Cardiovascular Conditioning Machine
For Sled Hockey Athletes

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by

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# TABLE OF CONTENTS

TABLE OF CONTENTS ...........................................................................................................II  
LIST OF FIGURES .................................................................................................................. III  
LIST OF TABLES ..................................................................................................................... III  
ABSTRACT .............................................................................................................................. IV  
PROBLEM DEFINITION AND RESEARCH ................................................................. 5  
  PROBLEM STATEMENT ................................................................................................. 5  
RESEARCH ........................................................................................................................... 5  
  BACKGROUND AND SCOPE OF THE PROBLEM .................................................... 5  
  CURRENT STATE OF THE ART ................................................................................... 6  
  END USER ....................................................................................................................... 6  
  CONCLUSIONS AND SUMMARY OF RESEARCH ..................................................... 7  
QUALITY FUNCTION DEPLOYMENT .............................................................................. 8  
  CUSTOMER FEATURES ............................................................................................... 8  
  ENGINEERING CHARACTERISTICS .......................................................................... 8  
  HOUSE OF QUALITY ..................................................................................................... 9  
  PRODUCT OBJECTIVES ............................................................................................... 10  
DESIGN ............................................................................................................................... 10  
  DESIGN ALTERNATIVES AND SELECTION ........................................................... 10  
  ENGINEERING CALCULATIONS .............................................................................. 13  
    List of equations .......................................................................................................... 13  
    Loading Conditions – required yield and tensile strength of material ..................... 14  
    Material Selection ...................................................................................................... 19  
    Factors of Safety ........................................................................................................ 20  
  MANUFACTURING DRAWINGS ............................................................................... 20  
  BILL OF MATERIAL ....................................................................................................... 21  
BUILD AND TEST ............................................................................................................. 22  
  DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED ..................... 22  
  TEST PROCEDURE AND CRITERIA .......................................................................... 24  
  TEST RESULTS AND FINDINGS .................................................................................. 24  
PROJECT MANAGEMENT ................................................................................................. 25  
  BUDGET, PROPOSED/ACTUAL ................................................................................ 25  
  SCHEDULE, PROPOSED/ACTUAL ............................................................................. 27  
  SUSTAINABILITY AND MATERIAL USAGE ............................................................ 27  
CONCLUSIONS ................................................................................................................... 28  
WORKS CITED .................................................................................................................. 29  
APPENDIX A – Manufacturing Drawings ................................................................. 30  
APPENDIX B – Manufacturing Photos ....................................................................... 58  
APPENDIX C – Properties Charts .............................................................................. 69
LIST OF FIGURES
Figure 1 – Proof of Concept, Viscous Damper .......................................................... 10
Figure 2 – Proof of Concept, Exer-Genie .................................................................. 11
Figure 3 – Proof of Concept, Resistance Band .............................................................. 11
Figure 4 – Diagram of Beams .................................................................................... 14
Figure 5 – Right Side View ....................................................................................... 14
Figure 6 – Back View ................................................................................................. 15
Figure 7 – Beam 4, Torque ....................................................................................... 15
Figure 8 – Beam 4, Bend ............................................................................................. 16
Figure 9 – Beam 5, Bend ............................................................................................. 16
Figure 10 – Beam 9, Bend ......................................................................................... 17
Figure 11 – Beam 6, Bend .......................................................................................... 17
Figure 12 – Beam 10, Tensile ................................................................................... 18
Figure 13 – Beam 7, Compression ............................................................................. 18
Figure 14 – Damper-Band Shank, Bend .................................................................... 19

LIST OF TABLES
Table 1 – House of Quality ....................................................................................... 9
Table 2 – Resistance Mechanism Selection Criteria .................................................. 12
Table 3 – Stress Chart ............................................................................................... 19
Table 4 – Material Properties ................................................................................... 20
Table 5 – Parent BOM ............................................................................................... 21
Table 6 – Footrest BOM ............................................................................................ 21
Table 7 – Seat BOM .................................................................................................... 22
Table 8 – Initial Purchase List ................................................................................... 25
Table 9 – Actual Purchase Orders ............................................................................. 26
Table 10 – Research and Development Cost ............................................................. 26
Table 11 – Projected Schedule .................................................................................. 27
Table 12 – Actual Schedule ...................................................................................... 27
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 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.
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](image)

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**

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](image)
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:**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Concept 1 Damper</th>
<th>Concept 2 Pulley</th>
<th>Concept 3 Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>10</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>9</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Resistance Range</td>
<td>8</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Weight</td>
<td>6</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>41</strong></td>
<td><strong>27</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

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**

\[ \sigma_b = \frac{MC}{I} = \frac{\text{Moment} \times \text{distance from centroid to edge}}{\text{Moment of Inertia of cross-section}} \]

\[ I_{\text{square}} = \frac{s^4}{12}; s = \text{length of edge} \]

\[ M = \frac{\pi D^4}{64} \]

**Direct shear stress**

\[ \tau_d = \frac{F}{A} \]

**Tensile stress**

\[ \sigma = \frac{F}{A} \]

**Torsional stress**

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

\[ J_{\text{square}} = .14s^4 \]

\[ J_{\text{square tube}} = \frac{2t(s - t)^4}{(2s - 2t)} \]
Loading Conditions
The majority of the components used in this device are loaded dynamically.

Assumptions:
\[ F = 50 \text{lb}_f, \text{ applied across two cables (25 lb}_f \text{ each).} \]
\[ m_{\text{player}} = 150 \text{ lb}_m \]

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.
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.

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

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

\[
\tau_4 = \frac{2TC}{J} = 2 * \frac{60 \text{ in} \cdot \text{lb} \cdot .625 \text{ in}}{.178 \cdot 1.25 \text{in}^4} = 337 \text{ psi}
\]
3. Using the vertical force (17.8 lb) on each pulley, a free body diagram of Beam 4 was constructed to calculate the bend moment.

**Beam 4 - Bend**

![Free Body Diagram of Beam 4](image)

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.

\[
M = 17.8 \text{ lb} \times 8.22 \text{ in} = 146 \text{ inlb}
\]

\[
l_{\text{square tube}} = \frac{H^4 - h^4}{12} = \frac{1.25^4 - 1^4}{12} = .12 \text{ in}^4
\]

\[
\sigma_b = \frac{MC}{I} = \frac{146 \text{ inlb} \times .625 \text{ in}}{.12 \text{ in}^4} = 760 \text{ psi}
\]

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

**Beam 5 - Bend**

![Free Body Diagram of Beam 5](image)

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.

\[
M = 25 \text{ lb} \times 7.22 \text{ in} = 180.5 \text{ inlb}
\]

\[
\sigma_b = \frac{MC}{I} = \frac{180.5 \text{ inlb} \times .625 \text{ in}}{.12 \text{ in}^4} = 940 \text{ psi}
\]

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.
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.

\[
I_{x,1\times3} = \frac{bh^3}{12} - \frac{bh^3}{12} = \frac{1(3)^3}{12} - \frac{.75(2.75)^3}{12} = .95
\]

\[
M = 158 \text{ lb} \times 4.5 \text{ in} = 711 \text{ inlb}
\]

\[
\sigma_b = \frac{MC}{I} = \frac{711(1.5)}{.95} = 1123 \text{ psi}
\]

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.

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.

\[
M = 90 \text{ lb} \times 6.5 \text{ in} = 585 \text{ inlb}
\]

\[
\sigma_b = \frac{MC}{I} = \frac{585 \text{ inlb} \times 1.5 \text{ in}}{.95 \text{ in}^4} = 923 \text{ psi}
\]

11. Beam 10 experiences tensile stress due to the upward force that Beam 9 exerts on it.
12. Beam 10 is subjected to 281 psi of stress.

\[ A = 1.25^2 - 1^2 = .5625 \text{ in}^2 \]

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

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.

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

\[ \sigma = \frac{F}{A} = \frac{25 \text{ lb} \times \cos 25^\circ}{(.97 \text{ in})^2} = 24 \text{ psi} \]


\[ \sigma = \frac{F}{A} = \frac{25 \text{ lb} \times \cos 25^\circ}{.5625 \text{ in}^2} = 40 \text{ psi} \]

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.

\[
I = \frac{\pi (D - d)^4}{64} = \frac{\pi (0.297 - 0.125)^4}{64} = 3.7 \times 10^{-4} \text{ in}^4
\]

\[
M = 208 \text{ lb} \times 0.5 \text{ in} = 104 \text{ inlb}
\]

\[
\sigma_b = \frac{MC}{I} = \frac{104 \text{ inlb} \times 0.1485 \text{ in}}{3.7 \times 10^{-4} \text{ in}^4} = 11.8 \text{ ksi}
\]

Material Selection

Below is a chart of the stress in each component:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beam/Bend/Shear</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>760</td>
</tr>
<tr>
<td>5</td>
<td>940</td>
</tr>
<tr>
<td>6</td>
<td>923</td>
</tr>
<tr>
<td>7_1</td>
<td>16</td>
</tr>
<tr>
<td>7_2</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>1123</td>
</tr>
<tr>
<td>10</td>
<td>281</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Shank</td>
<td>11800</td>
</tr>
</tbody>
</table>

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.

\[
\tau_d = \frac{s_{ys}}{2N}; \quad N = 4; \quad \tau_d = \frac{s_{ys}}{8}
\]

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

Table 4 – Material Properties

MANUFACTURING DRAWINGS
All manufacturing drawings can be found in Appendix A.
## Bill of Material

### Parent Assembly Bill of Material:

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

Table 5 – Parent BOM

### Footrest Bill of Material:

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

Table 6 – Footrest 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.

Seat Assembly Bill of Material:

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

Table 7 – Seat BOM
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.
The initial purchased components list is shown below:

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

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:

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

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:

<table>
<thead>
<tr>
<th>Date</th>
<th>From</th>
<th>Buyer</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/25/21</td>
<td>Wright Brothers Gas</td>
<td>Michael</td>
<td>$140</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Task</th>
<th>Date To Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finalize Design</td>
<td>1/15/2021</td>
</tr>
<tr>
<td>Order Materials</td>
<td>1/16/2021</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3/1/2021</td>
</tr>
<tr>
<td>Welding and Assembly</td>
<td>3/23/2021</td>
</tr>
<tr>
<td>Testing Completion</td>
<td>4/13/2021</td>
</tr>
<tr>
<td>Donate to Team</td>
<td>4/27/2021</td>
</tr>
</tbody>
</table>

Table 11 – Projected Schedule

Below is our actual schedule:

<table>
<thead>
<tr>
<th>Task</th>
<th>Date To Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finalize Design</td>
<td>1/15/2021</td>
</tr>
<tr>
<td>Order Materials</td>
<td>1/28/2021</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3/23/2021</td>
</tr>
<tr>
<td>Welding and Assembly</td>
<td>4/13/2021</td>
</tr>
<tr>
<td>Testing Completion</td>
<td>5/25/2021</td>
</tr>
<tr>
<td>Donate to Team</td>
<td>5/30/2021</td>
</tr>
</tbody>
</table>

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.
WORKS CITED
APPENDIX A
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**Tolerances:**
- Angular: ± 0.5 deg
- Mach: ± 0.025
- X: ± 0.000
- XX: ± 0.010
- XXX: ± 0.005

**Clean and Debur:**

**Title:**
1.25 X 1.25 x .12
Square Tube

**Rev:** A
**Beam:** 1
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<td>XX: ± .010</td>
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GrabCAD: https://grabcad.com/michael.bennett-22

SOLIDWORKS Educational Product. For Instructional Use Only.
Dimensions are in inches.

TOLERANCES:
- ANGULAR: ± 0.5 DEG
- MACH: ± 0.125
- X: ± 0.030
- XX: ± 0.010
- XXX: ± 0.005

CLEAN AND DEBURR

MATERIAL: 6061 Al
FINISH

TITLE:
1.25 X 1.25 x .12 Square Tube

SIZE
A Beam 3

SOLIDWORKS Educational Product. For Instructional Use Only.
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
- ANGULAR  ± 1.5 DEG
- X          ± 0.030
- XX         ± 0.010
- XXX        ± 0.005

CLEAN AND DEBURR

MATERIAL: 6061 Al

FINISH

Title: 1.25 X 1.25 x .12 Square Tube

Size: Beam 4

Rev: A

SOLIDWORKS Educational Product. For Instructional Use Only.
Added 1/4 clearance holes
MWB 04MAR21

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

 endless 2 1

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

TITLE:
1.25 X 1.25 x .12
Square Tube

SIZE  DWG. NO.  REV
A  Beam 5  A

SCALE: 1:8  WEIGHT:  SHEET 1 OF 1

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3.0 x 1.0 x .125 Rect. Tube

Material: 6061 Al

SOLIDWORKS Educational Product. For Instructional Use Only.
1.0 Square Bar

SOLIDWORKS Educational Product. For Instructional Use Only.
2.25

1.50 TYP.

24.00

.63

14X Ø .332 THRU ALL

1.25

1.25

.12

A

B

B

A

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

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CLEAN AND DEBURR

MATERIAL: 6061 Al

FINISH

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

TITLE: 1.25 X 1.25 x .12
Square Tube

SIZE: A

REV

DRAWN: MWB 26JAN21

DATE

NAME

SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.
### Table of Parts

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<td>Beam 9-plate</td>
<td>1.0 x .25 Flat Bar</td>
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### Diagram Details

- **Item #1 - Tube**
  - 2x φ .266 THRU ALL
  - 2.75 x .50
  - 15.00 x 1.00

- **Item #2 - Plate**
  - φ .332 THRU 3/8-24 UNF THRU
  - 3.00 x .50

### Notes

- **WELD AND GRIND FLUSH**
- **MWB 26JAN21**
- **Beam 9 A 3.0 x 1.0 x .125 Rect. Tube**
- **6061 Al**
- **GrabCAD:** https://grabcad.com/michael.bennett-22

---

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Added holes
MWB 01MAR21
Was 0.5 inches
MWB 04MAR21

TOLERANCES:
ANGULAR ± 0.5 DEG
MACH ± 0.125
X ± 0.003
XX ± 0.010
XXX ± 0.005
CLEAN AND DEBURR

MATERIAL 6061 Al
FINISH

TITLE: 1.25 X 1.25 x .12 Square Tube

SOLIDWORKS Educational Product. For Instructional Use Only.
Bushing Bracket

Material: Low Carbon Steel

Tolerances:
- Angular: ± .5 Deg
- Mach: ± .125
- X: ± .030
- XX: ± .010
- XXX: ± .005

Clean and deburr

Dimensions in inches

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

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

SOLIDWORKS Educational Product. For Instructional Use Only.
Damper Bracket

Material: Low Carbon Steel

Finish: None

Tolerances:
- Angular: ±0.5 deg
- Mach: ±0.125
- X: ±0.000
- XX: ±0.010
- XXX: ±0.005
- Clean and deburr

Dimensions are in inches.

Scale: 1:1

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

TITLE: Damper-Band Shank Assy

SOLIDWORKS Educational Product. For Instructional Use Only.
Title: Band Mount Damper Shank

Material: 1144 Round Steel

Finish: None

Tolerances:
- Angular: ±0.5 DEG
- Mach: ±0.125
- X: ±0.030
- XX: ±0.010
- XXX: ±0.005

Clean and deburr

SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

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

USED ON:

SOLIDWORKS Educational Product. For Instructional Use Only.
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<td>Horizontal Beam - .75 x .12 Round Tube</td>
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Apply adhesive to secure bushings

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**SOLIDWORKS Educational Product. For Instructional Use Only.**
1.25 X 1.25 x .12
Square Tube

Footrest Beam

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
- ANGULAR ± .5 DEG
- MACH ± .125
- X ± .000
- XX ± .010
- XXX ± .005

CLEAN AND DEBURR

MATERIAL
6061 T6 Alum

DRAWN
MB
DATE
06APR21

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SIZE
Dwg. No.
REV

SCALE: 1:4
WEIGHT:

SHEET 1 OF 1

Grabcad:
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USED ON:

SOLIDWORKS Educational Product. For Instructional Use Only.
.75 x .12 Round Tube

Material: 6061 T6 Al

Clean and Deburr

Tolerances:
- Angular: ± 0.5 deg
- Mach: ± 0.125
- X: ± 0.005
- XX: ± 0.010
- XXX: ± 0.005

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

TOLERANCES:
- Angular: ± 0.5 deg
- Mach: ± 0.125
- X: ± 0.005
- XX: ± 0.010
- XXX: ± 0.005

CLEAN AND DEBURR

MATERIAL: 6061 T6 Al

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

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APPENDIX B

LIST OF FIGURES
Figure 1 – Final Build ........................................................................................................... 59
Figure 2 – Final Build ........................................................................................................... 60
Figure 3 – Jason Welding Chassis ......................................................................................... 61
Figure 4 – Crimpers for Steel Cable ..................................................................................... 62
Figure 5 – Beam 9 End Caps ................................................................................................. 63
Figure 6 – Bushing Bracket ................................................................................................. 64
Figure 7 – Machining of Bushing and Damper Brackets ....................................................... 64
Figure 8 – Proto Trak Vertical Mill ....................................................................................... 65
Figure 9 – Turning Damper-Band Shanks on Clausing Lathe ................................................ 66
Figure 10 – Completed Turning Operation on Damper-Band Shanks ..................................... 67
Figure 11 – Test Fit of Damper, Bracket, and Shank ............................................................. 68
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

Figure 1 – Moment of Inertia Chart (9) ................................................................. 70
Figure 2 – Design Stress Guidelines (9) .................................................................. 71
Figure 3 – Aluminum Alloy Properties (9) ............................................................... 72
Figure 4 – 1144 Alloy Steel Properties (10) ............................................................ 73
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<tr>
<th>Shape</th>
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<th>$Z_x$</th>
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<td>$A = \pi D^2/4 = \pi R^2$</td>
<td>$r = D/4$ = $R/2$</td>
<td>$I = \pi D^4/64$</td>
<td>$J = \pi D^4/32$</td>
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<td>Hollow circle (tube)</td>
<td>$A = \pi (D^2 - d^2)/4$</td>
<td>$r = \sqrt{D^2 + d^2}/4$</td>
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<td>Square</td>
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<td>$r_x = s/\sqrt{12}$</td>
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<td>$I_y = bh^3/12$</td>
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Circumference = $\pi D = 2\pi R$

Figure 1 – Moment of Inertia Chart (9)

### Direct normal stresses

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<tr>
<td>Repeated loads</td>
<td>$\sigma_d = s_f / 8$</td>
<td>$\sigma_d = s_f / 10$</td>
</tr>
<tr>
<td>Impact or shock</td>
<td>$\sigma_d = s_f / 12$</td>
<td>$\sigma_d = s_f / 15$</td>
</tr>
</tbody>
</table>

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

- **AISC code**
  
  $\sigma_d = s_f / 1.67 = 0.60 \, s_f \text{ or } \sigma_d = s_f / 2.00 = 0.50 \, s_u \quad (\text{whichever is lower})$

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

- **Aluminum Association**
  
  $\sigma_d = s_f / 1.65 = 0.61 \, s_f \text{ or } \sigma_d = s_f / 1.95 = 0.51 \, s_u \quad (\text{whichever is lower})$

### Design bending stresses

<table>
<thead>
<tr>
<th>Manner of loading</th>
<th>Ductile materials (% elongation &gt;5%)</th>
<th>Brittle materials (% elongation &lt;5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static loads</td>
<td>$\sigma_d = s_f / 2$</td>
<td>$\sigma_d = s_f / 6$</td>
</tr>
<tr>
<td>Repeated loads</td>
<td>$\sigma_d = s_f / 8$</td>
<td>$\sigma_d = s_f / 10$</td>
</tr>
<tr>
<td>Impact or shock</td>
<td>$\sigma_d = s_f / 12$</td>
<td>$\sigma_d = s_f / 15$</td>
</tr>
</tbody>
</table>

#### A. General machine and structural design

- **AISC specifications: Structural steel, static loads on building-like structures**
  
  $\sigma_d = s_f / 1.5 = 0.66 \, s_f$

- **Aluminum Association specifications: Aluminum, static loads on building-like structures**
  
  $\sigma_d = s_f / 1.65 = 0.61 \, s_f \text{ or } \sigma_d = s_f / 1.95 = 0.51 \, s_u \quad (\text{whichever is lower})$

### Design shear stresses for beams in bending

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

$\tau_d = 0.40 \, s_f$

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

$\tau_d = s_f / N = 0.5 \, s_f / N = s_f / 2N$

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

Based on maximum shear stress theory of failure:

$\tau_d = s_f / N = 0.5 \, s_f / N = s_f / 2N$

<table>
<thead>
<tr>
<th>Manner of loading</th>
<th>Design factor</th>
<th>Design shear stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static loads</td>
<td>Use $N = 2$</td>
<td>$\tau_d = s_f / 4$</td>
</tr>
<tr>
<td>Repeated loads</td>
<td>Use $N = 4$</td>
<td>$\tau_d = s_f / 8$</td>
</tr>
<tr>
<td>Shock or impact</td>
<td>Use $N = 6$</td>
<td>$\tau_d = s_f / 12$</td>
</tr>
</tbody>
</table>

### Estimates for the ultimate strength in shear

<table>
<thead>
<tr>
<th>Formula</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_{uu} = 0.65 , s_u$</td>
<td>Aluminum alloys</td>
</tr>
<tr>
<td>$s_{uu} = 0.82 , s_u$</td>
<td>Steel—plain carbon and alloy</td>
</tr>
<tr>
<td>$s_{uu} = 0.90 , s_u$</td>
<td>Malleable iron and copper alloys</td>
</tr>
<tr>
<td>$s_{uu} = 1.30 , s_u$</td>
<td>Gray cast iron</td>
</tr>
</tbody>
</table>

Figure 2 – Design Stress Guidelines (9)
### Typical properties of aluminum alloys

<table>
<thead>
<tr>
<th>Alloy and temper</th>
<th>Ultimate strength, $s_u$ (ksi, MPa)</th>
<th>Yield strength, $s_y$ (ksi, MPa)</th>
<th>Percent elongation</th>
<th>Shear strength, $s_{sh}$ (ksi, MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alloys in wrought form</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100-H12</td>
<td>16/110</td>
<td>15/103</td>
<td>25</td>
<td>10/69</td>
</tr>
<tr>
<td>1100-H18</td>
<td>24/165</td>
<td>22/152</td>
<td>15</td>
<td>13/90</td>
</tr>
<tr>
<td>2014-0</td>
<td>27/186</td>
<td>14/97</td>
<td>18</td>
<td>18/124</td>
</tr>
<tr>
<td>2014-T4</td>
<td>62/427</td>
<td>42/290</td>
<td>20</td>
<td>38/262</td>
</tr>
<tr>
<td>2014-T6</td>
<td>70/483</td>
<td>60/414</td>
<td>13</td>
<td>42/290</td>
</tr>
<tr>
<td>3003-0</td>
<td>16/110</td>
<td>6/41</td>
<td>40</td>
<td>11/76</td>
</tr>
<tr>
<td>3003-H12</td>
<td>19/131</td>
<td>18/124</td>
<td>20</td>
<td>12/83</td>
</tr>
<tr>
<td>3003-H18</td>
<td>29/200</td>
<td>27/186</td>
<td>10</td>
<td>16/110</td>
</tr>
<tr>
<td>5154-0</td>
<td>35/241</td>
<td>17/117</td>
<td>27</td>
<td>22/152</td>
</tr>
<tr>
<td>5154-H32</td>
<td>39/269</td>
<td>30/207</td>
<td>15</td>
<td>22/152</td>
</tr>
<tr>
<td>5154-H38</td>
<td>48/331</td>
<td>39/299</td>
<td>10</td>
<td>28/193</td>
</tr>
<tr>
<td>6061-0</td>
<td>18/124</td>
<td>8/55</td>
<td>30</td>
<td>12/83</td>
</tr>
<tr>
<td>6061-T4</td>
<td>35/241</td>
<td>21/145</td>
<td>25</td>
<td>24/165</td>
</tr>
<tr>
<td>6061-T6</td>
<td>45/310</td>
<td>40/276</td>
<td>17</td>
<td>30/207</td>
</tr>
<tr>
<td>7075-0</td>
<td>33/228</td>
<td>15/103</td>
<td>16</td>
<td>22/152</td>
</tr>
<tr>
<td>7075-T6</td>
<td>83/572</td>
<td>73/503</td>
<td>11</td>
<td>48/331</td>
</tr>
<tr>
<td><strong>Casting alloys—permanent mold castings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>204.0-T4</td>
<td>48/331</td>
<td>29/200</td>
<td>8</td>
<td>—</td>
</tr>
<tr>
<td>206.0-T6</td>
<td>65/445</td>
<td>59/405</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>356.0-T6</td>
<td>41/283</td>
<td>30/207</td>
<td>10</td>
<td>—</td>
</tr>
</tbody>
</table>

*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/in.$^3$ (2770 kg/m$^3$).

---

Figure 3 – Aluminum Alloy Properties (9)
Easy-to-Machine 1144 Carbon Steel Rod
High-Strength, 5/8” Diameter

<table>
<thead>
<tr>
<th>Length, ft.</th>
<th>Each</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Material: 1144 Carbon Steel
Shape: Rod and Disc
Shape Type: Rods
Diameter: 0.070”
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
Straightness Tolerance: Not Rated
Coefficient of Thermal Expansion: 7.4 x 10^-5
Elongation: 0.6%

Figure 4 – 1144 Alloy Steel Properties (10)