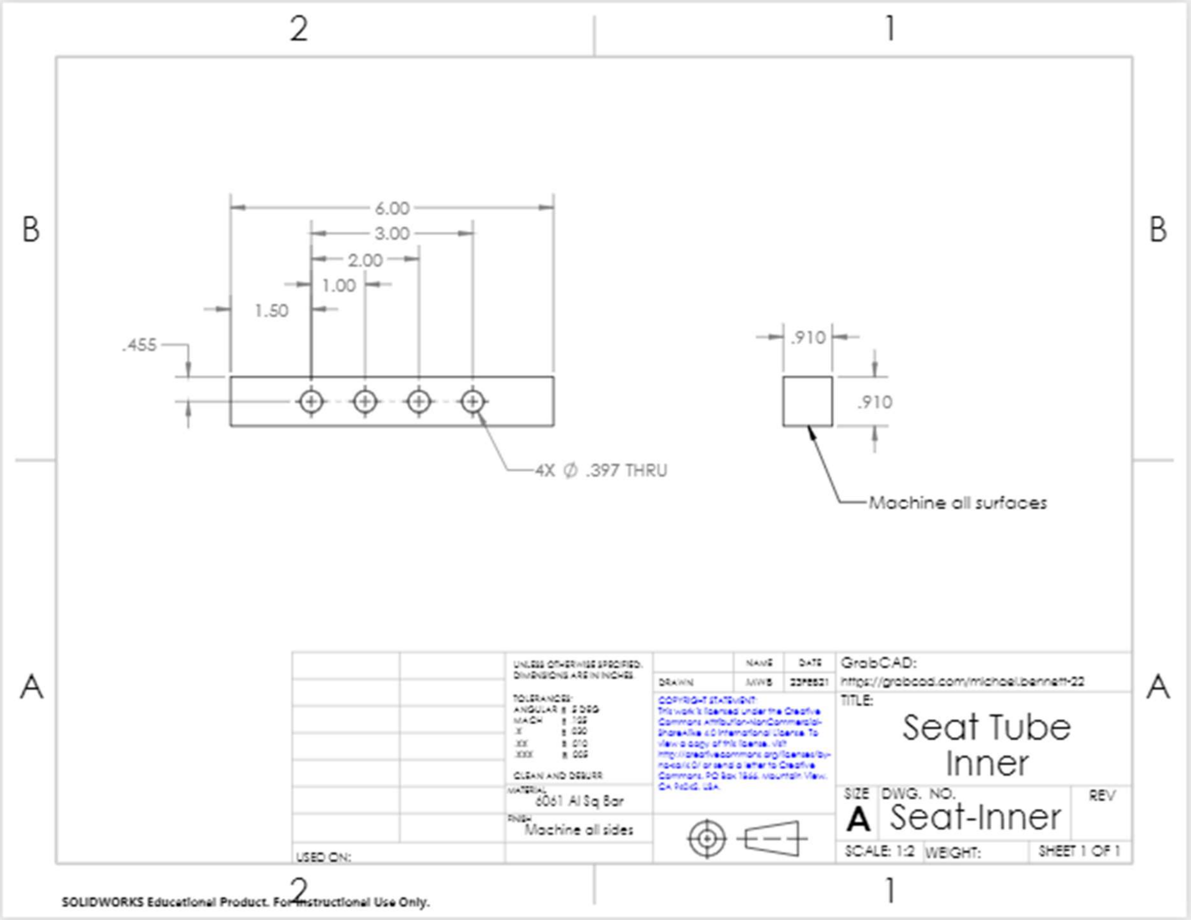


Figure 22. Seat Tube Inner Drawing

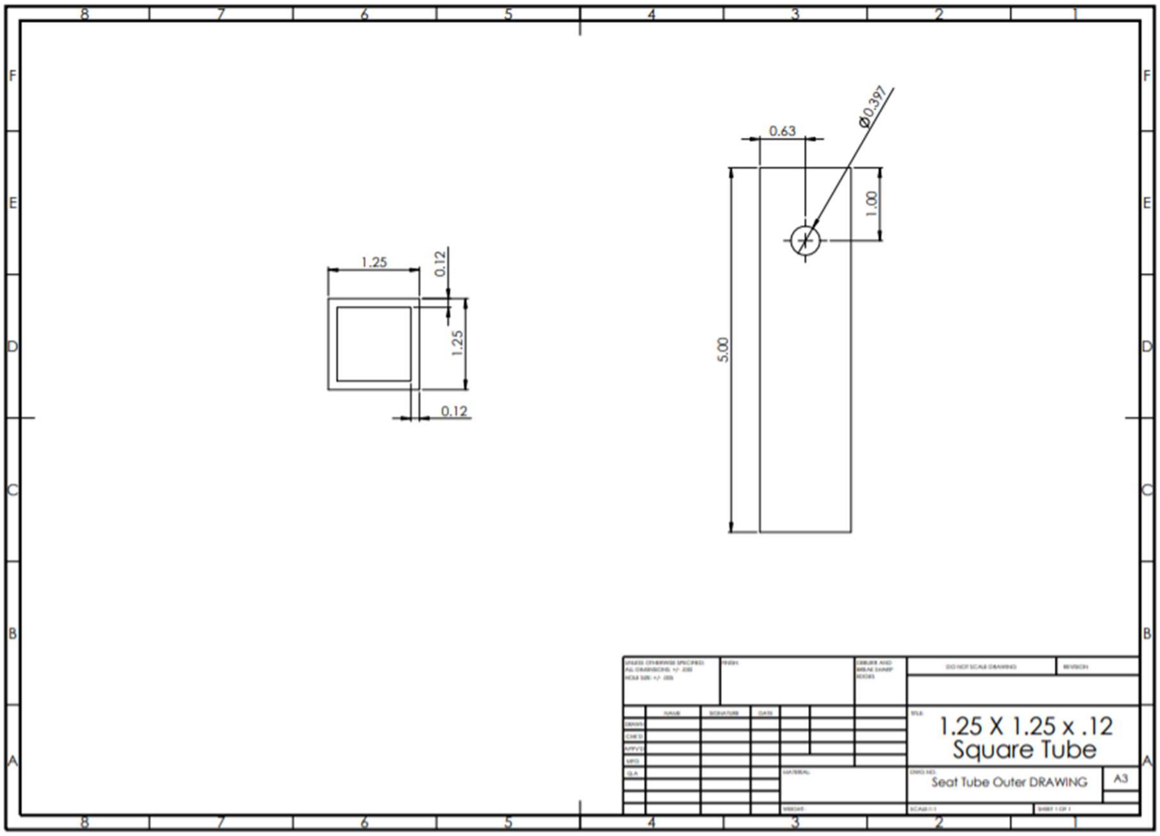


Figure 23. Outer Tube Drawing

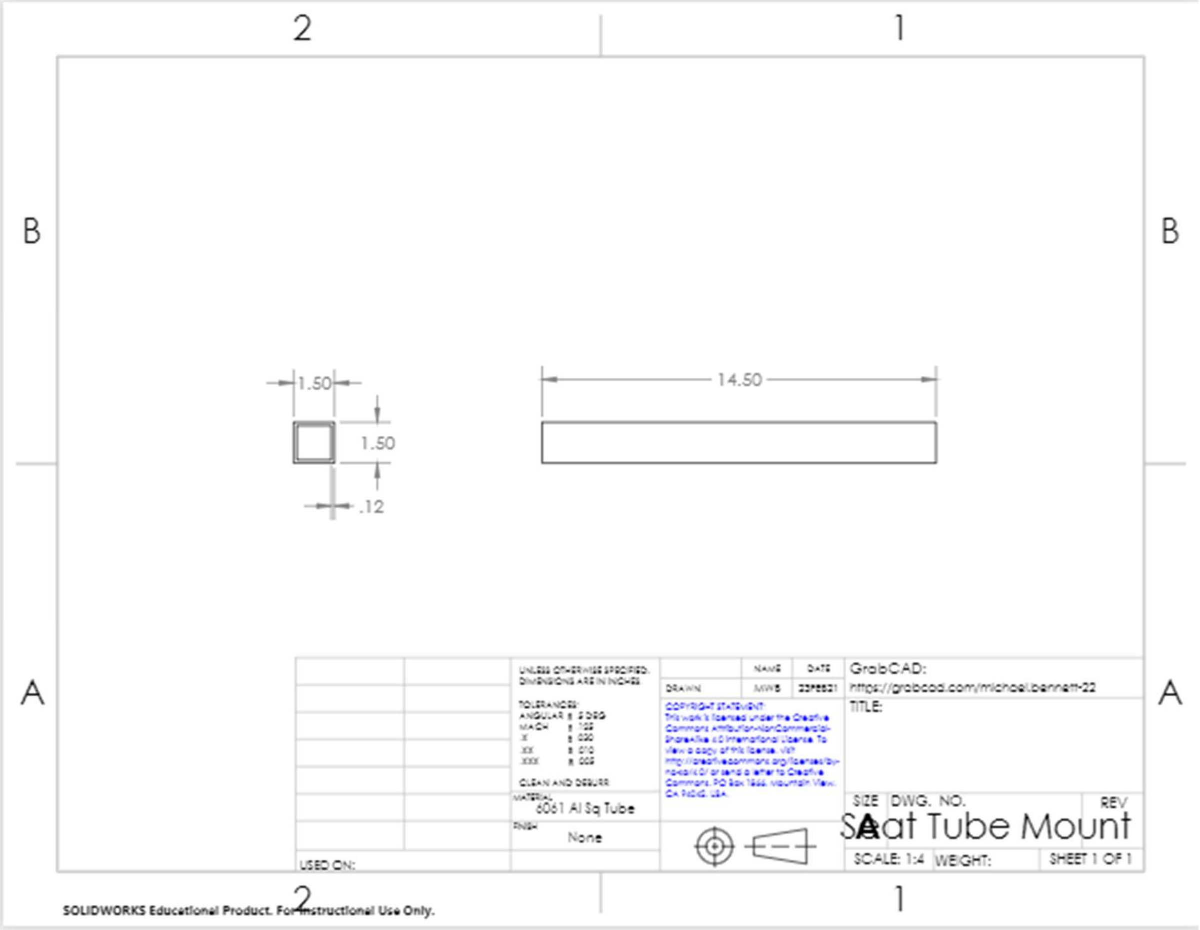


Figure 24. Seat Tube Mount Drawing

Footrest assembly components:

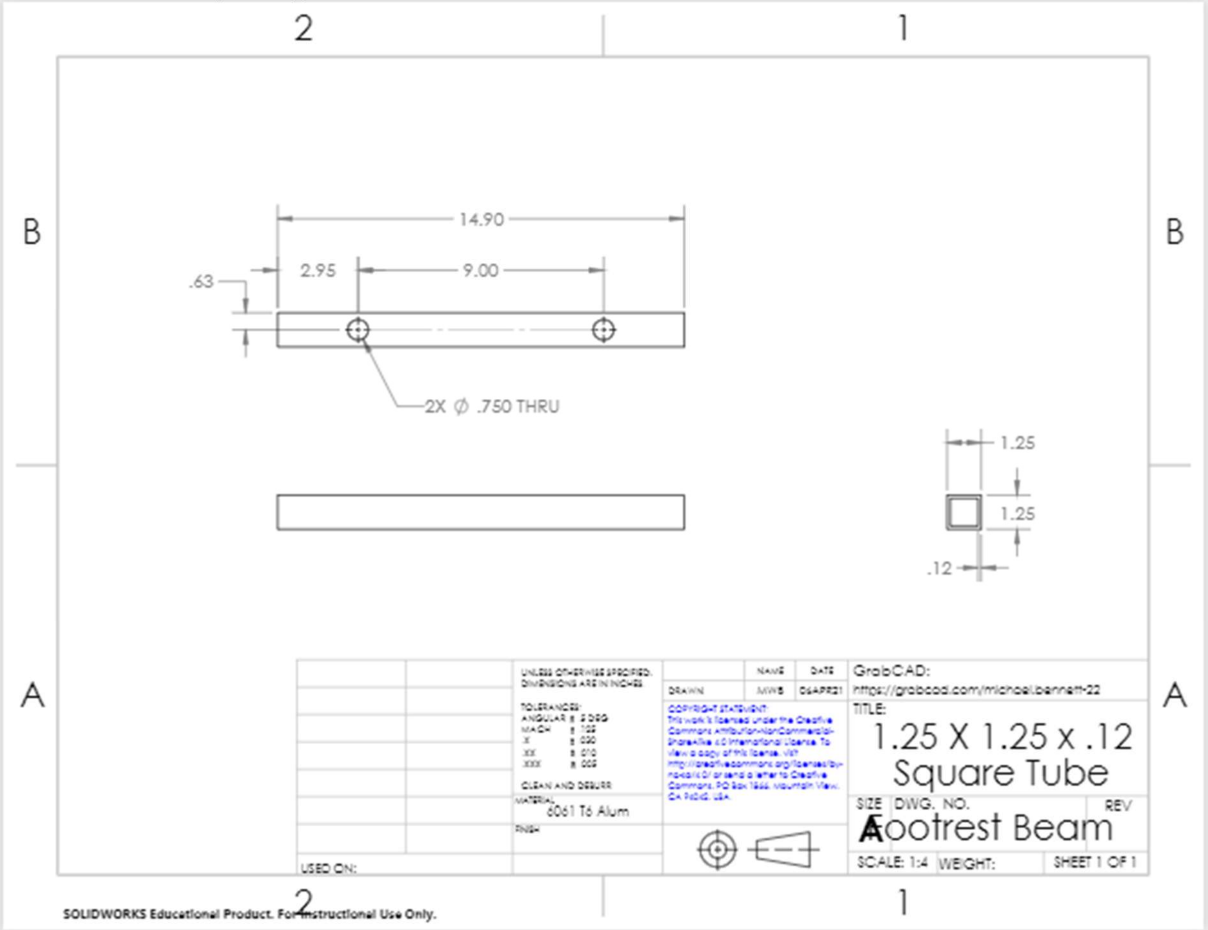


Figure 25. Footrest Beam 1 Drawing

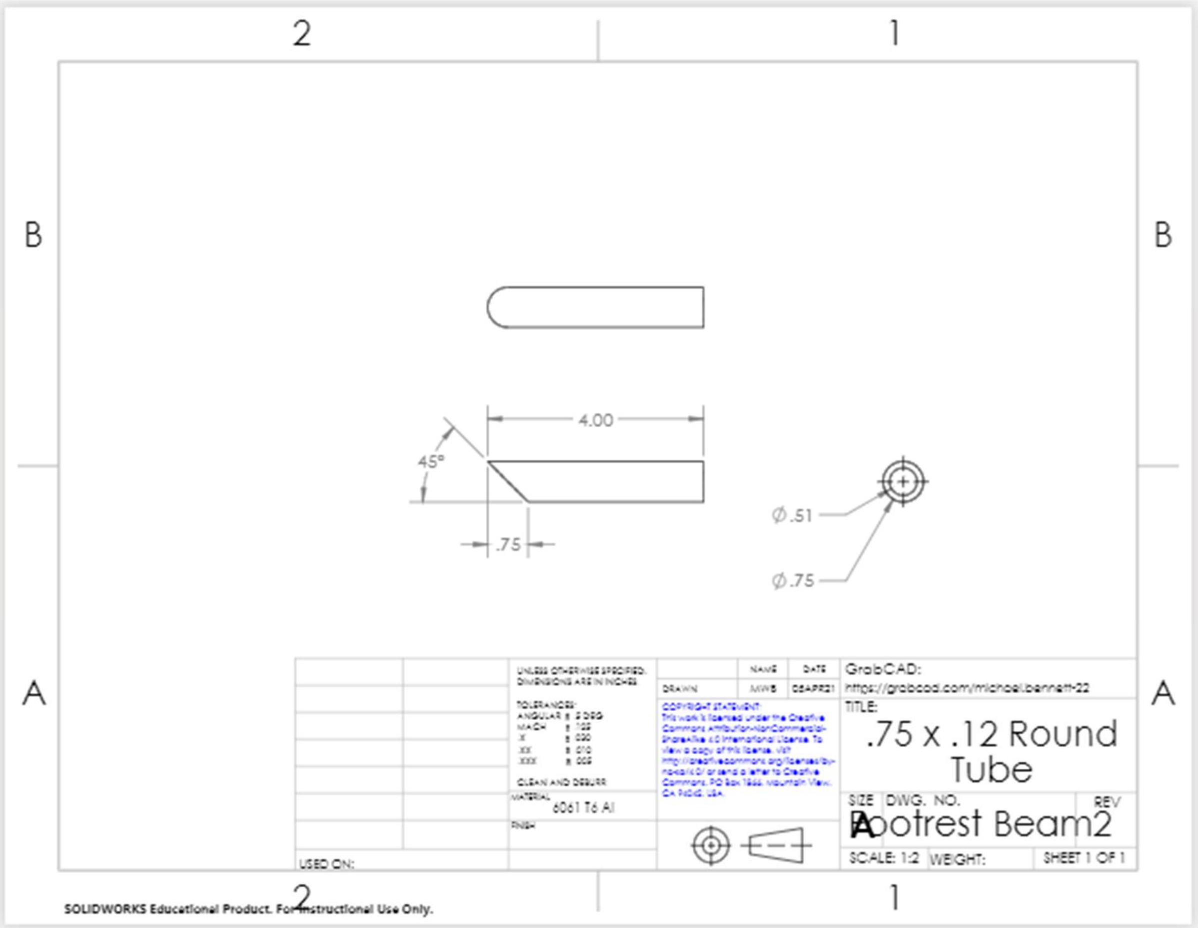


Figure 26. Footrest Beam 2 Drawing

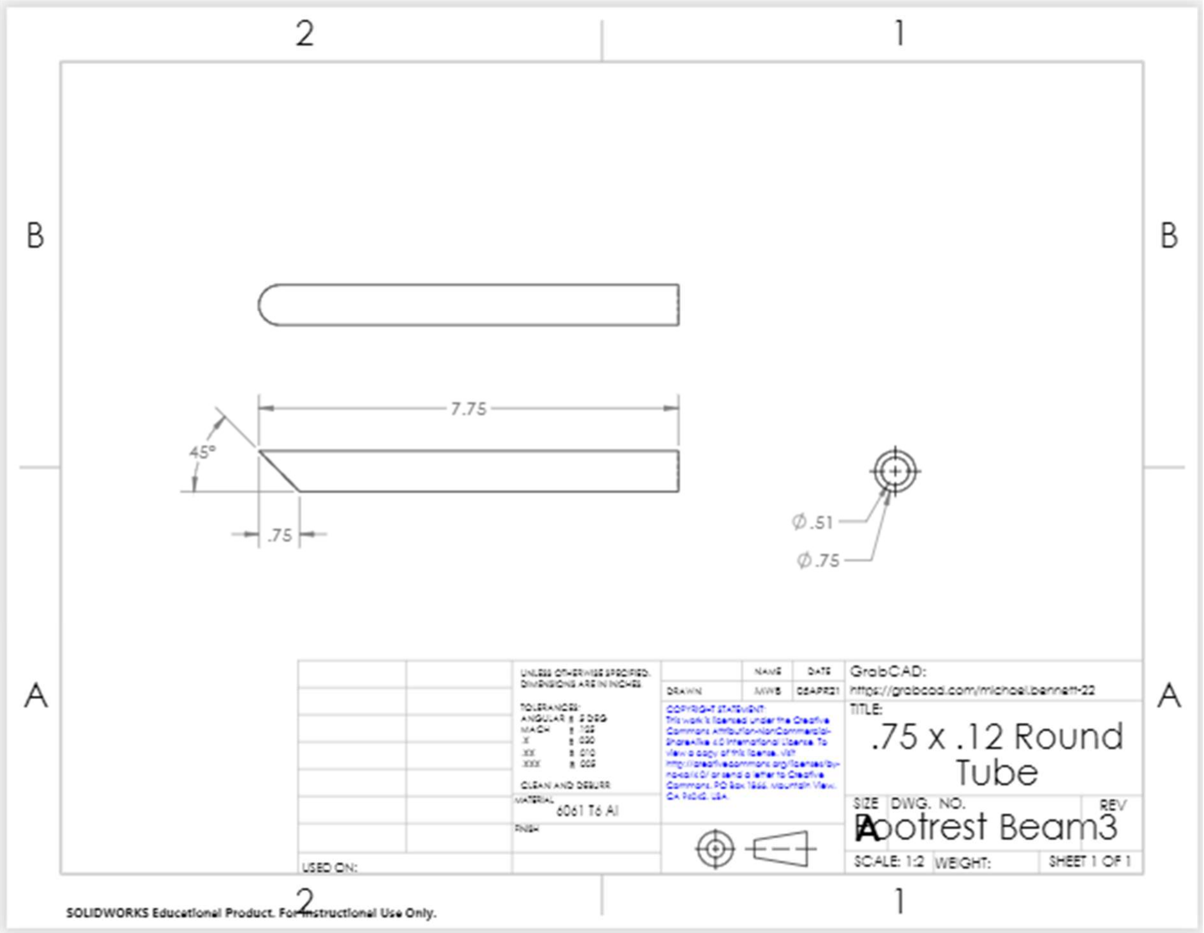


Figure 27. Footrest Beam 3 Drawing

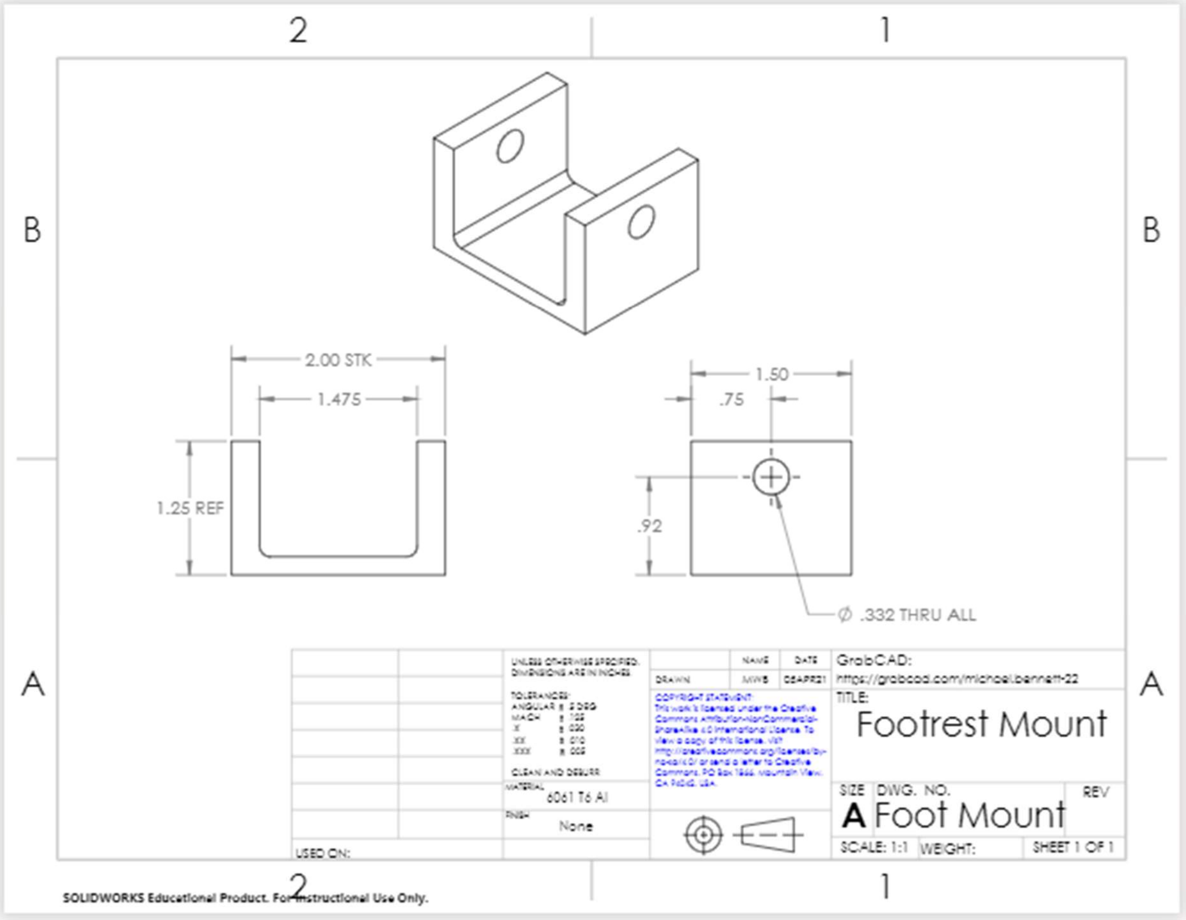


Figure 28. Footrest Mount Drawing

Reference Appendix A for full machine assembly manufacturing drawings.

BILL OF MATERIALS

In the table below, find the bill of materials for the Seat Assembly:

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 3. Bill of Materials for Seat Assembly

In the table below, find the bill of materials for the Footrest Assembly:

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 4. Bill of Materials for Footrest Assembly

Please reference Appendix C for full machine bill of materials.

BUILD AND TEST

DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED

To complete this project and maintain dimensional accuracy, it was necessary to employ several different manufacturing processes. 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.

Machining/Turning:

Machining was employed as a manufacturing process by utilizing VMC CNC machines (vertical machining center computer numerical control) 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 where applicable and finishing cuts were no greater than five thousandths of an inch. For finishing cuts, 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. Roughing cuts were at fifteen thousandth of an inch and finishing cuts were under five thousandths of an inch.

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 not tubing, one might employ a carbide drill to reduce overall diameter gain due to concentrated heat during drilling.

When performing the turning operations, standard high speed steel cutters were employed. Threading and drilling operations were also performed on the lathe. The threading operations used grooving tools that are specialized to produce the desired thread sizes on the outside of the part. The drilling operations used stationary drills while the work piece turned and was feed in at the appropriate feed rate.

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 on the surface, 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, C-clamps, and other table clamps were 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 on higher amps leaving more heat in the work piece which can cause the pieces to warp towards the area of the hot welds. This phenomenon 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.

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 specimen, but a player has volunteered themselves to be our test specimen. Our criteria consist of a measure of heart rate before and after trials and recorded feelings from the test subject after each trial. Heart rate is an easy way to measure how hard the heart is working to supply freshly oxygenated blood to the muscles in need. In theory, over our testing period we would like to see a decrease in the difference in heart rate between the before and after measurements. 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.) Record resting heart rate, 3.) Allow player to use the machine for three, five-minute periods recording their peak heart rate at the end of the five minutes and with enough of a break between periods for their heart rate to settle back to the previously recorded resting heart rate, and 4.) Assist player out of machine.

TEST RESULTS AND FINDINGS

Once the machine was fully constructed, Michael and I both tested it for proof of function and concept but were unable to test its impact on cardiovascular conditioning. As I sat in the seat, the seat felt stable and had very little to no wobble during repetitions. I leaned side to side on the seat to check stability in the lateral direction and once again the seat felt stable. Next, I began to perform repetitions at the lowest resistance setting. I was able to make a stroke in the motion that we desired to replicate with this machine and encountered the resistance at the right point in the stroke. Next, we began to increase the resistance to test the capabilities of the machine. About a third of the way through the resistances, we noticed that the machine began to rock. After further analysis, we found that the rocking motion occurred in the front half of the machine where the triangular frame resides. The rocking motion is created by the moment of the user pulling the cables. We continued to increase the resistances until we maxed out the resistance mechanism. The rocking motion continued and increased in magnitude slightly. To evaluate the structural rigidity of our welds, I performed numerous repetitions on the machine at the highest resistance setting. All welded joints were visually inspected for the presence of cracks or warpage in the joints. No cracks or visible warpage was detected. We began to consider modifications that could be added to the machine to assist with the rocking motion. The idea of adding a way to bolt this machine to the ground was considered but decided to be an inadequate solution as that would create more stress in the machine. Another idea we considered was adding a damping mechanism at the end of the triangular frame to quiet the rocking motion. This damping mechanism could be a 3D printed pad that is adhered to the bottom of the frame.

Ultimately, we found that our machine is capable of performing the motions we intended it to perform and held up structurally. A rocking motion did manifest itself during testing, but the machine remained stable where the user sat.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Our original budget summed up to $1500 breaking into $1100 for materials and hardware and a $400 cushion for unforeseen expenses and R&D. Some of these expenses may have included outsourcing manufacturing and ordering extra material.

Our actual budget summed up to be $745 out of $1100 for materials and $140 out of $400 for the R&D budget totaling $885 spent in total. The drastic difference in actual budget versus projected is due to design changes we made along the way. In initial concepts, there were some parts that were sourced from websites that were very high in cost.

Michael and I used money we earned from working part time during senior design III to pay for the project so anywhere we could safely reduce cost without jeopardizing structural integrity we took advantage of.

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 purpose and safety.

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 5. 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 6. Actual Schedule

SUSTAINABILITY AND MATERIAL USAGE

In terms of sustainability, 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 form 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

After performing research, our team concluded that no device currently existed with the desired parameters we had. The research we performed suggested that increasing cardiovascular performance could be measured by oxygen consumption, heart rate, and increased duration during performance. There are a multitude of training machines that exist to increase those three parameters listed above, but after interviewing coaches, players, and athletic trainers a machine that replicates an “on ice scenario” was desired therefore, none of the current state of the art was usable. To further enforce that a new design was needed, none of the current state of the art was capable of accommodating someone with physical disabilities from the waist down.

The machine was desired to be portable, serve a wide variety of players, and safe from conclusions drawn after performing interviews and the Quality Function Deployment. This led us to having the machine be constructed of lightweight materials, capable of being taken apart easily, and adjustable for different sized players. This impacted our design process by guiding us towards what materials and construction would satisfy the end user requirements. Once concepts were finalized and combined, our manufacturing process was impacted by these end user requirements as well. Since safety was just as important as portability and functionality, the strategy of welding was employed as it is permanent and can have equal or greater properties to fasteners.

Given the three parameters from our research, we developed our testing criteria. Also, from our research we figured out an appropriate method to conduct the testing. Since our desired outcomes are lower heart rate and increased “on ice performance” we designed our testing procedure to simulate the amount of time a player is on the ice during a period before they are substituted out to take a break. With this we hope to see an increase in performance in the allotted time each player gets before substitutions.

Areas of improvement lay in staying on schedule. Due to a variety of variables, our team was late to ordering materials which initially pushed back our schedule. Next, we encountered issues with the provided facilities by UC, namely the students spending more time proving they can use the equipment to the designated supervisors than actual time using the equipment. Other issue pertaining to equipment is our team lacking a strong background on specific machines and subsequently the supervisors not being capable of suggesting effective solutions when asked. Other issues pertaining to the facilities provided by UC were a lack of flatness of welding table and available fixturing equipment. This problem specifically set Jason back three plus days because the welding tables were not capable of being used since they were not flat which throws off tolerances. Some solutions to this were using other facilities such as Jason’s co-op to weld the project and repeated attempts to manufacture the same piece by Michael at the provided UC facilities.

Our team was capable of finishing the project before the technical expo and the project functioned as desired in all aspects aside from our testing criteria as we have not had a chance to test the machines impact on cardiovascular conditioning.

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16. ***MatWeb Material Property Data.***

APPENDIX A

Select this pdf to see the full machine assembly manufacturing drawings.

Appendix A.pdf

Select this link to see a video of the machine.

https://bit.ly/3e1VOgq

APPENDIX B

Material Data for 6061-T6 Aluminum

6061-T6 Aluminum	
Ultimate strength (psi)	45,000
Yield strength (psi)	40,000
Modulus of elasticity (psi)	1.00E+07
% elongation	17
Density (lbm/in3)	0.1

Table 7. Material Data for 6061-T6 Aluminum

Material Data for 1045 Carbon Steel

1045 Carbon Steel	
Ultimate strength (psi)	90,000
Yield strength (psi)	65,300
Modulus of elasticity (ksi)	29,900
% elongation	12
Density (lbm/in3)	0.284

Table 8. Material Data for 1045 Carbon Steel

Material Data for PLA (Polylactic Acid Biopolymer)

Polylactic Acid Biopolymer	
Ultimate strength (psi)	43,500
Yield strength (psi)	14,900
Modulus of elasticity (ksi)	2,000
% elongation	700
Density (lbm/in3)	.0892

Table 9. Material Data for PLA

APPENDIX C

Reference table below for full machine Bill of Materials

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 10. Full Machine Assembly Bill of Materials