ADAPTIVE EXERCISE EQUIPMENT

Final Design Review

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Abstract

This document outlines the senior design project carried out by a team of mechanical engineering students at California Polytechnic State University, San Luis Obispo. The task is to design adapted exercise equipment for the non-profit organization, Achievement House. The objective of this Final Design Review is to document the final design, manufacturing plan, design verification plan, and project management plan. In addition, this document includes previously presented information on the project background, objectives, and concept design. The background and objective sections document various forms of customer research and include the project goals developed by the athletes and fitness instructors of Achievement House. This section has been updated to reflect new data involving athlete height, arm span, and wheelchair dimensions. The concept design section has been updated to reflect a singular combined apparatus, as recommended by our sponsor. The final design section outlines the final design of our project, including material selection, drawings, cost analysis, and safety considerations. The manufacturing plan section includes the steps we will take to verify our design through prototyping. The project management section outlines the next steps that must be taken in order to complete the project in the future.

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1.0 Introduction

Our team consists of Spencer Goodman, Journey Martinson, Kalina Burns, and Jake Walejko, and for our senior project we are designing adaptive exercise equipment for Achievement House, which is a non-profit organization in San Luis Obispo County. Achievement House is in need of a variety of adaptable and engaging exercise apparatuses for people with mental and physical disabilities, particularly those in wheelchairs, to encourage large muscle group development that cannot be achieved with current equipment. This Final Design Review will document our progress thus far, and includes new information regarding the final design, manufacturing plan, design verification plan, and our next steps.

2.0 Background

Our initial background research consists of three main focuses: customer research, product research, and technical research. Customer research is based off of meetings and interviews with our clients at the Achievement House. This portion of the research also included gathering measurements of our clients and the fitness room. Product research focuses on current solutions available on the commercial market and delineates why they are not viable options for our sponsor. Technical research contains our research into journal articles, literature reviews, and past senior projects. This section has been tabulated as Appendix A, which includes our research into related patents, helping us gain a broader perspective of current technologies attempting to solve the same problem.

2.1 Customer Research

As an initial effort to fully understand our customer's problem, we met with our sponsor to discuss the challenges they are currently facing with the exercise equipment and resources available. The stakeholder is the athletes and the fitness instructors. The fitness instructors are motivated by providing the athletes with a full-body workout, while the athletes are looking to become stronger and have fun.

The Achievement House has the following exercise equipment available:

- Treadmill
- Dumbbells
- Stationary-sitting bike
- Balance ball
- Resistance bands

The Achievement House runs fitness classes every day, but not every athlete is able to participate due to the following challenges:

- Walking balance: The athlete is in danger of falling when attempting to balance, making it unsafe for both the client and the instructor.
- Wheelchair restricts range of motion: The athlete is unable to use equipment that requires walking, and is restricted to a small range of arm motion.

- Muscle control: The athlete is unable to safely move weights in a controlled path, and puts themselves and others at risk of injury.

The primary challenge being faced is that the equipment is not suitable for those in wheelchairs and that there is not a mounting structure for resistance band workouts. This severely limits the activities that are most desired by the athletes, which tends towards group activities and alternative forms of exercise, such as the stationary bike machine or using dumbells, which aren't efficient since neither are accessible to people with low motor function capabilities. Below is a summary of the needs and wants of the athletes and fitness instructors used to establish a scope for our project, and eliminate aspects of fitness that are not necessary.

Table 2.1. Summary of Customer's Needs/Wants

Needs	Wants
Safe to use	Sensory feedback to engage the mind
Accessible for those in wheelchairs	Guided mechanism for those with less muscle control
Focuses on major muscle groups	Adjustable weight resistance
Located in exercise room or outdoors	Accomodating for those with less grip strength

In addition, our team visited Achievement House and took measurements of the exercise room and of some clients who will be using the equipment. These can be seen below in Table 2.2, Table 2.3, and Figure 2.1. Danielle was not measured for the total wingspan or total standing height with arms raised because her mobility is not reflective of the athletes.

Table 2.2. Equipment Measurements

Equipment	Measurement
Wheelchair	32”x26”x36”
Standard Chair	25”x25”x40”
Walker	25”x16”x38”
Resistance band (with handles)	Length: 63”
Resistance band (without handles)	Length: 50”

Table 2.3. Client Measurements

Measurement Description	Client	
	John (LxWxH) *In Standard Chair	Danielle (LxWxH) *In Wheelchair
Individual seated in chair	25”x25”x49”	32”x26”x50”
Wingspan	65”	*N/A
Total seated height with arms raised	60”	66”
Total standing height with arms raised	75”	*N/A
Distance from rack of chair to fingertips with arms straight out	40”	32”
Vertical height from floor to arms with arms straight out	42”	36”
Distance From Back of Chair to Feet with Legs Straight Out	48”	56”

**Measurements not recorded because they were less than John’s measurements.*

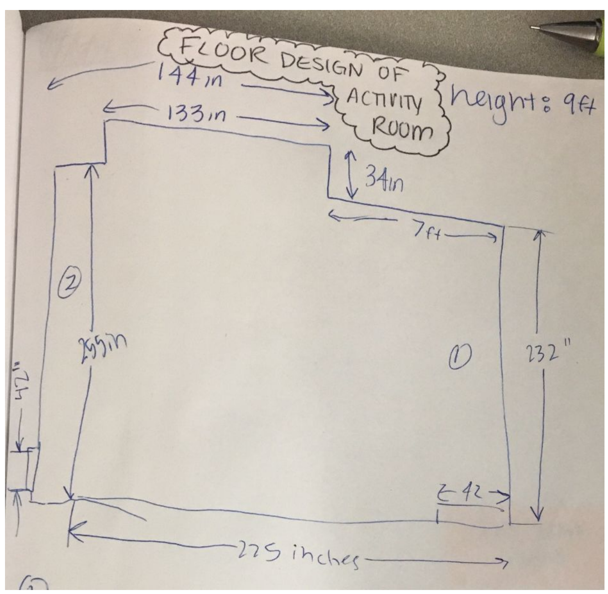


Figure 2.1. Achievement House Exercise Room Layout

2.2 Product Research

The biggest challenge currently being faced by Achievement House is a lack of exercise equipment that is adaptable for all of their athletes. In Table 2.4, we created a table of products currently on the market that have aspects related to potential solutions.

Table 2.4. Existing Product Descriptions and Images

Name	Image	Description	Price
The Seated Whole Body Pedaler		Device with hand crank and foot pedals that is operated while sitting down.	$99.95
Folding Upper & Lower Body Cycle		Low impact pedaling device with monitor that tracks time.	$21.99
Biodex Gait Trainer 3		Treadmill with balance harness that provides audio cueing and visual biofeedback of step length and step speed.	$22,322.30
Sammons Preston GlideTrak		Treadmill with balancing harness apparatus.	$807.39
Wheelchair Workout Kit		Contains resistance bands that can be strapped to the wheelchair and used, a finger/hand exerciser, and carrying container.	$24.9

In Table 2.5, we developed a scoring system capable of ranking these products based on how they relate to our project. Of the products that are currently on the market, the *Folding Upper & Lower Body Cycle* achieved the highest score with 29 points. This product is highly customizable and can target a large range of muscles in both the upper and lower body. The main design flaw is that the biking resistance cannot be adjusted. The product that least suited our needs is the *Sammons Preston GlideTrak*, which earned a score of 21 out of 40 points. This device serves as a safety harness for a specific type of treadmill and cannot be used by Achievement House because none of the staff is certified to remove someone from their wheelchair. After identifying the top products related to our customer needs, each product was ranked on a scale from 1 to 5, with a score of 5 being the best score, in terms of a range of parameters that were selected based on our customers primary needs. These scores were then added up in Table 2.5. A higher score corresponds to a product that is more likely to be helpful to us when drawing inspiration from current solutions.

Table 2.5. Benchmarking of Existing Products Based off of Customer Needs

Parameters	*The Seated Whole Body Pedaler*	*Folding Upper & Lower Body Cycle*	*Biodex Gait Trainer 3*	*Sammons Preston GlideTrak*	*Wheelchair Workout Kit*
Ease of use	4	5	2	2	4
Adjustability	2	3	5	5	4
Cost	3	5	1	1	5
Muscle Group Focus	3	3	3	3	2
Safety	5	5	5	4	5
Range of users	5	5	3	3	2
Maintainability	4	5	2	1	5
User Engagement	2	3	5	2	1
Total Score	**28**	**29**	**26**	**21**	**28**

2.3 Technical Research

A patent search was conducted in order to explore similar solutions that have already been invented. We identified several patents that were designed to be accessible for those with physical disabilities, primarily those in wheelchairs. Each patent has aspects that adhere to the different needs stated by our sponsor and athletes. Examples of ideas that could be utilized in our own designs include locking mechanisms to keep the wheelchair in place, propulsion aids that exercise different muscle groups, guided rail systems, etc. Each patent presents a unique solution to our problem. They can be seen in Appendix A: Technical Research.

In addition to our patent research, a search on related research journals was conducted. The following articles contained information beneficial to our own design:

(1) “Systematic Review of Physical Activity and Exercise Interventions to Improve Health, Fitness and Well-Being of Children and Young People who use Wheelchairs”, *BMJ Open Sport & Exercise Medicine.*

This article speaks on the trend of low activity levels in children with physical disabilities and how engaging exercises help promote healthy lifestyles for them. This goes hand in hand with our objective to develop engaging equipment that encourages the user to want to exercise.

(2) "Enabling participation for disabled young people: study protocol." *BMC Public Health.*

This article discusses the participation levels of people with disabilities in activities, sports, and educational or business events. Considering we want to encourage activity and exercise levels for our customers, we utilized this article to develop an engaging method of exercise as part of our preliminary design.

(3) "Cardiorespiratory Fitness in Individuals with Intellectual Disabilities—A Review." *Research in Developmental Disabilities*.

This research report was conducted in order to identify how cardiorespiratory fitness levels differ between people with disabilities and those without them. "Low cardiorespiratory fitness levels have been found in individuals with intellectual disabilities (ID), which puts them at higher risk for cardiovascular diseases and all-cause mortality (3)." Since people with disabilities are likely to have lower fitness levels than those without, it is important that we consider their level of fitness when designing our equipment. In order to optimize the exercise equipment to Achievement House's needs, our design must be adaptable to users of various fitness levels.

(4) "Development of Physical Fitness in Children with Intellectual Disabilities." *Journal of Intellectual Disability Research*.

This journal contains a study that was conducted on children with intellectual disabilities and compares their physical fitness development to that of children without disabilities. The present study showed lower aerobic and muscular fitness in children with ID compared with typically developing children between 8 and 12 years (4). From this study, we realized that there are a wide range of physical and mental conditions that our design parameters must consider.

(5) "Adaptive Control of an Exercise Machine." *Proceedings of the 15th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*.

This article discusses the use of an adaptive controller to limit the user to using the equipment in the most efficient way. This is related to our goal of using guides to limit the user's motions, ensuring they are using the equipment correctly.

Past senior projects were also studied so that we could see how other groups solved problems similar to ours. The information we used to design our prototypes was taken from the following senior projects:

(6) "Universal Weight Machine" was a project completed by Cal Poly students in 2016 that involved creating a universally accessible multi- station exercise machine for the physical and mental well-being of athletes of the Special Olympics and Pathpoint Life Education & Advancement Program. From this project, we narrowed down our ideas to designing an adjustable resistance band apparatus since it would allow for a wide range of exercises while also being usable by people with varying levels of fitness and varying conditions. The "Universal

Weight Machine" also included a low resistance pedaling station, which further supported our product research that showed the pedaling mechanism as the best option for exercise. An image of this project can be seen in Appendix A in Figure A.1.

(7) "Universal Play Frame VI" was a project designed by Cal Poly students in 2010 that consisted of an adaptive frame which supports a variety of devices that allows athletes in wheelchairs with limited range of motion to participate in physical activity. Dr. Kevin Taylor was the sponsor of this project, and we met with him in order to gain feedback on our ideas, as well as insight on what design parameters we should be considering for our project. From Dr. Taylor's advice, we realized that we needed to get to know our target consumers more, and also needed to design our project to match their abilities rather than just the average person's abilities. Figure A.2 in Appendix A displays an image of this project.

3.0 Objectives

This section of the Final Design Review documents the design considerations used to create the concept design. The design considerations were developed from the previously documented chapter on background research, and further developed by creating a problem statement, boundary diagram, and engineering specifications list.

3.1 Problem Statement

The overall objective of the project is to design and manufacture adaptive exercise equipment for people with varying levels of mental and physical disabilities. Non-adapted exercise equipment does not have the safety features, support, or wheelchair features necessary to allow a wide range of people to participate. In addition, adaptive exercise equipment on the market today is expensive, which makes it challenging for non-profit organizations such as Achievement House to provide such equipment for their clients. Achievement House does not have fitness racks or equipment required to provide diverse exercise classes. The equipment that they do have is tailored towards individuals who do not use a wheelchair. Introducing adapted exercise equipment into their fitness class will allow more athletes to participate, which will create a more inviting environment and help encourage socialization and community. Our goal is to develop adapted exercise equipment that will allow people with mental and physical disabilities to exercise various muscle groups at varying levels of difficulty and weight by developing specialized equipment adapted for their client's unique range of motion, strength, and dexterity.

3.2 Boundary Diagram

The purpose of a boundary diagram is to identify which aspects of the problem statement can and can not be adjusted using engineering methods. As mentioned, the device must be adaptable for people with varying levels of mental and physical disabilities. People who use a wheelchair have a narrower range of motion, as displayed in the first picture in Figure 3.1. This will have a large impact on the design of our product, because it limits what exercise movements are possible. In the second picture, the arrow highlights a critical structural component that will greatly impact how clients in wheelchairs may approach the product. Spacial awareness will guide the overall structural design of the device because of its impact on user ergonomics. After meeting our clients, it was determined that the device would not need to incorporate a wheelchair locking mechanism and that the wheelchairs would not be altered.

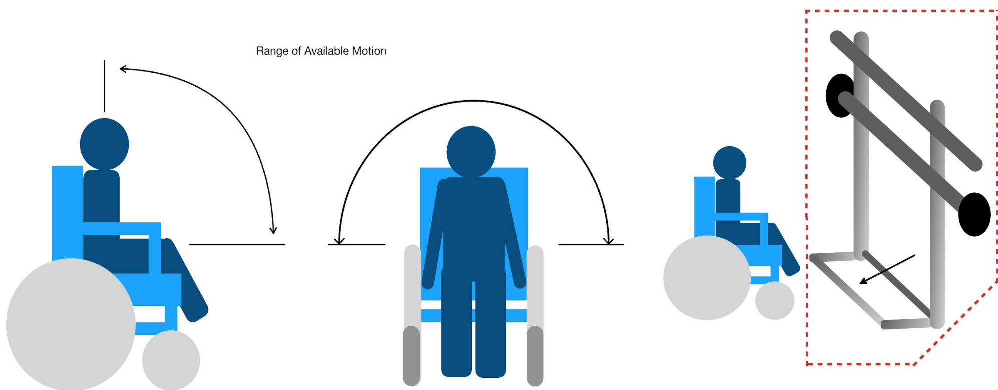


Figure 3.1. Boundary Diagram of Limitations of Wheelchair Users

Based on the desires of Achievement House and background research, our team used Quality Function Deployment (QFD) to create a “House of Quality”, included in Appendix B. QFD spurs product development by identifying the appropriate specifications for a design. The “House of Quality” weighs the different aspects of a design, how they meet the customer’s needs and wants, and how they compare to competing products. The specifications are listed from 1-5, (i.e. 1 - not important, 5 - extremely important). From the QFD, we developed the Engineering Specifications to evaluate how the “Basic Needs and Wants” could be tested and quantified; these can be seen in Table 3.1.

Table 3.1. Engineering Specifications

Spec. #	Spec. Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight of Apparatus	200 lb	+25	H	I
2	Size	Fits through door	n/a	M	A,I,T
3	Ease of Use	Pass/Fail	n/a	M	A,I,T,S
4	Comfort	Survey	n/a	M	A,T
5	Customizability	>3 muscle groups	n/a	M	A,T
6	Low Mechanical Complexity	Pass/Fail	n/a	H	A,I,T
7	Durability	Life of five years	+/- 2 years	M	A,T,S
8	Cost	$400	+/- $100	H	A

The specifications table lists the specification description, target value, tolerance, risk level, and compliance. The risk levels are (H) High, (M) Medium, and (L) Low. The compliance categories are (A) Analysis, (T) Test, (S) Similarity to Existing Design, and (I) Inspection. The compliance category indicates how each specification will be measured. The tolerance column indicates the range of acceptable values for each specification. For example, our target weight for the apparatus is 200lb, but if the device is 225 lbs, it will still pass our design requirements. In addition, our requirement for size is that the device can fit into the room. This criteria is pass or fail, thus indicated by “n/a”. The risk column indicates how critical the specification is in terms of designing a functional product. The higher this column is rated, the more of a risk it will be to the user or sponsor if we do not achieve it with our design. Specifications marked with (H) are high risk, and will have a large impact on the success of the design. For example, the cost of the design is high risk, because without adequate funding, the project can not be manufactured. Therefore, this is a critical specification that we must consider. This exercise helped identify the most critical aspects of the design that may cause challenges in the future. Each specification is outlined below in further detail.

- Weight of Apparatus: The product must not require a machine to be transported around the facility. This will be measured based on how many people are required to move the product
- Size (height, width, length): The product must fit through a standard door. If not, if must be easily disassembled and reassembled.
- Ease of Use: The product can be set up for the user with two people. This will be measured based on how many people are required to set up the product
- Comfort Survey: The product is comfortable to use for multiple body types. This will be measured using comfort surveys.

- Workout Customizability: The product can be used to target different muscle groups. This will be measured based on how many muscle groups the product can target.
- Mechanical Complexity: The product is easy to operate mechanically. This will be measured based on usage surveys by clients and instructors at Achievement House.
- Durability: Our goal is to have the product require maintenance once per year. This will be measured based off of a cycle test.

4.0 Concept Design

Our final concept design is the result of extensive brainstorming, prototyping, sponsor meetings, and ideation. We generated a method of weighing our top design models against the most important features of the exercise equipment, and used this model to generate a final design proposal.

4.1 Brainstorming

In the early stages of our idea development, our goal was to generate as many ideas as possible. This process was approached with creativity and openness, to allow for a wide range of unique ideas. A complete list of the generated ideas can be seen in Appendix C.

In addition, our team visited the Cal Poly Recreation Center to analyze exercise equipment and discuss its accessibility. This was followed by an ideation session where the goal was to figure out how we could make each machine more accessible to wheelchair users. After we had generated a substantial number of ideas, we had an additional meeting with our sponsor to review our concept models. Communication with our sponsor turned out to be a critical factor in the development of our final concept design. While we were focusing on creating equipment that would be fun and engaging, it was deemed that the most important function of our design was a product that can be used by all athletes and can target a wide range of muscles. From this meeting, we were able to narrow down the large list of ideas to a select few that we would develop concept models for.

4.2 Concept Modeling

The concept modeling phase consisted of creating physical models of the best ideas from the brainstorming phase. We used simple arts and crafts materials to do this, keeping in mind that the goal was to simply bring these ideas to life and analyze their potential as a solution.

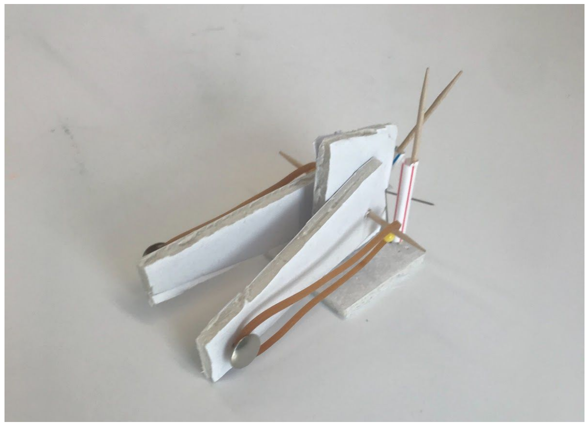


Figure 4.1. Concept Upper Body Elliptical

The upper body elliptical functions similarly to a typical elliptical machine, but it is designed for a wheelchair user to achieve cardio exercise with their upper body. It would have adjustable resistance so the user can control the difficulty of their exercise, and is designed to fit a wheelchair. The user would lift the two parallel arms to exercise their upper body.

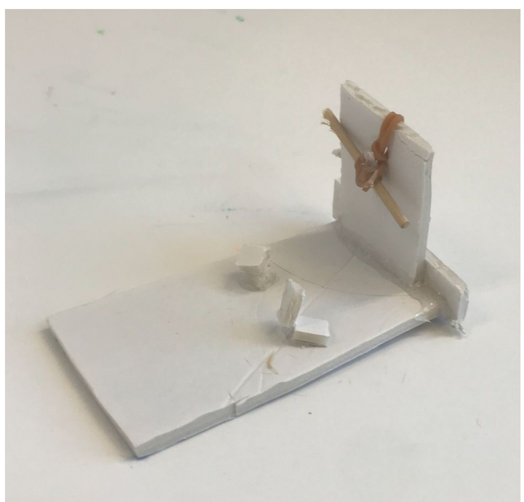


Figure 4.2. Concept Adaptable Rowing Machine

The adaptable rowing machine has space for a wheelchair user to lock into the machine and then perform a rowing exercise. The muscles being targeted with this machine are the major muscle groups in the back and also the arms. The resistance would be adjustable.

Figure 4.3. Concept Hand Pedaler

The hand pedaler works similarly to a stationary bike, but a wheelchair user is capable of rolling up to the machine and achieving a cardio workout using their arms. The resistance would be adjustable to allow the user to control the difficulty of the exercise. The stationary hand pedal could also be adjusted vertically for different heights.

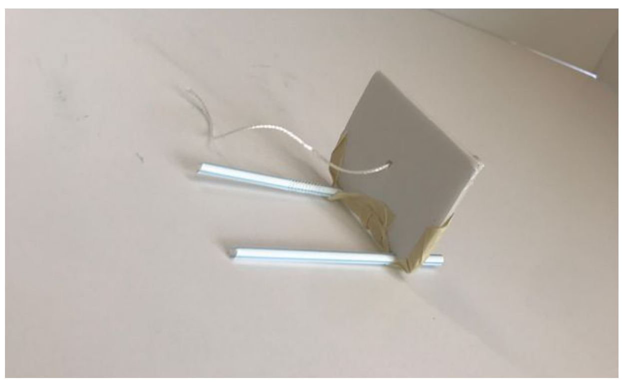


Figure 4.4. Concept Rope Pull Machine

The rope pull machine is meant to give the user an interactive workout of the back and arm muscles. The user would have resistance bands attached to the back of their wheelchair and would pull themselves towards the wall against this resistance. Then, they would utilize their arm muscles to slowly retreat from the wall using the rope.

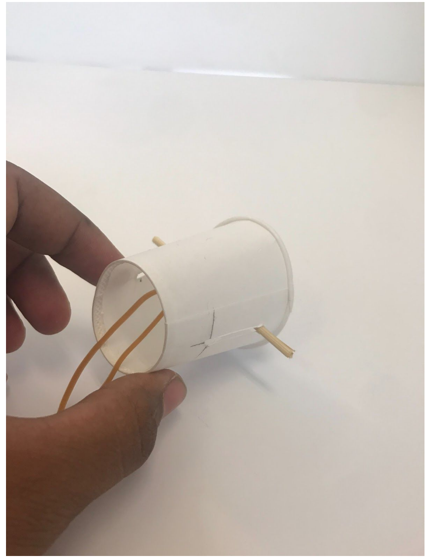


Figure 4.5. Resistance Band Pulling Device

This machine is used by pulling the resistance band attached, which causes the bar to move along the cutout path. The bar can also be anchored in a fixed position to perform stationary exercise. This would be a workout of the major muscle groups in the back and the arms.

4.3 Decision Matrices

In order to narrow down our ideas to a final design, we utilized a number of decision matrix methods recommended by our advisor. The first of these was developing Pugh Matrices for each of the functions our solution must perform. The Pugh Matrix allowed us to come up with the best designs for individual functions of the final design. We then used a System Morphological Table to combine the best aspects from the Pugh Matrices into a few potential final designs. We then analyzed these designs in a weighted matrix, which allowed us to create a scoring system to see which design most effectively met all of the criteria. The highest scoring design can be seen in Section 4.4. These matrices can be seen in Appendix D at the end of this report.

4.4 Final Concept Design

Our final design came as a result of the decision matrices and another conversation with our sponsor. It is a combination of a resistance band rack, pedaler, and punching bag - providing the users with a full body workout station. Below is a preliminary CAD model of our final concept. One of the primary changes we made after the preliminary design review was merging all aspects of the product into one chamber. Our client preferred this design because it was more space efficient.

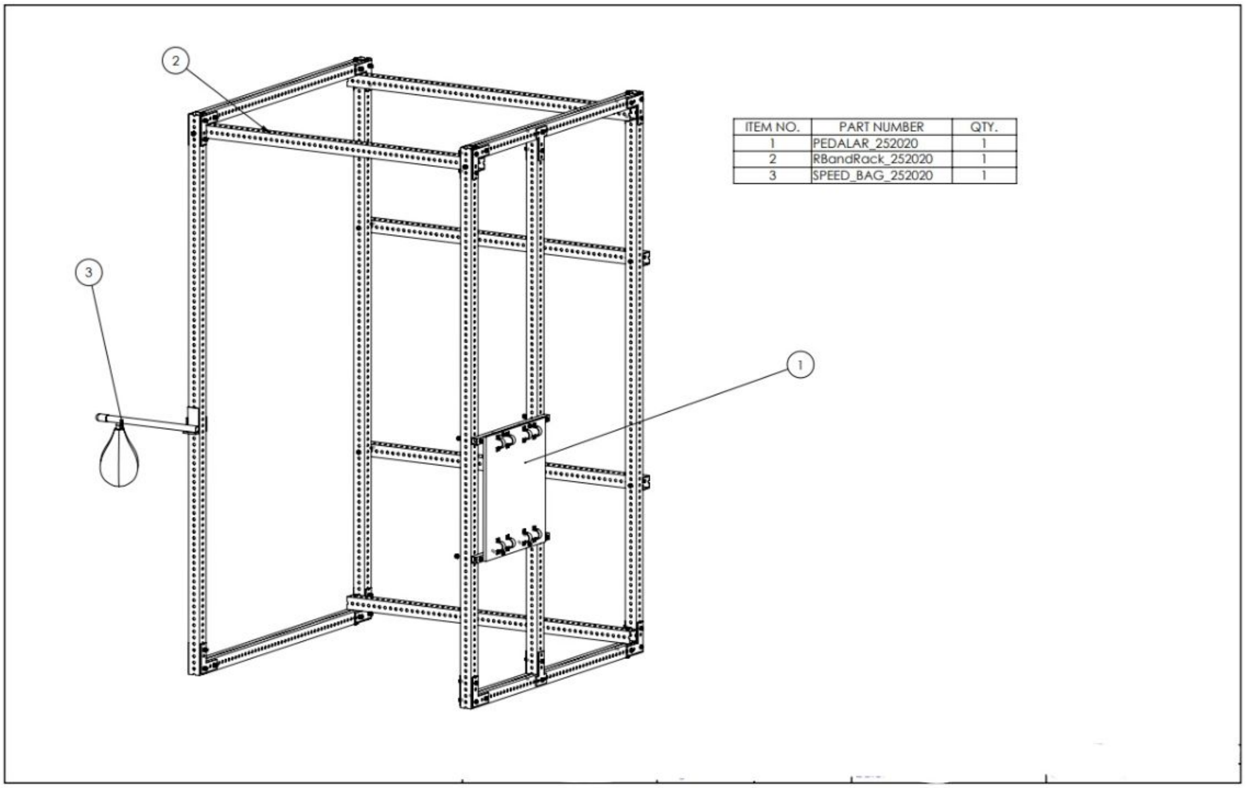


Figure 4.6. Final Concept CAD Model

The resistance band rack was chosen because the trainer at Achievement House already incorporates resistance bands into the clients' workouts. She currently is only able to attach the bands to the arm of a treadmill, so building an entire rack will allow her to add in more exercises and target more muscle groups. This type of exercise is also adaptable for a wide range of athletes, and has unlimited ways to adjust resistance.

The pedals located on the vertical plate on the right side of the CAD model were chosen because the athletes and the trainer are interested in incorporating a method of cardio exercise for users in wheelchairs. In this design, the resistance of the pedaler is adjustable such that the difficulty of the workout may be controlled.

The punching bag will be mounted on a removable bracket that can be placed anywhere on the main frame of the apparatus. A punching bag was chosen because the athletes at Achievement House expressed interest in exercising by performing punching and kicking motions. The bag can be adjusted vertically to accommodate standing and seated users.

The material used to build the main frame of the apparatus will be perforated galvanized steel beams because it is strong enough for our intended loads and cost effective. The punching bag bracket will be made from stainless steel. Stainless steel was chosen because it is chemically compatible with galvanized steel and is strong enough for our needs. The pedaler mount will be made from plywood and aluminum, allowing it to be lightweight and easier to adjust. Since there is a risk of corrosion when connecting aluminum and steel parts, we will need to coat the aluminum with a galvanizing compound spray that allows it to resist the corrosion.

4.5 Concept Prototypes

The next step was to develop more realistic physical prototypes. We used the concept prototypes to help us get a better idea of how we could potentially manufacture certain aspects of the final design. Our primary focus was to brainstorm how the steel beams would fasten together, and how the pedaler would adjust along the resistance rack.

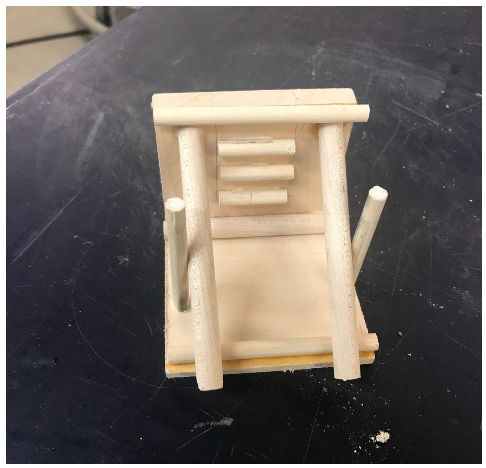


Figure 4.7. Resistance Band Rack Concept Prototype

This prototype is meant to serve as a potential way to assemble the resistance band rack. This would be a freestanding rack that the user could roll into and perform multiple workouts. The downside of this design is the angled supports making it difficult for the user to maneuver into different positions when switching workouts. In this concept prototype, the steel beams would be fixed together using bolts and washers. The bolts would slide through the holes on the two beams and be fixed in place with a washer on the other side. This design requires few fasteners, which makes it economically desirable.

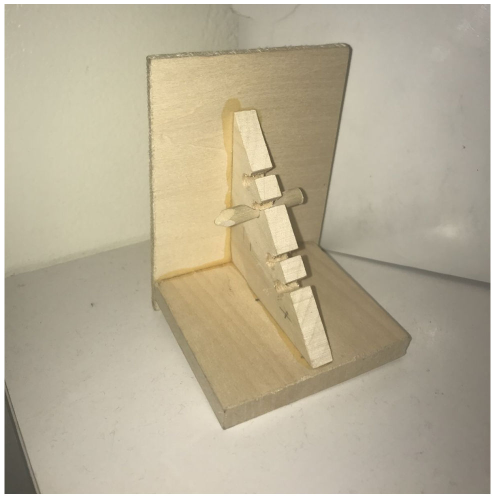


Figure 4.8. Pedaler Adjustable Height Concept Prototype

This prototype is a potential solution to making the pedal height adjustable. The pedals would be attached to the fixture shown in Figure 4.8, and the pin that controls the height can be removed and placed into the other slots depending on how the user wants to use the pedals. The benefit of this design is that moving the pedalar between slots is easy and quick, which satisfies our goal of engineering a user friendly apparatus.

4.6 Potential Risks

The primary risks associated with our design come from incorrect use and structural stability. As with all exercise equipment, there is a risk of injury if the device is used incorrectly. While performing customer research, we were informed that the athletes are supervised during every exercise class. Therefore, by educating the instructors of the risks and hazards of our device, we can better protect the athletes from injuring themselves. We predict that the most common mis-use of the device will be users hanging, swinging, or performing pull-ups on the rack and punching bag beam. To mitigate this risk, we will include diagrams on the final product that visually display what not to do on the rack. In addition, we may fix the structure to the wall of the exercise room as a safety precaution. While meeting with our sponsor, it was also decided that a plaque on the wall that displays visual images of different exercises would be useful. All potential risks and hazards and the corrective actions that will be taken can be seen in Appendix F at the end of this report.

5.0 Final Design

This portion of the Final Design Review provides a detailed account of the final design, including parts, subassemblies, functionality, analysis, and cost.

5.1 Final Design Explanation

Our final design, displayed in Figure 5.1, features a main rack constructed from perforated galvanized steel beams that will be bolted together using external brackets, bolts, and lock nuts. It will be fixed to the wall of the client’s exercise room. The dimensions of the frame will be 90 inches x 52 inches x 52 inches, which will allow a wheelchair to roll into the center. Beams on all sides of the user allow for innovative resistance band placement; depending on the placement angle and relation to the body, a number of large muscle groups may be engaged. On the right side of the resistance rack, the pedaler is mounted to an adjustable vertical plate that is fixed to the rack using four bolts and nuts. The vertical plate can be moved up and down the rack by simply removing four bolts that fix it to the resistance rack. A pedaler mounted to a vertical plate allows users to “bike” with their arms, an adaptive and engaging form of cardiovascular exercise. On the left side of the resistance rack, a punching bag on a removable bracket can be placed at any location on the rack, accommodating both seated and standing users.

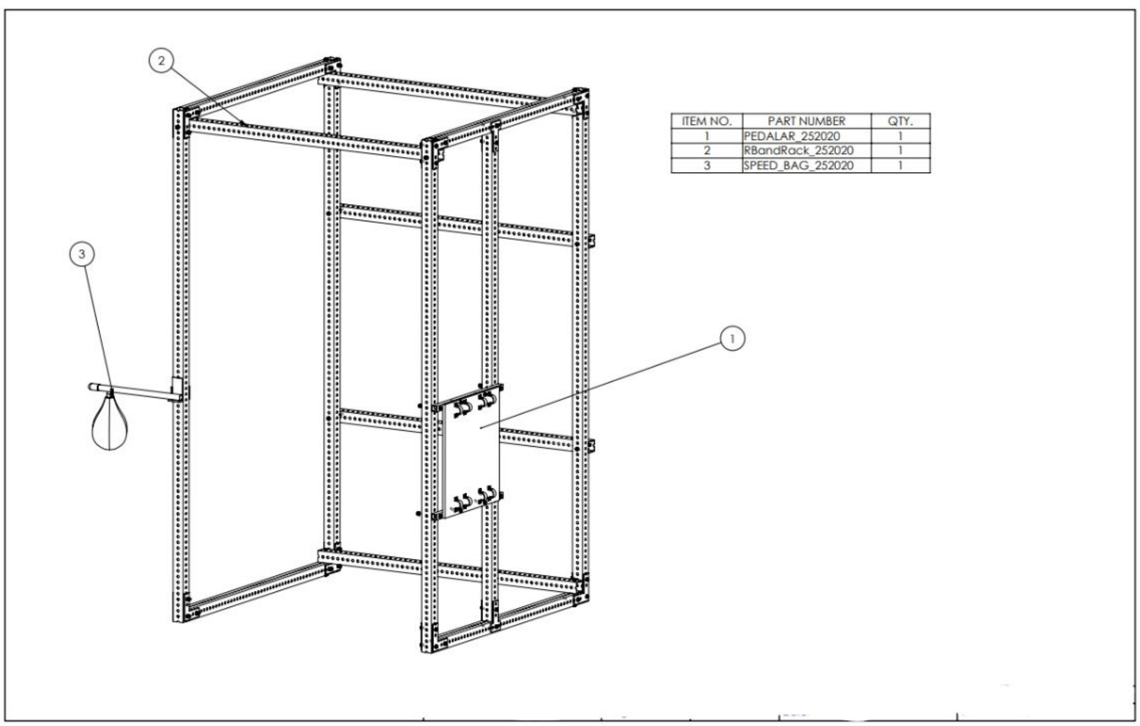


Figure 5.1. Full Assembly of Final Design CAD Model

5.2 Resistance Rack

The resistance rack shown in Figure 5.2.1 is made from perforated galvanized steel and is bolted together using 316 stainless steel external brackets. The brackets are held in place with ⅜''-16 Grade 5 Steel Hex Bolts Grade 5, ⅜''-16 Zinc-Plated Steel Nylon Insert Lock Nuts, and ⅜'' Aluminum washers. See the Manufacturing Plan in Section 6 for a step-by-step guide on how to assemble the resistance rack apparatus. The total cost of the resistance rack assembly is approximately $620.00. The full cost breakdown can be seen in the iBOM in Appendix G.

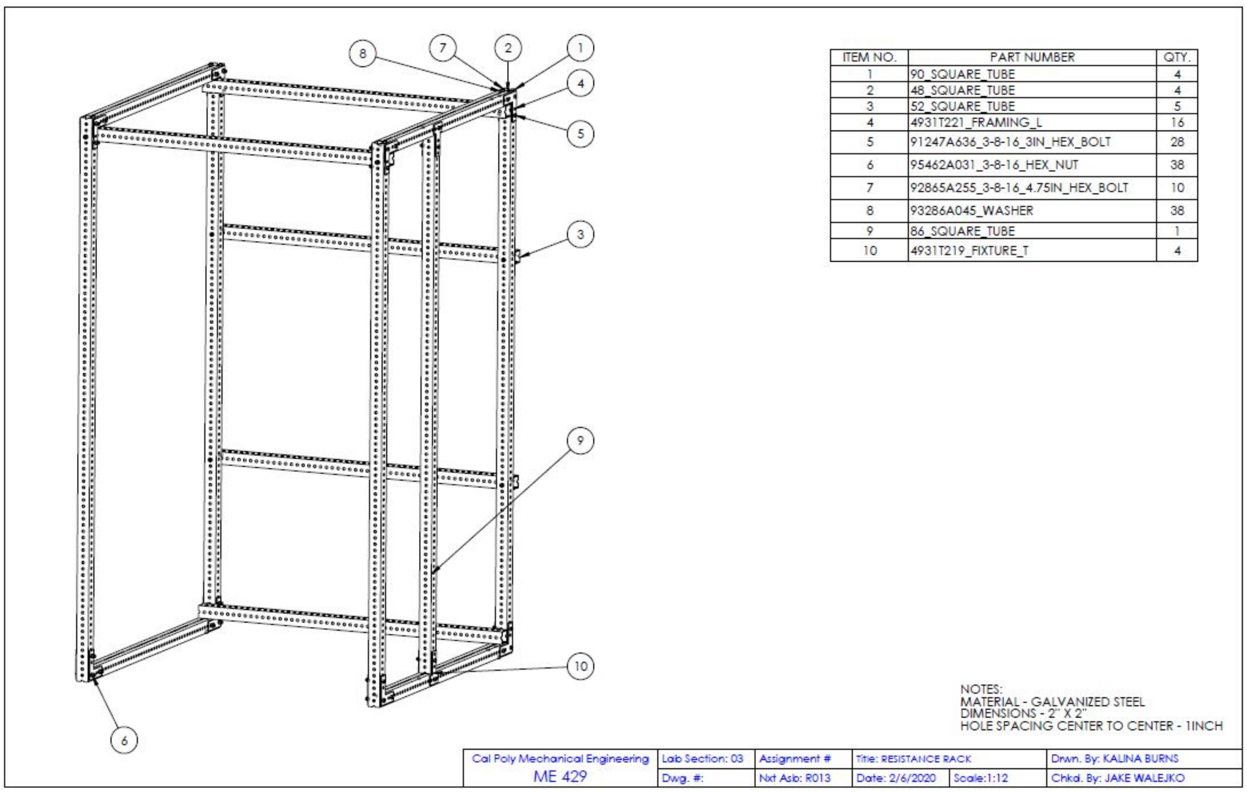


Figure 5.2.1. Resistance Rack Assembly Drawing

We chose to fix the steel beams using external brackets, as seen in Figure 5.2.2, because this is a common method of assembling weight lifting racks. Figure 5.2.3 displays a similarly designed power lifting rack, featured on FitnessFactory.com, and is also assembled using external brackets. The power lifting rack weighs 250lbs and is made from stainless steel. Our model weighs 205lbs, which is slightly lighter than similar designs on the market. But, because our design will only be used with resistance bands, we have concluded that the weight is sufficient enough to meet our safety hazard specifications for tipping.

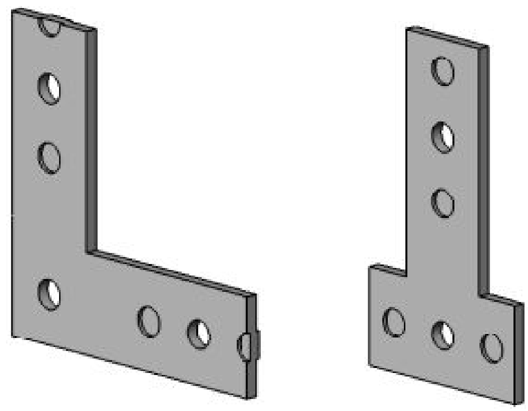


Figure 5.2.2. External Brackets

Figure 5.2.3. Alternative Design Comparison

Bending and deflection analysis was performed on the beam by the team. We used a design load of 400 lbf for this analysis to represent a very large load hanging from the center of the resistance rack, shown by a red arrow. The calculations can be seen in Figure 5.2.4 below.

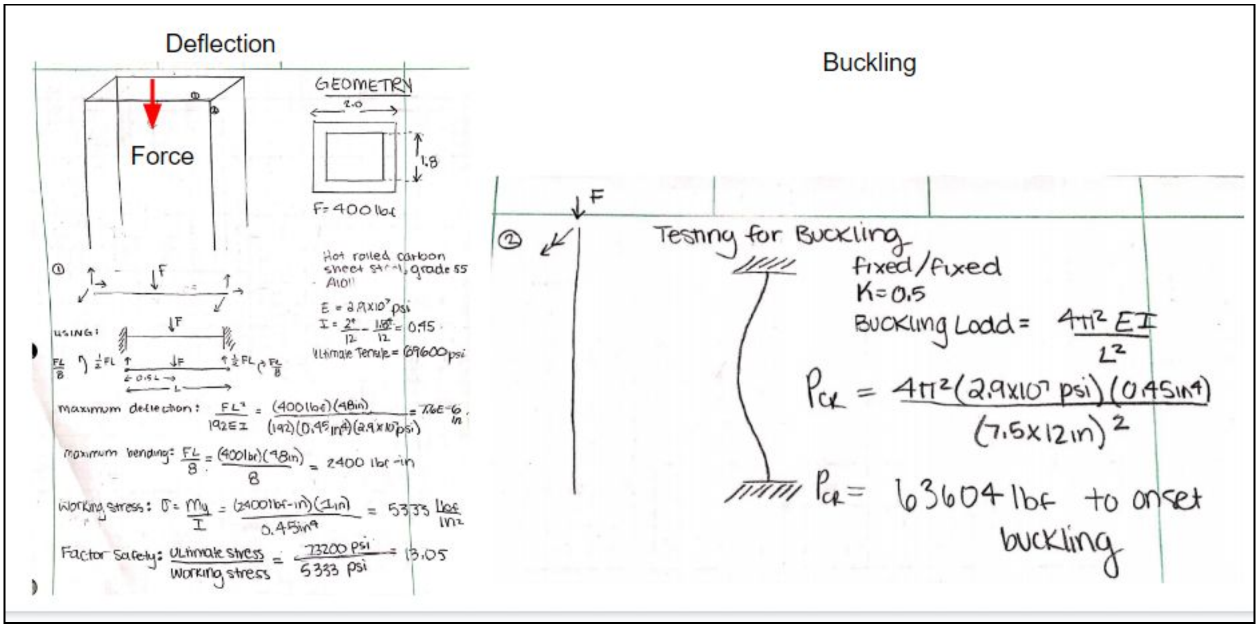


Figure 5.2.4 Resistance Rack Deflection and Buckling Analysis

Furthermore, there is an abundance of analysis that has been performed and made available to the public on UnistrutOhio.com by the manufacturer of the beams, Unistrut. For beam column loading, our biggest concern is with the longest beams so we will analyze the 90” beams on the resistance rack. The allowable loads for this length beam is around 2000 lbf, which is an order of magnitude larger than what we expect the rack to experience. For the bolts, manufacturer’s analysis was provided on Fastenal.com. We are looking at shear forces on the ⅜” and 7/16” grade 5 steel bolts. The loads can be upwards of 8000 lbf, which is orders of magnitude larger than we expect the bolts to experience on any component on our final design. These can be seen below in Table 5.2.1 and Table 5.2.2.

Table 5.2.1. Beam Column Loading for Perforated Galvanized Steel Beams

Column Loading - P9000					
Unbraced Height (in)	Allowable Load at Slot Face (lbs)	Max Column Load Applied at C.G. K=0.65 (lbs)	K=0.80 (lbs)	K=1.0 (lbs)	K=1.2 (lbs)
24	3,640	8,730	8,570	8,330	8,040
36	3,540	8,360	8,040	7,530	6,950
48	3,400	7,880	7,340	6,530	5,660
60	3,210	7,290	6,530	5,440	4,360
72	2,990	6,640	5,660	4,360	3,160
84	2,730	5,940	4,790	3,340	2,320
96	2,430	5,220	3,940	2,560	1,780

Table 5.2.2. Bolt Shear Load Analysis

SINGLE SHEAR CALCULATIONS, MIN. LBS					
NOMINAL BOLT DIAMETER	BODY SHEAR AREA, SQ IN	GR 2	A307A & B	GR 5 / A325	GR 8 / A490
1/4"	0.04908	2,179.2	1,766.9	3,533.8	4,417.2
5/16"	0.07669	3,405.0	2,760.8	5,521.7	6,902.1
3/8"	0.11044	4,903.5	3,975.8	7,951.7	9,939.6
7/16"	0.15033	6,674.7	5,411.9	10,823.8	13,529.7
1/2"	0.19634	8,717.5	7,068.2	14,136.5	17,670.6
9/16"	0.24850	11,033.4	8,946.0	17,892.0	22,365.0
5/8"	0.30679	13,621.5	11,044.4	22,088.9	27,611.1
3/4"	0.44178	19,615.0	15,904.1	31,808.2	39,760.2
7/8"	0.60132	21,647.5	21,647.5	43,295.0	54,118.8
1"	0.78539	28,274.0	28,274.0	56,548.1	70,685.1
1 1/8"	0.99401	35,784.4	35,784.4	62,622.6	89,460.9
1 1/4"	1.22718	44,178.5	44,178.5	77,312.3	110,446.2

DEFINITIONS:
- Ultimate Tensile Strength, UTS - PSI - Lbs/Square Inch
- Ultimate Shear Strength, USS - PSI USS = .6 X UTS
- Body Shear Area, BSA - Square Inches
- Single Shear Strength, SSS - Lbs SSS = USS X BSA

The resistance rack will require minimum maintenance. Table 5.2.3 outlines the type of maintenance and corresponding frequency recommended by our team.

Table 5.2.3. Maintenance Recommendations

Type of Maintenance	Frequency	Tool Needed	Provided
Retightening bolts	Every two months	Wrench	Yes
Cleaning beams	Once a week	Skin friendly cleaning and deodorizing spray	NA

5.3 Punching Bag

The punching bag sub assembly includes a speed bag attached to a stainless steel bracket, which is then screwed into a perforated stainless steel bar. The assembly is attached to the resistance rack by bolting the two L brackets to the resistance rack. By allowing the punching bag to be moved vertically along the columns of the main frame, it can be utilized by both standing and seated users. The cantilever beam that extends away from the bracket gives enough clearance for the punching bag to swing in all directions and avoid hitting the main frame. It also allows for extra space between someone using the punching bag and someone inside the main frame. Figure 5.3.1 shows an assembly of the punching bag attachment. See the Manufacturing Plan in Section 6 for a step-by-step guide on how to assemble the punching bag apparatus. The total cost of the punching bag assembly is approximately $93.00. The full cost breakdown can be seen in the iBOM in Appendix G.

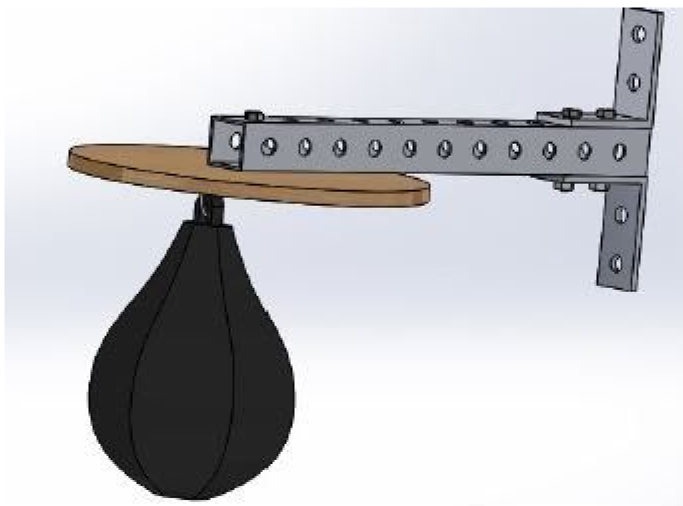


Figure 5.3.1 Assembly Model of Punching Bag Apparatus

The punching bag assembly includes a cantilever beam with a distributed force due to the beam weight and a point load due to the punching bag at the end. The area of concern with a design like this is the deformation in the beam and shear failure due to the moment that is created. This is addressed in the manufacturer's beam load tables. The punching bag beam is 18" long, so referring to the 24" beams our design is capable of experiencing loads upwards of 1700 lbf. This is about two orders of magnitude larger than the expected loads for the punching bag assembly. The manufacturer's analysis can be seen below in Table 5.3.1.

Table 5.3.1 Cantilever Beam Loading for 18” Round Steel Tubing

Beam Loading - P9000						
Span (in)	Max Allow. Uniform Load (lbs)	Deflection at Uniform Load (in)	Uniform Loading at Deflection Span /180 (lbs)	Span /240 (lbs)	Span /360 (lbs)	Lateral Bracing Reduction Factor
24	1,710	0.06	1,710	1,710	1,710	1.00
36	1,140	0.14	1,140	1,140	810	1.00
48	860	0.25	860	680	450	1.00

5.4 Pedaler Mount

The pedaler mounting apparatus will consist of the pedaler fastened to a vertical plywood platform The plywood will be bolted to two aluminum beams to provide support for the weight on the pedaler, and these beams will be connected to two steel columns on the main frame of the resistance band rack using four bolts and lock nuts. The pedaler is primarily designed for use by those with wheelchairs who cannot achieve a cardiovascular workout using normal cycling equipment due to having limited use of their legs. The user will be able to roll up to the pedaler and adjust their desired horizontal distance. The vertical height of the pedaler can be adjusted by removing four bolts and nuts that fix the vertical plate to the resistance rack, allowing it to be used for both leg and arm exercise. Figure 5.4.1 displays an isometric drawing of the pedaler mount, while Figure 5.4.2 displays an exploded subassembly of the pedaler mount. The total cost of the pedaler assembly is approximately $45.00. The full cost breakdown can be seen in the iBOM in Appendix G.

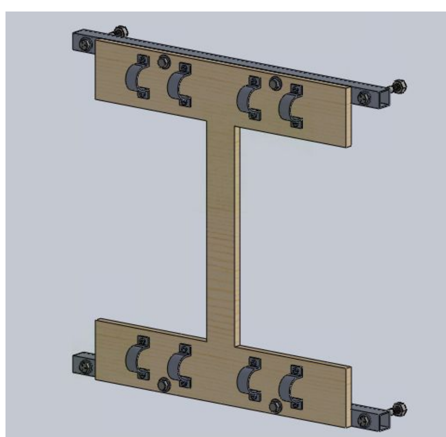


Figure 5.4.1. Isometric View of the Pedaler Mount

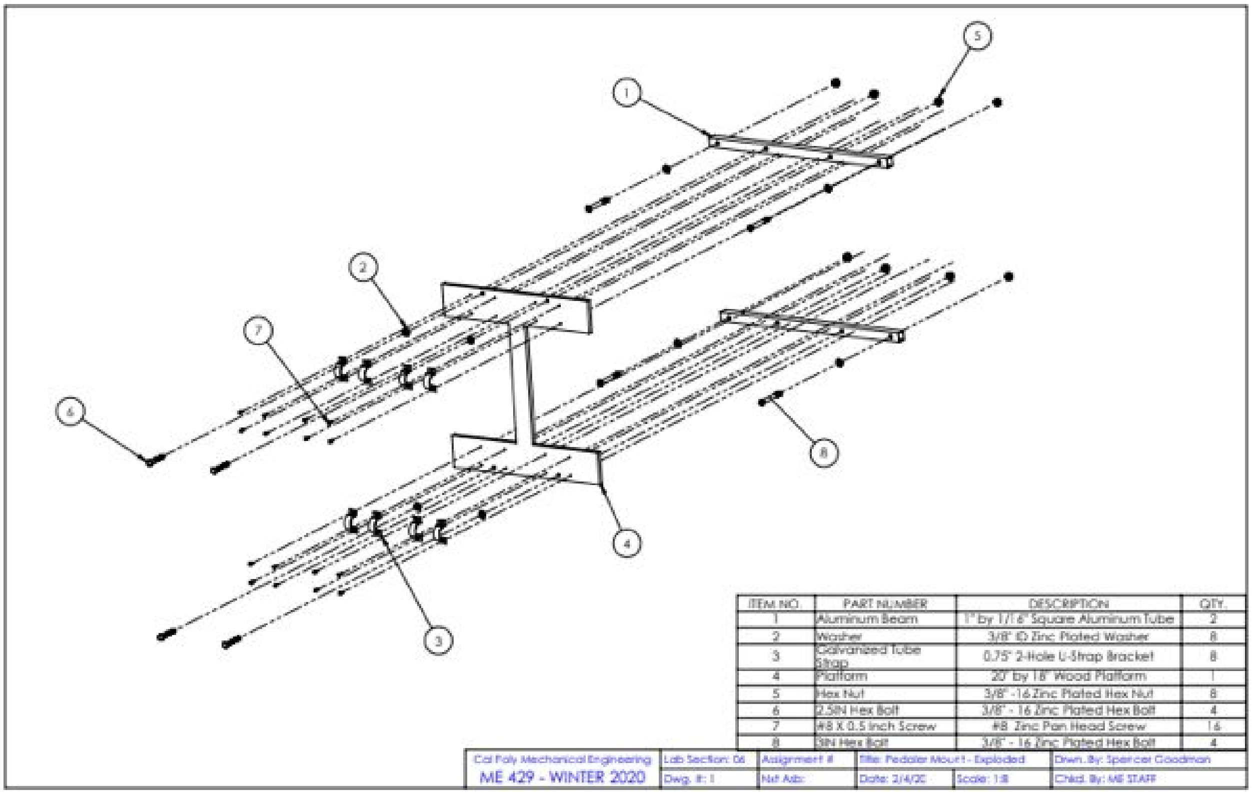


Figure 5.4.2 Exploded Subassembly of the Pedaler Mount

A structural prototype of the pedaler mount was built in order to test the strength of the brackets and if the bolts would be strong enough to support the shear stresses generated from the weight of the pedaler. From conducting tests on this prototype, we concluded that the strength of the screws supporting the galvanized tube straps was enough to keep the pedaler from shaking while being used. It was also concluded that the bolts were strong enough to support the load of a user exerting force upon the pedaler, which is also backed up by the bolt analysis that was conducted for the resistance rack in Table 5.2.2.

5.5 Cost Analysis and Funding

The components that make up our final design are a combination of custom manufactured parts and commercial off the shelf (COTS) parts that we modify to fit our design. In some instances, it makes more sense to purchase components instead of making them ourselves. For example, if we were to manufacture the perforated galvanized steel beams ourselves, it would take more time and money than if we were to just purchase them from the local supplier. This is the case with the majority of bracketry that we used throughout our design. The exception to this is with parts that are not available on the market, like the connecting bracketry in the punching bag assembly.

The total cost for our project is approximately $771.00. See Appendix G for the indented Bill of Materials (iBOM) detailing the full pricing estimate of our project.

Initially, we applied for grants from the Mechanical Engineering Student Fee Allocation Committee (MESFAC), as well as grants from CP Connect and Justin Wineries. From these grants, we received a total of $500 from MESFAC. We also reached out to local material suppliers for donations. We received donations from Traffic Management Inc., the suppliers of the beams, as well as Home Depot and Lowes, who supplied hardware and bracketry.

6.0 Manufacturing Plan

The following section describes the manufacturing plan for the verification prototype. In this section, the following aspects of the design will be addressed: material procurement, manufacturing steps, assembly and assembly steps.

6.1 Manufacturing Plan: Resistance Band Rack

6.1.1. Materials Procurement:

Table 6.1.1 below details the description, quantity, and supplier for the necessary materials to build the Resistance Band Rack. Refer to the Drawing Package in Appendix J for part details.

Table 6.1.1. Materials Required for Manufacturing of Resistance Band Rack

	Material	Quantity	Supplier
1	8'_SQUARE_TUBE	5	Traffic Management Inc.
2	10'_SQUARE_TUBE	3	Traffic Management Inc.
3	4931T221_FIXTURE_L	16	Mcmaster
5	91247A636_3/8”-16_3IN_HEX_BOLT	28	Granger
6	95462A031_3/8”-16_HEX_NUT	38	Granger
7	92865A255_3/8”-16_4.75IN_HEX_BOLT	10	Granger
8	93286A045_WASHER	38	Granger

6.1.2. Machining Process:

*Navigate to Appendix K for instructions on how to machine the perforated square tubing to length. The beams will henceforth be referred to as Beam A, Beam B, and Beam C as specified in Step 7 of Appendix K.

The L brackets will need to have 4, 7/16” holes drilled in them as shown in Figure 6.1.0 below. Refer to the drawing package in Appendix J for the locations of the drilled holes. It is recommended that the machinist align the L bracket on the desired joint and mark with a Sharpie marker where the holes need to be drilled to ensure that there is no misalignment.

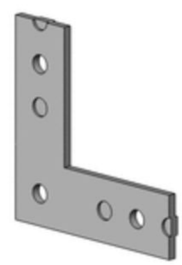


Figure 6.1.1. Holes drilled in L bracket

6.1.3. Assembly Process:

1. Assemble the structure shown in Figure 6.1.1 below by connecting two Beam A posts together with two Beam C posts. Refer to the Drawing Package for a detailed exploded view that shows how each joint should be assembled and what specific bolts to use. Refer to Joint A in Figure 6.1.2.

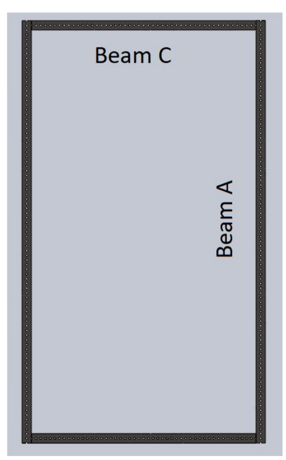


Figure 6.1.2. Back Frame of Resistance Rack

2. The top and bottom Beam C posts shall be connected to the Beam A posts using L-brackets as specified in Figure 6.1.2 below.
3. The L-bracketry will be fastened using the bolts, washer, and nut. The head of the bolt should be secured against the holes on the L-brackets. The backside of the bolt should be secured with a washer followed by a hex nut.
4. Create two frames that resemble the image in Figure 6.1.1. Flip the direction of the screws into the bracketry.

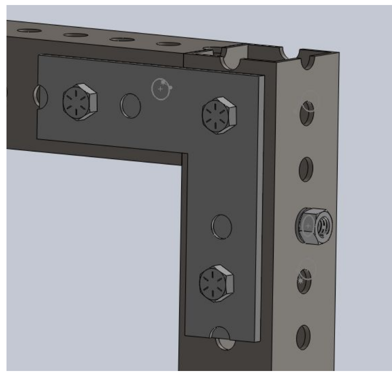


Figure 6.1.3. Rack Assembly Joint A

5. Refer to Step Six Take one of the frames assembled from Steps 1-4, and insert one Beam D post as seen in Figure 6.1.3. It is essential to place the Beam D post exactly 18'' away from the far right post. Secure the Beam D post in place by referring to Joint A in the drawing package and Figure 6.1.2.

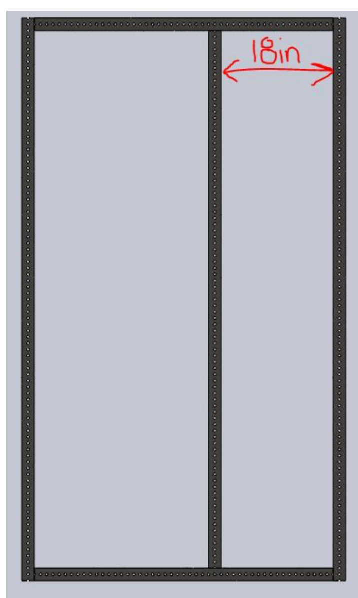


Figure 6.1.4. Inserting Beam D Post into Frame

6. In this step the two frames will be fixed together with two Beam B posts. Referring to Figure 6.1.5, rest the two frames lengthwise on a flat surface, and insert the Beam B posts (highlighted in blue). Refer to Joint D in the drawing package and Figure 6.1.6.

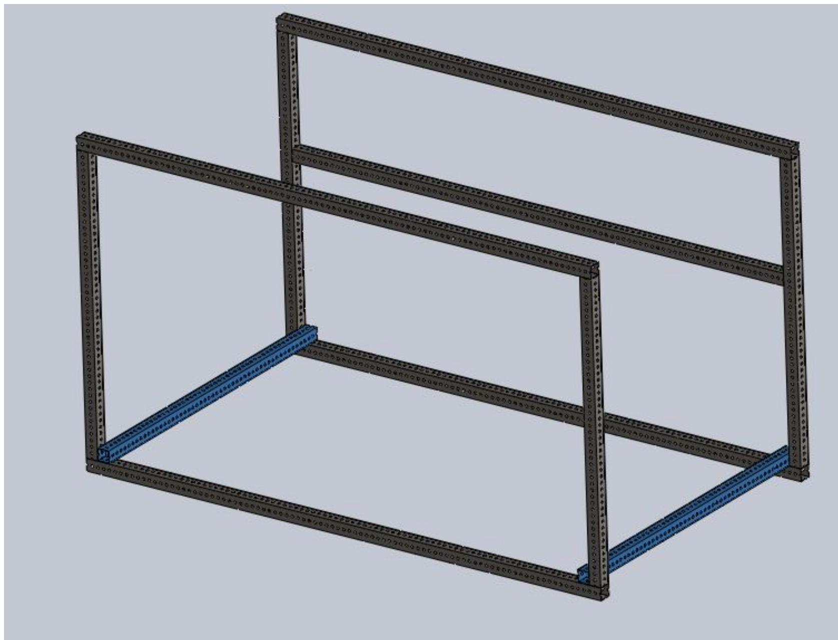


Figure 6.1.5. Connecting Two Frames Together

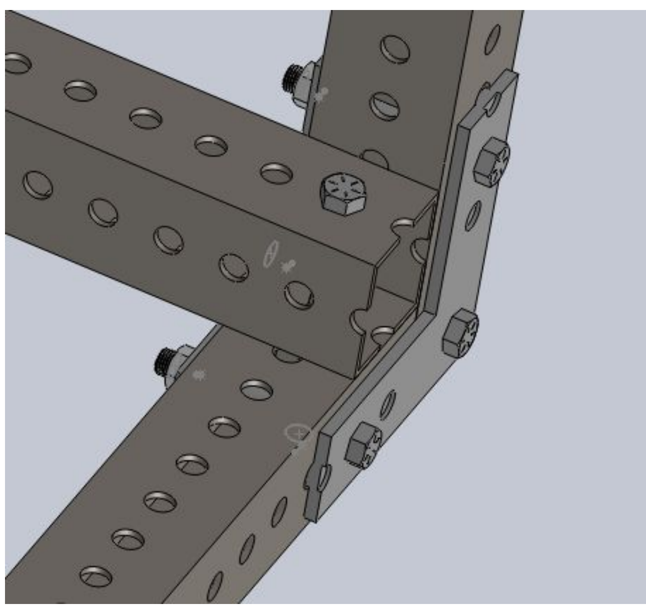


Figure 6.1.6. Rack Assembly Joint D

7. In this step we will fix one more Beam B beam to the resistance rack. Flip the assembly over as shown in Figure 6.1.7. Refer to Joint D in the drawing package and Figure 6.1.6.

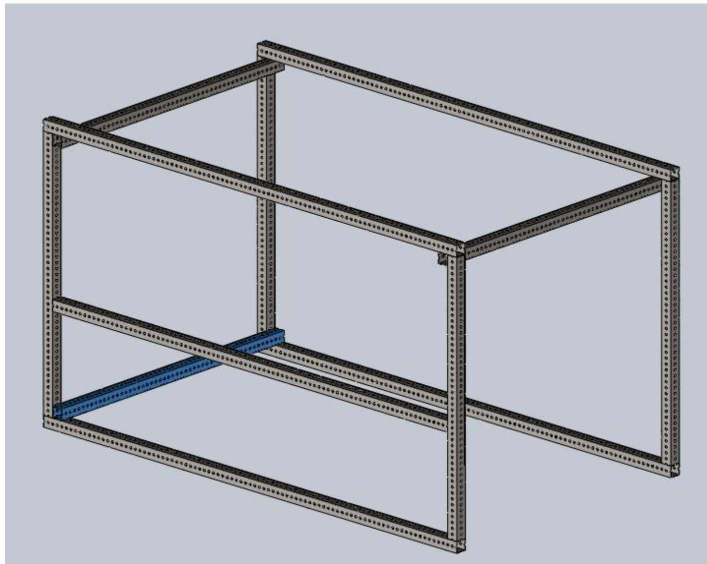


Figure 6.1.7. Assembly of Final Beam B Post to Frame

8. The last step of assembling the resistance rack is to fix two Beam B posts as shown in Figure 6.1.8. The assembler may decide how far apart the beams lay. Ensure that they are parallel to each other and perpendicular to the frame edges. Refer to Joint C in the drawing package and Figure 6.1.9.

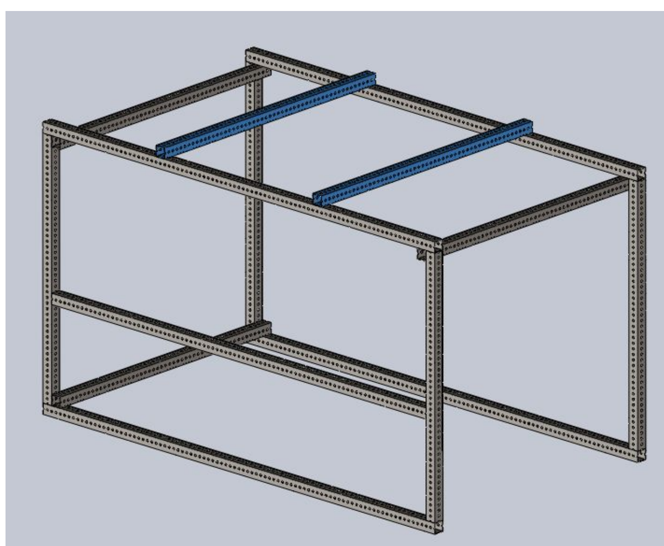


Figure 6.1.8. Assembling Ladder to Frame

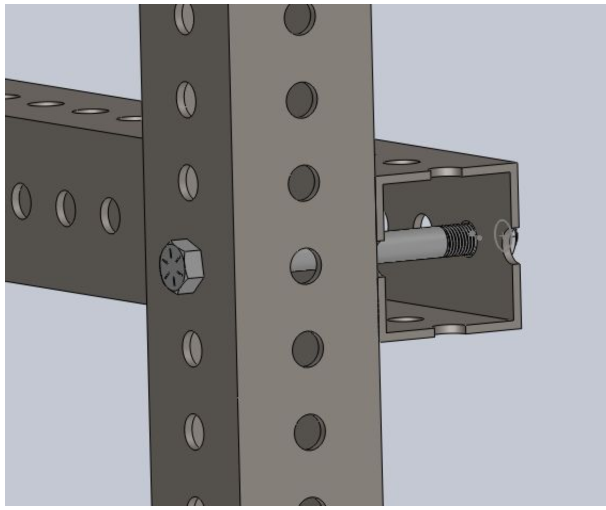


Figure 6.1.9. Rack Assembly Joint C

9. Assemble the two structures from above together so that they form the full resistance band rack seen below in Figure 6.1.5. The same process explained in Step 6 is used.

Figure 6.1.10. Completed Resistance Rack

6.2. Manufacturing Plan: Punching Bag

6.2.1. Materials Procurement:

Materials Procurement:

Table 6.2.1. Materials required for punching bag attachment

	Material	Quantity	Seller
1	18" x 2” Galvanized Steel Square Tubing	1	SLO Traffic co.
2	4” Long, 2” Wide Inside Corner Brackets	2	Lowe’s
3	Zinc-Plated Bolt, ⅜” 16 Thread Size, 3” Long, Partially Threaded Grade 5	5	Home Depot
4	Steel Hex Nut Grade 5, Zinc-Plated, ⅜” 16 Thread Size	5	Home Depot
5	Swivel Mount	1	Amazon
6	Speed Bag	1	Amazon
7	2” x 2” Rubber End Cap	1	Amazon

6.2.2. Manufacturing Process:

Reference Figure 6.2.1 below:

1. Cut the steel tube to a length of 18” using a bandsaw.
2. Line up corner brackets such that the corner is flush with one end of the square steel tubing. Use a pencil to mark the locations of two points on the bracket that coincide with two holes on the tubing.
3. Use a drill press to drill ⅜” holes in the bracket. These holes should match up with holes in the tubing when the corner of the bracket is flush with the edge of the tube.

6.2.3. Assembly Process:

1. Bolt swivel mount to perforated steel tubing through the last hole on the tube.
2. Working on the opposite end of the steel tube from the swivel, bolt an inside corner L-bracket to the top face, making sure the corner is in line with the edge of the tube.

3. Repeat Step 2 of the Assembly Process, except this time, the bracket is bolted to the bottom face of the tubing.
4. Measure about 12” from the base of the front left leg of the main frame.
5. Line up the metal tube such that the top surface is 12” from the floor.
6. Attach the whole assembly by bolting the top and bottom inside corner L-brackets to the frame.

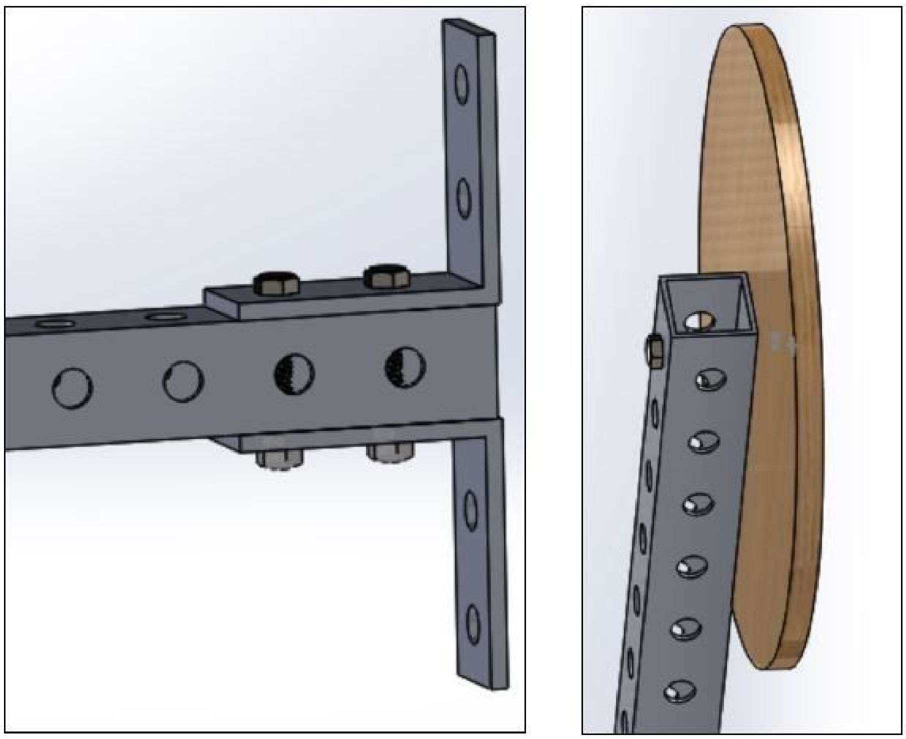


Figure 6.2.1. Model of Punching Bag and Rack Attachment Connectors.

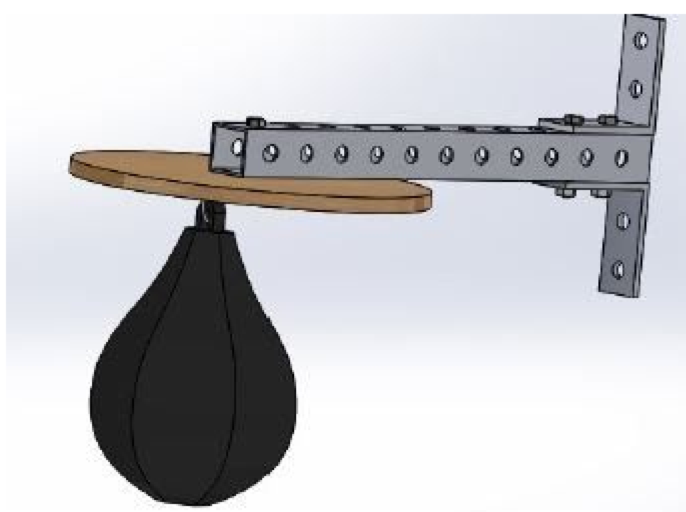


Figure 6.2.2. Final Assembly of Punching Bag Attachment.

6.3. Manufacturing Plan: Adaptive Pedaler Mount

6.3.1. Material Procurement:

Table 6.3.1 Materials Required for Adaptive Pedaler Mount Attachment

	Material	Quantity	Supplier
1	1" by 7/16" Aluminum Square Tubing 48"	1	Home Depot
2	3/8-16 Zinc plated hex bolts 2.5"	4	Home Depot
3	3/8" Zinc Plated Washers	8	McMaster-Carr
4	3/8"-16 Zinc Plated Hex Bolt 3.5"	4	McMaster-Carr
5	3/8"-16 Zinc Plated Hex Nut	8	McMaster-Carr
6	0.75 inch Two-Hole U-bracket	8	Home Depot
7	#8-32 1/2" Pan Head Screws	16	Home Depot
8	Plywood (24" x 24" x 0.5 ")	1	Home Depot
9	Pedaler	1	Facebook

6.3.2. Manufacturing Process:

1. Use a bandsaw to cut aluminum square tubing into two bars, each with a length of 22".
2. Use a table saw to cut plywood to the dimensions displayed in Figure 6.3.1.

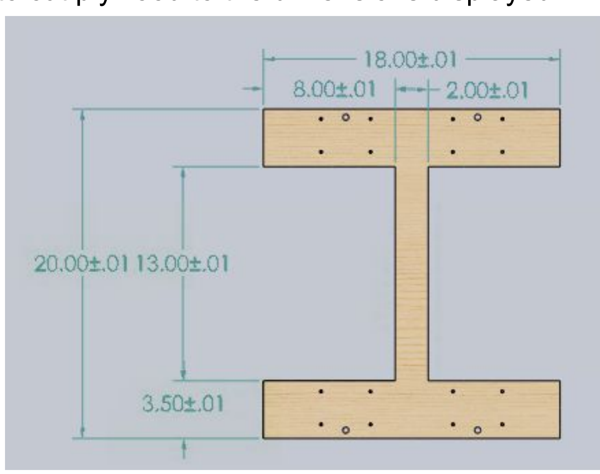


Figure 6.3.1. Wooden Platform Dimensions

3. Drill 3/8-inch holes in the aluminum tubing and wooden platform at the locations specified below in Figures 6.3.1 and Figure 6.3.2 using an endmill on the aluminum and a drill press on the wood.

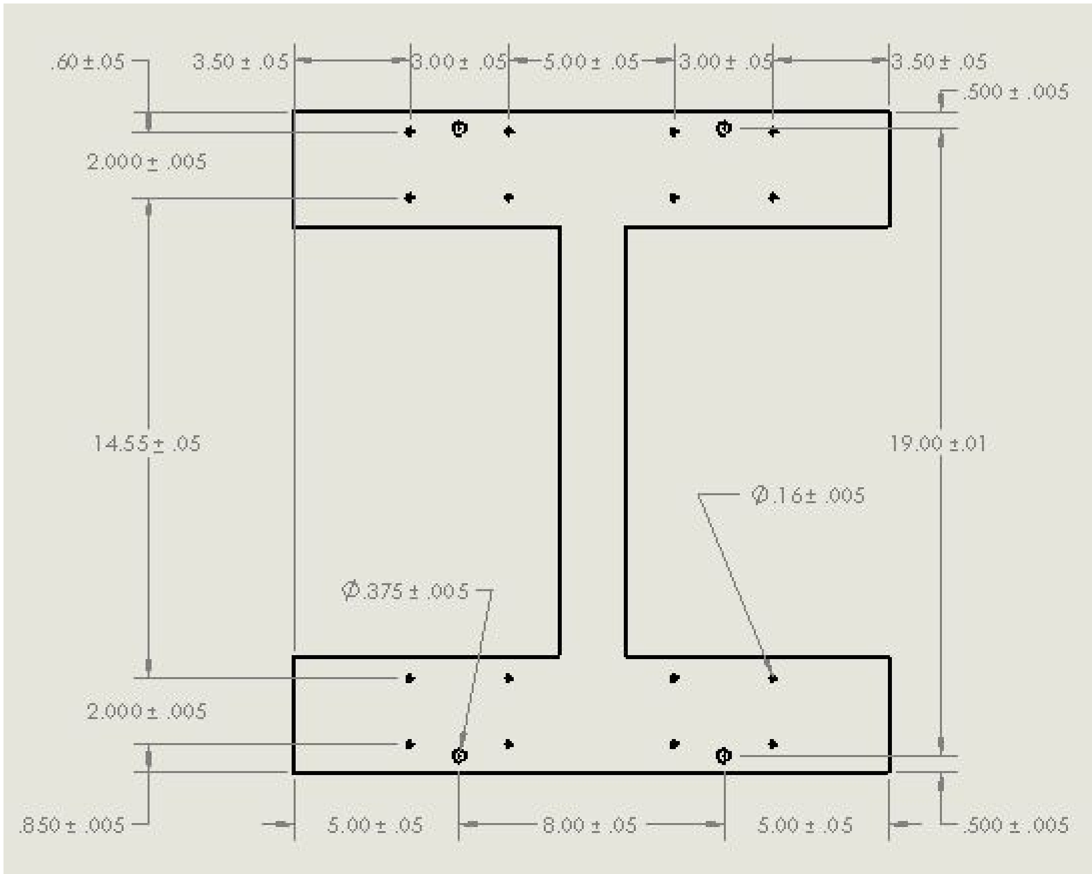


Figure 6.3.2. Hole Locations in Wooden Platform (Side View)

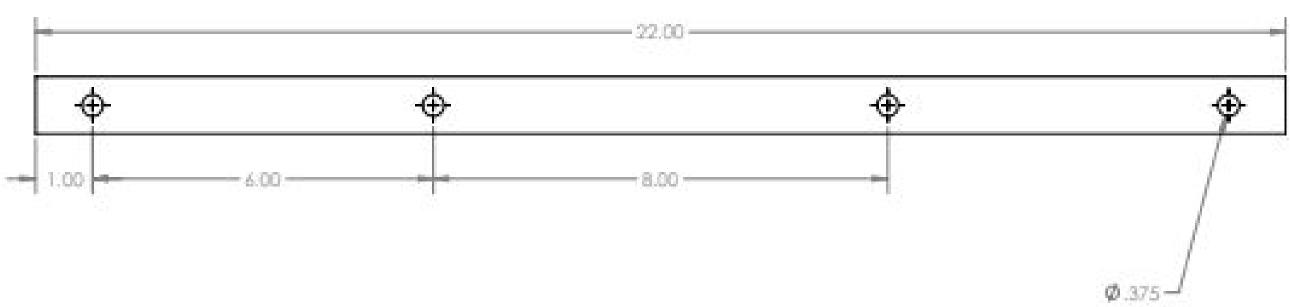


Figure 6.3.3. Hole Locations in Aluminum Tubing (Side View)

6.3.3. Assembly Process:

1. Connect the aluminum tubing to the top and bottom of the wood platform using two 2.5-inch hex bolts and washers. Fully secure the connection using a 3/8-inch hex nut on each bolt. The bolts should be secured at the two inner-most 3/8-inch holes for both the wooden platform and the aluminum tubing. Figure 6.3.4 shows how the tubing and platform should be bolted, and also which location they should be bolted together at.

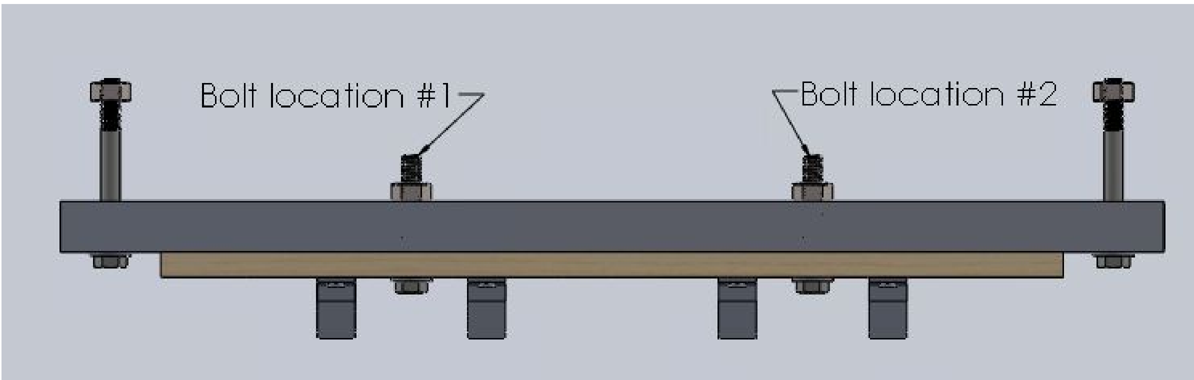


Figure 6.3.4. Aluminum Tubing Bolted to Wooden Platform (Top View)

2. Fasten the pedaler to the wooden platform by using the 0.75 inch U-brackets and power drilling them to the platform using the #8-32 1/2“ Pan Head Screws. Figure 6.3.5 shows how the brackets should be secured to the platform, and Figure 6.3.1 shows that each bracket should be screwed in at the location of each of the 0.16” diameter holes.

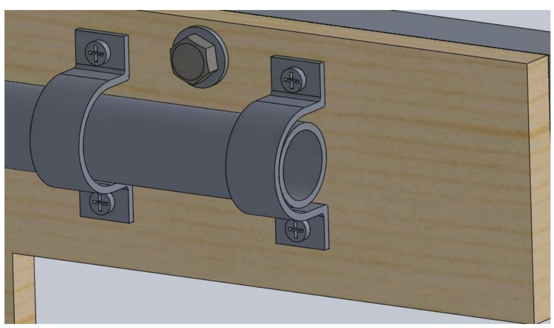


Figure 6.3.5. Bracket the Pedaler to the Platform

3. Connect the aluminum tubing to the resistance rack frame by connecting the holes at the ends of the tubing to the frame using 4-inch bolts as shown in Figure 6.3.6. The specific locations of these holes are shown in Figure 6.3.3.

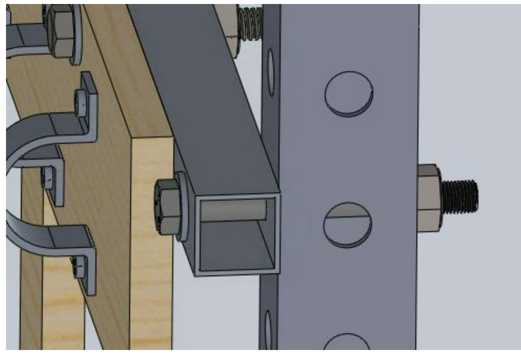


Figure 6.3.6. Aluminum Tubing on Rack Frame

6.4 Outsourcing

The perforated galvanized steel beams have been cut to length by Traffic Management Inc., a local supplier in San Luis Obispo. As mentioned in the manufacturing plan for the resistance rack, these beams need to be re-cut to their redefined lengths. All other manufacturing processes will be completed using Cal Poly's machine shops.

7.0 Design Verification Plan

7.1 Engineering Specifications Testing

We planned to conduct tests regarding the weight capacity of the beams on the main frame, how much force is required to topple the apparatus, the size of the final product, how much force is required to displace the punching bag bracket, and the life cycle of the pedaler. See Appendix H for the Design Verification and Testing Plan.

7.2 Testing Facility and Equipment Needs

We will utilize the testing labs on campus to collect numerical data to determine the life cycle of the pedaler apparatus. All other tests will not require a special testing facility. The load to be placed on the center of the horizontal beams will consist of weight plates hanging on a chain; these will be borrowed from the Athletic Department's weight room.

To test the weight capacity of the main frame, we will hang 250 lbs on the critical points of the beams to ensure that the frame can take the weight. This will back up our engineering calculations determining what loads the beams can take. To prevent toppling, we will put a 250 lb force located at the top beams to see if the frame will topple. Furthermore, the frame will be anchored to the wall when in use by the clients, adding an additional safety factor to the design. A complete testing plan can be seen in Appendix H of this report.

8.0 Project Management

Since submitting the Critical Design Review document, we have progressed significantly through the manufacturing and testing plans for our project.

However, due to the COVID-19 global pandemic, our spring quarter has been moved online. As a result, we are unable to physically manufacture and test our project. The project will be resumed by a team of students in the Fall of 2020, provided that it is safe for students to return to campus. Following are the processes we went through during Fall, Winter and Spring quarters of this senior project:

1.) **Define:** The first steps after receiving the project proposal were to conduct background research on related products, patents, and relevant information regarding our client. We visited our sponsors in Paso Robles, CA twice to speak with our main point of contact and to the athletes for whom we are designing this project for. To gain further insight into what is needed by our target community, we spoke with a Cal Poly professor with numerous years of experience designing equipment for people with disabilities. See Appendix B for the QFD, a chart to help us benchmark and prioritize our design process.

2.) **Create:** During the ideation phase, we used several methods to brainstorm ideas and came up with a multitude of individual concepts. Some of these ideas were amalgamated to form a few broad, overall designs. A combination of background research coupled with engineering intuition helped us create several solutions to our problem definition.

3.) **Evaluate:** Evaluation of our designs began with decision matrices (Appendix D) to clarify which ideas would best meet our design specifications. The decision matrices were important because they analytically and numerically categorized the designs without emotional input. Next, concept prototypes were constructed to further evaluate the feasibility of our ideas. This stage was particularly insightful as it revealed how a design might function in three dimensions. Using the preeminent concepts pushed forward by the decision matrices and the functionality and feasibility of our prototypes, a CAD model was created to show a realistic version of our chosen design. See Figure 4.6 for the concept CAD model. As of November 12, 2019, the evaluation phase of the design process is complete.

4.) **Specify:** Further design analysis and CAD was conducted to refine our ideas. A Failure Mode and Effects Analysis (FMEA) was completed to review the design and prompt ideas on how it might be improved. This is done by analyzing the ways in which the design might fail to perform its functions and how those failures might affect the users. This includes exploring potential safety risks and how those risks will be mitigated.

We have produced a Design for Manufacturing document in which preliminary materials and prototype building processes are specified. Further background research and cost analysis determined what materials needed to be purchased for the construction of a Structural Prototype. Our Structural Prototype is the final version of the pedaler attachment to the main frame. It provides further insight into the feasibility and critical functionality of the design with room for subsequent improvements.

Additionally, a detailed CAD model was created to specify dimensions and part assembly. From the CAD models, a Manufacturing Plan was produced to detail how we will build the verification prototype. This includes how and where wel purchased materials and components, a step-by-step manufacturing sequence, an assembly plan, and any outsourcing that may be required. Cal Poly shop technicians have reviewed and approved our Manufacturing Plan. See Chapter 6 for the full Manufacturing Plan.

A Design Verification Plan was created in which we assessed how our verification prototype meets all determined specifications. It includes plans to test our design and any facilities or equipment needed to do so.

5.) **Build:** Prior to the COVID-19 pandemic, we had purchased most of our materials. Unfortunately, we were unable to construct our final project due to our campus closing and school being moved online.

6.) **Test:** After assembling the final project, we would have conducted a hardware/safety demo and a test of the completed system. The project would have concluded in a final design review and the senior design project exposition where we would share our project with the public.

Due to COVID-19, we were unable to build our project and thus were unable to test it. Instead we revised our manufacturing plan for future students to take on the project. Instead of an in-person exposition in which all senior project teams would share their work, we have created a webpage detailing our final project. See Cal Poly SLO's senior project database to view this webpage.

To outline our project schedule, we created a Gantt chart which can be seen in Appendix E. Table 8.1 outlines major deliverables to be submitted to Achievement House and to Professor Self as well as the deadlines on which they are due.

Table 8.1 Timeline and Description of Major Deliverables

Major Deliverable	Description	Deadline
Preliminary Design Review (PDR)	First review of all preliminary solutions and problem statement. Deliverables are a presentation, report, and prototype. PDR will be presented to the sponsor.	11/12/2019
Failure Mode and Effects Analysis (FMEA)	Analysis of potential ways the design may fail and potential effects failures may have on users.	11/19/2019
Detailed CAD Model	CAD model of the verification prototype with specific dimensions and components	01/14/2019
Manufacturing Plan	Step-by-step process on how the third prototype will be manufactured.	01/28/2019
Design Verification Plan	Assessment of how the verification prototype meets design specifications and any changes to further improve the product.	01/28/2019
Critical Design Review (CDR)	Contains all the information needed to build design, including the manufacturing plan and design verification plan. Deliverables are a presentation, report, and prototype. CDR will be presented to the sponsor.	02/04/2020
Final Design Review (FDR)	Final project review. Includes any updates/changes made during the build stage. Deliverables are an updated manufacturing plan for future students to take on the project and a webpage detailing our work. FDR will be presented virtually to the sponsor.	06/05/2020

9.0 Conclusions

Outlined in this document is the Final Design Review for the Adaptive Exercise Equipment project proposed by Achievement House to the senior Mechanical Engineering students of Cal Poly. We began with conducting background research, clearly stating our objectives, and formulating a project management plan. Next, we brainstormed, created concept prototypes, and analyzed possible failure modes before deciding on a final design. Detailed CAD models, engineering analysis, and manufacturing feasibility ultimately became the deciding factors in our final design decisions. Following the Final Design Review, we look forward to seeing the design be manufactured by future mechanical engineering students at Cal Poly.

References

Texts/Articles/Research Reports:

1. Thomas D O'Brien, Jane Noyes, Llinos Haf Spencer, Hans-Peter Kubis, Richard P Hastings and Rhiannon Whitaker, Systematic review of physical activity and exercise interventions to improve health, fitness and well-being of children and young people who use wheelchairs, *BMJ Open Sport & Exercise Medicine*, 2016.

2. Carroll, Penelope, et al. "Enabling participation for disabled young people: study protocol." *BMC Public Health*, vol. 18, no. 1, 2018.

3. Oppewal, Alyt, Thessa I.M Hilgenkamp, Ruud Van Wijck, and Heleen M Evenhuis. "Cardiorespiratory Fitness in Individuals with Intellectual Disabilities—A Review." *Research in Developmental Disabilities* 34.10, 2013.

4. Hartman, E., J. Smith, M. Westendorp, and C. Visscher. "Development of Physical Fitness in Children with Intellectual Disabilities." *Journal of Intellectual Disability Research* 59.5 (2015): 439-49.

5. Li, P.Y, J. Shields, and R. Horowitz. "Adaptive Control of an Exercise Machine." *Proceedings of the 15th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (1993).

Past Senior Projects:

1. Oscar Andrade, Bibiana Koch, Robert Molloy, Haley Renfro, Emily Woods. “Universal Weight Machine.” Mechanical Engineering, June 2016.

2. Justin Bazant, Cullen Crackel, Anthony Franceschi. “Universal Play Frame VI.” Mechanical Engineering, December 2010.

Product Research:

1. *The Seated Whole Body Pedaler*
   https://www.ha...aAsxDEALw_wcB

2. *Folding Upper & Lower Body Cycle*
   https://www.wa...aAvc1EALw_wcB

3. *Biodex Gait Trainer 3*
   https://www.4m...aArz4EALw_wcB

4. *Sammons Preston GlideTrak*
   https://www.4m...lidetrak.html

5. *Wheelchair Workout Kit*
   https://www.th.../whwokit.html

Appendices

Appendix A - Technical Research

Name	Number	Description
Exercise apparatus for wheelchair bound persons	US5536228A	A simple, inexpensive exercise apparatus for wheelchair bound persons which allows them to exercise all upper body muscle groups while remaining in their wheelchair. A horizontal platform receives the wheelchair in a forward or rearward orientation, depending on which exercises are to be performed. The wheels of the chair are then locked, and an elastic rope with handles at each end is positioned behind one of several matched pairs of rope guides, situated on a mast, an overhead unit, or on the platform, again depending on the desired exercise.
Combination arm exercise apparatus and propulsion aid for a wheelchair	US6048292A	The invention is a combination arm exercise apparatus and propulsion aid for a wheelchair. Typically, a wheelchair user pushes a wheelchair using the triceps, pectorals, and deltoids, exercising these muscle groups extensively without exercising the opposing muscle groups: biceps, trapezius, and latissimus dorsi. The invention exercises the biceps, trapezius, and latissimus dorsi when stretched, and assists the triceps, pectorals, and deltoids in pushing the wheelchair forward as it retracts.
Wheelchair accessible weight training apparatus	US5044629A	An exercise equipment for use by people in wheelchairs has a stationary frame within which a user can readily locate their wheelchair, including attachment structure for securing the lower body of the user to the chair. A load bar is secured to the guide frame, for displacement there along by the user, in carrying out their selected exercise. The load bar is connected by its ends in load transfer relation with two sets of selectively adjustable weights. Use of a load bar in sliding relation with a guide frame diminishes the risk of loss of control of the weights.

Wheelchair aerobic exercise trainer	US5704876A	Invention includes a platform that is adapted to receive a wheelchair. A support mechanism is coupled to the platform and supports the majority of the weight of the wheelchair and a wheelchair occupant when the wheelchair is placed onto the platform. The wheelchair trainer includes a load mechanism that engages the wheels of the wheelchair and adds a variable resistance to rotation of the wheels thereby allowing the wheelchair occupant to achieve an aerobic workout.
Adapted fitness equipment	US20190254913A1	An exercise apparatus includes an adjustable frame being attachable to an assistive ambulation device. The adjustable frame includes removable handles, fitting arms located on a lower portion of the adjustable frame to receive a fitness attachment, and attachment points on located on the lower portion of the adjustable frame to couple a resistance device. The flexible tubing includes a soft sphere shaped object fastener to connect the soft sphere shaped object to the flexible tubing.

Prior Senior Projects:

Figure A.1. Universal weight machine senior project

Figure A.2. Universal play frame VI senior project

Appendix B - QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

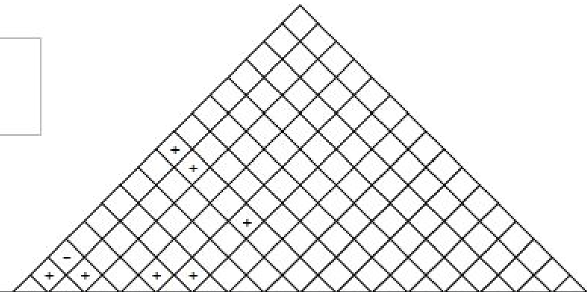
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: ADAPTIVE EXERCISE EQUIPMENT

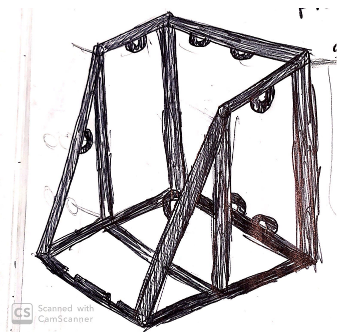
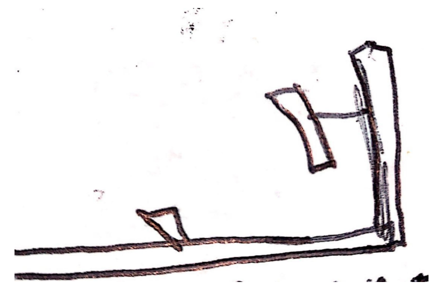
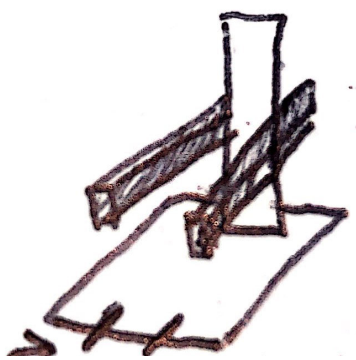
Revision Date: ______________



								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers							Direction of Improvement	▼	▼	◇	◇	▲	◇	▲	▲	◇								NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Persons in Wheelchairs	Other Disabilities	Achievement House		Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Weight of entire apparatus	Size (height, width, length)	Ease of Use	Comfort	Workout Customizability	Mechanical Components	Durability	Cost									Our Current Product	resistance bands	SciFit Hand Pedal Exerciser	VitaGlide Arm workout		Row #
1		6%	10	1	1		9	Stay in wheelchair		●		●	▽												0	5	1	5		1
2		11%	10	10	1		9	Variety of muscle groups engaged					●	▽											0	3	1	5		2
3		15%	10	10	7		9	Adjustable for different heights/sizes		●		●	●	○											0	3	4	5		3
4		17%	10	10	10		9	Safe				▽			●										0	5	5	5		4
5		10%	10	10	0		9	Adjustable weights/resistances	▽			●	●	●											0	3	4	5		5
6		2%	0	0	3		9	Fit in exercise room		●	●														0	5	5	5		6
7		0%	0	0	0		9	Inexpensive	●					○		●									0	5	1	1		7
8		6%	0	0	10		9	ADA compliant		●					▽										0	5	1	5		8
9		6%	0	0	10		3	Easily repairable/durable			○			○											0	5	2	4		9
10		7%	7	7	0		9	Muscle control/balance support/grip				●	●												0	3	4	5		10
11		3%	3	3	0		1	Sensory feedback (engaging)					▽												0	1	1	1		11
12		10%	10	10	0		9	Ergonomic/Easy to Use		▽		●	●												0	3	4	5		12
13		6%	0	0	10		9	Athlete can operate solo			●			○											0	5	5	5		13
14		0%																												14
15		0%																												15
16		0%																												16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	200 lbs	Can fit through Standard Door	Pass/Fail	n/a	>3 Muscle Groups	Pass/Fail	Life Cycle of 5 Years	$400								
	Max Relationship	9	9	9	9	9	9	9	9								
	Technical Importance Rating	10.23	271.2	94.23	451.1	487.7	185.5	156.1	0	0	0	0	0	0	0	0	0
	Relative Weight	1%	16%	6%	27%	29%	11%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Curr. Products	Our Current Product	0	0	0	0	0	0	0	0								
	resistance bands	5	5	5	5	5	5	0	5								
	SciFit Hand Pedal Exerciser	1	1	5	5	1	5	5	0								
	VitaGlide Arm workout	5	5	5	5	1	5	5	0								
	0																
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

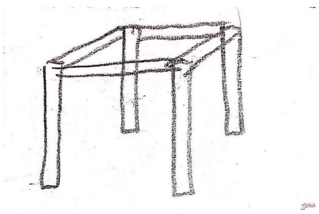
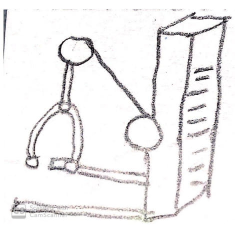
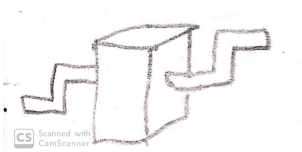
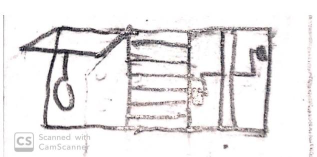
Appendix C - Idea List

Top Ideas	
 Resistance Band Structure	 Row Machine with Wheelchair Locks
 Weight Lifting Apparatus for Upperbody	 Resistance Band Wall Rack

Additional Ideas Generated

- Bungee cords
- Full body exercise
- Whack a mole
- Track with weights that roll
- Hammer
- Cycle
- Monkey bars
- Incorporating workout and games
- Wheelchair swing

Appendix D - Decision Matrix

Needs/Wants	Size	Portable	Adaptable	Low Cost	Manufacturing Simplicity	Workout Capability	Total
Weight	3	1	5	4	2	5	
 Bolted frame w/ hooks for resistance bands	1	1	5	4	5	3	68
 Bolted machine w/ weight plates and changeable grips	4	2	4	1	1	2	50
 Adjustable foot and hand pedaler	5	5	1	4	3	1	52
 Resistance band chamber w/ adjustable bike pedaler and punching bag	2	1	5	2	3	5	71

Appendix E - Gantt Charts

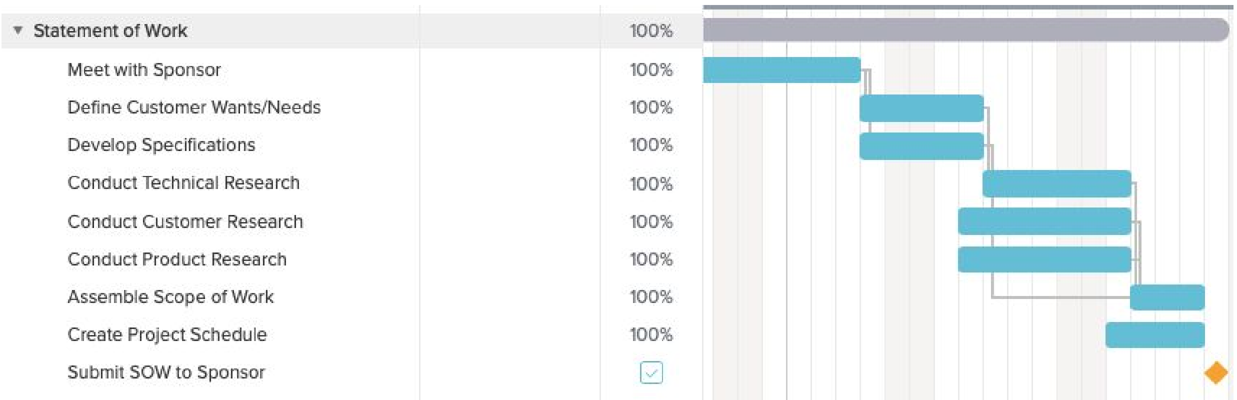


Figure E.1 Gantt chart through SOW milestone

Figure E.2 Gantt chart through PDR milestone

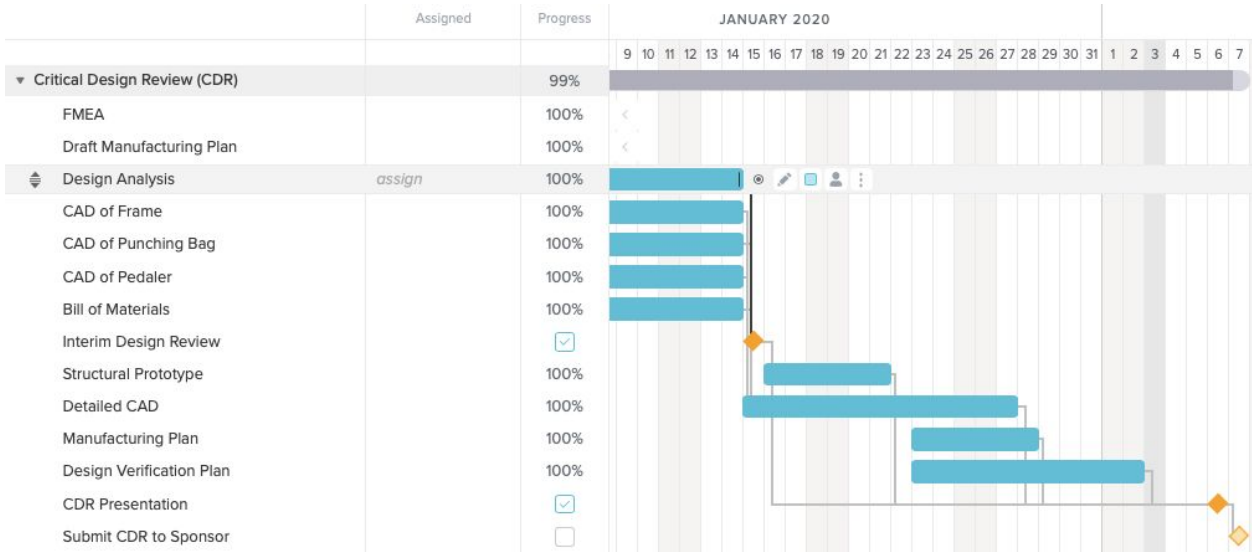


Figure E.3 Gantt Chart through CDR milestone

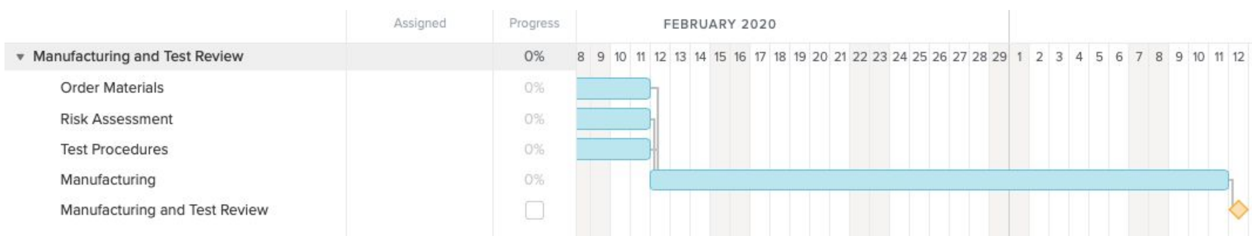


Figure E.4 Gantt chart through manufacturing and test review

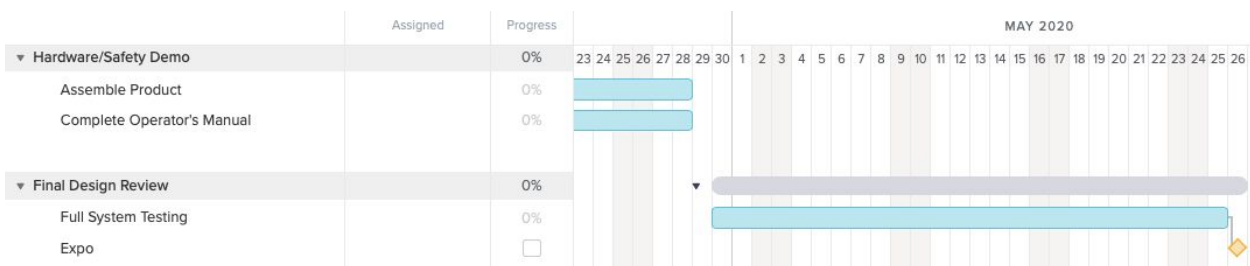


Figure E.5 Gantt chart through senior project expo

Appendix F - Design Hazard Checklist

DESIGN HAZARD CHECKLIST

Team: Adaptive Exercise Equipment Advisor: Brian Self Date: 2/03/20

Y	N	
✓	☐	1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐	✓	2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
✓	☐	3. Will any part of the design undergo high accelerations/decelerations?
☐	✓	4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐	✓	5. Could the system produce a projectile?
✓	☐	6. Could the system fall (due to gravity), creating injury?
✓	☐	7. Will a user be exposed to overhanging weights as part of the design?
✓	☐	8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐	✓	9. Will any part of the electrical systems not be grounded?
☐	✓	10. Will there be any large batteries (over 30 V)?
☐	✓	11. Will there be any exposed electrical connections in the system (over 40 V)?
☐	✓	12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐	✓	13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
✓	☐	14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐	✓	15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐	✓	16. Could the system generate high levels (>90 dBA) of noise?
☐	✓	17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
✓	☐	18. Is it possible for the system to be used in an unsafe manner?
☐	✓	19. For powered systems, is there an emergency stop button?
☐	☐	20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Corrective Actions

The punching bag will undergo high accelerations from being punched.	Punching bag will be designed to handle accelerations caused by user.	Design Complete
The punching bag and arm cycle will have adjustable heights, and have the possibility of falling due to gravity.	Both of these systems need to be designed with locking mechanisms to hold them in place. These mechanisms will need to be analyzed to ensure they can hold the weight of the system. The trainer will ensure the locking system is utilized correctly.	Design Complete
If the adjustable heights are achieved through sliding and locking mechanisms (similar to most weight systems) then the user could possibly pinch their fingers between sliding metal parts.	The trainer will need to be the one that adjusts the height of the mechanisms. We will ensure the trainer is informed on how to do this and that they understand the possibility of pinching.	No Pinch Points
Because these are exercise machines, the user will be required to exert abnormal forces. Also, because the heights of the equipment are adjustable, using systems at the incorrect height for the specific user could result in poor exercise posture and result in injury. This is a risk with all exercise equipment.	The trainer will need to ensure that the exercise equipment is set up in a way that is correct for the specific user. Also, the trainer will be the one instructing the user on which exercises to perform. Because our system is adjustable, this hazard will need to be controlled by the trainer – a trained kinesiology professional.	6/1/19
Incorrect use of any type of exercise equipment could result in injury. If the equipment is used in an unsafe manner, there is a risk of heavy objects falling on the user. Also, the user could be injured by performing exercises in improper positions.	The trainer will need to ensure that the user is utilizing proper exercise posture. The locking mechanisms should prevent the mechanisms from falling due to gravity – if they are used correctly. Correct use of the equipment falls on the trainer. We will ensure that the trainer is properly informed on the risks of the equipment, and how to use the equipment properly.	6/1/19
The hand pedaller will undergo rotational movement.	The hand pedaller is in an enclosed system and the bearings allowing rotational movement are not accessible.	Complete

Appendix G - Indented Bill of Materials

Adaptive Exercise Equipment Senior Project Indented Bill of Material (iBOM)											
Assembly Level	**Part Number**	**Description**					**Qty**	**Cost**	**Ttl Cost**	**Source**	**More Info**
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*	*Lvl4*					
0		Final Assy									
1			**Frame**								
2	1001			8'_SQUARE_TUBE			8	$35.00	$280.00	TMI	
2	1002			10'_SQUARE_TUBE			3	$45.00	$135.00	TMI	
2	1003			4931T221_FIXTURE_L			16	$8.66	$138.56	Mcmaster	
2	1004			4931T219_FIXTURE_T			4	$6.16	$24.64	Mcmaster	
2	1009			91247A636_3-8-16_3IN_HEX_BOLT			28	$0.43	$25.00	Mcmaster	
2	1005			95462A031_3-8-16_HEX_NUT			38	$0.09	$3.34	Mcmaster	
				92865A255_3-8-16_4.75IN_HEX_BOLT			10	$0.80	$8.00	Mcmaster	
				93286A045_WASHER			38	$0.53	$20.14	Mcmaster	
2				**Punching Bag Assembly**							
3	2001				Punching Bag		1	$30.00	$30.00	Target	
3	2002				Steel Plate 1/4"		2	$10.78	$21.56	Home Depot	
3	2003				Steel Round Bar, 3/8" diameter		1	$5.52	$5.52	Home Depot	
					36" x 3/4" x 1/16" Plain Steel Round Tube		1	$10.48	$10.48	Home Depot	
2				**Hand/Foot Pedaler**						------	
3	3001				18 x 20 Wood Platform		1	$20.00	$20.00	Home Depot	
3	3002				0.75 in Two-Hole Galvanized Tube Strap		8	$8.00	$8.00	Home Depot	
3	3003				Pedaler		1	$10.00	$10.00	Facebook	
	3004				91247A636_3-8-16_3IN_HEX_BOLT		4	$0.28	$1.12	Home Depot	
	3005				93286A045_WASHER		8	$3.98	$3.98	Home Depot	
	3006				3/8 - 16 2IN HEX BOLT		4	$0.39	$1.56	Home Depot	
	3007				95462A031_3-8-16_HEX_NUT		8	$3.56	$3.56	Home Depot	
	3008				1" x 48" x .0625" Square Alluminum Tube		1	$21.68	$21.68	Home Deopt	
	Total Parts						**184**		**772.1402**		

Appendix H - Design Verification/Testing Plan

Senior Project DVP&R													
Date: 02/03/2020		Team: Adaptive Exercise Equipment	Sponsor: Achievement House			Description of System: Steel rectangular prism frame with punching bag bracket and adaptive hand pedaller.					DVP&R Engineer: Journey Martinson, Kalina Burns, Jake Waleijko, Spencer Goodman		
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Weight capacity	250 lb person	All	0	5		4/30/2020	5/19/2020				
2	2	Toppling	250 lb force	All	0	4		4/30/2020	5/19/2020				
3	3	Size	90" x 52" x 52 "	All	0	1		4/30/2020	5/19/2020				
4	4	Hand pedaller fatigue analysis	10,000 cycles	All	0	50		4/30/2020	5/19/2020				
6													
7													
8													
9													
10													

Test Procedure Team Steam

Test #1: Tipping/translation with applied force

Description:

The force required to make the equipment tip or slide will be tested. The magnitude of the force will be increased steadily and the angle the force is applied at will be varied. The test will determine whether we will secure the equipment to the wall or floor.

Location: Cal Poly campus - Mustang 60

Required PPE:

- Closed toed shoes
- Long pants
- Safety Glasses

Required Materials:

- Force Gauge
- Protractor
- Eye bolt

Testing Protocol:

1. Assemble equipment entirely
2. Secure the eye bolt to the top, frontmost beam of the resistance rack
3. Connect the force gauge to “eye” of the eye bolt
4. Use the protractor to angle the force gauge at 0 degrees (parallel to floor)

5. Starting at 0 lbf, increase the tensile force applied by 10 lbf increments until the rack either translates or begins to tip
6. Record the results below
7. Decrease the angle of the force gauge by 15 degrees (should be angled downwards)
8. Repeat steps 5 and 6.
9. Continue this process until the angle of the force gauge is at 90 degrees (perpendicular to the floor)
10. Increase the magnitude of the force in 10 lbf increments until the rack begins to tip
11. Record final results below

Results:

Angle (degrees)	Type of motion to occur first (tipping/translation)	Force at which motion occurred
0		
15		
30		
45		
60		
75		
90		

Does the rack need to be secured to the wall/floor? Circle: YES NO

Test Procedure Team Steam

Test #2: Connection strength between rack and pedaler mount.

Description:
The load required to make the equipment tip or lose stability will be tested. The magnitude of the force will be increased steadily, and the deflection of the mounting platform due to stress will be measured. The test will determine the maximum load that the mount can sustain, as well as the required torque that must be applied to the bolts in order to sustain this load.

Location: Cal Poly campus - Mustang 60

Required PPE:

- Closed toed shoes
- Long pants
- Safety Glasses

Required Materials:

- Force Gauge
- Ruler
- Torque Wrench

Testing Protocol:

1. Assemble equipment entirely.
2. Secure the mount to the resistance rack.
3. Connect the force gauge at the center of mass of the pedaler.
4. Obtain the initial position of both of the mount's beams with no load applied.
5. Starting at 0 lbf, increment the applied force by 5 lbf until either beam has deflected 0.1 inches. Record results of each test below.
6. Measure the torque applied to the bolts at this point of maximum deflection using a torque wrench.

Results:

Applied Load (lbf)	Top Beam Position (in)	Bottom Beam Position (in)
0 lbf	0 in	0 in

What factor of safety is obtained from the maximum load and does it meet design criteria?

At what torque must the bolts be secured at in order to maintain this load?

Test Procedure Team Steam

Test #3: Beam deflection

Description:
Though the main frame is not meant to be swung on, a beam deflection test will be conducted to ensure that the structure will not fail if someone were to hang on it. Weights will be hung from the center of a top beam and the deflection of the beam will be measured.

Location: Cal Poly Mustang 60

Required PPE:
- Safety glasses
- Closed toed shoes
- Long pants

Required Materials:
- Mass scale
- Ruler
- Weight plate
- Chain

Testing Protocol:
1. Assemble full frame
2. Weigh the chain and weight plate
3. Hang weight plate from upper beam using the chain
4. Use ruler to measure beam deflection

Results:

Applied Load (lbf)	Deflection (in.)
0 lbf	0 in

Appendix I - Project Budget

Component	Part Identifier	Supplier	Location	Quantity
8' Square Tube	n/a	TMI	795 Buckley Rd Ste. 3, San Luis Obispo, CA 93401	8
10' Square Tube	n/a			3
L-Bracket	4931T221	McMaster	https://www.mcmaster.com/4931t221	16
T-Bracket	4931T219	McMaster	https://www.mcmaster.com/4931t219	4
3/8-16 3" Hex Bolt	91247A636	McMaster	https://www.mcmaster.com/91247a636	32
3/8-16 Hex Nut	95462A031	McMaster	https://www.mcmaster.com/95462a031	46
3/8-16 4.75" Hex Bolt	92865A255	McMaster	https://www.mcmaster.com/92865a255	14
3/8 Aluminum Washer	93286A045	McMaster	https://www.mcmaster.com/93286a045	46
Punching Bag	n/a	Target	https://www.target.com/p/everlast-platform-speed-bag-6-pc-set-black-red/-/A-10244188	1
1/4" Steel Plate	204325592	Home Depot	https://www.homedepot.com/p/Everbilt-1-4-in-x-4-in-x-12-in-Plain-Steel-Plate-800497/204325592	2
3/8" Steel Round Bar	204273959	Home Depot	https://www.homedepot.com/p/3-8-in-x-36-in-Plain-Steel-Round-Rod-802447/204273959	1
36" x 3/4" x 1/16" Plain Steel Round Tube	204225742	Home Depot	https://www.homedepot.com/p/Everbilt-36-in-x-3-4-in-x-1-16-in-Plain-Steel-Round-Tube-801237/204225742	1
0.5" x 18" x 20" Wood Platform	202093832	Home Depot	https://www.homedepot.com/p/Sanded-Plywood-Common-15-32-in-x-2-ft-x-2-ft-Actual-0-451-in-x-23-75-in-x-23-75-in-300888/202093832	1
0.75" Galvanized Tube Strap	303434704		https://www.homedepot.com/p/Oatey-3-4-in-Galvanized-Tube-Strap-2-Hole-10-Pack-33543/303434704	8

Pedaler	n/a	Facebook	n/a	1
#8 x 1/2 in. Pan Head Zinc Plated Screw	204275069	Home Depot	https://www.homedepot.com/p/Everbilt-8-x-1-2-in-Phillips-Pan-Head-Zinc-Plated-Sheet-Metal-Screw-100-Pack-801582/204275069	16
1" x 48" x .0625" Square Aluminum Tube	204273940	Home Depot	https://www.homedepot.com/p/Everbilt-1-in-x-48-in-Aluminum-Square-Tube-with-1-16-in-Thick-801307/204273940	1

Appendix J - Drawing Package

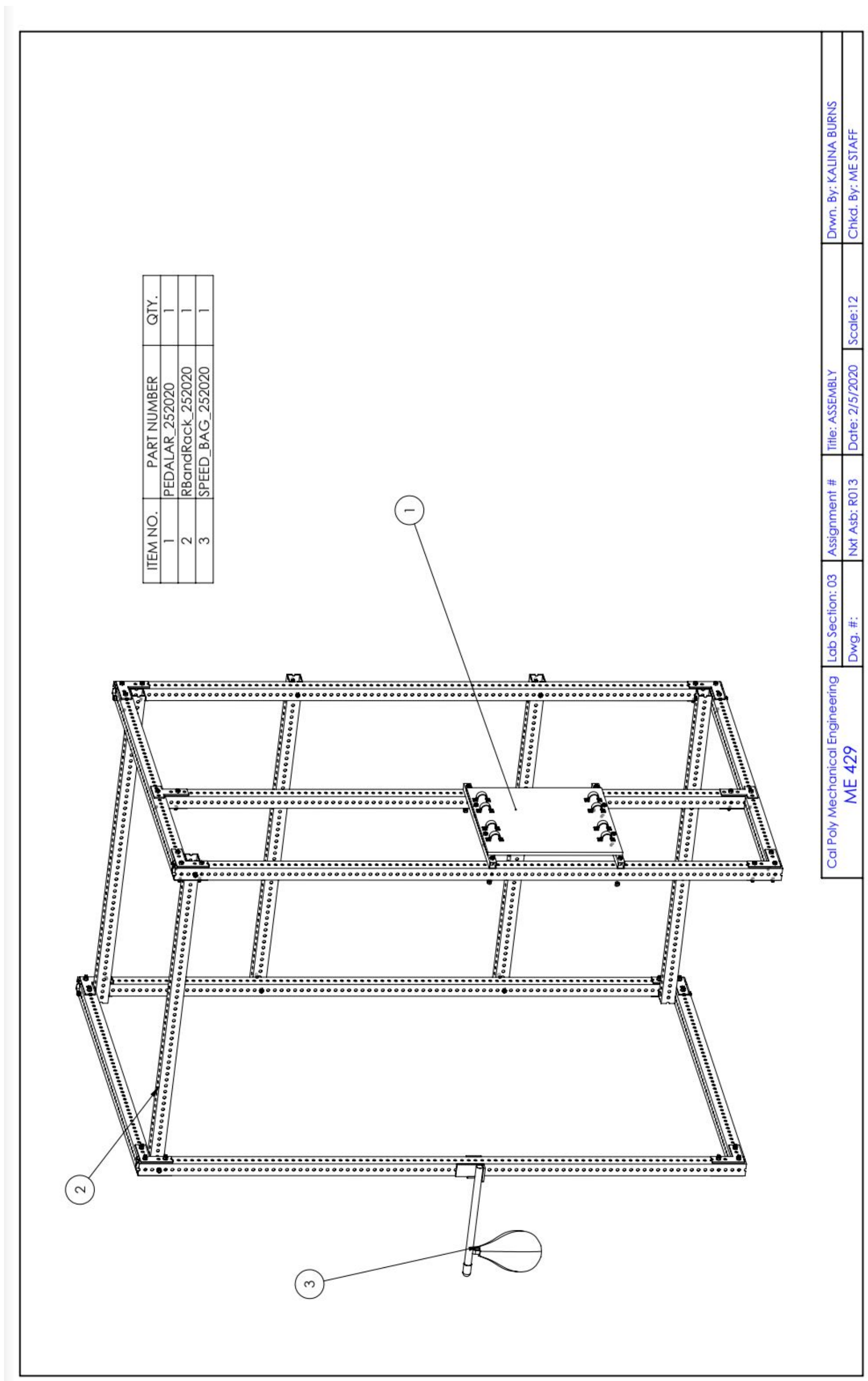
Indented Bill of Materials

Adaptive Exercise Equipment Senior Project

Indented Bill of Material (iBOM)

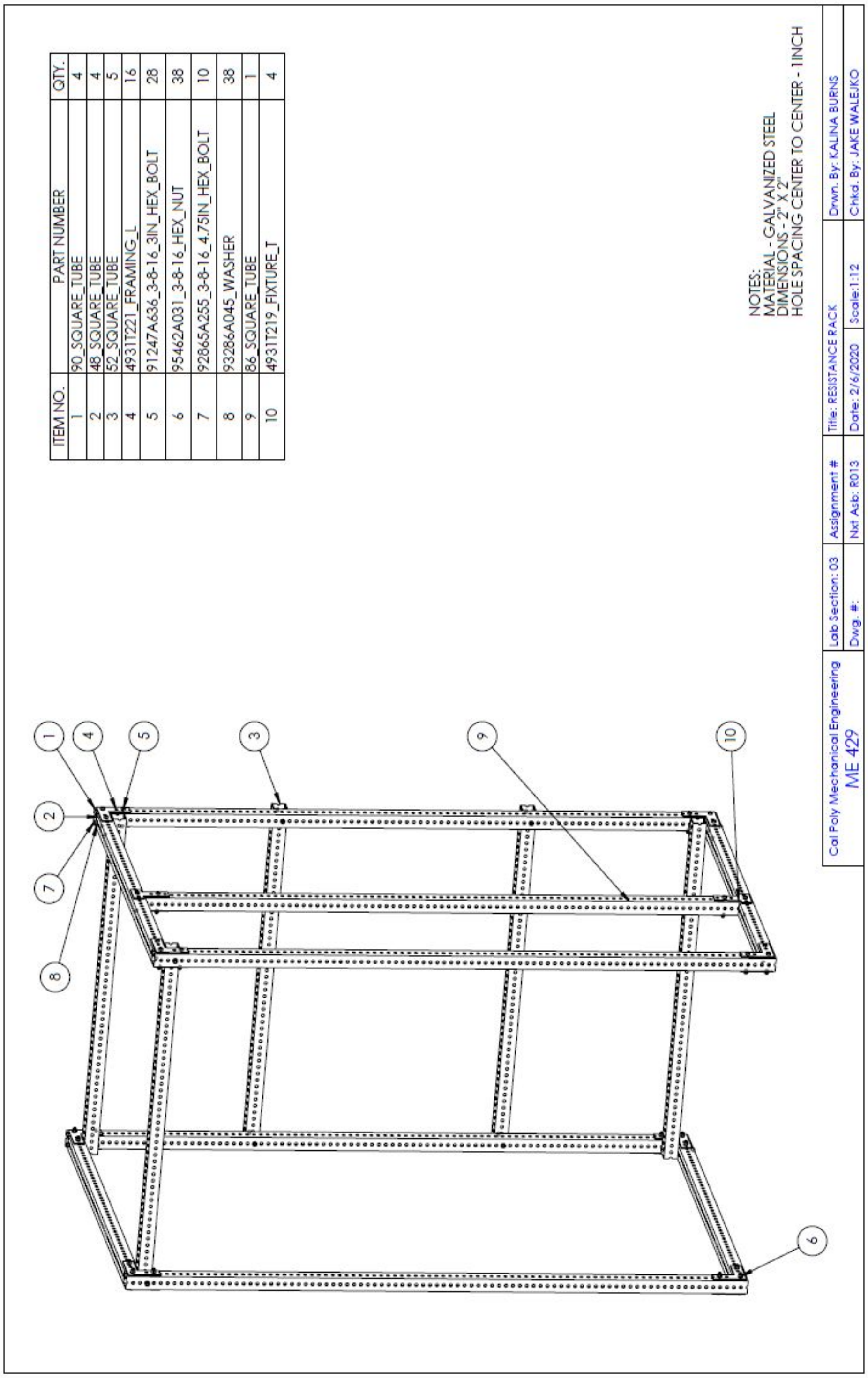
Assembly Level	Part Number	Description Lvl0	Lvl1	Lvl2	Lvl3	Lvl4	Qty	Cost	Ttl Cost	Source	More Info
0		Final Assy									
1			**Frame**								
2	1001			90"_SQUARE_TUBE			4				
2	1002			86"_SQUARE_TUBE			1				
				52"_SQUARE_TUBE			5				
				48"_SQUARE_TUBE			4				
				8'_SQUARE_TUBE			8	$35.00	$280.00		TMI
				10'_SQUARE_TUBE			3	$45.00	$135.00		TMI
2	1003			4931T221_FIXTURE_L			44	$4.00	$8.66	Mcmaster	https://www.mcmaste
2	1004			4931T219_FIXTURE_T			4	$6.16	$24.64	Mcmaster	https://www.mcmaste
2	1009			91247A231_3IN_HEX_BOLT			28	$25.00	$25.00	Mcmaster	https://www.mcmaste
2	1005			95462A515_HEX_NUT			38	$8.00	$8.00	Mcmaster	https://www.mcmaste
				91247A237_4.5IN_HEX_BOLT			10	$10.00	$10.00		https://www.mcmaste
				93286A045_WASHER			38	$21.10	$21.10		https://www.mcmaste
2				**Punching Bag Assembly**							
3	2001				Punching Bag		1	$30.00	$30.00	Target	https://www.target.co
3	2002				Steel Plate 1/4"		2	$10.78	$21.56	Home Depot	https://www.homedep
3	2003				Steel Round Bar, 3/8" diameter		1	$5.52	$5.52	Home Depot	
					36" x 3/4" x 1/16" Plain Steel Round Tube		1	$10.48	$10.48	Home Depot	https://www.homedep
2				**Hand/Foot Pedaler**					$0.00	------	
3	3001				18 x 20 Wood Platform		1	$20.00	$20.00	Home Depot	
3	3002				1 inch Two-Hole U-bracket		30	$8.00	$8.00	Home Depot	
3	3003				Pedaler		1	$10.00	$10.00	Facebook	
	3004				3/8-16 Zinc plated hex bolts 3"		12	$0.28	$3.36	Bolt Depot	
	3005				3/8" Zinc Plated Washers		16	$3.98	$63.68	Home Depot	
	3006				3/8"-16 Zinc Plated Hex Bolt 4"		4	$0.39	$1.56	Bolt Depot	
	3007				3/8" - 16 Zinc Plated Hex Nuts		16	$3.56	$56.96	Home Depot	
	3008				1" x 48" x .0625" Square Alluminum Tube		1	$21.68	$21.68	Home Deopt	
	Total Parts						**272**		**765.2**		

Total Assembly

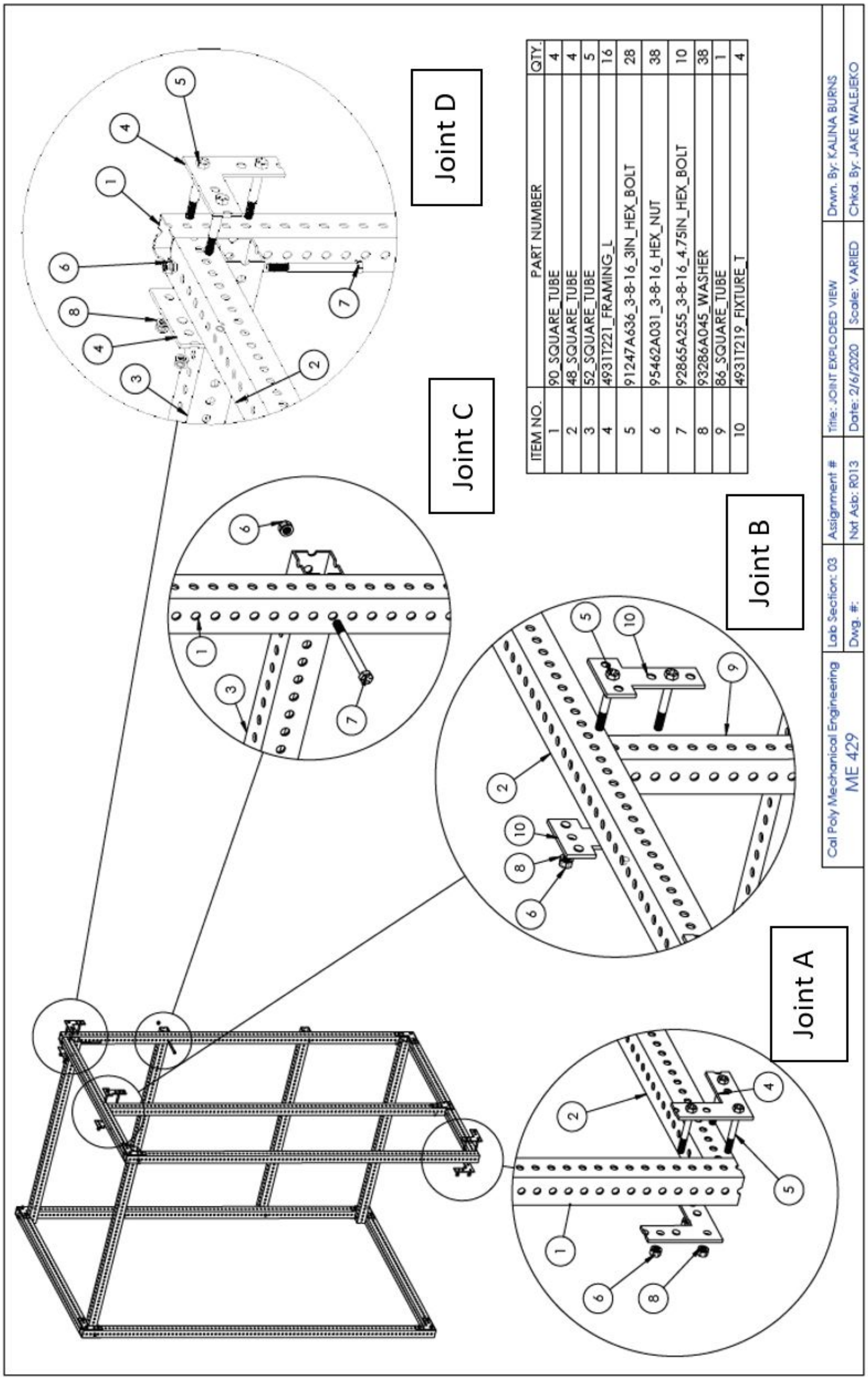


Resistance Band Rack

Assembly Drawing:

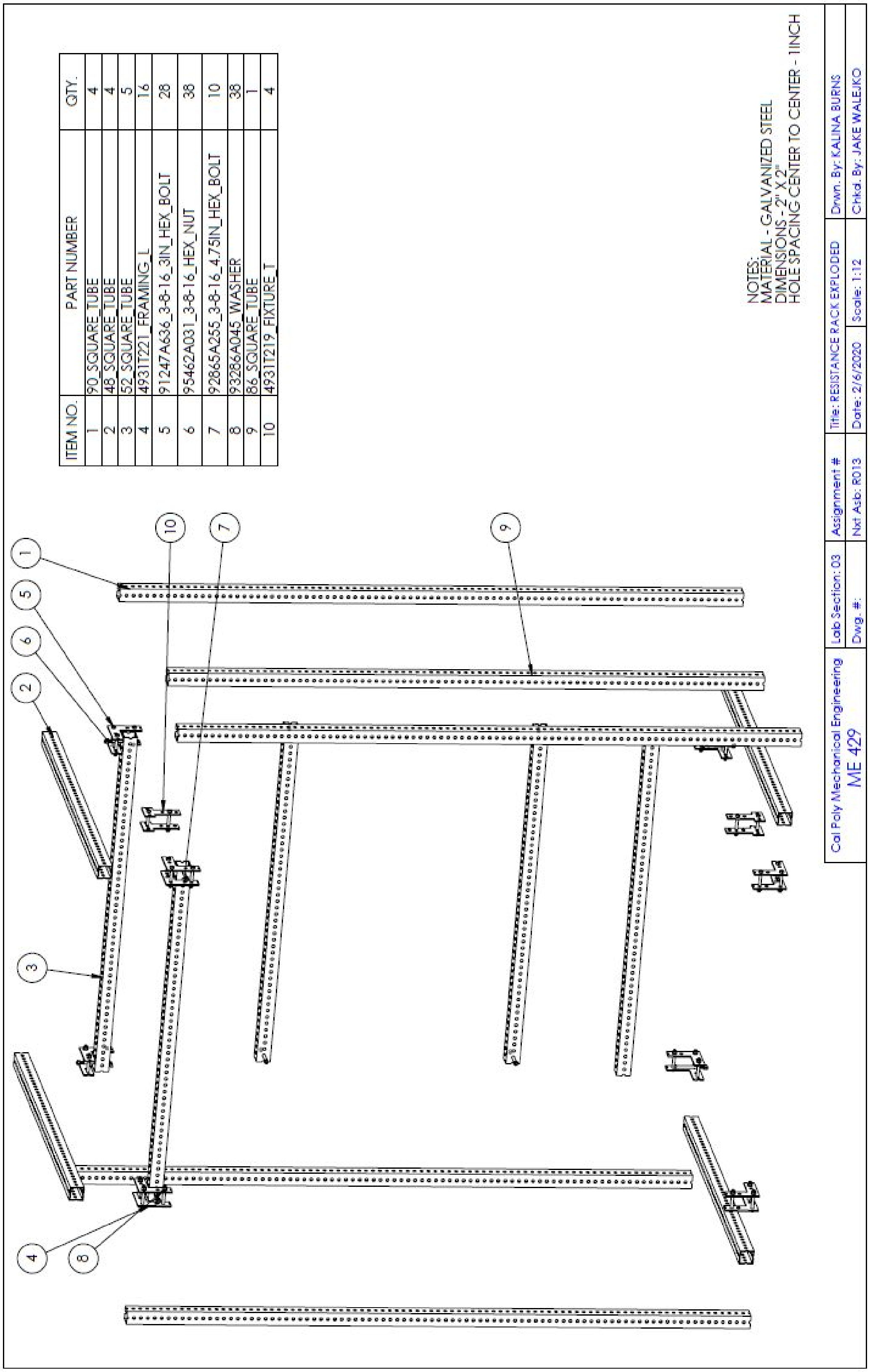


Exploded Assembly Drawing

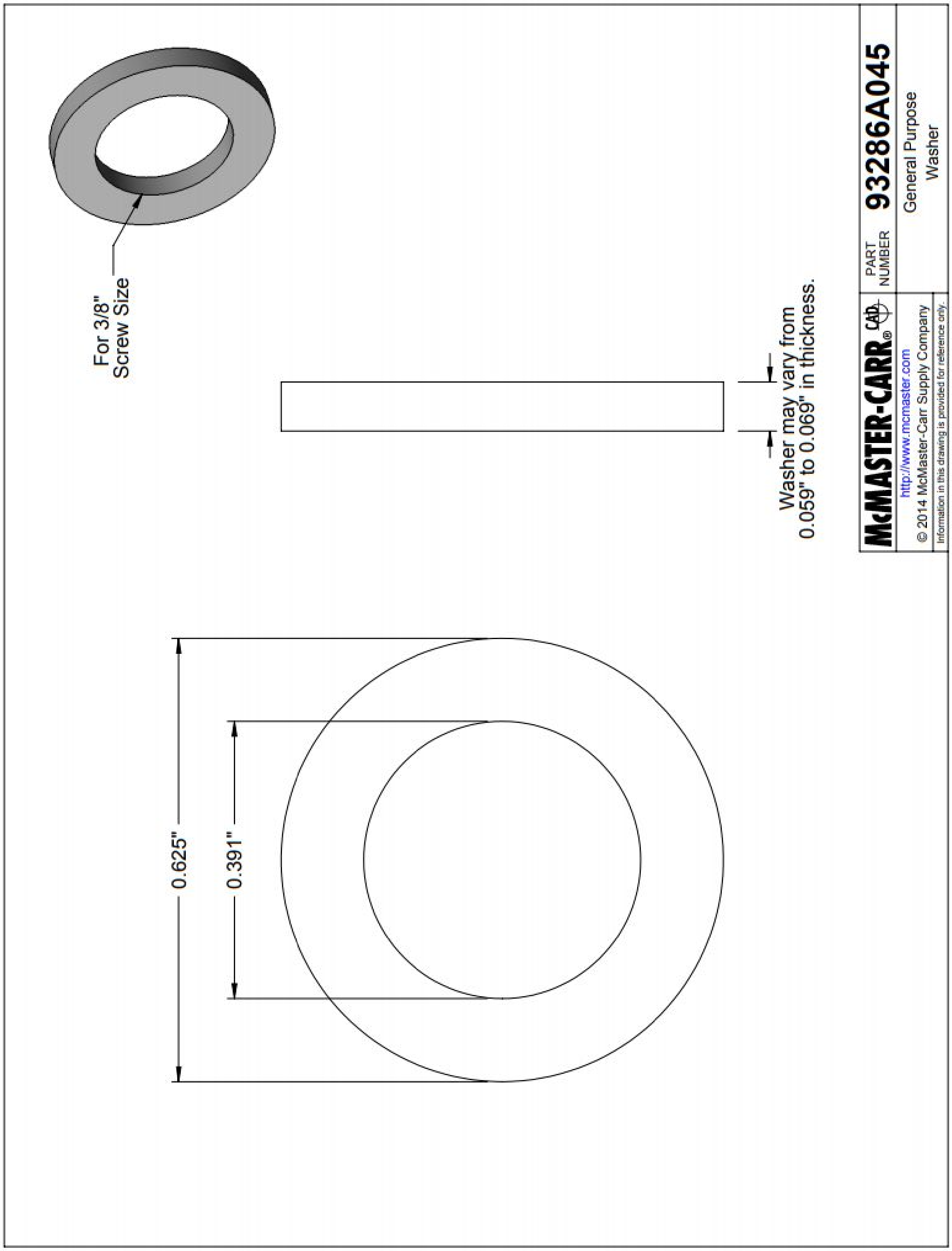


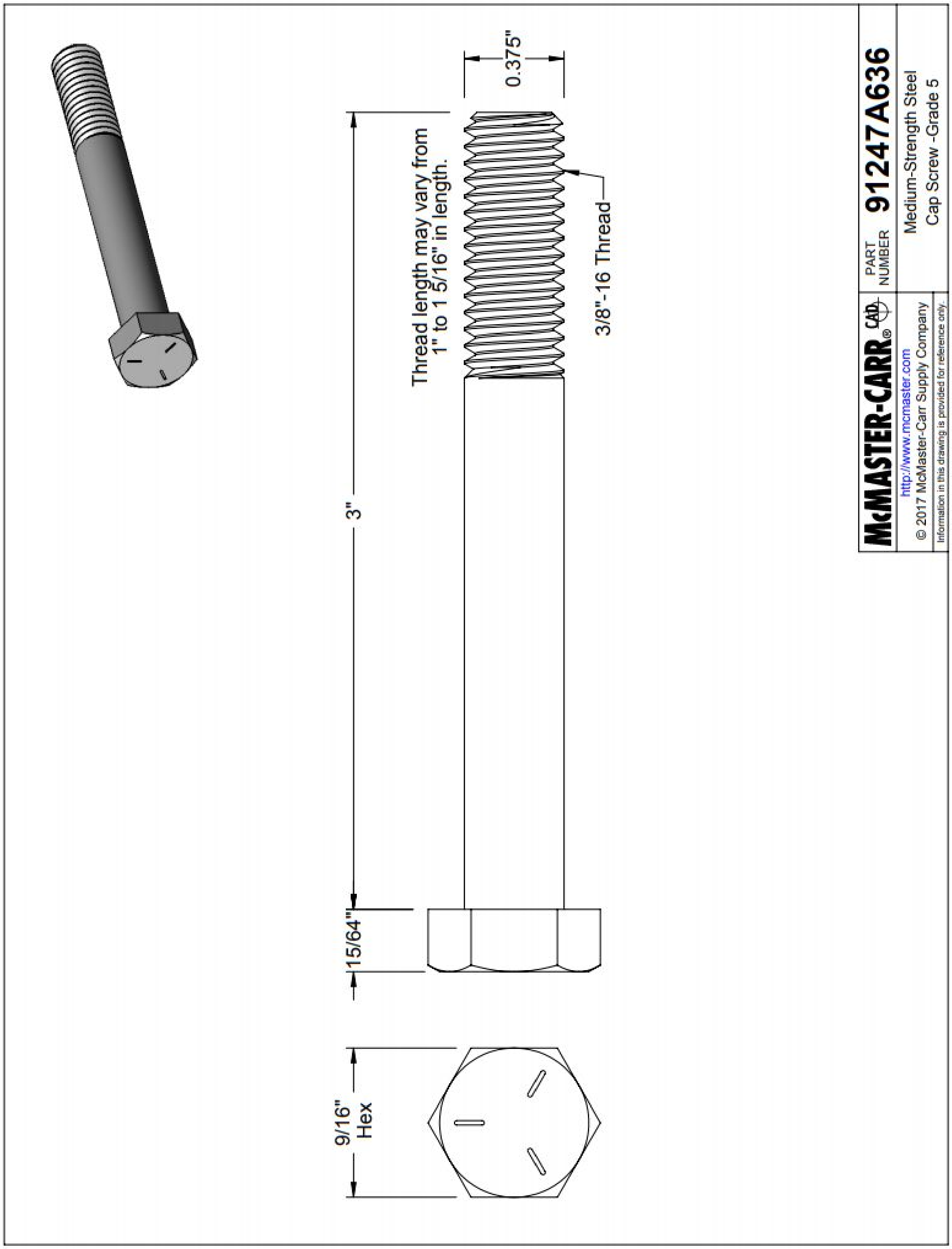
ITEM NO.	PART NUMBER	QTY.
1	90_SQUARE_TUBE	4
2	48_SQUARE_TUBE	4
3	52_SQUARE_TUBE	5
4	4931T221_FRAMING_L	16
5	91247A636_3-8-16_3IN_HEX_BOLT	28
6	95462A031_3-8-16_HEX_NUT	38
7	92865A255_3-8-16_4.75IN_HEX_BOLT	10
8	93286A045_WASHER	38
9	86_SQUARE_TUBE	1
10	4931T219_FIXTURE_T	4

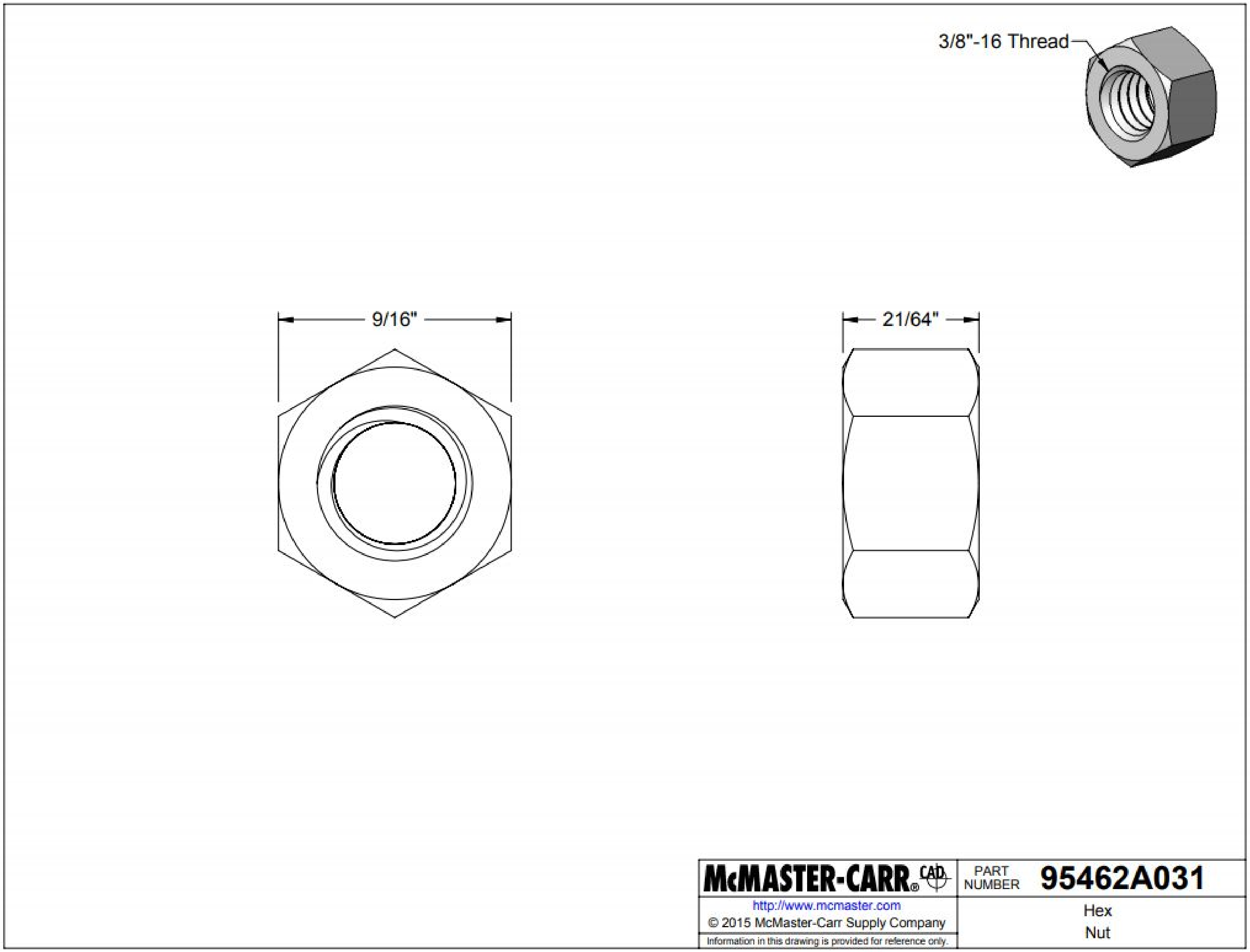
Exploded Assembly Drawing:

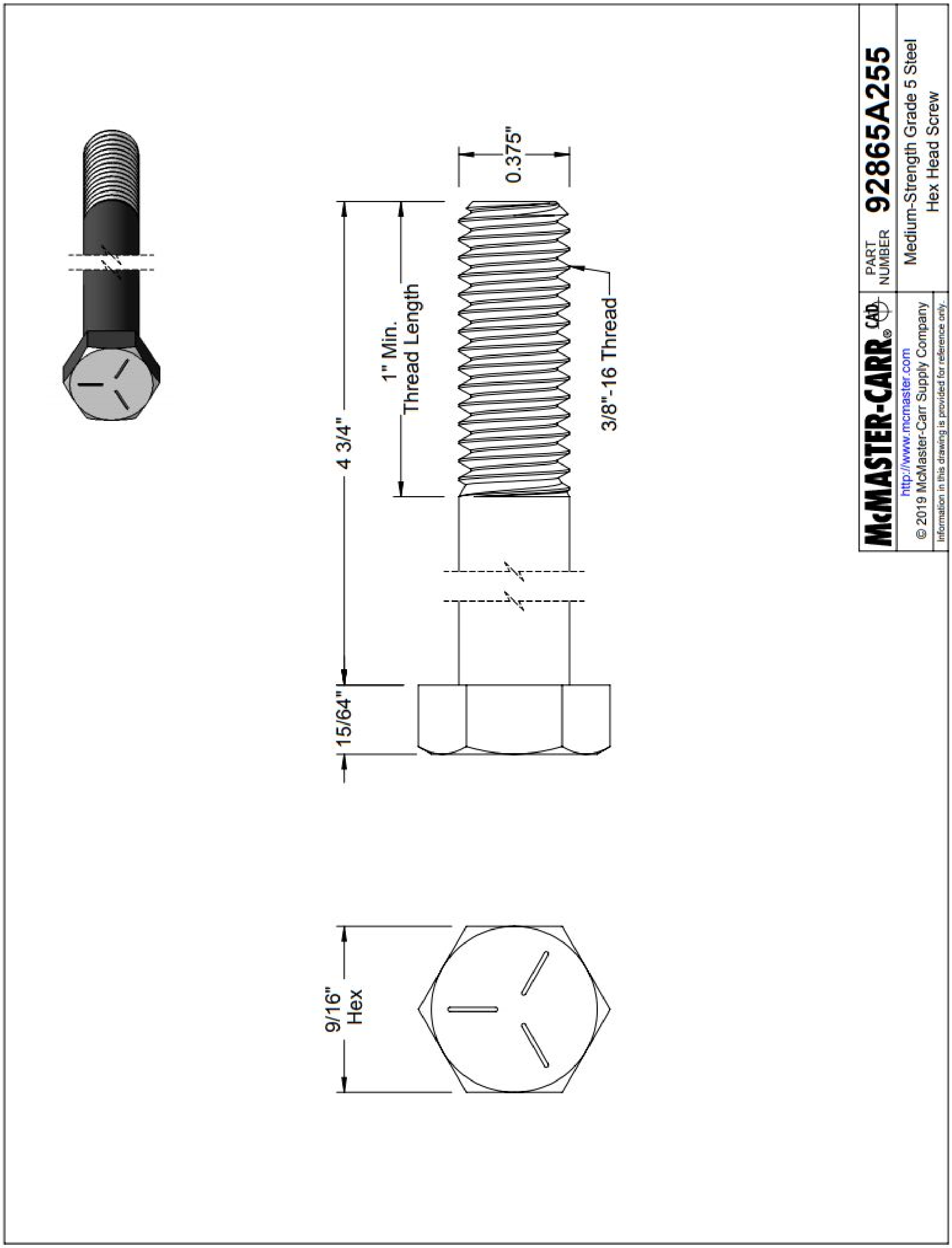


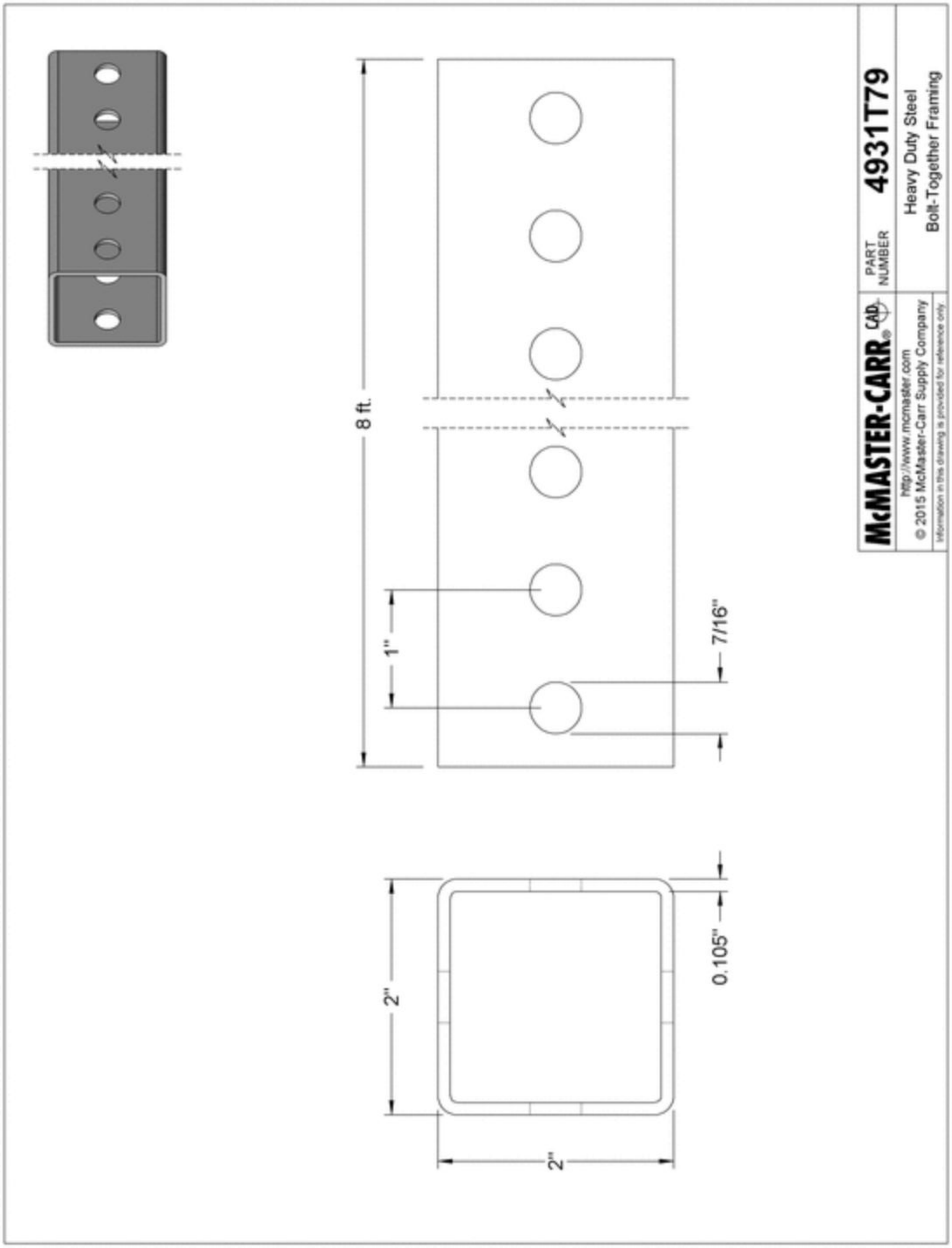
Detailed Part Drawings



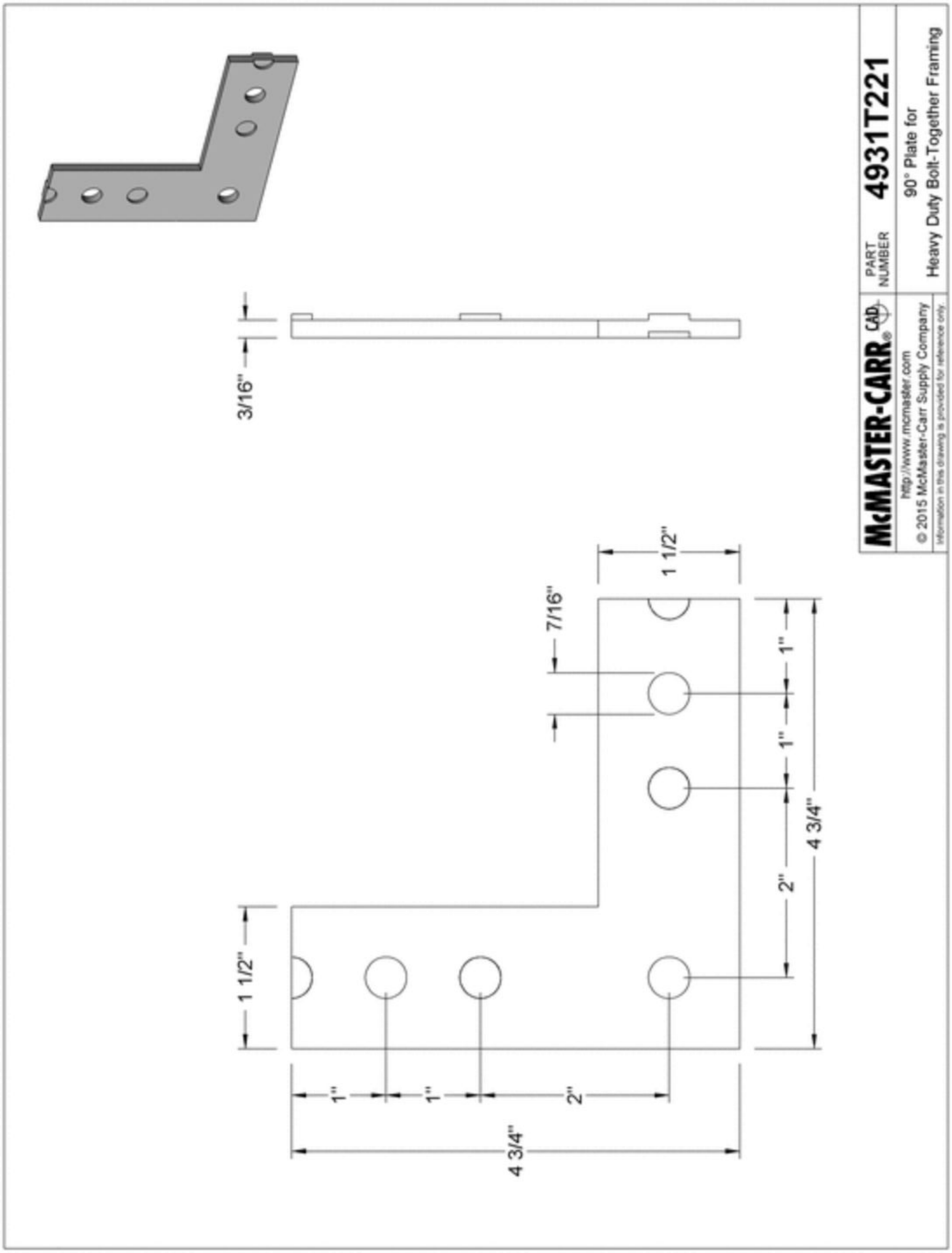

0.375"
Thread length may vary from
1" to 1 5/16" in length.
3/8"-16 Thread
3"
15/64"
9/16"
Hex
McMASTER-CARR
CAD
PART NUMBER
91247A636
http://www.mcmaster.com
© 2017 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Medium-Strength Steel
Cap Screw -Grade 5


3/8"-16 Thread
9/16"
21/64"
McMASTER-CARR
PART NUMBER
95462A031
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Hex
Nut


0.375"
4 3/4"
1" Min.
Thread Length
3/8"-16 Thread
15/64"
9/16"
Hex
McMASTER-CARR®
CAD
PART NUMBER
92865A255
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Medium-Strength Grade 5 Steel
Hex Head Screw


8 ft.
1"
7/16"
2"
2"
0.105"
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
4931T79
Heavy Duty Steel
Bolt-Together Framing

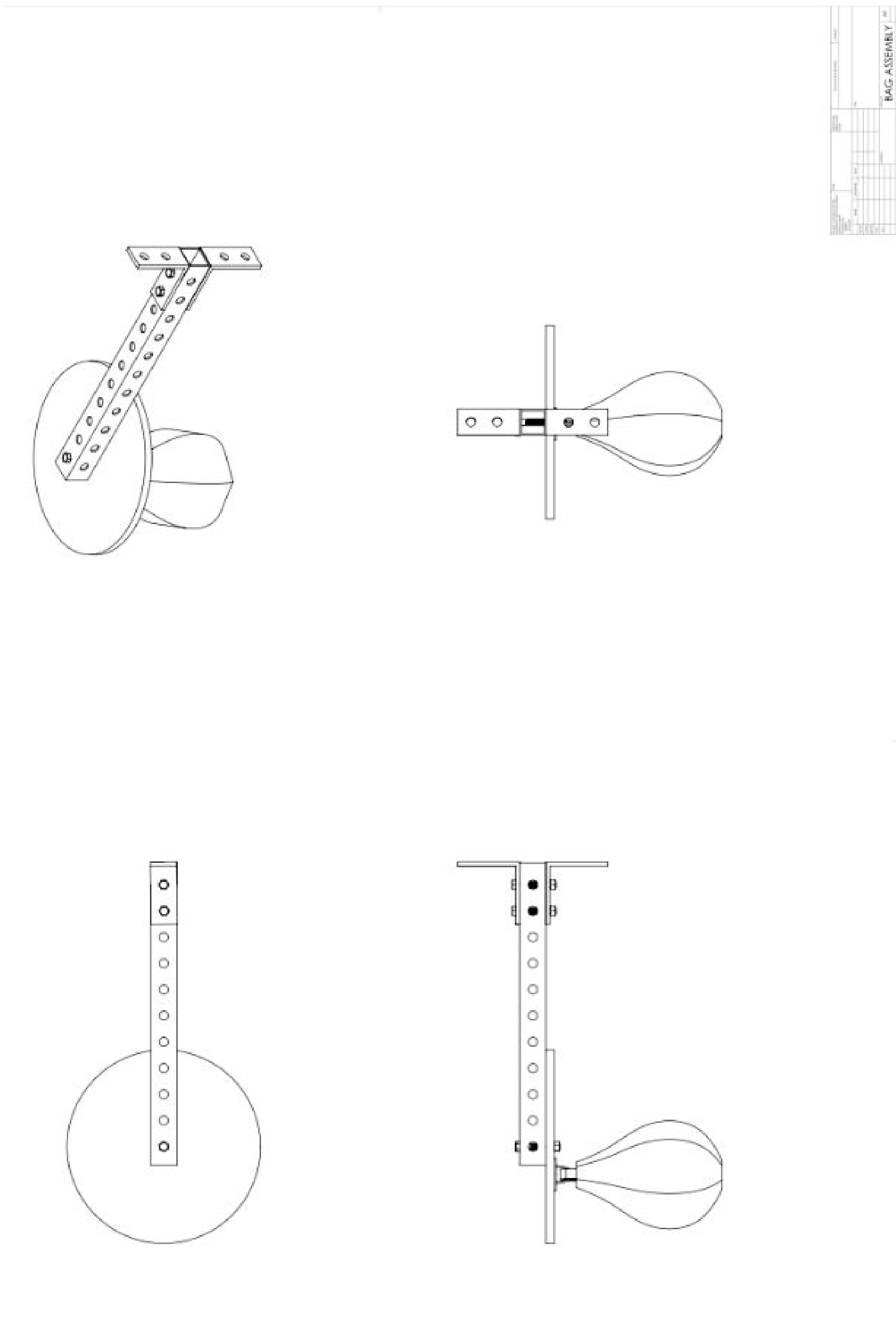
:



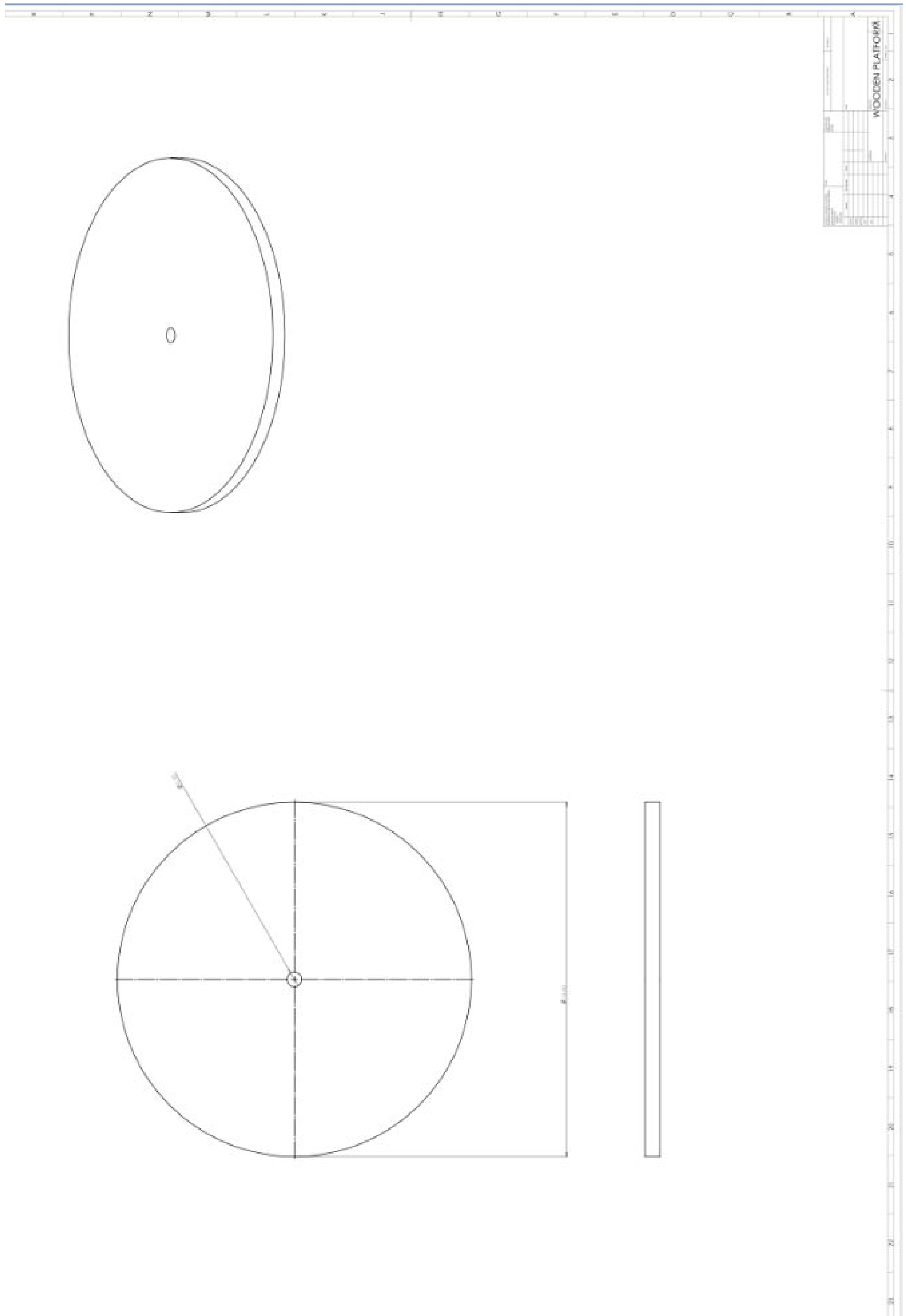
McMASTER-CARR® CAD
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
4931T221
90° Plate for
Heavy Duty Bolt-Together Framing
3/16"
7/16"
1 1/2"
1"
1"
2"
4 3/4"
1 1/2"
1"
1"
2"
4 3/4"

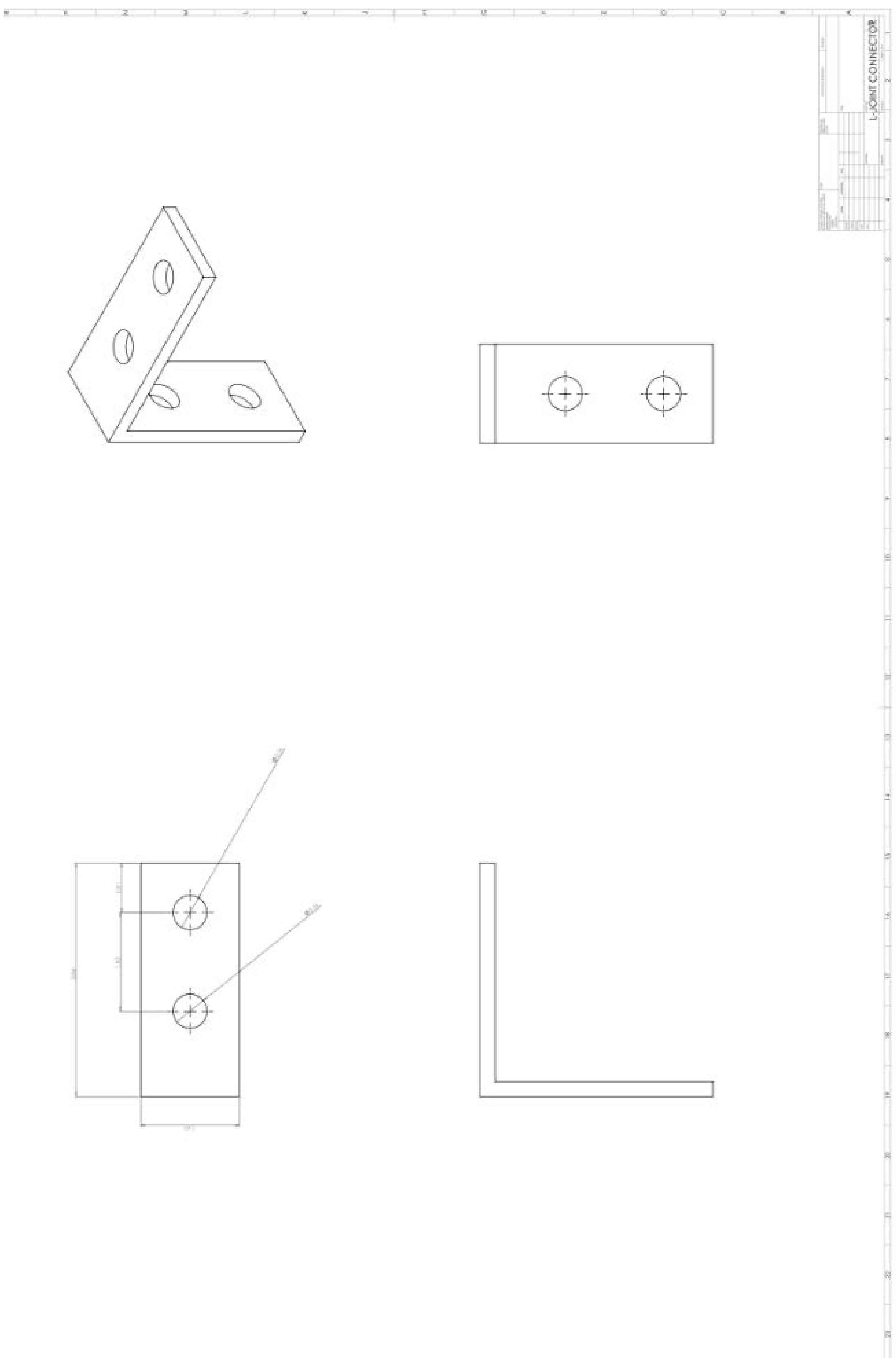
Punching Bag

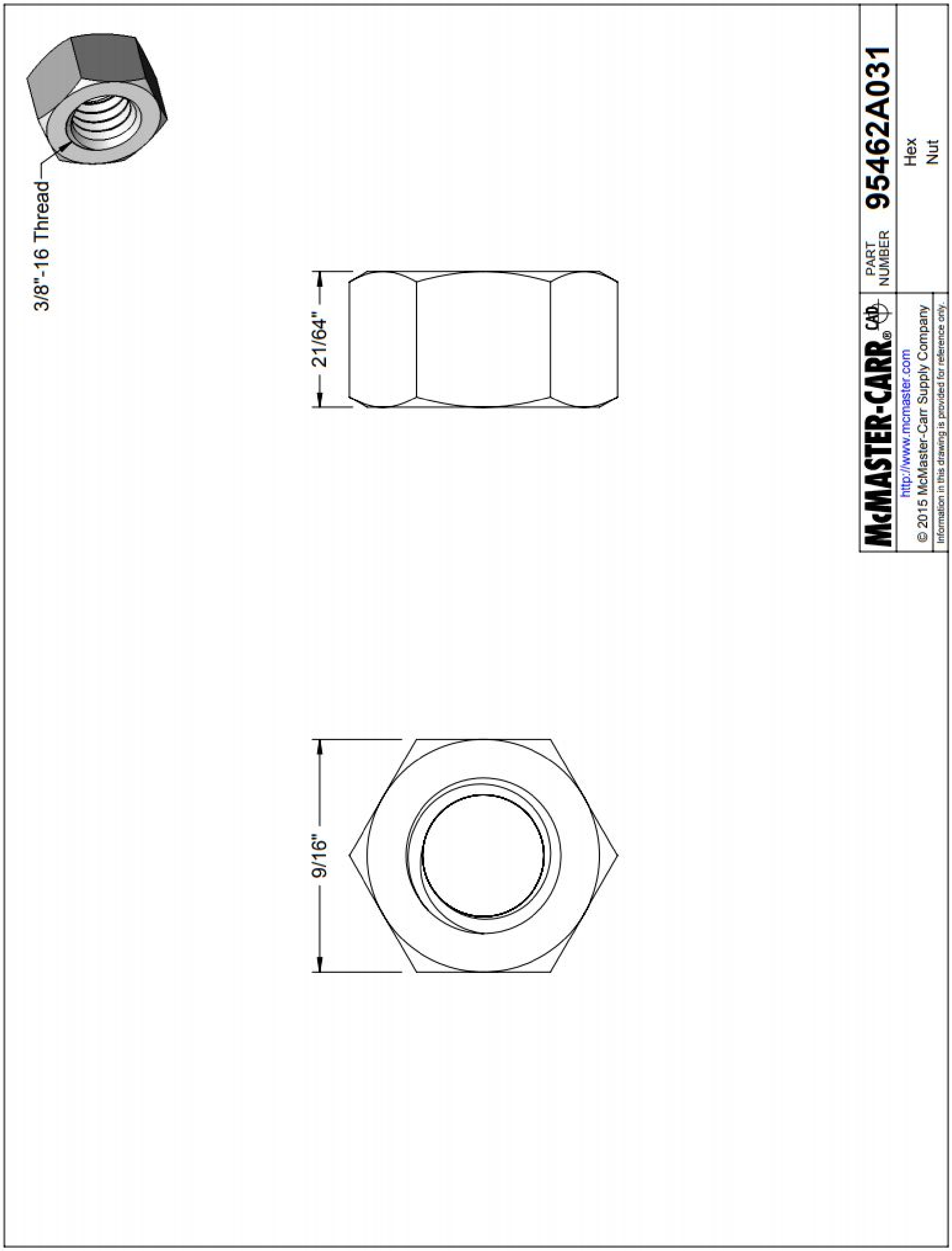
Assembly Drawing:

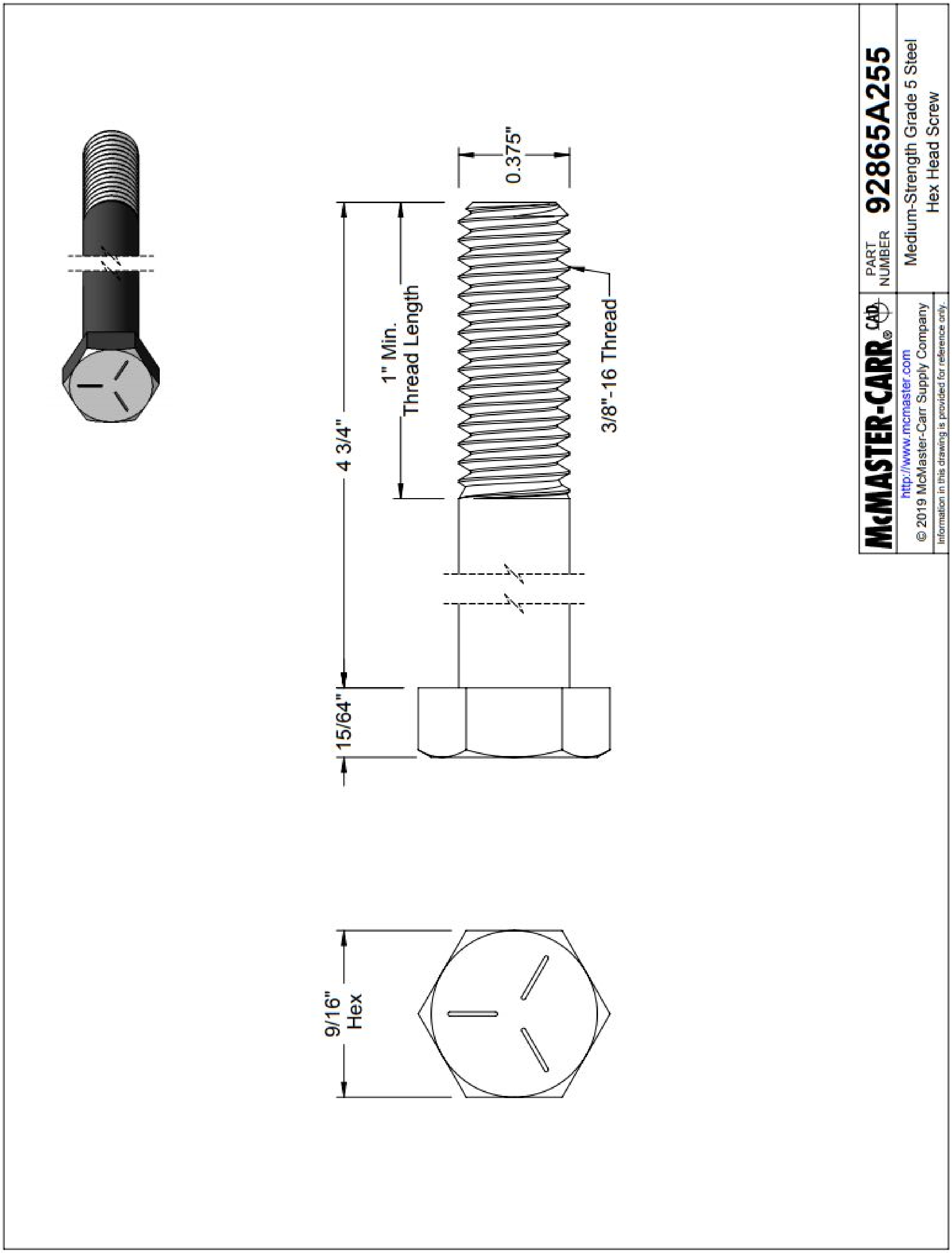


Detailed Part Drawings:



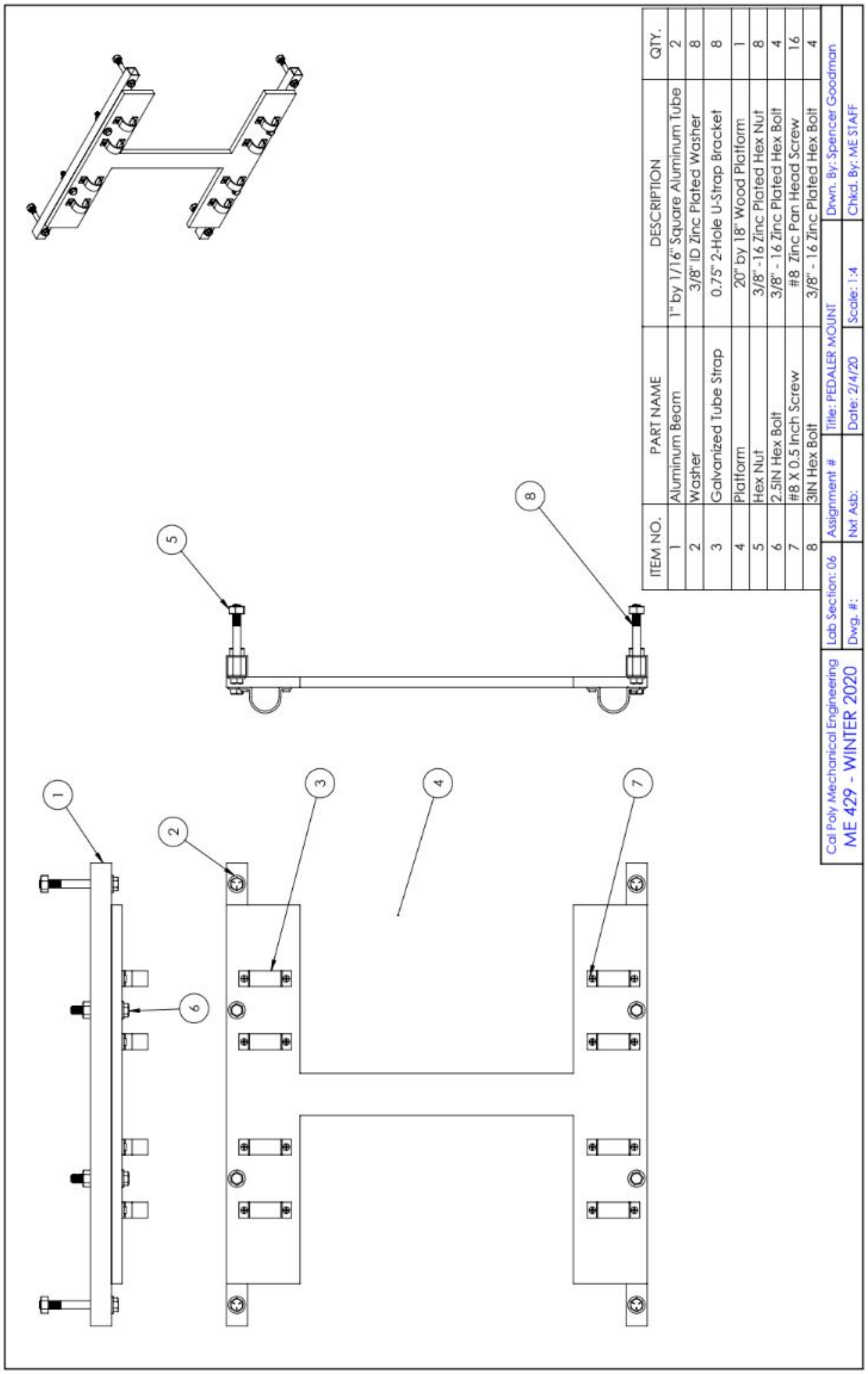

L-JOINT CONNECTOR


3/8"-16 Thread
21/64"
9/16"
McMASTER-CARR CAD
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
95462A031
Hex
Nut

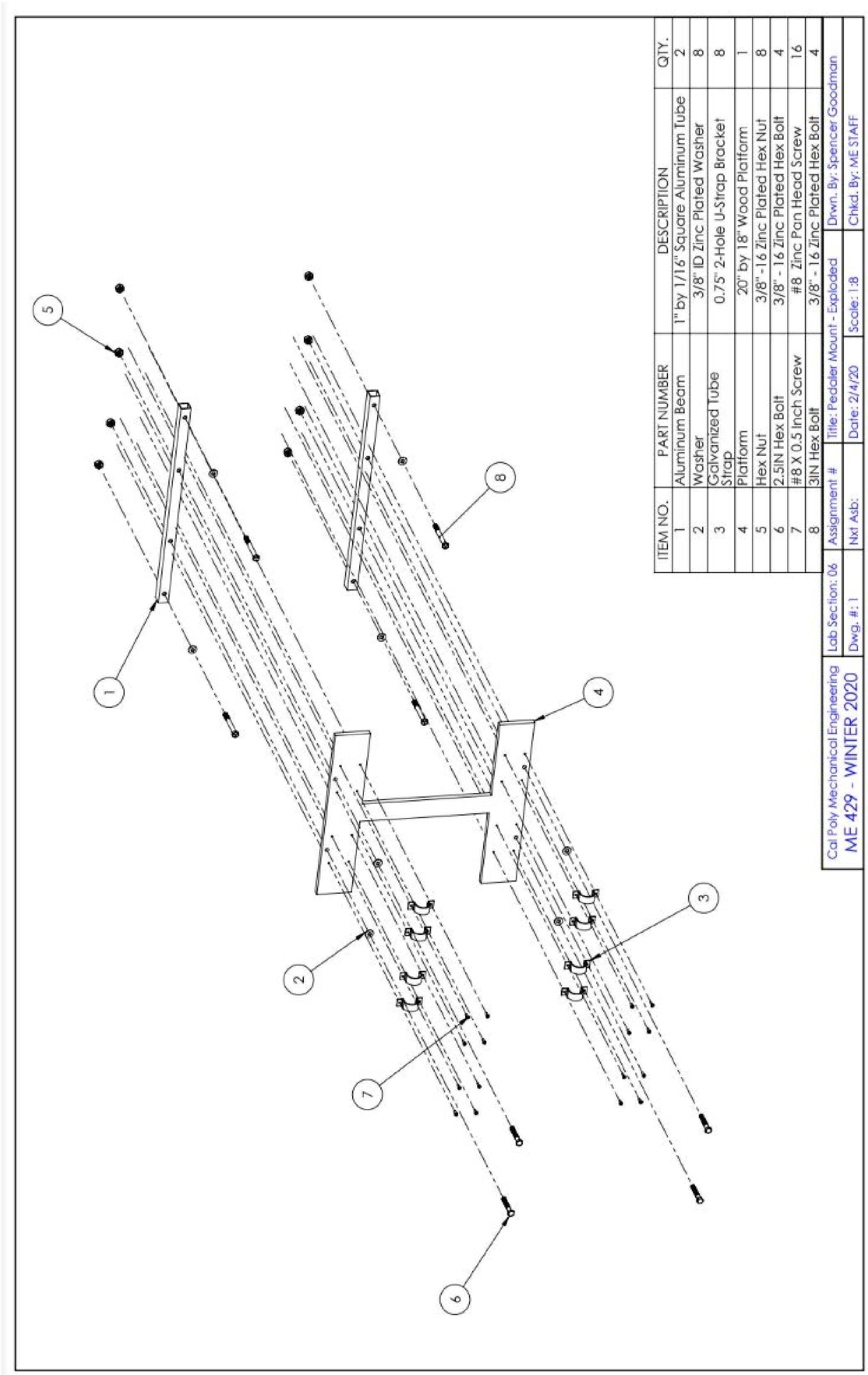

McMASTER-CARR
CAD
PART NUMBER
92865A255
Medium-Strength Grade 5 Steel Hex Head Screw
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
0.375"
1" Min. Thread Length
4 3/4"
3/8"-16 Thread
15/64"
9/16" Hex

Pedaler Mount

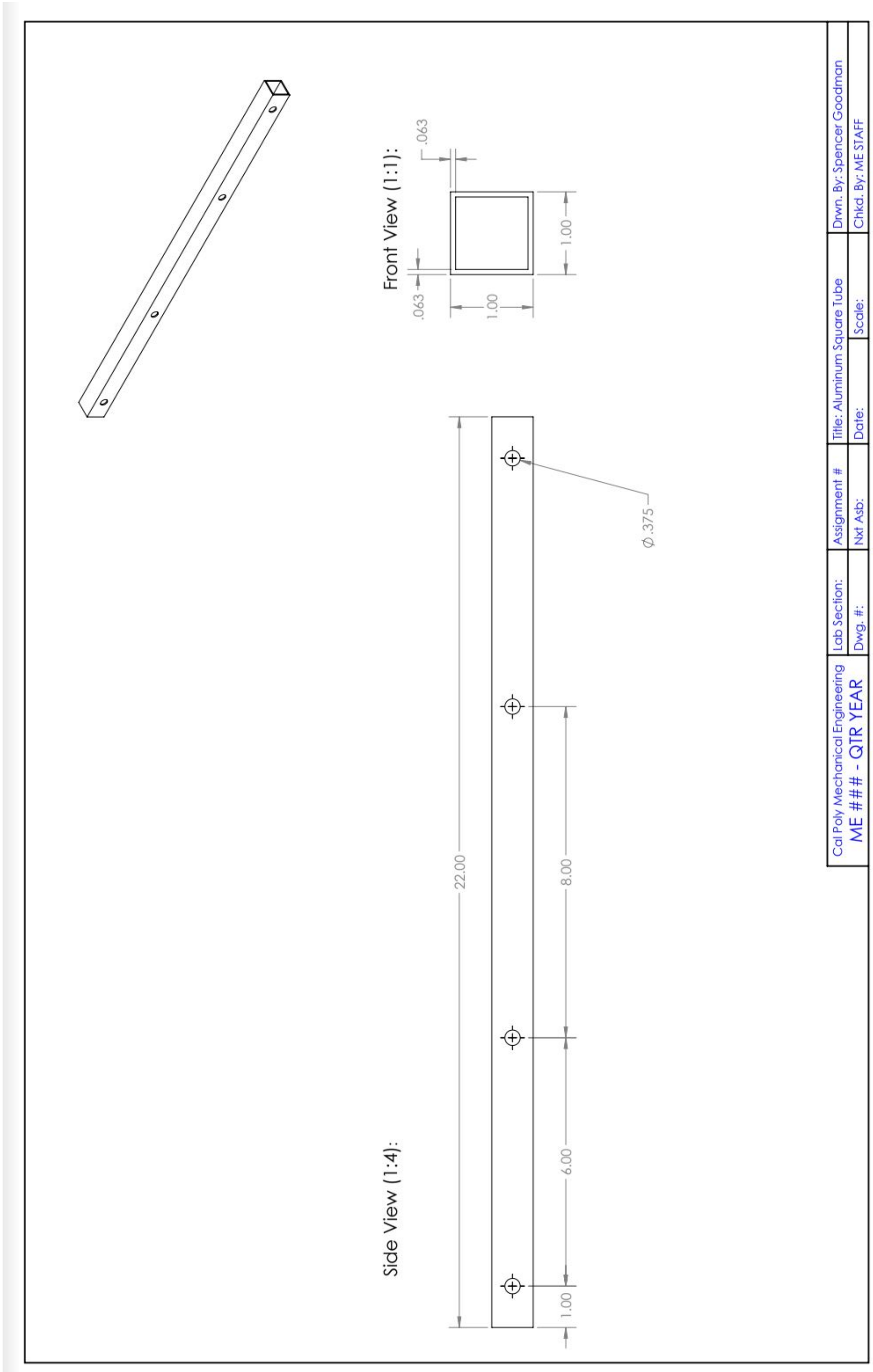
Assembly Drawing:

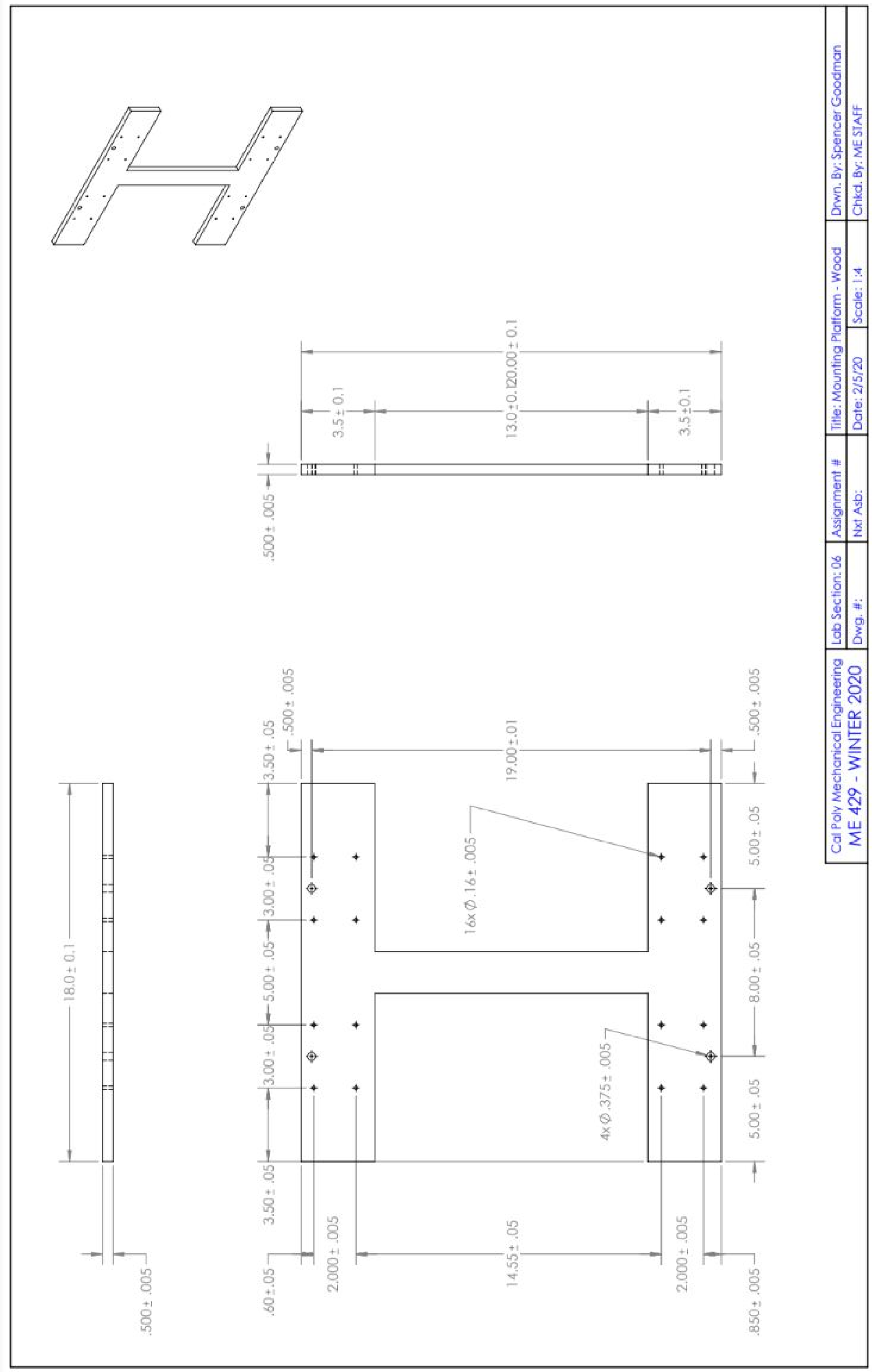


Exploded Assembly Drawing:



Detailed Part Drawings:




Cal Poly Mechanical Engineering
ME 429 - WINTER 2020
Lab Section: 06
Dwg. #:
Assignment #
Nxt Asb:
Title: Mounting Platform - Wood
Date: 2/5/20
Scale: 1:4
Drwn. By: Spencer Goodman
Chkd. By: ME STAFF
18.0± 0.1
.500± .005
3.50± .05
3.00± .05
5.00± .05
.500± .005
19.00±.01
16x ∅.16± .005
4x ∅.375± .005
.60±.05
2.000± .005
14.55± .05
.850± .005
8.00± .05
3.5± 0.1
13.0±0.1
20.00± 0.1

Appendix K - Revised Manufacturing Plan Resistance Rack

Adapted Exercise Equipment

Appendix Revised Resistance Rack Manufacturing Guidelines

Senior Project 2020

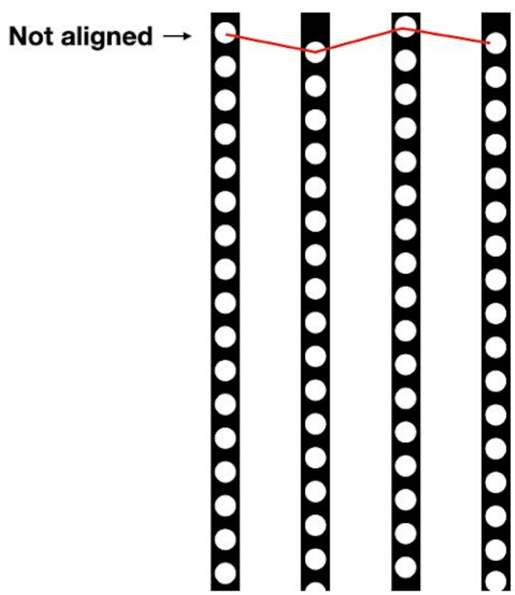
The Situation

Three days before COVID-19 outbreak became a global phenomena, our team finished gathering of all necessary parts to assemble the resistance rack structure. At this point, we had come to the realization that the steel beams were not cut accurately, and would need addition material removal in order for them to be assembled. The purpose of this document is to walk through, what we expect to be, the next steps in assembling the resistance rack structure.

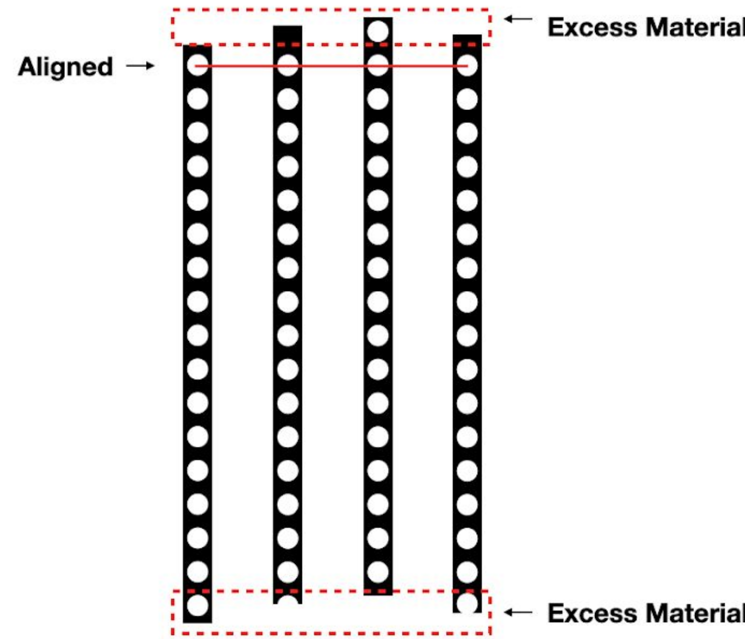
Please refer to the bill of materials in the critical design review as well as the manufacturing plan for more details regarding the assembly of the resistance rack

Step One: Re-cut the 90” Beams

What we currently have: four 90” beams, with unaligned holes. Therefore, the 48”,52”, and 86” beams can not be installed perpendicularly.

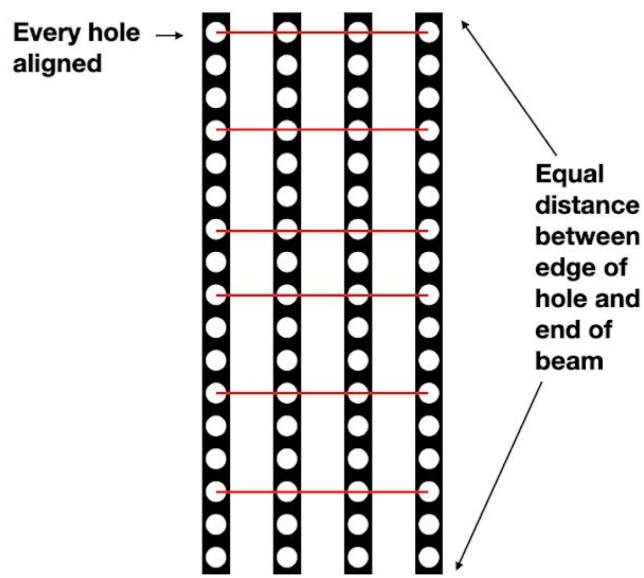


What we need to do: Align the holes on each of the 90” beams. This will require cutting off excess material, and making the entire structure shorter.



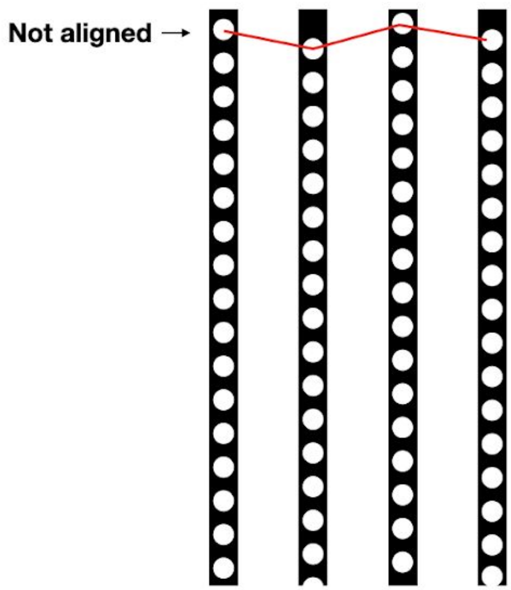
Step Two: Assess newly cut 90” pieces

What you should have: four 90” beams, with aligned holes, equal distance between hole and end of beam on both sides.

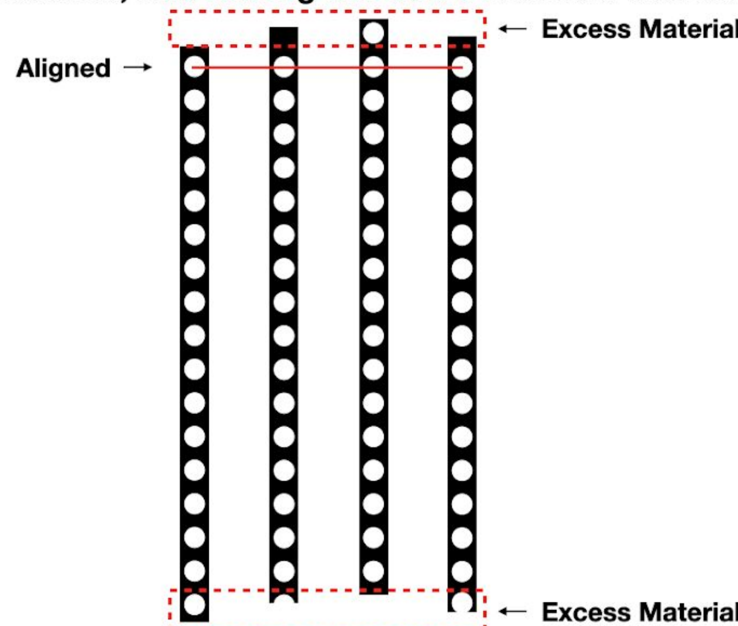


Step Three: Re-cut 48” beams

What we currently have: four 48” beams, with unaligned holes.

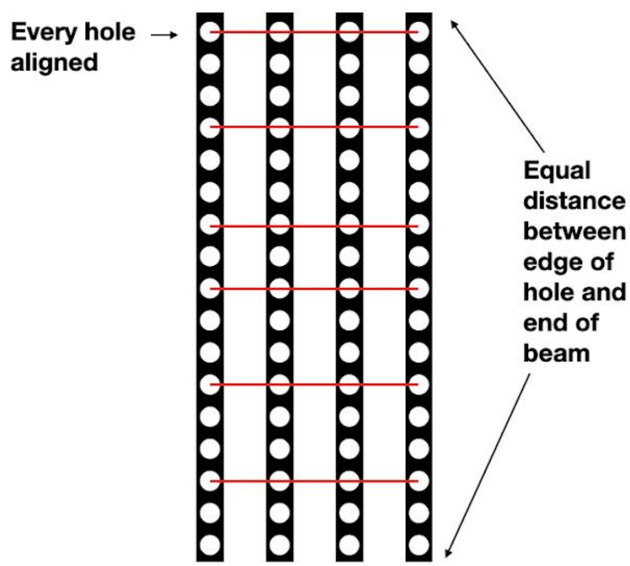


What we need to do: Align the holes on each of the 48” beams. This will require cutting off excess material, and making the entire structure shorter.



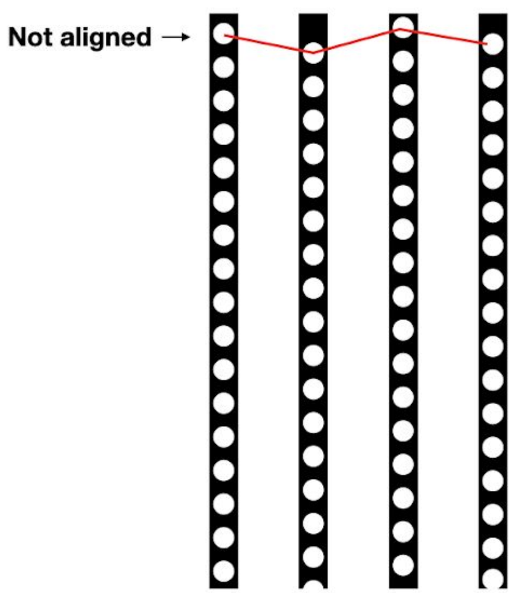
Step Four: Assess newly cut 48” pieces

What you should have: four 48” beams, with aligned holes, equal distance between hole and end of beam on both sides.

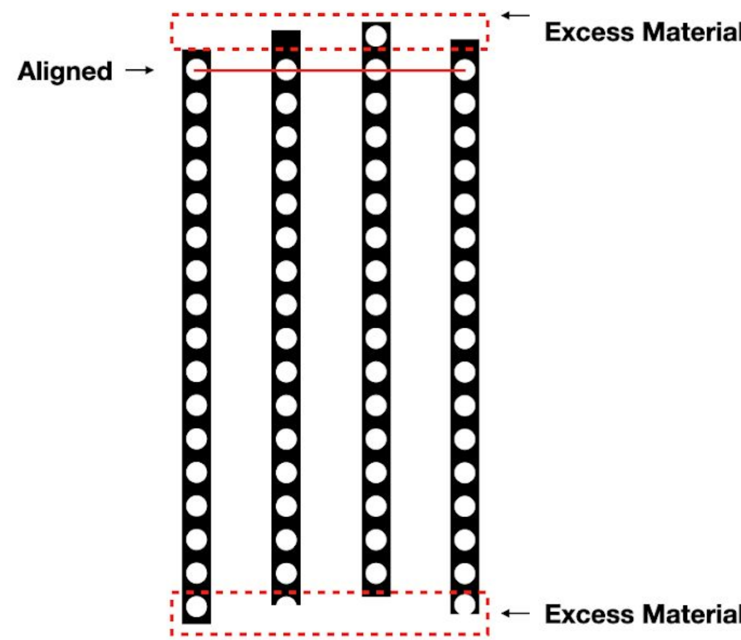


Step Five: Re-cut 52” beams

What we currently have: five 52” beams, with unaligned holes.



What we need to do: Align the holes on each of the 52” beams. This will require cutting off excess material, and making the entire structure shorter.



Step Seven: Assess new cut beams

In this step, re-familiarize yourself with the dimensions of the newly cut beams. They will be shorter then originally stated in the part drawings in Appendix J - Drawing Package. The new beams will be referred to as Beam A-B-C, as shown below

Beam Length (in)	Quantity	Beam Length (in)	
		What you used to have	What you currently have
90	4	90	Beam A: [measure and insert new dimension]
52	5	52	Beam B: [measure and insert new dimension]
48	4	48	Beam C: [measure and insert new dimension]
86	Beam D: (last step of assembly)		

Step Eight: Referring to 6.1.3 Assembly Process

At this point, you will be able to begin laying out the components. Before incorporating fasteners, however, you will need to drill holes in the L-shaped brackets that connect the square beams. Refer to the Exploded Assembly Drawing to see what brackets will be used for each joint.

After the brackets have all been drilled, you may begin assembling the beams as listed in the Manufacturing Guidelines starting at 6.1.3. The manufacturing plan will prompt you to drill holes into the brackets as needed.

Appendix L - Operation Manual

Operation Manual: Resistance Rack

Material Procurement:

Table 1.1 Materials Required for Resistance Rack

	Material	Quantity	Supplier
1	8'_SQUARE_TUBE	5	Traffic Management Inc.
2	10'_SQUARE_TUBE	3	Traffic Management Inc.
3	4931T221_FIXTURE_L	16	Mcmaster
5	91247A636_3/8”-16_3IN_HEX_BOLT	28	Granger
6	95462A031_3/8”-16_HEX_NUT	38	Granger
7	92865A255_3/8”-16_4.75IN_HEX_BOLT	10	Granger
8	93286A045_WASHER	38	Granger

Assembly Process:

Table 1.2. Beam Length Specifications.

Beam Length (in)	Quantity	Beam Length (in)	
		What you used to have	What you currently have
90	4	90	Beam A: [measure and insert new dimension]
52	5	52	Beam B: [measure and insert new dimension]
48	4	48	Beam C: [measure and insert new dimension]
86	Beam D: (last step of assembly)		

1. To distinguish between beams with different lengths, the beams will be referred to based on the labels specified for them under Table 1.2.
2. Assemble the structure shown in Figure 1.1 below by connecting two Beam A posts together with two Beam C posts. Refer to the Drawing Package for a detailed exploded view that shows how each joint should be assembled and what specific bolts to use. Refer to Joint A in Figure 1.2.

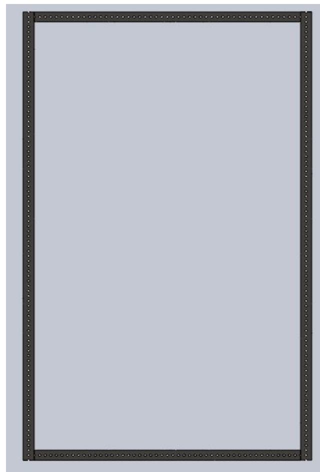


Figure 1.1. Back Frame of Resistance Rack

3. The top and bottom Beam C posts shall be connected to the Beam A posts using L-brackets as specified in Figure 1.2 below.
4. The L-bracketry will be fastened using the bolts, washer, and nut. The head of the bolt should be secured against the holes on the L-brackets. The backside of the bolt should be secured with a washer followed by a hex nut.
5. Create two frames that resemble the image in Figure 1.1. Flip the direction of the screws into the bracketry.

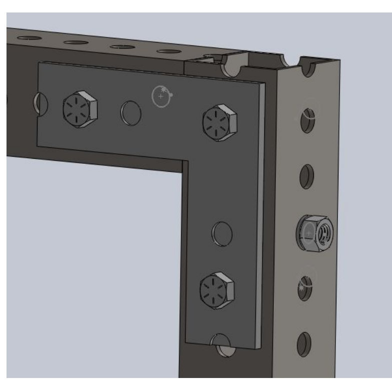


Figure 1.2. Rack Assembly Joint A

6. Refer to Step Six Take one of the frames assembled from Steps 1-4, and insert one Beam D post as seen in Figure 1.3. It is essential to place the Beam D post exactly 18’’ away from the far right post. Secure the Beam D post in place by referring to Joint A in the drawing package and Figure 1.2.

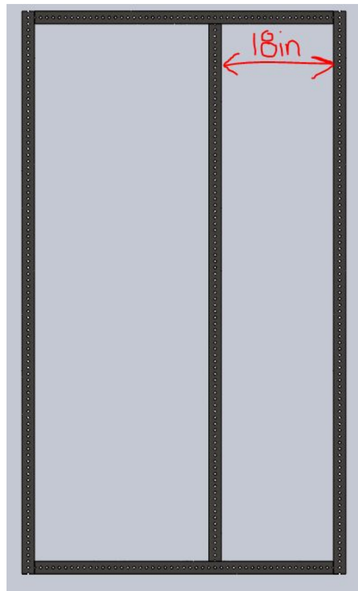


Figure 1.3. Inserting Beam D Post into Frame

7. In this step the two frames will be fixed together with two Beam B posts. Referring to Figure 1.4, rest the two frames lengthwise on a flat surface, and insert the Beam B posts (highlighted in blue). Refer to Joint D in the drawing package and Figure 1.56.

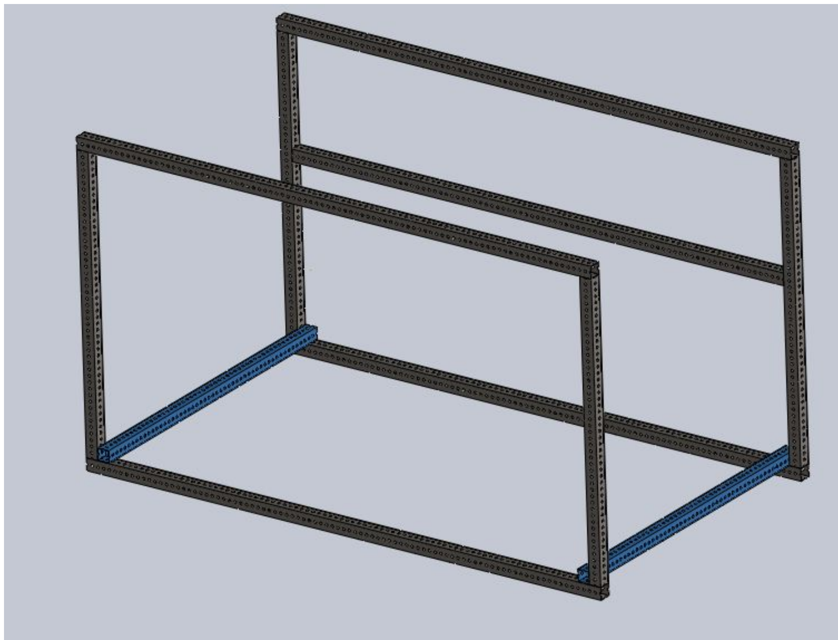


Figure 1.4. Connecting Two Frames Together

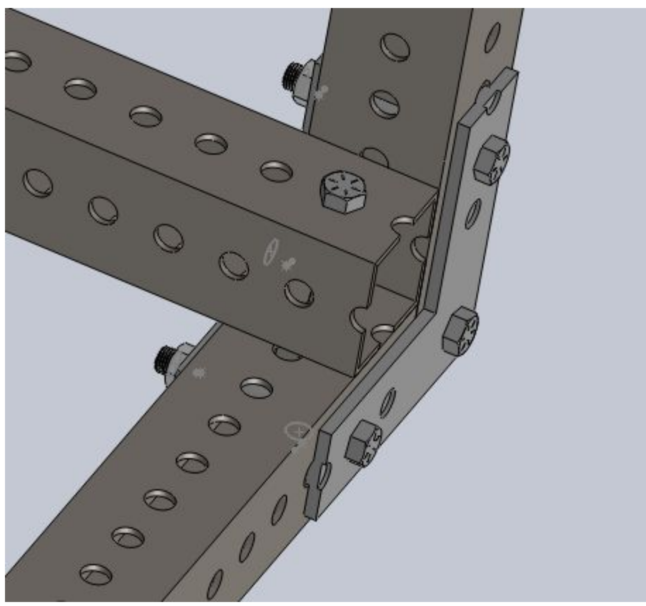


Figure 1.5. Rack Assembly Joint D

8. In this step we will fix one more Beam B beam to the resistance rack. Flip the assembly over as shown in Figure 1.6. Refer to Joint D in the drawing package and Figure 1.5.

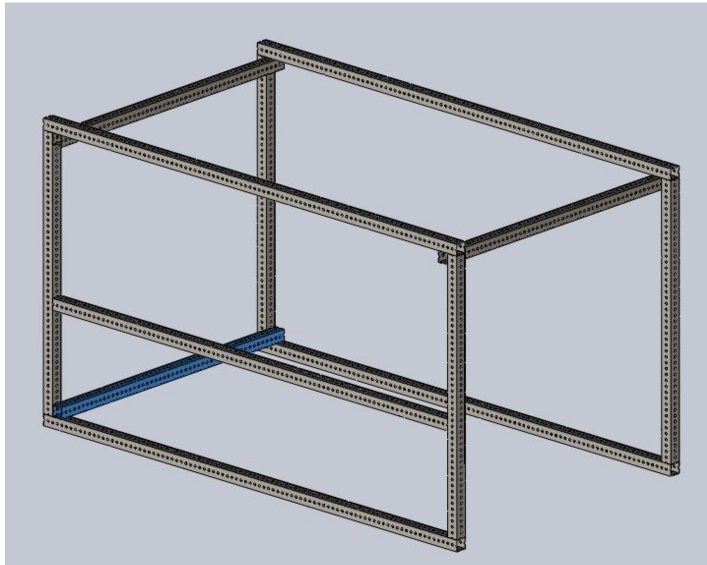


Figure 1.6. Assembly of Final Beam B Post to Frame

9. The last step of assembling the resistance rack is to fix two Beam B posts as shown in Figure 1.7. The assembler may decide how far apart the beams lay. Ensure that they are parallel to each other and perpendicular to the frame edges. Refer to Joint C in the drawing package and Figure 1.8.

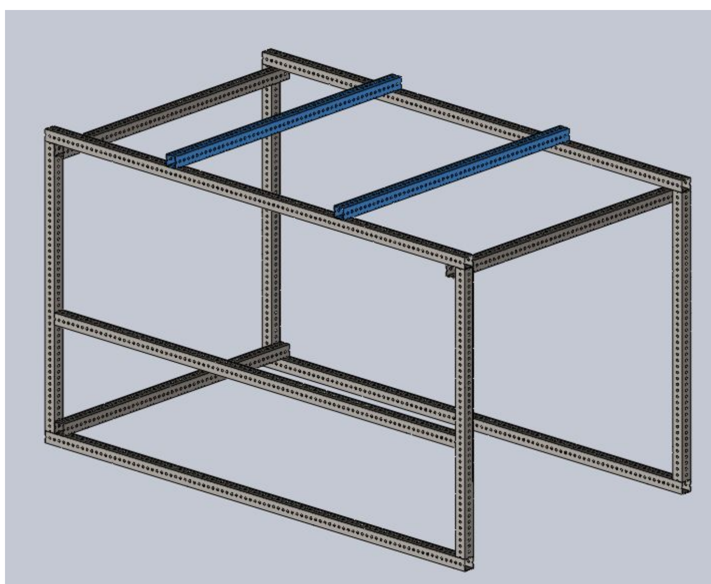


Figure 1.7. Assembling Ladder to Frame

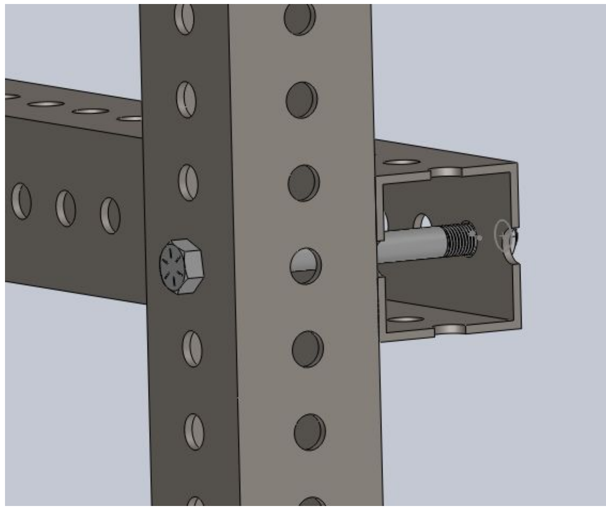


Figure 1.8. Rack Assembly Joint C

10. Assemble the two structures from above together so that they form the full resistance band rack seen below in Figure 1.9. The same process explained in Step 6 is used.

Figure 1.9. Completed Resistance Rack

Operation Guide:

The customer will have the opportunity to customize the placement of the resistance bands. The customer should inform the assembler of desired resistance band locations on the resistance rack. The assembler will place ⅜" J bolts in holes at the customer's desired locations. It would be best to use wing nuts to secure the J bolts to allow for easy removal and replacement of the hooks. Figure 1.10 shows a configuration below for the J bolts and wing nuts. Another nut should be added at the top of the threads to rigidly secure the J bolt to the beam.

Figure 1.10. Example of wingnut and J bolt configuration.

The Resistance Band Rack is a rigid structure that a user can attach resistance bands to in order to perform various exercises. The trainer will determine the location of the placement of the bands and the various exercises that the clients will perform. Figures 1.11 and 1.12 below show examples for how the resistance bands can be attached to the rack.

Figure 1.11. Examples for attaching a resistance band around a beam

Figure 1.12. Example for attaching a resistance band to a J Bolt

Maintenance:

The resistance rack will arrive at Achievement House fully assembled. To ensure the safety of the users, the employees at Achievement House should perform routine maintenance checks on the resistance rack:

1. Any looseness or wobbling should be addressed immediately by tightening the loose bolts.
2. The tightness of the bolts that fasten the beams together should be checked every 6 months.
3. The resistance bands should be checked before use for signs of tearing.

Part Replacement:

1. All extra hardware (bolts, nuts, J bolts.) will be given to Achievement House
2. Resistance bands can be purchased to the trainer's satisfaction
3. If additional parts need to be purchased refer to the part list at the beginning of this operator's manual.

Safety Warning:

As with all exercise equipment, there is risk of injury if the equipment is used incorrectly. The user of the resistance rack should only perform exercises under the supervision of the trainer on site at Achievement House. The trainer should inform the user how to perform the exercise and then stand by to ensure the user is performing the exercise correctly.

Operation Manual: Punching Bag

Materials Procurement:

Table 2.1. Materials Required for Punching Bag Attachment.

	Material	Quantity	Seller
1	Perforated Galvanized Steel Tube	1	Traffic Inc. SLO
2	1'x1', ¼" Thick Wooden Board	1	Home Depot
3	Swivel Mount	1	Amazon
4	Speedbag	1	Amazon
5	Corner L-Bracket	2	Lowe's
6	91247A636_3/8"-16_3IN_HEX_BOLT	5	Lowe's
7	95462A031_3/8"-16_HEX_NUT	5	Lowe's

Assembly Process:

1. Bolt the 2 corner L-Brackets to the top and bottom faces of the steel tube as shown in Figure 2.1. The corner edges should be flush with the end of the tube.

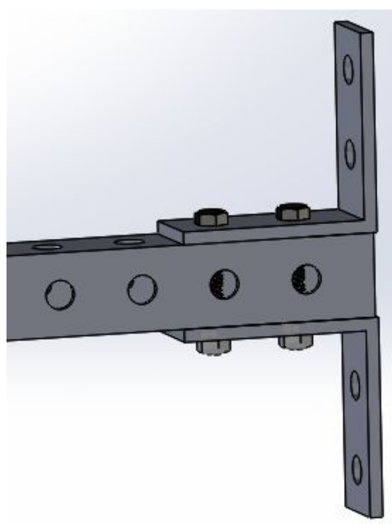


Figure 2.1: Corner L-Brackets Bolted to Steel Tube

2. Bolt the wooden circle from Step 3 to the last hole on the opposite end of the steel tube from the previously attached corner L-Brackets as shown in Figure 2.2.

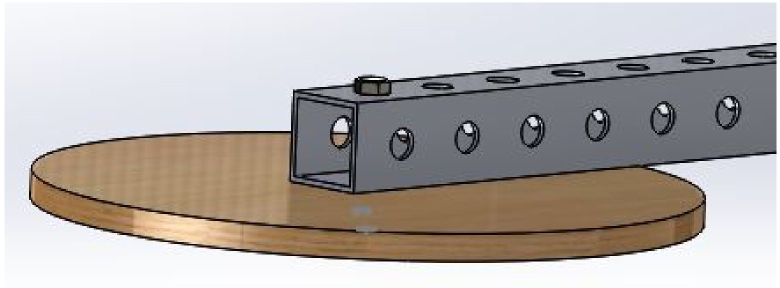


Figure 2.2: Wooden Plate Bolted to Steel Tube

3. Bolt the swivel mount to the wooden circle as close to the center as possible on the side opposite of the steel tube as shown in Figure 2.3.

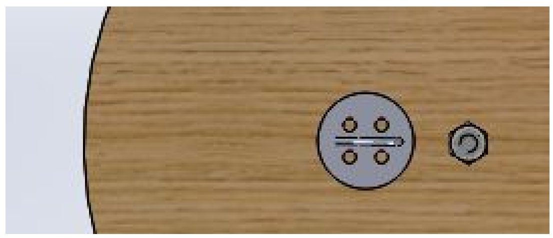


Figure 2.3: Speedbag Swivel Mount Bolted to Wooden Plate

4. Attach the punching bag to the swivel mount.

Operation Guide:

1. Curl fingers into a fist.
2. Extend arm and punch the bag as shown in Figure 2.4. Extending and retracting arms primarily exercises biceps and triceps. Deltoids and rotator cuff muscles are activated to keep the arm raised.
3. Alternating arms will strengthen obliques and other core muscles.

Figure 2.4: Punching the bag. (Photo from CanStockPhoto.com)

Maintenance:
The punching bag apparatus will be given to Achievement House fully assembled. If there is excessive rattling when the bag is being used, the bolts holding the assembly to the main frame may need to be tightened.

Part Replacement:
No spare parts for replacement will be given to Achievement House. Please see the Bill of Materials to see where each part was purchased from.

Safety Warning:
The punching bag apparatus is not designed to withstand any hanging, tugging, or pulling. The bag should be kicked or punched only. No object should be hung on the steel tube, and people should not hang on the apparatus.

This apparatus extends away from the main frame and could present a hazard if patrons walk into it or bump into. All patrons in the exercise room should be aware of their surroundings while exercising or moving about the room.

Operation Manual: Adaptive Pedaler Mount

Material Procurement:

Table 31. Materials Required for Adaptive Pedaler Mount Attachment

	Material	Quantity	Supplier
1	1” by 7/16” Aluminum Square Tubing 48”	1	Home Depot
2	3/8-16 Zinc plated hex bolts 2.5"	4	Home Depot
3	3/8" Zinc Plated Washers	8	McMaster-Carr
4	3/8"-16 Zinc Plated Hex Bolt 3.5"	4	McMaster-Carr
5	3/8"-16 Zinc Plated Hex Nut	8	McMaster-Carr
6	0.75 inch Two-Hole U-bracket	8	Home Depot
7	#8-32 1/2“ Pan Head Screws	16	Home Depot
8	Plywood (24” x 24” x 0.5 “)	1	Home Depot
9	Pedaler	1	Facebook

Assembly Process:

1. Connect the aluminum tubing to the top and bottom of the wood platform using two 2.5-inch hex bolts and washers. Fully secure the connection using a 3/8-inch hex nut on each bolt. The bolts should be secured at the two inner-most 3/8-inch holes for both the wooden platform and the aluminum tubing. Figure 3.1 shows how the tubing and platform should be bolted, and also which location they should be bolted together at.

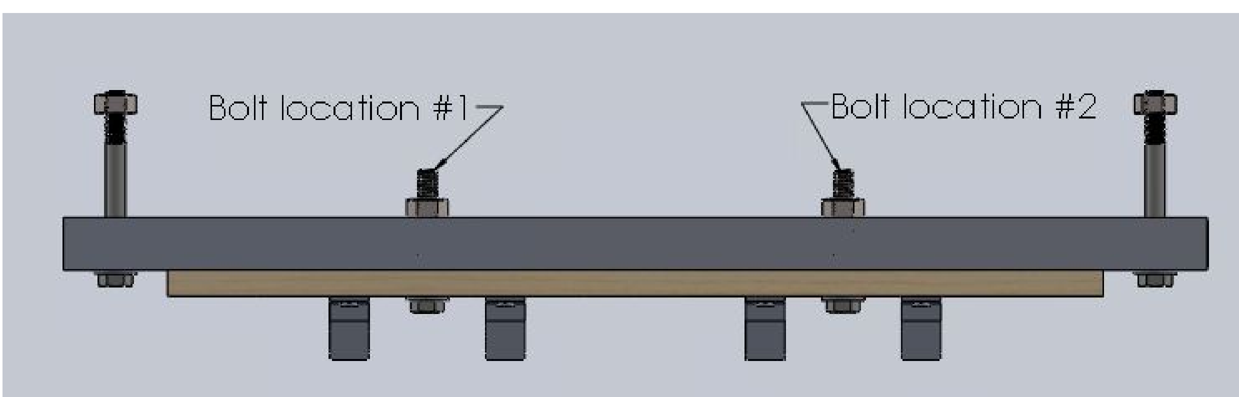


Figure 3.1. Aluminum Tubing Bolted to Wooden Platform (Top View)

2. Fasten the pedaler to the wooden platform by using the 0.75 inch U-brackets and power drilling them to the platform using the #8-32 1/2" Pan Head Screws. Figure 3.2 shows how the brackets should be secured to the plywood, and Figure 3.3 shows that each bracket should be screwed in at the location of each of the 0.16" diameter holes in order to ensure the tightest connection to the pedaler.

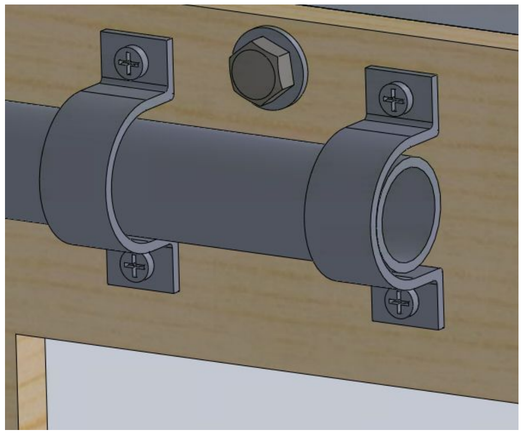


Figure 3.2. Secure Pedaler to the Plywood Using Brackets.

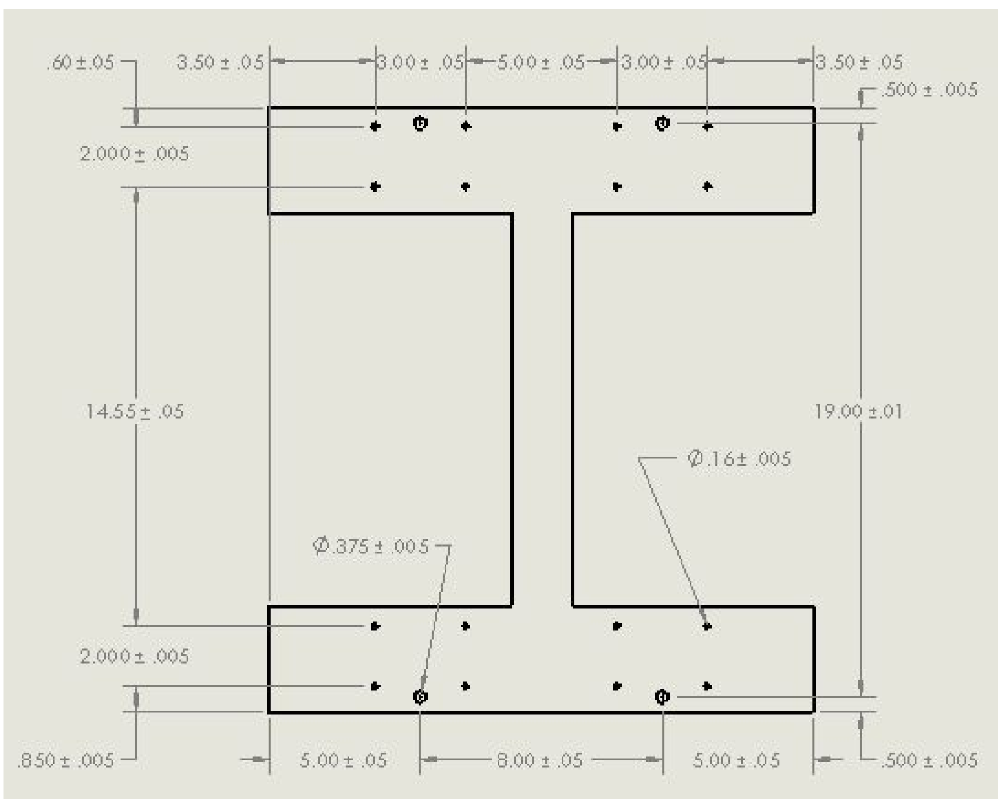


Figure 3.3. Hole Locations in Wooden Platform (Side View)

3. Connect the pedaler mount to the resistance rack frame by connecting the holes at the ends of the aluminum tubing to the frame using 4-inch bolts as shown in Figure 3.4. The specific locations of these holes are shown in Figure 3.5. Fasten with a wrench to ensure a secure connection.

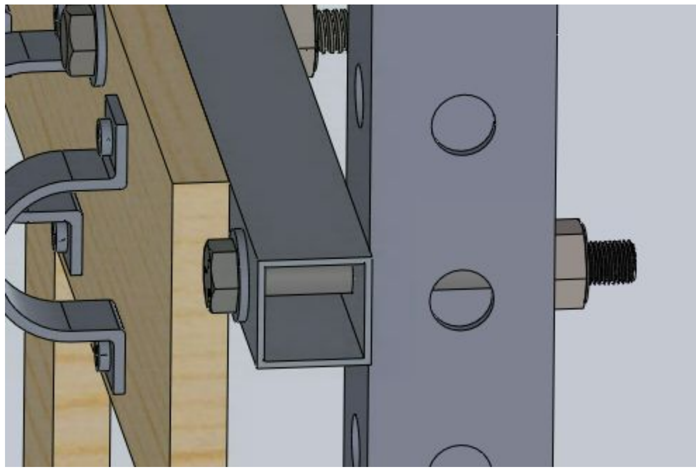


Figure 3.4. Fastener Connection Between Mount and Resistance Rack.

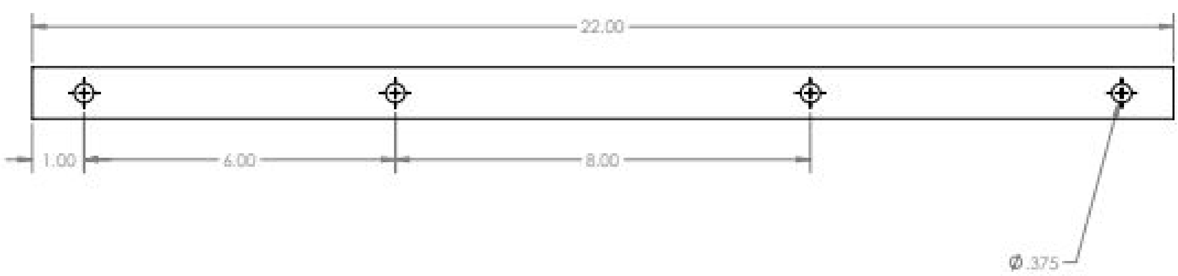


Figure 3.5. Hole Locations in Aluminum Tubing (Side View)

Operation Guide:

1. Height can be adjusted by fastening the pedaler mount at different hole heights on the rack frame, although it is recommended to keep the pedaler at one height for all users. If the height must be adjusted, make sure all of the bolts connecting to the resistance rack frame are properly connected.

2. Make sure feet or hands are strapped onto the pedals as shown in Figure 3.6 depending on the exercise being performed.

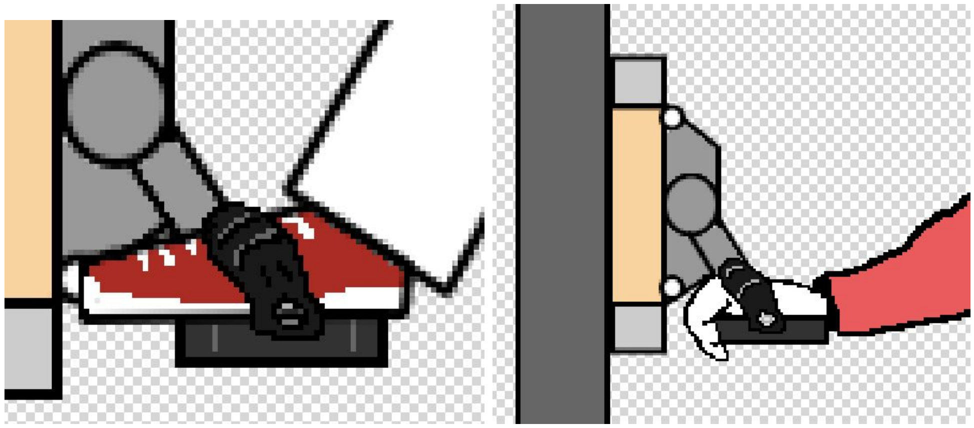


Figure 3.6. Examples of how feet and hands must be strapped to the pedal.

3. The user must be in a seated position when performing cycling exercises using their legs, as seen in Figure 3.7. Standing while using the pedaler for leg exercise is a safety hazard since it could cause the connection to fail, and could also cause the user to be injured due to not being able to maintain balance.

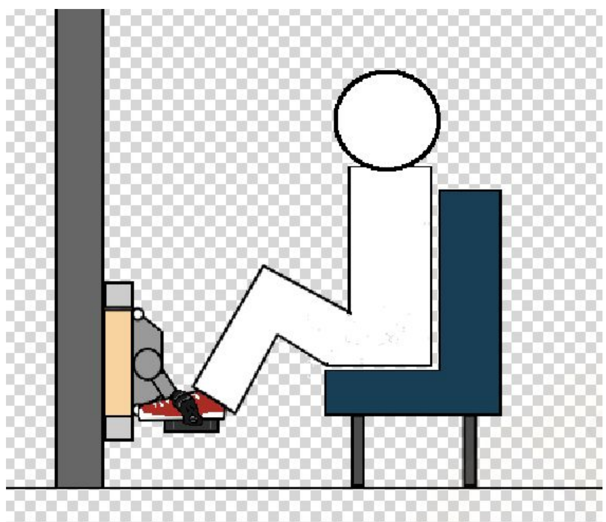


Figure 3.7. Example of proper use of the pedaler for leg exercise.

4. Adjust resistance knob on pedaler shown in Figure 3.8. in order to increase or decrease the difficulty of the exercise being performed. Turning the knob clockwise increases resistance, while turning it counter clockwise reduces resistance.

Figure 3.8. Pedaler Resistance Adjusting Knob.

Maintenance:

The pedaler mount will arrive at Achievement House fully assembled and attached to the resistance rack. To ensure the safety of the users, the employees at Achievement House should perform routine maintenance checks on the bolts and on the tube straps prior to using the equipment in order to ensure that all of the connections are secure and that the pedaler doesn't wobble while in use.

Part Replacement:

1. All extra hardware (bolts, nuts, washers) will be given to Achievement House
2. Replacement pedalers can be purchased via amazon at the following link: Replacement Pedaler. Follow the assembly instructions in order to ensure that the pedaler is properly secured to the mount.
3. If additional parts need to be purchased refer to the part list at the beginning of this operator's manual.

Safety Warning:

As with all exercise equipment, there is risk of injury if the equipment is used incorrectly. The user of the pedaler should only perform exercises under the supervision of the trainer. The pedaler mount is not designed to withstand tugging, pulling, or hanging, and should only be used for cycling exercise involving the legs or arms.

The connection between the mount and rack must also be tightly secured using a provided wrench, and also monitored regularly, in order to ensure that the mount does not fall whenever the height is adjusted or when the equipment is in use due to not being tightly secured.