Human Powered Vehicle Trainer
Final Design Review

PRESENTED BY

Gregory Bridges
Jacinta Garcia
Nick Nguyen
Mitch Smith
CPHPVSim18@gmail.com

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
Spring 2019

PREPARED FOR
George Leone

Statement of Disclaimer

Abstract

This Final Design Review (FDR) document describes the final design and completed prototype of a Mechanical Engineering senior project team at California Polytechnic State University, San Luis Obispo. The project goal is to create an adjustable human powered vehicle training bike for George Leone that allows a rider to gain confidence with the unique reclined bike geometry ahead of the World Human Powered Speed Challenge at Battle Mountain, Nevada. This document outlines the customer's needs and technical research performed which together determine the project's scope and engineering specifications. Next, we present the initial idea generation process and its results, along with the top mechanism designs, the decision matrices used to evaluate them, and the final design concepts. Each finalized subsystem design is then presented, including all required materials and components. Following this, the manufacturing section details the final project budget and the build processes followed for each subsystem and the overall bike. To ensure the bike met its design specifications, tests were performed with the completed prototype and their results are presented in the testing section. Additionally, we illustrate the overall project management plan and Gantt chart, and scheduling lessons learned from our project. Finally, the conclusion presents our final thoughts on the project – including what went well and what we would do differently – along with recommendations for our sponsor on how to improve and utilize the trainer in the future.

Table of Contents

Table of Contents 4
List of Figures 6
List of Tables 8
1.0 Introduction 9
2.0 Background 9
  2.1 Customer Research 10
  2.2 Existing Design and Patent Research 11
  2.3 Primal 1 Frame Initial Feasibility Analysis 13
3.0 Objectives 13
  3.1 Problem Statement 13
  3.2 Boundary Diagram 14
  3.3 Engineering Specifications 15
4.0 Concept Design 16
  4.1 Initial Idea Generation Process 16
  4.2 Concept Sketches and Decision Matrices 17
    4.2.1 Seat Track Adjustment Mechanism 17
    4.2.2 Seat Back Reclining Mechanism 20
  4.3 Selected Design Concepts 22
    4.3.1 Initial Design Analysis 23
    4.3.2 Issues, Risks, and Unknowns 25
5.0 Final Design 25
  5.1 Overall Design 26
  5.2 Seat Track Adjustment Mechanism 26
    5.2.1 Seat Track Adjustment Mechanism Design 26
    5.2.2 Seat Track Mechanism to Primal 1 Interface 27
    5.2.3 Seat Track Stress Analysis 28
    5.2.4 Seat Track Ergonomic Analysis 29
  5.3 Seat Back Reclining Mechanism 30
    5.3.1 Overall Seat Back Recliner Design 30
    5.3.2 Two Piece Seat and Hinge Design 31
    5.3.3 Seat Back Reclining Mechanism 31
    5.3.4 Seat Back to Support Arm Interface 32
    5.3.5 Support Arm to Rear Triangle Support Point 33

5.3.6 Support Arm Stress Analysis ... 33
5.4 Handlebars ... 34
5.4.1 Handlebar Adjustment Mechanism ... 34
5.4.2 Handlebar Ergonomics Analysis ... 34
5.5 Safety, Maintenance, and Repairs ... 35
5.6 Summary Cost Analysis ... 36
6.0 Manufacturing ... 36
6.1 Part Procurement Process and Final Budget ... 36
6.2 Manufacturing Process ... 38
6.2.1: Primal 1 Disassembly ... 38
6.2.2: Seat Modifications ... 39
6.2.3: Box Beam Preparation ... 40
6.2.4: Support Arm Manufacturing ... 40
6.2.5: Handlebar Manufacturing ... 41
6.2.6: Overall Welding Process ... 43
6.2.7 Final Steps ... 45
6.3 Manufacturing Challenges and Recommendations ... 45
6.3.1 Leveling the Front Box Beam Connection Point ... 46
6.3.2 Welding Tabs for Support Arm Pin Attachment Point ... 46
6.3.3 Interfacing Handlebar Holes ... 46
7.0 Design Verification ... 47
7.1 Maximum Adjustment Time ... 47
7.2 Available Seat Back Angles ... 49
7.3 Supportable Rider Weight ... 50
7.4 Minimum and Maximum Distance from Seat Back to Farthest Pedal ... 51
7.5 Recommendations for Future Tests ... 51
8.0 Project Management ... 52
9.0 Conclusion ... 53
9.1 Final Reflections ... 53
9.1.1 Seat Track Adjustment Mechanism ... 53
9.1.2 Seat Back Reclining Mechanism ... 53
9.1.3 Handlebar Adjustment Mechanism ... 54
9.2 Next Steps ... 54
9.3 Acknowledgements ... 55
10.0 References ... 56
11.0 Appendices ... 57

List of Figures

Figure 1. Primal 2 competing at Battle Mountain 10
Figure 2. Nick in Primal 1 for Initial Feasability Analysis 13
Figure 3. Boundary Diagram used for Problem Definition 14
Figure 4. Portions of Primal 1 frame to be removed, modified, or utilized 14
Figure 5. Unistrut Concept Sketch 17
Figure 6. Slot and Lever Concept Sketch 17
Figure 7. Bike Clamp Concept Sketch 18
Figure 8. Lead Screw Concept Sketch 18
Figure 9. Spring Loaded Pins Concept Sketch 18
Figure 10. Sawtooth Plates Concept Sketch 19
Figure 11. Crescents Concept Sketch 20
Figure 12. Dual Rods Concept Sketch 20
Figure 13. Pistons Concept Sketch 21
Figure 14. Overall Concept CAD 22
Figure 15. Concept Prototype 22
Figure 16. Chain Tensioning Mechanism to Allow for Pedal Location Adjustment 23
Figure 17. Bike with 95th Percentile Male 24
Figure 18. Bike with Smallest Size Person 24
Figure 19. Overall trainer model 26
Figure 20. Close-up view of square telescoping tubes 27
Figure 21. Close-up view of underside of seat 28
Figure 22. Load cases drawn in for Primal 1 in use 28
Figure 23. Structural prototype with participant and handlebar measurement device 29
Figure 24. Box and wisker plot of desired seat track adjustment 30
Figure 25. Overal seat back reclining mechanism and modified seat 30
Figure 26. Close-up of seat bottom and seat back connection point 31
Figure 27. Overall seat reclining mechanism in slightly upright position 32
Figure 28. Rear seat back to support arm pin connection point 32
Figure 29. Close-up view of rear pin support member 33
Figure 30. Final handlebar adjustment mechanism 34
Figure 31. Plot of preferred handlebar locations from ergonomics analysis 35
Figure 32. Separated front and back halves of Primal 1 frame 38

Figure 33. Fiberglass section and U-bracket attachment point 39
Figure 34. Hole spacing for rear box beam 40
Figure 35. Rear triangle welding tabs – welding set up 41
Figure 36. Miter pattern and desired end profile for the handlebar post 41
Figure 37. Handlebar post orientation and final mitered tube to collar connection 42
Figure 38. Handlebar stem with 7 mm holes drilled 42
Figure 39. Front half welding jig with front half of Primal 1 and front box beam 43
Figure 40. End plate alignment relative to the back beam 44
Figure 41. Seat bracket attachment distance from end plate 44
Figure 42. Finished back half of trainer frame – pre welding 45
Figure 43. Participant testing out bike fit after timed setup test 47
Figure 44. Box and whisker plots showing the adjustment times of subsystems and overall 48
Figure 45. Seat back angle verification test with angle gage 49
Figure 46. Measuring height of seat track at seat bolt location prior to load test 50
Figure 47. Measurment of pedal to seat bottom distance at closest seat location 51

List of Tables

Table 1. Existing Products 11
Table 2. Related Patents 12
Table 3. Engineering Specifications 15
Table 4. Decision Matrix for Seat Track Mechanisms 19
Table 5. Decision Matrix for Reclining Functionality Mechanisms 21
Table 6. Generalized cost breakdown for final prototype 36
Table 7. Detailed budget for the trainer 37
Table 8. Measured seat back angles for each support arm 49
Table 9. Seat track deflection test results 50
Table 10. Comparison of measured pedal to seat bottom distance to design values 51

1.0 Introduction

Human Powered Vehicles (HPVs), as the name implies, are any mode of transportation that are solely human driven. The International Human Powered Vehicle Association (IHPV) holds competitions every year for a variety of vehicle types, including land, water, and air. The World Human Powered Speed Championship (WHPSC) is an annual event held in Battle Mountain, Nevada where land-based HPV teams from across the world come to showcase their vehicles and break various speed records. For this competition, HPV riders must race in an extremely reclined position to reduce drag on the vehicle and maximize rider output. As a result of the unique positioning, traditional bike riders often experience difficulties when initially transitioning to HPVs.

The purpose of this project is to design and manufacture a training rig for George Leone from Atascadero, California. The training rig will allow a rider to comfortably transition from a traditional road bike to an HPV style recumbent. Additionally, the trainer will be fully adjustable to fit a range of rider heights and allow them to ride at different seat back angles. Therefore, the training rig will allow Mr. Leone's rider to practice in the unique HPV riding environment before the Battle Mountain speed challenge. In addition, the Cal Poly San Luis Obispo HPV team may use the training rig as they begin to prepare for the same competition. In the future, our project may serve as the foundation for a more advanced trainer, with later additions including a full vision system, tilt, and variable resistance.

The members of our team are Gregory Bridges, Jacinta Garcia, Nick Nguyen, and Mitch Smith. Our team of Cal Poly Mechanical Engineering students come from a variety of engineering backgrounds. We are excited to deliver a working bike trainer that will meet the requirements Mr. Leone set.

The scope of our project changed drastically after we submitted our scope of work document and before the Preliminary Design Review document. As such, much of the original research performed and some of the analysis techniques, such as the House of Quality, were no longer relevant for our project requirements. This information is stored in Appendices F-H for reference in the case of future updates to the trainer. For the Critical Design Review, we finalized the seat back reclining mechanism and the seat track adjustment mechanism designs, added a new handlebar location and positioning system, and removed of the chain tensioner design.

This document underwent additional updates since the Critical Design Review and serves as our Final Design Review for our sponsor. This includes a detailed description of our final budget and manufacturing process, along with an explanation of all testing performed and its results and our final reflections on the project.

2.0 Background

In this section, we outline the research completed to further our understanding of the project constraints and necessities. This includes both the information we gathered from our customer, Mr. Leone, and our research on existing products and patents that perform similar tasks to our subsystems.

2.1 Customer Research

Early in fall quarter, the team interviewed Mr. Leone to learn about his extensive experience with HPVs over the last several decades. His work has included helping a variety of college teams, including Cal Poly, compete at events for the American Society of Mechanical Engineering (ASME) and IHPV. Mr. Leone and his team are currently working on building their fourth individual bike and are preparing to compete at the WHPSC this year. With a new rider and frame design, Mr. Leone is hoping to reach 80 miles per hour, a feat accomplished by very few teams.

After interviewing Mr. Leone, the team interacted with the Primal 2 bike, which was is a similar setup to the desired trainer specifications. The Primal 2 bike competed at the Battle Mountain course several years ago, as seen in Figure 1. From interactions with Primal 2, the team experienced first-hand the confinement that the rider would experience during competition, and its unique frame geometry. We also learned that the maximum steering angle a rider could input while maintaining stability is approximately 5 degrees.

Figure 1. Mr. Leone's most recent HPV, Primal 2, at the Battle Mountain Race Course

Developing a training rig for Mr. Leone and his rider will be advantageous for the team before the competition. Mr. Leone's rider normally races on an upright road bike, so an HPV-specific recumbent trainer will allow his rider to practice and develop skills with the unique setup. Mr. Leone also wants the bike to function properly on a roller trainer. Rollers force the rider to balance the bike as they would during the race. This means the bike will need to have handling characteristics and vehicle dynamics similar to his actual racing HPV.

Mr. Leone also provided us his first HPV, Primal 1, as a possible foundation for our training bike. This bike positions the rider at a more vertical angle compared to Primal 2 and the bike that he is currently building, the Primal 3. Additionally, Mr. Leone originally designed Primal 1 solely for a six-foot tall rider, and consequently it has no adjustment mechanisms.

2.2 Existing Design and Patent Research

The HPV Race community is relatively small, and as such training bikes specific to HPVs are uncommon. As such, there are not many patents or existing products on the market for an HPV trainer. By narrowing our research to our subsystems alone, we found patents and existing products that perform actions similar to our desired adjustment mechanisms. We present the results of this research in Tables 1 and 2.

Table 1. Existing Products

Product	Key Characteristics
Weider Pro 255 Weightlifting Bench [1]	• This bench features a crescent style reclining mechanism • Uses a pin to select the angle of adjustment
Landmine Pivot [2]	• This pivot made for weightlifting could be used in conjunction with another mechanism for the reclining aspect • Durable and can withstand high loads
Rick Wianecke's Low Racer Project 2004 [3]	• Redesigned recumbent bike from an over the shoulder steel frame to a lighter standard recumbent bike • Includes adjustability of seat position through a collar and seat position. • Seat can be reclined by two rods slotted through collars that can adjust in length depending on desired seat angle
ODIER Bike Quick Release Seat Post Clamp [4]	• Clamps onto the outside of a tube to hold another tube in place with friction • Quick release clamp • Fits a variety of tube diameters
Sole SB700 Bike [5]	• Spin bike that has vertical and horizontal seat adjustment • Vertical seat adjustment uses two concentric rods that are locked in place by friction • Seat rests on a carriage and rail that can translate forwards or backwards, locked in place by a latch
235 CSX Exercise Bike [6]	• Recumbent bike trainer, only available adjustability is in the seat position • Bike seat attached to a carriage which rests on a rail, lever is released when bike seat needs to be moved

Researching current products provided valuable insights into methods for seat track and seat reclining mechanisms in our design. Both the weightlifting bench and landmine pivot were applications that were not specific to recumbent bicycles but provided two ways to design reclining seat functions. Many of the mechanisms in Table 1 come from stationary bike or weightlifting applications, which means they would likely be robust enough for our purposes.

Table 2. Related Patents

Patent Name	Patent Number	Key Characteristics
Pivoting twin arm support for free weights [7]	US8740760B2	• This patent describes a semi-circular reclining mechanism • The circular portion connects to a seat on either side of the pivot • A pin locks the angle selection in place
Exercise rowing machine with seat carriage lock [8]	US4756523A	• Patent contains rowing seat that could lock into place • Seat positioned on a carriage that can freely translate along a rail • Friction pad can be rotated in a lock position on either side to prevent rollers from moving
Semi-recumbent exercise cycle [9]	US4932650A	• Patent contains design for a semi-recumbent exercise cycle • Two adjustability mechanisms, one for the pedals the other for the seat • Seat rests on a slotted rail that has predefined locations • Pedals on a diagonal slot that has a range of infinitesimally small adjustment positions locked in place by nuts
Exercise bicycle [10]	US7226393B2	• Upright stationary spin bike, with several adjustment mechanisms • Both the handlebars and vertical seat position can be adjusted using concentric rods with a series of holes, and secured in place by a spring-loaded pin • Horizontal seat position adjusted by concentric square tubing and secured in place by a friction lever
Adjustable pedal system for exercise bike [11]	US20090211395A1	• Patent includes designs for pedal adjustment for a standard recumbent trainer bike • Slot and carriage design to adjust pedals away or toward the user • Set holes and pin design to move pedals away at set distances

We found various patents that relate to our design challenges. One patent of note was the adjustable pedal system, which allowed for movement of the entire pedal assembly relative to the rider. We can employ a similar system for our own design to account for multiple rider heights in the form of an adjustable seat track and adjustable pedal location. There was a large emphasis on seat track designs for our patent research, as we found this mechanism the most challenging to implement for our bike frame. Similar to our product research, patents related to exercise equipment were used to draw inspiration from for our designs.

2.3 Primal 1 Frame Initial Feasibility Analysis

As stated earlier, our sponsor Mr. Leone provided us his original HPV bike, the Primal 1, for the bike trainer. As part of our initial background research, the team attempted to ride the bike and analyzed the components. Consequently, we realized there were several challenges to using the original frame in conjunction with adjustability mechanisms. For example, to add in an adjustable seat track, the overall seat height relative to the ground would need to be increased. However, this addition would cause potential interference between the rider's knees and the Primal 1's fixed handlebars during pedaling. Figure 2 shows an example of this potential interference.

Figure 2. Maximum clearance between Nick's legs and the handlebars with current seat configuration

In addition, Mr. Leone designed the original bike for a six-foot-tall rider. We realized that due to the resulting frame geometry and a limiting down tube in front of the seat, shorter riders could not reach the farthest pedals without the addition of a non-robust method such as pedal blocks. We deemed that both issues would be difficult to overcome in order to implement a new adjustability mechanism on the original frame. As such, it is important to evaluate the necessity and challenges of building a new frame and analyze the feasibility of using the entire Primal 1 bike or any of its components.

3.0 Objectives

In this section, we outline the exact goals for the Battle Mountain HPV Trainer. In the problem statement, we cover the project's motivations, and the boundary diagram section delineates what is included in our project scope. The boundary diagram changed since the Preliminary Design Review, as we decided to utilize more portions of the original frame and create an adjustment mechanism for the handlebars.

3.1 Problem Statement

Mr. Leone's new rider for the Battle Mountain Human Powered Vehicle (HPV) speed challenge traditionally races on a road bike. As such, the rider requires a training device to become more comfortable with the extremely reclined pedaling position of a recumbent HPV speed bike.

The training device must also be adjustable to fit a variety of rider heights and allow for a range of seat back angles that the rider can choose from to practice.

3.2 Boundary Diagram

Our team created a boundary diagram shown in Figure 3 to fully define the bounds of our senior project. We decided that the current Primal 1 frame cannot accommodate all planned modifications as is, but due to budget constraints we must use as much of the original frame as possible. Therefore, we will utilize the front portion of the frame and the rear triangle for the trainer and only remove the center bar where the seat attaches. This maintains the current drivetrain components and allows for the freedom to redesign the middle sections of the frame and related seat hardware, while also adjusting the handlebars. The seat back reclining (1), seat track adjustment (2) and handlebar positioning (3) subsystems are labeled in Figure 3 as the updated boundary diagram.

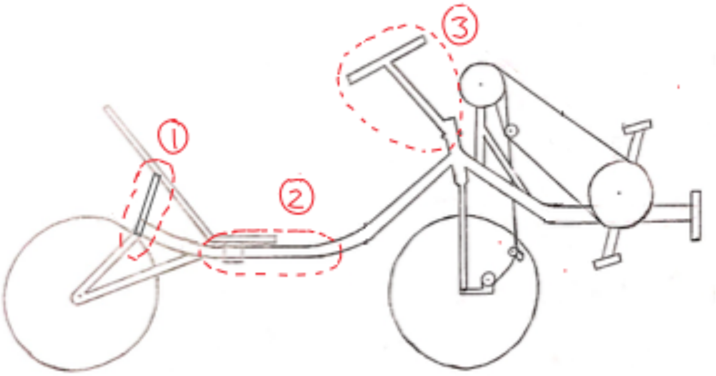

Figure 3. Boundary Diagram used for Problem Definition

Additionally, we include the sliding collar portion highlighted in yellow in Figure 4 in our scope, as we will permanently move the pedal location closer to the rider to accommodate shorter riders. Moving the pedals will create slack in the drivetrain's front chain, so we also remove chain links to compensate.

Figure 4. Portions of the primal 1 bike that will be removed, modified or utilized as shown for the trainer – highlighted in red, yellow, and green, respectively.

In Figure 4, we highlighted in green the portions of Primal 1 we plan to utilize as is for the trainer frame.

The lower beam highlighted in red is not included in the new design, as this is where our seat track adjustment mechanism will be located. The portions highlighted in yellow will be used on the new trainer but modified slightly. By allowing for modifications in these areas, we can better integrate the new adjustability mechanisms.

3.3 Engineering Specifications

Table 3 summarizes the updated engineering specifications for our project. Tolerances for the targets and requirements are also included, along with the risk associated with each parameter. The compliance column shows the manner in which we will determine if we meet the specifications. The letters A (analysis), T (test), S (similarity), and I (inspection) are used to describe how each engineering specification can be verified. We rank each specification L (low), M (medium), or H (High). A low risk specification is easily achievable, whereas a high-risk specification is one that is more difficult to achieve and must meet the tolerance requirements. We identified two high-risk specifications: the minimum and maximum distances from the seat back to the farthest pedal. Both of these are crucial specifications we must meet in order to fit the desired range of rider heights.

Table 3. Engineering Specifications

Specification Number	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Maximum Adjustment Time	3 minutes	±10 seconds	L	T
2	Available Seat Back Angles	90°-150°	Min	M	I, A
3	Supportable Rider Weight	250 lbs	Min	M	A, T
4	Minimum Distance from Seat Back to Farthest Pedal	33 in	±0.5 in.	H	I, A
5	Maximum Distance from Seat Back to Farthest Pedal	39.4 in	±0.5 in.	H	I, A
6	Total Cost	$200	Max	M	I

The methods of testing our specifications are listed in detail below:

1. **Maximum Adjustment Time.** The bike needs to be able to be adjusted quickly and with ease. Changing the seat location, pedal location, and angle of the seat should take less than 3 minutes. We will test this by timing multiple people adjusting all three mechanisms.
2. **Available Seat Back Angles.** The seat needs to be able to recline and be fully supported from a 90 degree angle to a 150 degree angle. We will analyze our design to make sure the reclining mechanism can span this range, and we will verify the prototype meets the requirement by measuring the angles.

3. **Supportable Rider Weight.** The bike should be able to support at least a 250-pound rider without breaking. We will first analyze our frame with hand calculations or finite element analysis (FEA) software to ensure that it will not break under this load. Additionally, we will use weights to test that the final manufactured bike does not break when loaded.
4. **Minimum Distance from Seat Back to Farthest Pedal**. The seat back must be able to be positioned at a location 29.1 inches away from the farthest pedal at full extension.
   This matches the hip height for a fifth percentile female. This will be analyzed thoroughly during detail design and will be measured once the prototype is built.
5. **Maximum Distance from Seat Back to Farthest Pedal.** The maximum distance the seat back can be from the pedals should be 39.4 inches. This will make sure we can accommodate 95th percentile males, which will thereby include George's rider. Like the minimum distance specification, we will analyze this dimension during detail design and measure it on the final bike.
6. **Total Cost**. The total cost of the project must be less than $500. We will keep track of all our expenses and perform a cost analysis of all our necessary components and manufacturing costs before we buy anything to prevent running out of money.

4.0 Concept Design

This section outlines the concept development process used to determine the preliminary designs for both the seat back reclining and seat track adjustment mechanisms. This process began with multiple idea generation sessions that produced the initial design concepts. From here, we used decision matrices to comparatively evaluate the top mechanism design and establish each mechanism's design direction.

4.1 Initial Idea Generation Process

After performing product and patent research our team performed two different idea generation sessions. For the first idea generation session, the team split into two groups. Each group focused on creating original or inspired concepts for one adjustability mechanism, either the reclining seat or adjustable seat track. To do so, each team member sketched different mechanisms for a five-minute period, stressing quantity over quality.

For the second idea generation session, our team performed additional focused product and patent research. This research primarily focused on seat track mechanisms and reclining functions used with existing recumbent and HPV bikes. Rather than generating entirely new adjustability mechanisms, our team wanted to investigate if there were common mechanisms used by HPV teams.

After completing both idea generation sessions, our team began prototyping concept models based on a few of the ideas from brainstorming. The primary goal of creating the concept models was to understand the ergonomics required to accommodate a 5th percentile female and 95th percentile male in our bike frame. To achieve this, we created two scaled clay models to represent our two rider heights. In addition, two seat track and reclining mechanisms were created based on our idea generation sessions. By placing our models in the concept models, we gained an initial idea of how much adjustment we would need to accommodate our two rider heights in a scaled down version. These initial concept models can be found in Appendix A.

The concepts formed in each of the ideation sessions were separated by their adjustment mechanism and then evaluated through Pugh matrices. Pugh matrix analysis evaluates multiple concepts against a baseline concept for specific parameters.

Concepts that performed better than the baseline were investigated further and were considered as top concepts. The Pugh matrices used to evaluate each series of adjustment mechanisms are in Appendix B.

4.2 Concept Sketches and Decision Matrices

We generated sketches of our top concept ideas to help visualize the mechanisms and analyze their viability. We created a series of sketches for both the seat track and seat back adjustment mechanisms and used weighted decision matrices to choose the top concept.

4.2.1 Seat Track Adjustment Mechanism

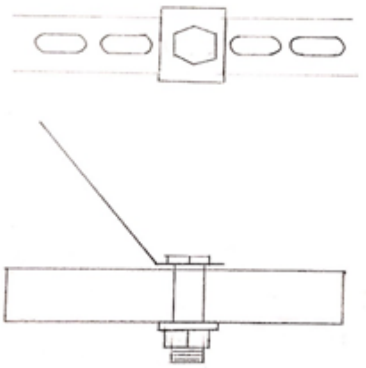

Figure 5. Unistrut beam and bracket seat track mechanism

The unistrut concept in Figure 5 relies on proprietary unistrut metal framing. Each frame beam has a series of channels that allow a threaded rod to clamp the bike seat to the unistrut with the use of a special nut. The unistrut would act as the main frame for the middle portion of the bike between the wheels. Since unistrut is generally box beam shaped, its cross-section geometry varies from the tubular bike frame.

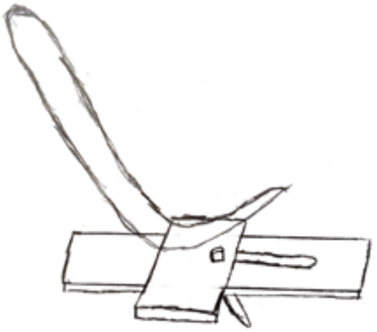

Figure 6. Slot and lever seat track mechanism

The slot and lever design shown in Figure 6 utilizes a carriage that can slide on a slotted beam that acts as the fixed center bar of the frame. For this design, a threaded rod attaches to the top of the carriage and is constrained to travel in the slot, and the lever locks the carriage in the desired location. The combination of the threaded rod and lever handle thereby allows for easy adjustment.

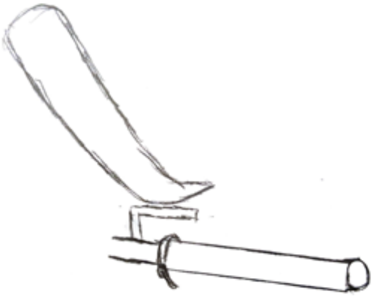

Figure 7. Concentric tube and bike seat post clamp seat track mechanism

The bike clamp design in Figure 7 utilizes a quick release lever found on many bike seat posts, in conjunction with two concentric cylinders with very low clearance between the inner diameter of the larger cylinder and the outer diameter of the smaller. When the lever is locked in place around the tubes, the clamp compresses the outer cylinder, which locks the inner cylinder in place.

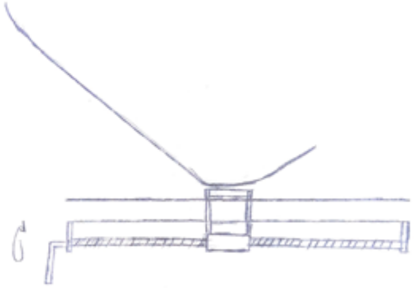

Figure 8. Use of a lead screw to adjust longitudinal seat position

The lead screw in Figure 8 design consists of a carriage that fits around the main frame and a lead screw that adjusts the position of the carriage on the frame. The carriage has a threaded portion that fits on the lead screw, and the lead screw is fixed in bearings that attach to the frame. A crank makes it easy to rotate the lead screw. Note that there is no additional lock for this design besides the lead screw threads.

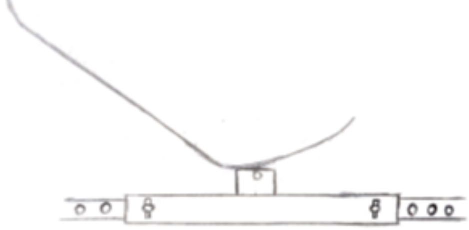

Figure 9. Seat track mechanism with spring-loaded pins and holes

The spring-loaded pin design shown in Figure 9 uses two different size box beams, one within another.

The smaller center beam is the center bar of the bike frame, while the other serves as the seat carriage. Both beams have equally spaced holes drilled in them, and two spring-loaded pins allow the user to lock the seat in place in the corresponding fixed locations.

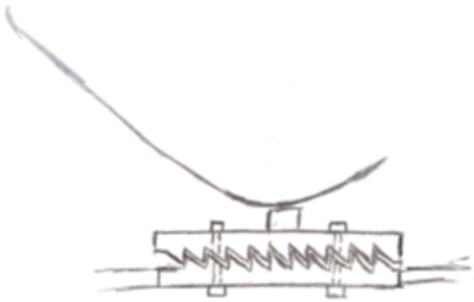

Figure 10. Bolted sawtooth plates seat track mechanism

Figure 10 presents a visual of the sawtooth plates design, which is comprised of two plates with interlocking sawtooth patterns and a series of holes for a screw and nut to clamp the plates together. One of the plates can function as part of the frame or they can both be attachments to the frame. Note that the seat and the top plate must be raised above the lower plate in order to adjust the longitudinal seat position. Once the seat is at the desired location and bolted, the matched teeth would not allow the seat to translate.

We evaluated each of the top concepts for the seat track mechanisms against one another using a decision matrix shown in Table 4. In order to give larger influence to more important criteria, we assigned relative weights to each, with higher scores indicating greater importance. Criteria with the highest weights included precision of adjustability, mechanism durability and ease of manufacturing. Due to large variation in anthropometric data between our maximum and minimum riders, a system that can be continuously adjusted scored higher in our decision matrix. In addition, we deemed that the chosen adjustment mechanism must be durable and last through the predicted life of the trainer. Finally, since we will manufacture both adjustability mechanisms at Cal Poly, we valued a design that could be manufactured by novice to moderately skilled machinists.

Table 4. Decision Matrix for Seat Track Mechanisms

Criteria	Weight	Seat Track											
		Sawtooth Plate		Crutches		Bike Clamp		Lead Screw		Unitrack		Slot and Lever	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Precision of Adjustability	4	3	12	2	8	5	20	5	20	2	8	5	20
Cost	2	2	4	4	8	4	8	1	2	4	8	3	6
Ease of Adjustability	2	3	6	4	8	2	4	4	8	4	8	4	8
Quick setup time	3	1	3	3	9	2	6	1	3	2	6	4	12
Durability	4	4	16	4	16	3	12	3	12	4	16	4	16
Ease of Manufacture	4	3	12	5	20	5	20	1	4	5	20	3	12
	TOTAL:		**53**		**69**		**70**		**49**		**66**		**74**

From our decision matrix presented in Table 4, the slot and lever, bike clamp, and crutches design performed the best out of our top six concepts.

Due to the continuous range of adjustability for seat track length and the high ease of adjustment, the slot and lever design stood out as the best seat track mechanism. However, compared to the bike clamp and crutches design, the slot and lever design had a much lower score for ease of manufacturability.

After we consult with our sponsor, if the manufacturing plan and integration for the slot and lever proves to be too difficult, the bike clamp design will serve as a backup. For now, the current design direction for the seat track mechanism is the slot and lever design.

4.2.2 Seat Back Reclining Mechanism

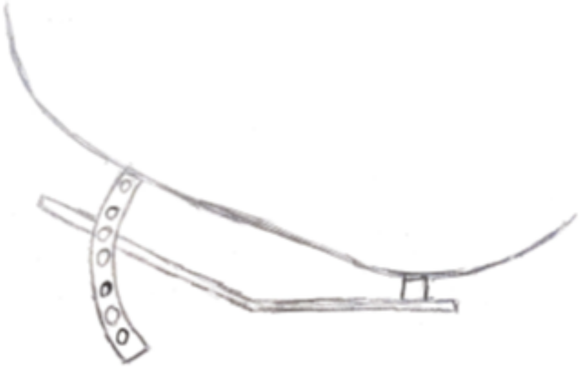

Figure 11. Seat back angle changed by moving pin in two crescent design

The crescent angle adjust design in Figure 11 is similar to reclining mechanisms commonly found in exercise benches. The design uses two crescent-shaped arcs that connect to the back of the seat directly. With the seat able to pivot at the bottom, the user selects an angle by choosing one of the holes on the crescents to put a pin through to fix to the support bar.

Figure 12. Seat back angle adjusted via dual rods with pins and holes

The dual rods design shown in Figure 12 has two rods mounted on the back of the seat where each has set hole locations to lock the seat at predetermined angles. If more precise angle adjustment is desired, rather than using predefined hole locations, the frame can have two collars that allow the dual rods to slide freely. Tightening the collars prevents the rods from translating along the collar path and thus fixes the angle of the seat.

Figure 13. Seat back supported and reclined by two telescoping rods

Figure 13 shows a sketch of the telescoping rods design, which has two telescoping rods that attach to the back of the seat from support bars. Each rod needs to be able to pivot at both ends as the angle of the seat changes. The design has a smaller diameter inner rod that is able to slide in and out of the larger outer rod. A friction clamp holds the inner rod in place relative to the outer rod. This clamp holds each telescoping rod at a specific length.

Similar to the top seat track concepts, we evaluated the reclining seat mechanisms against one another using a decision matrix shown in Table 5. The overall design criteria remained the same as the seat track criteria; however, there were slight adjustments to the weighting of a few parameters. The team reduced the weighting for precision of adjustability to a lower value because set angles for adjustment are the minimum requirement. While higher precision in angle adjustment would be a bonus, angle adjustment does not greatly affect the ergonomics of pedal stroke for different rider heights. Ease of adjustability was weighted higher for the reclining functions, as our sponsor desired an intuitive angle adjustment mechanism.

Table 5. Decision Matrix for Reclining Functionality Mechanisms

Criteria	Weighting	Reclining Functionality					
		Crescents		Dual Rods		Telescoping Rods	
		Score	Total	Score	Total	Score	Total
Precision of Adjustability	2	2	4	4	8	2	4
Cost	2	4	8	4	8	2	4
Ease of Adjustability	3	4	12	3	9	3	9
Quick setup time	3	4	12	3	9	3	9
Durability	4	4	16	4	16	3	12
Ease of Manufacture	4	5	20	4	16	5	20
	TOTAL:		**72**		**66**		**58**

After evaluating our top concepts, the crescent design stood out as the best concept. The crescent design provided a low-cost option, and an easily manufactured part, which in turn resulted in the highest score. Almost all of the top concepts utilize a set angle adjustment as a key component of their design. Some of the designs are limited to this set angle adjustment such as the telescoping rods design. However, the crescent design can be modified to incorporate a finer adjustment range, by changing to a slot design rather than set hole positions. For our current design direction, the crescent design will be our chosen angle adjustment mechanism and will utilize a series of fixed angles to recline the seat.

4.3 Selected Design Concepts

As mentioned above, the concepts we selected are the slot and lever design for the seat track and the crescent for the reclining mechanism. Figure 14 is a CAD model of our concept prototype and Figure 15 is the concept prototype that we built. For Figure 14, segments in green will be maintained from the Primal 1; parts in blue will be new designs or significant modifications.

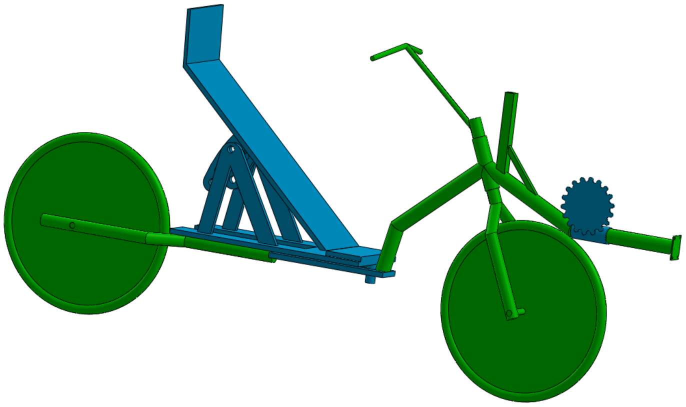

Figure 14. Overall concept CAD for the adjustable HPV trainer.

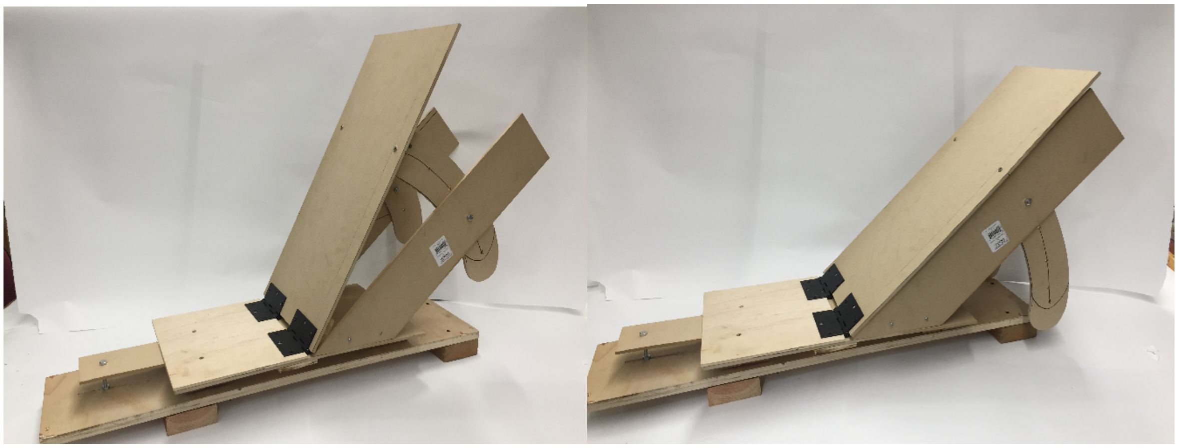

Figure 15. Concept prototype of slot and lever seat track and crescent reclining mechanism

The slot and lever will function by tightening or loosening a clamp underneath the slot that uses friction to hold the seat in place along the slot. To engage or disengage the clamping action on the slot, the lever is used. When the user loosens the clamp by using the lever, the pin is able to slide forward and backward in the slot, which allows the seat to move forward and backward. The seat can move along the slot to accommodate different rider heights so that the rider feels comfortable sitting in the trainer and pedaling.

A pedal adjustment mechanism will be used from the Primal 1 frame to prevent the slot and lever seat track from needing to account for the entire adjustability for different rider heights. The drivetrain connects to a collar that can freely translate on the straight bar at the end of the frame. This allows the pedals to move towards or away from the rider to fit the rider's in-seam length.

However, the current mechanism lacks a chain tensioning mechanism if the pedal distance changed. As such, our team has designed a post to extend off the front half of the frame. The chain-tensioning sprocket can move by changing the pin placement through a series of sequential holes to properly tension the chain. Below is Figure 16, a sketch of the chain tensioning mechanism.

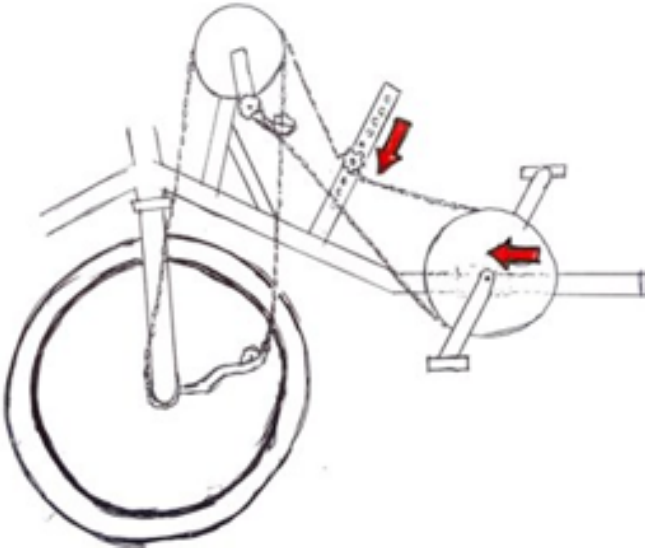

Figure 16. Chain tensioning mechanism to allow for pedal location adjustment

For reclining the seat, the crescent functions by inserting a pin through the different holes in the crescent into the pin hole in the frame. When the pin is removed, the seat and crescent are able to rotate and can be adjusted to a specific angle once the pin hole on the crescent lines up with the hole in the frame. This allows the angle of the seat back to rotate through several set angles from 90 degrees to 135 degrees.

The crescents will likely be made of aluminum because we are planning to use a waterjet to cut the desired geometry and aluminum will be easy to machine. Because the waterjet might not produce the best finish on the edges that it cuts, we might want to use a drill or reamer to produce a clean finish on the pin holes. Drilling or reaming the pin holes will ensure that user can easily take out and put in the pins. We will likely be using bolts and nuts to pin the crescents to the frame.

4.3.1 Initial Design Analysis

To analyze the concept of our designs, we created some rough ergonomic models in SolidWorks to understand how a rider would fit in our concept frame. Shown in Figures 17 and 18 are two of these ergonomic models.

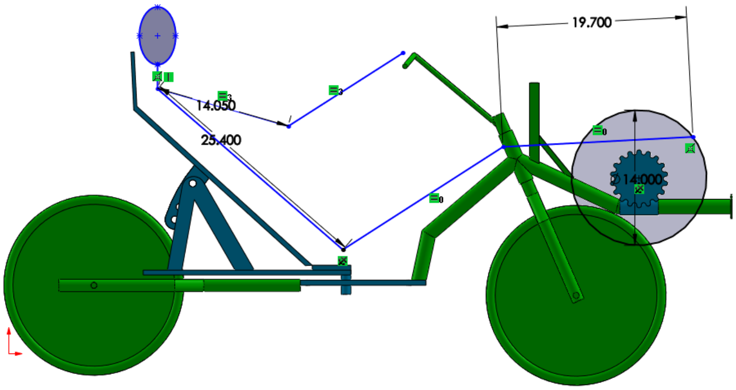

Figure 17. Bike with 95th percentile male

In Figure 17, a wireframe rider of a 95th percentile male is positioned in our HPV Trainer. The seat has been moved back in the slot so that someone with longer legs is able to reach the pedals without feeling cramped or having their knees bump into the handlebars. To model this stick figure, we used the data from FSAE Anthropometric Reference Data- located in Appendix C. The length for each half of the leg was assumed to be half of the overall Hip Height value.

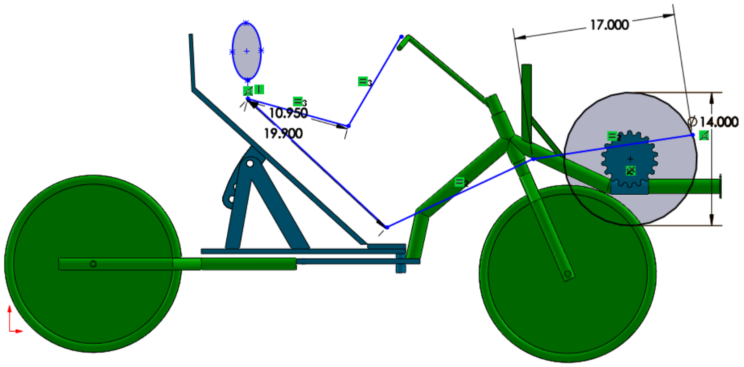

Figure 18. Bike with smallest size person that could reach pedals

Similar to Figure 17, Figure 18 shows a smaller wireframe rider sitting in the HPV Trainer. Figure 18 shows the model with the shortest legs that is able to reach the position on the pedals to be able to rotate over the drivetrain. The resulting hip height is 33 inches, which is a few inches greater than the hip height of the 5th percentile female. Initially, the 5th percentile female was our goal for the shortest rider to be able to use the HPV Trainer.

Since the bike frame does not currently accommodate short riders, we need to consult our sponsor regarding whether or not we can reduce the range of rider heights or if we must reach a different solution. With the current design, shorter riders could still potentially use the trainer but would need to use pedal blocks to accommodate for the additional pedal distance. We are hoping that after consulting with our sponsor, we will be able to determine a different solution before PDR

With the shortest rider configuration, there is potential interference between the wheel and the pedals. The circle around the blue sprocket in Figure 18 represents the overall pedal stroke.

If the wheel turns more than five degrees, the pedal and wheel will collide depending on the pedal position. However, there is a solution that resolves this issue by placing a wheel fairing or cover over the front wheel. The stationary cover will prevent the wheel from steering five degrees in either direction and prevent the pedals from potentially running into the wheel.

4.3.2 Issues, Risks, and Unknowns

We have identified a few potential issues that may arise later on in our project. Redesigning the bulk of the bike frame will require a large amount of welding. These welds will have to support heavy riders and be durable enough to withstand impact from the bike tipping over. Some of the welded joints could be very complex. For example, we may need to weld rectangular beams to circular parts of the frame. In addition, we will have to strip the paint on the portion of the frame containing the drivetrain if we want to weld it to the new frame sections that we are designing. We will need to investigate outside resources if we want to proceed with a welded frame.

We could also encounter issues integrating our adjustability mechanisms with the portion of the frame that we are keeping. The location of Primal 1's downtube will limit how much we can slide the seat forward, since this is where we must attach the front part of the seat track to stay close to the original bike dynamics. The crescent mechanism relies on the presence of a bar to pin to the crescent holes. This bar needs to move with the seat for the mechanism to work which may lead to a large moment on either the seat or the support bar depending on where the crescents attach to the seat back.

By moving the seat and the back half of the frame to accommodate different riders, we will be changing the center of gravity and wheelbase of the trainer with each rider. This is not an issue for when the bike is used as a stationary trainer, but it will be an issue when the bike is used on rollers. Changing the center of gravity will affect the vehicle dynamics and may not simulate the feel and balance of the bike as desired.

The training bike carries a few innate hazards that we will work to mitigate. We will shield the rider from the wheels and drivetrain to prevent any body parts catching in rotating mechanisms. A seatbelt or five-point harness can be added later to secure the rider and protect them in case the trainer is used on the road. We will also keep the bike in a secure location to prevent any negligent riders from accessing the bike. A full list of safety hazards is located in Appendix D.

5.0 Final Design

After many iterations, we settled on a final design which incorporates three main subsystems, and we will discuss the overall design and each subsystem in detail in this section. The first subsystem discussed is the seat track mechanism, which adjusts the distance between the seat and the pedals. The second subsystem is the seat back reclining mechanism, which allows the rider to set the seat back at fixed angles from 90 to 150 degrees. The third subsystem is the handlebar adjustment mechanism, which lowers the overall handlebar angle and allows for a set range of lengths. This subsystem is a new addition since PDR, and it was incorporated due to the common occurrence of knee and handlebar interference when people were using the structural prototype. Note that the final designs for both the seat track mechanism and the seat back recliner underwent significant changes since PDR and as such the designs presented here vary significantly from the concepts presented in Chapter 4.

5.1 Overall Design

The final recumbent bike trainer is shown in Figure 19. As in previous CA D iterations, green components come directly from the original Primal 1 frame, and those in blue represent new or modified parts that will be separately manufactured and added on. Several components, such as the seat and handlebars, are from the existing bike but have been heavily modified to accommodate different rider heights.

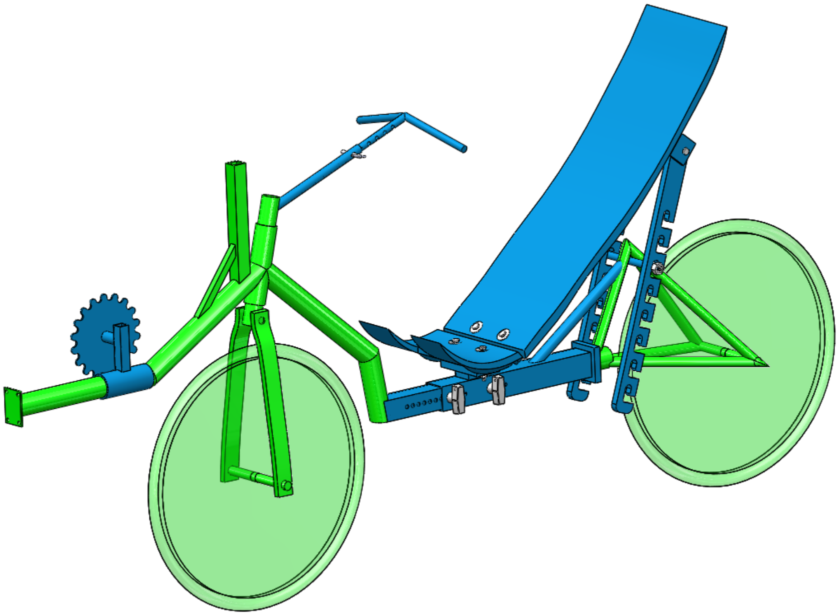

Figure 19. Overall trainer model; drivetrain components not pictured

The assembled trainer can be separated into its front and rear halves – one attached to each part of the telescoping seat track. The inner, smaller square tube of the seat track mechanism attaches at the bottom of Primal 1's original downtube, where the center tube previously attached. The outer square tube attaches to the rear triangle of Primal 1, through a portion of the previous center tube. The bottom of the trainer seat mounts onto the outer tube at a set location, and the seat back attaches to the rear triangle at adjustable positions through the reclining mechanism. Through this, an adjustment in the seat track changes the wheelbase while maintaining the location of the seat relative to the rear wheel.

5.2 Seat Track Adjustment Mechanism

This subsection details the final adjustable seat track design, its interfaces with the rest of the trainer frame, along with the stress and ergonomics analyses performed to size components.

5.2.1 Seat Track Adjustment Mechanism Design

The final mechanism design outlined here allows for a total seat track adjustability range of 7.5 inches, occurring at half inch intervals with a quarter inch of fine tuning available. This range is achieved through the integration of two telescoping square tubes, where the position of the trainer's two halves changes relative to one another as the seat track is adjusted. Once a rider finds their desired seat track length, the two halves of the bike are secured to one another through two quick release pins set in holes through the square tubes.

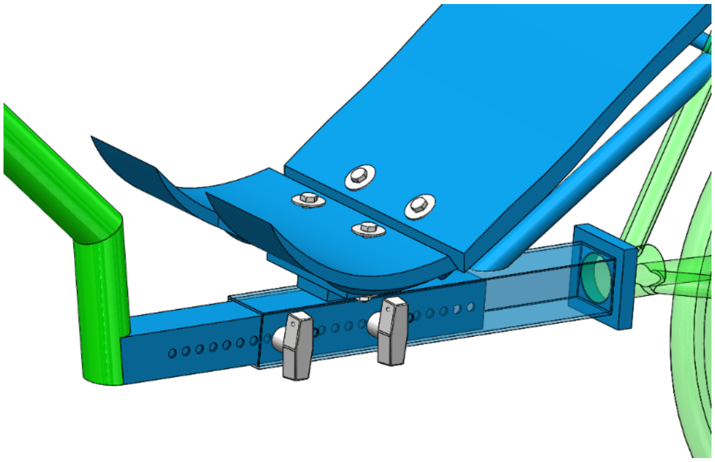

Figure 20. Close-up view of square telescoping tubes

Both the inner and outer tubes are made from 16 gage carbon steel square tube. The nominal outer dimension of the larger tube is 1.75 inches, while the inner tube is 1.5 inches. The inner square tube has 23 holes along its length, with half inch spacing between each hole. In the outer tube, two sets of equally spaced holes serve as set positions for the quick release pins, which can be inserted when the inner and outer holes are properly aligned. The second set of holes in the outer tube is set back 1.25 inches from the first set of holes, thereby allowing the seat location to be shifted another quarter inch in either direction if an intermediate position is desired, requiring the pins to be set there instead.

5.2.2 Seat Track Mechanism to Primal 1 Interface

As previously mentioned, the inner square tube attaches to the front half of the Primal 1 at the original downtube through a welded interface. In order to increase weld area and reduce stress at the rear weld location, the outer square tube attaches to the rear half of Primal 1 through an additional weld plate. The weld plate has a circular cutout that fits the circular tubing attached to Primal 1's rear triangle, as shown in green on the right side of Figure 20. Through this, the outer tubing is welded to the back portion of Primal 1, and this plate is then welded to the outer seat track tube. Additionally, we have repurposed the original rear gusset tube from Primal 1 by changing the angled cuts on each end and will reconnect the larger square tube to the rear triangle through this piece for additional support. This gusset piece is shown as the blue angled rear bar in Figure 20.

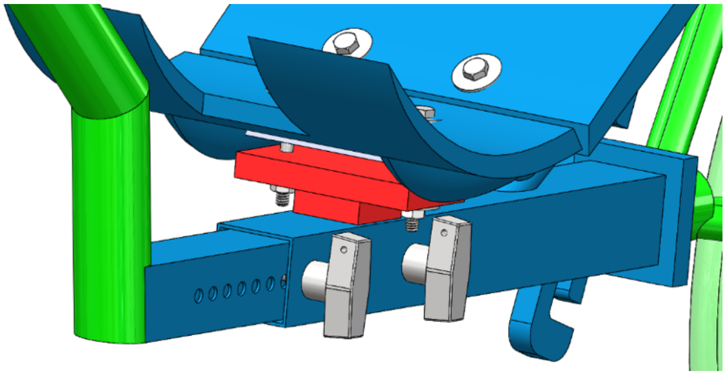

Figure 21. Close-up view of underside of seat with box and plate in red

The seat itself attaches to the seat track through a small box and plate assembly welded to the top of the outer tube, as highlighted in red in Figure 21. This assembly is made of a steel plate welded to a half inch long segment of the 1.5 inch square tube, which in turn is welded to the outer square tube. The plate has two holes that line up with corresponding holes in the seat bottom and hinge to bolt the three parts together.

5.2.3 Seat Track Stress Analysis

To ensure that the chosen square tubing sizes can withstand predicted load cases, we performed hand calculations to determine the stress in regions of interest. After drafting up a Design Failure Modes and Effects Analysis document, which can be found in Appendix M, we felt that these load case calculations would be of great help. The first hand calculation focused on determining the stress developed in the inner box beam near the front weld. Using a worst-case pedal load of 350 lb. and rider weight of 250 lb., we calculated the wheel reactions, using the overall FBD shown in Figure 22.

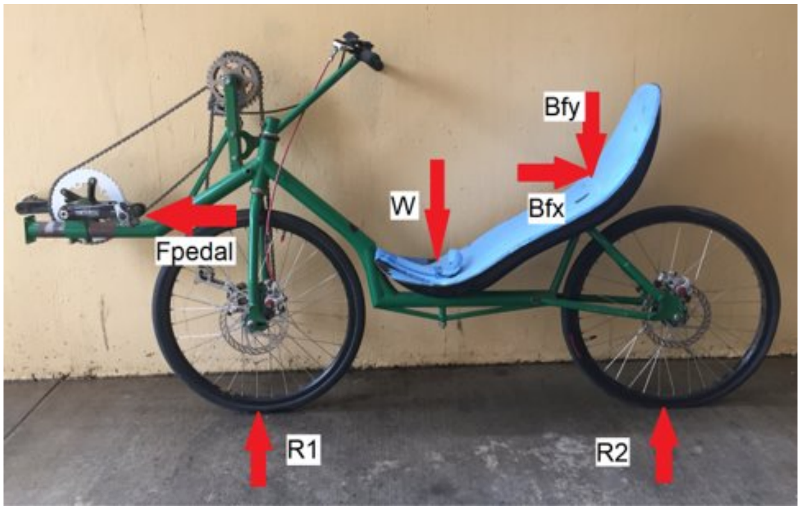

Figure 22. Load cases drawn in for Primal 1 in use

From the overall FBD a “cut” can be made after the weld at the interface of the down tube and the box beam. By transferring loads to the cut plane, the overall stress state at the box beam was determined. With part failure defined as yielding in the box beam, this calculation produced a factor of safety close to 2. The in-depth hand calculations and MATLAB code can be found in Appendix I.

To properly size the holes in the box beam, we calculated the bearing stress in each hole and compared it to the steel's yield strength. For this calculation, we applied a max load case of 250 pounds to each quick release pin in the telescoping square tube section. The initial hand calculations provided a factor of safety of 7.6, which further justifies the chosen hole sizing. The in-depth hand calculations and associated FEA simulation can be found in Appendix I.

5.2.4 Seat Track Ergonomic Analysis

To determine the overall seat track length required to fit the rider height range, we utilized the structural prototype shown in Figure 23, made of three main components.

The front portion consisted of the front half of the Primal 1 Frame with the pedals attached, set on a stand to mimic the heights of all components in the final frame. The back half was an independent stand that supported the bike seat at its design height, with the seat back set to 150 degrees.

Figure 23. Structural prototype with participant and handlebar measurement device

To test for proper seat to pedal distances participants sat in the seat and the distance to the front portion of the prototype was adjusted until they could reach the farthest pedal with a slight bend in their knee and pedal comfortably. The third part of the prototype allowed us to collect data on comfortable handlebar positions, and it will be discussed further in Section 5.4.

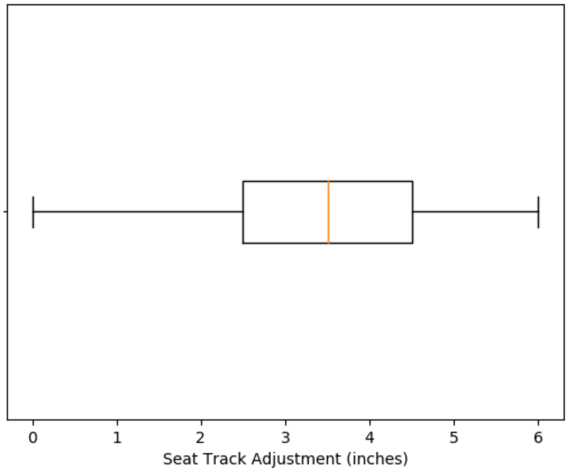

Figure 24. Desired seat track adjustment distances from structural prototype tests

The structural prototype was tested by 13 participants with heights spanning the required rider height range of 5’4” to 6’2”. From the participant’s preferred distances between the front and rear halves, we found the minimum and maximum pedal distances our design must accommodate. The shortest participant required the seat to be set flush with the front half of the frame, and the tallest participant required the seat to be set 6 inches back, as shown in Figure 24. To allow for slightly taller riders, or riders with particularly long in-seam length, our seat track mechanism will have a total of 7.5 inches of travel, accomplished with the 23 holes at 0.5 inch spacing.

5.3 Seat Back Reclining Mechanism

This section outlines in detail the overall seat track reclining mechanism, how it interfaces with the rest of the trainer, and stress calculations performed to size critical components.

5.3.1 Overall Seat Back Recliner Design

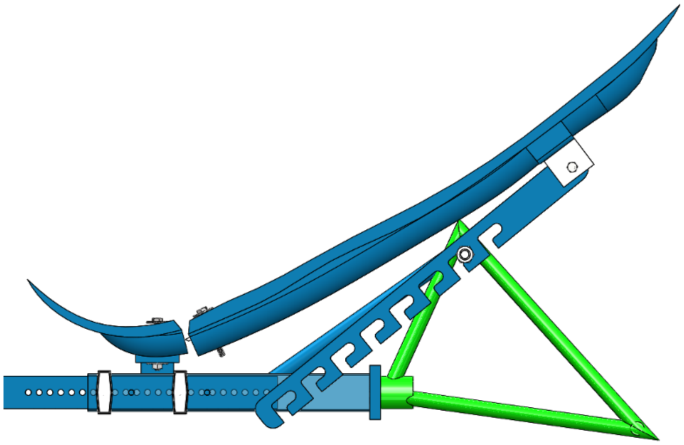

Figure 25. Overall seat back reclining mechanism and modified seat

The seat back reclining subsystem consists of two smaller sub-assemblies that together allow the seat to recline and be secured at the set intervals between 90 and 150 degrees. The first sub-assembly consists of a hinge for the carbon fiber seat provided by Mr. Leone, and the additional parts required to attach the hinge to both halves. The second sub-assembly, which includes the support arms and pin connections, provides means for the seat to be secured at a desired angle. The overall design and each sub-assembly are examined in greater detail in the following sections.

5.3.2 Two Piece Seat and Hinge Design

The original seat provided by our sponsor is made of carbon composite with layers of reinforcement fiberglass on the outer surface. In order to allow the support arms to adjust the seat back angle independent of the bottom, the seat will be cut into two pieces – one piece to support the rider's back and a bottom portion to support their butt.

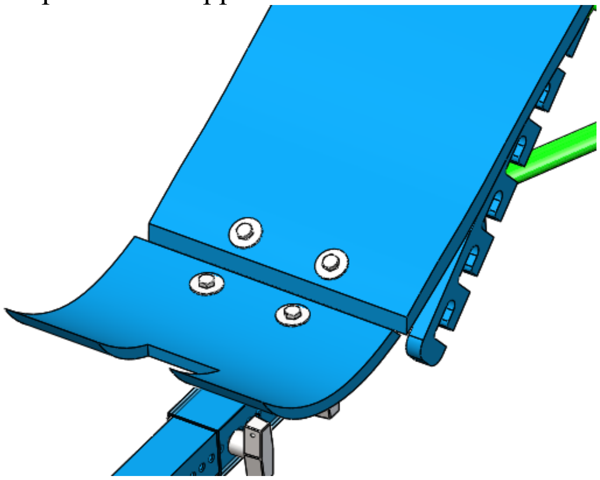

Figure 26. Close-up of seat bottom and seat back connection point

As seen in Figure 26, this allows the two seat parts to pivot about one another, as a hinge will be attached at the cut location. Since drilling and bolting into composite parts can significantly weaken the strength at the holes, we will bond a 1/16 inch thick aluminum sheet to the bottom surface of the seat. Concentric holes drilled through the seat, aluminum plate and hinge allow for connection of all components through quarter inch bolts that will be secured with oversized washers and nuts as shown in Figure 26. The oversized washer helps distribute the load through the bolt hole while the bonded aluminum plates help prevent catastrophic shear out, as both the seat and aluminum plate would need to fail first.

5.3.3 Seat Back Reclining Mechanism

To support the seat back at set angles within the design range of 90 to 150 degrees, two notched support arms are used to adjust and secure the seat back position. The support arms are 19 inches long, ½ inch thick, and manufactured from mild steel. The slots in the support arms are evenly spaced and provide an average angle adjustment of eight degrees.

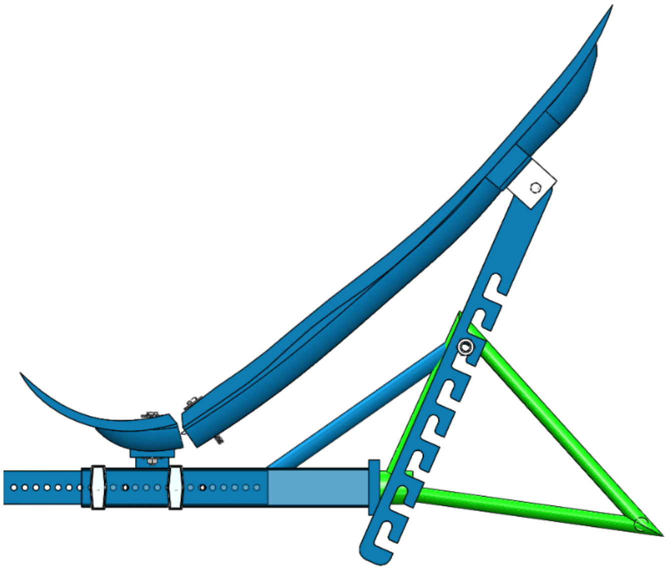

Figure 27. Overall seat reclining mechanism in slightly upright position

As shown in Figure 27, the reclining arms are supported by pin connections at the top and bottom, thereby they are free to rotate when not in a slot. To adjust the seat back angle the arms must be translated upward and then towards the seat to free them from the bottom pin, aligned with the desired slot, and replaced in opposite order. The notched slot design ensures that the seat back is secure once a rider is in the trainer and eliminates the need for additional adjustment hardware.

5.3.4 Seat Back to Support Arm Interface

To securely attach the support arms to the carbon fiber seat back without inlaying any support hardware, the seat back will be permanently modified near the top of the stiffening ribs. The modification provides a flat, protruding surface for U brackets to adhere to. Two quarter inch shoulder bolts and a nut secure through both sides of the brackets and the support arms, thereby providing a smooth upper pin connection, as shown in Figure 28.

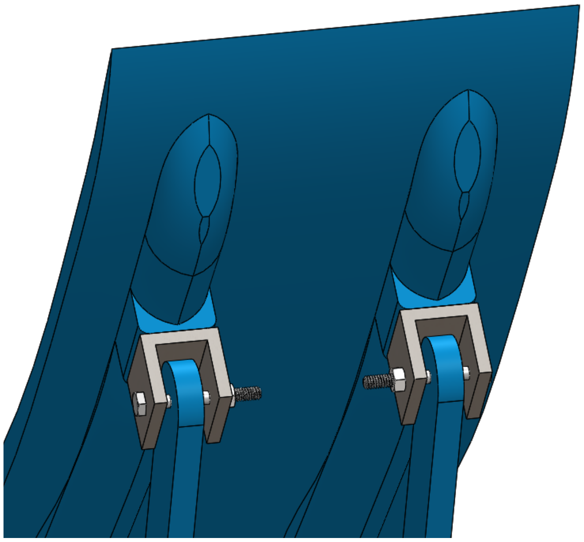

Figure 28. Rear seat back to support arm pin connection point

To provide the flat, raised connecting surface for the support arms, a section of the stiffener ribs will be removed near the top of the seat, and a piece of foam will be inserted in its place. The foam block will then be reinforced with fiberglass, and the U brackets will be attached with epoxy. This updated, pin connection method allows the support arms to freely rotate while adjusting, eliminating the need for a curved support arm.

5.3.5 Support Arm to Rear Triangle Support Point

In order to keep both support arms parallel with the trainer's main axis, the bottom connection points for the arms must lie on a perpendicular plane. Additionally, the point of attachment must be high enough on the rear triangle that the support arms and their required lengths clear the ground at all positions.

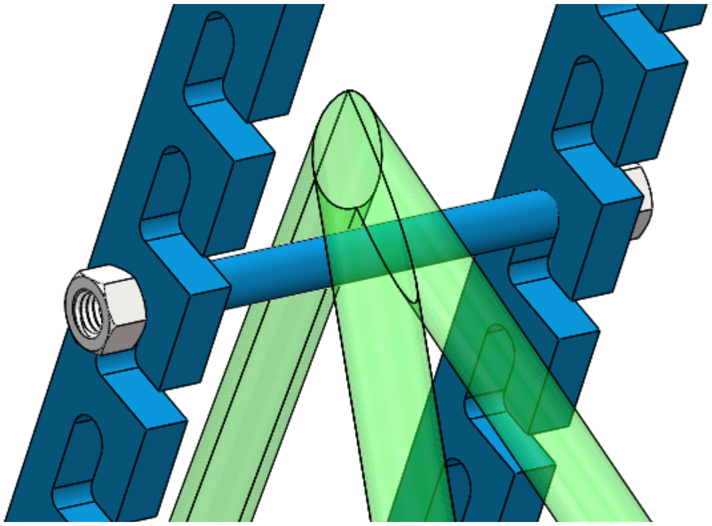

Figure 29. Close-up view of rear pin support member

Consequently, the second connection point for the support arms consists of a half inch round tube with nuts welded on each end.

The nuts are then welded to the interior connection point of Primal 1's rear triangle, as shown in Figure 29. This position allows for perpendicularity with the support arms, and the bar can extend far enough to prevent interference with other components on the bike frame, especially the rear wheel. The two nuts welded to the ends also restrict the support arms' lateral movement, as they are larger than the slot width.

5.3.6 Support Arm Stress Analysis

To ensure that the support arms were sized properly, hand calculations were performed to approximate the maximum stress in the support arms. With a compressive, 300 pound load applied to the end of the support arms and the seat in its most upright position, we calculated the resulting stress state at the lowest slot. From the hand calculations, for a ½ inch thick support arm, the factor of safety was 6.55. We ran an FEA study of the load case and the factor of safety decreased to 4.75. The FEA simulation can better estimate bearing stress created in the slot in comparison to the hand calculations- which resulted in a lower safety factor. Due to these results, and the fact that a 300 lb load is rather unlikely for our application, we are confident in the sizing of the support arms as they were able to handle extreme load cases for our application. The hand calculations and FEA images can be found in Appendix I.

5.4 Handlebars

From the ergonomic tests we performed through our structural prototype, we found the current handlebar position was not ideal for the variety of riders that will be using the bike trainer as most rider's knees collided with the handlebars when trying to pedal. As such, we recorded comfortable potential handlebar positions with our structural prototype and used this data to find a new handlebar location and determine that it must telescope to accommodate different sized riders.

5.4.1 Handlebar Adjustment Mechanism

Our final handlebar adjustment mechanism design uses telescoping tubes and a quick release pin to select the extension distance of the handlebars. The model of the assembly can be seen in Figure 30.

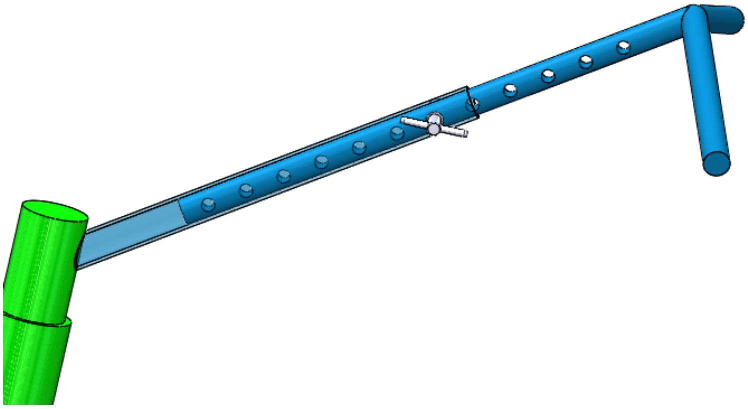

Figure 30. Final handlebar adjustment mechanism design; outer bar shown as transparent for clarity – will be solid metal in final design

The larger tube is a 1.125 inch outer diameter tube with a wall thickness of 0.065 inches. One 0.257 inch diameter hole will be drilled through both sides of the tube to create a tight fit with the 0.25 inch detent pin. The inner tubing is the original 0.875 inch tube handlebar assembly that we are cutting off at the head tube. This tube will have twelve holes drilled at uniform spacing which provides many options of handlebar stem length.

5.4.2 Handlebar Ergonomics Analysis

The geometry of the handlebar adjustment mechanism was selected based on our ergonomics analysis. As shown in Figure 23, a piece of lumber with holes drilled through was used to help riders find their ideal handlebar location. We had riders try a range of different horizontal locations by moving the wooden post back and forth as well as a range of vertical locations by moving the PVC tubing up or down to different holes. Once the rider identified the handlebar position they found most comfortable, we recorded the chosen horizontal and vertical positions. All of our recorded data from this analysis can be found in Appendix J.

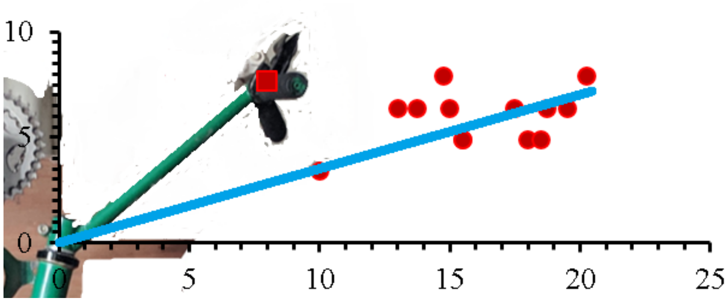

Figure 31. Plot of the preferred horizontal and vertical locations of the handlebars in inches from the mounting point of the head tube

The results of our ergonomics analysis showed a wide range of preferred handlebar positions. While we would have liked to design a mechanism that incorporated both linear and angle adjustments, we did not have enough money remaining in the budget to buy or manufacture these complex parts. We decided to design for accommodating as many riders as possible with only a translating adjustment mechanism. Our resulting final handlebar design places the handlebars at a lower angle than the previous handlebars as shown by the green line in Figure 31. The new handlebar angle allows the length to change due to telescoping circular tube. The lower angle allowed for the handlebars to capture a majority of the preferred handlebar positions, with the telescoping length allowing for additional flexibility for comfort. The total length adjustment is close to 8 inches. The handlebar position can be set close to the head tube, like the current handlebar position, thereby allowing riders to still use the handlebars when the seat back is in its 90 degree position, although they will be quite close to their torso.

5.5 Safety, Maintenance, and Repairs

We want to make sure our prototype is safe to use and will function as intended, therefore we analyzed its safety hazards, along with points for maintenance and repairs. Overall, the trainer's safety hazards are similar to those of common bikes. To make our design is safe, pinch point hazards are one risk that must be mitigated. To do this, we will make user manuals that explain the safe procedures for using the adjustment mechanisms. The most hazardous pinch points are the front wheel and the drivetrain.

If our sponsor feels the need to pursue safety precautions on these hazards that are universal among any bike with a chain and spinning wheel, we will investigate both designing a cage for the wheel similar to the cage on a fan and creating a cover for the chain. Both these modifications will block riders from the pinch points but will potentially interfere with the already limited space for the rider's legs.

To maintain the prototype, the nuts on the U-brackets should be checked every month of regular use to verify they are tight and that the bolts will not fall out. Additionally, the quick release pins should be inspected every few months to make sure the spring-loaded ball has not worn down. If there are signs of wear, the pin should be replaced. Drivetrain components should be lubricated as they would be on any bike.

We do not anticipate any repairs being necessary. However, should the bike fall and withstand impact loading then the welds should be inspected for any signs of cracking or other failure. Any welds or parts that appear to be damaged should be repaired accordingly. For more information regarding use and maintenance of the bike, see the Operator's Manual in Appendix O.

5.6 Summary Cost Analysis

Here we present a generalized cost breakdown of the final prototype, broken down by the subsystems presented above. In all, the trainer has an overall budget of roughly $200, which we aimed to stay below during the manufacturing phase.

Table 6. Generalized cost breakdown for final prototype

Subsystem	Hardware and Raw Material Costs
Seat Track Adjustment Mechanism	$ 69.33
Seat Back Recliner	$ 126.00
Handlebar Adjustor	$ 19.24
Overall Frame	$ 15.99
Total Cost:	**$ 226.08**

From Table 6, it is evident that the seat back recliner subsystem requires the largest portion of our budget. This is mainly due to the cost of the steel plate that will also be used for parts in the seat track adjustment mechanism. However, since most of the material goes towards the support arms, the cost was all assigned to the reclining mechanism. Currently, the estimated project cost is slightly over budget, but we will look for lower quantities of certain hardware, such as the hex nuts, at hardware shops like Ace Hardware. If we can buy individual pieces of hardware rather boxes of 100 items, we will be able to reduce the current cost. For a full cost analysis broken down by component, reference Appendix K.

6.0 Manufacturing

Because our confirmation prototype consists partially of existing parts and components from Mr. Leone's previous bike, the Primal 1, our manufacturing process included both modifications to old components and construction of new parts. The new components include the reclining mechanism support arms, a telescoping handlebar extension, and telescoping box beams. Changes to existing parts include all seat modifications, the hinge mechanism, and overall frame assembly manufacturing.

In order to make these modifications we purchased hardware and steel stock, and a final budget breakdown is presented in the following subsection. Following this, the final subsection covers the manufacturing process and all steps followed. For those who may want to produce a similar product in the future, we also include a subsection on the manufacturing challenges faced and resulting recommendations.

6.1 Part Procurement Process and Final Budget

Most modified parts on the bike required the purchase of additional materials, such as the steel box beams for the adjustable seat track. Commonplace items like bolts were procured at local hardware stores, while specific metal stock parts were purchased from online retailers or the leftover material bins from the Cal Poly shops. This section outlines the source of all parts and their final costs and how each contributed to the total cost breakdown for the bike.

Table 7. Detailed budget for the trainer

Subsystem	Component	Source	Cost
Seat Track Mechanism	Front Square Tubing	Discount Steel	$ 18.75
	Rear Square Tubing	Discount Steel	$ 18.75
	Detent Pins	McMaster Carr	$ 9.82
	Rear Weld Plate	McMaster Carr	*Made from excess support arm plate material*
	Seat Mount Plate	McMaster Carr	
	Washers	Miner’s Ace Hardware	$ 3.00
	1/4-20 Hex Nuts	Miner’s Ace Hardware	$ 2.00
	1/4-20 Bolts	Miner’s Ace Hardware	$ 3.60
	Carbon Fiber Seat	George Leone	*Donation*
SUBTOTAL:			**$ 55.92**
Seat Reclining Mechanism	Support Arms (½" Steel Plate)	Discount Steel	$ 85.00
	U-Brackets (Cut from U-Channel Steel Strut)	Cal Poly Machine Shop	*Free*
	Rear Support Tube	Cal Poly Machine Shop	$ 1.00
	Seat Hinge	Miner’s Ace Hardware	$ 7.99
	Aluminum Plates for Hinge Mount	McMaster Carr	$ 2.00
	T-Nuts	Miner’s Ace Hardware	$ 5.00
SUBTOTAL:			**$ 100.99**
Handlebar Mechanism	Outer Handlebar Tube	McMaster Carr	$ 20.00
	Detent Pin	McMaster Carr	$ 6.24
SUBTOTAL:			**$ 26.24**
Miscellaneous	Brake and Shifter Cable & Housing	Cal Poly Bike Shop	$ 5.05
	Teardrop Mallet	Harbor Freight	$ 9.00
	Spray Paint	Miner’s Ace Hardware	$ 16.00
TOTAL:			**$ 213.20**

As shown in Table 7, the largest part of the budget went to the seat reclining mechanism, due largely to the ½ inch steel plate that we made the support arms from. The seat track was the second most expensive mechanism with the box beams constituting most of the cost. The total cost ended up being slightly less than the estimated cost even though we purchased additional miscellaneous items such as spray paint and a tooling hammer. This was mostly due to the box beams and hinge costing less than expected and the welding filler rods being free.

Note that components sourced from ‘Cal Poly Machine Shop’ were made from material in their scrap material bin that was either purchased at a corresponding low cost or free. Additionally, the rear weld plate, seat mount plate, and the support arms were all originally waterjet from the same ½ inch thick steel plate to utilize more of the material necessitated by the support arms. The cost of these items is thereby attributed entirely to the support arms.

6.2 Manufacturing Process

The following section outlines the processes followed in order to build the confirmation prototype. The processes can be grouped into the main sections of: Primal 1 disassembly, seat modifications, box beam manufacturing, seat support arm system manufacturing, handlebar modifications, welding, and final assembly.

6.2.1: Primal 1 Disassembly

Stage 1a: Initial Cuts

The first stage of the manufacturing plan involved cutting the Primal 1 frame at the necessary locations to produce the sections seen in Figure 32. We used an angle grinder to remove Primal 1's central tube at the downtube connection point and near the rear wheel just past the mounting holes for the fairing. The remainder of the bottom support triangle was also removed. This separated the bike into the rear and front assemblies for further modifications. Additionally, the handlebars were cut off right at the point where they connect to the head tube collar.

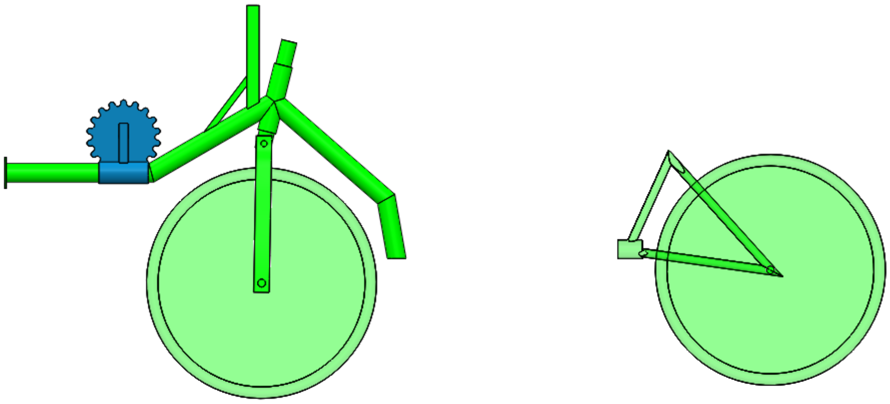

Figure 32. Separated front and back half of Primal 1 frame after angle grinding

Any unwanted protruding material exposed after angle grinding was removed with a deburring tool on a Dremel until smooth. Since the surface at the rear cut merely inserts into the welding plate for connection to the outer box beam, its finish was not critical, and it was simply deburred. The attachment point at the front required a tight angle tolerance to maintain proper bike geometry, therefore its surface finish was given greater attention and detailed in the following subsection.

Stage 1b: Leveling the Downtube Connection Point

The cut surface of the downtube needed to be level with the ground while also keeping the attachment height for the tubing the same in order to maintain proper bike geometry. We placed the front of the frame in a vise and put a level on the tubing where the pedal collar attaches to establish a datum. Once this tube was made level, we used a Dremel and deburring tool to grind away material left from angle grinder cut on the downtube until we had a level and uniform surface at the correct height.

6.2.2: Seat Modifications

The second stage of manufacturing entailed modifying the current seat to work with our adjustment mechanisms. To do so, we cut the original seat and added a hinge, and modified the back of the upper seat to add support arm attachment points

Stage 2a: Seat Hinge Modifications

To add in the hinge, we first used a bandsaw to cut the seat into two sections at the base of the seat back, as shown in the drawing package, Appendix L. We then attached the hinge and its two aluminum support plates on either side of the cut. To match the aluminum plate's geometry to the seat, the 1/16-inch-thick plates were heat treated with an oxy-acetylene torch then hammered into shape, in a technique taught to us by our sponsor, Mr. Leone. To do so, we first coated the plate's surface with acetylene alone, then burned off the resulting black coating with the oxy-acetylene torch lit – therefore heating up the metal. Placing the heated plates on a pouch of lead balls and against the back of the seat where the hinge would attach, we then used a rubber hammer for shaping. Due to the inexact nature of shaping metal with a hammer, the entire process was quite iterative and time consuming. Once close to the seat geometry, the aluminum plates were bonded to the carbon fiber seat using epoxy. After the epoxy cured, holes were drilled through the plates and seat to match the hinge's hole location, and the hinge was bolted to the seat to reconnect the two halves.

Stage 2b: Support Arm Attachment Points

To create mounting points for the support arms, cuts need to be made in the seat back and inserts added. To remove a section of each stiffener rail on the back side of the seat we used a Dremel with a cutting head. Each cut out section was approximately 3.5 inches long, spans the width of the rail and is located 9.25 inches measured from the top of the seat. Then both stiffener rails were sanded until the foam inside each rail was level to the other, and wood was bonded to the foam using epoxy and microballoons. After the epoxy cured, we inlaid t-nuts in the wood, and bolted the U-brackets to the t-nuts.

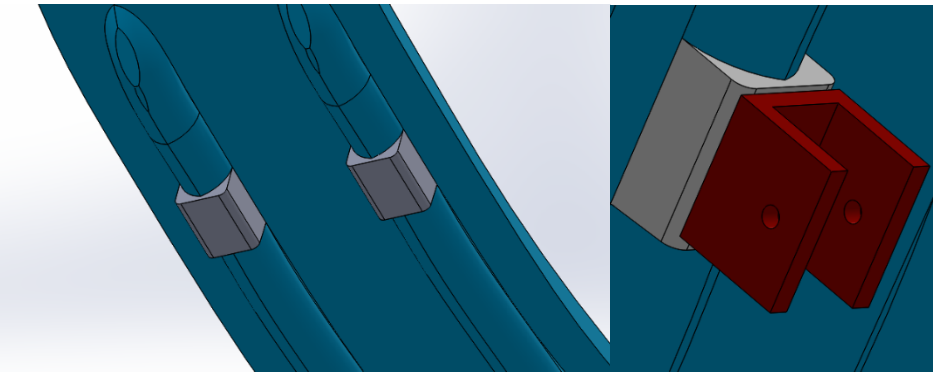

Figure 33. Fiberglass section and U-bracket attachment point

6.2.3: Box Beam Preparation

Stage 3a: Machining Holes for the Rear Box Beam

To manufacture the rear box beam the stock 1.75 inch square tubing was cut to just over 13 inch length using a steel chop saw and both ends were faced with a mill until flat. The tube was then placed in a vise on the mill and both sets of holes were milled out using a Letter F drill bit while using the mill's digital readout to obtain the spacing shown in Figure 34.

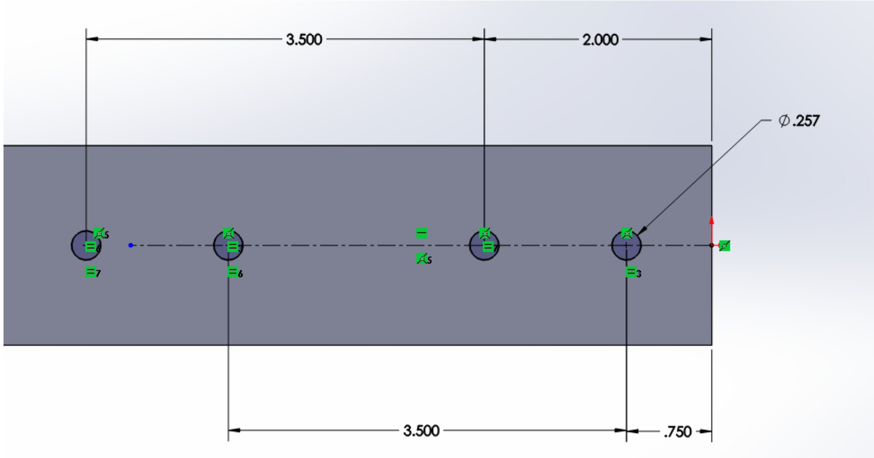

Figure 34. Hole spacing for rear box beam

Stage 3b: Front Square Tubing Manufacturing

For the front square tube, the 1.5 inch square tubing was cut to 13.5 inches in length and the rear end faced flat with the mill. From the flat face datum, we moved in 0.5 inches on a side face using the mill and center drilled a hole on that face, then 22 more holes were center drilled at 0.5 inches increments. We used a 7mm drill bit to drill the holes. Once all necessary holes were drilled, the tube was ready to be welded to the front part of the frame.

6.2.4: Support Arm Manufacturing

Stage 4a: Support Arm Alignment and Fit Test

The fourth part of the manufacturing process entailed modifying the rear half and testing the geometry and function of the support arms using wooden prototypes made with the laser cutter. The jig from the original structural prototype held the rear square tube and wood mockups to simulate the waterjet parts and was temporarily adhered to the metal. Once the test of the wooden prototype was complete, the parts were removed.

Stage 4b: Water Jet Processes and Refining

The next process was water jetting all the 0.5 inch thick steel parts: the refined support arms, the rear end plate for the larger box beam, and the seat mounting plate. The slots in the support arms were purposefully undersized to ensure the large draft angle associated with the water jet did not make the slots too large to securely fit the pin. The support arm slots were then enlarged on the mill to their correct size. Additionally, the top holes of the support arms were enlarged with a drill press and a Letter F bit.

Stage 4c: Rear Triangle Welding Tabs for Support Arm Pin

The welding tabs were made from 16 gauge steel sheet to the approximate shape of the top section of the rear triangle. To do so, we first traced the approximate shape of the top of the rear triangle, then used a shear press brake to cut the two triangular pieces. We chose a location for holes to hold the rear support tube and drilled one oversized hole in each piece using the drill press. Using a Dremel with a deburring tool, the holes were then enlarged to better hold the support tube. The fit was checked throughout using the support pin, a level, and two notched wooden blocks to ensure the holes were level to one another. Because the flat sheet did not match the curvature of the rear triangle, we MIG welded the front part of the tab to the rear triangle before using a ball peen hammer and clamp to hammer the sheet to the correct contour. The other intersecting side was then welded. The Dremel was used again with the until the rear support tube fit in both holes and was level to the ground.

Figure 35. Rear triangle welding tabs – welding set up.

6.2.5: Handlebar Manufacturing

Stage 5a: Handlebar Post Mitering

Using the SolidWorks sheet metal toolbox, we made a stencil for the miter angle of the handlebar post to obtain the desired tube end profile, as shown in Figure 39. We then taped the stencil to the new handlebar tube and marked the material to be mitered with a paint pen. Using a bench grinder, we removed material to get the tube close to the desired profile, then used a Dremel with a deburring tool to miter more material until the tube fit well with the handlebar mount collar.

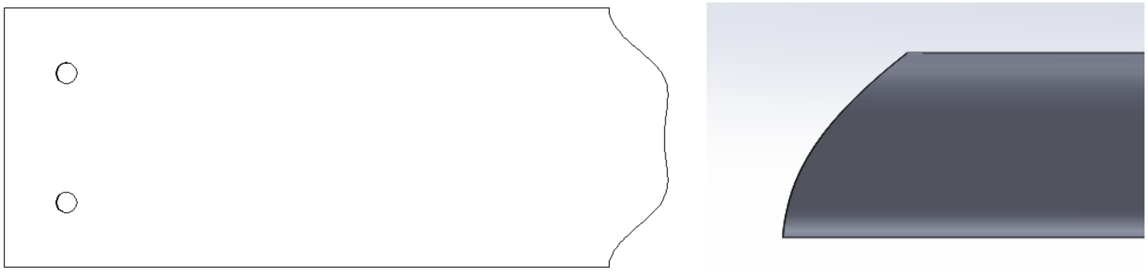

Figure 36. Miter pattern and desired end profile for the handlebar post

Stage 5b: Handlebar Detent Pin Hole

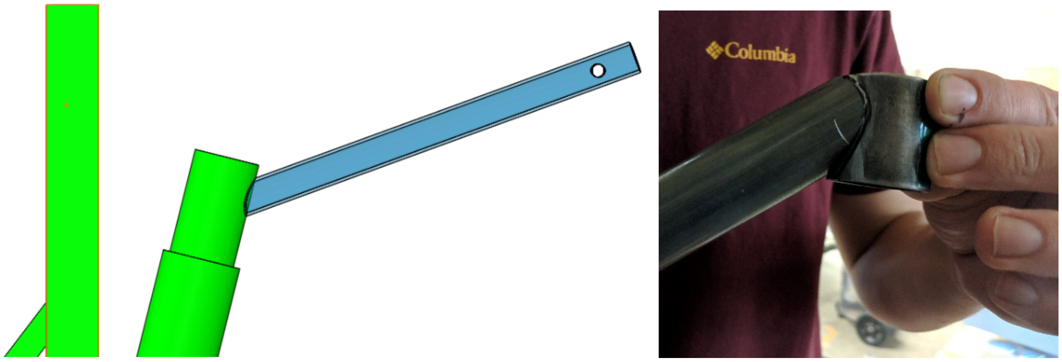

Figure 37. Handlebar post orientation and final mitered tube to collar connection

After the miter was finished, we placed the tube in a vise on the mill. After located the flat, non-mitered edge, we moved in 0.75 inches and center dilled a hole. After center drilling, a 0.25 inch hole was drilled through both sides. Once this process was completed, the tube was ready for welding to the head tube collar of Primal 1 at the original handlebar connection point as shown in Figure 37.

Stage 5c: Handlebar Stem Machining

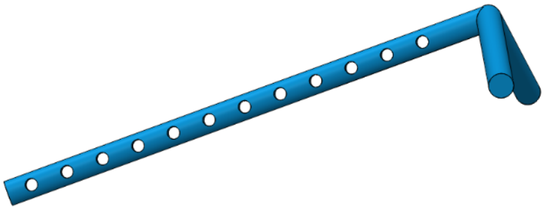

Figure 38. Handlebar stem with 7 mm holes drilled

To interface with the outer telescoping handlebar post, the original handlebar post needed to be modified. First, we used the mill to face the cut end of the original flat using the mill. Due to the two handlebar handles located at the end of the post, using the mill to drill the series of holes was difficult. As such, the 0.5-inch markings along the handlebar post were marked and measured by hand. In addition, the alignment of the handlebars with respect to the rider was determined before drilling as well. This was done by sight, by marking the hole position in the handlebar location which felt most aligned from the rider's perspective. We then fixtured and secured the handlebar post with a vise and used the drill press to drill out each hole using a 7 mm drill bit. After drilling 2-3 holes, the handlebar post was removed and checked for alignment and fit with the outer telescoping handlebar post. Once all of the holes were drilled with the drill press, a hand drill was used to ream the holes to ensure a clean fit with the detent pin. All drilled holes were deburred using the conical deburring tool and a flat file to ensure safety during operation.

6.2.6: Overall Welding Process

Upon completion of all previous manufacturing steps, the bike parts were brought to an experienced welder on the Cal Poly HPV team and joined in the following processes.

Stage 6a: Front Half Welding

In order to maintain proper orientation between the front box beam and the leveled downtube, we constructed a wooden welding jig, as shown in Figure 42. The front support piece ensured that the front part of the bike where the pedals mount was level to the same degree as the front box beam, to stay true to the bike's original geometry. The connection point was then TIG welded all around to join the downtube and the box beam.

Figure 39. Front half welding jig with front half of Primal 1 and front box beam

Stage 6b: Back Half Assembly and Welding

The end plate was centered on the end of the back beam and tack welded until aligned. To accomplish this, we included a raised section of the end plate to allow for easy alignment between the box beam and back beam. Vertical alignment was assured by having the back end of the bike and bottom edge of the end plate being level and flush on the weld table.

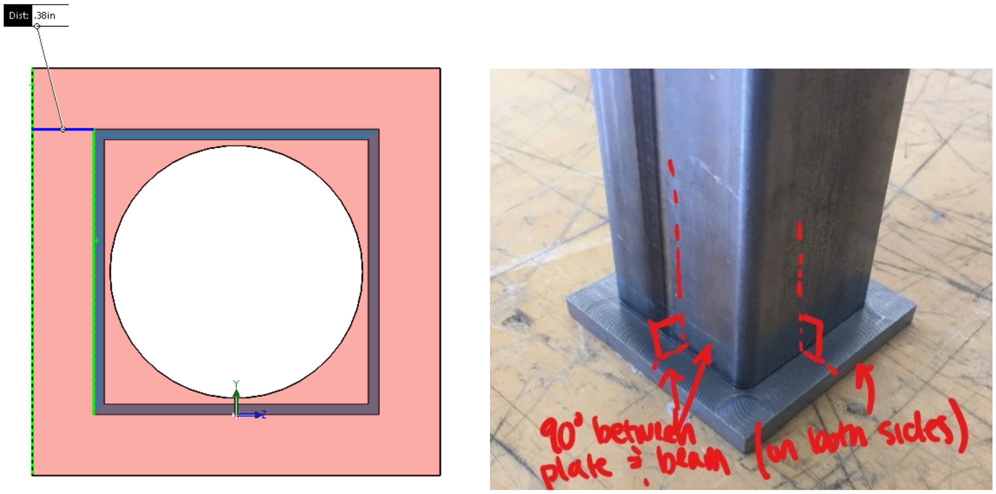

Figure 40. End plate alignment relative to the back beam

All the edges were fillet welded, all the way around for the end plate and back beam. A 0.5 inch section of the 1.5 inch square tubing was cut with the miter saw and faced flat and parallel with the mill. Lines were then marked for the placement of the small box beam on the seat mounting plate. Tack welds were made on both sides to check alignment, parallelism, for the small box beam on the large box beam. The other end of the small box beam was welded to the top of the 1.75 inch box beam with the edge to edge distance of approximately 9 inches to the end plate as shown in Figure 41. The rear tubing of the rear assembly was then inserted into the end plate and fillet welded on the edge.

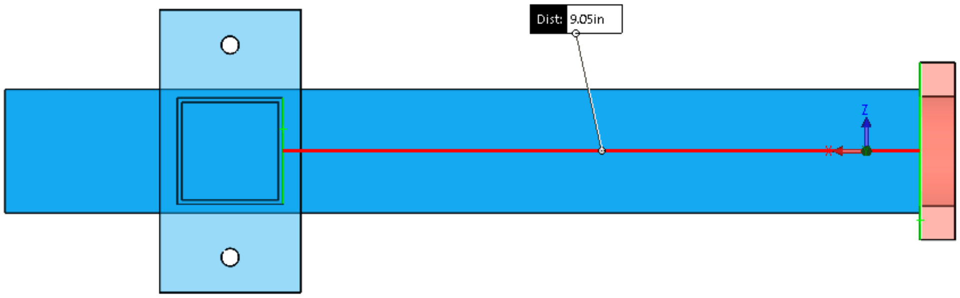

Figure 41. Seat bracket attachment distance from end plate

To increase support, the old support tube that went from the top of the main tubing to the rear triangle intersection was reattached at a steeper angle. We accomplished this by facing the bottom end of the support tube with the mill at a 60-degree angle. The tube was then welded to the back box beam and the rear triangle intersection in the orientation shown in Figure 42.


Figure 42. Finished back half of trainer frame – pre welding

6.2.7 Final Steps

Stage 7a: Painting

In this stage, we disassembled the bike, removed any remaining paint, and repainted the bike with spray paint to inhibit rusting on the steel components. We then used numbered stencils to mark the different seat track locations for better ease of adjustment.

Stage 7b: 3D Printed Spacers

Once all parts of the bike were welded together and therefore their relative geometry fixed, we measured the gap between the two parts of the box beam and the two telescoping portions of the handlebar tubes. Using these measurements, we designed spacers to attach to the inner parts of each. These were 3D printed and then permanently adhered to the inner part to take up slop between telescoping components.

Stage 7c: Final Assembly

All drivetrain and steering components were reassembled, and several chain links in the chain connected to the pedals were removed to compensate for the new, closer pedal position. The derailleur position was then tuned by a bike technician to account for the altered drivetrain geometry. The shifter and front brake cable lengths were also replaced with longer versions to accommodate the telescoping handlebars and then reinstalled.

With all other modifications complete, the front and back half of the frame could then be joined together. The back half box beam slides over the front half box beam once the two halves are aligned, and the spacers are in place. Once the desired seat track length is chosen the two halves of the frame can be secured through the 3-inch-long quick release pins. Additionally, the two telescoping pieces of the handlebar were secured in a similar manner.

6.3 Manufacturing Challenges and Recommendations

Here we outline the design and manufacturing related issues encountered while building the prototype, along with related recommendations should another party pursue a similar project in the future.

6.3.1 Leveling the Front Box Beam Connection Point

One of the greatest challenges in manufacturing came as we attempted to make the mating surface on the bottom of the original Primal 1 downtube level to the desired front box beam orientation. The main issue was that there was no good way to track exactly how level the surface was as we removed more material with the Dremel; besides a roughly level paint pen line we had drawn around the cut surface which was supposed to be at the same orientation. This led to a high degree of uncertainty that the surface was where it was supposed to be – therefore we wasted a lot of time checking parts of the surface with a level since we were removing material somewhat blindly. While we were able create a level enough surface for welding in the end it was an incredibly time-consuming process due to all the guess and check.

Due to these issues, if a similar process was repeated in the future, we suggest determining the height of the cut surface required to keep the front half of the bike level, and drawing a corresponding line using a height gage while the bike is secured with the pedal post level to the ground. Then the Dremel could be used to bring the cut surface to this more accurate line with a greater degree of confidence and therefore a much shorter work time and most likely a better finish.

6.3.2 Welding Tabs for Support Arm Pin Attachment Point

Similar to the downtube connection point manufacturing, creating the welding tabs was an inexact process due to the unique rear triangle geometry. Since the overall triangle dimensions did not matter, the inexact way in which we made those was fitting – cutting them roughly to size, welding one end and then hammering the other to the required geometry. But this left little room to make the support arm pin hole correct before, therefore the hole was originally made extremely oversize and the Dremel with a deburring tool was used extensively to make the rod level while resting in both holes. This left a large gap around the rod when in both holes which could be easily filled with MIG welding but was not ideal. Therefore, should a similar process be performed in the future we would recommend making the hole closer to the rod size at first, then enlarging it in required directions with the dremel, in order to reduce the gap.

6.3.3 Interfacing Handlebar Holes

We encountered some issues with consistent holes for the handlebars because we were not able to use the mill to drill the holes. The handlebars had to be constantly adjusted to fit properly in the vise and they needed to be checked for alignment with every series of holes. As a result of this, we found that some series of holes were better aligned to the rider in comparison to others. Additionally, the vise and fixturing for the handlebars was not as robust as we would have liked, and the handlebars sometimes rotated and moved during the drilling process. This caused some differences in alignment depending on the chosen hole for the handlebars.

If the handlebar manufacturing were to be repeated, the order of manufacturing should be reconfigured for a simpler and more robust manufacturing process. Since the handlebar handles were welded on the inner handlebar post (this was from the existing design), if these were completed after the series of holes were drilled, this would greatly help with alignment. This way, the holes could be drilled using the mill, giving consistent spacing and orientation of the post. Next, the outer telescoping tube could be properly aligned and welded to the frame after the inner telescoping handlebar post had been completely manufactured. This alignment would be easier to check and fix, rather than drilling of a few holes and then checking for alignment-which is what we needed to do with our handlebar post. Overall, these changes would allow for a consistent spacing for the telescoping handlebar post and a consistent alignment of the handlebars for the rider.

7.0 Design Verification

In this section we review in detail the tests and intermediate prototypes used to ensure our confirmation prototype met the design specifications laid out in Section 3.3, along with their results. For the simplified, tabular version of the Design Verification Plan, see Appendix N. In total, upon completing manufacturing we performed 4 tests to determine the bike's functionality and compliance with design specifications. These tests analyzed: maximum adjustment time, available seat back angles, supportable rider weight and min and max pedal distance. For convenience, all tests were completed in the Bonderson High Bay, however, each only truly required a flat surface for the bike. For full testing procedures, see Appendix P.

7.1 Maximum Adjustment Time

Any rider within the specified range should be able to adjust the bike to a known position in less than three minutes

To ensure the bike's adjustability mechanisms are quick and easy to use, we constructed a test to determine the time required to change the seat back angle, seat track position, and handlebar length with our adjustment mechanisms. To have comparable results between trials, we chose one seat angle, seat position and handlebar length for each participant to adjust to, with one starting position. To begin the experiment, we demonstrated the adjustment mechanisms to participants, including proper pin grip and methods to remove them to prevent injury. We then timed the participants as they set up the bike and recorded the subsystem specific and overall adjustment times. In addition, we asked participants to fill out a short survey about any mechanisms that they thought were difficult to handle or too time consuming to adjust.

Figure 43. Participant testing out bike fit after timed setup test

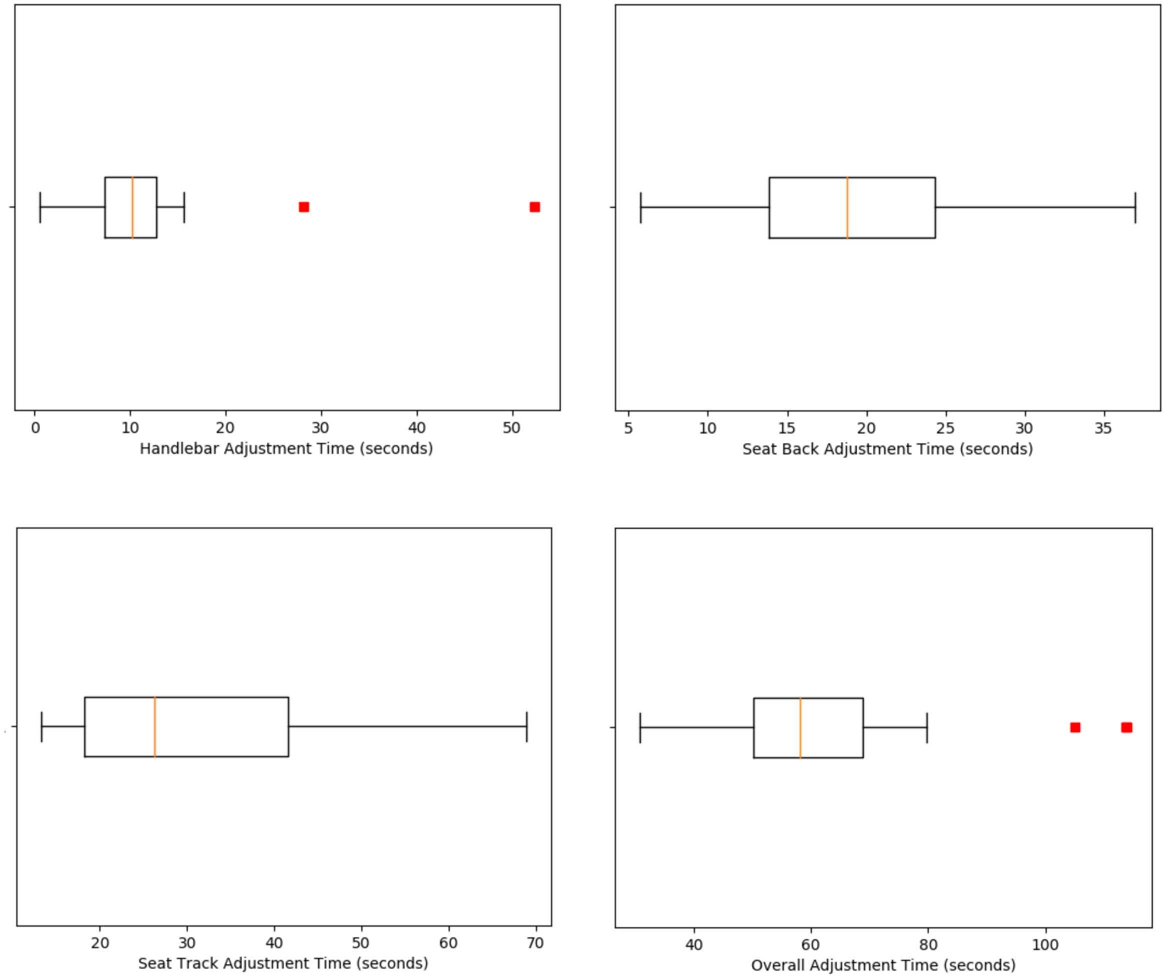

Figure 44. Box and whisker plots showing the adjustment times of each subsystem and the overall adjustment time of the bike for all 23 test subjects.

After testing with 20 participants, we found that we were able to meet our goal of the overall system taking 3 minutes to adjust, with the average time to adjust the entire system only taking about one minute and only outliers taking longer than 90 seconds. We found that the seat track subsystem took the most time to adjust which can be primarily attributed to the friction between the box beams and that there are two separate detent pins, as indicated by our survey. The majority of test subjects found the seat back position easy to change, although around a quarter of responses put the difficulty of adjustment as a four out of five with five being difficult. For full data on adjustment time and survey responses, see Appendix Q.

7.2 Available Seat Back Angles

The seat must recline from 100 degrees to 150 degrees

To verify the support arm mechanism works well with the seat and achieves the specified reclining angle range, we measured the seat back angles associated with closest and farthest pin locations on the support arms. We found that the desired angles were met and our sponsor approved the available range of motion.

Figure 45. Seat back angle measurement verification test with angle gage

Should the seat back have not met the required angle range, we planned to fine tune the support arms by modifying the u-bracket placement on the seat back.

Table 8. Measured seat back angles for each support arm slot

Arm Position Number	1	2	3	4	5
Seat Back Angle (Degrees)	98.1	107.6	118.2	128.5	149.1

7.3 Supportable Rider Weight

The bike must support a 250 lb rider without deflection under seat exceeding 1/4 inch

Figure 46. Measuring height of seat track at seat bolt location prior to load test

The bike was tested to support a static 250 lb load, which was accomplished by having one of our members sit in the bike with additional weights on top of him. This test was necessary to measure the deflection of the central box beam. If any of these components deflected more than our acceptable limit of 0.25 inches, we would need to add additional material/components to increase the stiffness of the supports for the bike. We measured the box beam deflection at the longest box beam position at both the most upright and most reclined seat back angle. To measure the deflection, we set measured the change in height from the ground to the bottom surface of the outer box beam due to loading. All welds were inspected for signs of cracking or other indications of potential failure. With this method for measuring deflection, we needed to also perform uncertainty analysis since there was potential error that could be propagated through due to how we measured deflection. Even with this uncertainty analysis we found that we were able to meet the criteria set by our test. The uncertainty calculation can be found in Appendix R.

Table 9. Seat track deflection test results

Seat Track Location	Seat Back Position	Final Weight (lb)	Height of Center Beam before Loading (in)	Height of Center Beam with Load (in)	Calculated Deflection using Ruler Measurements (in)	Deflection Uncertainty (± in)
Far	Inclined	251.3	16-3/8	16-1/4	1/8	0.04
Far	Reclined	251.3	16-3/8	16-3/16	3/16	0.04

7.4 Minimum and Maximum Distance from Seat Back to Farthest Pedal

The seat back distance from the farthest pedal needs to range from 33 in to 39.4 in

Figure 47. Measurement of pedal to seat bottom distance at closest seat location

To verify that our seat track adjustment mechanism provided the design range of seat back to pedal distance, we measured the length with the seat at its closest and farthest positions. To do so, we set the pedal cranks parallel to the tube they are mounted on and measured the distance between the pedal and the seat bottom's mounting holes. From our measurements, the minimum and maximum distances are 33 and 40 inches, respectively. Therefore, the bike can accommodate riders with inseam lengths in this range.

Table 10. Comparison of measured pedal to seat bottom distance to design values

Seat Location	Measured Value (in.)	Comparison	Design Specification (in.)
Closest	33	Less than or equal to	33.0
Farthest	40	Greater than or equal to	39.4

7.5 Recommendations for Future Tests

In the future, our team would recommend verification tests after a few months. These verification tests would be used to check the condition of the bike to ensure that key components are still working properly and are safe for use. These components include the support arms, the support arm brackets, the inner and outer box beams as well as the handlebars of the bike. If any of these components have significant wear (loose connections between the box beams and handlebars for example) they should be replaced to ensure the users of the bike are safe. All primary welds (such as the box beam to down tube weld as well as the rear support welds) should be checked for cracks to ensure they are safe for use as well.

8.0 Project Management

In general, our project fell into the main sequential processes of research & design, design analysis, building, and testing. To begin, we presented our original project research, problem definition and specifications in the Scope of Work document as part of the initial research and design phase. Working from this point, we created concept models, CAD models and concept prototypes in order to develop and present our initial design ideas in the Preliminary Design Review, marking the end of the first phase.

After PDR, we obtained sponsor feedback on our design direction. Upon receiving sponsor approval, we incorporated this feedback into finalized design decisions and moved to the design analysis phase. In this process, we performed analysis on the adjustment mechanisms, overall frame, and part integration in order to present a complete trainer design. After receiving feedback from our classmates and considering other options, we altered parts of design until we settled on our final design direction.

Following this, we moved into the build phase and constructed a structural prototype from our design. We then moved to the initial test phase to validate our frame and mechanism design and integration. As part of our initial test phase, we performed an in-depth ergonomic analysis to study the adjustment needed by various riders. This ensured proper mechanism packaging such that they will not inhibit training motion for a variety of riders.

After ensuring that all design requirements and specifications were met, we presented our final design in the Critical Design Review and performed a risk assessment followed by a safety review. With sponsor approval, we ordered all trainer parts and began manufacturing. Within the manufacturing phase, we partook in a manufacturing and test review, wrote an operator's manual for the trainer, and finalized our testing procedures. After completion of the final prototype build, we applied the testing procedures outlined for each engineering specification and made final preparations for prototype delivery to our sponsor and completed the Final Design Review report. For a visual representation of our project's overall timeline with detailed events, reference the Gantt chart of Appendix E, which outlines our required processes.

Overall, we were able to stay on track with our Gantt chart and the senior project timeline for most of the process. Having one team member who always had a good idea of the project's current progress and steps was the greatest asset. The greatest obstacle to maintaining the schedule tended to stem from missing dependent steps in the project plan and Gantt chart. When these dependent tasks were brought to attention, they had to be taken care of before subsequent steps, thereby pushing the timeline back slightly. This was especially prevalent during manufacturing, where we had to complete all tasks within limited shop hours, which left less room for catch up. In future projects we therefore recommend maintaining a detailed project plan and paying special attention to dependencies during the initial planning process.

9.0 Conclusion

In this final section of the report we reflect on what we achieved with the HPV trainer, what we could not accomplish, and recommendations for improvements to the existing design for future iterations.

9.1 Final Reflections

The Human Powered Vehicle trainer was completed on time and meets the specifications of the project with room for improvement in specific areas.

9.1.1 Seat Track Adjustment Mechanism

As verified by our testing, the seat track mechanism allows for riders with X-seam lengths of 33 to 40 inches to pedal the trainer with optimum leg position – which roughly corresponds to rider heights of 5’4” to 6’4”. While we would have liked to accommodate shorter riders, the fixed hard points of the front half of the bike prevented this without major redesign – although pedal blocks could be incorporated if a shorter rider desire to use the trainer in the future.

The seat track was relatively easy for our test subjects to adjust, as the detent pins are easy to remove, and the box beams slide relatively well. We were able to keep the cost of our box beams down by buying two closely sized tubes instead of telescoping tubing, but consequently the two inner and outer dimensions did not match up perfectly. Therefore, we used 3D printed spacers placed in between the holes to remove slop. This accomplished the goal of fixing the hole alignment, but the outer box beam still faces resistance from the friction between its inner surface and the spacer. Making the spacers from a more lubricous plastic such as Delrin instead of PLA could improve the seat track translation further.

9.1.2 Seat Back Reclining Mechanism

In the end, our seat angle adjustment mechanism allows for adjustment between 100 and 150 degrees through 5 fixed positions which provide approximately 12-degree increments. Through use of our test wooden support arms and consultation with our sponsor, the original minimum angle goal of 90 degrees was deemed unnaturally upright and therefore changed to 100.

Although the slots in the support arms provide a tight fit with the support rod that prevents too much translation or rotation of the seat back in use, this lack of clearance also makes removing the arms more challenging. While we believe the tighter fit during use is more important, further filling of the support arm slots could be performed to make adjusting the arms easier. Additionally, several of our survey respondents said that the arms would be easier to adjust if they were attached to one another. To accomplish this, a rod could be fastened or welded between the two arms, which would also create a more ergonomic, easier to use grip point. We did not pursue this with our prototype due to the parallelism thereby required by the two support arms and its potential conflicts with the inexact geometry of our seat back and U-brackets, but connecting the two arms has the potential to make the seat back adjustment both easier and faster. Additionally, we could modify the support arms by adding another hole to attach to the seatback. This second hole would allow the support arms to change their pin location, thus reclining the seat even farther back to a more horizontal angle. This hole should be placed approximately 0.8 inches away from the current support arm hole, towards the support arm slots. This is half the distance from one slot to another slot. The justification for this is that in the lowest slot position, at the most reclined angle, the seat seems to be able to recline a little bit more but not enough to warrant another slot.

Another aspect that could be improved is the rigidity of the seat bottom. During operation the seat bottom will move as the rider's weight distribution changes. We have tried applying a large amount of preload to the bolts securing the bottom half of the frame. Initially, this appears to resolve the issue as the bottom half of the seat remains relatively fixed in place. However, after operating the trainer and applying varying loads to the seat, the seat bottom begins to rotate with the upper half of the seat. Using lock nuts or applying Loctite threadlocker could help prevent the loosening of the bolts and nuts holding the seat bottom in place. The seat back also tends to move during place. While we did not think the hinge we selected had excessive slop, switching to an even more secure hinge could help provide more rigidity between the two seat components.

9.1.3 Handlebar Adjustment Mechanism

The handlebar system provides length adjustment of the handlebars via two telescoping tubes and is secured in place with a detent pin. The set angle of the handlebar tube was chosen through analysis of our ergonomic data, and therefore provides an adequate handlebar position for most people. Although the length of the handlebars can change, the lack of an angle adjustment does not allow for each rider to find their optimal handlebar position. If we were to do another design iteration for the handlebars, a simple lengthening and rotating mechanism would be preferable.

Additionally, the hole alignment on the inner tube was not perfectly consistent along the tube's length. Because of this, the handlebars are turned while the wheel is pointing straight for some of the hole positions. While this is not a large issue when the bike is on a stationary stand, the misalignment between the wheel orientation and handlebar position will be an issue if the bike is put on rollers. One possible way to fix this is to drill out the holes to be a larger size that corrects for the misalignment. This would require buying larger detent pins to match the holes. There is also slop present in the inner tube that reduces the responsiveness of the steering. While we have 3D printed round spacers to help combat this, there is still slop present in the entire system. Possible options to reduce this slop include adding another detent pin to prevent rotation, further iterating spacer design, or purchasing a tighter fit telescoping tube for the handlebars.

9.2 Next Steps

Besides the potential modifications mentioned earlier in the conclusion, there are further improvements that can be made to transform the trainer into a more robust training system. While we modified a bike stand to allow for stationary resistance training, rollers would provide a system that forces the rider to balance which would better prepare them for the race conditions at Battle Mountain. The addition of an enclosure and video system would help simulate the fairing and vision system that riders will need to become comfortable with for the race. Additionally, including a wattmeter and RPM sensor would provide useful training data for a rider. Our trainer has provided a foundation for a complete HPV training system that we hope can be completed by other projects in the future.

9.3 Acknowledgements

We would like to thank George and Carole Leone for all of their support and guidance throughout the project. Their resources and knowledge helped keep the project moving forward. We want to thank our mentor Sarah Harding for providing technical insight and challenging the team to produce the best results possible. We also want to thank Kyra Schmidt for manufacturing guidance, and Eliot Briefer for welding the majority of the bike. We would also like to thank the entire HPV club for their support and resources, both during the design and manufacturing phases. Finally, we want to thank the Cal Poly Shop Techs for helping us through our manufacturing challenges.

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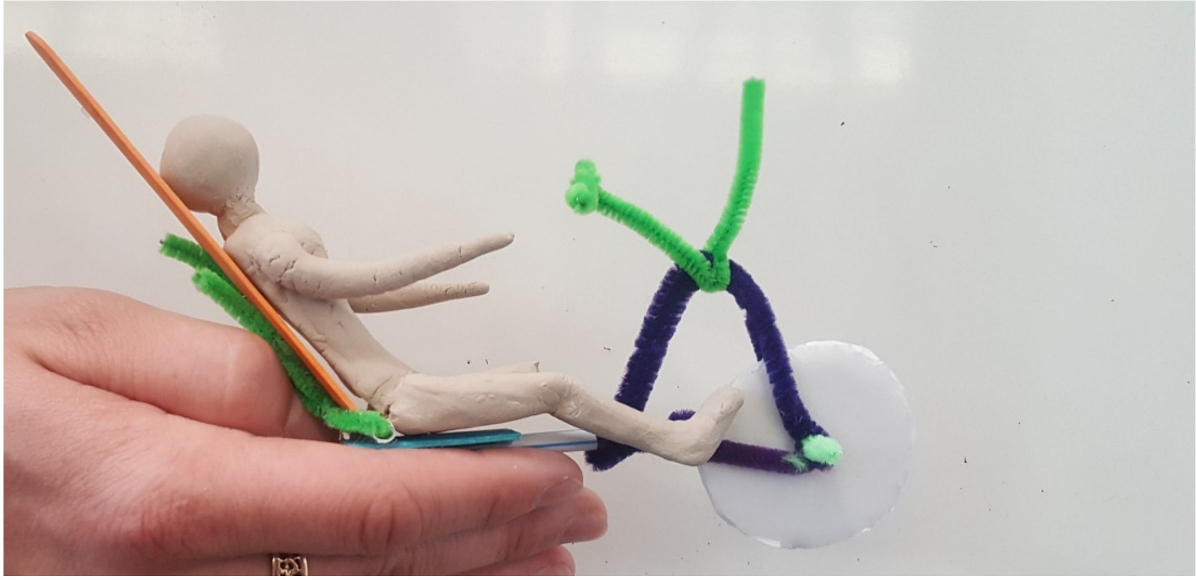
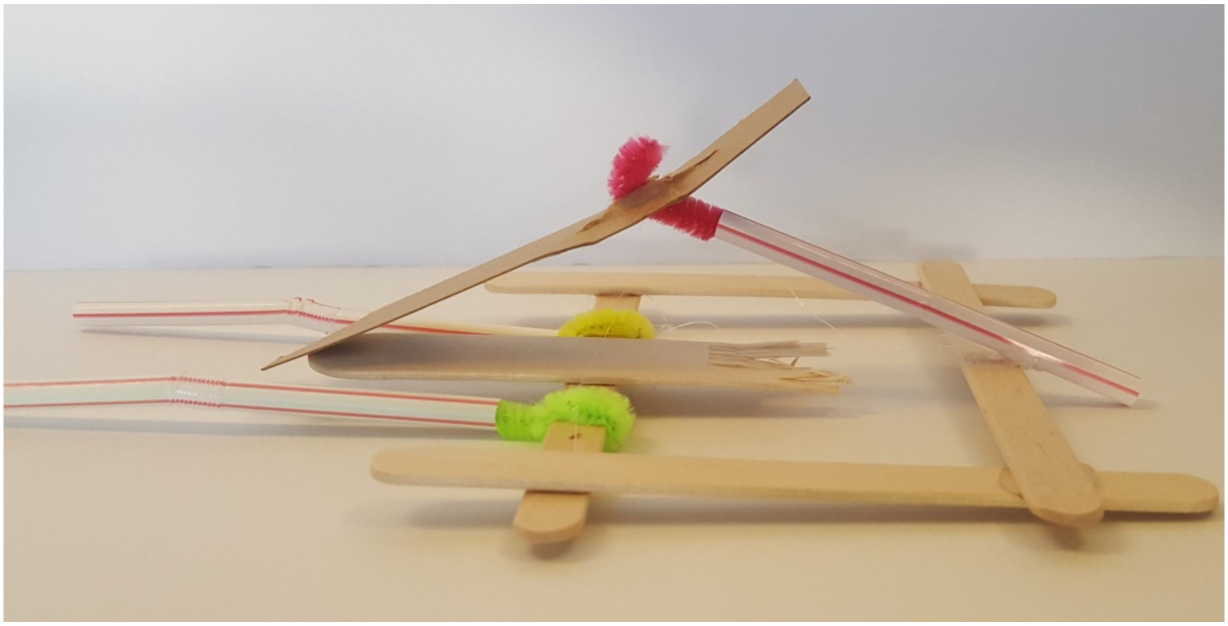
11.0 Appendices

A. Concept Models
B. Pugh Matrices
C. FSAE Anthropometric Reference Data
D. Design Hazard Checklist
E. Gantt Chart for Project Planning
F. References from Scope of Work
G. Patent and Product Research from Scope of Work
H. QFD from Scope of Work
I. Hand Calculations and Finite Element Analysis
J. Structural Prototype Results
K. Bill of Materials and Cost Detailing
L. Drawing Package
M. Failure Modes and Effects Analysis
N. Design Verification Plan
O. Operator's Manual
P. Test Procedures
Q. Usability Survey Results
R. Uncertainty of Deflection Test

Appendix A. Concept Models

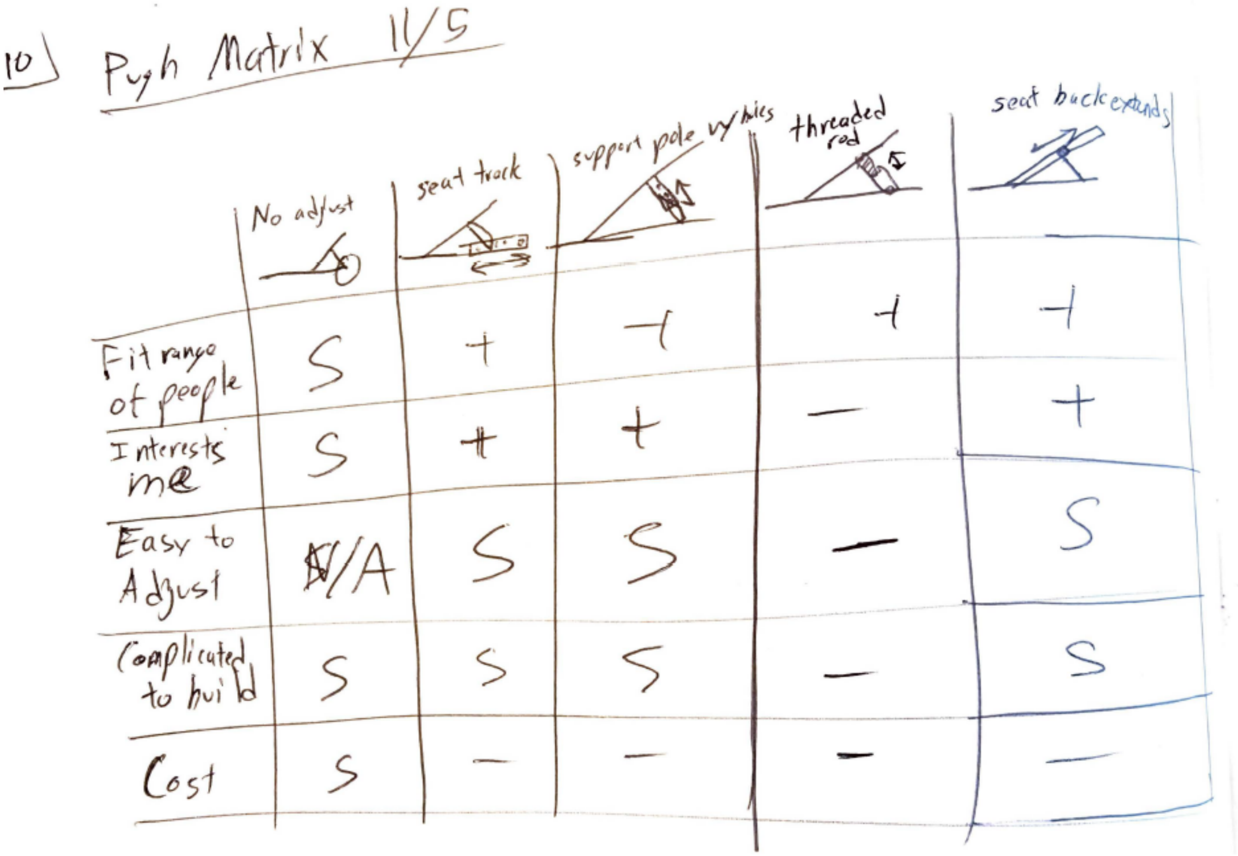


Scaled 5th percentile female in adjustable seat



Seat Track and Reclining Seat Mechanism

Appendix B. Pugh Matrices



10) Pugh Matrix 11/5

	No adjust	seat track	support pole w/ holes	threaded rod	seat back extends
Fit range of people	S	+	+	+	+
Interests me	S	+	+	—	+
Easy to Adjust	N/A	S	S	—	S
Complicated to build	S	S	S	—	S
Cost	S	—	—	—	—

Pugh matrix:

→Seat Track Design ideas:

① Crutches style:

Pops & locks into place

②

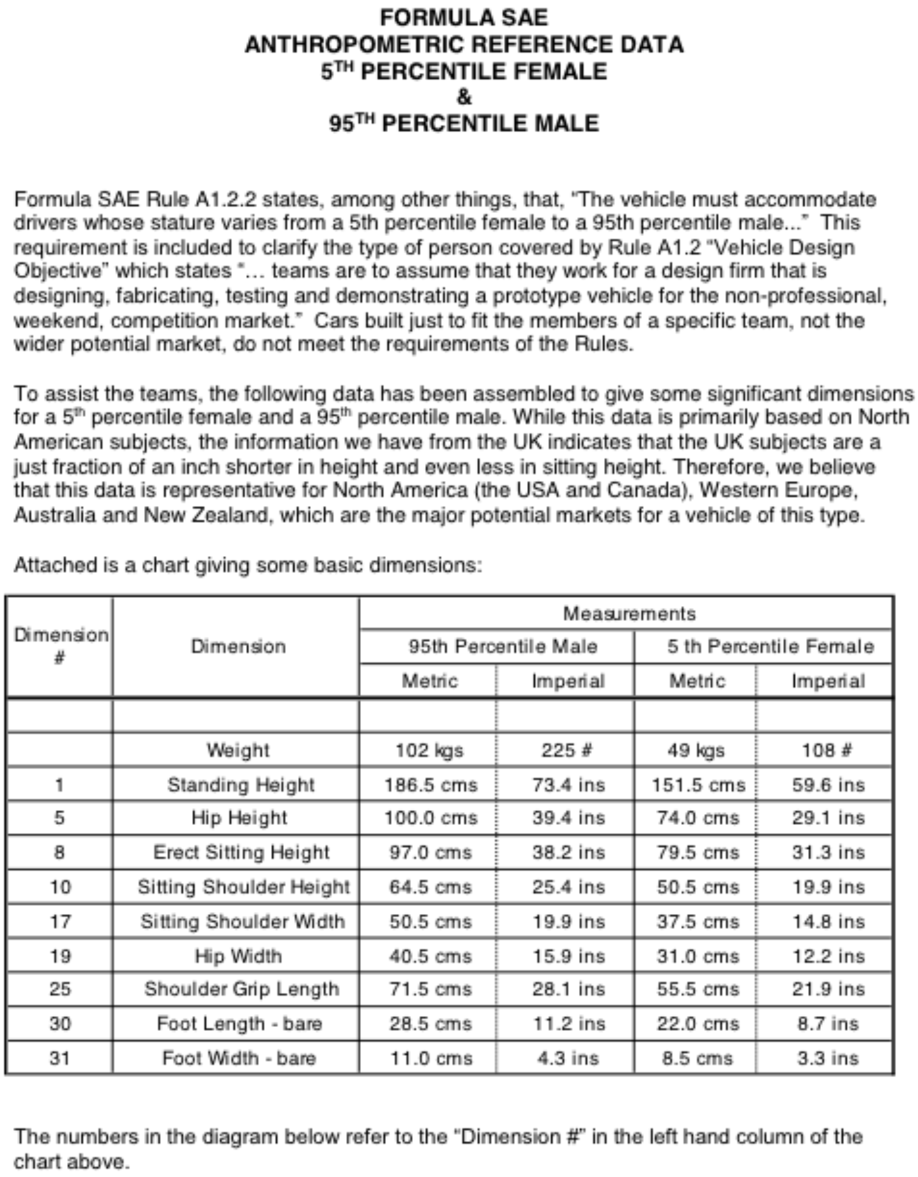
Twist & lock mechanism (Trekking Poles?)

③ cotter Pin (similar)

④ Snap in extenders

	Set Screw 	① Crutches style	② Twist & Lock	③ Cotter Pin	④ Snap in Extenders
Operable by 1 person?	S	S	S	S	S
Durable?	S	+	−	S	−
No pieces to lose?	S	+	+	−	−
Quick to use	S	+	−	+	S
tools required?	S	+	+	+	+
Pinch/snag Points?	S	−	S	S	−

Appendix C. FSAE Anthropometric Reference Data [13]



FORMULA SAE
ANTHROPOMETRIC REFERENCE DATA
5^{TH} PERCENTILE FEMALE
&
95^{TH} PERCENTILE MALE

Formula SAE Rule A1.2.2 states, among other things, that, "The vehicle must accommodate drivers whose stature varies from a 5th percentile female to a 95th percentile male..." This requirement is included to clarify the type of person covered by Rule A1.2 "Vehicle Design Objective" which states "… teams are to assume that they work for a design firm that is designing, fabricating, testing and demonstrating a prototype vehicle for the non-professional, weekend, competition market." Cars built just to fit the members of a specific team, not the wider potential market, do not meet the requirements of the Rules.

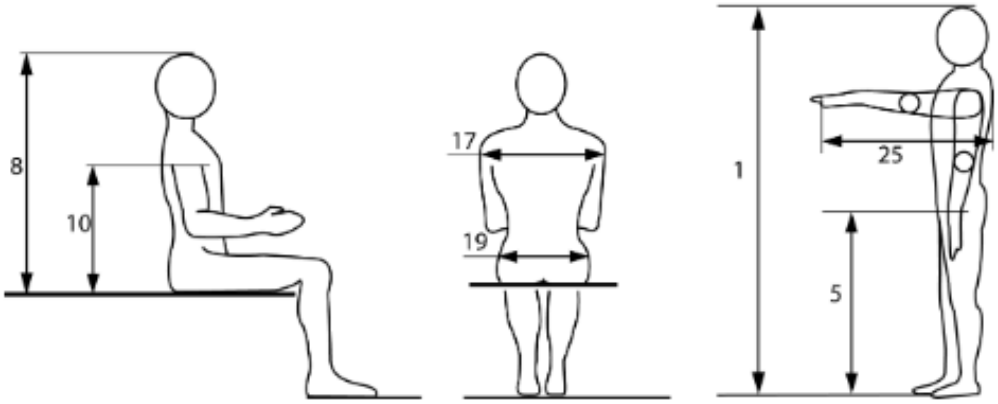
To assist the teams, the following data has been assembled to give some significant dimensions for a 5^{th} percentile female and a 95^{th} percentile male. While this data is primarily based on North American subjects, the information we have from the UK indicates that the UK subjects are a just fraction of an inch shorter in height and even less in sitting height. Therefore, we believe that this data is representative for North America (the USA and Canada), Western Europe, Australia and New Zealand, which are the major potential markets for a vehicle of this type.

Attached is a chart giving some basic dimensions:

Dimension #	Dimension	Measurements			
		95th Percentile Male		5 th Percentile Female	
		Metric	Imperial	Metric	Imperial
	Weight	102 kgs	225 #	49 kgs	108 #
1	Standing Height	186.5 cms	73.4 ins	151.5 cms	59.6 ins
5	Hip Height	100.0 cms	39.4 ins	74.0 cms	29.1 ins
8	Erect Sitting Height	97.0 cms	38.2 ins	79.5 cms	31.3 ins
10	Sitting Shoulder Height	64.5 cms	25.4 ins	50.5 cms	19.9 ins
17	Sitting Shoulder Width	50.5 cms	19.9 ins	37.5 cms	14.8 ins
19	Hip Width	40.5 cms	15.9 ins	31.0 cms	12.2 ins
25	Shoulder Grip Length	71.5 cms	28.1 ins	55.5 cms	21.9 ins
30	Foot Length - bare	28.5 cms	11.2 ins	22.0 cms	8.7 ins
31	Foot Width - bare	11.0 cms	4.3 ins	8.5 cms	3.3 ins

The numbers in the diagram below refer to the "Dimension #" in the left hand column of the chart above.

FORMULA SAE
ANTHROPOMETRIC REFERENCE FIGURES

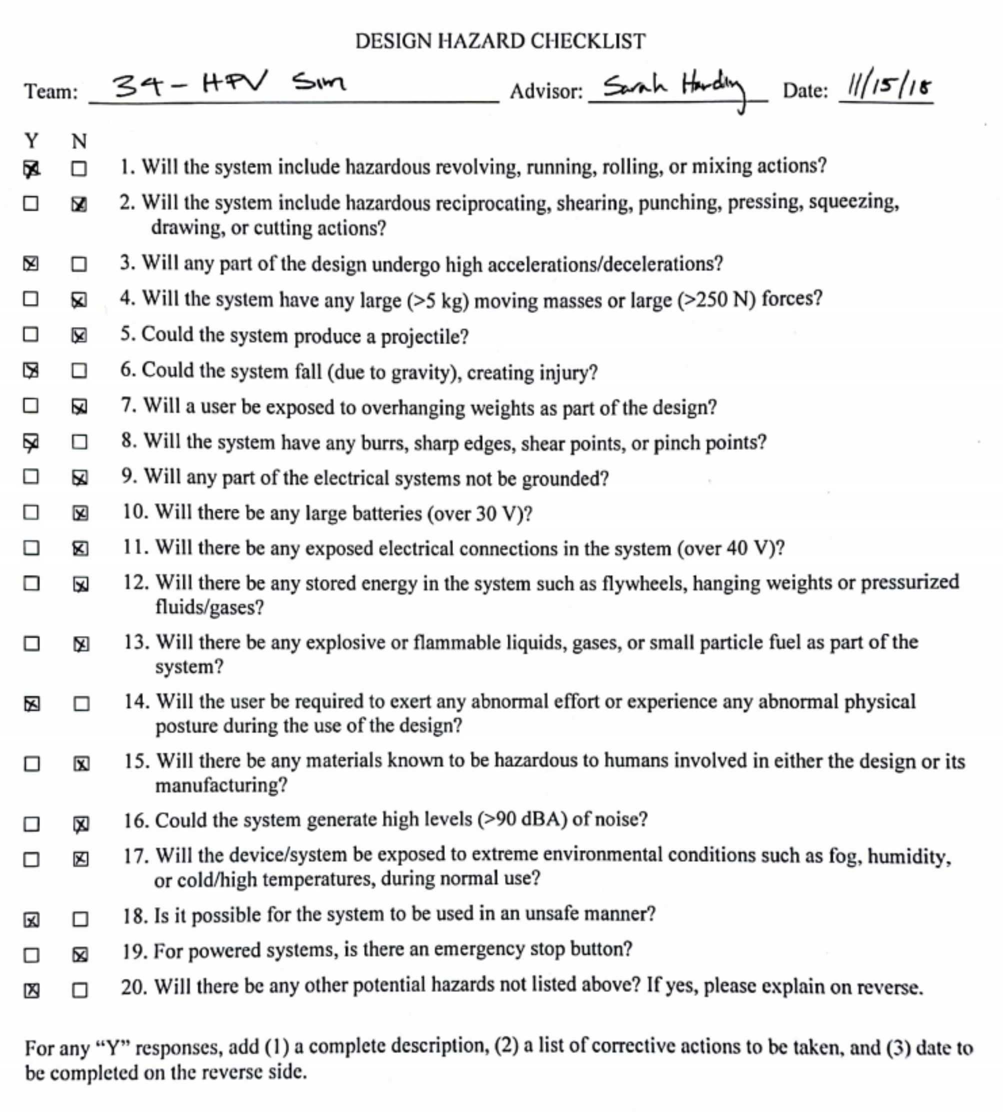


In designing your car for this range of builds, you do not have to have the same seat or seat insert for all drivers. The idea is that the one basic car design should be able to accommodate, and hence be saleable to, drivers of a range of statures from the 5th percentile female to the 95th percentile male.

Apart from the mandated requirement that your roll hoops meet the "Percy" rule (B3.9.3), covering this range of statures will mean attention to driver visibility, steering wheel and shifter locations, pedals, and lap and shoulder belt angles. And do not forget the head restraint!

Updated: 23-Nov-2015, B. Riley

Appendix D. Design Hazard Checklist



DESIGN HAZARD CHECKLIST

Team: 34 – HPV Sim Advisor: Sarah Harding Date: 11/15/18

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.

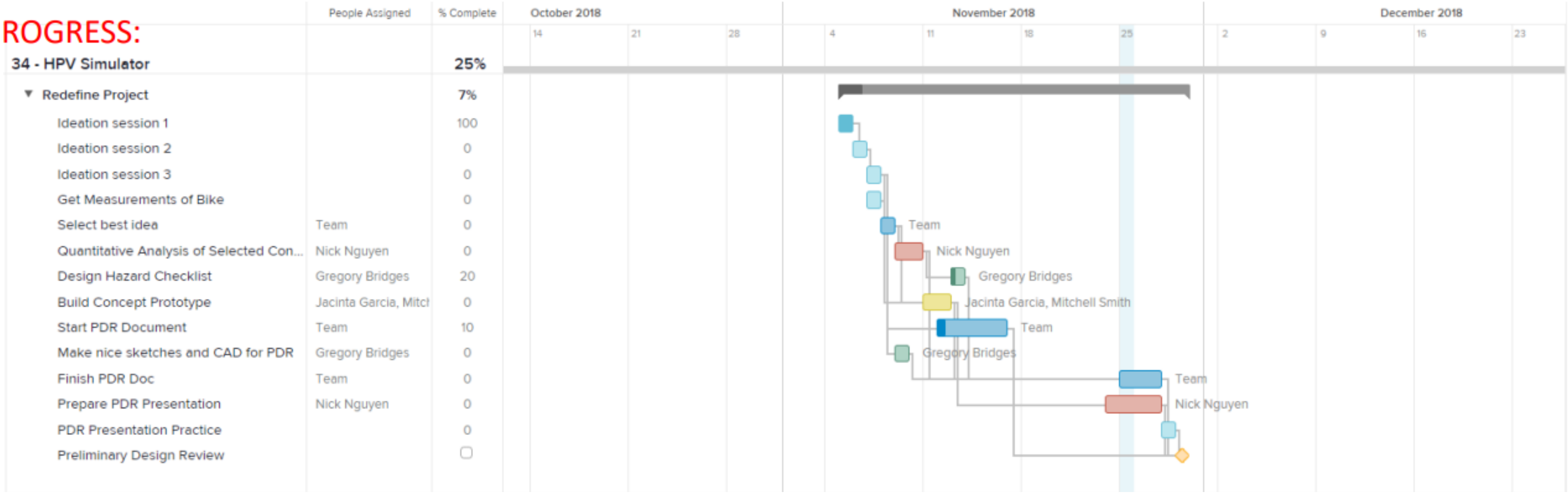
For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Rolling/Revolving Action	The wheels will be rotating at high speeds so we will shield the rider’s legs from the wheel with a bar or cover.	3/16	TBD
Accelerating/Decelerating Parts	The wheels and the drivetrain components will undergo rotational acceleration and deceleration. Similar to the rolling/revolving corrective action above, we will shield the wheel and drivetrain components so that no one can become injured by them during start up and stop.	3/16	TBD
System falling/tipping	The bike has a risk of tipping over so we will make sure the seatbelt harness is functioning to help protect the rider during any accidents. Additionally, we will design the supports such that the bike cannot tip under normal training loads, times a safety factor.	2/13	5/27/19
Abnormal Effort/ Abnormal Posture	The HPV requires a unique position to operate and an incredible amount of effort to reach high speeds. We will work to make our adjustability mechanisms as robust as possible to get riders in their optimal position.	4/24	5/25/19
Bike used in dangerous manner such as someone riding it down a large hill	We will keep the bike in a secure location and only allow riders who have been told about the safety precautions to have access.	1/4	5/29/19
Burrs and Pinch Points	The drivetrain exposes many pinch points, so we will try to keep those points from being too exposed and will allow riders room to operate without getting too close to any pinch points. The bike will be inspected thoroughly for any burrs.	2/29	5/30/19
Rider Fatigue	Intensive use of the simulator and bike can cause extreme fatigue of the user. As such, they may experience muscle fatigue or dehydration. Users must be accompanied by someone else to monitor the health of the user.	3/16	4/27/19

Appendix E. Gantt Chart for Project Planning

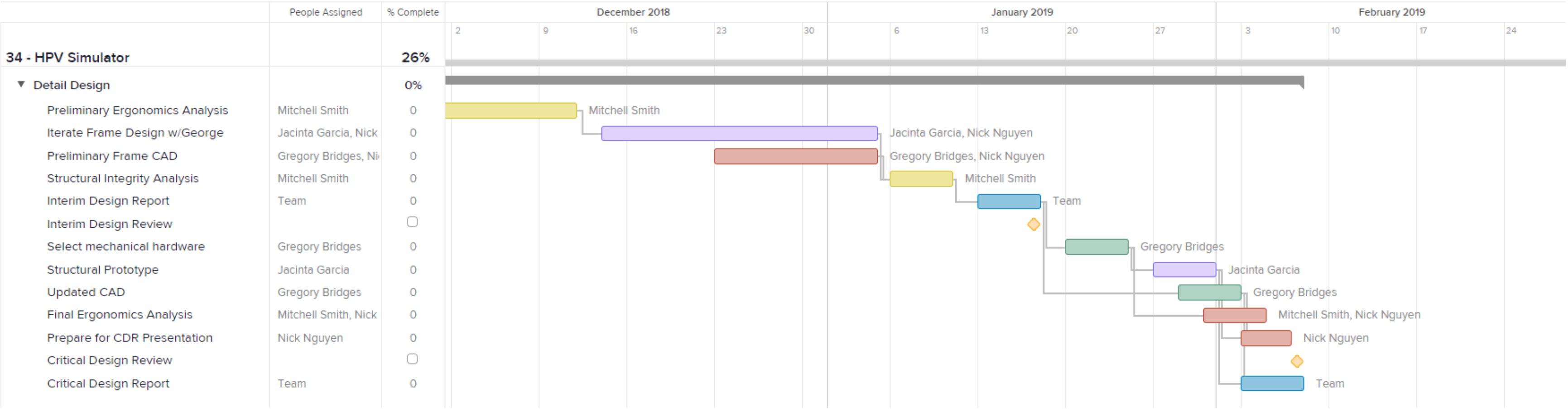
Late Fall Quarter through early Winter Quarter:

PDR PROGRESS:



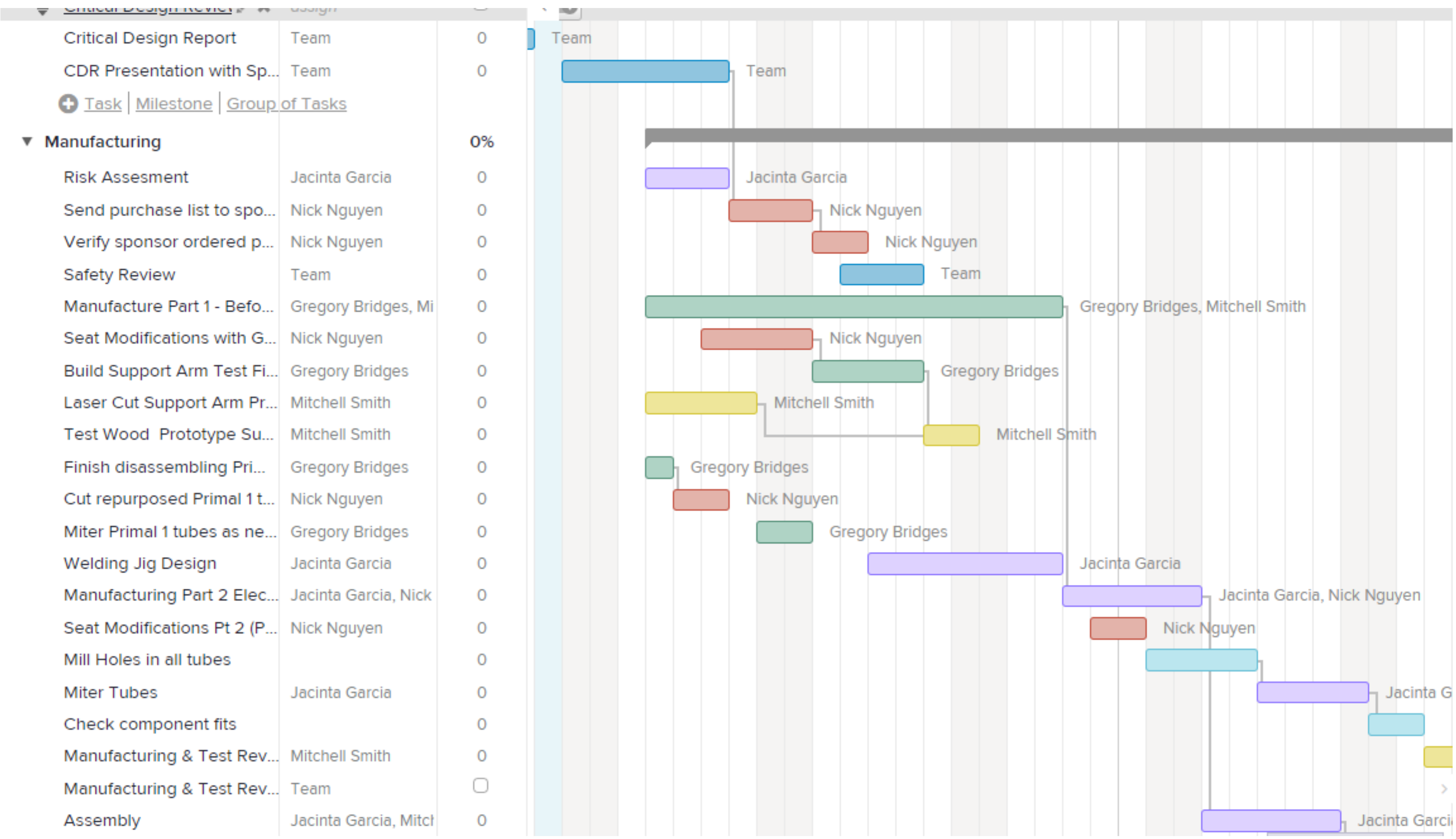
	People Assigned	% Complete
34 - HPV Simulator		**25%**
▼ Redefine Project		7%
Ideation session 1		100
Ideation session 2		0
Ideation session 3		0
Get Measurements of Bike		0
Select best idea	Team	0
Quantitative Analysis of Selected Con...	Nick Nguyen	0
Design Hazard Checklist	Gregory Bridges	20
Build Concept Prototype	Jacinta Garcia, Mitcl	0
Start PDR Document	Team	10
Make nice sketches and CAD for PDR	Gregory Bridges	0
Finish PDR Doc	Team	0
Prepare PDR Presentation	Nick Nguyen	0
PDR Presentation Practice		0
Preliminary Design Review		☐

THROUGH CDR:



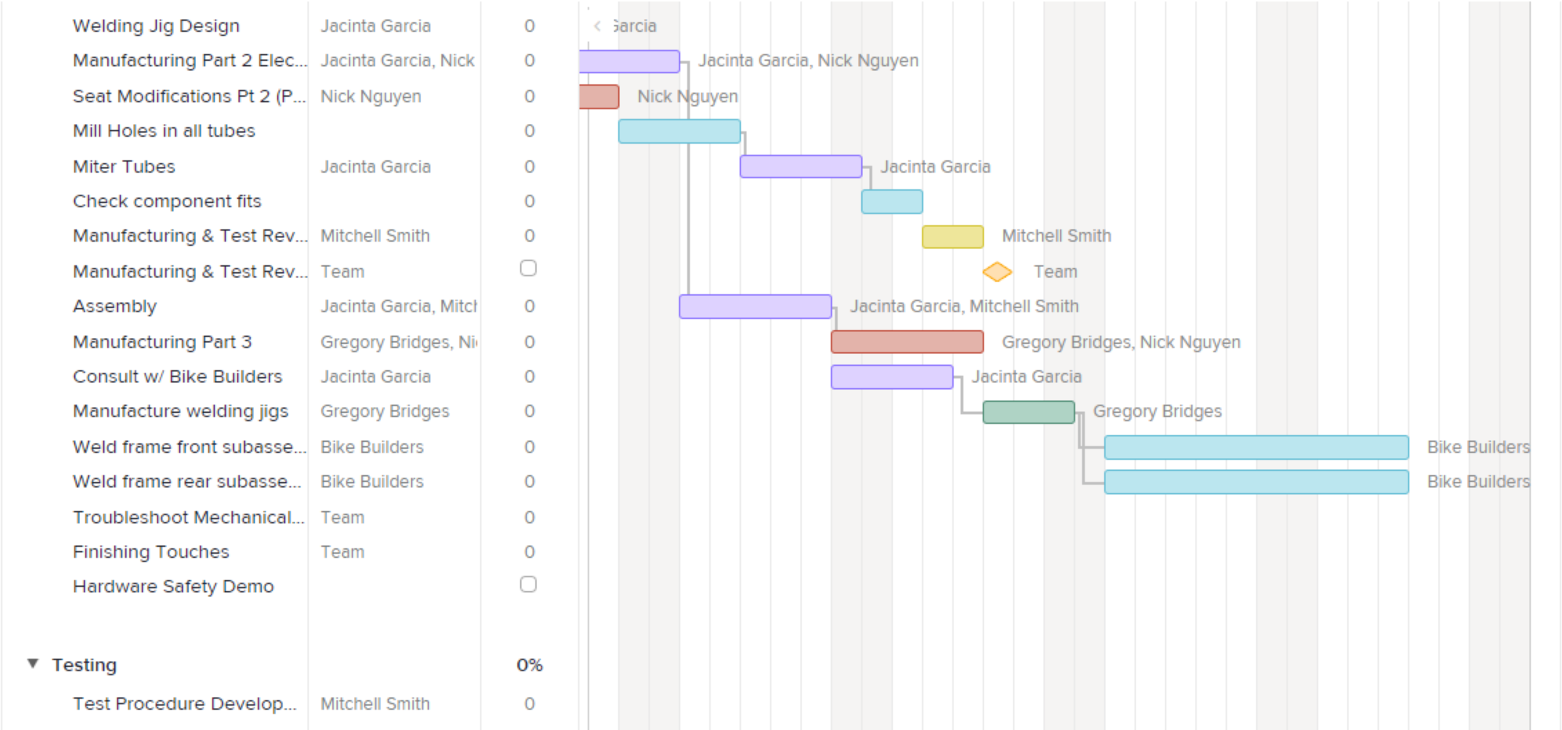
	People Assigned	% Complete
34 - HPV Simulator		**26%**
▼ Detail Design		0%
Preliminary Ergonomics Analysis	Mitchell Smith	0
Iterate Frame Design w/George	Jacinta Garcia, Nick	0
Preliminary Frame CAD	Gregory Bridges, Ni	0
Structural Integrity Analysis	Mitchell Smith	0
Interim Design Report	Team	0
Interim Design Review		☐
Select mechanical hardware	Gregory Bridges	0
Structural Prototype	Jacinta Garcia	0
Updated CAD	Gregory Bridges	0
Final Ergonomics Analysis	Mitchell Smith, Nick	0
Prepare for CDR Presentation	Nick Nguyen	0
Critical Design Review		☐
Critical Design Report	Team	0

Gantt Chart of Middle Winter Quarter to End of Spring Quarter:



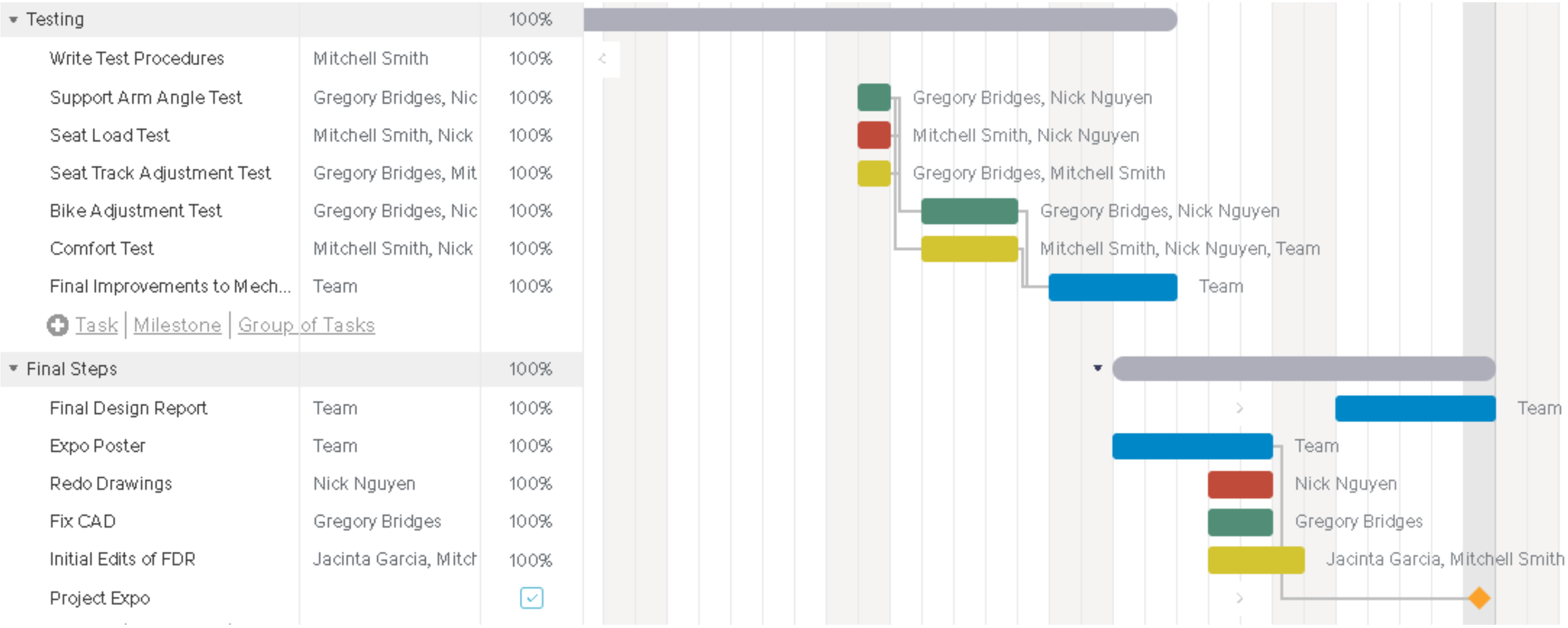
Critical Design Report	Team	0
CDR Presentation with Sp...	Team	0
Task | Milestone | Group of Tasks		
▼ Manufacturing		0%
Risk Assesment	Jacinta Garcia	0
Send purchase list to spo...	Nick Nguyen	0
Verify sponsor ordered p...	Nick Nguyen	0
Safety Review	Team	0
Manufacture Part 1 - Befo...	Gregory Bridges, Mi	0
Seat Modifications with G...	Nick Nguyen	0
Build Support Arm Test Fi...	Gregory Bridges	0
Laser Cut Support Arm Pr...	Mitchell Smith	0
Test Wood Prototype Su...	Mitchell Smith	0
Finish disassembling Pri...	Gregory Bridges	0
Cut repurposed Primal 1 t...	Nick Nguyen	0
Miter Primal 1 tubes as ne...	Gregory Bridges	0
Welding Jig Design	Jacinta Garcia	0
Manufacturing Part 2 Elec...	Jacinta Garcia, Nick	0
Seat Modifications Pt 2 (P...	Nick Nguyen	0
Mill Holes in all tubes		0
Miter Tubes	Jacinta Garcia	0
Check component fits		0
Manufacturing & Test Rev...	Mitchell Smith	0
Manufacturing & Test Rev...	Team	☐
Assembly	Jacinta Garcia, Mitcl	0

Gantt Chart of End of Spring Quarter:



Welding Jig Design	Jacinta Garcia	0
Manufacturing Part 2 Elec...	Jacinta Garcia, Nick	0
Seat Modifications Pt 2 (P...	Nick Nguyen	0
Mill Holes in all tubes		0
Miter Tubes	Jacinta Garcia	0
Check component fits		0
Manufacturing & Test Rev...	Mitchell Smith	0
Manufacturing & Test Rev...	Team	☐
Assembly	Jacinta Garcia, Mitcl	0
Manufacturing Part 3	Gregory Bridges, Ni	0
Consult w/ Bike Builders	Jacinta Garcia	0
Manufacture welding jigs	Gregory Bridges	0
Weld frame front subasse...	Bike Builders	0
Weld frame rear subasse...	Bike Builders	0
Troubleshoot Mechanical...	Team	0
Finishing Touches	Team	0
Hardware Safety Demo		☐
▼ Testing		0%
Test Procedure Develop...	Mitchell Smith	0

Gantt Chart of End of Spring Quarter:



Testing		100%
Write Test Procedures	Mitchell Smith	100%
Support Arm Angle Test	Gregory Bridges, Nic	100%
Seat Load Test	Mitchell Smith, Nick	100%
Seat Track Adjustment Test	Gregory Bridges, Mit	100%
Bike Adjustment Test	Gregory Bridges, Nic	100%
Comfort Test	Mitchell Smith, Nick	100%
Final Improvements to Mech...	Team	100%
Final Steps		100%
Final Design Report	Team	100%
Expo Poster	Team	100%
Redo Drawings	Nick Nguyen	100%
Fix CAD	Gregory Bridges	100%
Initial Edits of FDR	Jacinta Garcia, Mitch	100%
Project Expo		☑

Appendix F. References from Scope of Work

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17. Bingham, JR (2011). US20120322621A1. Alexandria, VA (US): United States Patent Office
18. Pizolato, J (2002). US20040053751A1. Alexandria, VA (US): United States Patent Office

Appendix G. Product and Patent Research from Scope of Work

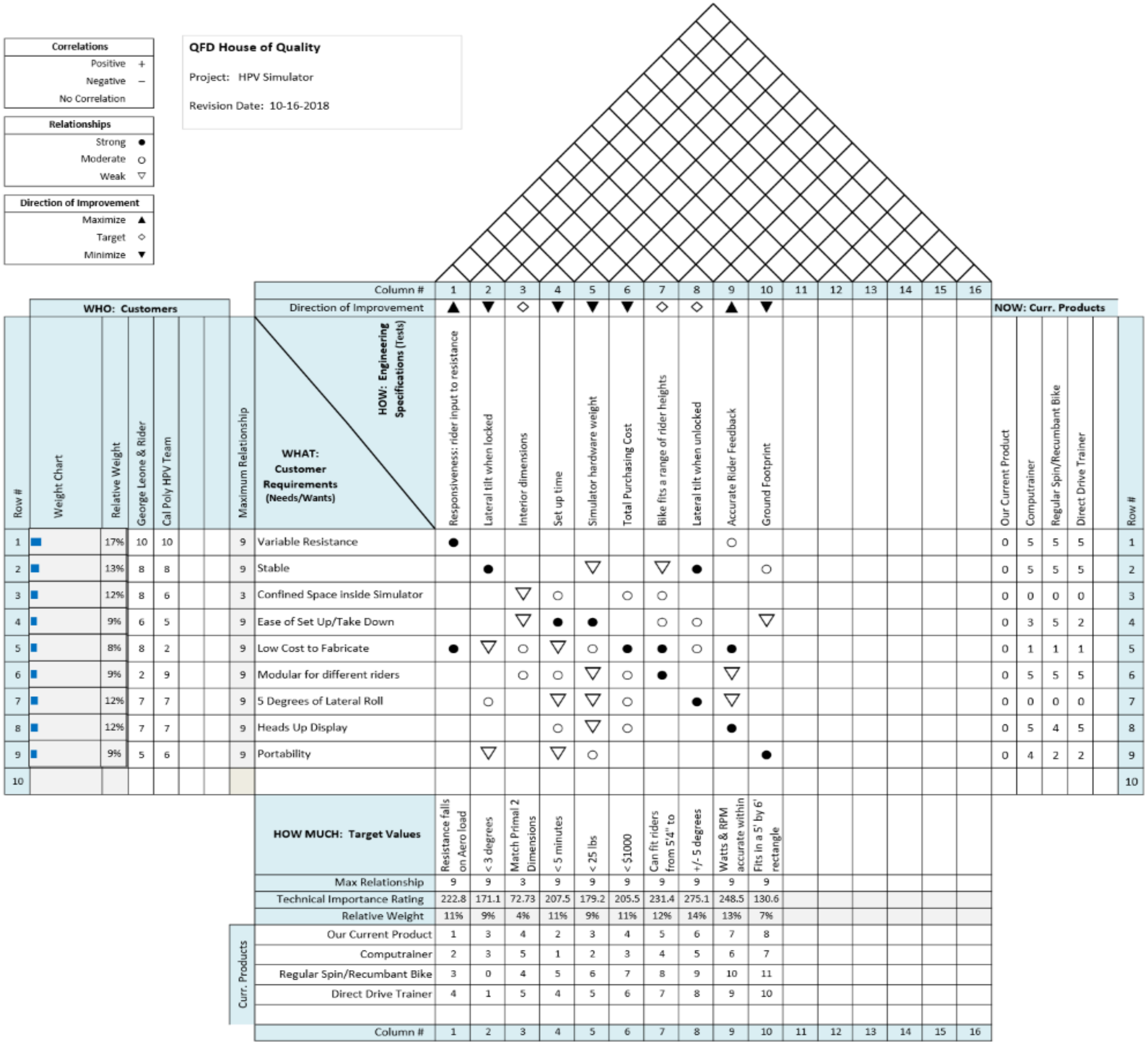
Table 1. Existing Products

Product	Key Characteristics
SUAOKI Transmission Bike Cycling Computer [9]	• Displays RPM, time, and speed of bike. • Easily mounts onto bikes. • $22
Garmin Vector 3 Power Pedals [10]	• Measures total power, cadence, left right balance, and cycling dynamics. • Compatible with any other standard pedal. • $1000
Delft University's Velox 2 HPV [11]	• Delft University has been using the camera-monitor vision system over windows since their 2012 HPV- Velox 2. • The Velox series HPVs have been performing incredibly well and have set many records.
GeChic 1101P Portable Monitor [8]	• 11.6 inch monitor with tripod mounts. • 1080dp IPS screen with multiple universal display ports. • $230
Samsung Galaxy Tab 2 Tablet [7]	• 7 inch tablet with AMOLED screen. • AMOLED has faster response time than conventional IPS and TN panels. • ~$90
Computrainer [12]	• Simulates uphill and downhill resistance based on simulated track. • Applies resistance to rear wheel via drum rolling against rear tire. • Utilizes a flywheel and spindle.
Kickr Direct Drive Trainer [13]	• Mounts directly to bike's rear chain ring. • Uses electromagnets to control resistance (0-2000 W).
Mount-it! Single Monitor Desk Mount Arm [6]	• Single monitor arm, universal compatibility fits different monitors from different manufacturers (common bolt pattern). • Can tilt monitors up and down by 90 degrees and can rotate from landscape to portrait orientations. • Position locked in place through screws located on arm.

Table 2. Related Patents

Patent Name	Patent Number	Key Characteristics
Power measurement device for a bike trainer [17]	US20120322621A1	• Uses a fan coupled to bike via freewheel mechanism along with a velocity sensor and power console unit to calculate rider power output. • Formula in power console accounts for operating conditions such as mechanical drag. • Mounts directly to chain via cassette where the rear wheel would be.
Detachable universal display mount [14]	US6585201B1	• Display mount used for front or rear seat viewing displays in cars. • Mount has telescoping motion to control user distance from display. Can pivot and rotate as well. • Mount comes in 3 pieces, a base, telescoping rod, and display mount.
Computer display screen system and adjustable screen mount, and swinging screens therefor [15]	US6343006B1	• Modular display system meant for computer monitors. • Consists of 4 components, 3 support arms allow for adjustability of monitors. • Adjustability comes in the form of rotating/tilting support arms to optimal positions for user.
Rear hub power meter for a bicycle [16]	US8336400B2	• Hub located power meter that measures your output power while cycling. • Difficult to install and uninstall so it is not good for moving from one bike to another. • Connected to the free hub assembly to measure torque applied to the free hub from the rear cassette.
Bicycle trainer allowing lateral rocking motion [18]	US20040053751A1	• Consists of multiple U-shaped supports that attach to rear wheel of bike with pivots. • Uses a spring/shock on either side of the supports to provide a force to keep the bike upright. • Allows lateral motion of 30 degrees on either side of a bike.

Appendix H. QFD from Scope of Work



Correlations
Positive +
Negative –
No Correlation

Relationships
Strong ●
Moderate ○
Weak ▽

Direction of Improvement
Maximize ▲
Target ◇
Minimize ▼

QFD House of Quality

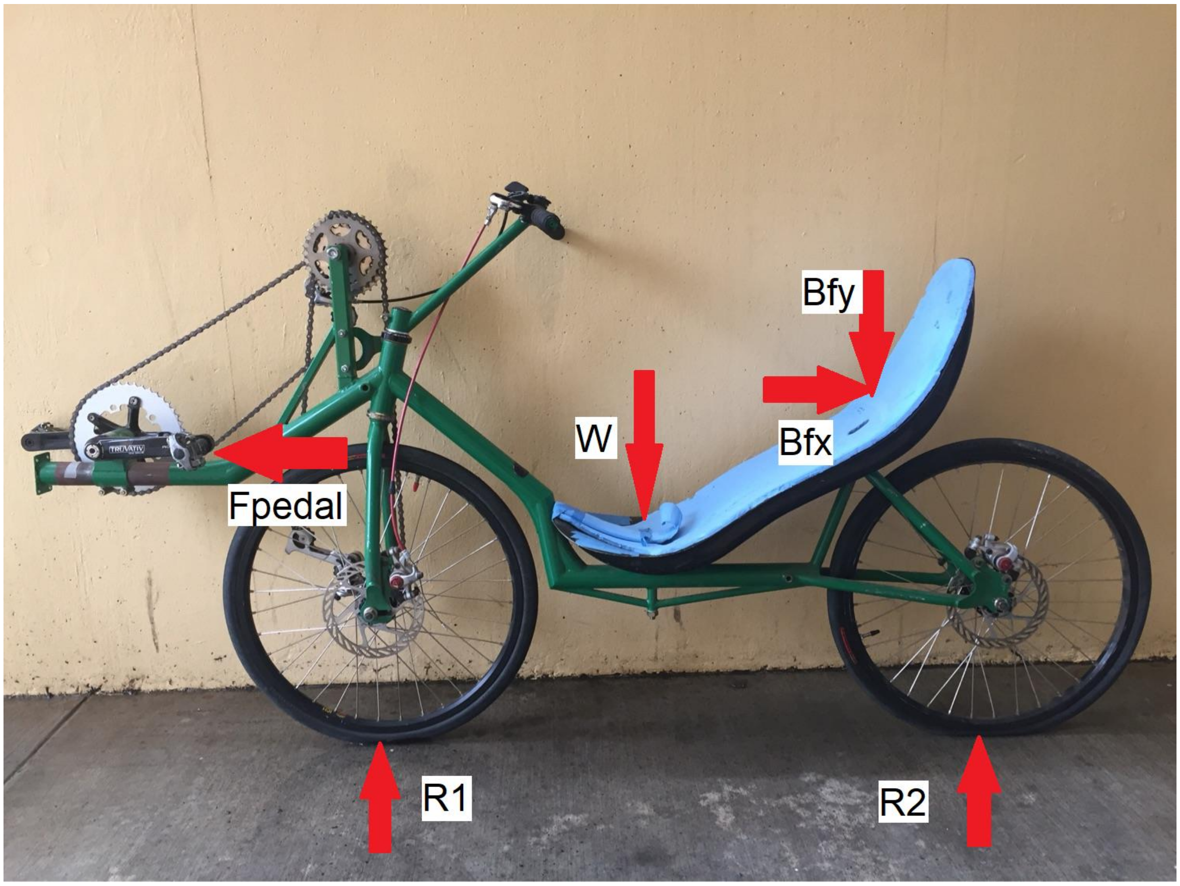
Project: HPV Simulator

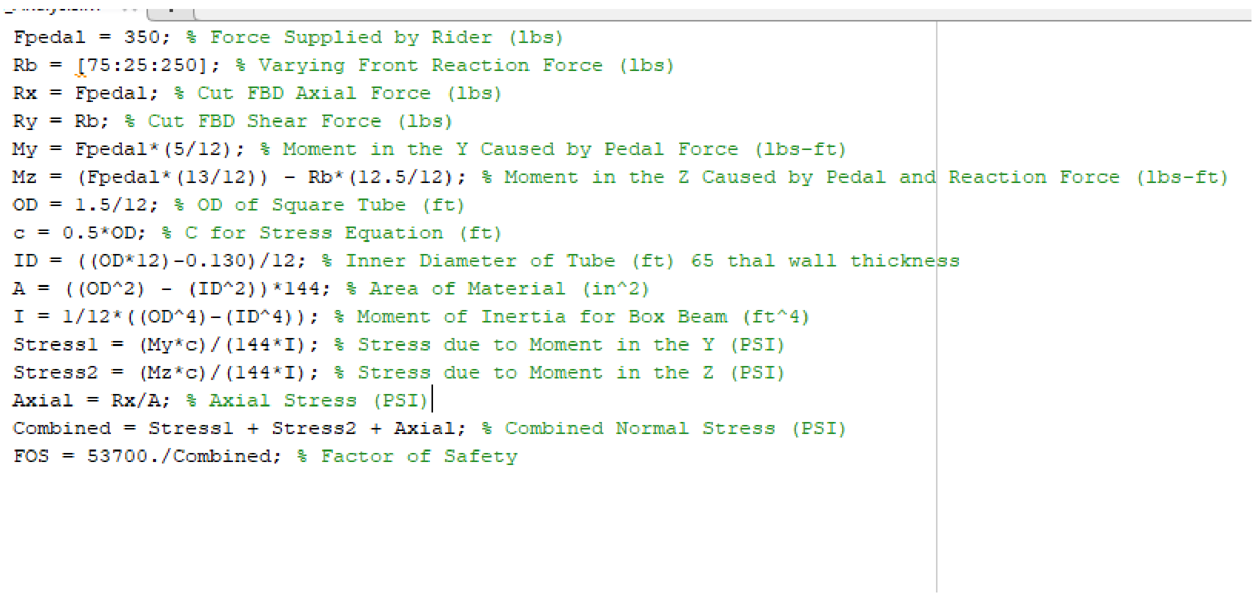
Revision Date: 10-16-2018

Row #	Weight Chart	Relative Weight	George Leone & Rider	Cal Poly HPV Team			Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	1 Responsiveness: rider input to resistance	2 Lateral tilt when locked	3 Interior dimensions	4 Set up time	5 Simulator hardware weight	6 Total Purchasing Cost	7 Bike fits a range of rider heights	8 Lateral tilt when unlocked	9 Accurate Rider Feedback	10 Ground Footprint	11	12	13	14	15	16	Our Current Product	Computrainer	Regular Spin/Recumbant Bike	Direct Drive Trainer		Row #
								Direction of Improvement	▲	▼	◇	▼	▼	▼	◇	◇	▲	▼												
1	■	17%	10	10			9	Variable Resistance	●								○								0	5	5	5		1
2	■	13%	8	8			9	Stable		●			▽		▽	●		○							0	5	5	5		2
3	■	12%	8	6			3	Confined Space inside Simulator			▽	○		○	○										0	0	0	0		3
4	■	9%	6	5			9	Ease of Set Up/Take Down			▽	●	●		○	○		▽							0	3	5	2		4
5	■	8%	8	2			9	Low Cost to Fabricate	●	▽	○	▽	○	●	●	○	●								0	1	1	1		5
6	■	9%	2	9			9	Modular for different riders			○	○	▽	○	●		▽								0	5	5	5		6
7	■	12%	7	7			9	5 Degrees of Lateral Roll		○		▽	▽	○		●	▽								0	0	0	0		7
8	■	12%	7	7			9	Heads Up Display				○	▽	○			●								0	5	4	5		8
9	■	9%	5	6			9	Portability		▽		▽	○					●							0	4	2	2		9
10																														10

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	Resistance falls on Aero load	< 3 degrees	Match Primal 2 Dimensions	< 5 minutes	< 25 lbs	< $1000	Can fit riders from 5'4" to	+/- 5 degrees	Watts & RPM accurate within	Fits in a 5' by 6' rectangle						
	Max Relationship	9	9	3	9	9	9	9	9	9	9						
	Technical Importance Rating	222.8	171.1	72.73	207.5	179.2	205.5	231.4	275.1	248.5	130.6						
	Relative Weight	11%	9%	4%	11%	9%	11%	12%	14%	13%	7%						
Curr. Products	Our Current Product	1	3	4	2	3	4	5	6	7	8						
	Computrainer	2	3	5	1	2	3	4	5	6	7						
	Regular Spin/Recumbant Bike	3	0	4	5	6	7	8	9	10	11						
	Direct Drive Trainer	4	1	5	4	5	6	7	8	9	10						
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix I. Hand Calculations and Finite Element Analysis

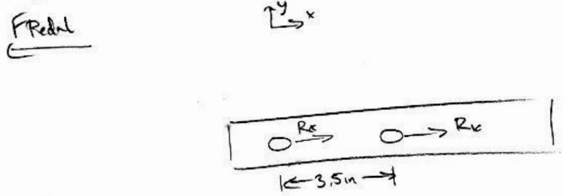




```
Fpedal = 350; % Force Supplied by Rider (lbs)
Rb = [75:25:250]; % Varying Front Reaction Force (lbs)
Rx = Fpedal; % Cut FBD Axial Force (lbs)
Ry = Rb; % Cut FBD Shear Force (lbs)
My = Fpedal*(5/12); % Moment in the Y Caused by Pedal Force (lbs-ft)
Mz = (Fpedal*(13/12)) - Rb*(12.5/12); % Moment in the Z Caused by Pedal and Reaction Force (lbs-ft)
OD = 1.5/12; % OD of Square Tube (ft)
c = 0.5*OD; % C for Stress Equation (ft)
ID = ((OD*12)-0.130)/12; % Inner Diameter of Tube (ft) 65 thal wall thickness
A = ((OD^2) - (ID^2))*144; % Area of Material (in^2)
I = 1/12*((OD^4)-(ID^4)); % Moment of Inertia for Box Beam (ft^4)
Stress1 = (My*c)/(144*I); % Stress due to Moment in the Y (PSI)
Stress2 = (Mz*c)/(144*I); % Stress due to Moment in the Z (PSI)
Axial = Rx/A; % Axial Stress (PSI)
Combined = Stress1 + Stress2 + Axial; % Combined Normal Stress (PSI)
FOS = 53700./Combined; % Factor of Safety
```

From Overall FBD:

Increase Pedal Load to 500 lbf



Assumptions:

1) Assume pins take equal load.

$\sigma_{Bear} = \frac{R_x}{DT}$ ← Being conservative should be $\frac{R_x}{2DT}$ due to 2walls

$\sigma_{Bear} = \frac{250\text{ lbs}}{(0.25\text{in})(0.065\text{in})}$

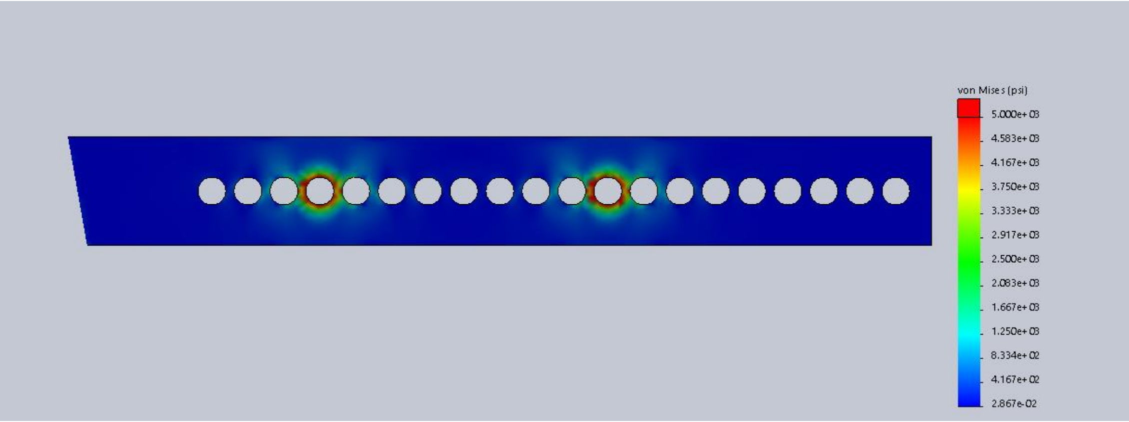
$\sigma_{Bear} = 15.3$ ksi

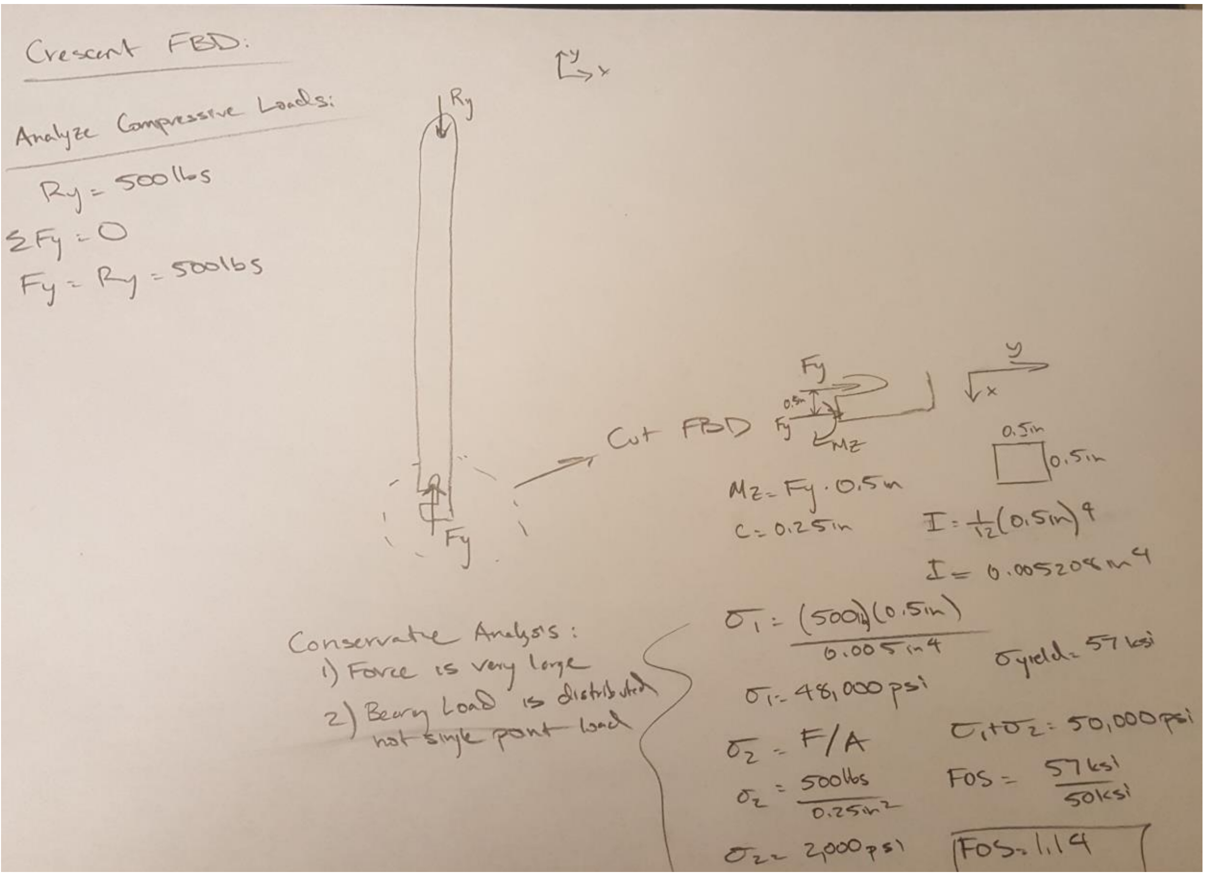
$\sigma_{yield} = 57$ ksi

w/ 2DT $\sigma_{Bear} = 7.7$ ksi

FOS = 3.705

FOS = 7.41





Crescent FBD:

Analyze Compressive Loads:

$R_y = 500\text{lbs}$

$\Sigma F_y = 0$

$F_y = R_y = 500\text{lbs}$

Cut FBD

$M_z = F_y \cdot 0.5\text{in}$

$c = 0.25\text{in}$

$I = \frac{1}{12}(0.5\text{in})^4$

$I = 0.005208\text{in}^4$

Conservative Analysis:
1) Force is very large
2) Bearing Load is distributed not single point load

$\sigma_1 = \frac{(500\text{lb})(0.5\text{in})}{0.005\text{in}^4}$

$\sigma_{yield} = 57\text{ksi}$

$\sigma_1 = 48{,}000\text{psi}$

$\sigma_2 = F/A$

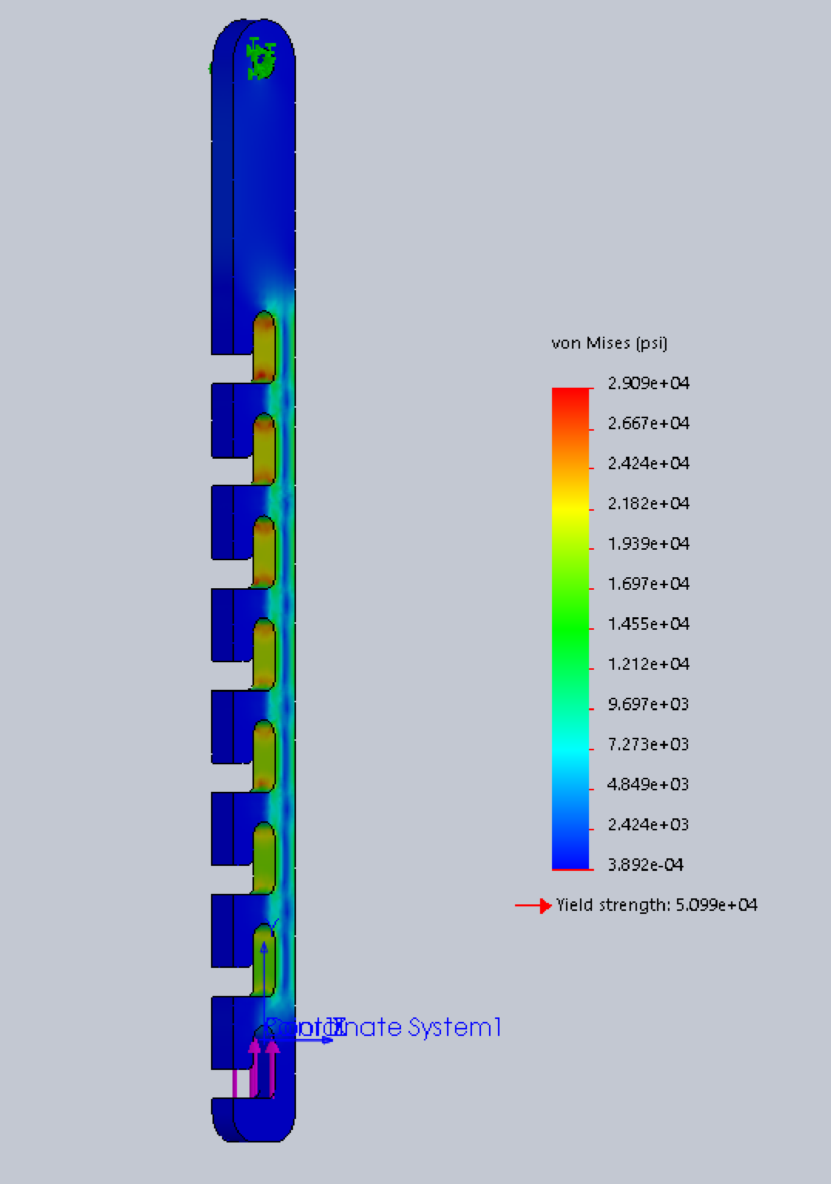
$\sigma_1 + \sigma_2 = 50{,}000\text{psi}$

$\sigma_2 = \frac{500\text{lbs}}{0.25\text{in}^2}$

$FOS = \frac{57\text{ksi}}{50\text{ksi}}$

$\sigma_2 = 2{,}000\text{psi}$

$\boxed{FOS = 1.14}$


von Mises (psi)
2.909e+04
2.667e+04
2.424e+04
2.182e+04
1.939e+04
1.697e+04
1.455e+04
1.212e+04
9.697e+03
7.273e+03
4.849e+03
2.424e+03
3.892e-04
Yield strength: 5.099e+04
Coordinate System1

Appendix J: Structural Prototype Data

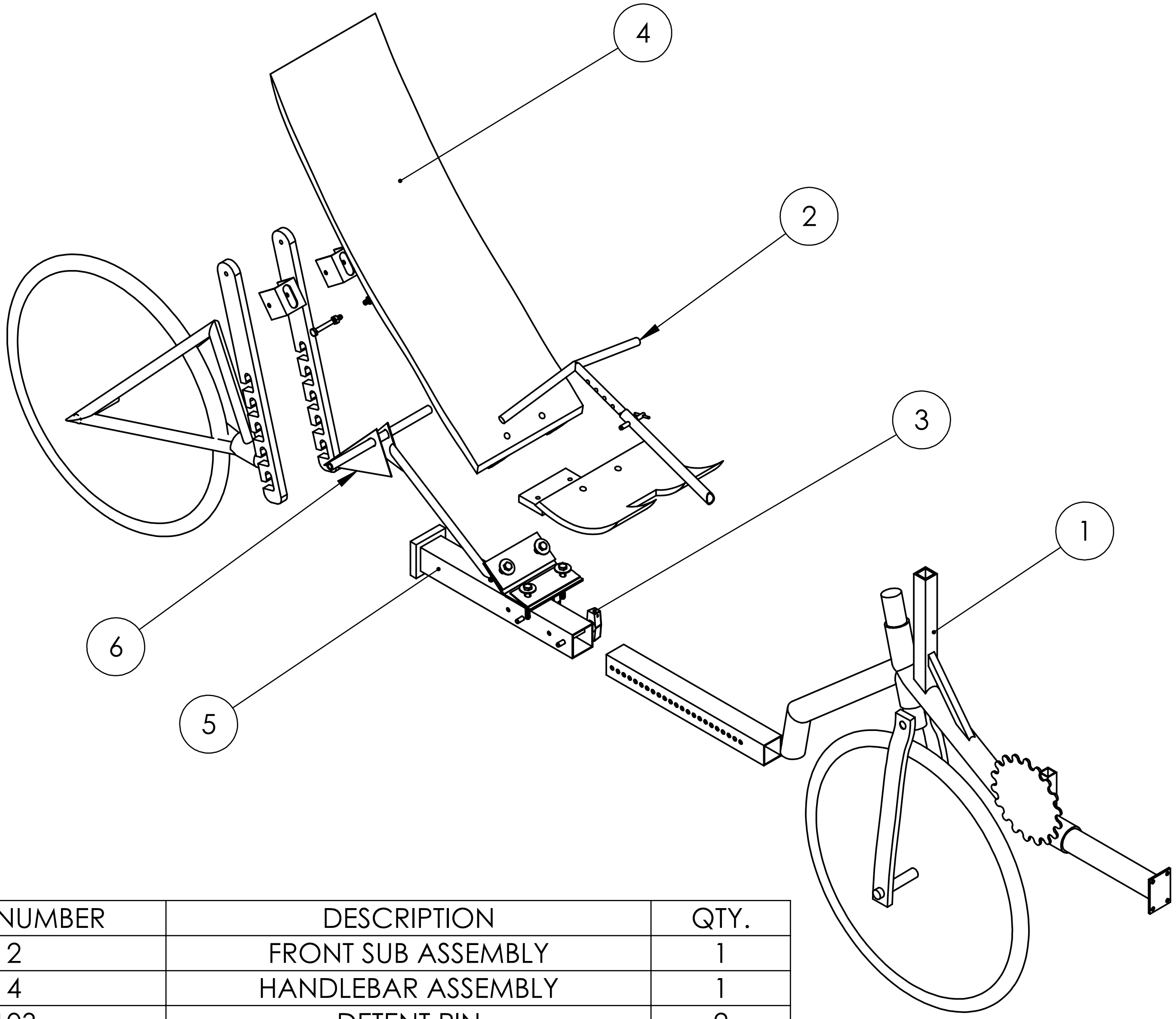
Rider Dimensions			Seat Track Measurements	Handlebar Measurements					
Rider Height [ft, in]	X-Seam [in]	Arm Length [in]	Distance Between Front & Back Halves [in]	Peg Position [-]	Corresponding Handlebar Height [in]	Distance from back half of structural prototype to center of handlebar test post [in]	Stem to Handlebar Distance [in]	Desired Longitudinal Handlebar Position from Head Tube [in]	Desired Handlebar Height Above Head Tube [in]
5'9.75"	38	27.5	4.5	5	34.25	3.0	15.0	19.50	6.375
5'10.5"	41	30	3.5	6	32.75	0.0	12.0	15.50	4.875
5'11.9"	38	29	2.8	4	35.75	0.0	12.0	14.75	7.875
5'7"	40	28	4.0	6	32.75	2.0	14.0	18.00	4.875
6'1"	36.5	32.5	3.8	4	35.75	4.5	16.5	20.25	7.875
5'5.8"	35.25	26.5	0.3	5	34.25	0.8	12.8	13.00	6.375
5'8"	35	27	2.5	5	34.25	0.5	12.5	15.00	6.375
5'4"	36.5	25	0.0	7	31.25	-2.0	10.0	10.00	3.375
5'5"	33	27.5	0.5	5	34.25	1.3	13.3	13.75	6.375
6'2"	44.25	30.5	6.0	5	34.25	-0.5	11.5	17.50	6.375
5'11"	39.75	29.5	4.5	6	32.75	-1.0	11.0	15.50	4.875
5'9"	36	31	3.0	6	32.75	3.5	15.5	18.50	4.875
6'2"	39	29	5.8	5	34.25	1.0	13.0	18.75	6.375

Appendix K

Indented Bill of Material (BOM)

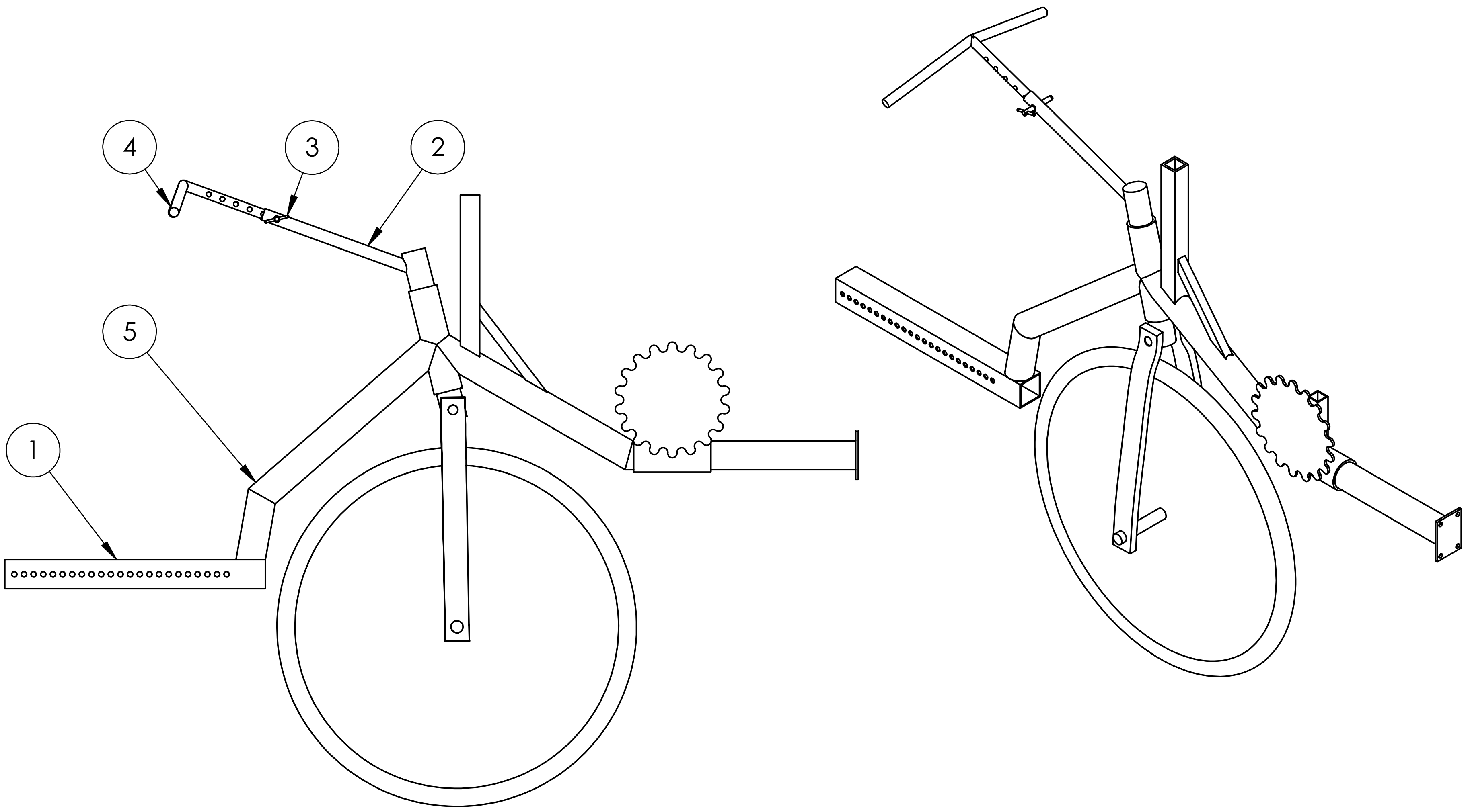
HPV Trainer Assembly

Assembly Level	Part Number		Description		Material	Vendor	Vendor Part No.	Qty	Cost	Ttl Cost	Notes	Subsystem Cost
		Lvl0	Lvl1	Lvl2								
0		Final Assy				------						
1			Seat Track Mechanism			------						55.92
1	101			Back Box Beam	4130 Steel	Discount Steel		1	18.75	$ 18.75		
1	102			Front Box Beam	4130 Steel	Discount Steel		1	18.75	$ 18.75		
1	103			Détente Pins	316 Stainless	Mcmaster Carr	92490A651	2	4.91	$ 9.82		
1	104			Box Beam Mount	4130 Steel	Discount Steel		1	0	$ -	From Inner Box Beam	
1	105			Seat Backing Plate	Steel	Mcmaster Carr	8910K12	1	0	$ -	From Crescent Material	
1	106			Seat Bottom	Carbon/Fiber	Custom		1	0	$ -		
1	107			Rear Weld Plate	Steel	Mcmaster Carr	8910K12	1	0	$ -	From Crescent Material	
1	108			Oversized Washer	316 Stainless Steel	Miners	91525A120	6	0.2	$ 3.00		
1	109			1/4-20 Hex Nut	Steel	Miners	95505A601	8	0.25	$ 2.00		
1	110			Seat Back	Carbon/Fiber	Custom		1	0	$ -		
1	111			1/4-20 Bolt	18-8 Stainless Steel	Miners	92198A551	8	0.45	$ 3.60		
2			Reclining Mechanism									96.99
2	201			1/2" Steel Plate (Reclining Support Arms)	Steel	Mcmaster Carr	8910K12	1	85	$ 85.00		
2	202			U-Brackets	Steel	Cal Poly Machine Shop		1	0	$ -		
2	203			Rear Support Tube (.5" tube)	Steel	HPV		1	0	$ -		
2	204			Modified Hinge	Steel	Miner's Ace Hardware	HG-6020	1	7.99	$ 7.99		
2	205			Back Hinge Plate	Aluminum	Mcmaster Carr	8975K206	1	2	$ 2.00		
2	206			Bottom Hinge Plate	Aluminum	Mcmaster Carr	8975K206	1	2	$ 2.00		
				T-Nuts	Steel	Miner's Ace Hardware		2	2.5	$ 5.00		
3			Handlebars									26.24
3	301			Handlebar Post (1" OD, .083 wall thick)	4130 Steel	Mcmaster Carr	89955K649	1	20	$ 20.00		
3	302			Détente Pins	Steel	Mcmaster Carr	98405A130	2	3.12	$ 6.24		
3	303			Telescoping Handle Bar	4130 Steel	George		1	0	$ -	Repurpose from old frame	
4			Frame									0
4	401			Front Assembly	4130 Steel	George		1	0	$ -		
4	402			Rear Assembly	4130 Steel	George		1	0	$ -		
4	405			Gusset Support	4130 Steel	George		1	0	$ -		
5	N/A			Brake Cable and Housing		Cal Poly Bike Shop		1	5	$ 5.00		
				Tear Drop Mallet		Harbor Freight		1	9	$ 9.00		
5	N/A			Spray Paint		Miner's Ace Hardware		1	16	$ 16.00		
										$ 214.15		



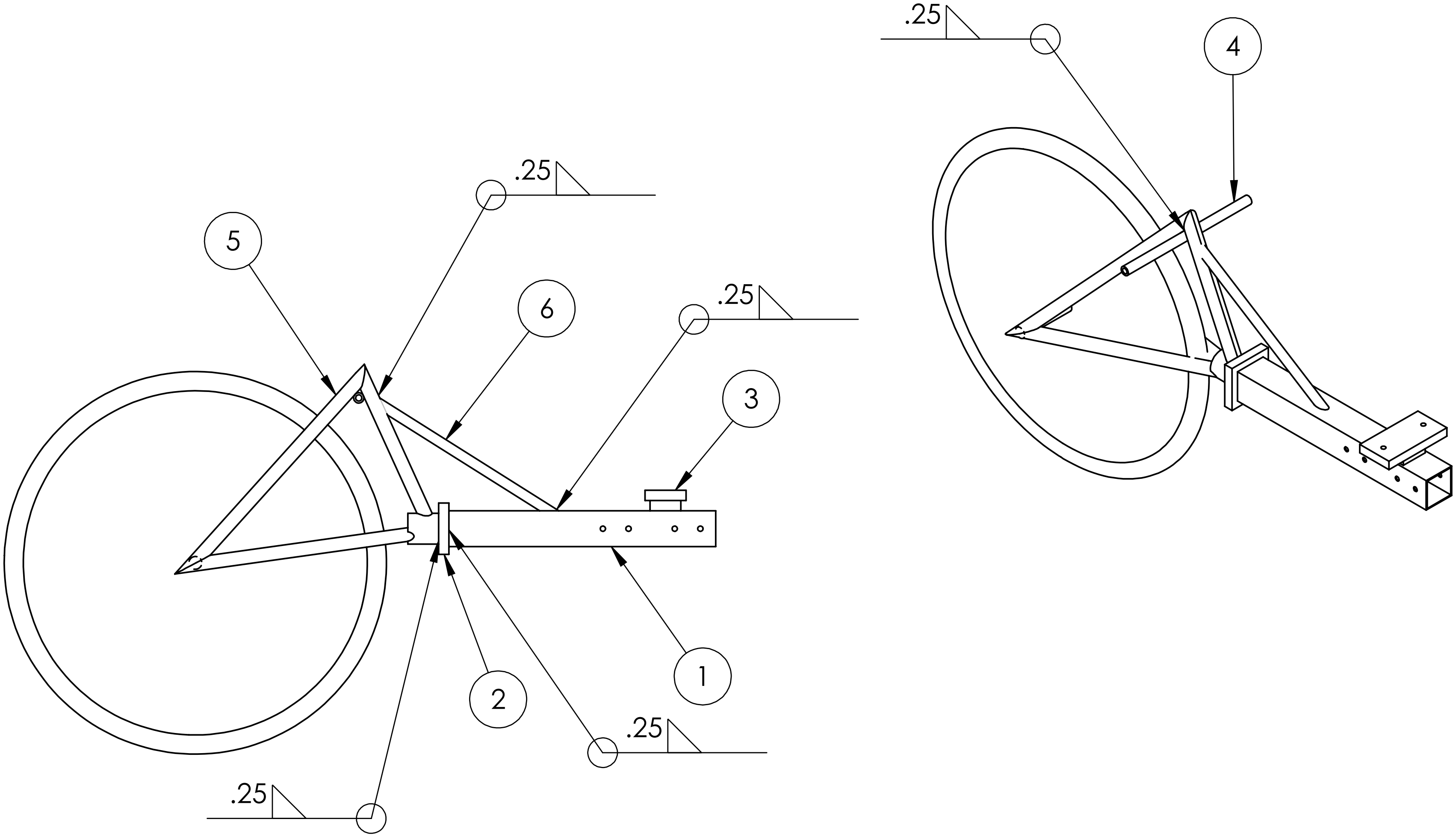
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2	FRONT SUB ASSEMBLY	1
2	4	HANDLEBAR ASSEMBLY	1
3	103	DETENT PIN	2
4	5	SEAT ASSEMBLY	1
5	3	REAR SUB ASSEMBLY	1
6	400	WELDING TAB	2

Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: BIKE FRAME ASSEMBLY		Drwn. By: G. BRIDGES
	Dwg. #: 1		Date: 5/31/19	Scale: 1:10	Chkd. By: N. NGUYEN



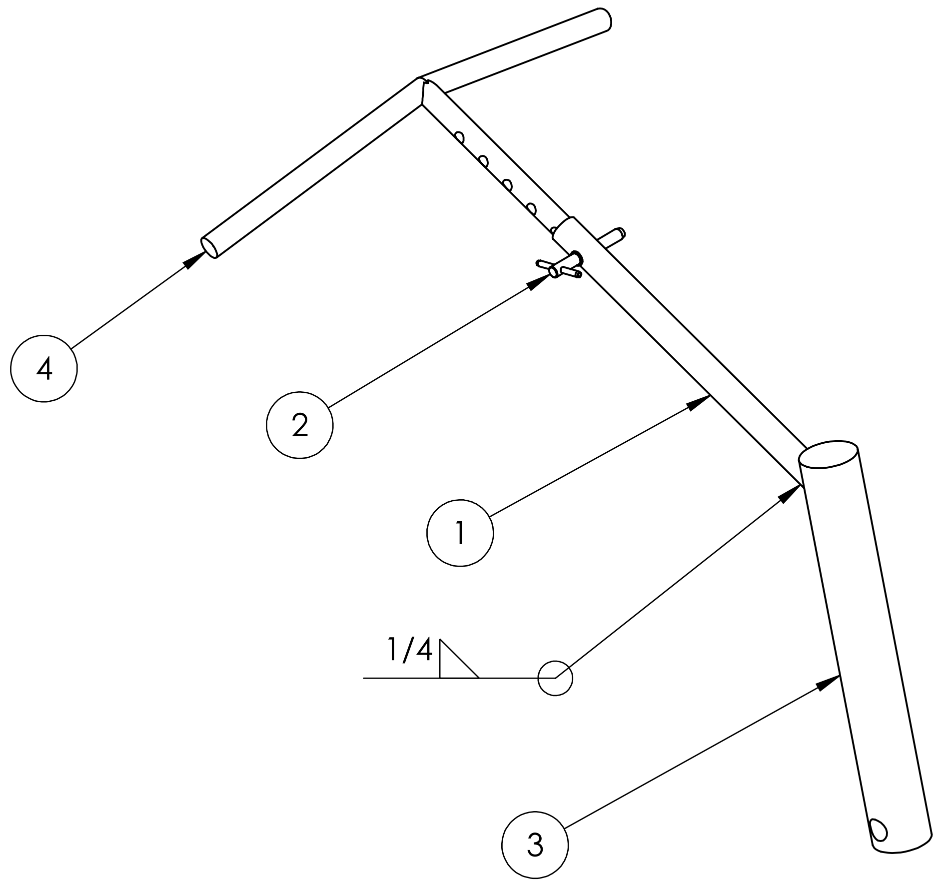
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	102	FRONT BOX BEAM	1
2	301	HANDLEBAR POST	1
3	302	STEERING DETENT PIN	1
4	304	HANDLEBAR GRIPS	1
5	403	MODIFIED PRIMAL FRAME	1

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: FRONT SUB ASSEMBLY		Drwn. By: G. BRIDGES
ME 430 - SPRING 2019	Dwg. #: 2	Nxt Asb:	Date: 5/30/2019	Scale: 1:8	Chkd. By: N. NGUYEN



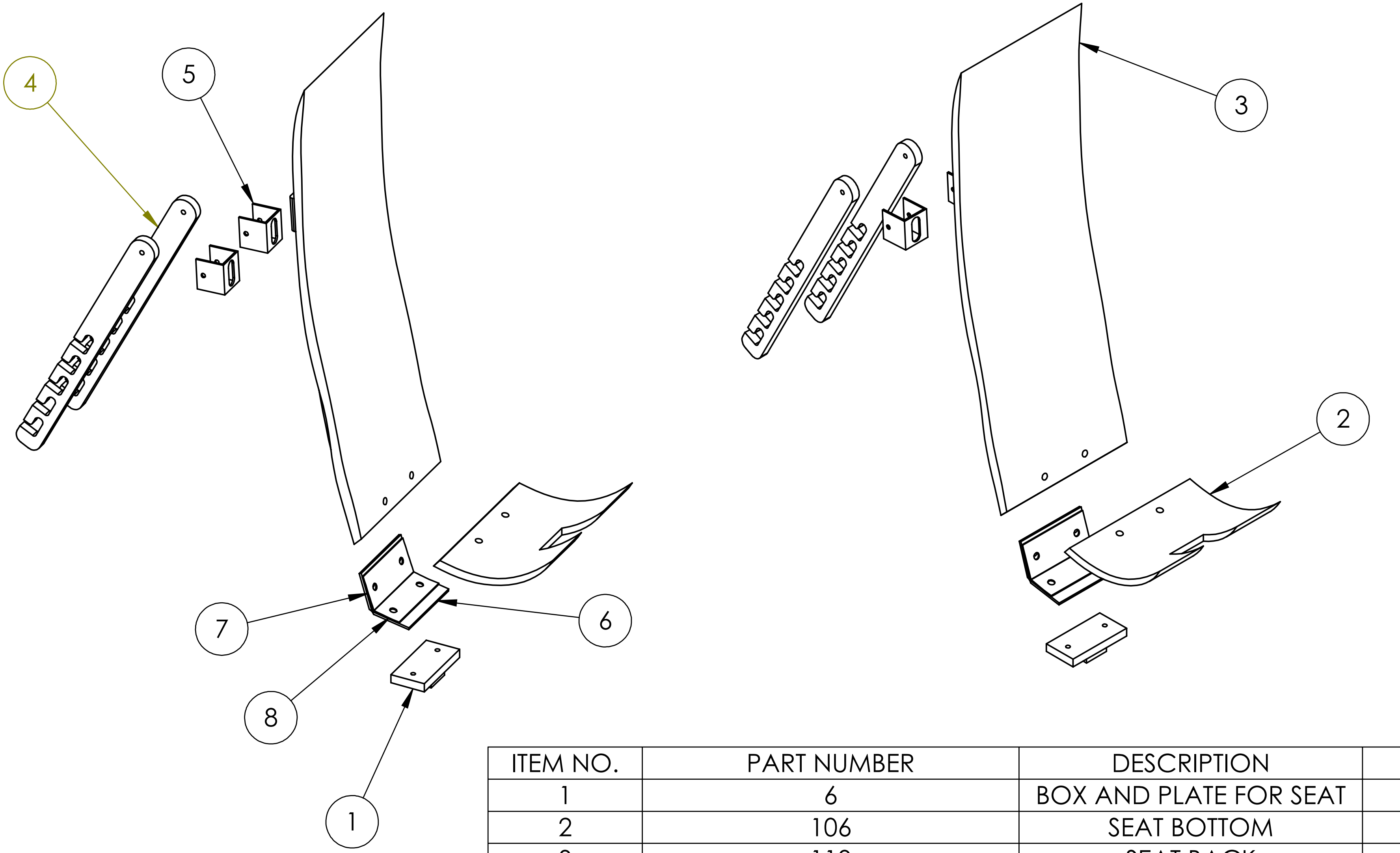
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	101	BACK BOX BEAM	1
2	107	WELD PLATE	1
3	6	BOX AND PLATE FOR SEAT	1
4	203	BACK SUPPORT TUBE	1
5	404	BACK FRAME	1
6	405	GUSSET SUPPORT	1

Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: BACK SUB ASSEMBLY	Drwn. By: G. BRIDGES
	Dwg. #: 3		Date: 5/30/2019 | Scale: 1:8	Chkd. By: N. NGUYEN



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	301	HANDLEBAR POST	1
2	302	DETENT PIN	1
3	303	MODIFIED YOKE	1
4	304	HANDLEBAR TUBE AND GRIPS	1

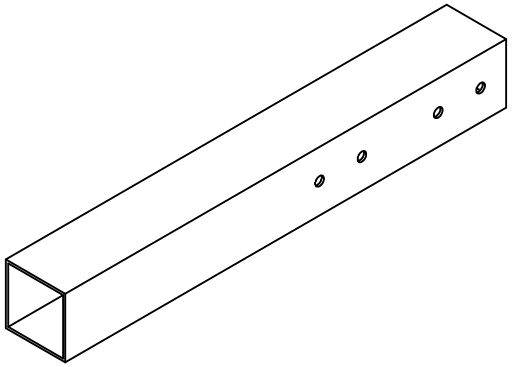
Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: HANDLEBAR SUB ASSEMBLY	Drwn. By: G. BRIDGES
	Dwg. #: 4		Date: 5/30/2019 Scale: 1:4	Chkd. By: N. NGUYEN

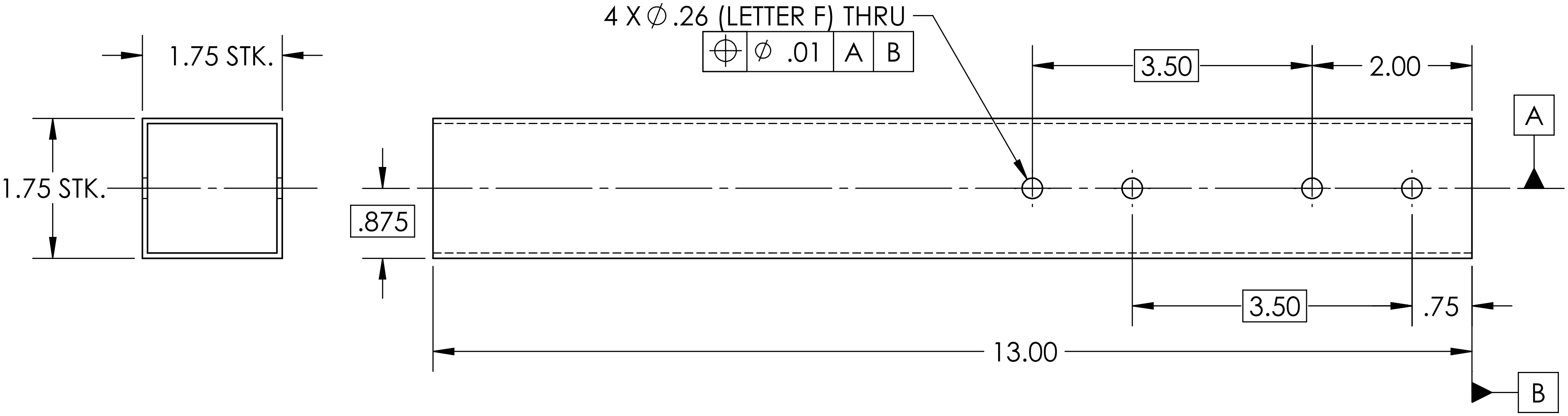


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6	BOX AND PLATE FOR SEAT	1
2	106	SEAT BOTTOM	1
3	110	SEAT BACK	1
4	201	SUPPORT ARMS	2
5	202	U-BRACKET	2
6	204	HINGE	1
7	205	HINGE PLATE FOR BACK	1
8	206	HINGE PLATE FOR BOTTOM	1

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: SEAT SUB ASSEMBLY		Drwn. By: G. BRIDGES
ME 430 - SPRING 2019	Dwg. #: 5		5/30/2019	Scale: 1:8	Chkd. By: N. NGUYEN

NOTES:
1. ALL DIMENSIONS IN INCHES
2. PURCHASED SQUARE TUBING, 1.75 X 1.75, 16 GAUGE
WALL THICKNESS: .0625 ± .007
3. MATERIAL: CARBON STEEL
4. TOLERANCES:
X.XX ± .01
X.XXX ± .005

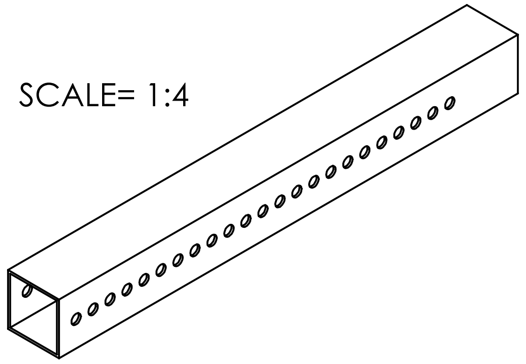


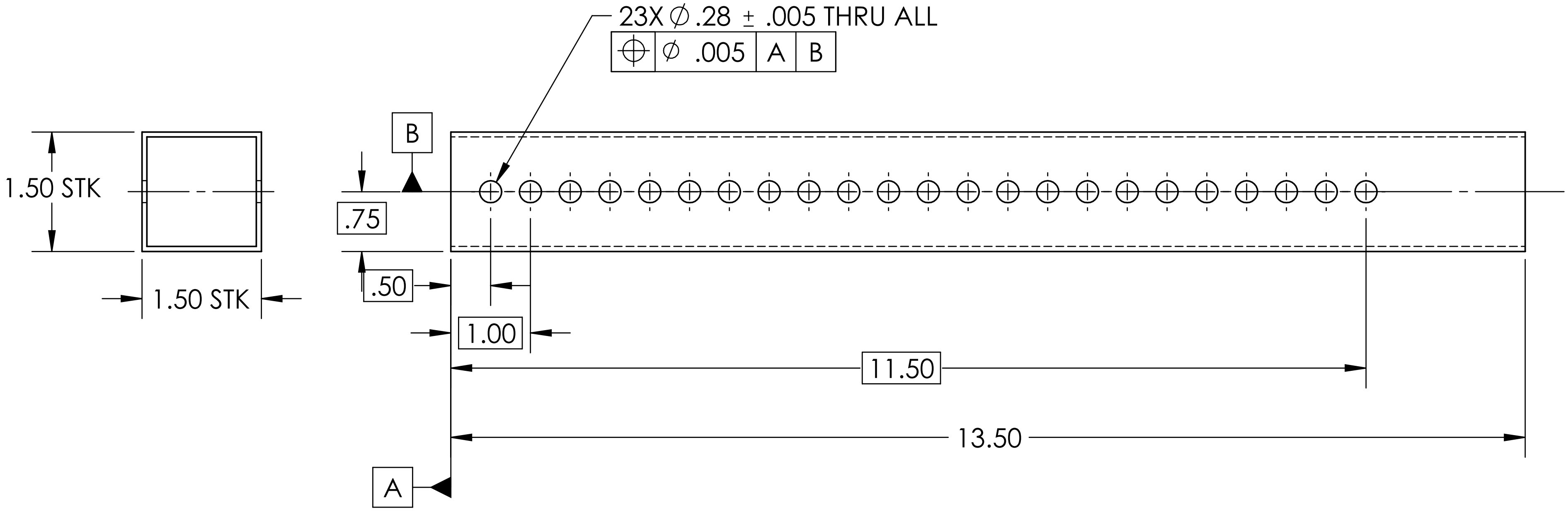


Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: BACK BOX BEAM	Drwn. By: MITCH SMITH
	Dwg. #: 101		Date: 5/30/2019 | Scale: 1:2	Chkd. By: NICK NGUYEN

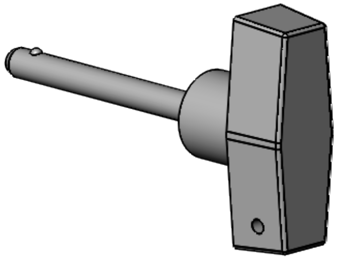
NOTES:

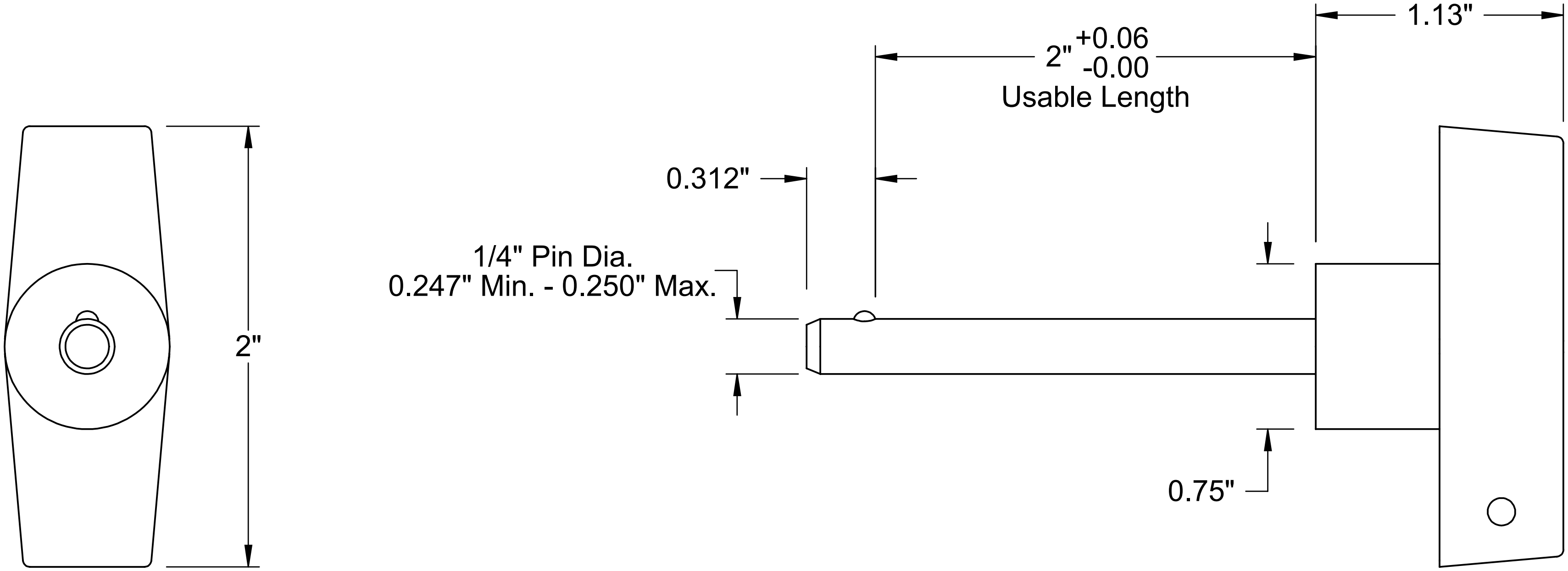
1. ALL DIMENSIONS IN INCHES
2. PURCHASED SQUARE TUBING, 1.5 X 1.5, 16 GAUGE
   WALL THICKNESS: .0625 ± .007
3. MATERIAL: LOW CARBON STEEL
4. TOLERANCES:
   X.XX ± .01
   X.XXX ± .005
5. REPEATED PATTERN SPACING OF .50 INCHES CENTER TO CENTER
6. END CUT WITH HOLE SAW, ANGLE CUT AT 80 DEGREES FROM HORIZONTAL





Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: FRONT BOX BEAM		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 102		Date: 5/30/19	Scale: 1:2	Chkd. By: MITCH SMITH

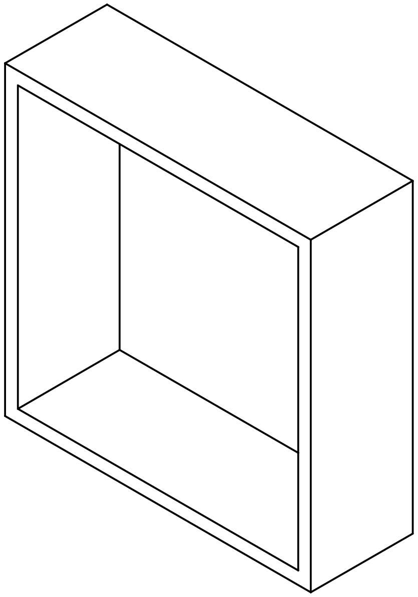


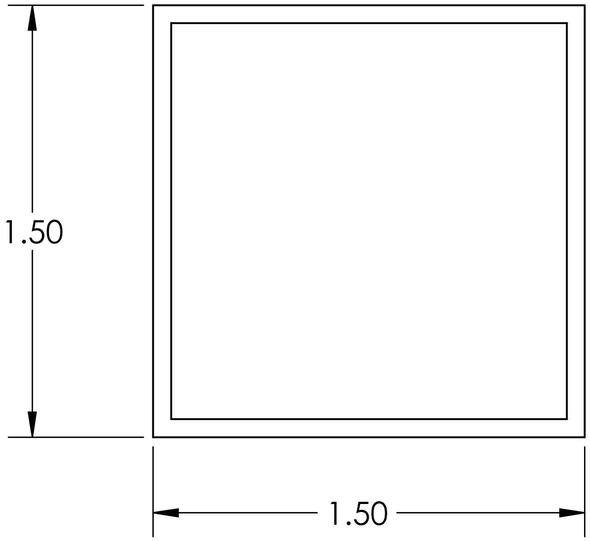


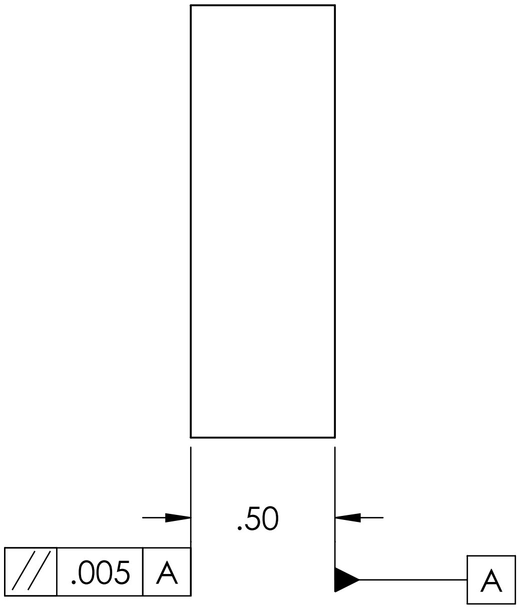
McMASTER-CARR® CAD	PART NUMBER **92490A651**
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company	Plastic-Handle Quick-Release Pin
Information in this drawing is provided for reference only.	

<u>NOTES:</u>

1. ALL DIMENSIONS IN INCHES
2. STOCK CARBON STEEL SQUARE TUBE 1.5 INCHES
   16 GAGE WALL THICKNESS
3. TOLERANCES:
   X.XX ± .05

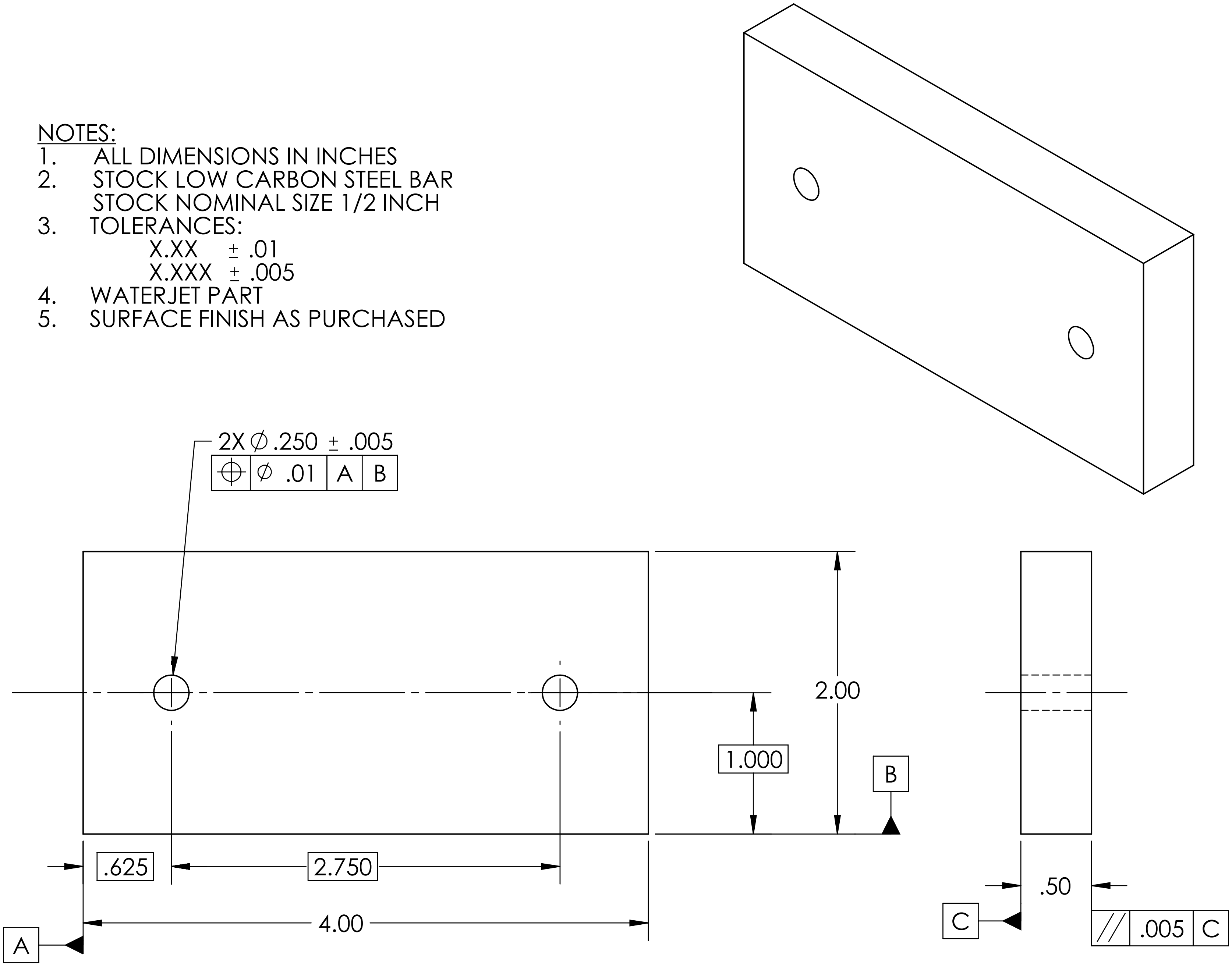




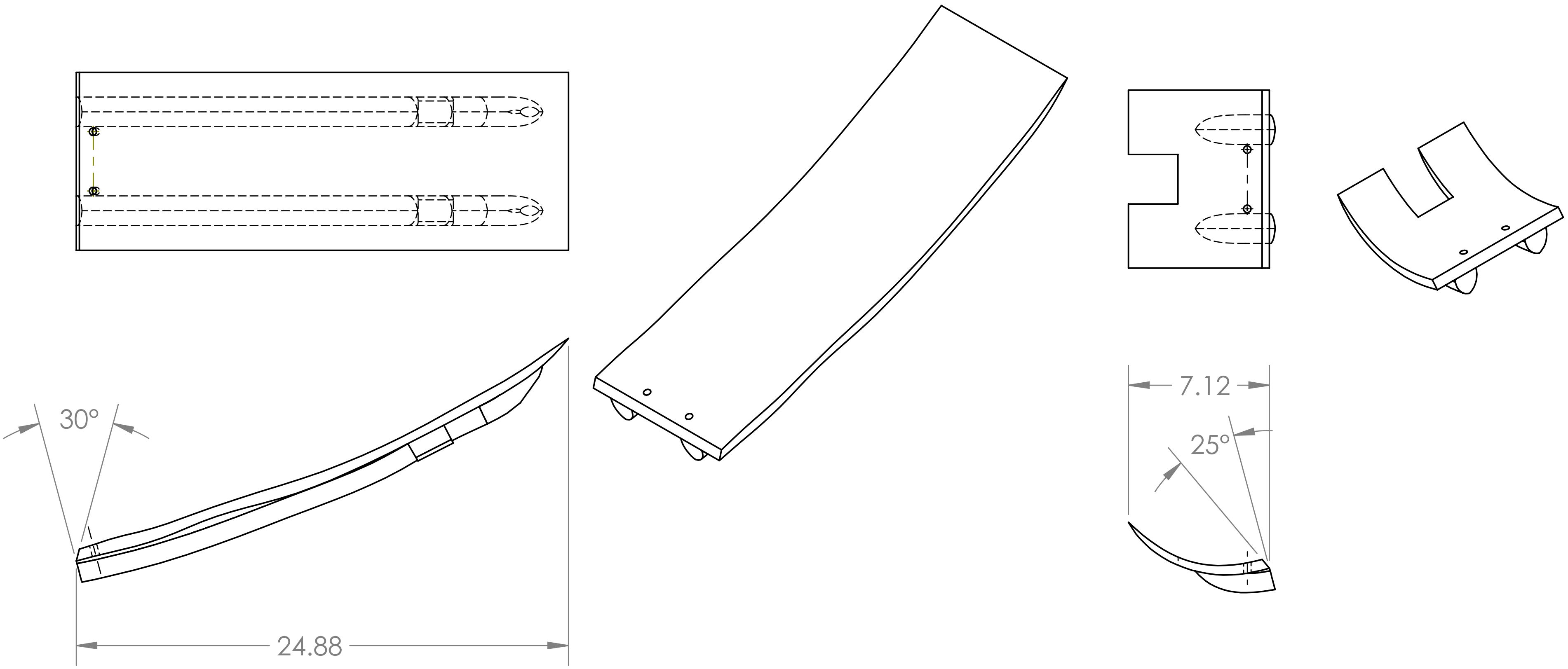


Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: BOX BEAM MOUNT		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 104		Date: 5/30/2019	Scale: 3/2	Chkd. By: GREG BRIDGES

NOTES:
1. ALL DIMENSIONS IN INCHES
2. STOCK LOW CARBON STEEL BAR
STOCK NOMINAL SIZE 1/2 INCH
3. TOLERANCES:
X.XX ± .01
X.XXX ± .005
4. WATERJET PART
5. SURFACE FINISH AS PURCHASED



Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: SEAT BACKING PLATE		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 105		Date: 5/30/2019	Scale: 1:1	Chkd. By: JACINTA GARCIA

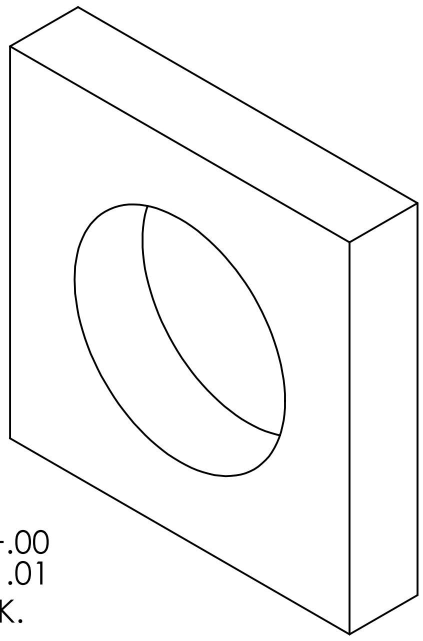


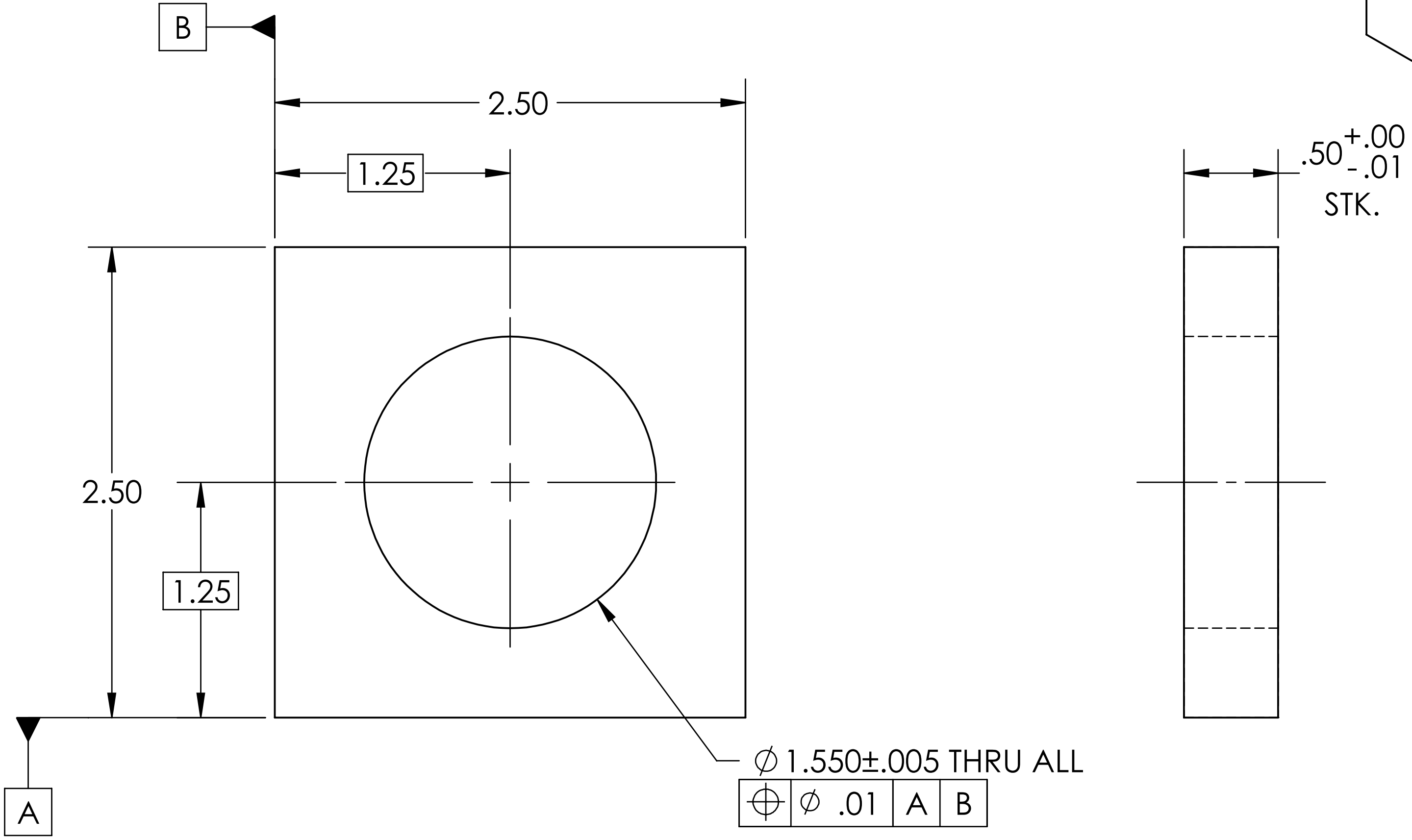
NOTES:

1. ALL DIMENSIONS IN INCHES
2. MATERIAL: OLD PRIMAL 1 SEAT
3. TOLERANCES:
   X.XX ± .01
   UNLESS OTHERWISE SHOWN
4. THE PRIMAL 1 SEAT IS CUT INTO TWO HALVES: BOTTOM AND BACK TO ALLOW ANGLE CHANGE
5. RELIEF CUTS AT 30 DEGREES AND 25 DEGREES FOR THE BACK AND BOTTOM PIECES OF THE SEAT, RESPECTIVELY, GIVE ROOM FOR THE SEAT BACK TO ROTATE

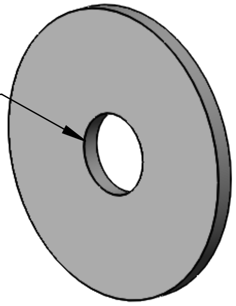
Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: SEAT BOTTOM AND BACK		Drwn. By: G. BRIDGES
	Dwg. #:106 & 110		Date: 5/30/19	Scale: 1:8	Chkd. By: J. GARCIA

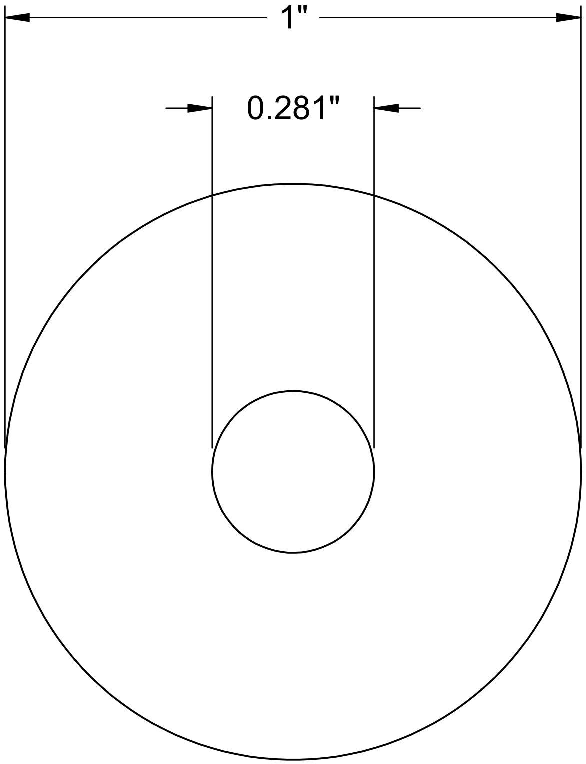
NOTES:
1. ALL DIMENSIONS IN INCHES
2. LOW CARBON STEEL - STOCK 1/2 INCH BAR
3. ALL TOLERANCES ± .01 UNLESS OTHERWISE SHOWN
4. WATERJET PART

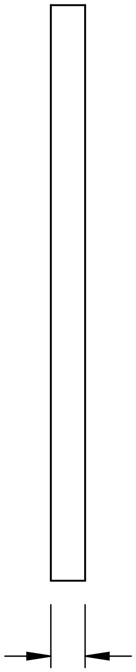




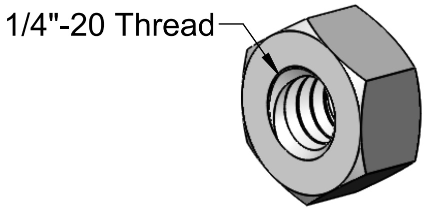
Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: REAR WELD PLATE		Drwn. By: JACINTA GARCIA
ME 430 - SPRING 2019	Dwg. #: 107		Date: 5/30/19	Scale: 1:1	Chkd. By: MITCH SMITH

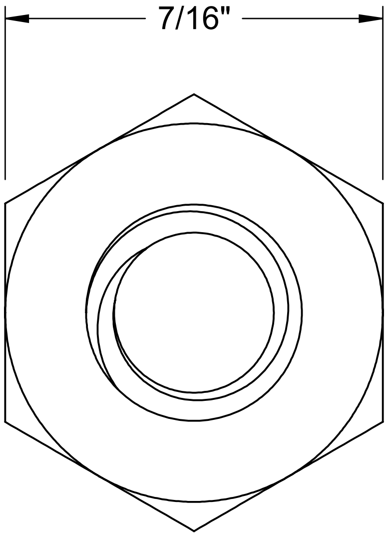

For 1/4"
Screw Size

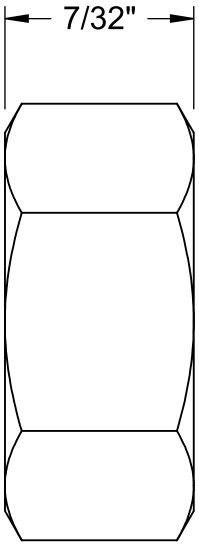



Washer may vary from
0.04" to 0.06" in thickness.

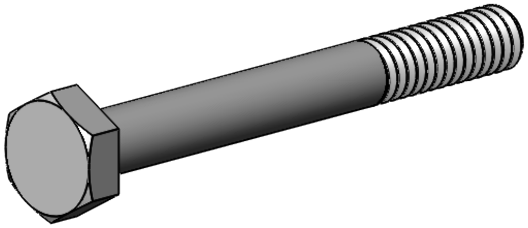
McMASTER-CARR® CAD	PART NUMBER	**91525A120**
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Oversized Washer	

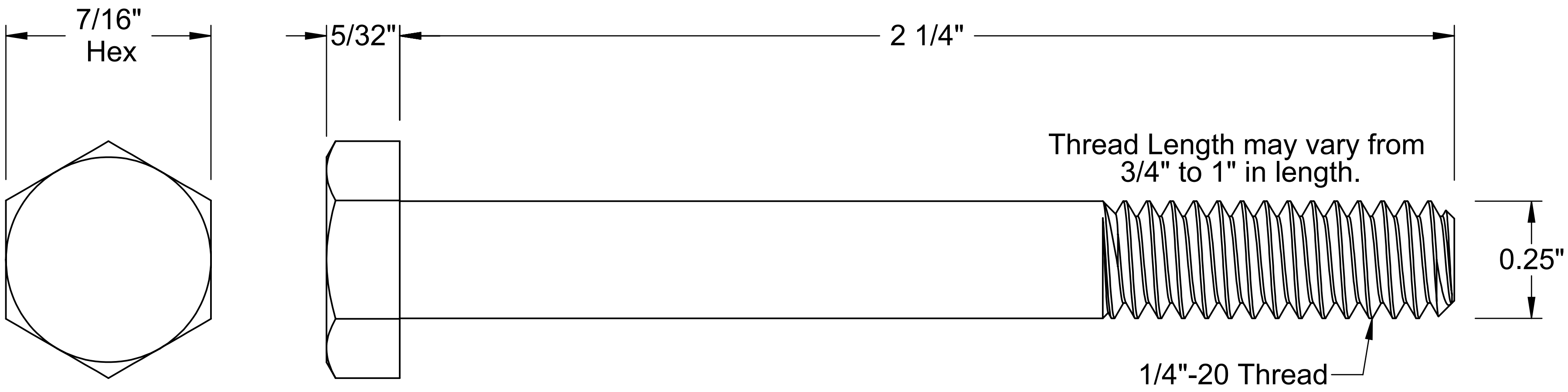






McMASTER-CARR® CAD	PART NUMBER	**95505A601**
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company	Hex Nut	
Information in this drawing is provided for reference only.		



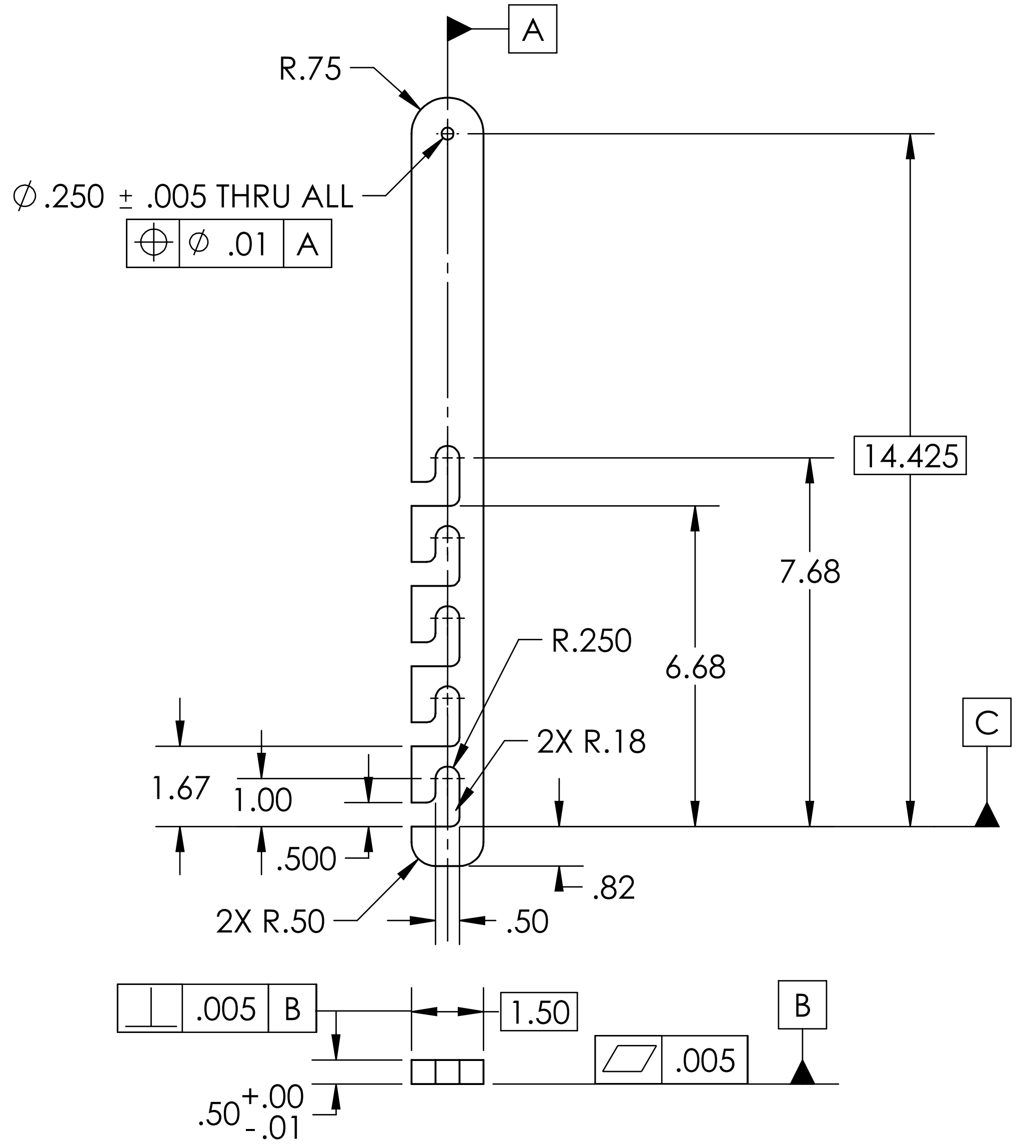


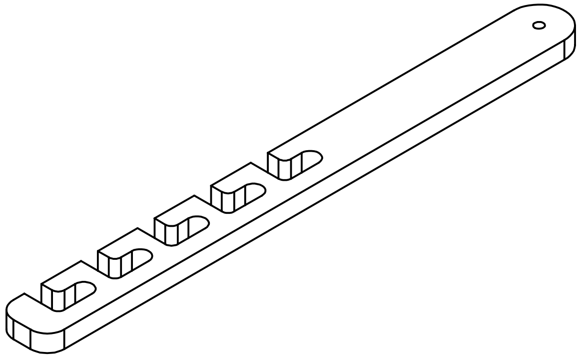
McMASTER-CARR® CAD

PART NUMBER **92198A551**

http://www.mcmaster.com

Stainless Steel
Cap Screw



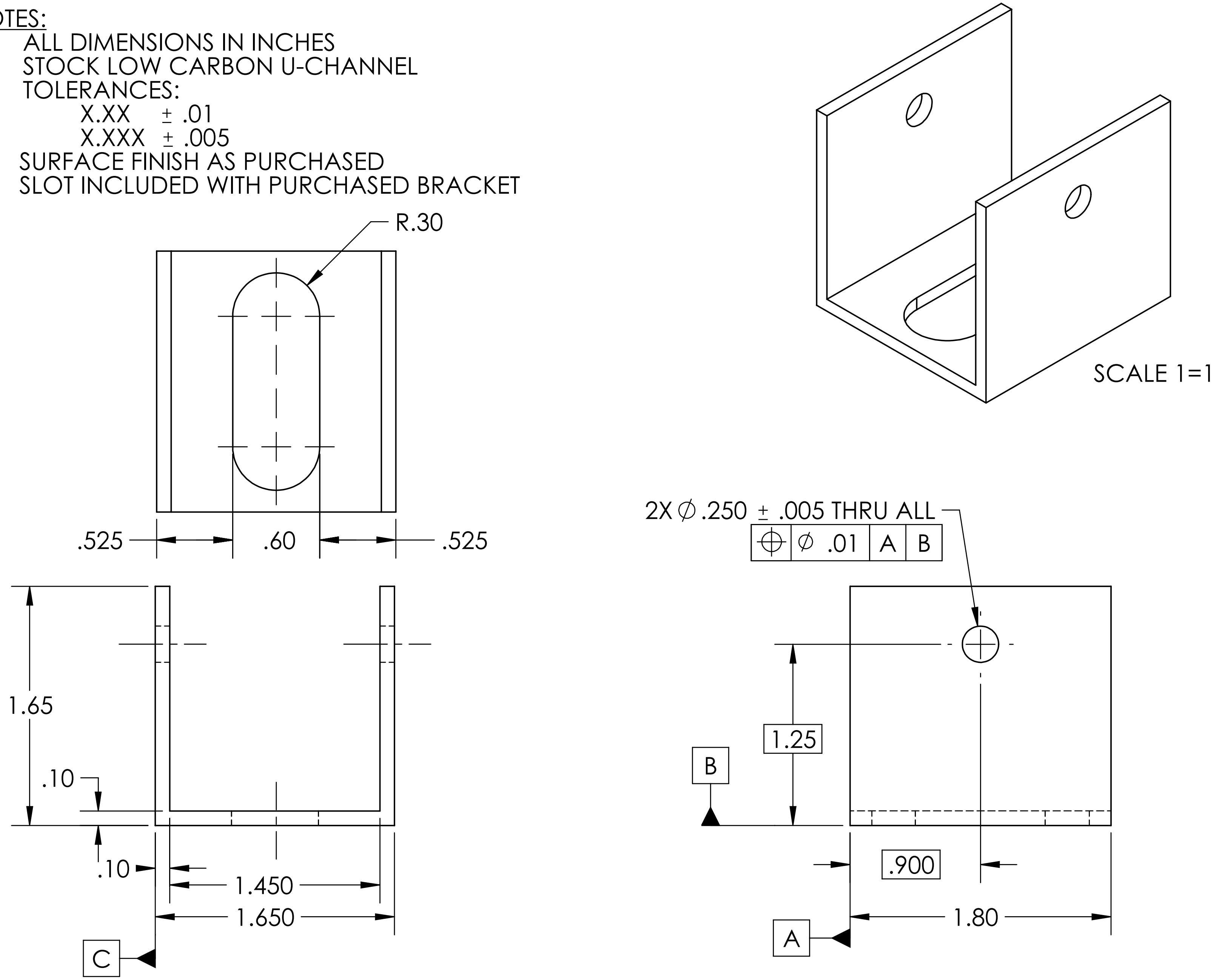


NOTES:
1. ALL DIMENSIONS IN INCHES
2. LOW CARBON STEEL - STOCK
1/2 INCH BAR
3. TOLERANCES:
X.XX ± .01
X.XXX ± .005
UNLESS OTHERWISE SHOWN
4. WATERJET PART
5. SLOT PATTERN REPEATS 5X
6. SURFACE FINISH AS PURCHASED

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: RECLINING SUPPORT ARMS		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #:	Nxt Asb:	Date: 5/23/19	Scale: 1:4	Chkd. By: GREG BRIDGES

NOTES:

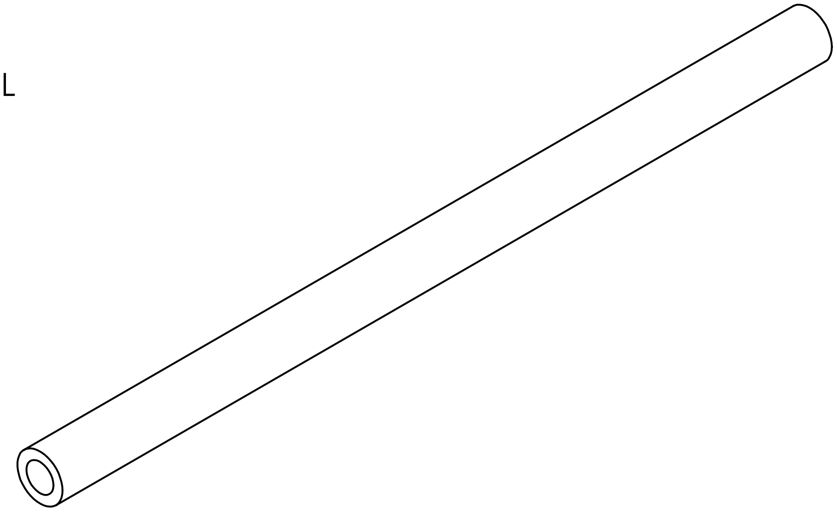
1. ALL DIMENSIONS IN INCHES
2. STOCK LOW CARBON U-CHANNEL
3. TOLERANCES:
   - X.XX ± .01
   - X.XXX ± .005
4. SURFACE FINISH AS PURCHASED
5. SLOT INCLUDED WITH PURCHASED BRACKET

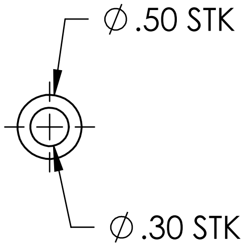


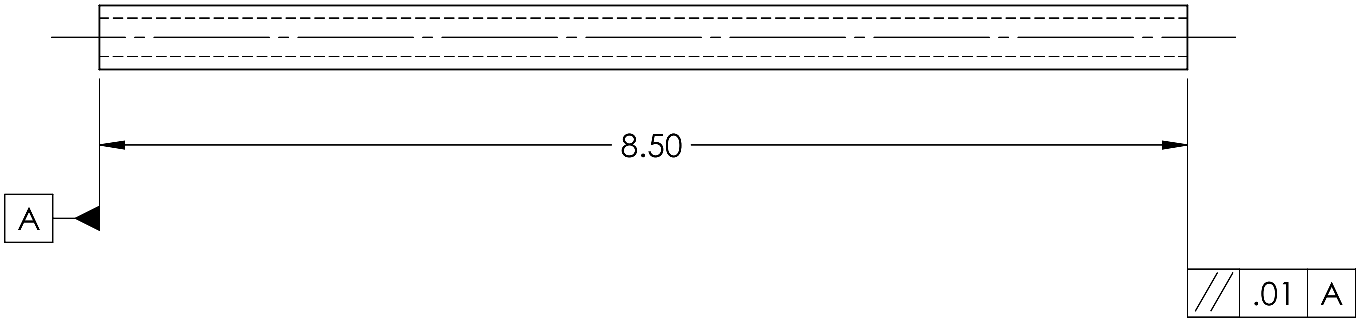
Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: U-BRACKET	Drwn. By: NICK NGUYEN
	Dwg. #: 202		Date: 5/23/19 · Scale: 1:1	Chkd. By: MITCH SMITH

NOTES:

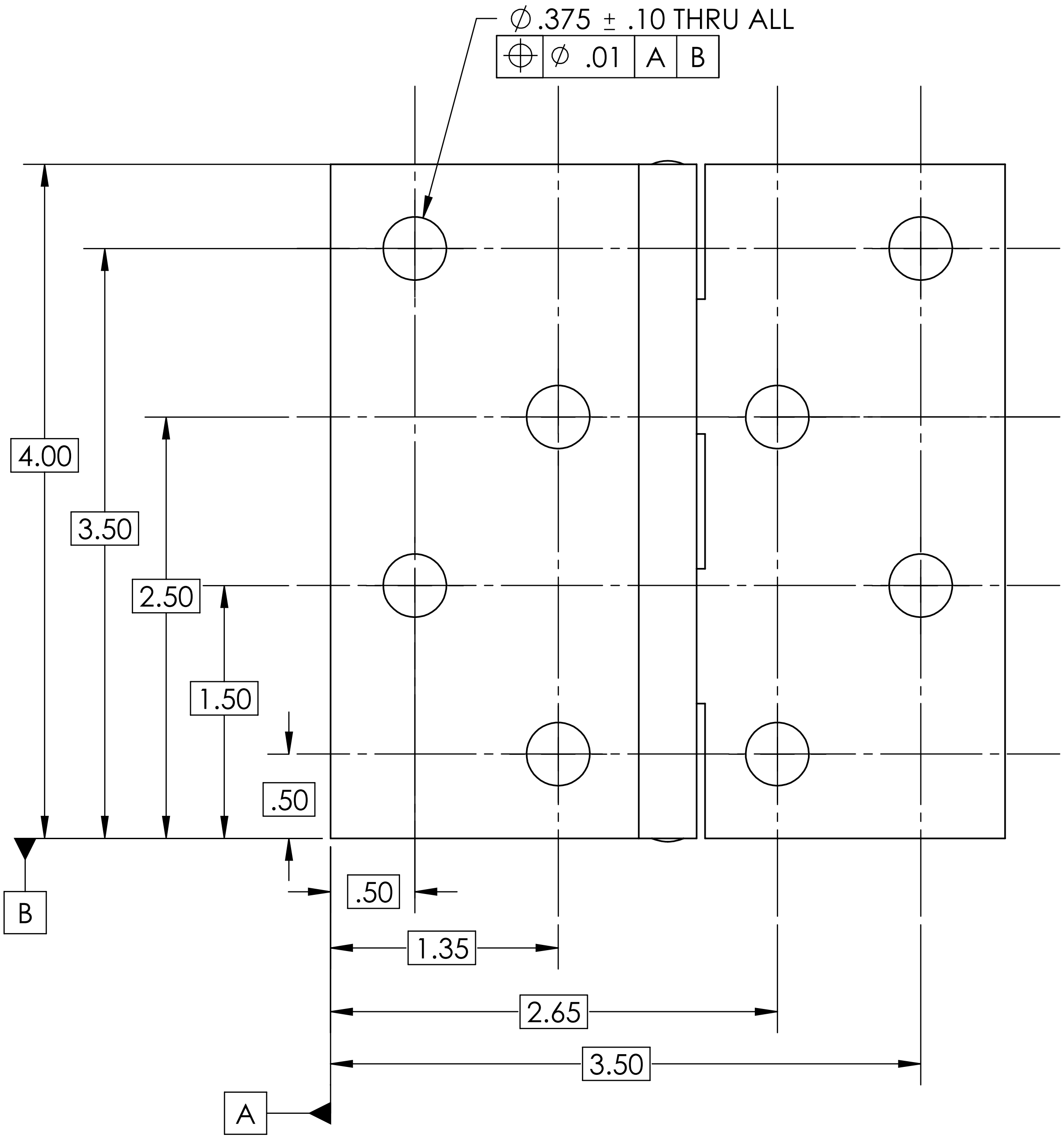
1. ALL DIMENSIONS IN INCHES
2. PART CUT TO LENGTH FROM STOCK MATERIAL
3. TOLERANCES:
   X.XX ± .01
   UNLESS OTHERWISE SPECIFIED

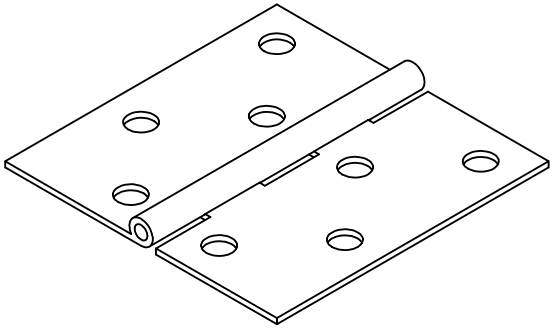






Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: REAR SUPPORT TUBE		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 203		Date: 5/23/19	Scale: 2:3	Chkd. By: GREG BRIDGES

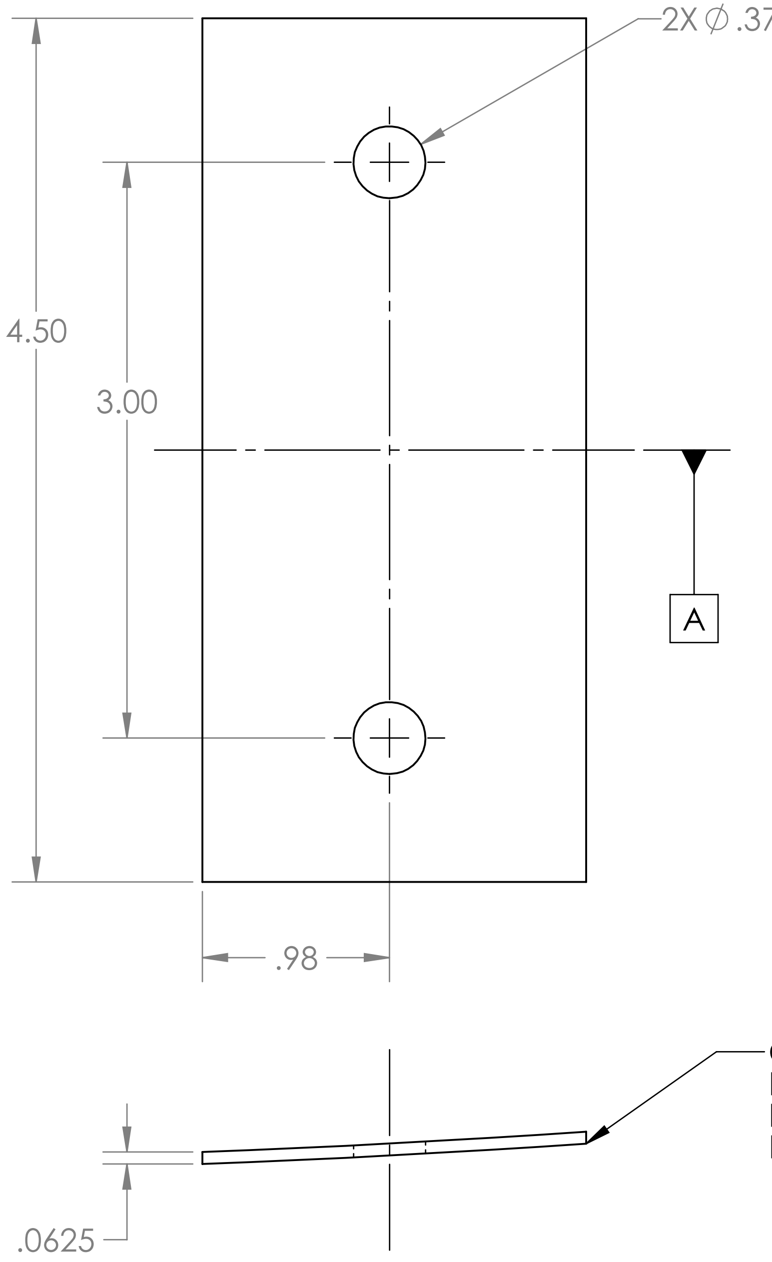




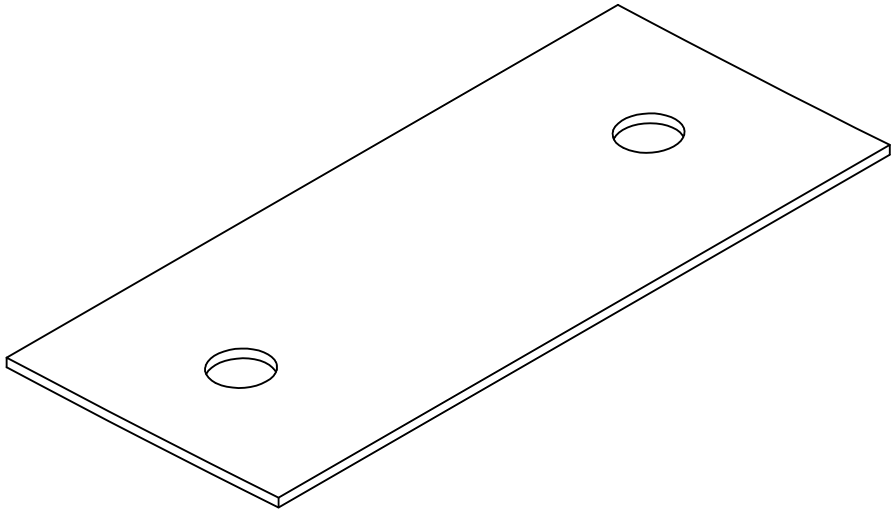
SCALE = 1:2

NOTES:
1. ALL DIMENSIONS IN INCHES
2. PURCHASED HINGE, MODIFYING PART BY DRILLING 4 HOLES
3. TOLERANCES:
X.XX ± .01
UNLESS OTHERWISE SPECIFIED

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: MODIFIED HINGE		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 204		Date: 5/23/19	Scale: 1:1	Chkd. By: GREG BRIDGES



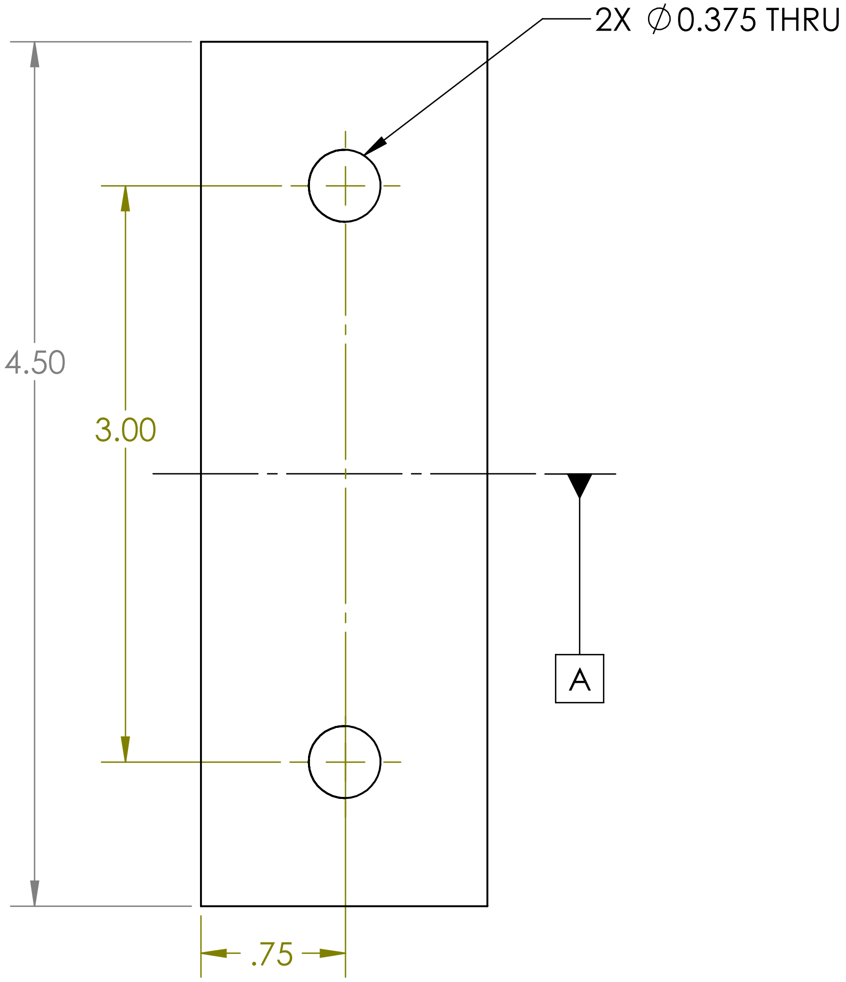
CONTOUR OF BOTTOM PLATE COMES
FROM MANUALLY SHAPING ALUMINUM
PLATE TO MATCH COUNTOUR OF SEAT
BY HEATING AND HAMMERING THE PLATE

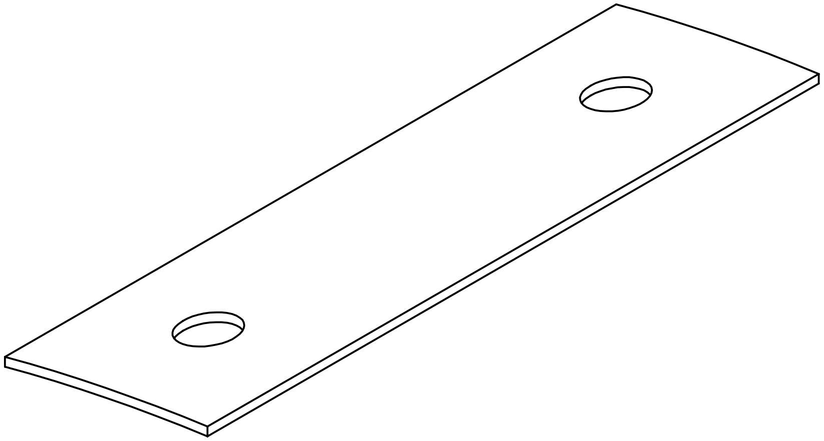


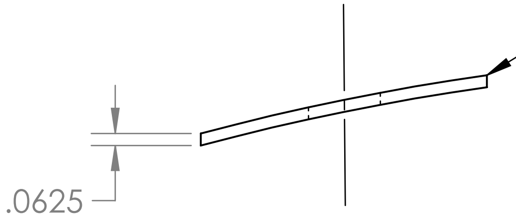
NOTES:

1. ALL DIMENSIONS IN INCHES
2. STOCK ALUMINUM PLATE 1/16" THICK
3. TOLERANCES:
   X.XX ± .05
   X.XXX ± .005

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	TITLE: BACK HINGE PLATE		Drwn. By: G. BRIDGES
ME 430 - SPRING 2019	Dwg. #: 205		Date: 5/30/19	Scale: 1:1	Chkd. By: N. NGUYEN





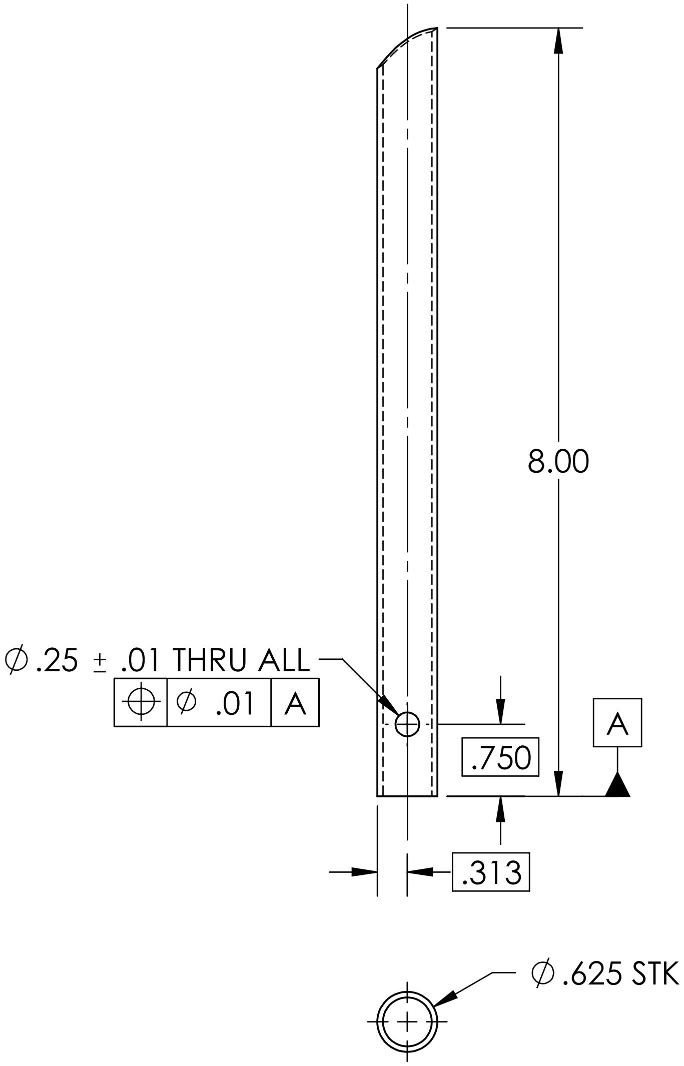


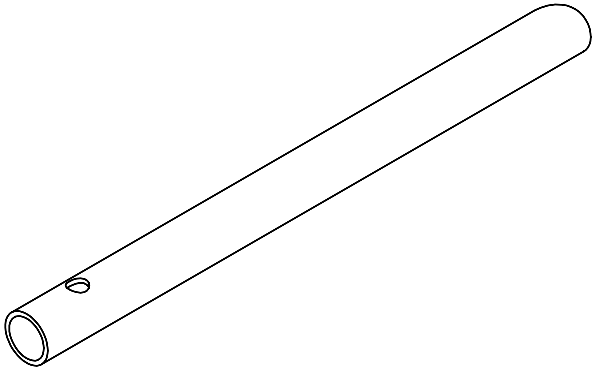
CONTOUR OF BOTTOM PLATE COMES
FROM MANUALLY SHAPING ALUMINUM
PLATE TO MATCH COUNTOUR OF SEAT
BY HEATING AND HAMMERING THE PLATE

NOTES:

1. ALL DIMENSIONS IN INCHES
2. STOCK ALUMINUM PLATE 1/16" THICK
3. TOLERANCES:
    X.XX ± .05
    X.XXX ± .005

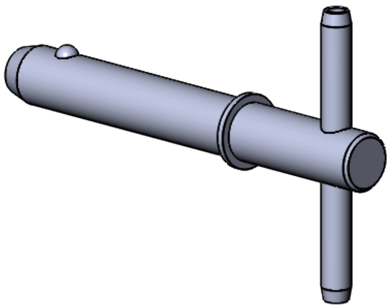
Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	TITLE: BOTTOM HINGE PLATE		Drwn. By: G. BRIDGES
ME 430 - SPRING 2019	Dwg. #: 206		Date: 5/30/19	Scale: 1:1	Chkd. By: N. NGUYEN

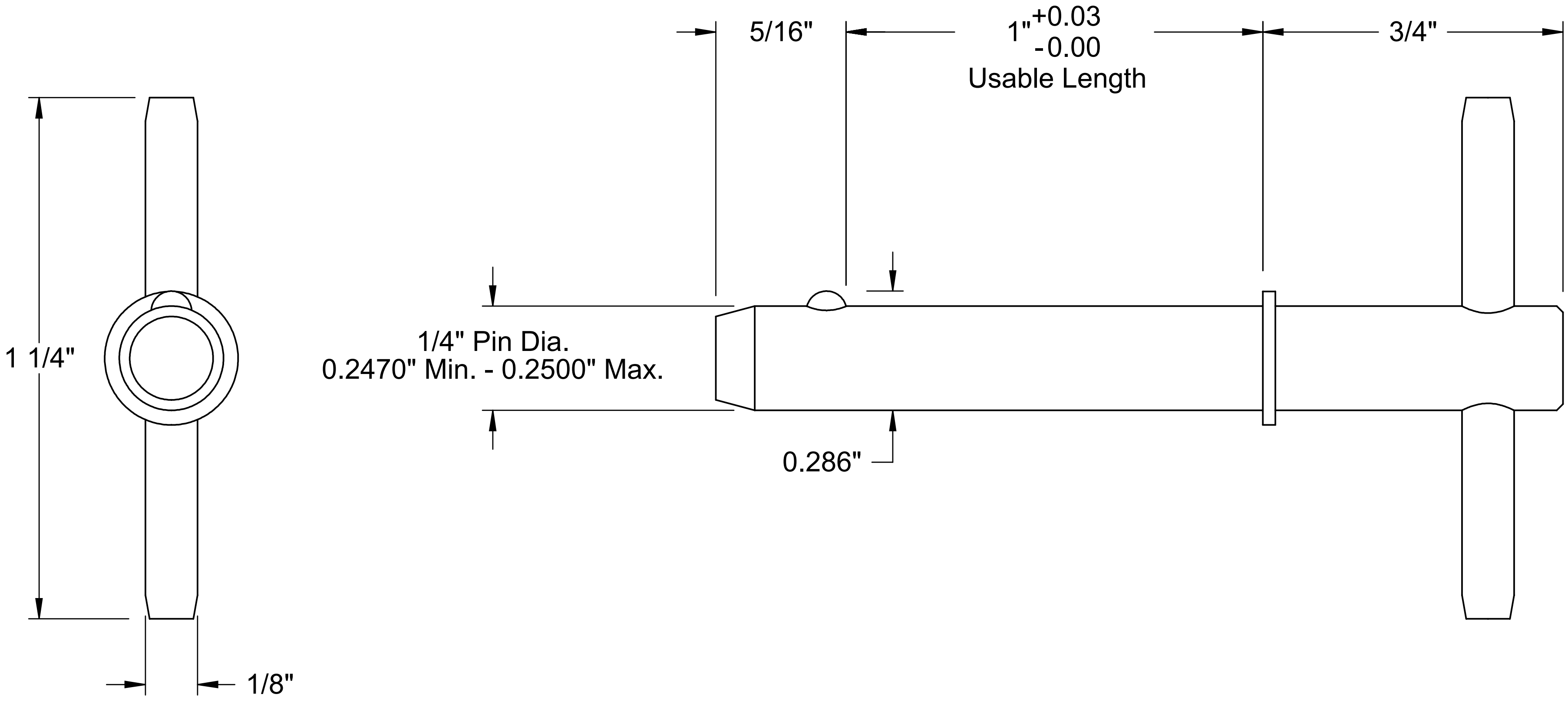




NOTES:
1. ALL DIMENSIONS IN INCHES
2. 4130 STEEL - STOCK 5/8 INCH TUBE
3. TOLERANCES:
   X.XX ± .01
   X.XXX ± .005
   UNLESS OTHERWISE SHOWN
4. SURFACE FINISH AS PURCHASED
5. ANGLE CUT AT EDGE CUT BY HOLE SAW WITH 1.25 INCH DIAMETER SAW. ANGLE IS SET FOR 38° ± .5°

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: HANDLEBAR POST		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 301		Date: 5/30/2019	Scale: 1:2	Chkd. By: GREG BRIDGES



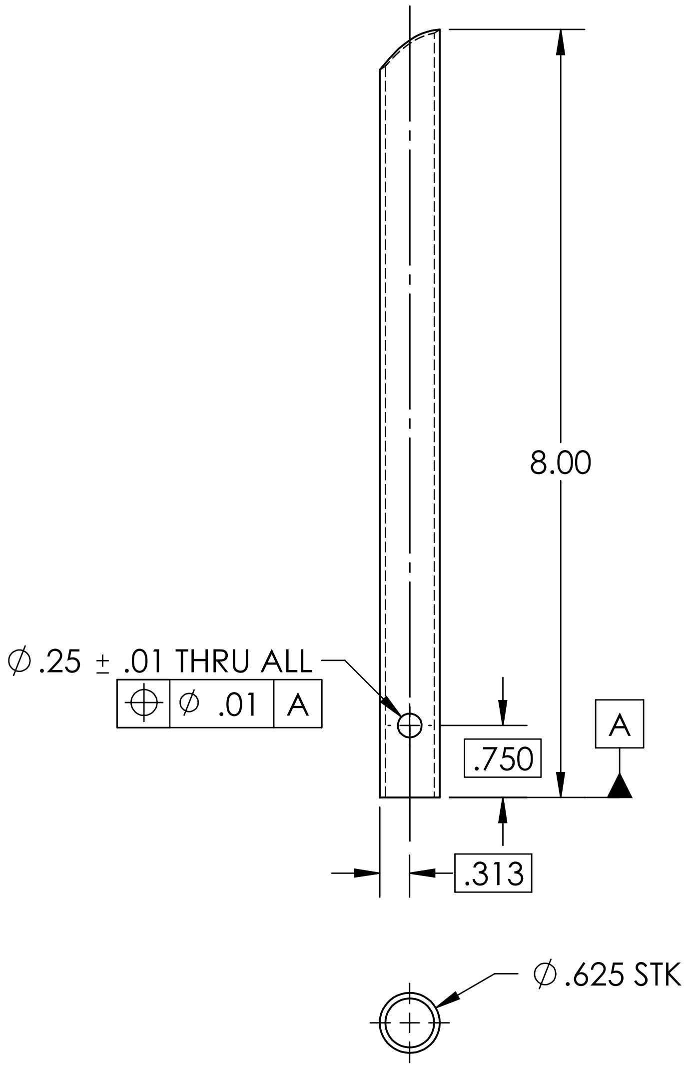


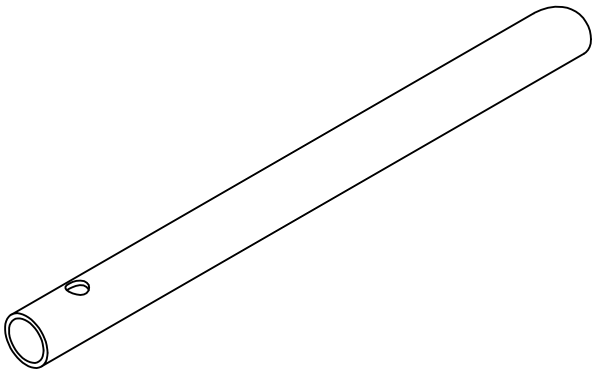
McMASTER-CARR® CAD

PART NUMBER **98405A130**

http://www.mcmaster.com

18-8 Stainless Steel
Shoulder-Style Quick-Release Pin



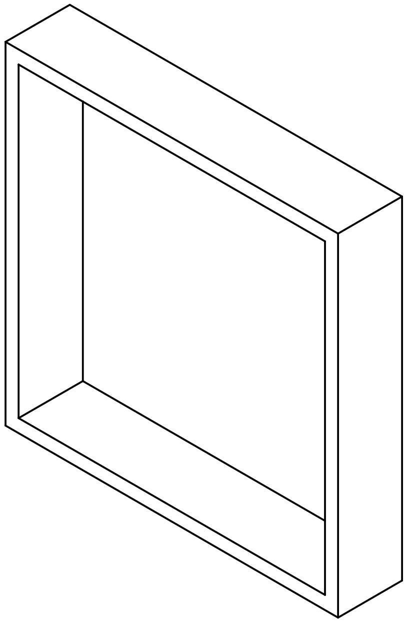


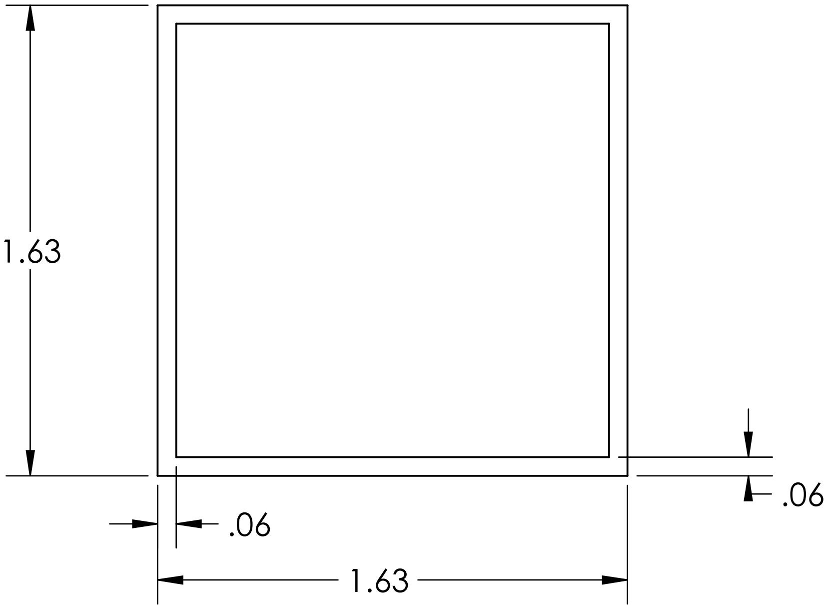
NOTES:

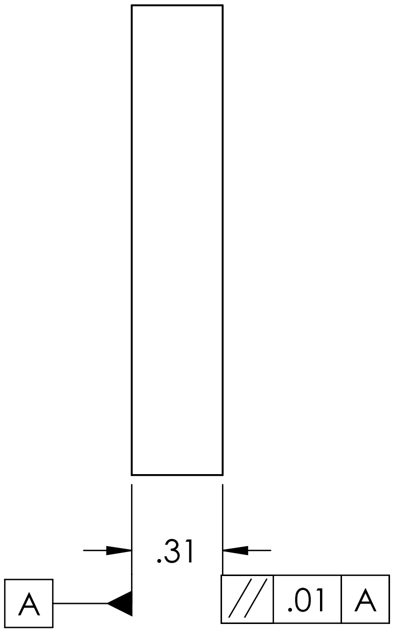
1. ALL DIMENSIONS IN INCHES
2. 4130 STEEL - STOCK 5/8 INCH TUBE
3. TOLERANCES:
    X.XX ± .01
    X.XXX ± .005
    UNLESS OTHERWISE SHOWN
4. SURFACE FINISH AS PURCHASED
5. ANGLE CUT AT EDGE CUT BY HOLE SAW WITH 1.25 INCH DIAMETER SAW. ANGLE IS SET FOR 38° ± .5°

Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: HANDLEBAR POST		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #: 301		Date: 5/30/2019	Scale: 1:2	Chkd. By: GREG BRIDGES

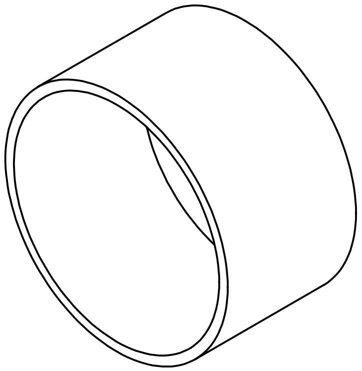
NOTES:
1. ALL DIMENSIONS IN INCHES
2. 3-D PRINTED PART, MATERIAL: PLA
3. TOLERANCES:
X.XX ± .05



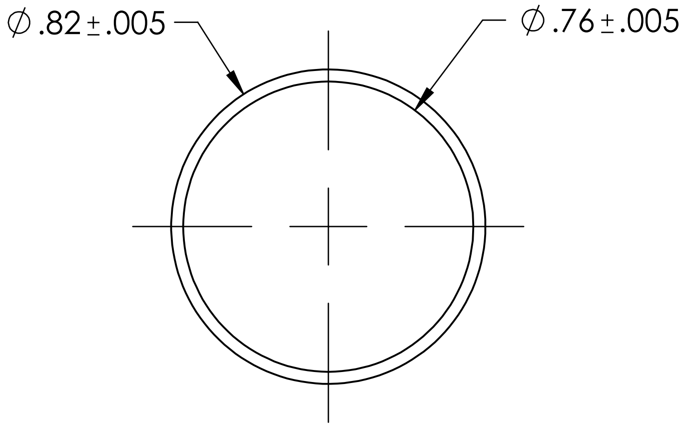


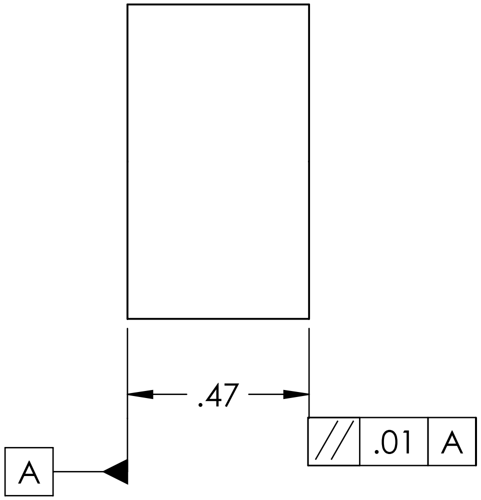


Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 03	HPV TRAINER	Title: BOX BEAM SPACER		Drwn. By: NICK NGUYEN
	Dwg. #:		Date: 5/23/19	Scale: 3:2	Chkd. By: MITCH SMITH



NOTES:
1. ALL DIMENSIONS IN INCHES
2. PART IS 3-D PRINTED, MATERIAL: PLA
3. TOLERANCES:
X. XX ± .005





Cal Poly Mechanical Engineering	Lab Section: 03	HPV TRAINER	Title: HANDLEBAR SPACER		Drwn. By: NICK NGUYEN
ME 430 - SPRING 2019	Dwg. #:		Date: 5/23/19	Scale: 2:1	Chkd. By: JACINTA GARCIA

Design Failure Mode and Effects Analysis

Product: ______________________________

Prepared by: ______________________________

Team: ______________________________

Date: ________________ (orig)

Appendix M												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	
Frame / Holds Components	Weld Fails	Bike Breaks, Damage to mechanisms, Rider injured	9	1) Poor Weld Quality 2) Excessive Load	1) Professional Welder 2) Stress Analysis	3	1) Visual Inspection 2) FEA/Hand Calcs	5	135	Consult experienced welder	Greg 2/12/19	Finally Found Welder to Weld bike through HPV. Welds Complete 4/27/19	9	2	5	90
	Major Deflection	Uncomfortable Ride, Bike Breaks, Interference between components	8	1) Poor Material Selection 2) Poor Weld Quality 3) Improper Use	1) Stress Analysis 2) Professional Welder 3) User Manual	2	1) FEA/Hand Calcs 2) Visual Inspection 3) Covers/Limiters	3	48	Consult experienced welder and sponsor. Load Test for Bike	Nick 5/10/19	Load Tested for Deflection, No major deflections found 5/28/19	9	2	4	72
Frame / Looks Good	Looks Bad	Less incentive to use	4	1) Bad Paint Job 2) Poor Welds 3) Sloppy Manufacturing/Integration	1) Proper Painting Equipment 2) Professional Welder 3) Manufacturing Plan	8	1) Visual Inspection 2) Visual Inspection 3) Part Inspection	2	64	Consult sponsor and HPV team on how to properly paint the frame	Mitch 5/20/19	Frame Painted and looked sharp 5/12/19	1	5	5	25
Drivetrain / Powers Bike	Chain Breaks	Bike no longer functional	9	1) Chain improperly tensioned 2) Chain Rust/Fatigue	1) Adjustable Chain Tensioner 2) Chain Lube 3) Replace chain as necessary	2	1) Visual Inspection 2) Ride/Feel Test	1	18	Find back up chain in case of failure	Greg 4/20/19	Chains functional and in good shape 5/25/19	3	7	3	63
	Chain Slips Off	Drivetrain temporarily unusable	6	1) Chain improperly tenshioned 2) aggresive gear change 3) collision between wheel and chain	1) Adjustable Chain Tensioner 2) User Manual/Rider training 3) Wheel Cover	7	1) Visual Inspection 2) Rider Training 3) Turning Test	1	42	Perform testing to ensure chain is properly secured with the drivetrain. Include section in operators manual to fix chain.	Nick 5/17/19	Derailer limit screws tuned to prevent chain falling off 5/30/19	4	2	2	16
Drivetrain / Pedals Position Adjust	Pedals moves during operation	Rider cannot pedal, Chain Slips/Breaks	6	1) Pedal adjustment was not secured properly 2) Wear and tear	1) User Manual/Easy to Secure 2) Component Maintained properly	3	1) Rider Training 2) Visual Inspection	2	36	Perform testing to ensure components are securely attached and will not move during operation.	Mitch 5/23/19	Pedals tightened and have not shifted during testing 5/29/19	3	3	2	18
Seat Track / Moves People	does not lock, does not stay straight	rider cannot supply max power and stay stable. Short riders cannot use	9	1) Not enough friction in locking mechanism 2) slot is not straight/uniform	1) Multiple bolts/pins 2) Using mill to make slot	5	1) Hand calculations 2) Overall testing	3	135	Detailed hand calcs, quality assurance for parts	Mitch 2/14/19	Hand calcs finished and checked with a consulting professor. 1/31/19 Detent pins tested 5/23/19	9	3	3	81
Seat Track / Supports Bulk Weight	Seat track breaks	rider gets hurt, other components get damaged	9	1) components cannot support loading	1) Stress Analysis 2) Stronger materials 3) Larger fasteners	3	1) Hand calculations 2) Overall testing	6	162	Stress analysis and Design consultation. Testing once frame has been built	Jacinta 1/31/19	Deflection tests were passed 5/25/19	9	2	5	90
Recliner/ Recline People	Unable to Recline	Rider has to sit at an angle they don't want to	7	1) Crescents break 2) hinge doesn't work 3) Frame pin holes tear through 4) pin holes in crescent and frame don't line up	1) Stress analysis of holes, crescents, and hing pin	2	1) Stress analysis 2) Visual inspection	3	42	Perform preliminary testing and final testing to ensure reclining mechanism works as intended.	Jacinta 3/5/19	Wooden support arm test was completed and successful. Angle tests and load tests completed 5/29/19	4	2	2	16
Recliner / Holds People	breaks	Rider cannot sit in bike	7	1) Seat material cannot handle loading 2) supports cannot handle loading	1) stress analysis	3	1) Stress analysis 2) Visual inspection	6	126	Stress analysis, Hand calculations and FEA. Testing	Greg 2/14/19	Adjustment and load testing complete 5/20/19	7	2	6	84

Design Failure Mode and Effects Analysis

Product: ______________________________

Prepared by: ______________________________

Team: ______________________________

Date: ________________ (orig)

Appendix M												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	
Recliner / Comfortable for Rider	Uncomfortable for rider/ non opitmal position	rider cannot move optimally, cannot use for long periods of time	4	1) poor integration of seat 2) bad seat shape	1) design around integrating seat 2) Shape to fit rider bodies 3) Use foam	6	1) Test riders of many heights 2) Ergonomics analysis	2	48	Ergonomic and fit and finish tests.	Nick 5/23/19	Ergonomics study performed 2/19/19, adjustment test completed 5/30/19	4	7	3	84

Senior Project DVP&R

Appendix N	Team:	Sponsor:	Description of System:	DVP&R Engineer:

TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Time people adjusting the bike to fit their body size and proportions.	Time < 3 minutes	Mitch	FP	1	Sys	5/30/2918	5/30/2019	Pass, Time < 3 minutes	1	1	23 test subjects adjusted bike, mean time was ~ 1 minute
2	2	Using laser cut wood support arms, recline seat through all pin locations and measure the angle of the seat back relative to the ground	Reclines from 90-150 degrees	Jacinta	SP	2	Sub	3/25/2019	3/28/2019	Pass	1	1	Originally designed support arms was not suited for angle adjustment range, and fit for the bike frame. Support arms were redesigned to maximize angle adjustment
3	2	Using waterjet steel support arms, recline seat through all pin locations and measure the angle of the seat back relative to the ground	Reclines from 90-150 degrees	Jacinta	FP	1	Sub	5/19/2019	5/29/2019	Reclines from 100-150 degrees	1	0	Bike reclines through a range that our sponsor deems as acceptable
4	3	Put 250 pounds on the seat and inspect the bike for any deflections/ cracks forming	No Fail	Greg	FP	1	Sys	5/25/2019	5/25/2019	No cracks, deflection less than .25 in	1	0	The bike did not deflect more than the allowable amount and all welds were inspected
5	4	Move seat track mechanism to closest position and measure the distance from the seat back to the pedals	D <= 33 inches	Nick	FP	1	Sub	5/28/2019	5/28/2019	Pass, D = 33 inches	1	0	Bike reached specified closest distance
6	5	Move seat track mechanism to closest position and measure the distance from the seat back to the pedals	D >= 39.4	Nick	FP	1	Sub	5/28/2019	5/28/2019	Pass, D = 40 inch	1	0	Bike reached specified farthest distance

Appendix O:

Operator’s Manual:

This user manual details the safe and proper operation of the Human Powered Vehicle Trainer. The manual begins with a General Use Guide before going into specific procedures for the Seat Track, Reclining, and Handlebar adjustment mechanisms. Scheduled maintenance, repair/replacement and troubleshooting procedures are also included.

General Use Guide:

1. Adjust the bike seat track position and reclining position to fit the rider. These instructions are found below for the seat track guide and reclining mechanism guide.
2. Once the seat and reclined position have been chosen, perform a general walkthrough of all key components to ensure they are secured in place. This includes the following components.
    a. Both detent pins are secured in the seat track before sitting in the seat of the bike.
    b. Both support arms are secured at the same height and that the rod they are resting on is at the maximum height of the designated slot.
    c. The bolts and nuts for the U-brackets are properly secured and tightened to ensure the support arms will not fail during operation.
        i. Visually check that spacers are in between each U-bracket wall to prevent any slop and movement of the support arms during operation.
    d. The detent pin for the handlebar is properly secured and the handlebars are in a proper location for the rider and do not interfere with their pedal stroke.
    e. The front wheel stand is properly attached to the front wheel of the bike and is stabilizing the entirety of the bike.
    f. The back wheel is properly secured in the back wheel stand to prevent any forward or sideways translation during operation.

Figure 1. Back wheel properly secured in back support stand

3. Once all key components have been secured and checked the trainer bike can be prepared for operation.

NOTE: This bike is intended for use by one rider at a time, having multiple people sit in the seat at once may cause failure of components and injury to the user.

4. To properly enter the seat, straddle the center of the seat track with the rider's rear above the seat bottom.
5. Using the handlebars to stabilize themselves, have the rider slowly lower themselves until their rear touches the seat bottom.
6. Once contact has been made, the rider may slowly recline themselves backwards until their back and shoulders are in contact with the seat back.

Figure 2. Steps 4-6: Proper Method for Sitting in Seat

7. The rider should place one foot at a time on the pedals and check their pedal stroke is comfortable by attempting to pedal for a short period of time.
    a. If the rider is positioned too close or far away to the pedals, the seat track length should be adjusted to match the necessary pedal distance for the rider. This ensures long term comfort for the user during periods of operation.

Figure 3. Ensure there is enough clearance between the handlebars and the rider's legs during operation

8. Once the rider is comfortable in the seat, the bike may be used for operation. A few notes regarding safe operation of the bike are listed below.
    a. This bike can be operated similarly to other recumbent bikes, with the user gripping the front handlebars for stability while pedaling like a normal bike.
    b. The user should avoid quick swaying of their body side to side while in the seat. This may cause the bike to tip over and cause injury to the user.
        i. If the user feels that the bike will tip over, they should stop pedaling and plant their feet on the ground to prevent the bike from falling over.
    c. Prolonged use of the bike and overexertion may cause bodily harm to the user. As such the user should be aware of their physical capabilities when using the bike to prevent harm to themselves.

d. In case of an emergency, the user should be accompanied by someone else in case injury to the user occurs or medical attention is required.

Seat Track Guide:

Adjusting the Seat Track Position:

CAUTION: Do not adjust seat track position without the bike secured in a stand or by another person. The bike can tip when unsecured.

1. Remove Detent Pins: Grab the handle of each detent pin and pull away from the bike to remove the fully from the slot. Repeat with second pin. The two box beams are now free to move relative to one another - be careful of pinch points at the sliding tube interface.

Figure 4. Proper Removal of Detent Pins

2. Adjusting Seat Track Position: With pins still removed, grip the outer box beam and move the back half of the frame towards the front to decrease the seat to pedal distance, or away from each other to increase the distance from seat to pedals. Set positions are indicated by markers on the inner box beam – once the marker lines up with the outer beam, both pins can be reinserted.

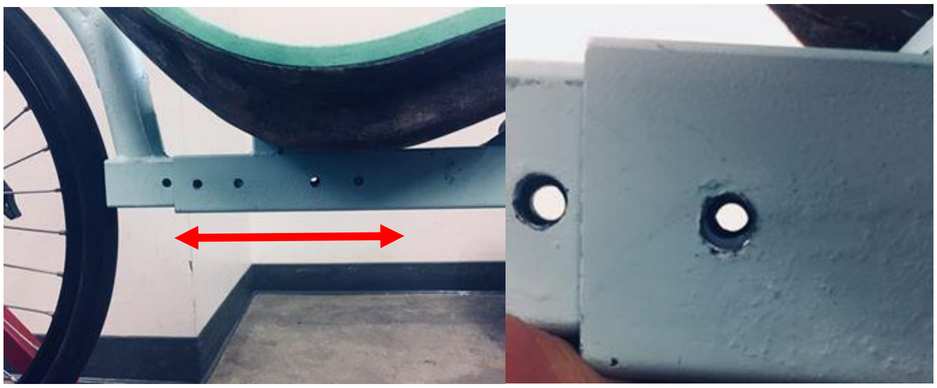


Figure 5. Proper alignment of new seat track position

NOTE: Ensure that the front half of the bike is secured while the other is free to move back and forth during the adjustment process. Do not sit in the seat and attempt to pedal before the pins are reinserted. When moving the back half of the frame, the rear support stand should also be moved along with the seat track.

3. Securing a Seat Track Position: Make sure that the indicator lines on the inner beam line up with the outer beam. Holding one detent pin handle, insert the pin into the rightmost hole until the handle base is flush with the beam surface, and the small spring-loaded ball on the metal end of the pin is visible on the other side of the beam. Repeat with second pin in the second pin from the left to set the seat track length.

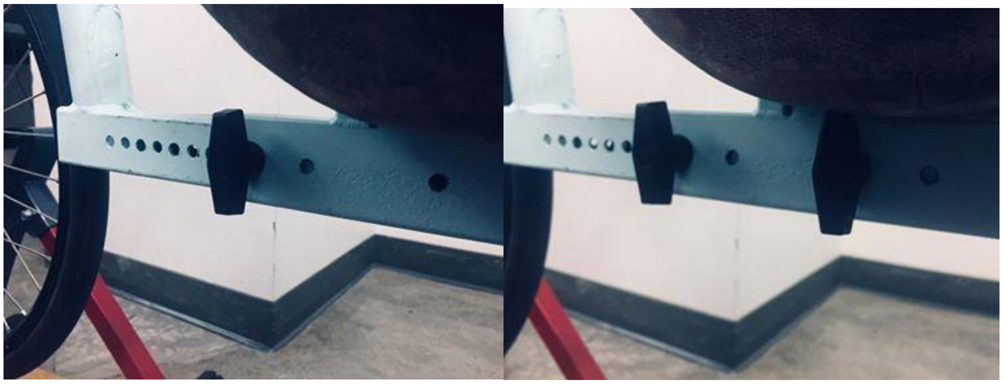


Figure 6. Insertion of detent pins at new seat track location

4. To Fine Tune Seat Position: If it feels as though the ideal seat track length falls in-between two hole locations, then the second set of holes in the outer beam can be used to achieve an extra ¼ inch of tuning. First, follow steps 1-2 as written above. Then, before reinserting the pins as stated in step 3, shift the outer beam a quarter inch in the desired direction until the front end of the outer beam lines up with the half-length indicator lines on the inner beam. To secure in place, follow the instructions of step 3, but insert the pins into the first and third holes from the left.

Reclining Mechanism Guide:

CAUTION: Do not adjust seat reclining mechanism without the bike secured in a stand or by another person. The bike can tip when unsecured.

1. Stand behind seat with one leg on either side of the back wheel and grab the support arms at least 2 inches away from the support pin to prevent any pinching.
2. Pull the support arms up and push them towards the front of the bike until they slide off the support pin.

Figure 7: The motions required to remove the support arms from their current position

3. Line up the support pin with the slots on the support arms that correspond to the desired seat back angle. The angle of the slot is engraved next to opening of the slot. Make sure both arms are set to the same angle.

Figure 8. The motions required to secure the support arms at a new position

4. Pull the support arms back and down into the support pin until the pin rests at the top of the slot.

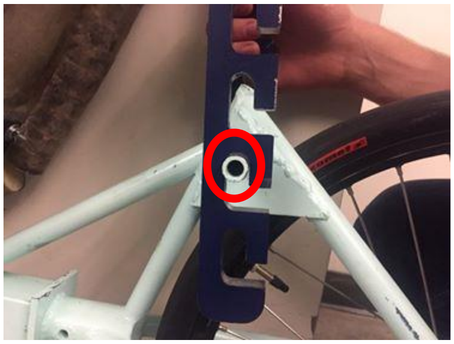


Figure 9. The final resting position of the support arms to ensure they are completely secured

Handlebar Adjustment Guide:

CAUTION: Only perform handlebar adjustment while bike is secured in fixture or by another person to prevent any risk of the bike tipping. Handlebars should be adjusted slowly and carefully to prevent any sudden jerking motions that can damage the gear shifter and brake cables.

1. Firmly grasp handlebars with one hand while using the other hand to pull out the handlebar detent pin
2. Slide the handlebars in or out to achieve the desired stem length

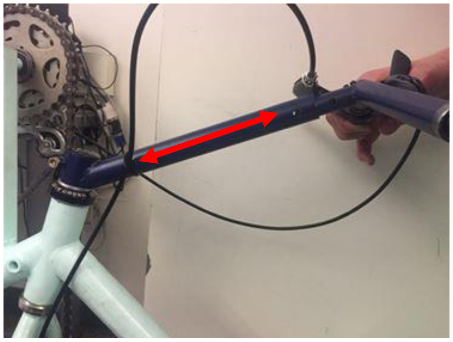


Figure 10. Appropriate motion to properly adjust the handlebar position

3. Once the desired stem length is reached, make sure the through holes on the inner tube and outer tube line up and insert the detent pin. Ensure the detent pin is secured completely, as the push button should be visible on the other side of the tubing.

Figure 11. Proper alignment for detent pin and detent pin fully engaged in handlebar

4. Repeat these steps as necessary to find the most desirable handlebar position

Note:

The handlebar position can be changed while a rider is sitting in the seat. This should only be performed if there is a second person to hold the frame steady and the rider’s feet are firmly planted on the ground to prevent the bike from tipping over.

General Maintenance Guide:

To maintain a good condition for the bike, there are a few components of the bike that should be regularly checked. These components include the tires and chain.

Tires:

- The bike tires should be checked to see if they are properly inflated. The tires should be checked semi-frequently. At minimum, this should be once a week during times of operation, or multiple times a week depending on how often the trainer is used.
    - The current bike tires are rated for a maximum pressure of 110 psi.
    - The outer wheel should be inspected for any tearing or holes.
        - If significant damage is found, the outer tire should be replaced.

Chain:

- The chain of the bike should be lubricated to maintain a high quality and performance. The chain can be cleaned and lubricated bimonthly.
    - When inspecting the chain look for dirt collected in the chains, or significant wear in any of the links.
    - REI provides an excellent source for cleaning and maintaining a bike chain. The article can be found at the following link: https://www.rei.com/learn/expert-advice/bike-chain.html

Repair/Replacement Guide:

Many of the new components to the bike are custom made and would require a new part to be manufactured from stock. However, there are a few components that may fail where standard off the shelf items can be used to replace them. This includes the tires, chain and detent pins. In the case of catastrophic failure of the detent pins (shear failure or permanently deformed) new pins should be purchased.

Common failures with regards to the tires is the inner tube of the tire deflating. As such, it may require a patch or to be completely replaced. A step by step guide to replace an inner tire can be found here: https://www.instructables.com/id/How-to-Change-an-Inner-Tube-on-a-Bike/

A common failure with regards to a chain, is the chain slipping off the drivetrain. The chain can be reinstalled by following the provided guide at: https://www.ifixit.com/Guide/How+to+Fix+a+Slipped+Bicycle+Chain/37682

Detailed Parts List:

Below is a detailed parts list that outlines the parts used for the main components of each subsystem for the bike. Most hardware was bought from local stores, with a few exceptions from online vendors for raw material stock.

Subsystem	Component	Source	Cost
Seat Track Mechanism	1 – ½’ x 1- ½’ x 16ga Front Square Tubing	Discount Steel	$ 18.75
	1 – ¾ ’ x 1- ¾ ’ x 16ga Rear Square Tubing	Discount Steel	$ 18.75
	Detent Pins	McMaster Carr	$ 9.82
	Rear Weld Plate	McMaster Carr	*Made from excess support arm plate material*
	Seat Mount Plate	McMaster Carr	
	¼ Oversized Washers	Miner’s Ace Hardware	$ 3.00
	1/4-20 Hex Nuts	Miner’s Ace Hardware	$ 2.00
	1/4-20 Bolts	Miner’s Ace Hardware	$ 3.60
	Carbon Fiber Seat	George Leone	*Donation*
SUBTOTAL:			**$ 55.92**
Seat Reclining Mechanism	Support Arms (½" Steel Plate)	Discount Steel	$ 85.00
	U-Brackets (Cut from U-Channel Steel Strut)	Cal Poly Machine Shop	*Free*
	Rear Support Tube	Cal Poly Machine Shop	$ 1.00
	Seat Hinge	Miner’s Ace Hardware	$ 7.99
	Aluminum Plates for Hinge Mount	McMaster Carr	$ 2.00
	T-Nuts	Miner’s Ace Hardware	$ 5.00
SUBTOTAL:			**$ 100.99**
Handlebar Mechanism	Outer Handlebar Tube	McMaster Carr	$ 20.00
	Detent Pin	McMaster Carr	$ 6.24
SUBTOTAL:			**$ 26.24**
Miscellaneous	Brake and Shifter Cable & Housing	Cal Poly Bike Shop	$ 5.05
	Teardrop Mallet	Harbor Freight	$ 9.00
	Spray Paint	Miner’s Ace Hardware	$ 16.00
	SRAM PC-48 Chain	George Leone	*Donation*
	Tires (Primo Comet 20 x 1 1/8)	George Leone	*Donation*
TOTAL:			**$ 213.20**

Appendix P: Test Procedures

Test #1: Adjustment Test for Varying Rider Sizes

Description of Test:

Determine time required for people to adjust the bike to one desired position

Materials Required:

- 2 Stopwatches
- HPV Trainer Frame
- Tape to identify desired seat track and seat back positions
- Bike fixture to hold front half of frame
- 10 Participants

Location for Test:

Open space with level ground.

Safety Procedure:

1. Secure front half of bike in fixture for stability during testing
2. Identify possible pinch points to user before each test

Pass Criteria:

Participants must be able to adjust the bike to the desired position in under 3 minutes. All 10 participants must be able to meet this criteria for the design to pass this test.

Testing Protocol:

1. Set bike at most upright seat back position and closest seat track location
2. Point out to participants the desired seat back angle and seat track location, along with the desired handlebar position, as identified with tape on the bike
3. Start one stopwatch when participant is in position next to bike
4. Have the participant move to the handlebars, starting the second stopwatch when they grab the détente pin, and stop the clock when the pin is reinserted at the desired position. Record this time in the table. Continue to record on the first stopwatch.
5. Have the participant move to the seat track, starting the second stop watch when they grab at least one détente pin. Stop timing when both détente pins are reinserted at the correct positions. Record this time in the table. Continue to record on the first stopwatch.
6. Have the participant move to the seat back, starting the second stop watch when they place a hand on the seat back or support arms. Stop both stopwatches when the seat back is in the desired position. Record seat back and overall setup times in table.
7. Repeat steps 1-6 for the remaining participants.

Data:

Test	**Setup Time** (seconds)			
	Seat Track	**Seat Back**	**Handlebars**	**Overall**
1	34.9	16.2	12.0	63.1
2	18.5	24.5	7.4	50.4
3	13.2	13.4	4.1	30.7
4	34.5	13.0	8.6	56.1
5	44.6	32.3	28.2	105.1
6	46.6	5.7	15.6	67.9
7	22.2	34.4	14.9	71.5
8	53.5	15.9	10.4	79.8
9	24.7	14.0	10.6	49.3
10	15.0	20.0	7.0	42.9
11	13.6	8.5	10.7	32.8
12	14.0	13.0	11.2	38.2
13	19.9	18.3	15.1	53.3
14	22.8	24.3	4.9	52.0
15	17.2	37.0	10.0	64.2
16	41.0	20.4	52.4	113.8
17	26.7	19.8	3.3	49.8
18	40.5	19.3	0.5	60.3
19	68.9	35.0	10.0	113.9
20	43.4	14.3	8.0	65.7
AVG	**30.79**	**19.97**	**12.25**	**63.04**

Test #2: Seat Back Reclining Verification Test

Description of Test:

Test the different seat back locations and measure the angle of the seat back

Materials Required:

- Camera with Tripod
- HPV Trainer Frame
- Bike fixture to frame
- SolidWorks

Location for Test:

Open space with level ground.

Safety Procedure:

1. Identify possible pinch points to operator before each test

Testing Protocol:

1. Use fixture to hold the bike frame and prevent it from changing position
2. Begin with seat back at most upright position allowed by the support arms
3. Hold an angle gage against the flat, middle section of the seat back. Mark this location on the seat back with tape. Record the angle reported by the angle gage in the table.
4. Cycle through the rest of the possible seat back angles, placing the angle gage at the same position and recording the angle.

Data:

Arm Position Number	1	2	3	4	5
Seat Back Angle	98.1	107.6	118.2	128.5	149.1

Test #3: Max Weight and Deflection Test

Description of Test:

Measuring the deflection of key stress components of the confirmation prototype under a max load case (heaviest rider).

Materials Required:

- 1 Participant
- Several Bags of Clay ~ 25 lb each
- Confirmation Prototype
- Stand to support front half of bike frame
- Scale with Capacity of 300 lb minimum

Location for Test:

Open space with level ground.

Safety Procedure:

1. Secure frame in fixture to keep static throughout test
2. Gently place bags of clay on human
3. Have spotters on either side of the tester in case of bike failure or tipping

Pass Criteria:

Test will be considered a success if no components fail during the maximum load test as well as deflection of the center beam is less than 0.25 inches.

Testing Protocol:

1. Place front part of frame in fixture and set seat track the position of maximum extension and the most inclined position.
2. Record the height of the bottom surface of the outer box beam directly under the seat bottom mounting holes.
3. Measure the weight of the human test subject.
4. Allocate the appropriate number of bags of clay to reach a total weight of ~250 lb
5. Sit the test subject in the bike and place the clay bags on top of the human along their frame.
6. Record the height of the center beam
7. Remove the subject and clay from the bike stand.
8. Adjust the reclined angle to be the maximum reclined position (~135 degrees)
9. Repeat Steps 2-7 for the maximum reclined position.

Data:

Seat Track Location	Seat Back Position	Final Weight (lb)	Measured height of Center Beam with Ruler before loading (in)	Measured height of Center Beam with Ruler with loading (in)	Calculated Deflection using Ruler Measurements (in)	Uncertainty of Deflection (± in)
Far	Inclined	251.3	16-3/8	16-1/4	1/8	0.04
Far	Reclined	251.3	16-3/8	16-3/16	3/16	0.04

Test #4: Min. And Max. Pedal Distance Test

Description of Test:

Setup seat track mechanism in closest position to the pedals and then measure the maximum distance from the upper surface of the bottom half of the bike where the holes are located to the farthest away pedal when the crank is parallel to the front tube. Do this procedure again with moving the seat track mechanism to the farthest back location.

Materials Required:

- HPV Trainer Frame
- Bike fixture to hold front half
- Tape measurer

Location for Test:

Open space with level ground.

Safety Procedure:

1. Secure front half of bike in fixture
2. Identify possible pinch points to user before each test

Testing Protocol:

1. Set bike at most upright seat back position and closest seat track location
2. Measure the distance from specified seat location to the furthest pedal and record this measurement
3. Repeat steps 1 and 2 but for the seat track in the farthest away location
4. Compare measured values to reference values
    a. Note any discrepancies between measured and reference values. Change values in operator's manual as necessary.

Data:

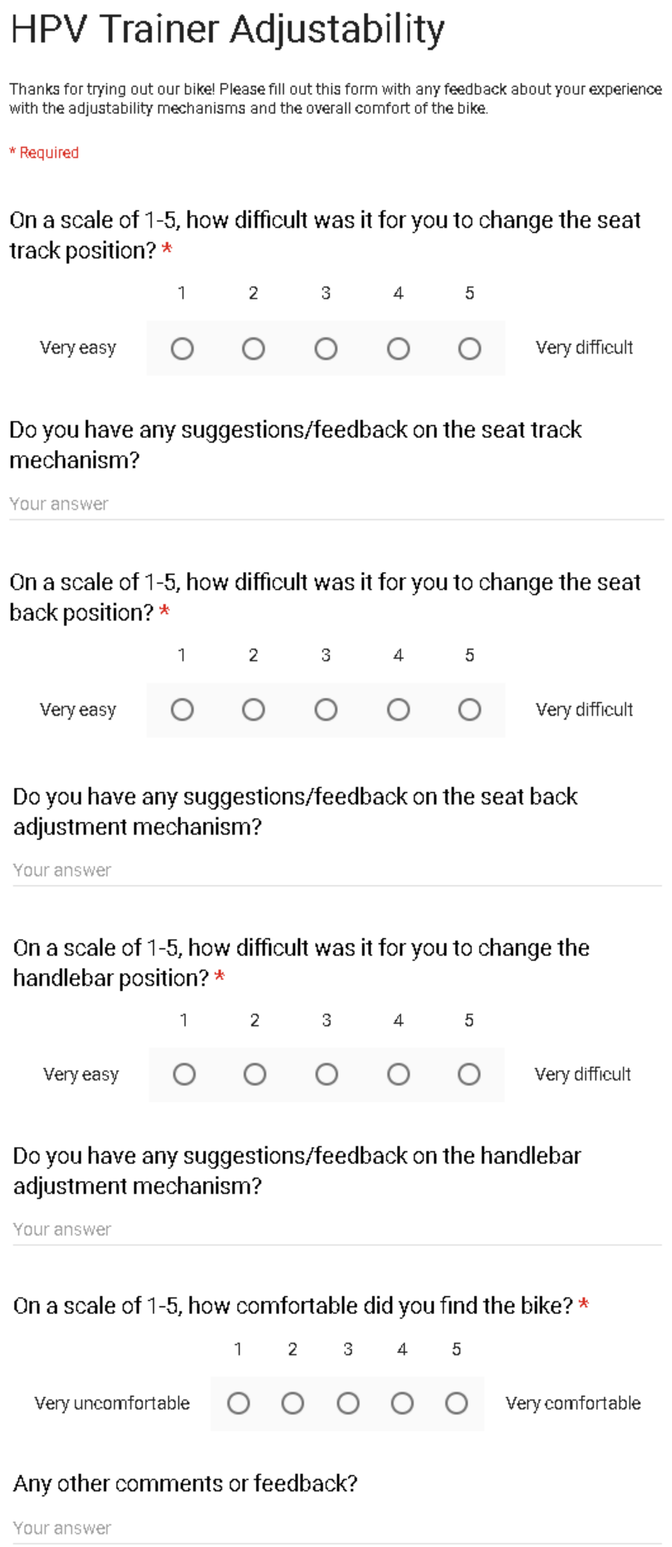
Position	Measured Value (inches)	Comparison	Reference Value (inches)
Closest	33	Less than or equal to	33.0
Farthest	40	Greater than or equal to	39.4

Appendix Q. Adjustability Mechanism Testing Results

Setup Test Results:

Test	**Setup Time** (seconds)			
	Seat Track	**Seat Back**	**Handlebars**	**Overall**
1	34.9	16.2	12.0	63.1
2	18.5	24.5	7.4	50.4
3	13.2	13.4	4.1	30.7
4	34.5	13.0	8.6	56.1
5	44.6	32.3	28.2	105.1
6	46.6	5.7	15.6	67.9
7	22.2	34.4	14.9	71.5
8	53.5	15.9	10.4	79.8
9	24.7	14.0	10.6	49.3
10	15.0	20.0	7.0	42.9
11	13.6	8.5	10.7	32.8
12	14.0	13.0	11.2	38.2
13	19.9	18.3	15.1	53.3
14	22.8	24.3	4.9	52.0
15	17.2	37.0	10.0	64.2
16	41.0	20.4	52.4	113.8
17	26.7	19.8	3.3	49.8
18	40.5	19.3	0.5	60.3
19	68.9	35.0	10.0	113.9
20	43.4	14.3	8.0	65.7
AVG	**30.79**	**19.97**	**12.25**	**63.04**

Original Survey, as it appeared to participants*:*



HPV Trainer Adjustability

Thanks for trying out our bike! Please fill out this form with any feedback about your experience with the adjustability mechanisms and the overall comfort of the bike.

* Required

On a scale of 1-5, how difficult was it for you to change the seat track position? *

	1	2	3	4	5	
Very easy	○	○	○	○	○	Very difficult

Do you have any suggestions/feedback on the seat track mechanism?

Your answer

On a scale of 1-5, how difficult was it for you to change the seat back position? *

	1	2	3	4	5	
Very easy	○	○	○	○	○	Very difficult

Do you have any suggestions/feedback on the seat back adjustment mechanism?

Your answer

On a scale of 1-5, how difficult was it for you to change the handlebar position? *

	1	2	3	4	5	
Very easy	○	○	○	○	○	Very difficult

Do you have any suggestions/feedback on the handlebar adjustment mechanism?

Your answer

On a scale of 1-5, how comfortable did you find the bike? *

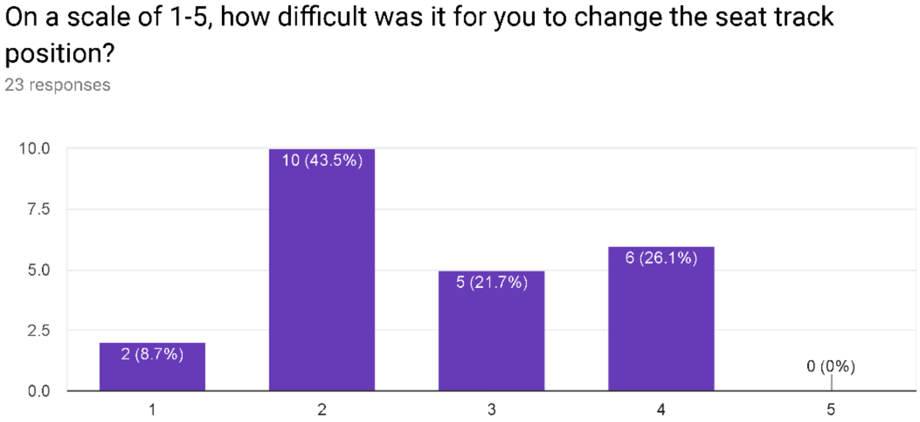
	1	2	3	4	5	
Very uncomfortable	○	○	○	○	○	Very comfortable

Any other comments or feedback?

Your answer

Survey Results

Seat Track



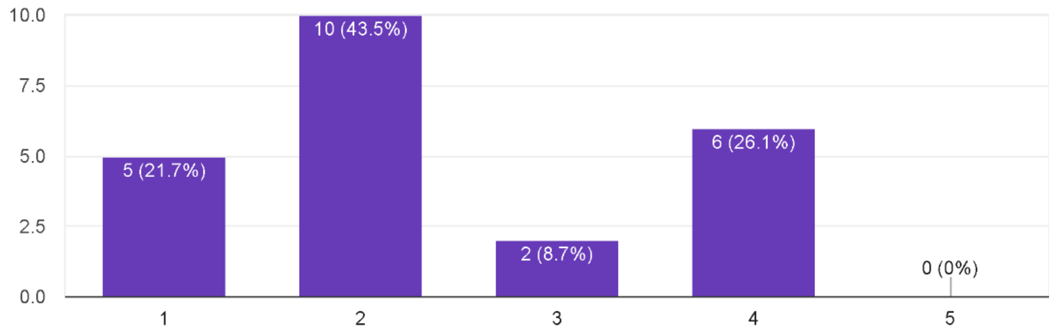
On a scale of 1-5, how difficult was it for you to change the seat track position?

23 responses

Participant Suggestions for Seat Track Adjustment Mechanism [unedited]:

- use lock nuts to make sure bolts dont come loose, scratch in what pin number each hole is,ise shims for slop and low friction
- Maybe put a "pull" label
- tie seat back adjustment together
- Perhaps add linear bearings to the track to make fine adjustments easier
- detents sprimgs
- n/a
- One pin instead of two
- two pins is a bit much and so much adjustability makes it hard to change
- put the rear wheel on a track so it slides easily.
- The holes seem to misalign taking time to align
- seemed good easy to use
- Lessen the friction between parts
- bigger holes and lube to joints
- It would be slightly better is the outer beam could slide more efficiently with less friction and more precision
- More clearance on the holes,
- Make the seat sink less, and secure the pegs more
- Hard to align the holes when changing the seat

Seat Back:



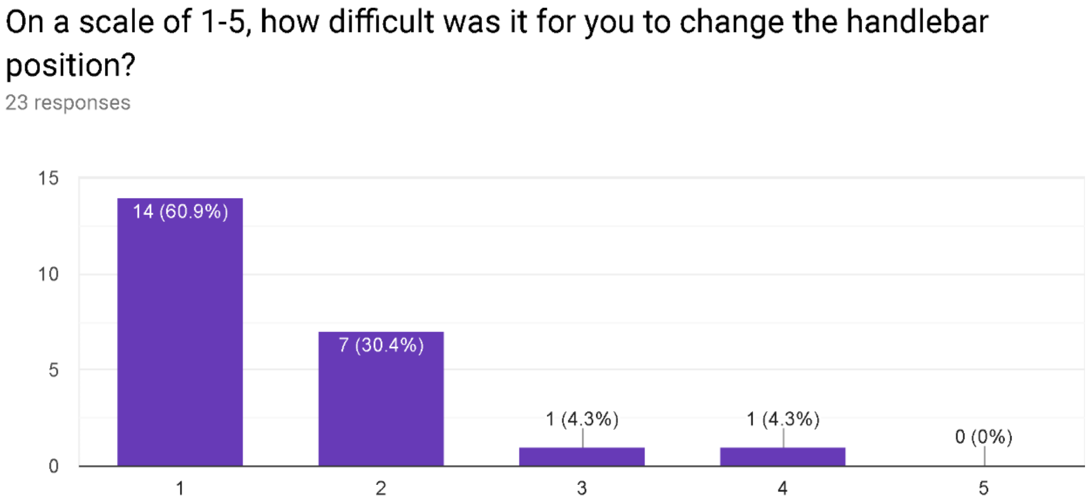
On a scale of 1-5, how difficult was it for you to change the seat back position?

23 responses

Participant Suggestions for Seat Back Adjustment Mechanism [unedited]:

- make both seat arms attched so that they move together
- It was hard to take it out of the hole but it was easier putting it into a new position
- The slots are a little bit tight
- tie the arms together
- Maybe make both brackets fixed to each other.
- Make the clearance between the bar and holes larger.
- Connect the two separate brackets
- they bars should move together so you only have to grab one side. a crossbar
- make the whole bar thin enough to slip notch onto
- If the support arms aligned better it would be easier to change
- Coat the metal bar so it is not metal rubbing on metal
- Not that I can think of
- Number the holes
- I thought it was good and quite sturdy!
- a little more clearance
- Knobs maybe?

Handlebars



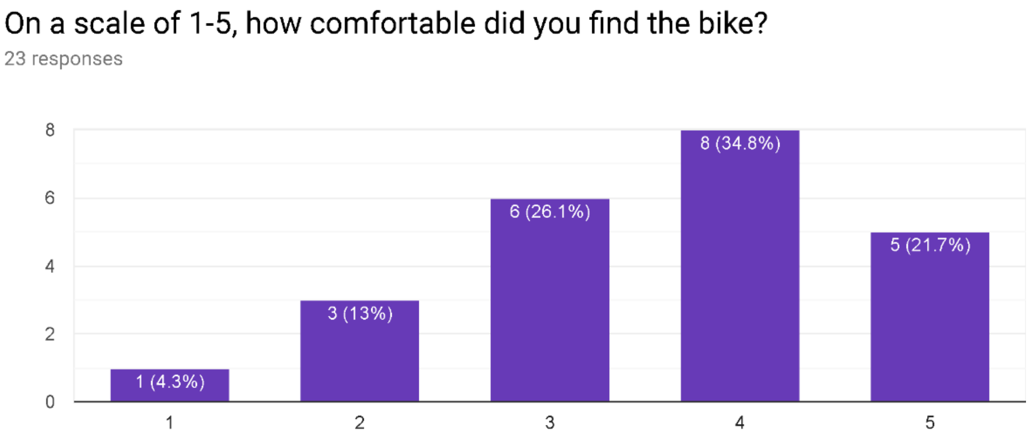
On a scale of 1-5, how difficult was it for you to change the handlebar position?

23 responses

Participant Suggestions for Handlebar Adjustment Mechanism [unedited]:

- make the handle bar pin no collide with knees during travel
- It was pretty easy. GREAT JOB
- the pin was a bit crunchy but it was fine
- super mellow.
- nope
- Very easy to use
- It's simple to remove
- Number the wholes
- Easy money

Overall Bike Feedback



Other comments/feedback on bike [only comments pertaining to usability/improvements included]:

- Super cool! I could see the adjustability being useful not only for different people but also for increased portability.
- head support
- This was too manual I am used to all the automatic switches
- Make the seat taller and lube those joints.
- My tochus was a wee bit uncomfortable (tailbone region)

Appendix R

Uncertainty of Deflection test

$U_{measurement} = \pm 1/32$ in   Measurement uncertainty of ruler with 1/16 in graduations

Deflection = $H_{preload} - H_{postload}$

Both heights have the same uncertainty associated with them

$$U_{tot} = \sqrt{\left(\frac{1}{32}\right)^2 + \left(\frac{1}{32}\right)^2}$$

$$U_{tot} = .044 \text{ in}$$