FRAMED

Final Design Report
May 31st, 2019

Human Powered Vehicle Frame
Cal Poly Human Powered Vehicle Club
California Polytechnic State University, Mechanical Engineering Department

Kyra Schmidt
kschmi12@calpoly.edu
Keyanna Henderson
kehender@calpoly.edu
Brendon Morey
bhmorey@calpoly.edu
Austin Henry
ahenry05@calpoly.edu

Client: George Leone
georgelleone@gmail.com

Statement of Disclaimer

Table of Contents

List of Figures

List of Tables

Abstract

The following is the Final Design Review (FDR) Report for Framed, a team tasked with designing and fabricating the frame of the 2018-2019 Cal Poly Human Powered Vehicle (HPV) Club bike. The bike is to be raced at the 2019 World Human Powered Speed Challenge in Battle Mountain, Nevada with the goal of breaking the American collegiate speed record. The purpose of the FDR Report is to introduce the project's background and objectives, discuss the final design, and present the results of manufacturing and testing.

Prior to beginning work on the design of the frame, the group conducted extensive research on human powered vehicles. This began with interviews and observations at Battle Mountain 2018, where Cal Poly HPV club members got a first-hand account of the competition, its top competitors, and their bikes. Shortly thereafter, the project team was assembled and began working to better understand how to build a bike. The team investigated existing designs of both custom and mass-produced bikes. Research was performed on material selection, aerodynamics and ergonomics, and loading cases. Applicable standards and regulations of the competition were also researched.

This research clearly defined the project outline. The team identified the problem and the customer's needs and wants. The major systems under the project scope were determined to be the frame, fork, and steering system, and the customers to be both the Cal Poly Human Powered Vehicle club and the rider, Josh Gieschen. This allowed the team to make considerations that addressed a wide range of specifications and compile a list of needs and wants. After identifying specifications and their target values, several testing procedures were developed that would verify the success of the design.

Moving forward with the specifications led to the concept design process. The team began with several methods of brainstorming in order to come up with ideas for components, materials, and functions. Prototypes were then constructed that highlighted specific concepts and demonstrated their functionality. The next step was narrowing down design choices, which was accomplished with a series of matrices. The weighted decision matrix brought the team to its final concept design – a steel frame with a roll hoop, side supports with trusses, and a bottom support. The design was presented at a Preliminary Design Review (PDR) and iterated upon for the Interim Design Review (IDR). Valuable feedback was received and implemented into the design and several improvements and additions were made for the Critical Design Review (CDR). The design was supported with extensive research and analysis, as well as designs for jigs to help build the frame and fork. The team also included corresponding risks, challenges, and unknowns.

The Final Design Report contains the entire design and manufacturing process, as well as successes and issues encountered. It also presents in detail all testing procedures conducted, their results, and the final values met for all specifications. Although the specification of speed will not be measured until the World Human Powered Speed Challenge, the team can confirm that all other specifications were met, and the final design was manufactured and tested with complete success. An operator's manual is included to provide instructions for both the rider and bystanders during testing and racing.

1 Introduction

The Human Powered Vehicle Frame Team, known as Framed, is responsible for designing, manufacturing, and testing the frame for the 2019 vehicle for the Cal Poly Human Powered Vehicle Club. The vehicle will race at the World Human Powered Speed Challenge (WHPSC) sponsored by the International Human Powered Vehicle Association (IHPVA) with the goal of breaking the American collegiate speed record. This project was conducted within a three quarter long mechanical engineering senior design course. The Framed team includes Mechanical Engineering seniors Kyra Schmidt, Keyanna Henderson, Brendon Morey, and Austin Henry. George Leone, a longtime builder of human powered vehicles and mentor for the club, will serve as the client throughout the project. The group worked closely with both the senior project team designing the vehicle's drivetrain and with the club.

The design of the Cal Poly Human Powered Vehicle frame involved considering a wide range of variables internal and external to the project. Internally, the design of the frame covered: geometry and handling characteristics, material selection, safety, rider ergonomics, structural analysis, and vehicle packaging. Externally, the team worked closely with the rider, drivetrain, fairing, braking, and various other subsystems of the bike. The following is a summary vehicle's frame design and overall project.

This report will detail the project's research summary, objectives, design, manufacturing, testing, and project management. The background portion of this document details the initial research that was done early in the design process. The objectives chapter goes into detail on the scope of the project, specifications, and the needs and wants of the customer. The next section details conceptual designs and shows the concepts that were considered during initial design phase of the project. The final design section comes next detailing the full computer aided design (CAD) model along with design validation. Next is the manufacturing plan which details the methods and procedures that were used to build the frame. Design verification comes next with specifications and testing results. And the absolute final chapter tells of the project management process; the purchasing, analysis, deliverable dates, and scheduling. Any supplementary information mentioned in the body of this report is attached in the appendices.

2 Background

Through observations of vehicles at Battle Mountain, interviews with the sponsor, previous findings from the club, and additional background research, the team has investigated and defined the customer's design needs and wants. Using these design inputs, a formal list of product specifications was developed. This section of the document details the research and technical background that led to the design specifications.

2.1 Geometry

To begin technical research, one of the main aspects analyzed was how the geometry of bicycle frames affect their handling qualities. This is important to account for as it affects the rider's power output, safety, and comfort while riding the bike. Some of the main geometry factors affecting bicycle handling are trail, wheelbase, and weight distribution. The wheel size also plays an integral role in vehicle handling, as can component choice.

The trail is the distance between where the line of the steering axis intersects the ground and where the tire intersects with the ground, as shown in Figure 1. Most standard bicycles have positive trail, meaning that the contact point between the wheel and the ground is behind where the steering axis intersects with the ground. The trail is determined by the head tube angle, which determines the steering axis, and the fork offset, which refers to the distance from hubs to steering axis.

Figure 1. Graphic showing fork offset and trail [1].

A larger trail causes a bike to feel more stable. In recumbent bicycles, the steering angle is smaller than that of a standard road or mountain bike frame. Some streamliner frames observed at Battle Mountain have a fork offset that places the fork behind the front wheel axle. This includes team Aerovelo's bike, Eta Prime, shown in Figure 2, which holds the world speed record, as well as Primal 3, George Leone's latest bike. When asked, the designers of Eta Prime stated this was due to spatial constraints with the drivetrain. In contrast, other streamliners, such as VeloX by the Delft and Amsterdam Team and Taurus by the Italian team Policumbent, have a fork that extends directly down to their axle without a second member offsetting the fork [2].

Figure 2. Picture displaying Eta Prime's fork offset.

A standard bicycle has a head tube angle between 71.5-74.5° from horizontal. By increasing the fork offset (the distance from the wheel hubs to the steering axis), trail is decreased. Because of this, if bikes have a very shallow steering angle, they often have more fork offset to keep the balance. "Road bikes usually ranges from 40 to 55 mm [of trail] ... Motorcycles usually have 80 mm of trail… but can feel sluggish at slower speeds" [3].

The wheelbase is the horizontal distance between the front and rear axles of a bike. The longer the wheelbase, the more stable a bike feels and the easier it is to keep the bike traveling in the direction it is headed. The high speeds recorded at Battle Mountain require bikes to be stable at high speeds. A balance must be found between stability and maneuverability, which will be based heavily on dynamic modeling and physical verifications with testing.

In a streamlined recumbent bicycle, a rider's position is as laid back as possible without compromising power [4]. While at Battle Mountain this year, every bicycle observed was in the recumbent position. The world record holding bike, Eta, has a recumbent seating position, as shown in Figure 3 [20]. The rider is given ample time to train to become accustomed to the non-standard so they can put out peak performance during the race. "Recumbents hold all human powered speed records. Period!" [5]. Additional research performed on aerodynamics and ergonomics can be found in Appendix A.

Figure 3. Eta with rider, showing the rider's position in the frame [6].

Due to the recumbent position, the bottom bracket location on streamliners seen at Battle Mountain is much higher than in a traditional road bike. Because of spatial constraints, many Battle Mountain bikes have been observed to be "short wheelbased", meaning that the bottom bracket is positioned in front of the front wheel [7]. This positioning can be observed in Figure 4, on Primal 2, another HPV designed by George Leone. This causes bikes to ride less smoothly, but the compromise is rectified in other areas of the geometry to assure good handling characteristics.


Figure 4. Primal 2's drivetrain and bottom bracket height in relation to the wheels.

Analysis can be performed regarding many different aspects of frame geometry, however due to the resources available and time constraints, the team will start with known and tested geometries. Consequently, the team will not have to begin from "ground zero" and can instead focus on creating a frame that is custom fit to the rider and as optimized as possible. The team plans to use dynamic modeling and physical testing to ensure that the model for the frame is a robust option.

The wheel and head set choices are important considerations that also affect the frame's geometry and structural integrity [8]. The research regarding these components in detailed in Appendix B.

2.2 Material Selection

The material choice for the frame has a fundamental influence on every aspect of the vehicle design. This choice is based on a variety of factors including material properties, cost, and ease of manufacturing. The team's decision-making process considered three materials that are commonly used in frame building: aluminum, chromoly steel, and carbon fiber.

The primary properties analyzed were strength, manufacturability, ease of repair, and cost. Through evaluation of the three materials it was found chromoly steel was the best for the project. Chromoly is isotropic and easy to weld and machine with the resources available in the Mechanical Engineering shops. It can be easily repaired and is readily available for purchase. In addition, it has been extensively researched so its properties are well understood [9]. Analyses for carbon fiber and aluminum are detailed in Appendix C.

2.3 Safety and Loading Cases

The frame is the vehicle's main structural element, so safety plays an integral role in its design. Since the IHPVA competition does not have rigorous safety standards, the design of the frame will be dictated by standards set by the team with help from department faculty and governing bodies such as American Society of Mechanical Engineers (ASME) and Society of Automotive Engineers (SAE). The safety requirements for the frame will involve the use of mandatory safety equipment like a roll hoop, helmet, and 5-point racing harness, shown in Table 1. Physical testing and finite element analysis (FEA) will also be required of the vehicle before it can run.

Table 1. Safety Equipment Regulations

Safety Equipment Required	Governing Body	Reference
Roll Hoop	ASME	Appendix D
Helmet	ASME	Appendix D
Racing Harness	SAE Baja	Appendix D

Loading cases are an important part of the design of the vehicle. Unlike the ASME colligate competition, the IHPVA does not have frame loading requirements. Because of this, research needed to be done on the loading cases that would be appropriate for the vehicle. ASME's loading cases were used as a starting point for the design loading. ASME requires all vehicles raced in competition to verify their roll hoop through physical load testing. The loads required by ASME are a vertical load of 600 lbf and a side loading of 300 lbf (see Appendix D). These loading cases were implemented at a time when the competition saw top speeds of approximately 50 mph. Comparing this to the speed that a human powered vehicle is designed for (roughly 70 mph), the kinetic energy would increase by a factor of 1.96. Therefore, the team designed the vehicle to support double the loads required by ASME – 1200 lbf vertically and 600 lbf laterally.

In addition to passing internal regulations set by the team, the design must be consistent in abiding by Battle Mountain regulations (Appendix E). This includes vehicle requirements, course structure, and chase vehicle rules. The bike and rider will also adhere to applicable ASME HPV, Baja SAE, and Formula SAE safety standards and requirements. These standards can be found in Appendix D.

2.4 Observations from Battle Mountain

While at the Battle Mountain competition in 2018, many different bikes were observed and some of the teams were interviewed. The main designers of both Eta Prime and Wahoo, Aerovelo and Cal Poly alumni Larry Lem, respectively gave extensive information regarding different aspects of frame and vehicle design. Observations and notes regarding the vehicle's frame are listed below and selected pictures of the vehicles present at the competition are shown in Appendix F.

Notes from Eta:

- Frame brace top and bottom
- Beam element optimizer was used by Toronto
- Torsional stiffness important between the wheels
- Need stiffness at pedal input, loaded by pedaling forces at cranks (front of bike)
- Front of bike loaded by pedaling force
- Chain must not interfere with fork
- Frame must be strong, but fairing protects rider a lot too
- Frame designed around constraints, general, then seeing where need geometry
- Bending load requires a lot of material to resist, brace with more than one member to reduce this (i.e. top and bottom)

Notes from Wahoo:

- Beware tire rub
- Tie in fork to fairing (bearings)
- Idea: have blocks to have rim hit first, before tire can hit fairing
- Limit steering with hard stop (tabs off stem- idea)
- Tack on tabs for steering, gradually reduce angle as rider gets used to bike
- Some considerations for tubing frames: wall thickness, bending constraints

2.5 Patents

Table 2 below shows a list of patents that are related to the design, materials, and manufacturing processes that was used to develop the frame.

Table 2. Relevant Patents on Designs, Materials, and Manufacturing.

Patent	Description
Front Wheel Drive Recumbent Bicycle (Patent US7753388B2)	Specially designed to remain stiff under pedaling loads to maximize drivetrain efficiency.
Fitted recumbent bicycle frame building process (Patent US5584494A)	A design and manufacturing patent for recumbent bicycles in particular.
Wind-and rain-proof high-speed totally enclosed bicycle (Patent CN2412825Y)	This is a patent related to the “fairing” that the frame will eventually be encapsulated.
Streamlined bicycle design (Patent US4411443A)	This patent relates the importance of having low-frontal area for the frame. It describes how this will influence the resistance (or drag) that the bike will experience.
Recumbent Bicycle (Patent US4541647A)	This patent describes the geometry and materials used for making a recumbent bicycle.

2.6 Handling Analysis

The handling characteristics of the frame were analyzed using the Patterson Control Model [10]. The Patterson Control model is an analysis tool derived using dynamics applied to bicycle geometry assuming small angles. The equations derived in the model relate a variety of geometry factors in the bicycle to control response. Figure 5 shows the geometry inputs to the model. Appendix G details definitions of what each of the variable parameters represent.

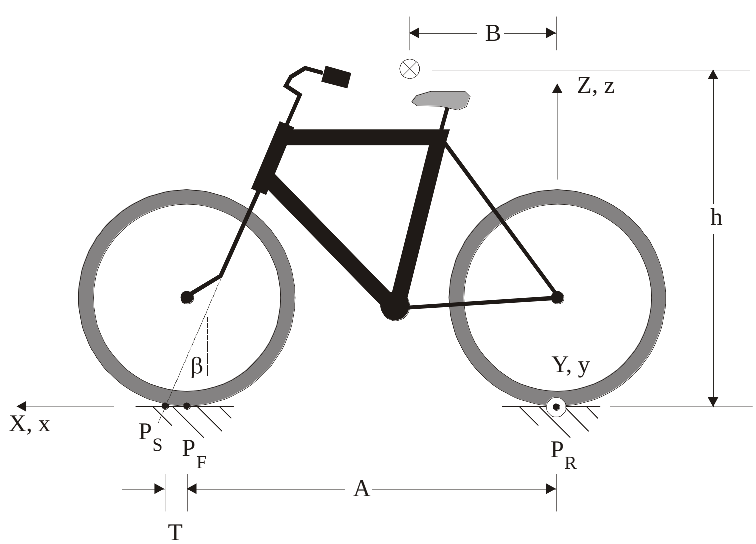


Figure 5. Visual representation of geometric parameters used in the Patterson Control Model.

The main outputs of the Patterson Control Model are control spring and sensitivity, both as a function of vehicle speed. Control spring represents “…the force feedback through the steering as a function of vehicle speed” [11]. The control spring is plotted against vehicle speed. From this plot the point where the control spring curve goes from positive to negative is the speed at which the bike goes from unstable to stable. The “… control sensitivity… represents the sensitivity of the roll response of the vehicle as a function of vehicle speed” [11]. The sensitivity describes how likely the bike is to roll over if a steering input is applied.

In Battle Mountain competition, the vehicle must be able to be started from a static start, with support provided by the team members for up to 15 meters [12]. Thus, the peak sensitivity for the frame must not be too high, or it will be extremely difficult for the rider to start the bike moving under their own power at low speeds. The frame must also have a control spring curve that passes through the x-axis at a low speed, so that it goes from unstable to stable before the bike is brought up to a higher, and thus more dangerous, speed. The frame is expected to reach speeds of over 60 mph, thus, the control spring curve at high speeds must be a steep slope so that the rider is able to easily ride in a straight line without compromising their safety and the steering is not "twitchy". In addition, the sensitivity must also be low at high speeds, so the bike is unlikely to roll over and compromise rider safety. However, sensitivity cannot be too low at high speeds, or it will be difficult for the rider to change directions in the event of an unforeseen circumstance, such as a gust of wind.

In order to get an idea of what values are "high" or "low" for the sensitivity and control spring values, past chassis that raced at Battle Mountain were measured and their geometry was put into a spreadsheet that calculates control spring and sensitivity plotted against vehicle speed. The team also reached out to the owners of the old chassis for physical descriptions of pros and cons their riders experienced. A list of information about the measured chassis, given to the team at a meeting with George Leone, is shown in Appendix H.

One of the inputs to the Patterson Control Model is longitudinal radius of gyration. While all other values are determined as the bike is designed, this value cannot be known until the bike is built and the value is experimentally determined. Because of this, research was done to determine a radius of gyration value that would be comparable to the frame the team plans on designing. A report detailing testing done at Cal Poly on recumbents with various seat angles was used to determine a rough radius of gyration for the frame [13]. Table 3 summarizes the findings from the paper.

Table 3. Radius of Gyration for Various Seat Angles.

Frame Geometry	Longitudinal Radius of Gyration (m)
Vertical rider	0.5
Classic Road Bike (Diamond Frame) Rider	0.5
90° Seatback Angle Recumbent Rider	0.44
60° Seatback Angle Recumbent Rider	0.41
45° Seatback Angle Recumbent Rider	0.35
30° Seatback Angle Recumbent Rider	0.31

3 Objectives

The Cal Poly Human Powered Vehicle club rider needs a safe, structural, and aerodynamic vehicle frame in which to race at the IHPVA Speed Challenge Championships to compete for the American Collegiate Land Speed record. The frame required for the two-wheeled streamliner must have vastly different geometry and handling characteristics than trikes made by the club in the past, in order to reach speeds over 62 miles per hour. The primary responsibilities of this project are to design and fabricate the frame and fork, to specify the headset and the safety harness, and to design seat mounting. Additionally, the frame team is responsible for the safety of the rider which includes the roll hoop, safety harness, and impact foam padding to protect the rider in a crash.

3.1 Boundary Diagram

The boundary sketch for the frame is shown below in Figure 6. The black shows the parts of the vehicle that the frame is directly responsible for, and the other colors show the main subsystems that interface with the frame. Table 4 lists the different subsystems and their respective interactions with the frame.

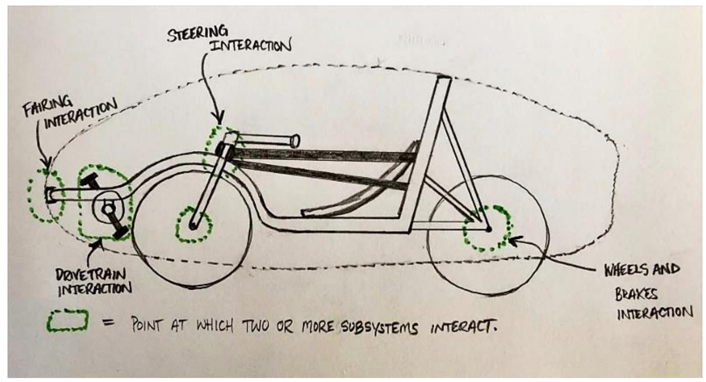


Figure 6. Boundary Diagram depicting main subsystems of the vehicle.

Table 4. Boundary Diagram Definitions.

Subsystem	Interface
Fairing	Frame and fairing both have input into frame connection design (number of connections, spacing, placement, type); frame must fit into fairing; low frontal area; frame must be as tight as possible in the front and at the roll hoop
Steering	Head tube sized according to chosen headset; frame defines steering angle; frame defines fork offset; frame supplies mounting points for steering limiters
Rider Ergonomics	Frame supports seat and decides frame connections; rider must fit in frame and be able to ride frame as a bike; frame must support the rider in normal and crash loading
Drivetrain	Frame must provide a location to weld the bottom bracket to, but frame defines bottom bracket height; the frame provides the structure to support a shaft for the mid drive; the fork must be sized to the hubs of drivetrain's choosing; the frame provides all mounting points for the drivetrain components
Wheels and Brakes	Frame must include mounting for the braking system; brake defines cable routing, but frame must approve; frame defines axles with wheel's input; frame must fit around wheel shroud; frame provides standard dropouts sized to wheel, hub, and axle

3.2 Customer Needs and Wants

In order to design a strong, efficient frame, the team identified several design goals. These were categorized as either a want or a need based on necessity and attainability.

The goal of reaching a speed of at least 61.2 mph was defined as a need since the purpose of the project is to break the American Collegiate Record. Essential to this are the needs to be stable at speeds over 60 mph, be available to race at Battle Mountain 2019, and comply with race rules and safety standards. By considering one of the customers to be the rider, Josh, it was deemed necessary to add the needs of a custom frame tailored to him and his ability to produce a high-power output. Lastly, the frame must have mounting for other systems, a structural roll hoop, and low frontal area.

Wants, though not necessary, will be accomplished to enhance the performance of the frame and bike. With the rider in mind the team added the want of comfort in order to boost speed during use. To improve the efficiency of the project, the wants of a frame that is cost-effective, lightweight, easy to manufacture, and easy to maintain were added. A complete list of needs and wants can be found in Appendix I.

3.3 Quality Function Deployment

With the customers and their needs and wants defined, their voice was brought into the planning process. This required answering the questions: who are they, what are their needs, what products are available to them now and how good are they, and how will the team meet their needs? This was done with the quality function deployment methodology, a structure that draws relationships between the answers to these questions - it describes the means by which the solution will be created.

Using QFD and filling in a house of quality allowed the team to quantify the relationships between the customers, their needs and wants, potential specifications, and current products. This process made clear which wants and needs current products boast and how strongly connected wants and needs are to potential specifications. The results of the house of quality are technical importance ratings of each specification. The top two specifications were found to be structural integrity and speed – a combination for a superior frame. An attachment of the house of quality is in Appendix J and following is the table of specifications.

3.4 Specifications

The specifications for the project were determined based upon customer needs and wants and the background research. Using these specifications, the team was responsible for the designing, manufacturing and testing of the frame itself, the fork for the front wheel, and the harness system for rider safety. The technical specifications chosen are shown in Table 5 shown below.

Table 5. Engineering Specifications.

Specifications					
No.	**Description**	**Target**	**Tolerance**	**Risk**	**Compliance**
1	Speed	61.3 mph	+ 10 mph	H	T
2	Frontal Area	475 in^2	± 75 in^2	L	A
3	Height of Center of Gravity Above Ground	0.433 m	+ 0.12 m, -0.03 m	M	A, T
4	Cost	$1,500	± $300	L	A
5	Weight	40 lbs	< 40 lbs	L	A, T
6	Instability Peak	10 mph	± 5 mph	H	A
7	High Speed Sensitivity (at 60 mph)	< 8 rad/s/m	+3 rad/s/m, -2 rad/s/m	H	A
8	Low Speed Sensitivity	< 21 rad/s/m	± 2 rad/s/m	H	A
9	Control Spring Intersection with X Axis	< 10 mph	< 10 mph	M	A
10	Deflection Under 1200 lbf Vertical Load to Roll Hoop	0.25 in	< 0.25 in	H	A, T
11	Deflection Under 600 lbf Side Load to Roll Hoop	0.25 in	< 0.25 in	H	A, T
12	Deflection of Bottom Bracket	0.20 in	< 0.20 in	H	A
13	Radius of Gyration	> 0.29	> 0.29 m	M	T

All specifications should either be minimized, maximized, or targeted and should be measurable or follow a pass-fail test. Speed will be measured using a speedometer when the bike is complete and being tested on a flat road both locally and at Battle Mountain. The specification of frontal area pertains to both the frontal area of the frame and of the completed bike. Both cost and weight (low risk specifications) are quantified upon completion of the frame. The instability peak refers to the velocity at which the highest sensitivity occurs, and the high-speed sensitivity corresponds to the bike's sensitivity at 63 mph. Both specifications are measured theoretically using the Patterson Control model for analysis. Deflection under vertical and side loading are calculated theoretically using FEA and physically using a load frame. The deflection of the bottom bracket is measured theoretically using FEA. Lastly, the radius of gyration is tested using a jig available in the Cal Poly shops.

Due to the inherent risks of racing for a land speed record, high speed is the first design specification that was considered "high-risk". In order to mitigate this risk, design efforts were focused on the structural integrity of the frame, as well as implanting safety precautions such as helmets and roll-bars. The next risk in the specifications is stability. Since the rider will be fully enclosed, stability at high speed is a must. This required careful planning using existing models to optimize the stability to speed ratio.

4 Concept Design

In order to gain insight into the best solution, several different concepts for the fork and frame were developed that addressed the chosen specifications. The team first brainstormed ideas for the materials, components, and structural design for the frame of the bicycle. Using the ideas generated in the brainstorming phase, five iterations of different frame structures were sketched. Using these sketches and more ideas developed in brainstorming sessions, the team created small concept models that integrated the best structural and material options. The concept models provided a visual proof of concept and enabled the team to create several top designs for both the frame and fork. The last step was inputting the top design components into a weighted decision matrix and identifying the "winning" designs that made up the final concept. This concept was presented at the Preliminary Design Review presentation where the team received critical feedback and suggestions.

4.1 Concept Evaluation

The design process began with an idea generation phase. Using the knowledge gained from research, the team began solidifying different concepts for how to achieve the project's specifications. Brain writing, drawing, and prototyping were some of the tools utilized to generate ideas. Concept models made with filler rod and craft materials were created to see on a small scale how certain concepts could work together. Photos and descriptions of the models can be found in Appendix K. The different concepts produced in the ideation phase were evaluated based upon their fulfillment of the requirements for the frame as well as their feasibility. Pugh matrices, in conjunction with less formal activities such as creating pros and cons lists were used to narrow down the initial concepts. The main functions that the frame needs to satisfy are rider protection from both a material standpoint and structural standpoint. These two functions were analyzed in the Pugh matrices to determine the best material and best frame geometry.

The material Pugh matrix, shown in Table 6, analyzed frame material choices. The materials available were compared to that of George Leone's bike Primal 2. Primal 2 used a steel tubing frame, so since steel was one of the materials considered, it was rated the same as Primal 2 in every category. Aluminum and Carbon Fiber are known to absorb more energy in a crash loading situation which gave them higher marks than steel. Both materials however are more prone to deforming under load and are less versatile at being adjusted after initial fabrication due to welding and layup characteristics. Aluminum is much softer than steel leading to its low marks in structural integrity but similar in fabrication processes to steel. Carbon fiber is much stiffer than steel by weight however is much harder to build with than either steel or aluminum.

The Rider protection matrix, shown in Table 7, found side supports and impact foam to be features that led to increased safety in every category when compared to Primal 2. Roll hoops and frontal impact supports were already used in the design of Primal 2 and therefore were very similar to its design. A bottom support design was shown however to provide very little rider protection.

Table 6. Pugh matrix of Rider Protection that focuses on material selection.

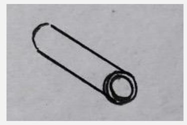
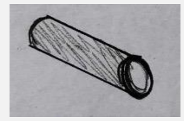
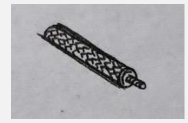
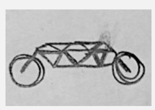
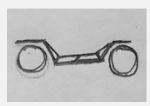
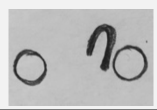
Function:	**Protect Rider (Material)**			
Concept / Criteria	Datum: Primal 2	Aluminum 	Steel 	Carbon 
Impact Absorbent	S	+	S	+
Deformation Resistant	S	–	S	–
Roll hoop Manufacturing	S	S	S	–
Structural Integrity	S	–	S	+
Adaptability/ Adjustability	S	-	S	–

Table 7. Pugh matrix of Rider Protection that focuses on frame structure options.

Function:	**Protect Rider (Structure)**					
Concept / Criteria	Datum: Primal 2	Side Support 	Bottom Support 	Roll hoop 	Frontal Impact Support 	Impact Foam 
Impact Absorbent	S	+	–	S	S	+
Deformation Resistant	S	+	–	S	S	+
Protects Internal Organs	S	+	–	S	S	+
Protects Head	S	+	–	+	S	+

4.2 Initial Frame Concepts

The Pugh matrices provided visual support to help narrow down both material and component choices. The structure matrix suggested that the team keep the same components as the datum and add impact foam. These concepts were used to develop the top five concepts which are detailed in the following sections. While they vary in frame construction and bracing, all ideas contain a roll hoop, as rider safety is the number one concern in the team's design.

4.2.1 Composite Monocoque Frame with Roll Hoop

The first idea considered, sketched in Figure 7, was a fully integrated frame and fairing (a monocoque). All of the bike's structure and mounting points would be contained within the fairing shell, and thus the frame would also be made of composite material – likely carbon fiber and honeycomb core. This design would be safe for the rider assuming manufacturing is carried out correctly, but it leaves little ability to change any parts of the design once manufacturing has begun.

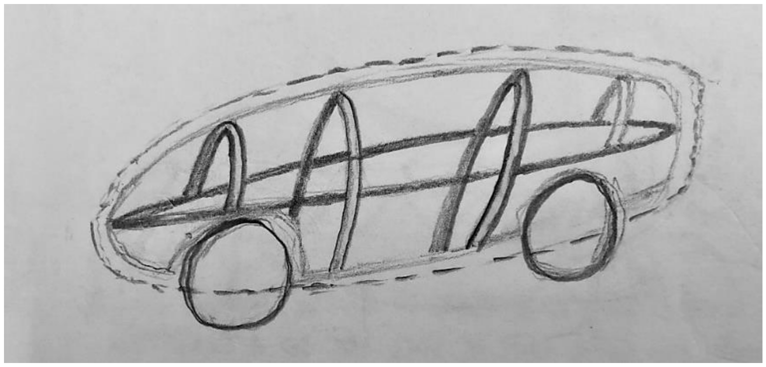


Figure 7. Carbon fiber monocoque design with roll hoop.

4.2.2 Steel Tubing Frame with Roll Hoop and Bottom Bracing

The next idea, sketched in Figure 8, utilized steel tubing instead of composite material. Round steel tubing would be used and would allow for ease of integration with standard bicycle geometry and components. One or two frame members would run under the rider, beginning from the bottom of the roll hoop and extending forward to the bottom bracket. This member would support the seat, pedaling loads, and any external impact loads. It would also dictate the bicycle's geometry, such as wheelbase and steering angle.

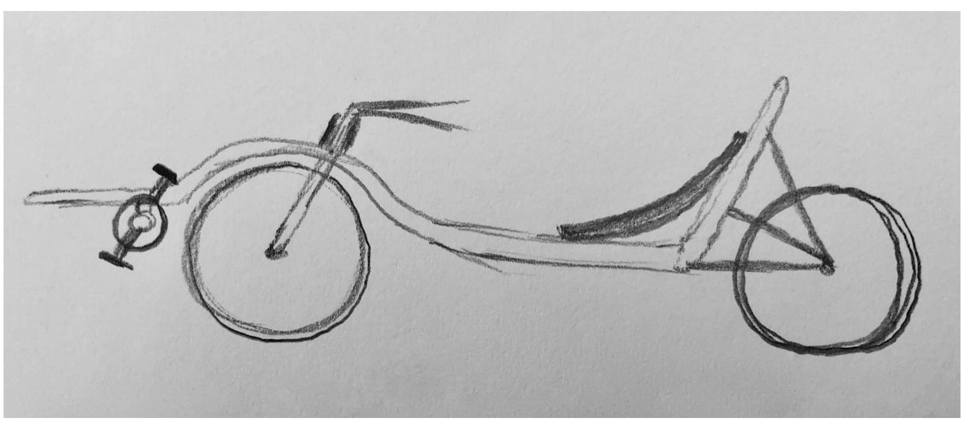


Figure 8. Steel tubing design with roll hoop and bottom bracing.

4.2.3 Steel Tubing Frame with Roll Hoop, Bottom and Side Bracing

Another iteration of a frame constructed from steel, sketched in Figure 9, contained the same main elements as the idea directly above; however, it also contained structural members extending from the roll hoop around the sides of the rider and ending at the steer tube. This concept was considered to increase torsional stiffness and rigidity of the frame, and to better protect the rider in case of a crash.

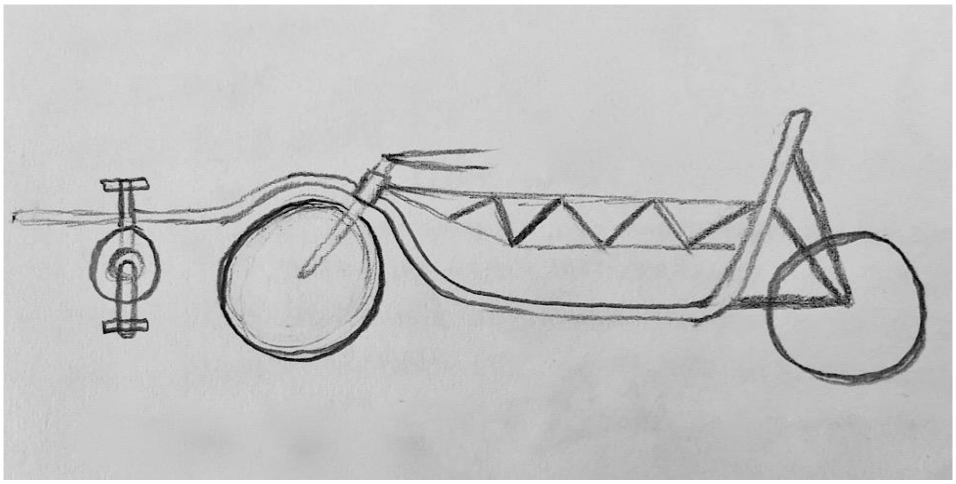


Figure 9. Steel frame design with roll hoop, bottom, and side bracing.

4.2.4 Steel Tubing Frame with Roll Hoop and Limited Bottom Bracing

The frame sketched in Figure 10 shows the steel tubing design with side support tubing without the bottom bracing. This design utilized the side supports as the main structure. This reduces the weight of the frame since it does not include the bottom tube. The main considerations in this design were to make sure the rider's legs could use their full range of motion, to ensure the structure could support the load cases, and to design the frame to be optimized in torsional resistance.

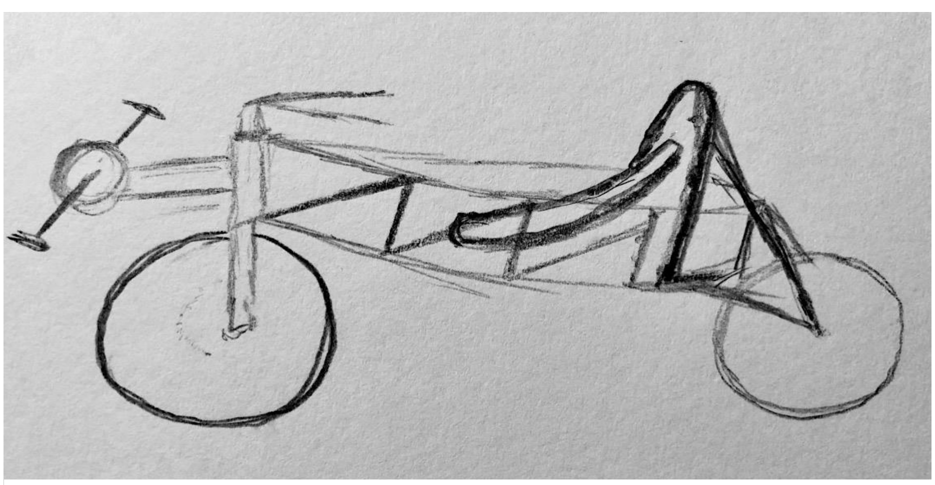


Figure 10. Design sketch of frame with roll hoop and limited bottom bracing.

4.2.5 Aluminum Frame with Roll Hoop, Side, and Bottom Bracing

The last concept, sketched in Figure 11, was an aluminum frame with a roll hoop, side, and bottom bracing. Although aluminum is lightweight, it would not offer ease in manufacturing and post-manufacturing adjustability because it must initially be heat treated. While the concept was going in the right direction by including three forms of bracing/support, it was evident that aluminum would be too difficult of a material to work with.

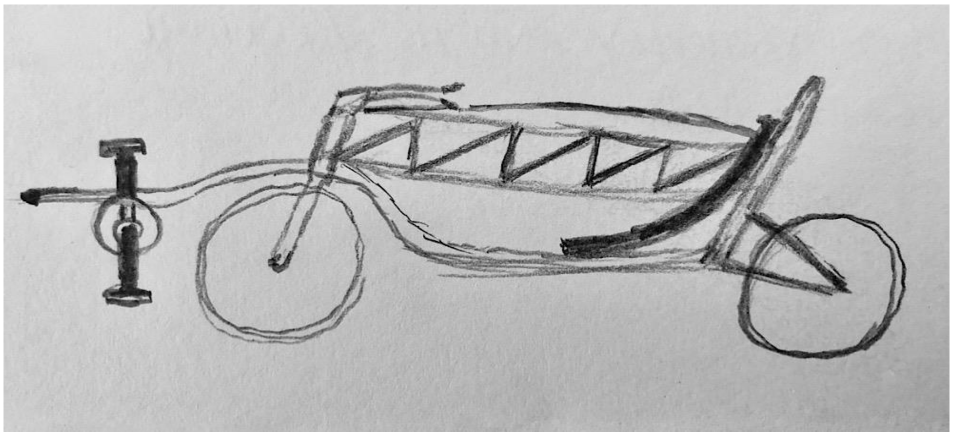


Figure 11. Design sketch of an aluminum frame with roll hoop, side, and bottom bracing.

4.3 Initial Fork Concepts

While the overall frame tubing and supports are a large portion of the project, the fork is also an integral subsystem. Due to the complexity and manufacturing challenges presented by the fork, three different concepts were developed. By focusing on the fork alone, the concepts were able to be developed independently of the frame tubing routing.

4.3.1 Standard Fork with Offset Plate

The first concept considered was a standard road bicycle fork with an offset plate. Most standard road bikes have about 40-50 mm of offset, and most of the forks for 650c wheels were found have 40mm of offset. Due to the fork offset's impact on stability and handling, the team found that a larger fork offset would be advantageous for the bike's dynamic handling (about 60mm). Thus, in order achieve the trail desired, the standard fork's blades would be connected to the axles with a machined plate, as shown in Figure 12. This would increase the fork's offset without having to manufacture a fork in-house. However, since the plate is the frame's connection to the wheels, stiffness is a big issue to consider with this design. Designing a plate such that it is light and extremely stiff to not allow flex at the axles would be difficult, and the team foresaw this design being heavier than other options.

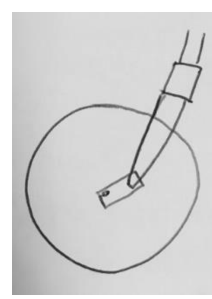


Figure 12. Sketch of standard fork with plate connecting axle to fork blades.

4.3.2 Bent Fork Blades using Straight Tubing

Another option, shown in Figure 13, for achieving the desired fork offset was utilizing straight (not tapered) chromoly tubing as the fork material and a roller bender to put in a large radius. These tubes would be welded into a fork crown at the top and dropouts would be welded on at the bottom for connection to the axle. Then, a curved beam analysis could be performed as hand calculations or in FEA to ensure the forks would be able to support the frame as a standard fork would. The analysis of this design would have to be rigorous as the team needs to be sure that a custom-designed and custom-built fork will function the same as a standard fork. Safety and stiffness were high priorities with this concept. In addition, the tolerances and criticality of this component would make manufacture and jigging a challenge.

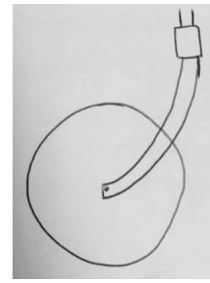


Figure 13. Sketch of fork constructed from bent tubing.

4.3.3 Standard Fork Blades welded with Custom Offset

The last option considered, shown in Figure 14, was to use a standard fork kit to manufacture a fork with custom geometry. A fork kit is a set of tubes with standard radii, diameters, and wall thicknesses for frame builders, but that can be configured in different ways for each fabricator to choose his or her exact geometry. The team would cut and miter the tubes according to the final design and use the fork building jig available through the Bike Builders Club to accurately hold the fork while it is welded. The jig is capable of 0-100mm of offset, and the range of offsets the team envisions using is well within that range. This option was manufacturing intensive, but still used well-accepted standard components, and with the resources available the team did not forecast the manufacturing to be unrealistic.

Figure 14. Sketch of standard fork blades with custom offset.

4.4 The Decision Process

Once a wide base of ideas had been generated, concept selection began. The team iterated upon the most favorable characteristics of potential frames found from the Pugh matrices and top five concepts to find ideal combinations of attributes for the frame. These combinations were then ranked against each other in a decision matrix. A decision matrix is a useful tool in the evaluation of an idea. First, a list of the criteria an idea needs to satisfy is created and a number from 1 to 5 is assigned to represent the weight of the importance of the criteria. Then, a column for the idea is added and a number from 1 to 5 is assigned to how well the idea accomplishes the criteria. Lastly, the two weights are multiplied, and the columns' sum is calculated at the bottom. This allows a quantifiable way to determine which concept is the best. The final decision matrix for the frame is shown below in Table 8. Aluminum was eliminated from material choices for the frame because of its less favorable outcome from the Pugh matrix. Since any frame design combined with any fork design was a feasible option, the frame and fork matrices were analyzed separately. The final matrix for the fork is shown in Table 9.

Table 8. Final Weighted Decision Matrix for Frame. Based upon the criteria and weights considered, a frame constructed from steel tubing, including roll-over, side, bottom, and frontal support would be considered for PDR.

		Options							
Criteria	**Weight**	Carbon Monocoque		Non-Integrated Carbon		Steel with Roll hoop, Side, Bottom, and Frontal Impact Support		Steel with Roll hoop and Bottom Support, without Side or Frontal Impact Support	
Cost	2	2	4	1	2	4	8	5	10
Speed	4	4	16	4	16	3	12	4	16
Frontal Area	2	4	8	3	6	3	6	4	8
Vertical Loading	3	3	9	3	9	4	12	4	12
Side Loading	4	3	12	3	12	5	20	1	4
Frontal Loading	3	5	15	2	6	4	12	1	3
Protects Rider	5	5	25	4	20	5	25	2	10
Integration with All Components	5	2	10	2	10	4	20	4	20
Weight	2	4	8	4	8	2	4	3	6
Ease of Manufacturing	4	1	4	1	4	5	20	5	20
	SUM:		111		93		139		109

Table 9. Final Weighted Decision Matrix for Fork. Based upon the criteria and weights considered, a fork constructed using standard fork components and welded with custom geometry would be considered for PDR.

		Options					
Criteria	**Weight**	Standard Fork with Offset Plate		Custom Curved Bladed Fork		Standard Fork with Custom Offset	
Cost	1	1	1	4	4	3	3
Structure	2	4	8	3	6	4	8
Stiffness	2	2	4	2	4	4	8
Ease of integration	3	3	9	4	12	4	12
Ease of manufacture	4	4	16	3	12	3	12
Ability to hold tolerances	3	3	9	1	3	4	12
	SUM:		47		41		55

4.5 Final Concept

The final concept presented at the Preliminary Design Review was a 4130 chromoly steel tubing frame that included a roll hoop as well as side, bottom, and frontal impact supports. It received the highest score in the weighted decision matrix, both overall and in significant criterion such as protecting the rider and being easy to manufacture. Utilizing steel as a construction material was more cost-effective than carbon fiber, while maintaining the ability to support the loading cases.

4.5.1 Description

The PDR concept was a recumbent bicycle frame with dimensions tailored to the rider's geometry. Figure 15 shows the initial concept in CAD of the frame, and the locations of important aspects of the frame.

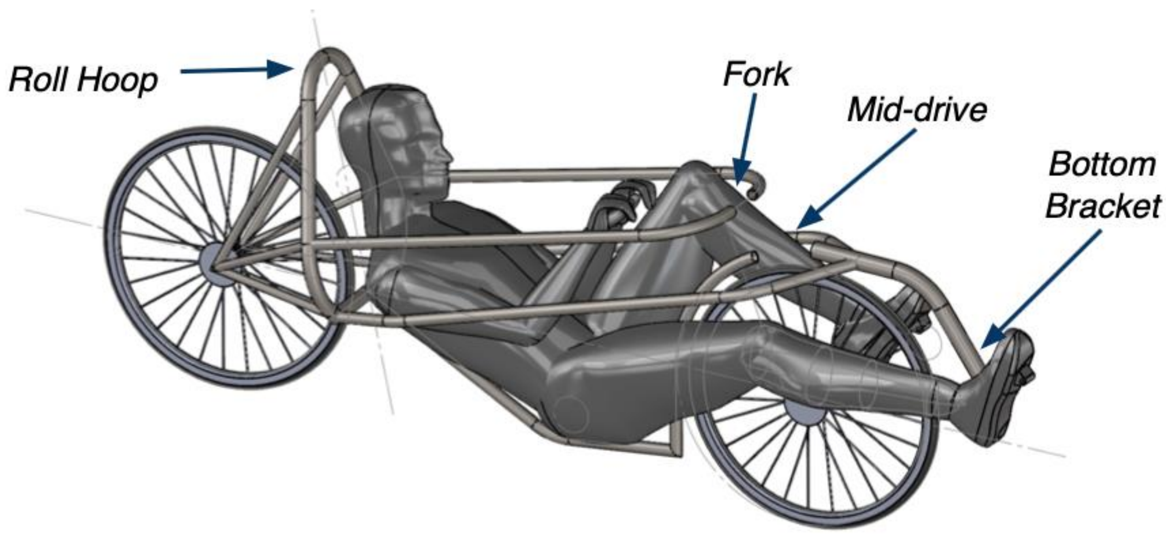


Figure 15. 3-D CAD Model of PDR concept of frame.

The frame was fabricated from steel tubing and included side bracing members, bottom support tubing, and a roll hoop. The extra frame bracing serves to increase stiffness and structural integrity of the frame, as well as protecting the rider in the event of a crash. Additionally, foam padding and soft cushioning were placed in areas where the rider may contact the frame. The fork would be fabricated from standard steel fork blades and a steer tube. It was welded using a frame building fork jig to set the custom geometry defined by the team's design.

The geometry of the frame is a function of many different constraints. The vehicle dynamics and handling were considered, as well as rider packaging and comfort, structural integrity, and integration with all other subsystems of the vehicle. Preliminary geometry analysis for handling characteristics and rider position were completed to support the PDR design. The rider for the vehicle was measured, and testing was performed to determine his ideal riding position. The handling characteristics were analyzed utilizing the Patterson Control Model. They were then integrated with spatial constraints that were determined during rider testing. Both tests are detailed in Section 4.4.4. Table 10 shows the geometry for the PDR frame design, based on inputs to the Patterson Control Model, visually shown in Figure 5. Appendix G gives physical descriptions for each of the variable parameters in the model listed below.

Table 10. Current Values for Frame Geometry.

Variable	Value	Units
a	1.45	m
b	0.847	m
h	0.433	m
kx	0.31	m
beta	18	degrees
s	-0.06	m
Rt	0.3085	m
m	118	kg
Rh	0.18	m

The frame was constructed from 4130 chromoly steel tubing and joined by tungsten inert gas (TIG) welding. Components and jigging materials were machined in-house utilizing manual or computer numeric control (CNC) machines, depending on the geometry and tolerances necessary. Moving forward from PDR with the steel frame concept, the remaining work lied in identifying the final values for specifications. CAD models provided proof that the design would function with the chosen dimensions. From there they were put into the Patterson Control Model to ensure that outputs match target values and are within tolerance.

4.5.2 Layout Models

The layout model that was created started with an analysis of the rider dimensions that were found during testing. The most important measurements gathered were the locations of the bottom bracket, seat, and the seat angle the rider preferred. Using the data, the team was able to create a line sketch using simple 2D line drawings. This 2D line sketch then served as a basis to create a 3D line sketch. The 3D line sketch was created after a mannequin of the rider had already been made by the club. Finally, when the team was satisfied with the 3D line sketch, the weldments feature on SolidWorks was used to extrude a 3D tubing profile around the 3D line sketch. This resulted in the 3D model presented in section 4.5.2.2.

4.5.2.1 Two-Dimensional CAD Model

Another tool utilized for preliminary analysis of the frame was building a two-dimensional SolidWorks model to check rider fit. Pictures and measurements taken during rider testing were scaled and put into a SolidWorks file. They were then overlaid with the initial frame dimensions found from handling analysis (see 4.5.4.2). All the inputs to the Patterson Control Model can be defined in two dimensions, so a two-dimensional model was the starting point for design constraints. Compromises were made between the ideal handling characteristics and physical constraints of the rider’s size and preferred riding position. Iterations were performed on both the CAD model and the Excel document for handling until a combination that satisfied both was found. A picture of the model built on top of the rider picture is shown below in Figure 16. The frame is shown in green, the wheels and angle definitions are shown in pink, and the lines defining the rider’s limbs are shown in grey. Construction lines (dotted lines) represent non-physical parameters (such as the wheelbase or the horizontal distance between rear axle and center of gravity). Solid lines represent actual frame members or bicycle components (such as the bottom bracing or the wheels). Figure 17 shows the line sketches of the frame, frame constraints, and rider angles without the picture overlay. While only one picture of the rider can be displayed at a time, the rider angles were defined from pictures of the rider at 8 different leg positions. This allowed the team to design around the rider's pedal circle and thigh circle to make sure there would be no clearance issues.

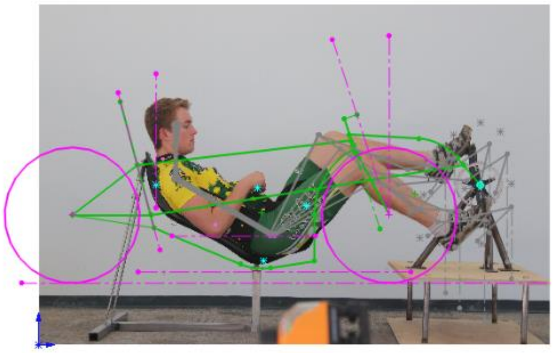


Figure 16. Two-Dimensional Line drawing of the frame overlaid over pictures taken during rider testing, displays how the rider will fit into the bike.

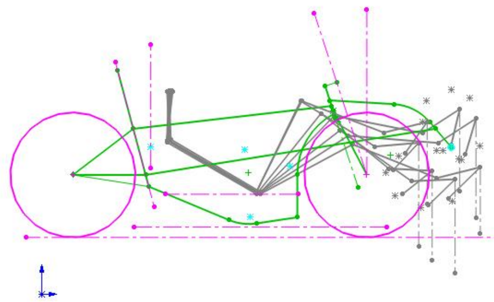


Figure 17. Two-Dimensional Line drawing, with rider measurements shown in grey, frame shown in green, center of gravity point shown in blue, and other important non-frame dimensions shown in pink.

4.5.2.2 Three-Dimensional CAD Model

The 3D model created can be seen below in Figures 18. These models were preliminary in the fact that there were some components missing and measurements that lacked validation. The number of main members, their rough locations and sizes, and their angles were relatively well-placed; however, further validation with hand calculations and FEA analysis were necessary before finalizing the 3D CAD. The model still required integration with the fork and other subcomponents. Attachment points with drivetrain, fairing, and other components were all necessary and were completed after Preliminary Design Review but prior to the Critical Design Review.

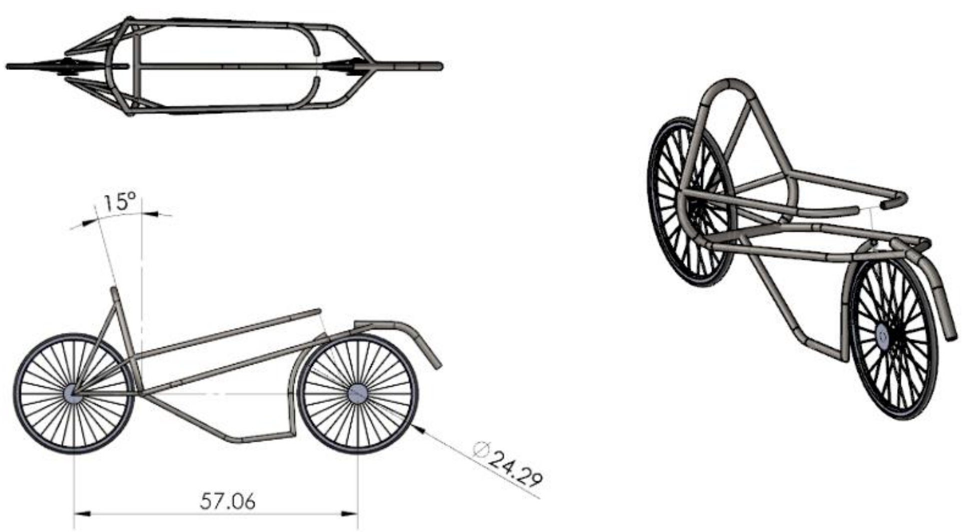


Figure 18. Drawing view of the 3D profile of the frame. Important dimensions called out: roll hoop angle from vertical, wheelbase, and wheel outer diameter.

4.5.3 Concept Prototype

The concept that the team decided to demonstrate with the concept prototype was the roll hoop manufacturing process. The roll hoop being used in the vehicle would be made of round steel tubing with a relatively thin outer wall to save weight. This thin outer wall presented a challenge to manufacturing as the tubing tended to deform or crinkle during the bending process. There are many different methods that could be used to minimize this crumpling effect. However, the capabilities of the shops and the team budget limited the team to two primary options: cold working using a dedicated tubing bender and hot working using an oxy acetylene torch and a custom-made die.

The team tested which of the two processes produced better results using round steel. Six different stock sizes (listed below) were tested, which were all cut to a length of 3 feet and bent in the center to 140 degrees (or as far as permitted). For the hot working, the tubes were bent using 3.5-inch radius bending dies specifically made for the outer diameter (OD) of the tubing. For the cold working, the tubes were bent using a 3.5-inch radius die and a bending jig. Initially the team planned to do visual inspections as well as out of round inspections with calipers, but after observing testing, it was found that the latter was no longer necessary. The results are detailed below in Table 11, and photos of the process and results can be found in Appendix L.

Although the results of testing were helpful in the fact that they provided useful information, they were poor in terms of performance. None of the tubes bent met the visual inspection standards; crinkling, visual deformation, and inconsistent bend radius were observed. This was likely due to a combination of too tight of a bend radius, lack of structural support during bend, inconstant heating, and too thin of a side wall.

Table 11. Concept Prototype Test Results.

Tubing Size	**Visual Inspection**	
	Hot Working	**Cold Working**
0.049” Wall Thickness 1” Outer Diameter	Poor	N/A
0.058” Wall Thickness 1” Outer Diameter	N/A	Unacceptable
0.035” Wall Thickness 1.25” Outer Diameter	Unacceptable	N/A
0.049” Wall Thickness 1.25” Outer Diameter	Potentially Viable	Unacceptable
0.058” Wall Thickness 1.25” Outer Diameter	N/A	N/A

From the testing performed on both hot and cold working thin tubing, it seemed very unlikely that the team would be able to manufacture the roll hoop in-house. None of the wall thicknesses nor methods attempted gave satisfactory results. To be sure, team members consulted other faculty that have experience bending thin tubing on and off campus. Jim Gerhardt, an experienced tube bender, was working with thin tubing for a frame he was building with the team's client, George Leone. Jim Gerhardt informed the team that he was unable to bend any tubing over 7/8" in diameter of 0.035" wall thickness anywhere on campus.

Jim Gerhardt provided the team with a resource to contact to get the critical tube bending done professionally. Due to the large time investment and limited results that were anticipated from attempting to bend in-house, the team decided to get the critical bends done out of house for the frame. This allowed the team to work on manufacturing other important components, such as the frame jigs, while the tubing was being bent and then was ready for manufacturing once it was finished. The team planned to utilize benders on campus for smaller diameter tubing, and to perform all cutting, mitering, grinding, welding, machining, and assembling of the frame in-house.

4.5.4 Preliminary Analyses and Tests

In order to further prove that the preliminary design satisfied the previously set specifications, the team conducted a series of calculations in the Patterson Control Model. Further definition and background of the Patterson Control Model can be found in Section 4.5.4.2. Prior to entering all values into the model, values were acquired that stemmed from the rider's measurements and riding preferences.

4.5.4.1 Rider Testing

In order to design the frame, several measurements and datums related to the rider's body size and preference were needed. Collecting this data was done in two parts. First, measurements of the rider's body were taken. This was done by identifying the rider's joints with florescent stickers, measuring the distance between these joints, and then photographing the rider while on an adjustable bike jig. There were additional measurements taken by the rider model subsystem of the HPV Club in order to create a representative CAD model of the rider. This rider model was critical in creating the frame, as it was used to verify that there was no interference between the rider's body and the frame.

The second part of data collection was used to collect measurements on the rider's preferences with regards to the fit of the frame. The measurements that the team was most concerned with were the bottom bracket position, seat angle, and relationship between the seat and the bottom bracket. This testing was done by fabricating independent seat and bottom bracket jigs that allowed the seat angle and bottom bracket position to be adjusted (see Figure 19). This allowed the team to develop datums that were used in the CAD models of the frame.

Figure 19. Rider testing setup with chosen rider, Josh.

4.5.4.2 Patterson Control Model

The bicycle dynamics, developed by William Patterson, were used to analyze the handling characteristics of the frame. Calculations were made using an excel document programed with the relationships derived by Mr. Patterson. The results are shown as plots of both control spring and sensitivity versus velocity. The Patterson Control Model is only valid for small steering angles, on two-wheeled inline vehicles, with front wheel steering systems. The frame will have a front-wheel steering system and two inline wheels. Since the vehicle will only have a possible turning angle of ± 5º, the Patterson Control Model is a valid model to use to analyze the dynamics of the vehicle.

The values that the team wanted to attain were found through research from experienced Battle Mountain participants. George Leone, a participant and builder for Battle Mountain for over 30 years, has certain accepted values for some of the outputs that he uses when designing his frames. The team decided to follow these standards as they have years of proven results. In addition, as detailed in Section 2.7 Handling Analysis and Appendix G, old chassis were measured, and their geometries were analyzed using the same tools utilized for the new frame. The holistic opinion of each old chassis' rider was considered in conjunction with their respective Patterson curves in order to give physical meanings to the Excel plots. The preliminary design plots are shown below in Figure 20 and Figure 21.

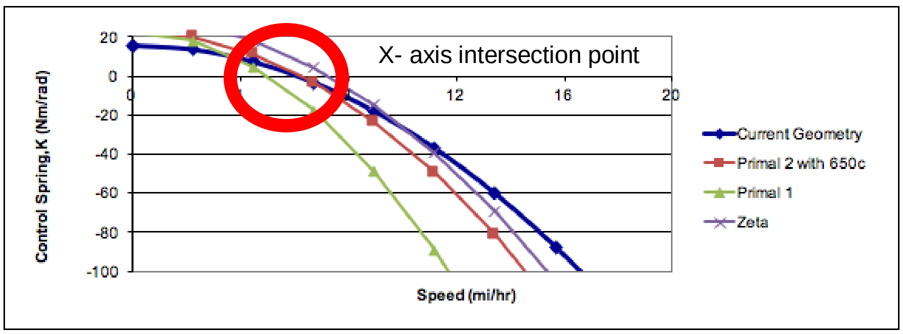


Figure 20. Plot displaying Control Spring versus Speed for the current iteration of the frame geometry, overlaid over the old chassis' measurements.

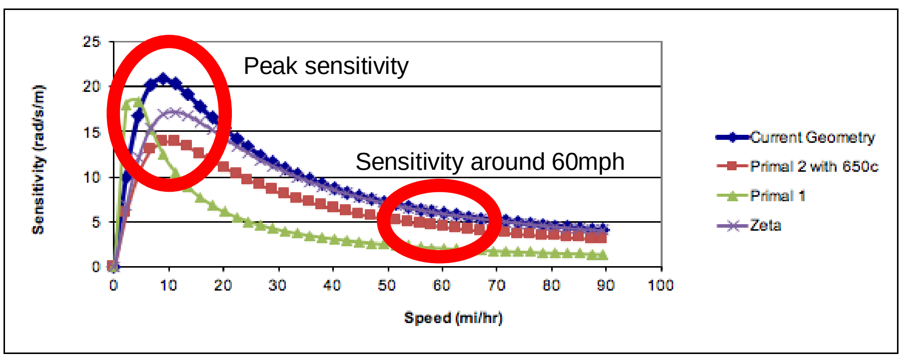


Figure 21. Plot displaying Sensitivity versus Speed for the current iteration of the frame geometry, overlaid over the old chassis' measurements.

The main aspects of the handling dynamics analyzed for are shown circled on the plots in Figures 20 and 21. The x-axis intersection point on the control spring graph is where the vehicle goes from unstable to stable. This value was aimed to be at a low speed, so that the vehicle would become stable as quick as possible after launching. The peak sensitivity as well as the sensitivity at the vehicles target speed were also checked for. Sensitivity is a measure of how likely a vehicle is to roll given a steering input. This value was aimed to be minimized at all speeds. However, due to the nature of the dynamics of the single-track recumbent, it will always have a peak. This peak was aimed to be kept under 24 rad/s/m at first, according to ASME standards. However, this was later changed in the final design as inputs from George and Carole Leone showed that this number was too high to be practical to ride. The sensitivity at roughly 60mph was aimed to be minimized as much as possible, to give the rider the most stable feeling ride at high speeds. This model was iterated and changed many times during the design process, so the final design values are shown in 5.3.1 Geometry: Handling Dynamics.

4.5.5 Risks, Challenges, and Unknowns

Several factors could present themselves that induce risks and challenges during manufacturing and testing of the frame, and during the racing of the bike. During manufacturing the team could have been exposed to shearing, cutting, and pinch points as well as hazardous materials. During testing and racing the rider will be subject to high accelerations, large forces, and hazardous weights. Because it was important to be aware of unknowns or what may occur, even if possibility is low, the team completed a design hazard checklist. The checklist can be found in Appendix M.

5 Final Design

The final design for the Human Powered Vehicle chassis is a recumbent bicycle with a full frame that encloses the rider and is fabricated with 4130 steel tubing. The frame is custom-built to the rider's geometry and ergonomic preferences while maintaining a focus on safety and speed. The frame is built to protect the rider and includes a roll hoop to keep the rider safe during a rollover crash. In addition to the frame itself, also included in the scope of the senior project is the safety harness that the rider wears, the impact foam between the rider and the frame tubing, and the fork that connects the front wheel to the bike and provides ability for the bike to be steered.

5.1 Description

The final design for the frame and fork assembly is shown in the render, Figure 22, below.

Figure 22. Final frame and fork assembly design.

The frame defines the vehicle's geometry and supports all other components. Figure 23 shows the frame assembled with other subsystems and how they each interface with the frame.

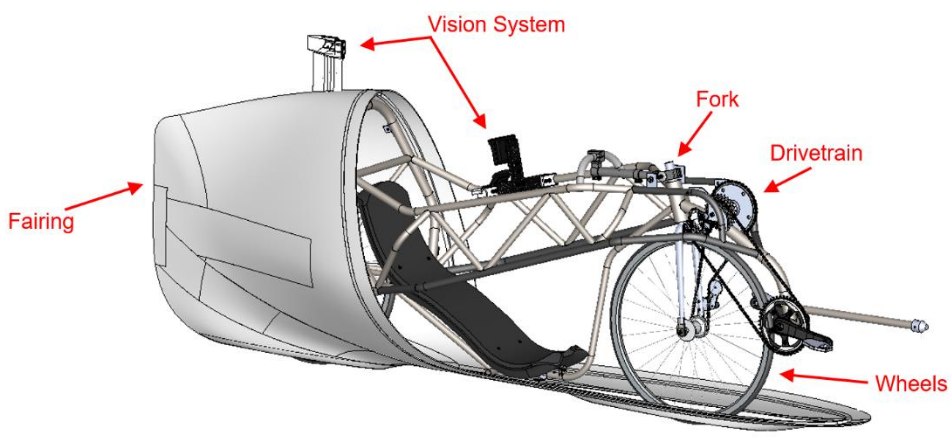


Figure 23. Assembly of vehicle's frame, wheels, seat, vision system, drivetrain, and fairing.

5.1.1 Frame

The frame assembly consists of the frame, the rear dropouts, seat mounting bosses, mid-drive mounting bosses, harness mounting tabs, the racing harness, and impact foam. Figure 24 shows the frame in grey, dropouts in pink, seat mounting bosses in green, mid-drive mounting bosses in orange, and harness mounting tabs in yellow.

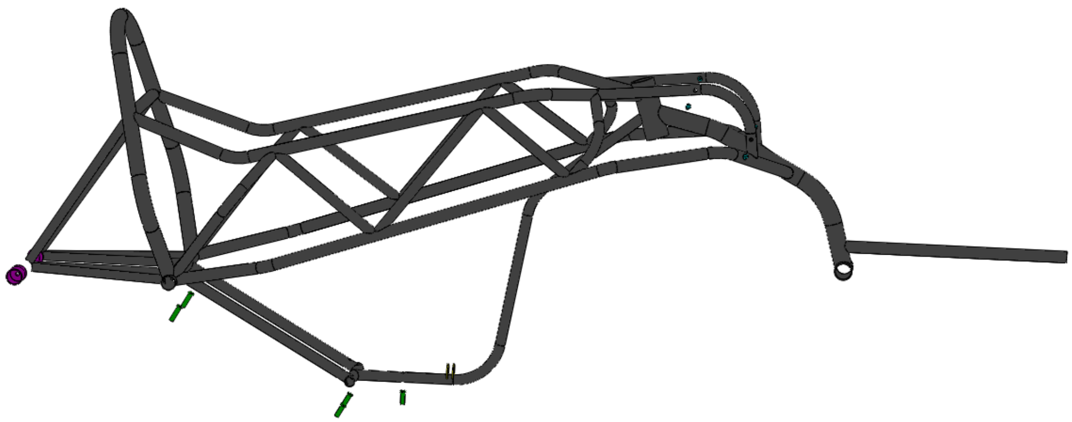


Figure 24. Frame assembly.

5.1.1.1 Frame Weldment

A standard three view drawing of the frame weldment, displayed in Figure 25, shows some critical geometry constraints of the frame.

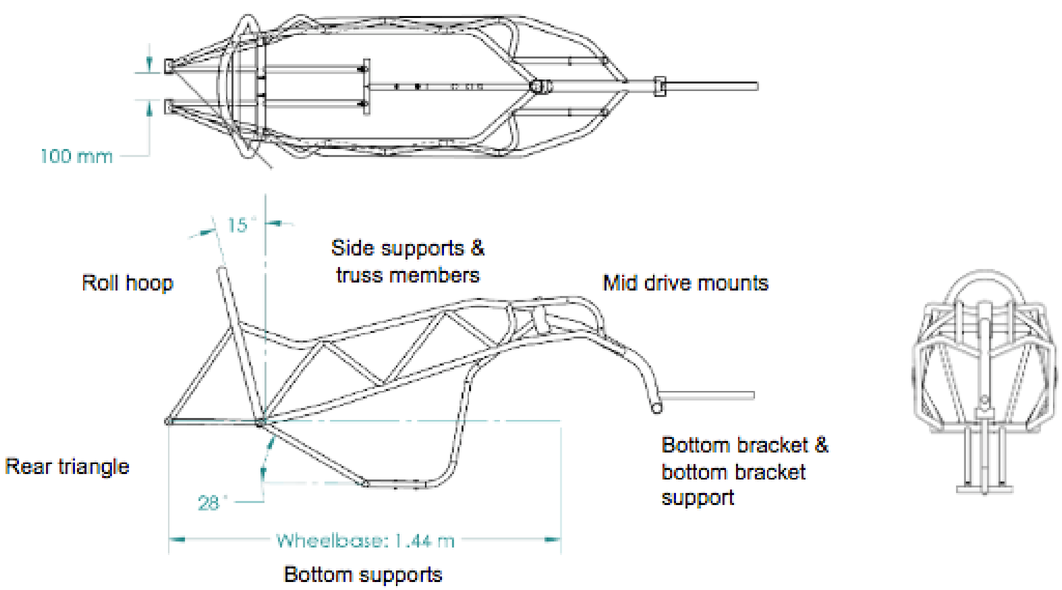


Figure 25. Standard 3-view of final frame design.

The frame weldment is constructed from 4130 round chromoly tubing. All wall thicknesses are .035”, except for the roll hoop, bottom bent support, and bottom bracket support, which are .049”. The .049” thick tubes are shown in blue below, in Figure 26.

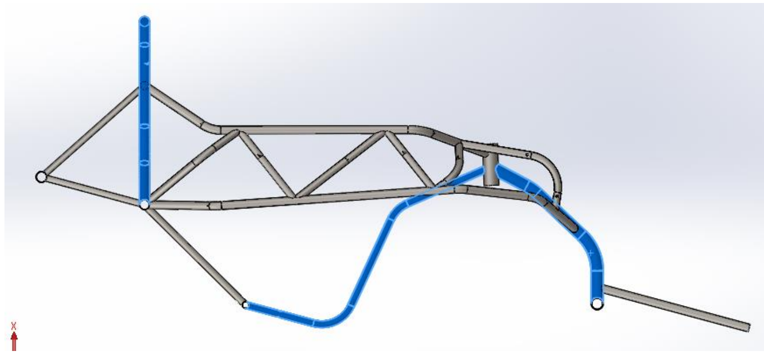


Figure 26. Side view of frame. All .049” tubes are shown in blue, and all .035” tubes shown in grey.

The rear dropout spacing is set at 100mm for compatibility with the rear hub. The rear triangle includes two horizontal members which run parallel to the centerline of the bike to allow for disc brake mounting. The roll hoop is inclined at 15° off vertical to provide better coverage over the area where the rider is sitting. The seatback angle is set at 28° off horizontal, which was found to be the most comfortable position for the rider through testing. The two under seat members allow for seat and racing harness mountings to the frame. The wheelbase is about 1.44m, which gives the rider enough space back from the wheels but still works well in the bike’s overall handling dynamics. The side members include out of plane bends in order to give the rider’s legs clearance during his full pedal circle, without increasing the bike’s frontal area.

5.1.1.2 Safety

The Speed Challenge is conducted by the IHPVA, which requires all riders to be restrained in their vehicle. When selecting a harness, the team referenced the Baja SAE safety standards [19]. Baja requires riders to wear a five-point safety harness that utilizes a latch mechanism, is made of polyester, has an SFI 16.1 or 16.5 safety rating, and whose shoulder belts use the wraparound mounting method. These requirements were met with the chosen harness: The G-FORCE Latch and Link Individual Shoulder Harness. The harness attaches to the frame at the locations shown in Figure 27. As required by Baja, the shoulder belts are mounted using the wraparound method and angled downward from the shoulders in order to properly restrain the rider. The lap belts come over his waist and wrap around the parallel tubes of the bottom support. The antisubmarine belt comes down between the rider’s legs and bolts into the mounting tabs welded onto the bottom support.

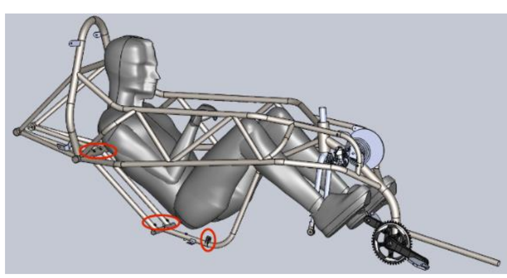


Figure 27. Frame schematic showing mounting locations for harness.

To further increase rider safety and comfort, the team decided to implement impact foam throughout the frame. Ethylene-vinyl acetate (EVA) foam was used because it is lightweight, absorbent, and moldable by heat. Figure 28 shows where impact foam is used. Along the side support members and inside the roll hoop, panels of foam were inserted. These panels include a fiberglass layup in order to stiffen the foam and distribute the load during impact. The panels attach to the side support using hook and loop, industrial strength Velcro that wrap around the top and bottom of the side supports.

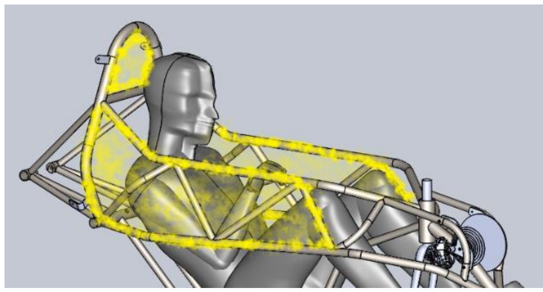


Figure 28. Frame schematic showing locations where impact foam will be used.

5.1.1.3 Bosses and Tabs

To mount various components on a round tubing frame securely, both bosses and tabs were used. Bosses, which weld into predrilled holes in the frame, were used to mount the mid-drive and the seat, and tabs were used to mount the racing harness. The locations for mounting points are shown in Figure 29, with mid-drive mounts shown in orange, seat mounts shown in yellow, and harness mounts shown in red.

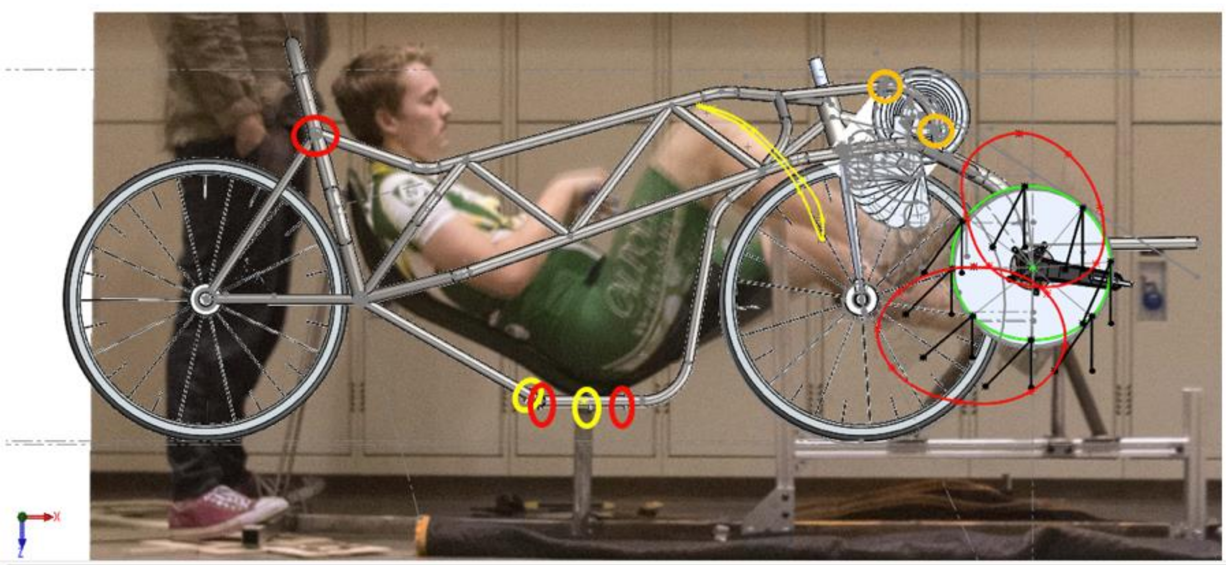


Figure 29. Overlay of frame with picture of rider, Josh, in testing jig set at final seat back angle and bottom bracket location.

5.1.1.4 Rear Dropouts

Dropouts, which connect the wheels and hubs to the frame, were designed to interface with the vehicle's custom hubs. The rear triangle tubes were mitered and welded to the dropouts in the frame jig, which set the dropout spacing for the hub. The solid model of the design of the rear dropouts is shown in Figure 30 and a test fit with the hub spacer and machined dropout is shown in Figure 31.

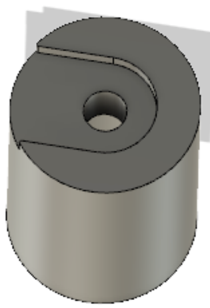


Figure 30. Test fit of hub spacer and rear dropouts.

Figure 31. Solid model of rear dropout.

5.1.2 Fork

The fork assembly consists of the fork blades, the front dropouts, the steer tube, the head tube, and the headset. In addition, the fork has two threaded bosses welded into one fork blade to allow a chain tensioner to be mounted for drivetrain. Figure 32 shows the initial, planned design for the fork blades in grey, dropouts in pink, and steer tube in turquoise. The fork initially had an asymmetric design to allow for chain clearance with drive train. However, once the CAD model for the fork blades was refined based upon the actual fork blades themselves, it was discovered that an asymmetrical fork was not needed. Figure 33 shows the final fork CAD model. The fork offset and head tube angle were set using optimization with the Patterson Control Model, and the dropout spacing was set based upon the vehicle's custom front hub (Figure 33). The offset and head tube angle were kept the same when the fork blades design was changed. The hole locations for the bosses were set based upon the fork tensioner's mount geometry.

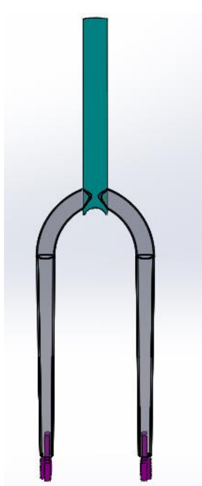


Figure 32. Solid model of final fork assembly.

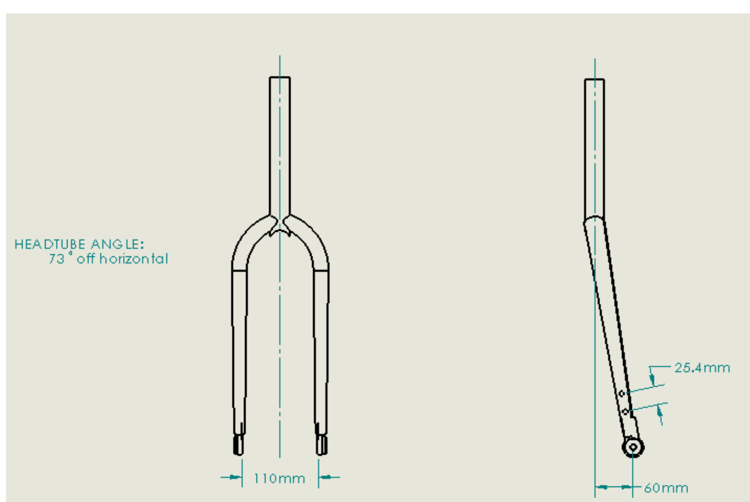


Figure 33. Front and side views of final fork assembly.

5.1.2.1 Fork Blades

The fork blades were sourced from Nova Cycles, an online frame building supply website, and welded in house. The blades specified are 25mm Road Unicrown Cyclocross fork blades (Figure 34). Unicrown refers to the fact that they are unmitered fork blades and cyclocross refers to a heavier wall thickness compared to typical road fork blades. These blades were chosen because the bike will be seeing higher loads than a standard road bike, with a front wheel drive system and fairing, in addition to higher speeds. The blades were custom mitered in house to account for the fork's custom geometry. Holes were drilled near the bottom of the left fork blade and bosses inserted to mount a chain tensioner. The blades chosen are designed for mounting disc brake tabs, and thus have an increased wall thickness near the bottom. This gave the team confidence that drilling and using bosses to mount the chain tensioner would not impact the rigidity of the fork.

Figure 34. Fork blades from Nova Cycles.

5.1.2.2 Headset

Figure 35. Headset chosen to be used with the fork assembly.

A zero-stack headset was chosen for the frame (Figure 35). The headset consists of the bearing system that allows the fork to rotate in the head tube and thus steer the bike. A zero-stack headset offers a low profile spacing outside of the head tube and comes with larger bearings than a standard headset. Because the bearings are larger, they are designed to withstand more force and are housed in a larger diameter head tube. Since the bike will be seeing higher than normal loading cases, the zero-stack headset was chosen. In addition, since many of the frame tubes connect to the head tube, the larger diameter head tube was advantageous for weldability.

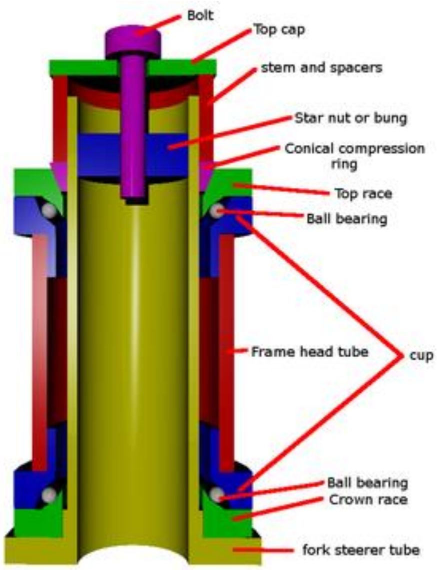


Figure 36. Internal features of a threadless headset.

5.1.2.3 Steer Tube and Head Tube

The steerer and head tube chosen were sized around the headset. The steer tube, part of the fork, was inserted through the inner races of the bearings of the headset, shown in Figure 36 in yellow. The head tube surrounds the whole assembly, and is the component that the bearings are pressed into, shown in Figure 35 in red. The head tube is stationary and welded to the main frame. The steerer can turn inside the head tube because of the head set bearings, and thus steers the bike. A 1-1/8" straight steerer was selected, as it was recommended to the team at PDR that a tapered steerer would be too oversized for the loads the vehicle would be seeing. Tapered steerers are commonly seen on mountain bikes with suspension, and since the Human Powered Vehicle will be raced on the road it will see very little impact load. A 44mm ID head tube was also selected, providing plenty of weld area for the frame. The steerer and head tube chosen are shown below in Figure 37.


Figure 37. Left, HT2010, 44mm ID 130mm long. Right, 1-1/8" steerer.

5.1.2.4 Front Dropouts

The front dropouts were designed to interface with the vehicle's custom front hub. The fork blades are slotted, and the dropouts were welded into the blades using the fork jig, which sets the dropout spacing for the hub. The solid model of the design of the front dropouts is shown below in Figure 38.

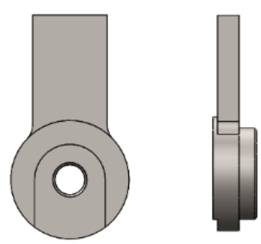


Figure 38. Front and side views of the front dropouts.

5.1.3 Frame Jigs

The complex geometry of the frame required jigging to ensure that the final geometry of the bike would conform to specifications. The use of the jigs is detailed in the manufacturing plan, in 6.3 Assembly, but their overall designs are presented here.

5.1.3.1 First Stage Frame Jig

The first stage frame jig set most of the critical locations for frame members. A side and an isometric view of the jig is shown below in Figure 39 and 40, respectively.

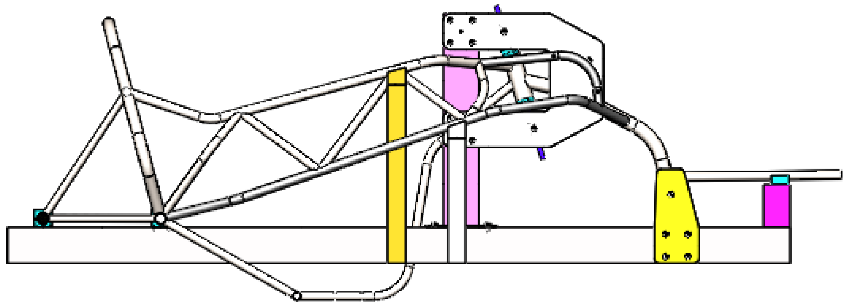


Figure 39. First stage frame jig, side view.

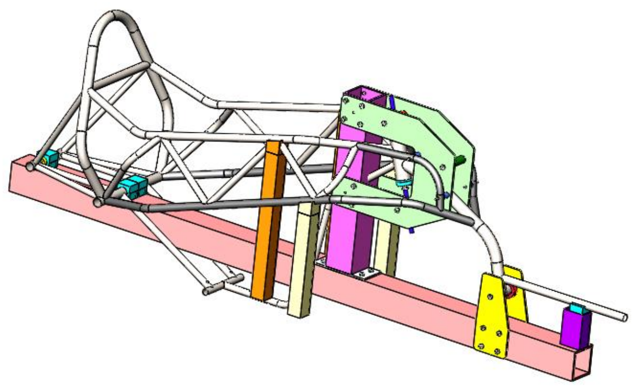


Figure 40. First stage frame jig, isometric view.

Less critical geometry that was not set by the frame jig was set using angle gauges, levels, and other similar tools. Below is a list of the geometry aspects that the first stage frame jig sets.

- Distance from rear hub to roll hoop
- Rear dropout spacing
- Height and distance from centerline of top side support tube at critical fairing clearance location
- Height and distance from centerline of middle side support tube at critical rider leg clearance location
- Head tube angle, height, and distance from roll hoop
- Bottom bracket height and distance from roll hoop
- Mid-drive truss hole locations for mid-drive plate mounting
- Fairing connection height

5.1.3.2 Second Stage Frame Jig

The second stage frame jig was used once the top part of the bike had been mostly fabricated. It elevated the frame high enough to test fit wheels and hubs into the frame and allowed the bottom members to be added. Figure 41 shows the second stage frame jig assembly model.

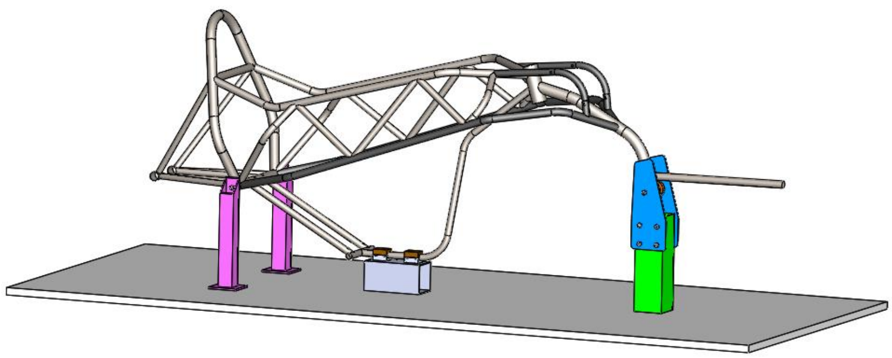


Figure 41. Second stage frame jig model.

The second stage frame jig allowed for the following members to be set:

- Bottom member level to ground and fit between head tube and harness mount member
- Seat mounting members angle checked
- Test fit of wheels with rear triangle and fork in front of frame

5.2 Functionality

The overall function of the frame is to provide structure and form to the vehicle and protect the rider in the event of a crash. The frame shall protect the rider by taking the impact loading and deforming as little as possible in critical areas near the rider. This is accomplished with the robust design that the team developed with an extensive truss system, both side and bottom support members, a roll hoop, and impact foam. The side members, which include trusses to increase rigidity, will protect the rider if the bike tips over or crashes. The bottom members, which the seat attaches to, will support the entire weight of the rider. In the event of a tip over or crash, the rider's head is protected by the roll hoop.

Another critical function of the frame is to integrate other components and subsystems of the bike. While the team designed for several of its own connections, it had to be ensured that mounting designed by other subsystem teams would be possible on the frame. Locational connection to the fairing is accomplished with the fairing cantilever support that extends from the front of the frame. In addition, various metal tabs were welded onto the frame to secure the fairing onto the frame. Integration with the rear and front wheels and hubs is accomplished with the rear and front dropouts. The dropout faces have slots that allow the hubs to slide into their correct position and are concentric with the hole to bolt through the dropouts. The designs for both dropouts were validated with Philwood Hubs, the company that produces the custom hubs the bike is using this year. The drivetrain system is mounted between specific truss members designed for that purpose. The bottom bracket shell is welded into the frame, and the crank system and bottom bracket are mounted in and off the shell. The braking system is mounted on horizontal rear triangle members also designed for that purpose. The handlebars and steering system are mounted onto the steerer, and the seat mounted in the seat mount bosses in the frame. The vision system is mounted non-permanently (with snaps for ease of removal) between the two top side supports of the frame so the rider has a clear view of the screens.

The main function of the fork subsystem is to connect the front wheel to the frame and provide steering capability for the bike. Steering is made possible by the headset, which fits inside of the head tube and rotates on bearings in the headset. The steer tube, or steerer, is welded to the fork blades and fits through the inner diameter of the headset bearings. The fork blades then fit around and connect to the wheel via the front dropouts.

Lastly, the function of the jigs was to allow the team to manufacture the frame with as much accuracy as possible, while providing the opportunity to mitigate any issues that may arise. It ensured that critical distances, heights, and angles were met. Two stages of the frame jig allowed the team to build upon smaller components first and then to add in larger components.

5.3 Validation

Due to the high speeds the frame is expected to see, extensive validation was performed on the design. A mix of computer simulations and models, as well as in-person physical testing, was employed to ensure that the bike was designed with as much information the team could acquire. Using the engineering specifications from Table 5 as a guide, the team made purposeful decisions for geometry and material selection of the final design.

5.3.1 Geometry: Handling Dynamics

The theoretical center of gravity of the vehicle had to be estimated before other handling qualities could be analyzed. A standard estimation for height of center of gravity was used. The center of gravity was approximated at the height of the rider's stomach. This approximation was approved for use by Professor John Fabijanic, who teaches a single-track vehicle dynamics class at Cal Poly. Figure 42 shows the approximated center of gravity used for handling calculations, denoted with a red star.

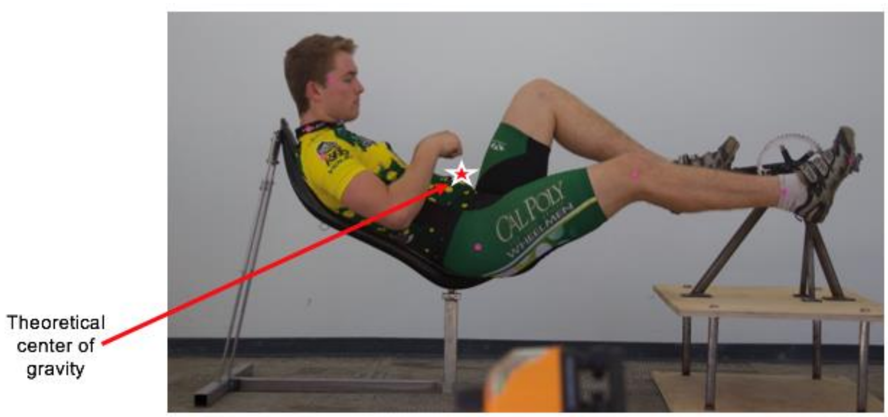


Figure 42. Approximation for center of gravity, shown with red star.

In order to find the most optimal handling characteristics possible within the physical constraints of the rider, the geometric inputs from the PDR design were iterated on until they fell within specifications. Figure 43 and Figure 44 show a comparison of the control spring and sensitivity, respectively, from PDR to the final geometry the bike was fabricated based upon.

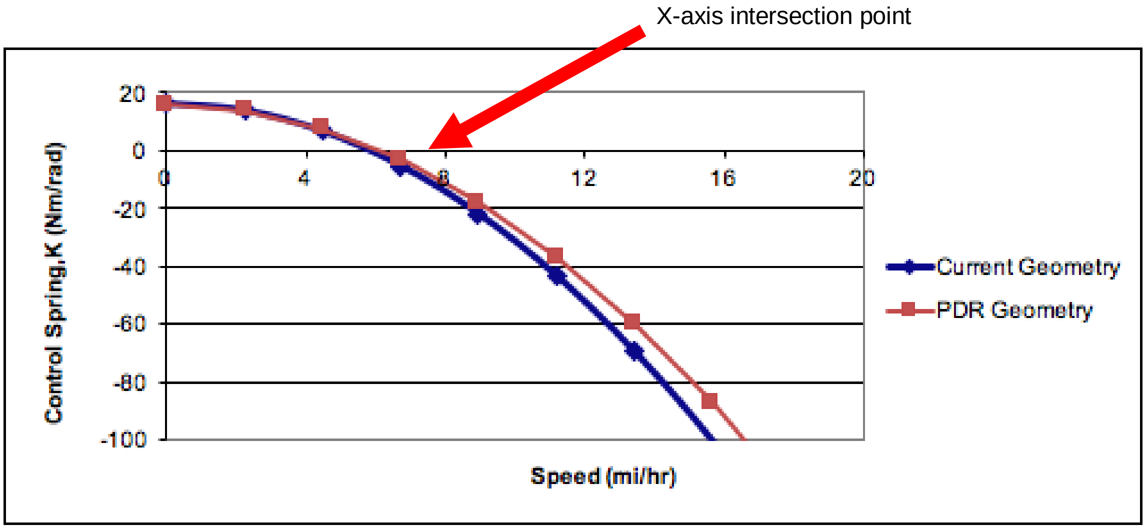


Figure 43. Control Spring v. Speed plot for the frame's handling characteristics, showing the PDR and CDR geometries.

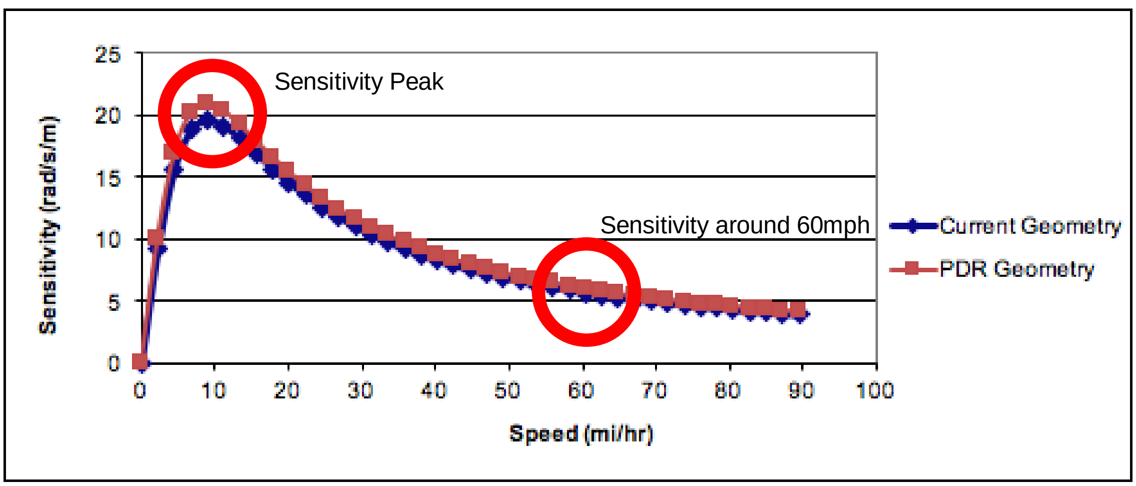


Figure 44. Sensitivity v. Speed plot for the frame's handling characteristics, showing the PDR and CDR geometries.

Since PDR, the main aspects of geometry that were able to be iterated on were the head tube angle, fork offset, and handlebar radius. Other characteristic parameters, such as wheelbase or wheel radius, were not able to be changed as they are dependent on the rider's height, other subsystem components, or various other fixed constraints.

One important change to the model was an approximation for tiller steering that was incorporated to make the model more accurate for recumbent bicycles. The derivation for this approximation is shown in Appendix Y. Due to the large difference in geometry between the steering set up for a recumbent bicycle and a standard diamond frame, the handlebar radius input to the Patterson Model can be approximated as the vehicle's stem length. This was incorporated into the final dynamic modeling of the frame geometry.

The control spring plot was analyzed primarily for its x-axis intersection point and its slope (shown in Figure 43). The control spring was able to be stiffened (resulting in a steeper sloped graph), which would allow the bike to need more of a steering input to give the same response. This is advantageous at higher speeds, as small, unintentional movements by the rider will have less of an impact on the bike's direction of travel. Where the control spring crosses the x-axis is the speed at which the bike will go from unstable to stable. This is still at a relatively low speed, meaning the rider will spend most of his riding time in the stable region.

The sensitivity plot was analyzed for its sensitivity values at both low speeds (starting – 15mph) and high speeds (60mph), as seen in Figure 44. The highest value of sensitivity the plot reaches is 19.1 rad/s/m (a measure of how quick the bike will want to continue a turn). A value of 20 rad/s/m for peak sensitivity was set forward by George Leone as the maximum value that bike designers would want to have to keep the bike within a ridable range. In addition, the peak sensitivity of the bike is reached around 12 mph, so the vehicle will be decreasing in sensitivity as the speed increases for most of the run. The sensitivity at 60 mph, the target speed for the bike, is 5.7 rad/s/m. This value is comparable to the geometry of other recumbents that have been successfully raced at high speeds (50-75 mph).

A summary of some of the parameters analyzed in the handling model are shown in Table 12. Since the values for the proposed geometry either fall within or close to the values for proven, successful recumbents, the team is confident that the bike will be ridable and comfortable at both low and high speeds. Table 13 shows the final values for all Patterson Control Model inputs.

Table 12. Final Geometry comparison to target values and proven vehicles

Specification	Target	Final Geometry	Primal 2 with 650c wheels	Primal 1	Zeta
Peak Sensitivity [rad/s/m]	Less than 20	19.1	16	18.2	17
Sensitivity at 60 mph [rad/s/m]	Less than 7	5.7	4.5	2.2	5.9
Control Spring x-intercept [mph]	Less than 10	6.5	6.7	5	7.5

Table 13. Final values for Patterson Control Model inputs for frame geometry

Variable	Value	Units
a	1.43	m
b	0.847	m
h	0.433	m
kx	0.31	m
beta	17	degrees
s	-0.06	m
Rt	0.3085	m
m	118	kg
Rh	0.19	m

5.3.2 Geometry: Frontal Area

With aerodynamic drag being the largest barrier to top speed, the frontal area of the vehicle and frame are critical. Early in the design process, the fairing subsystem requested that the frame meet a frontal area requirement of 475 in^2. However, this value was set before a rider was chosen. The team was not able to meet this requirement because the chosen rider is larger than anticipated. However, since the bike must be built to fit the rider, it is impossible for the frame to meet the initial specification. Not passing this specification does not have an impact on safety or functionality of the vehicle, and the fairing team has since revised their requirements. The frame has a frontal area of approximately 540 in^2 when evaluated using the SolidWorks model. This value was accepted by the fairing team.

5.3.3 Geometry: Physical Fit Tests

To solidify the final geometry of the rider in the bike, a more robust rider testing jig was created. The second rider testing jig was able to set the Josh's preferred seatback angle and bottom bracket location, while allowing him to pedal under load and feel stable and secure on the jig. Figure 45 shows Josh in his final preferred location on the rider testing jig. The measurements of components on the rider testing jig were then converted to locations on the frame's solid model and incorporated into the final design.

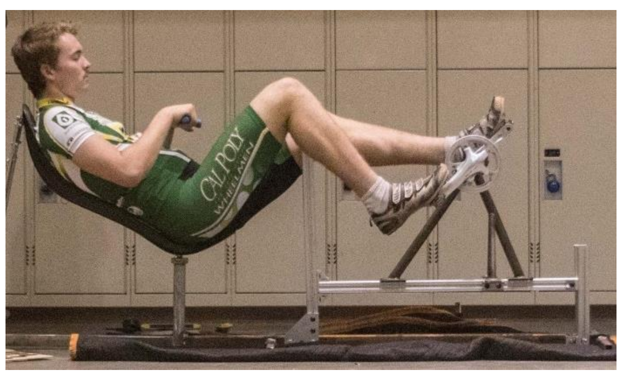


Figure 45. Josh in his final preferred position on second rider testing jig.

Once the rider's position was firmly set, the team needed to verify that the solid model of the frame was accurate to the size of the rider in real life. Physical gauges that could be set to varying distances were used to measure the rider at areas of concern, such as between his legs or around his shoulders. The rider's physical dimensions were then verified against the frame CAD to ensure the designed frame would fit around the rider once it was built. Figure 46 shows the physical gauges around the rider to verify clearances. A detailed list of measured quantities with the second rider testing jig is detailed in Appendix R.

Figure 46. Testing with physical gauges around potential pinch or hazard points of the rider with frame or drivetrain.

5.3.4 Material Selection: Hand Calculations

While the bike was primarily analyzed with Finite Element Analysis (FEA) because of its complex geometry, it was necessary to verify that the values returned in FEA were true and accurate. To do this the team approached the bottom bracket and bottom bracket support with two simplifications: as a curved, cantilever beam in bending and as a straight, cantilever beam in bending. A single, vertical load was placed coming down on the support and simulated the same scenario in Ansys. Downward deflection was calculated in both and the final values were very similar, confirming the validity of the FEA. These hand calculations and Ansys simulation and result can be found in Appendix U.

5.3.5 Material Selection: Finite Element Analysis

The following section discusses the FEA simulations and results that were used to determine the final design of the bike. Table 14 is a summary of the three loading cases, target values, resultant values, and whether the test was passed or failed. Table 15 shows the constraints used in the FEA modeling of the three loading cases.

Table 14. Summary of FEA Loading Cases and Results.

Loading Case	Target Value	Result Value	Pass/Fail
Vertical Deflection	0.236 in	0.0425 in	Pass
Side Deflection	0.236 in	0.169 in	Pass
Pedaling Input Deflection	0.197 in	0.098 in	Pass

Table 15. Constraints used for loading cases in FEA.

Loading Case	Headset Pin Restraint	Rear Triangle Pin Restraint	Rear Triangle Fully Fixed
Frame Vertical Deflection	X	X	
Frame Side Deflection	X	X	
Frame Pedaling Input Deflection	X	X	
600 lbf Testing Side Load			X
1200 lbf Testing Top Load			X

In the specifications table (Table 5), there are three deflection related requirements. The first required specification is the vertical deflection of the roll hoop. In order to meet the specification, the bar must deflect less than 6mm when loaded with 5350 N at 12° from vertical per the ASME crash load specification. After solving the model in FEA, the maximum deflection of the frame is around 0.0425 inches in the vertical direction. Since the engineering specification from Table 5 requires the value to be less than 0.236 inches of deflection, the team can safely say that the frame passes this test. The model setup and results can be seen in Appendix V.

The next loading scenario modeled was the side loading that could be experienced during a lateral crash. The load was applied to the side members and the side of the roll hoop of the bike frame to best approximate the distribution of the impact that would be seen in the event of a tip-over. Doubling ASME specifications, a load of 2700 N was distributed to the members applied in the lateral direction, as shown in Appendix W. The results from the Ansys simulation show that the top and middle member each deflect in the y-direction. Focusing on the critical areas, such as the rider's shoulder and torso area, the deformation of the frame due to the load applied was measured. The side that has the load applied directly to it deflects roughly 0.472 inches in the negative direction, while the opposite side of the frame deflects 0.303 inches in the negative direction, as shown in Appendix W. Using the difference of these two values yields the relative deformation in relation to the centerline of the bike, which was calculated to be approximately 0.169 inches. Table 5 specifies that the deflection due to this loading case must be less than 0.236 inches, which the design satisfies.

The last specification tested using FEA was the deflection of the bottom bracket due to pedal input from the rider. Per the engineering specifications provided by the Drivetrain Team, the deflection of the bottom bracket is allowed at most 0.197 inches. The model was set up with each of the torques, moments, and chain forces calculated and input the necessary boundary conditions as shown in Appendix X. After running the simulation in Ansys, the maximum deflection of the bottom bracket in the y-direction was calculated to be approximately 0.098 inches as shown in Appendix X.

5.3.6 Material Selection: Weight

The weight of the frame is another critical specification of the vehicle. The initial goal for the weight of the frame was 40 pounds or less; this weight includes the frame weldment and the fork. Analyzing these components in SolidWorks, the predicted weight of the vehicle was found to be 24.88 lbs.

5.4 Safety, Maintenance, Repair Considerations

Safety considerations of the frame followed a risk assessment formatting set by the Human Powered Vehicle club safety officer. This risk assessment technique involved creating a list of possible failures and incidents that would endanger the rider. Next, these failure modes were analyzed based on severity and predicted probability using a risk assessment matrix. The team then mitigated these risks through careful design and analysis of the vehicle frame. Finally, these failure modes were analyzed again using the same risk assessment technique to verify that the mitigation efforts have brought the risk to an acceptable level. This process was completed during the design of the vehicle and the results and analysis can be seen in Appendix S.

Maintenance of the vehicle frame is not a very involved process. With the frame being composed of the main weldment, the fork, steering system, and racing harness, there is little that will require maintaining over the short lifetime that the vehicle is designed for. The first level of preventative maintenance will involve painting the vehicle's frame in order to prevent rust from forming. This will be done using powder coating or conventional painting depending on the price of the procedures. Maintenance regarding the fork assembly will be accomplished by replacing head tube components and bearings when necessary. The bearings and seals will be installed with waterproof grease to prevent rust and dirt entering the headset. The racing harness will be replaced when the certification expires.

Repair of the vehicle was only lightly considered while designing the frame for the club. Because the project only involves making one frame for the vehicle, which is of extremely high tolerance and complex weldment, the likelihood of being able to execute a safe repair in the event of a crash is somewhat unlikely. If a repair was deemed necessary and safe, the use of chromoly steel in the manufacture of the vehicle allows the team to be able to repair the vehicle in the using standard welding and steel bending techniques. It is important to note that in the event of a crash that would require welding or bending of the vehicle frame, there would be an extreme amount of scrutiny involved in deciding how or if the team should repair the vehicle frame. In order to race at the speeds that the vehicle is expected to be capable of, there is a huge amount of geometric precision required of frame components. The team is aware of this fact, and the decision to repair the vehicle would be made on a case by case basis using input of club safety officers, George Leone, the rider, and the University.

During the design process the team compiled a list of hazards that the team or rider could experience during manufacturing, testing, or at the competition. By detailing these activities and scenarios ahead of time, the team was much more aware and cautious when carrying actions out. This design hazard checklist can be found in Appendix M. In addition, the team wanted to be prepared for things that could go wrong with the frame. By creating a failure modes and effects analysis (FMEA), the team explored all things that could fail, and the causes and effects of those failures. With the analysis complete, the failures were then ranked according to the possibility of them occurring, how detectable the failure would be, and how severe the failure would be. These rankings direct the team to which failures to pay the most attention to and approach with the most considerations. The FMEA table can be found in Appendix S.

5.5 Summary of Cost Analysis

The cost of the chassis was broken down into 6 main categories: the frame, the fork, the frame jigs, the fork jig, materials for testing, and tooling. Overall, the cost of the project was about $2,000. The team utilized discounts, donations, and sponsorships wherever possible to keep cost low. Due to the extremely high number of components in the system, the frame came out to be about $500 over budget. The team however is confident that they will be able to fundraise the difference. A summary by category of the cost is shown below in Table 16, and a complete list is shown in Appendix O.

Table 16. Summary cost analysis by subsystem of Frame

Category	Cost
Frame	$900.17
Fork	$176.39
Frame Jigging	$256.61
Fork Jigging	$0.00
Testing	$415.50
Tooling	$223.04
Total	$1,971.71

6 Manufacturing

The manufacturing of the Human Powered Vehicle Chassis included predominately machine tool processes performed on metal, though some composites parts were made. Due to the extent of the parts that were made, the manufacturing plan is broken down by process, with the parts made with that process are listed within. Because the vehicle is custom fit to one rider, nearly all components are custom. The team completed most of the machining, welding, and bending in house, with a few parts made out-of-house by the team's sponsor, Advance Tube.

6.1 Procurement

Stock procurement for the frame and jigging came from a mix of online and in person purchases. Frame specific components, such as the head tube and fork blades, were purchased from online frame building suppliers. Chromoly steel tubing (4130) for the frame itself was purchased from Aircraft Spruce. Frame jigging materials, such as standard round stock or plate, was purchased in person from Industrial Metal Supply. A complete list of where each component was sourced from and the cost associated is shown in Appendix O.

6.2 Manufacturing

In order to organize for manufacturing season, the parts to be made were organized into four general categories: Manual Machining, CNC Machining, Bending/ Grinding/ Welding, and Composites. The parts totals are as follows:

Manual Machining - 36
CNC Machining - 10
Bend/ Grind/ Weld - 75
Composites - 20.

In total, there were 141 parts to be made. This manufacturing plan further breaks down those sections and gives detailed information on non-standard processes the team carried out to manufacture the chassis. A section on the custom parts fabricated out of house is also included. A complete list of each component made is shown in Appendix P.

6.2.1 Manual Mill

A list of parts utilizing the manual mill is shown below.

- 04-A03-001-JIG_BOTTOM
- 04-A03-001-JIG_PILLAR
- 04-A03-014-JIGPILLARPLATE
- 04-A03-016-PILLAR_BASE
- 04-A03-002-TUBE_BLOCK_0.875_BOTTOM
- 04-A03-002-TUBE_BLOCK_1.25_BOTTOM
- 04-A04-003-CENTER_SUPPORT

Standard milling practice was observed and end mills, drill bits, and taps were used where required. Dial indicators were employed to ensure squareness for all parts, as well as edge finders to ensure precise locational tolerances. Layout fluid, digital calipers, spring calipers, rulers, and squares were used for marking of large parts. Round parts were held in a rotary vice and edge found to ensure perpendicularity of holes where required. All parts were test fit as needed at each critical stage to ensure the jig functioned as it should.

For the jig base, because the part was so long, two vices were squared at either end of the table, as seen is Figure 47. The base was moved as needed to access all the holes without crashing the mill and re-indicated after each set up change.

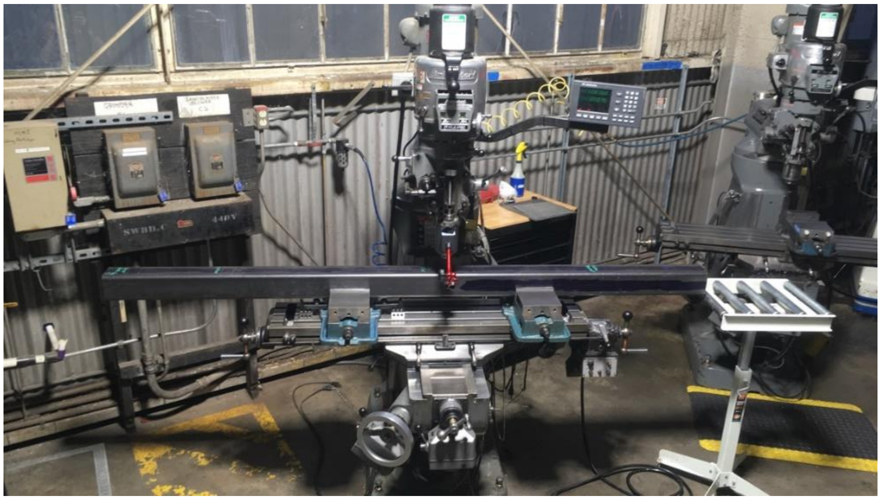


Figure 47. Set up of the Jig Base on the manual Bridgeport.

6.2.2 Manual Lathe

A list of parts utilizing the manual lathe is shown below.

- 04-A01-005-SEATBOSS; 04-A01-007-SEATBOSSLONG
- 04-A01-004-MIDDRIVEBOSS
- 04-A03-011-DUMMYFRONTAXLE
- 04-A03-004-BB_PLUG
- 04-A03-007-CONICAL_PLUG
- 04-A03-010-DUMMYREARHUB
- 04-A03-006-HEAD_TUBE_MOUNT
- 04-A03-006-HEAD_TUBE_MOUNT_SPACER
- 04-A03-009-MID_DRIVE_SPACER
- 04-A04-005-ROLL_BAR_PLUG2

Standard turning practice was observed and right, left, or neutral tools were used where needed, as well as drill bits and taps. Tap guides were used for all tapped holes to ensure straight threads. Micrometers were employed to ensure precise tolerances and all parts were test fit as needed at each critical stage to ensure the jig functioned as it should.

6.2.3 CNC Mill

A list of parts utilizing the CNC mill is shown below.

- 04-A01-002-REARDROPOUTS
- 04-A02-003-FRONTDROPOUTS

Due to the difficult geometry and high tolerances needed, certain parts were elected to be made on a computer numerically controlled (CNC) mill. Both the front and rear dropouts are custom to the hubs of the vehicle and required geometry that was complex enough it would be simpler to make utilizing a CNC. A CNC's repeatability and ability to perform complex tool paths very difficult to execute on the manual mill made it a viable choice for the chassis' dropouts.

Soft jaws were made to hold the non-square parts, such as the rear dropouts shown in Figure 48 and the front dropouts in Figure 49. All computer aided manufacturing (CAM) was done in Fusion 360 and posted using general HAAS G-Code to transfer to the machine. A tool setting probe and spindle probe were used to set offsets and location the parts. Once the code was proved, many more components could be run with vastly less time investment. An example set up sheet showing the tools used and feeds and speeds is shown in Appendix Q.

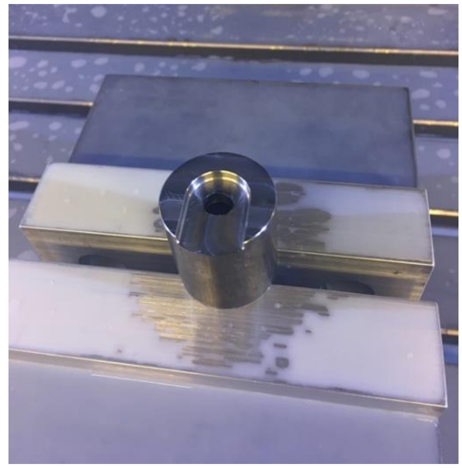


Figure 48. First operation of rear dropouts in softjaws on the VF3, a CNC mill.

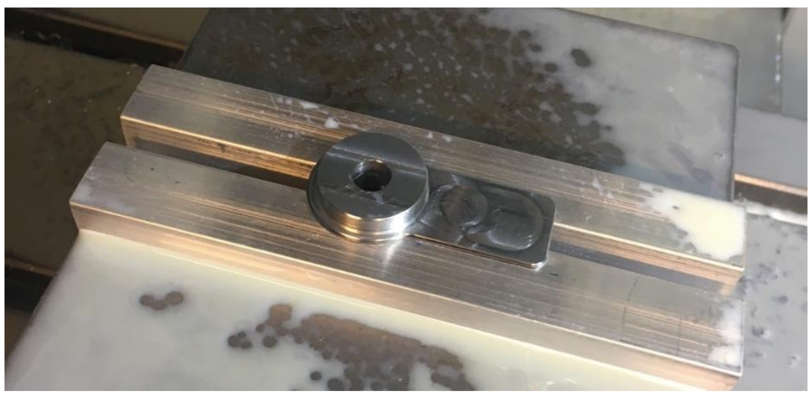


Figure 49. Second operation of front dropouts in softjaws on the Minimill.

6.2.4 Water Jet

A list of parts utilizing the water jet is shown below.

- 04-A03-014-JIGPILLARPLATE
- 04-A03-016-PILLAR_BASE
- 04-A03-003-FRONT_PLATE
- 04-A01-006-HARNESSTABS
- 04-A03-008-TOP_PLATE

The water jet was utilized for cutting profiles of flat parts. Cut sheets were created using the stock dimensions of plate to be used. All hole locations were set by the water jet, but the holes themselves were undersized and drilled out to account for the size tolerance of the machine. All flat plate profiles were water jet cut, and the pieces were post machined as necessary. Enough stock was purchased such that the water jet was comfortably able to cut the profiles and still clamp the stock down, as seen in Figure 50.

Figure 50. Top and Front plates being cut on the water jet.

6.2.5 Cutting and Grinding

Nearly all parts that were manufactured in house utilized saws, grinders, sanders, or wire wheels to help rough cut or finish the parts. A variety of saws, such as abrasive saws, band saws, and toothed saws were used to cut stock into manageable sizes. Wire wheels and grinders were used to deburr and clean up parts. Many of the mitered parts were ground close to fit on the bench grinders. Angle grinders were used to rough cut many tubes, as seen in Figure 51.

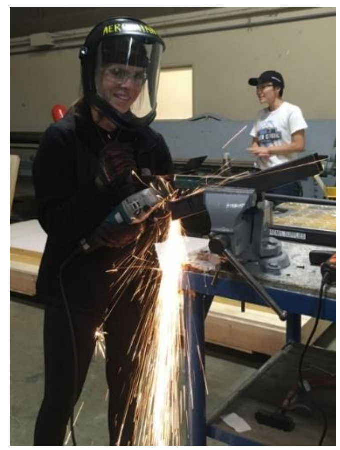


Figure 51. Keyanna Henderson using an angle grinder to cut a jig piece.

6.2.6 Bending

A list of parts that bent in house are shown below.

- 04-A01-001-FRAME-BottomMemberBent
- 04-A01-001-FRAME-BentTrussRight
- 04-A01-001-FRAME-ShoulderTrussSupportRight
- 04-A01-001-FRAME-BentTrussLeft
- 04-A01-001-FRAME-ShoulderTrussSupportLeft
- 04-A01-001-FRAME-MidDriveTrussRight
- 04-A01-001-FRAME-MidDriveTrussLeft

All single plane bends on tubing of 1” OD or smaller were bent in house. A die of radius 4” was used, on a manual hydraulic tubing bender, as seen in Figure 52. Each tube was sized such that the minimum straight distance between bends (if applicable) was compatible with the benders on campus and no special fixtures needed to be made. Tubes were cut long and mitered after bending. The distances between the start and stop of the bend were used to measure straight sections. For a bent section, the radius of the die and the degree of bend (in the plane of bend) were used to get the correct dimension. Care was taken to make sure parts were correct mirrors of each other on the right and left sides of the frame.

For tubes, such as the bottom bent member, that had more than one bend, an angle gauge was used to ensure they remained in their correct planes. One to one (1:1) scale templates were also cut to help gauge when the bend was long enough, as the incrementations available on the tubing bender were not very accurate.

Figure 52. Set up of the bottom bent member on the bender.

6.2.7 Mitering

All frame tubing had to be mitered to fit. Because much of the tubing was thin walled (.035” or .049” wall thickness), the miters had to fit as snugly as possible to avoid burning a hole in the tubing when welding. In order to achieve this high level of accuracy, a rigorous mitering process was followed.

The first step in the process used the mitered solid model of whichever tube is being cut. The solid model was indexed to the center line and then unwrapped using the sheet metal function of SolidWorks. If the tube was straight and sufficiently short such that it fit on one piece of paper, then no indexing was needed. If there were bends or the tube was longer than a piece of paper, the miters on either end of the tube had to have a way of relating to each other. A triangular notch was placed on the center line (see Figure 53) pointing in the same direction on either end of the tube miters, shown in Figure 54. A known distance was set between the notches. Then the tube was unwrapped in SolidWorks and viewed as a flat pattern at 1:1 scale, as seen in Figure 55.

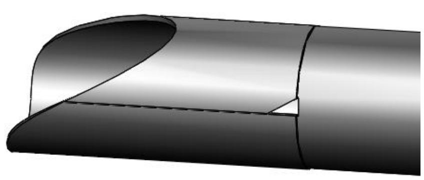


Figure 53. Solid model of a miter with indexing cut.

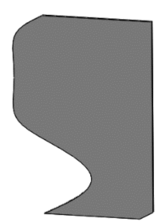


Figure 55. Unwrapped model of indexed cut, shown in Figure 50.

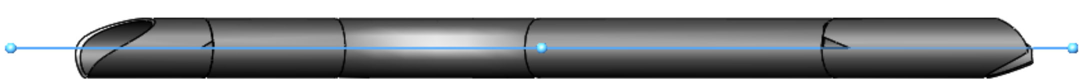


Figure 54. Solid model of bent tube, showing indexes on centerline in plane of bend.

From this step, the pattern was printed out at 1:1 scale. It was then cut out and the paper was wrapped around the ends of the tube to be mitered. The right-side tubes were printed and labeled, and then when those tubes were done the paper could be flipped inside out and worked to make the left side tubes. The notch on the center line was placed (visually) on the center of the tube to be cut and the matching miter was placed in the same notch orientation. The notches were also placed at the known set distance apart. Then the paper was taped to the tube and the profiles of the miter were traced onto the tube, as shown in Figure 56.

Once the profiles were marked, the tube is labeled. The rough profiles were cut using a bench grinder or 4" angle grinder. Then, they were cleaned up and brought closer with a Dremel and carbide burr tool. Finally, the tubes were filed to a final fit. Due to the difficulty of some of the miters, not every miter was a very close fit. However, the team's welder, Eliot Briefer, was able to compensate for this and did not have any trouble welding.

Figure 56. Fork blade wrapped with paper template showing the miter.

6.2.8 Welding

The entire 4130 chromoly chassis was joined using TIG welding. Parts of the jig were tacked together or to the welding table using either MIG or TIG welding. Frame members were tacked together first and test fit with the rider and then full welded. A more detailed order of operations for welding is detailed in 6.3 Assembly. Some in-progress pictures of welding the frame are shown in Figure 57, 58, and 59.

Figure 57. Middle and top side supports full welded, in progress welding the mid-drive truss members.

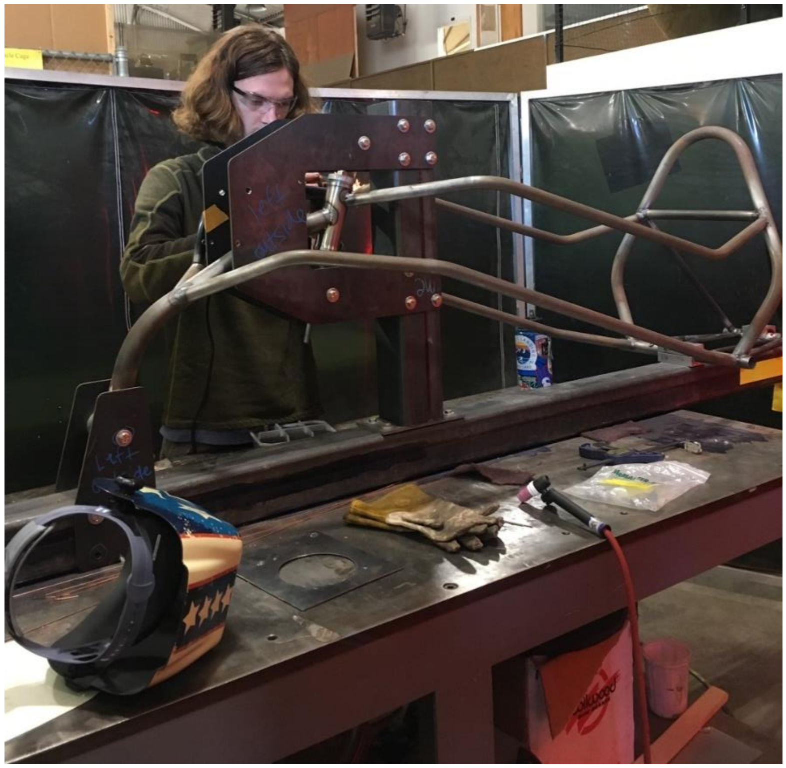


Figure 58. Eliot, the team welder, prepping joints for welding.

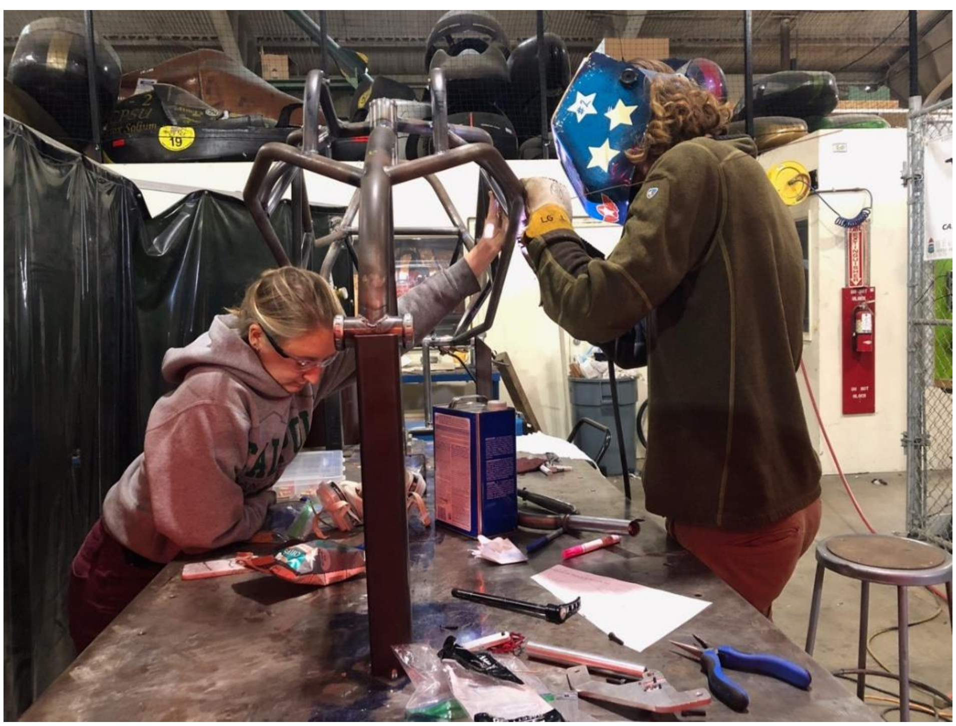


Figure 59. Kyra Schmidt holds a truss member in place while Eliot Briefer tacks it into the frame.

6.2.9 Composites


Figure 60. Keyanna Henderson wetting out fiberglass cloth.

Fiberglass layups were utilized to stiffen impact foam and aid in the frame's safety. The team did standard wet lay-ups that were air cured and not under vacuum. Safe manufacturing practices, such as using gloves and respirators were followed when doing fiberglass layups. Cloth and other materials were fully measured out and cut before mixing the resin and hardener to give the team as much work time as possible. A standard ratio of 7/9 resin to 2/9 hardener by weight was followed. Standard cutting practice was used to achieve one ply each of 45° and 90° weave. The fiberglass was made in flat sheets, of two plies thick. Peel ply was used on one side of the composite in case further layers needed to be added, and to aid in bonding the foam to the fiberglass. Figure 60 shows part of the layup process.

6.2.10 Out of House Parts

A total of 6 frame tube members were sent out to be bent at Advance Tube, on mandrel tubing benders. The tubes being bent out of house are listed immediately below.

- 04-A01-001-FRAME-BottomBracketSupport
- 04-A01-001-FRAME-RollhoopUpper
- 04-A01-001-FRAME-TopSideSupportRight
- 04-A01-001-FRAME-TopSideSupportLeft
- 04-A01-001-FRAME-MidSideSupportRight
- 04-A01-001-FRAME-MidSideSupportLeft

Because the tubing had such a thin wall and because of die sizing available on campus, certain tubes had to be sent out to a professional bender. The machine shops did not have a die of large enough outer diameter to fit with the bending the team needed to achieve.

Team members visited the Advance Tube manufacturing floor in person and met Alex Alvarez, the owner. Advance Tube agreed to sponsor the team and bent six tubes for the team, free of charge. The team paid for the stock, but all set-up and manufacturing were donated. The tubes bent by Advance Tube are shown in Figure 61 and Figure 62.


Figure 61. Bottom bracket support, roll hoops, bent by Advance Tube.


Figure 62. The middle side supports and top side supports, bent by Advance Tube.

6.3 Assembly

The frame was built in two stages using custom made frame jigs and the fork was welded using a production fork jig from Anvil.

6.3.1 First Stage Frame Jig

The first stage frame jig, shown in Figure 63 and 64, was used to locate most of the tubes. All members besides the bottom members and truss members were located with the first stage jig.

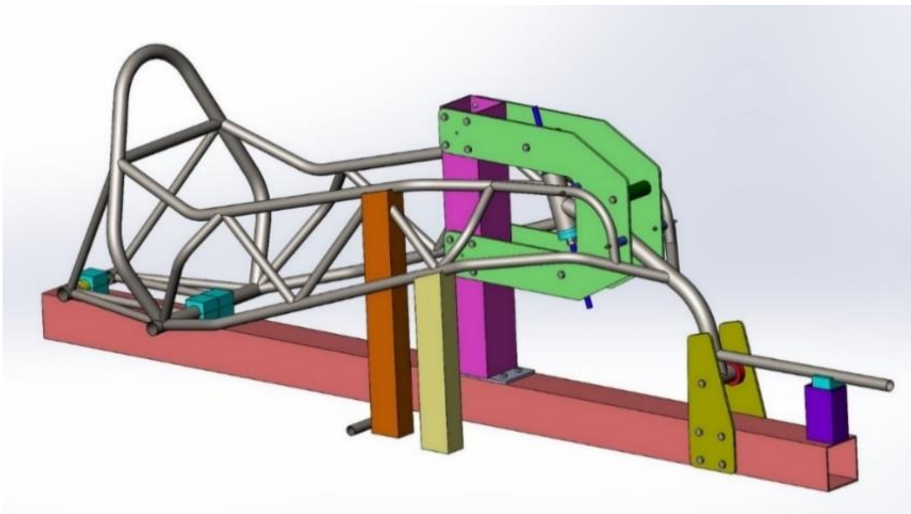


Figure 63. Overall first stage frame jig assembly, solid model.

Figure 64. Overall first stage frame jig assembly, as built.

The jig was located on the welding table using layout fluid, scribes, rulers, squares, and spring calipers. Once all components were located correctly in relation to each other, they were tacked to the welding table using a MIG welder.

The roll hoop was welded first, flat on the table. From there, the roll hoop was set in the jig and the rear triangle welded using the jigging shown in Figure 65 and Figure 66. A custom dummy rear hub sets the correct dropout spacing.

After the rear triangle was done, the rest of the frame was built off of the other side of the roll hoop. The head tube angle and location were set by the frame jig (Figure 67 and Figure 68), as well as the bottom bracket location. The bottom bracket support was located between the head tube and the bottom bracket and tacked into place. Then, the side supports were fit between the roll hoop and the head tube. The first stage frame jig without side supports is shown in Figure 69.

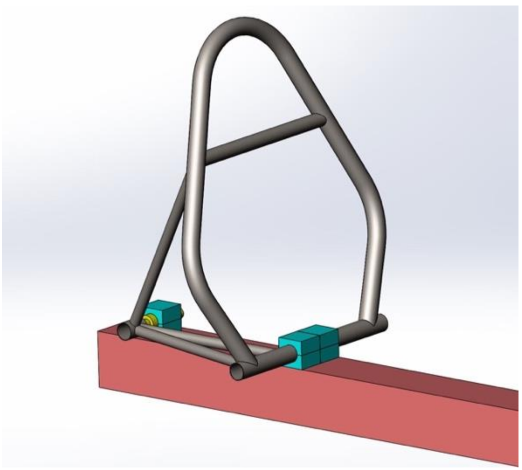


Figure 65. Roll hoop and rear triangle set up, using tube blocks to locate for wheel spacing, solid model.

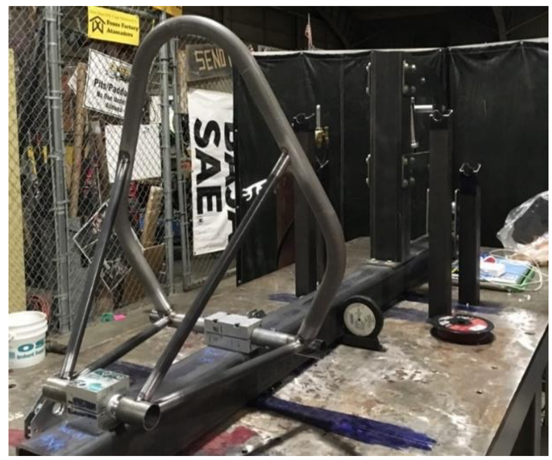


Figure 66. Roll hoop and rear triangle set up, using tube blocks to locate for wheel spacing, as built.

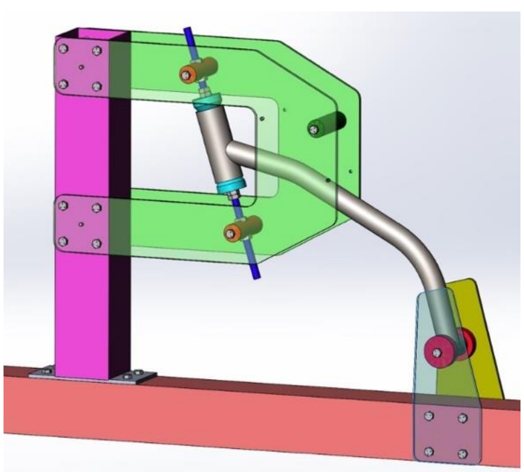


Figure 67. Front part of first stage frame jig, locating headtube and bottom bracket, solid model.

Figure 68. Front part of first stage frame jig, locating headtube and bottom bracket, as built.

Figure 69. First stage frame jig with roll hoop, rear triangle, head tube, bottom bracket, and bottom bracket support located.

The next step was to miter and tack in the side supports. These proved the most difficult to miter, as even with templates printed, any error compounded from the out of plane bends caused the templates to be off. They were mitered mostly by eye with a file and a Dremel tool.

Once the side supports were tacked, the frame was removed from the first stage frame jig and test fit with Josh. Clearances with the side support members while pedaling is a big concern for the team. The test fit schedule is detailed below, in 6.5.3 Test Fit Schedule.

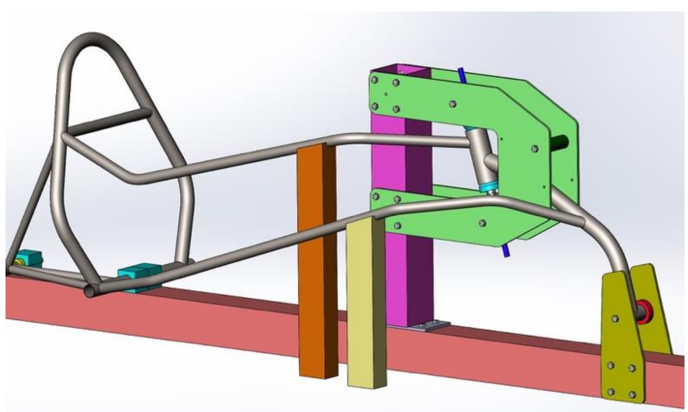


Figure 70. First stage frame jig with all members except mid-drive truss members, solid model.

Figure 71. First stage frame jig with all members except mid-drive truss members, as built.

After test fitting and ensuring rider clearances, the mid drive truss members were fit with the side supports and located using the frame jig. This was a critical step, as the accuracy of the mid drive trusses determines how the drivetrain mounts to the frame. The locational holes on the frame jig, shown in Figure 70 and 71, as well as the use of levels and transfer punches, allowed the team to get an accurate position for the mid drive truss members.

First, the two ends were mitered roughly to fit with both side supports. Then, they were placed against the jig plates with the correct spacers (shown in blue in Figure 72 and the physical aluminum rounds in Figure 73). It was ensured that the miters allowed the tube to fit where the holes would be located along its center line. Next, the tube was covered in layout fluid and a transfer punch and ball peen hammer were used through the other side of the plates to mark where the hole center locations were. The tube with marked holes and a punch are shown in Figure 74. Then, the holes for the bosses were drilled at the marked location using a drill press, as well as a vice and v-block for holding. They were then placed back on the jig and the final filing was done to get the best fit possible.

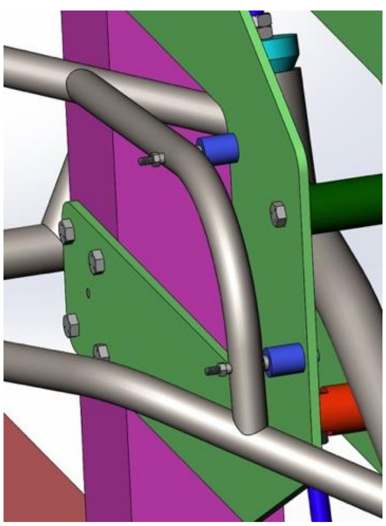


Figure 72. Jigging for mid drive truss, solid model.

Figure 73. Jigging for mid drive truss, as built.

The truss members had to be mitered correctly to both side support members and had to have holes drilled in the correct locations and perpendicular to the surface to allow for accurate drive train mounting. Fitting up to four different aspects of one tube was a long process, but the results were satisfactory. The drive train team was able to mount their components with no issues. The hole locations ended up less than a millimeter off and the degree difference between the right and left side was 1°.

Figure 74. A marked and mitered mid drive truss, ready to drill.

Once the mid drive truss members were welded, the drivetrain team could begin incorporating their subsystem onto the chassis. The frame was then moved to the next stage of jigging at this point to allow for the bottom members to be added.

Since warpage for the frame was such a big concern, as many joints as could be accessed on the frame were welded with the frame still in the first stage jig. The head tube was a specific area of concern and was held in its place in the jig during at least 75% of the full welding done on it.

6.3.2 Second Stage Frame Jig

The second stage frame jig was used to locate the bottom members of the frame, and elevated the frame off the welding table such that wheels and hubs could be fit in. The bottom members were located along the centerline of the bike with the frame jig and ensured level. The bottom bent member was located between the harness mount bar and the head tube. This setup is shown in Figure 75 and 76. Lastly, the truss members will be fit in the around the rider in the bike and triangulated according to SAE standards. Figure 77 shows team members and the team welder inserting the last truss member into the frame.

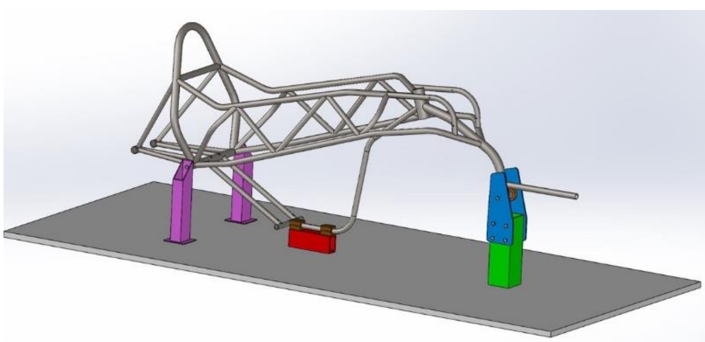


Figure 75. Second stage frame jig layout on welding table, solid model.

Figure 76. Second stage frame jig layout on welding table, as built.

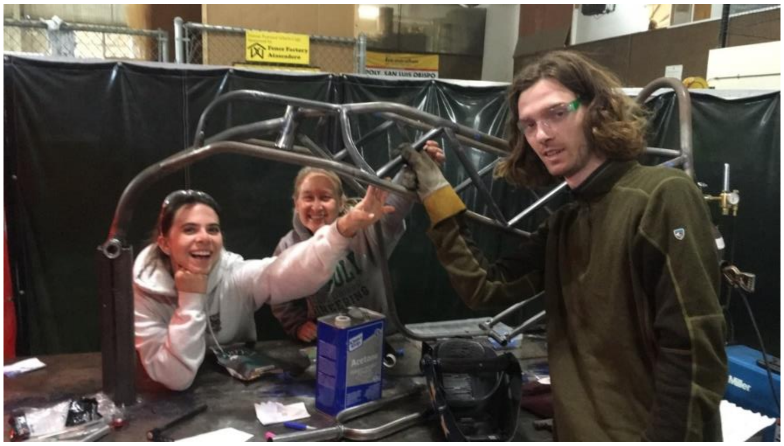


Figure 77. Eliot Briefer, Keyanna Henderson, and Kyra Schmidt, with the last truss member to go into the frame.

6.3.3 Fork Jig

The fork was welded on a standard fork jig, shown in Figure 78, that allows the user to set fork blade offset and dropout spacing. A custom front axle was made compatible with the jig to set the non-standard fork width. Miters were ground and filed due to the complex geometry of the fork blades. Figure 79 shows the mitered blades with the fork in the jig. The drivetrain team provided a jig to verify that the fork was welded with the correct spacing for the chain-line.

Figure 78. Anvil fork jig to be used in fork manufacture.

Figure 79. Fork assembled on fork jig, before welding, with steerer, front dropout, and custom dummy front axle.

As stated in 5.1.2. Fork, the fork also contains mounting points for the chain tensioner. The locations of these mounting points were given to the team by the drivetrain team, and then holes were drilled, and bosses welded into the fork blades. The setup for drilling the boss holes is shown below, in Figure 80.

Figure 80. Fork boss set up on the drill press.

6.3.4 Steering Assembly

Once the fork had been welded and the head tube full welded, the fork, head tube, and headset could be assembled. 5.1.2.2 Headset details what the headset is comprised of.

A standard facer-reamer sized for the 44mm head tube on the bike was used to post machine the head tube after welding. Then the headset bearing cups were pressed into the head tube using a headset press (see Figure 81) and the fork steer tube inserted through the head tube and bearings. The stem and handlebars were placed over the steerer to mark where to cut the steerer. The steerer was cut to size with a hacksaw and a jig to keep the blade cutting straight. The race ring was press fit on the fork steerer. Finally, the whole assembly was pressed into place. The headset bearings were always removed before any new welding was done on the frame, to avoid the possibility of arcing across bearings. When the fork was assembled for the last time, some grease was put on the headset seals to help keep dirt and water from getting into the bearing assembly.

Figure 81. After post machining, pressing in bearing cups with headset press.

6.3.5 Test Fit Schedule

Due to the tight clearances expected from designing the chassis for one specific rider, regular test fits were employed during the manufacturing process. The rider was fit into the bike at all critical stages. Before full welding, all members were tacked into place until the fit was verified.

The first major test fit occurred after the side supports were put into the bike. At this point the bottom members were not in, so the frame's upper half was placed over Josh in the testing jig. The rider testing jig set him at the correct seatback angle, and measurements in CAD allowed the team to place the frame over him at the correct position relative to his body. This test fit is shown in Figure 82.

Figure 82. Test fit with Josh, top half of the bike and Josh in rider testing jig.

The second major test fit occurred once the bike was moved to the second stage jig and the bottom members were welded in. This allowed the team to test Josh getting in and out of the bike, as well as his fit with the seat in the actual bike. A representative set of cranks and a bottom bracket were installed in the bike and his pedal circle was able to be ensured fit with the side support members. This test fit is shown in Figure 83 and Figure 84.

Figure 83. Second major test fit, with representative length cranks, fork, bottom members and seat.

Figure 84. Second major test fit, side view, checking Josh's pedal circle clearance with the frame.

The third critical test fit occurred when all the final bent truss members were put into the frame. These members were the last with a potential for interfering with the rider. During this test fit, the headset was also assembled, and the fork put into the bike to get a final idea of the rider's clearances with the frame and other systems. The front wheel was placed into the fork, and the rear wheel placed into the rear triangle. The cranks to be used on the final bike were assembled and Josh was fit sitting on the final seat. Thus, with the frame fabricated and the drivetrain in its final position in the bike, the seat could incorporate any final rider comfort changes. This allowed Josh to give feedback and find his best possible position with the frame and drivetrain. Pictures from this test fit are shown in Figure 85 and 86.

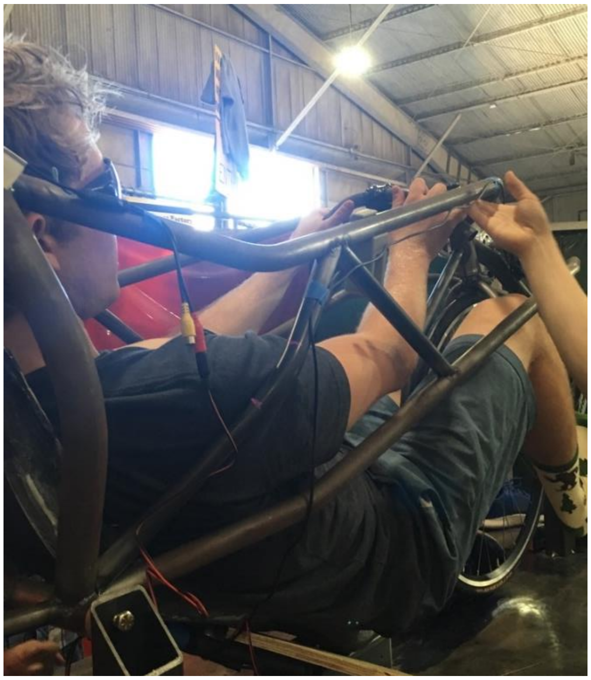


Figure 86. Third test fit with Josh, checking clearance on the shoulder truss members, with steering system and handlebars assembled.

Figure 85. Test fit checking clearances with leg truss members, fork with wheel assembled, and final cranks on the vehicle. Vision system and mid-drive also assembled.

The final test fit, shown in Figure 87, conducted included the fully welded frame, fully assembled drivetrain, fully assembled steering system, and final seat position. The frame was verified to have clearance within Josh's full range of motion and that Josh was in a comfortable position for riding the bike. Once the Josh was positioned correctly, the seat was finalized according to Josh's input.

Figure 87. Josh in final position in bike, with all frame members full welded.

6.3.6 Assembly Issues

The largest issue the team ran into during manufacturing was the orientation of the bottom bracket shell. The bottom bracket shell is threaded to allow for the bottom bracket to be screwed in. It is left hand threaded on one side and right had threaded on the other. Thus, it had to be welded into the frame in the correct orientation.

However, the team did not accurately verify the orientation of the bottom bracket shell before welding this year. The drivetrain team was consulted after welding, and the bottom bracket shell was said to be fine. However, it was later figured out when the drivetrain components came in that the shell was in the wrong orientation.

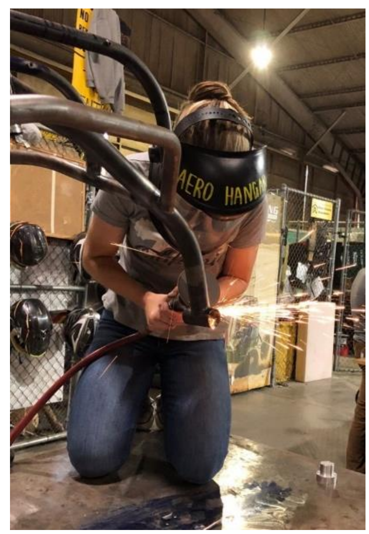


Figure 88. Kyra Schmidt cutting out the incorrect bottom bracket shell.

Thus, the shell had to be cut out of the frame, as shown in Figure 88, and welded in again. The structural integrity of this decision was discussed with Dr. Joe Mello and Jim Gerhardt, who both agreed that this action would have a negligible impact on strength of the frame. The most difficult part of the process was jigging the bottom bracket such that it would be held straight. Because the frame was so far along by the time the bottom bracket shell error was recognized, it could no longer be put on the First Stage Jig to locate the bottom bracket. The team used the Second Stage Jig to locate the bottom bracket and brought it into square using a machinist's square and measurements.

6.3.7 Future Recommendations

The biggest recommendation the team has for future years is double and triple checking the orientation of the bottom bracket shell. As detailed earlier, the team did not verify the orientation of the threaded bottom bracket shell before it was welded onto the frame and thus had to cut it out and re-weld it. To avoid this happening in future, it is recommended to have the drivetrain components on hand when the bottom bracket is welded. Thus, drivetrain can be assembled, and the bottom bracket clearly marked and placed into the jig in a known orientation. Then it can be welded.

Some other recommendations the team has for future years is the importance of jigging. Originally, the team had planned to only tack the frame on the jig and do most of the full welding off the jig, as is traditional for diamond frames. However, after discussions with Jim Gerhardt, the ME Department Safety Technician, the team decided to full weld as much as possible in the jig. This was due to the large number of joints and the unconventional geometry of the bike.

In addition, the team realized that doing non-standard miters and bringing them in by hand takes longer than usually anticipated. The importance of patience and not cutting too far when mitering by hand cannot be stressed enough. Plenty of extra stock should also be purchased, because no matter how careful the team thinks they are, mistakes will always happen during manufacturing season.

Finally, the team recommends that future teams learn as much bike jargon as possible. There are many unfamiliar terms used to describe bicycle components and if any team members do not have a solid background in bicycle terminology, it is highly recommended they do research until they are comfortable. Utilizing resources such as peers or professors who are proficient in bicycle terminology and components is encouraged.

7 Design Verification Plan

The next stage in the process further serves to support the final design by verifying manufacturing and testing. To do this the team looked to the specifications, first presented in chapter 3, to confirm that the final design, would meet all specifications. Specifications which would be verified at a later point were set aside using a specific testing procedure and discussed with further detail in a design verification plan, found in Appendix T.

7.1 Specifications

The specifications are shown below in Table 17, with results presented for those that have been measured thus far. All specifications that have been measured, aside from cost, are within tolerance of their target values. Testing for speed of the frame will be conducted over July and August 2019, in preparation for racing in September 2019. The final speed test will take place at competition, in Battle Mountain, Nevada. All tests conducted for the frame are detailed in 7.2 Testing.

Table 17. Specifications with results to date.

Specifications					
No.	**Description**	**Target**	**Tolerance**	**Result**	**Pass/ Fail**
1	Speed	61.3 mph	+ 10 mph	TBD	n/a
2	Frontal Area	475 in^2	± 75 in^2	540 in^2	Pass
3	Height of Center of Gravity Above Ground	0.433 m	+ 0.12, -0.03 m	0.493 m	Pass
4	Cost	$1,500	± $300	$1,971.71	Fail
5	Weight	40 lbs	< 40 lbs	22 lbs	Pass
6	Instability Peak	10 mph	± 5 mph	12 mph	Pass
7	High Speed Sensitivity (at 60 mph)	< 8 rad/s/m	+3, -2 rad/s/m	5.7 rad/s/m	Pass
8	Low Speed Sensitivity	< 21 rad/s/m	± 2 rad/s/m	19.1 rad/s/m	Pass
9	Control Spring Intersection with X Axis	< 10 mph	< 10 mph	6.5 mph	Pass
10	Deflection Under 5350 N Vertical Load to Roll Hoop	0.25 in	< 0.25 in	0.141 in	Pass
11	Deflection Under 2700 N Side Load to Roll Hoop	0.25 in	< 0.25 in	0.066 in	Pass
12	Deflection of Bottom Bracket	0.2 in	< 0.20 in	0.098 in	Pass
13	Radius of Gyration	0.31 m	> 0.29 m	0.35 m	Pass

7.2 Testing

The team conducted both qualitative and quantitative tests on the frame. These tests were conducted both on the frame itself and on representative models of certain frame components.

7.2.1 Load Testing

Load testing for the HPV frame involved testing a sample of the frame's roll hoop, the main structure responsible for protecting the rider's body. For this test, a roll hoop identical to the one used in the frame was fabricated to analyze how the roll hoop in the frame would perform in crash scenario. The load testing was done with three tests: a 1200 lbf vertical loading test, a 600 lbf side loading test, and a destructive vertical loading test. These tests were meant to collect data of deflection at designed crash loading cases (inches), the yield point of the roll hoop under vertical loading (lbf), energy absorbed by the roll hoop (foot-lbf), stress versus strain curve characteristics (qualitative), and failure characteristics of the part (qualitative). To conduct these tests, the team used the ME Department's servo-hydraulic load frame, an Instron 1331, along with test fixturing that was built to fit the load frame's connection points. The testing setup can be seen in Figures 88 and 89 below.

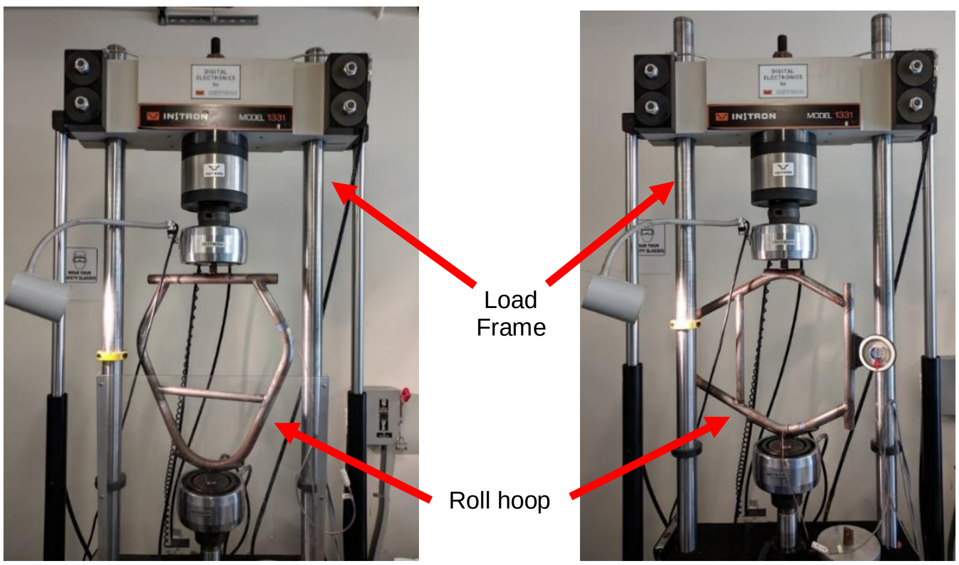


Figure 89. Vertical loading setup.

Figure 90. Horizontal Loading Setup.

Table 18. Roll hoop Deflection Testing Results

Roll Hoop Orientation	Force Applied	Allowable Deflection	Deflection Observed	Pass/Fail
Vertical	1200 lbf	0.25"	0.141"	Pass
Horizontal	600 lbf	0.25"	0.066"	Pass
Vertical	3600 lbf	n/a	Permanent Deformation	Pass

The first two tests conducted in the load frame were the vertical and horizontal load tests. These two tests were meant to certify that the frame could support the crash loads that were established using the ASME HPVC standards. These tests required that the roll hoop support the loads provided while not experiencing displacement greater than 0.25" and not entering a plastic region of deformation. As can be seen in Table 18 and Figures 91 and 92, these requirements were met in both tests. Load versus displacement data can be seen to be linear for both tests proving that the deformation of the roll hoop remained plastic. Likewise, maximum deformations for the vertical and horizontal load tests were 0.141" and 0.066" respectively which were well within the 0.25" specification

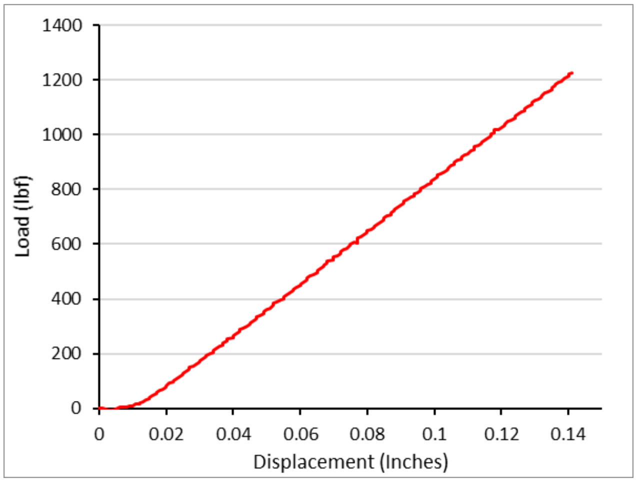


Figure 91. Vertical Loading.

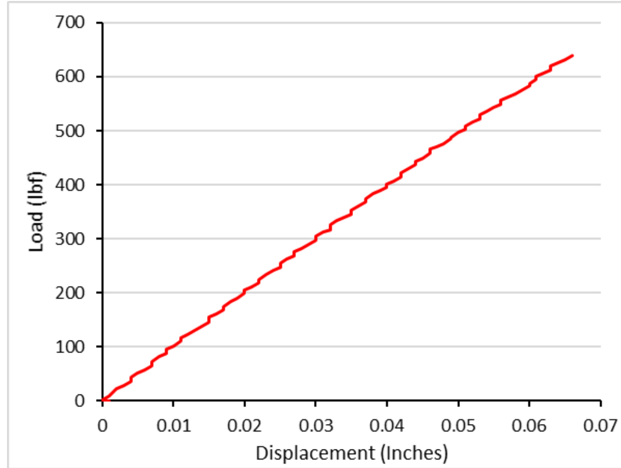


Figure 92. Horizontal Loading.

The final load test conducted was a vertical load to failure test. This test used an identical setup as the 1200 lbf vertical loading test. The results of this are shown in Figure 93 and they show the roll hoop failing similarly to what FEA predicted. The roll hoop yielded at approximately 1,690 lbf which was almost 500 lbf above the requirement. The ultimate load that the roll hoop was able to support was approximately 3,600 lbf. These loads are both well above the requirements that were altered from the ASME HPV competition regulations, so the team is confident that the roll hoop will be able to protect the rider in the unlikely event of a crash.

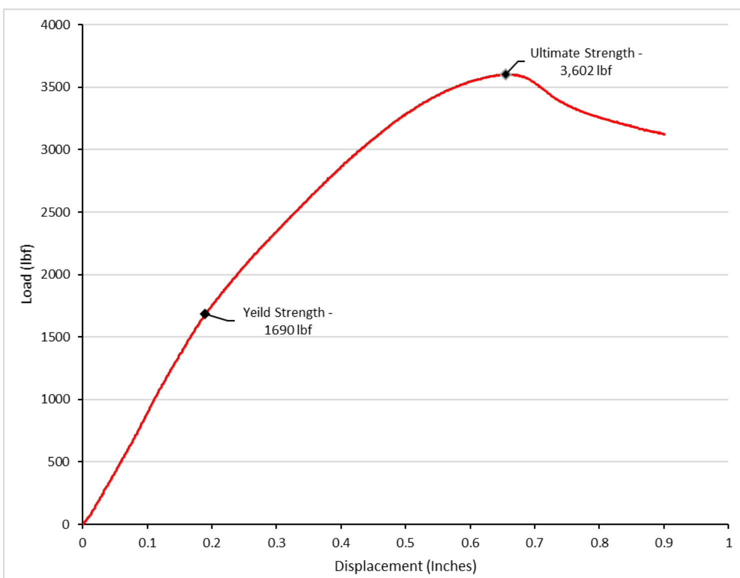


Figure 93. Destructive vertical loading.

FEA modeling indicated that the roll hoop would be able to pass this testing with a comfortable margin for error. This was proven to be true, giving the team further confidence in the structural modeling that was unable to be tested physically.

7.2.2 Test Fitting

The test fit schedule with Josh is detailed above, in 6.3.5 Test Fit schedule. Because test fits were such an integral part of the manufacturing processes, they were detailed in the manufacturing section. All test fits occurred at the Aero Hangar Machine Shop on Cal Poly's campus.

7.2.3 Weld Testing

Weld quality testing was conducted in accordance with the Baja SAE safety regulations, detailed in Appendix D. This testing involved a destructive test and a penetration inspection test. For the destructive test, a 90-degree joint is tested until failure to ensure that failure occurred within the base metal (Figure 94). The second testing procedure was a visual inspection of a 30-degree offset weld; this testing involved sawing the test sample in half along the axis of the part to confirm that the weld achieved full penetration (Figure 95).

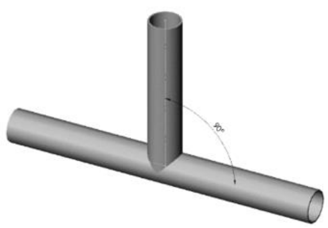


Figure 94. 90- degree destructive test.

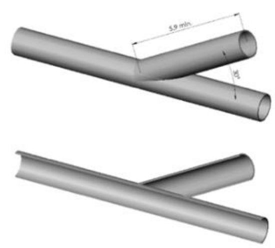


Figure 95. 30- degree inspection test.

The test samples were constructed using 1.25" OD x 0.035" wall thickness 4130 chromoly tubing. This was the same diameter tubing as the roll hoop structure and is the thinnest wall thickness used on the frame. This is representative of the most critical conditions for welded joints on the frame.

The team's welder, Eliot, welded the required sample joints. Both samples were welded at the Aero Hangar Machine Shop on Cal Poly's campus, with a Dynasty 200 TIG welder, manufactured by Miller. Both tests were carried out per Baja SAE regulations Kevin Williams, Cal Poly's welding instructor, inspected both samples, shown in Figure 96, and verified that they passed. Weld testing results are tabulated in Table 19.

Figure 96. Left to Right: 90-degree sample, showing base metal failure; 30-degree sample, cross section showing full penetration; 30-degree sample, top view.

Table 19. Weld Testing Results

Joint	Pass/ Fail	Notes from Kevin Williams
90- degree	Pass	Heat affected zone rip, failure of base metal
30- degree	Pass	Full penetration at either end of cross section, small amounts of burn through for how thin tubing was, good controlled weld

7.2.4 Weight

Overall weight of the frame was verified once all members had been welded or tacked into the frame. The weight of the headset and impact foam were taken to be negligible, as well as the small amounts of filler material added as full welding was finished.

The frame was weighed using a Longacre Racing Computer Scale, borrowed from Cal Poly's FSAE club, shown in Figure 97. The scale measures in one-pound increments. This testing was completed at the Aero Hangar. The frame and the fork were weighed individually first, and then a final measurement of both their combined weights was verified to equal that of the individual components within ±1 pound.

Figure 97. Scale used for weighing the completed frame.

To weigh the bike, the scale was plugged into power. The scale has the capability to measure from four scale pads, however since only overall weight was required, one scale pad was used. The scale pad was connected to the scale's readout via a wire. The corresponding scale pad was plugged into the readout, and the frame was placed onto the scale pad, as seen in Figure 98. The weight of the bike was read off the scale's readout, as shown in Figure 99. This procedure was repeated for the fork alone, and again for the frame and fork together.

Figure 99. Setup for weighing of the frame.

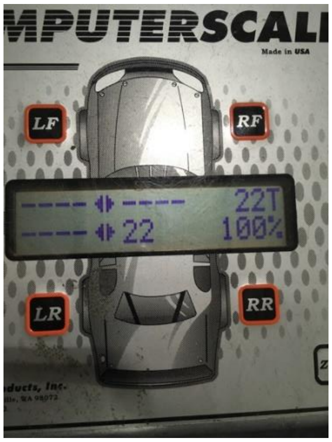


Figure 98. Readout when weighing the frame individually.

The results of the weights measured are documented below, in Table 20. The weight of the frame individually as well as the frame and fork together are shown.

Table 20. Weight Testing Results

Component	Specification Weight	Measured Weight	Pass/ Fail
Frame	< 40 lbs	22 lbs	Pass
Fork	n/a	2 lbs	Pass
Frame and Fork	< 40 lbs	24 lbs	Pass

7.2.5 Center of Gravity and Radius of Gyration Testing

Center of gravity and radius of gyration testing was conducted according to the lab procedures followed in ME 441 Single Track Vehicle Design, a class on bicycle handling dynamics taught at Cal Poly. Both the vehicle's center of gravity and moment of inertia, from which radius of gyration is derived, played a large role in the overall handling dynamics of the vehicle. To initially find the Patterson Control Model inputs, an estimation for these inputs were used. This test was conducted to validate the approximations used. The full testing procedures are detailed in Appendix AA.

7.2.5.1 Center of Gravity

To find center of gravity, the weight distribution across the vehicle with the rider had to be calculated. A schematic showing the variables measured to find center of gravity is shown in Figure 100.

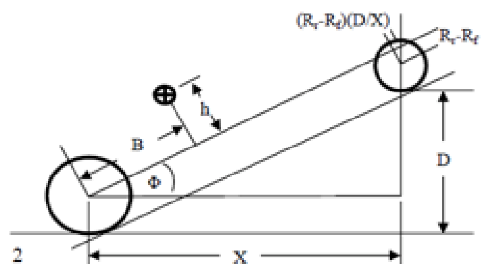


Figure 100. Schematic of measured parameters for horizontal and vertical positions of center of gravity.

To find the horizontal component of center of gravity (horizontal distance from rear axle to center of gravity, labeled as "B"), the weight distribution of the vehicle was found on flat ground. The center of gravity's distance from rear axle was found to be 2.84 ft, or 0.866 m. Hand calculations for the derivation of this test are shown in Appendix AB. The excel document used to perform these calculations is shown in Appendix AD.

Uncertainty analysis was performed on this calculation. There were two different measurement tools used in this test, a Parktool tape measurer used to measure distance and a Longacre racing scale used to measure weight. The total uncertainty for the test was found to be 0.0039 ft. In comparison to the center of gravity's location of 2.84 ft, this uncertainty is negligible. It is also well within the tolerance of + 0.39, - 0.098 ft for center of gravity. The tolerance for this test was found by testing how much of a change could be made to the center of gravity before the overall handling dynamics no longer met the other specifications. Because of this, any measurement within the tolerance is acceptable, as it correlates to acceptable handling qualities. Hand calculations for uncertainty analysis are shown in Appendix AE. The excel document used to perform these calculations is shown in Appendix AD.

To find the vertical component of center of gravity (vertical distance from center of gravity point to ground), the weight distribution of the vehicle was found on flat ground. This was accomplished by raising the front wheel on foam blocks while leaving the rear wheel on the ground. The vehicle was inclined at 5 different known angles, and the weight distribution measured for each angle, as seen in Figure 101.

Figure 101. Inclined testing for center of gravity, with Josh in vehicle, and front wheel raised on foam blocks. Team members stand by to stabilize the vehicle.

This test found the vertical distance from axle height to center of gravity, labeled as “h” in Figure 99. The radius of the wheel was added to this measurement to find the center of gravity’s distance from the ground. An average of the 5 trials was found this value to be 1.62 ft, or 0.493 m. Hand calculations for the derivation of this test are shown in Appendix AB. The excel document used to perform these calculations is shown in Appendix AD.

Uncertainty analysis was performed on the vertical component of center of gravity. There were two different measurement tools used in this test, a Parktool tape measurer to measure distance and a Longacre racing scale to measure weight. The total uncertainty for the test was found to be 0.0062. In comparison to the center of gravity’s location of 1.62 ft, this uncertainty is negligible. It is also well within the tolerance of + 0.39, - 0.098 ft for center of gravity. However, it is larger than the horizontal center of gravity position uncertainty. This is to be expected as the horizontal position of center of gravity is used as an input to calculate the vertical position, so any errors propagate. Hand calculations for uncertainty analysis are shown in Appendix AE. The excel document used to perform these calculations is shown in Appendix AD. The final results for center of gravity testing are tabulated below in Table 21.

Table 21. Center of gravity testing results

Center of Gravity Location	Approximation	Measured	Tolerance	Pass/ Fail	Uncertainty
Horizontal	0.847 m	0.866 m	+ 0.12, - 0.03 m	Pass	0.0039
Vertical	0.433 m	0.403 m	+ 0.12, - 0.03 m	Pass	0.0062

7.2.5.2 Radius of Gyration

The radius of gyration is derived from the mass moment of inertia. To measure the mass moment of inertia of the vehicle and rider, the vehicle and rider were swung on a swing with a known mass moment of inertia (Figure 102).

Figure 102. Josh Gieschen on the frame in the radius of gyration testing swing.

The period of oscillations was measured from the swing in 5 different trials (Figure 103).

Figure 103. Kyra Schmidt starts the swing and counts cycles, while Eliot Briefer times oscillations.

The average of the period measurements was used to calculate the moment of inertia for the total swing, bike, and rider system. Then, the moment of inertia of the swing was subtracted, leaving the moment of inertia of bike and rider. This was used to calculate the vehicle's radius of gyration. The approximate value for radius of gyration used in initial vehicle handling calculations was 0.31 m. To be acceptable, the radius of gyration had to be greater than 0.29 m. The measured value was found to be 0.35 m, shown in Table 22. Hand calculations for the derivation of this test are shown in Appendix AC. The excel document used to perform these calculations is shown in Appendix AF.

Table 22. Radius of Gyration testing results

Radius of Gyration	Approximation	Measured	Tolerance	Pass/ Fail
About longitudinal (x) axis	0.31 m	0.35 m	< 0.29 m	Pass

7.2.5.3 Conclusions

Once the experimental values for center of gravity and radius of gyration were calculated, they were fed back into the Patterson Control Model. Then, the handling qualities were analyzed the same way as in 5.3.1 Geometry: Handling Dynamics. The model was shown to pass all the specifications both with the approximations used and the physical values calculated. Overlay plots of the vehicle's predicted handling qualities with the experimentally determined values are shown in Figure 104 and 105.

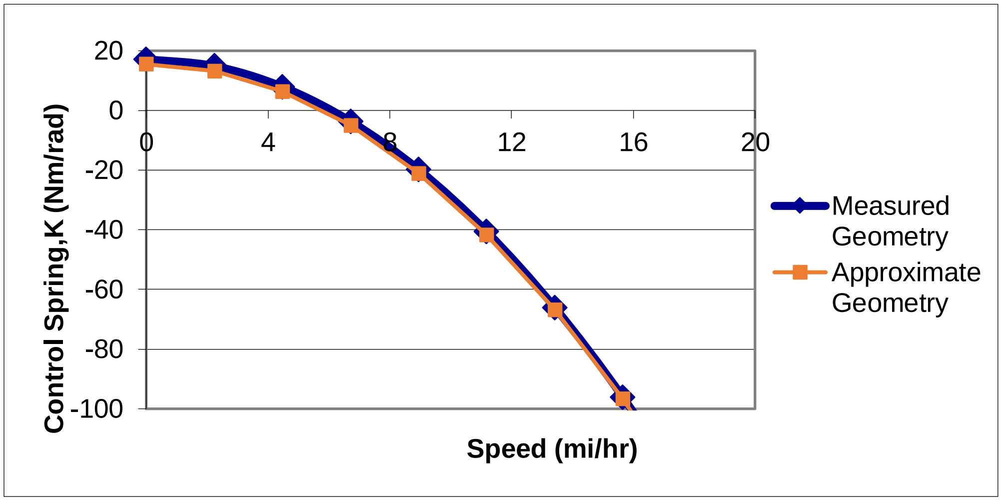


Figure 104. Control spring versus speed, overlaying approximate inputs and as-built measured inputs.

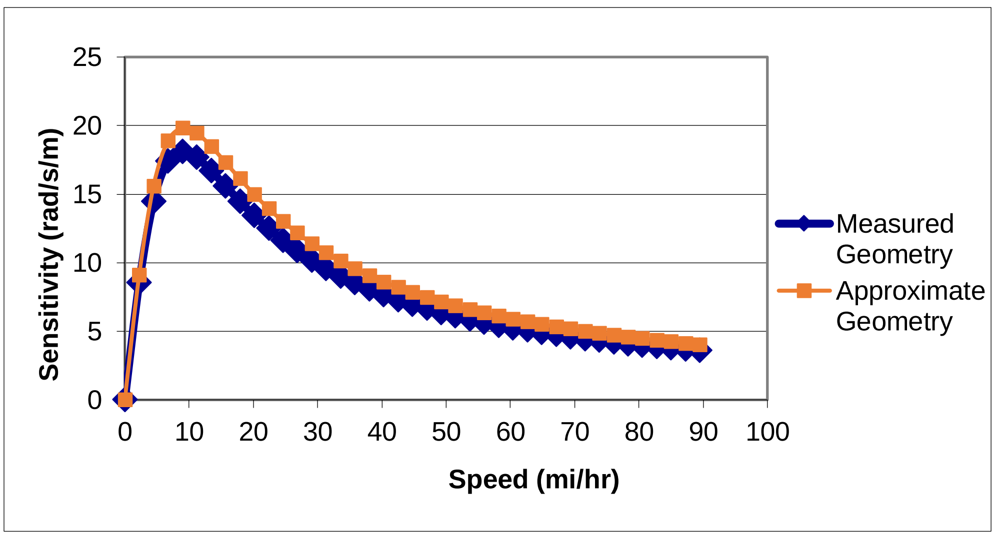


Figure 105. Sensitivity versus speed, overlaying approximate inputs and as-built measured inputs.

The vehicle's control spring stayed very close to its approximated value. Since the previous plot of control spring was satisfactory, this was acceptable. The vehicle's sensitivity, however, was found to have a predicted decrease in its peak. This was an improvement for the vehicle's specifications. A final table of the as-built Patterson Control Model inputs is shown below, in Table 23. The center of gravity, control spring, and total weight were adjusted according to their measured values.

Table 23. Final, as-built Patterson Control Model inputs

Variable	Value	Units
a	1.43	m
b	0.866	m
h	0.493	m
kx	0.35	m
beta	17	degrees
s	-0.06	m
Rt	0.3085	m
m	113	kg
Rh	0.19	m

8 Project Management

The design of the frame followed an iterative design process, in which the team spent roughly three months in each of the designing, manufacturing, and testing phases. Each of these phases have been completed, and the project has reached its conclusion. In preparation for the competition in September of this year, the team and club members will finalize the necessary public relations documents and continue to test the bike.

8.1 The Process

In order to design a bike frame that was stable, structural, and custom fit, the team used an iterative process to develop the final design. The frame was built in CAD around a custom rider model that matched the rider's dimensions. Concurrently, the Patterson Control Model calculator was used to find an optimal combination of geometric inputs (such as wheelbase, fork offset, etc). This allowed the team to design a frame that accounted for rider spatial constraints, geometric constraints, stiffness requirements and the chosen wheel size. It was then analyzed using FEA to test for structural integrity both under rider loads and crash loads. From there, changes were made to improve the design's robustness. Now, the final design presents the best combination of factors and a design that was verified to be manufacturable.

8.2 Analysis

In this project, the techniques used to analyze the frame were standard. The first stage consisting of building the model in SolidWorks. Then values were iterated using the Patterson Control Spring Model to dictate handling geometry and output resulting values such as instability peak and high-speed sensitivity. FEA was used to analyze the structural integrity of the frame and to ensure that side, bottom, and frontal impact loading cases would be met.

8.3 Purchases

As a club funded project, the team first tried to source materials and components from companies who wanted to support the project either cost-free or a discounted price. If this was not possible, club funds were utilized. Purchasing details can be found in Appendix O.

8.4 Key Deliverables and Dates

Now that the project has concluded, this section reviews the major deliverables and dates that occurred throughout the entire project (Table 24 and Figure 105). The next milestone in the project is the competition at Battle Mountain in September 2019. Between the submission of FDR and then, the team will work rigorously to prepare the vehicle and train the rider. The team utilized the Team Gantt software to organize and delegate tasks. A copy of the Gantt chart can be found in Appendix N.

Table 24. Key Deliverables and Due Dates.

Deliverable	Due Date
Scope of Work	10/19/18
Preliminary Design Review	11/13/18
Interim Design Review	1/17/19
Critical Design Review	2/7/19
Manufacturing and Test Review	3/14/19
Confirmation Prototype Review	4/30/19
Senior Project Expo	5/31/19
Battle Mountain Competition	9/7/19

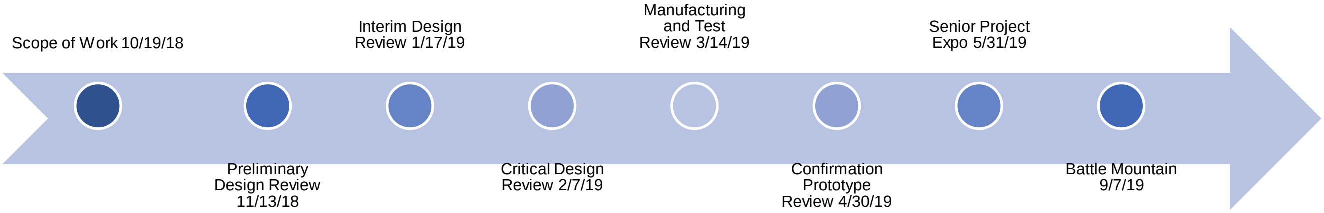


Figure 106. Overall project timeline.

9 Conclusion

This Final Design Review (FDR) report is a summarization of the research conducted, ideas developed, designs investigated, and prototype manufactured for the Human Powered Vehicle Frame.

The Human Powered Vehicle Frame team was responsible for designing and building the frame, the steering system, and rider-specific safety concerns. The frame was custom fabricated to fit the rider using 4130 Chromoly round tubing. The steering system utilized a custom-built bicycle fork and standard headset. Rider safety and comfort was addressed throughout the fabrication and installation of impact foam panels and a racing harness.

All safety specifications for the frame project were passed. Thus, it is recommended that the frame be raced at Battle Mountain 2019, during which the final tests for speed can be run. The frame is currently in the process of being integrated with other subsystems of the vehicle and will be rideable by June 15th, 2019. It is also recommended that the frame be used June through August 2019 for rider testing and practice.

For future years, many aspects of the frame can be optimized and iterated upon. The team recommends that teams in future years do a more thorough optimization of the truss and beam elements of the frame. While the current frame passes all specifications, the team believes it is over-built and its weight and frontal area can be decreased through optimization. Now that an initial frame is built, the rider can give physical feedback as to his or her comfort level and rider-specific concerns can be addressed.

In addition, with a physical prototype that will be raced at high speeds, the handling dynamics of the frame can be further iterated upon. With the combination of rider feedback and the predicted handling qualities of the vehicle, future teams can adjust the handling curves of the vehicle. It is recommended that the vehicle's behavior be tuned based upon rider preference.

Finally, the team recommends that the frame shift to being constructed from steel to composites when future teams are prepared to do so. If done correctly, a composite frame can be lighter and stiffer than a steel frame and provide extremely rider specific ergonomic elements.

With the conclusion of a year-long project dedicated to the vehicle, the team is ready to see the bike race. The scope of the senior project on the frame is over—however, outside of senior project, the team's next steps will be to work with the rider to test and practice riding the vehicle. This will prepare the rider for racing at Battle Mountain.

The team will be in touch throughout the rider training process and to deliver the results in September 2019.

Works Cited

[1] ArtsCyclery. “Tech Talk: How Frame Geometry Affects a Bike's Handling - Mtbr.com.” *Mountain Bike Review*, 20 Nov. 2015, reviews.mtbr.com/tech-talk-how-frame-geometry-affects-a-bikes-handling.

[2] “HPV Streamliner Speeds.” *Adventuresofgreg.com*, www.adventuresofgreg.com/HPVlog/VehicleDrags.html.

[3] “Geometry of Bike Handling.” *Calfee Design*, calfeedesign.com/geometry-of-bike-handling/.

[4] “Types of Recumbents: Long & Short.” *Types of Recumbents*, TALU, 2010, talu.com/typesofbents.php.

[5] Anderson, John. “Recumbent Bikes.” *Recumbent Bikes*, www.bicyclinglife.com/PracticalCycling/FancyBikes.htm.

[6] “Eta: Technical Info.” *Aerovelo*, www.aerovelo.com/past-bikes. “General Information -

[7] Glaskin, Max. “How Does Frame Geometry Affect a Bike?” *Cyclist*, 31 Aug. 2018, www.cyclist.co.uk/in-depth/816/how-does-frame-geometry-affect-a-bike.

[8] “Headset Standards.” *Park Tool*, 17 Aug. 2015, www.parktool.com/blog/repairhelp/headset-standards.

[9] Teplukhina, I.V., Bogdanov, V.I., Zaitseva, O.Y. et al. Metallurgist (2018) 61: 787. Retrieved from https://doi.org/10.1007/s11015-018-0565-6

[10] Davol, Andrew, and Frank Owen. *Model of a Bicycle from Handling Qualities Considerations*. *Model of a Bicycle from Handling Qualities Considerations*.

[11] Knaus, Benjamin, et al. “ASME Human Powered Vehicle.” *Cal Poly Digital Commons*, Cal Poly , 2010, digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1065&context=mesp.

[12] “Competition Rules.” *Ihpva.org*, International Human Powered Vehicle Association, Aug. 2018, www.ihpva.org/rules.htm.

[13] *Longitudinal Radius of Gyration*, www.calpoly.edu/~wpatters/wave4.doc.

[14] Kyle, C. R., & Weaver, M. D. (2004). Aerodynamics of human-powered vehicles. Proceedings of the Institution of Mechanical Engineers, 218(3), 141-154. Retrieved from http://ezproxy.lib.calpoly.edu/login?url=https://search.proquest.com/docview/219206330?accountid=10362

[15] Too, Danny and Landwer, Gerald E., "Maximizing Performance in Human Powered Vehicles: A Literature Review and Directions for Future Research" (2008). Kinesiology, Sport Studies and Physical Education Faculty Publications. 102. https://digitalcommons.brockport.edu/pes_facpub/102

[16] “What's the Difference between 650cc and 26’ Wheels?: Triathlon Forum: Slowtwitch Forums.” *Forum.slowtwitch.com*, 21 Feb. 2005, forum.slowtwitch.com/forum/Slowtwitch_Forums_C1/Triathlon_Forum_F1/Whats_the_difference_between_650cc_and_26_wheels_P329062/.

[17] “Chase Vehicle Rules .” *Recumbents.com* , World Speed Challenge at Battle Mountain , recumbents.com/wisil/whpsc2018/RacersandTeamsinfo2018.pdf.

[18] “Rules for the 2019 Human Powered Vehicle Challenge.” *Human Powered Vehicle*

Challenge | ASME Engineering Network, ASME, 23 Sept. 2018, community.asme.org/hpvc/m/default.aspx.
[19] *Baja SAE Collegiate Design Series Baja SAE® Rules*. SAE, 2018, bajasae.net/content/2018-BAJA-RULES-FINAL-2017-08-30.pdf.
[20] "Battle Mountain 2016: An Unbelievable Leap to 89.59 Mph (144.17 Km/Hr)." *Aerovelo*, 19 Sept. 2016, www.aerovelo.com/mission-log/2016/9/19/battle-mountain-2016-an-unbelievable-leap-to-8959-mph-14417-kmhr.

Appendix A: Research on Aerodynamics and Ergonomics of Human Powered Vehicles

This appendix details more research on aerodynamics & ergonomics of human powered vehicles.

Aerodynamics of human powered vehicles is a heavily studied topic. It has been found that on a smooth, flat road, air resistance is the greatest force against the normal road cyclist. A wind speed of approximately 25 MPH can constitute over 90% of retarding forces [14]. When aerodynamics is improved the normal road cyclist can experience a decrease in wind resistance of 20% and the human powered vehicle – over 95%. While there are several factors to adjust/include in order to decrease wind resistance against any type of cyclist, there are three that apply significantly to human powered vehicles: decreasing the frontal area, streamlining components, and smoothing the surfaces.

Frontal area is a specification of the vehicle that falls under the breadth of the fairing, but it is something that impacts the frame as well. The width of the front of the frame has a positive relationship with the frontal area and should therefore be a factor that is minimized. The bike as will then displace less area when in motion and move more swiftly. Next is streamlining. Streamlining reduces air turbulence and energy waste and is the reason why HPV's are shaped the way they are. It also explains the recumbent position – riders are literally streamlining their bodies. Last is smoothing the surfaces. Wind resistance can be seriously decreased by simply avoiding a rough and uneven surface.

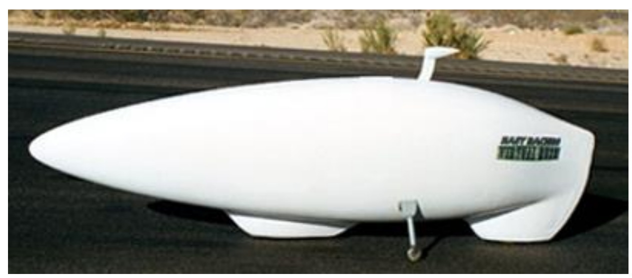


Figure 107. The Virtual Edge by Matt Weaver.

The Virtual Edge, in Figure 107, designed by Greg Weaver, is an excellent example of a bike that has nearly eliminated the effects of wind resistance. It features a laminar flow streamlined body, a smooth outer surface, and no windshield.

Speed of human powered vehicles is maximized just as, if not more, by the rider. The rider's body position has a great influence on the maximum power output that he can achieve. When comparing the standard road to the recumbent bicycle, you see a reasonable amount of power loss. This is because [based on the force length relationship] muscles are able to produce the greatest force when they are at a resting length. However, the recumbent position's contributions to aerodynamics, and consequently speed, are so great that it is used. Therefore, designers of HPV's must ensure that all angles the rider assumes when in the recumbent position will have a positive correlation with power output.

The forces and torques that a rider uses to produce power are function of how internal biomechanical factors of the body interact with external mechanics of the bike. Hip, knee, and ankle angles work with the constraints of the seat to pedal distance, the seat angle, and more. It is important to identify values for these angles and then to make incremental adjustments to distances and dimensions. One of the main dimensions that was focused on is the seat angle. Many studies, including that of Too and Landwer in *Maximizing Performance in Human Powered Vehicles* have found that the range of values for a seat angle producing maximum power fall between 20 and 30 degrees [15].

Appendix B: Research on Bicycle Components that Directly Interface with the Frame

This appendix details the research done on the main bicycle components affecting frame design.

Wheel choice affects not only the handling of the frame, but also rolling resistance and the drivetrain power to speed conversions. Due to their widespread availability, variety of tube, tire, and rim options, and relatively small profile, the team has decided to use 650cc road bicycle wheels with the frame. 650c is the size of wheel commonly seen on children's or very small road bikes. It translates to roughly 26" in diameter, though that is not an exact conversion [16]. A smaller wheel is valuable for a Battle Mountain bike because it can be more compactly fit under the fairing, and thus reduce the overall frontal area of the bike. While a 650c is by no means the smallest wheel available, it has the most standard options available and is still relatively compact. In addition, having larger wheel rims means the rider will not have to pedal at quite as fast an RPM to reach the same speeds (all other factors held constant). This makes the drive ratio less aggressive, freeing up more space in the bike and making component integration to the frame an easier task. Eta, the human powered vehicle that currently holds the World Speed Record, also used 650c wheels.

Some other recommendations that were given to the team regarded component choice. The frame must accommodate the headset chosen and the headset chosen must be structurally sound with the frame. Standard, semi-integrated, and integrated headsets are commercially available as shown in Figure 108.

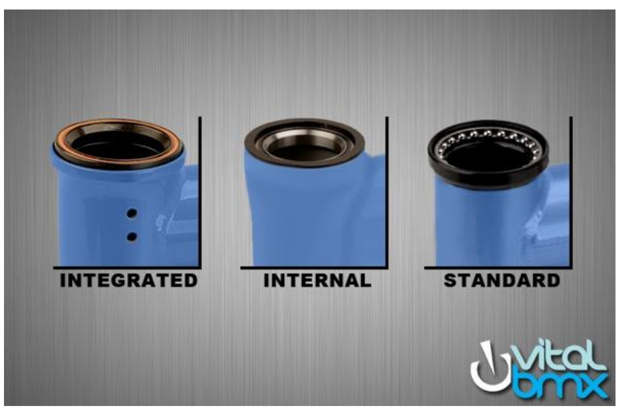


Figure 108. Pictorial depiction of the different types of headsets.

It was recommended to the team by Jim Gerhardt that a "semi-integrated" headset be used. This type of headset offers a larger head tube, thus allowing for more area to weld to for the frame, and bearings that are internal to the head tube. However, there is currently debate in the bicycle industry whether this style has an advantage in performance than another. Ultimately, the quality of a headset is largely determined by the quality of the bearings used and its manufacture. In contrast to a fully integrated headset, a semi-integrated headset still has bearing cups (they are simply sunk into the head tube), and thus retains its ability to be serviced.

Appendix C: Material Selection

This appendix details the material selection process for the frame that involved carbon fiber and aluminum.

One material that was considered for the manufacture of the vehicle was carbon fiber. Carbon fiber has been used by the Human Powered club for decades in the fairing and other components; in addition, just last year the club designed and manufactured a carbon fiber monocoque. Advantages of carbon fiber include strength and strength to weight ratio. Of the materials considered, carbon fiber has the best strength to weight ratio by a large margin. Its strength is also outstanding; however, there are additional considerations that must be taken as carbon fiber is only strong in the direction of the weave. In areas of manufacturability, ease of repair, and cost carbon fiber quickly shows its limitations. Carbon fiber is the most expensive material that was considered. Although carbon fiber was donated in years past, the molds, man hours, chemicals, and other materials used in manufacture all make working with carbon an extremely expensive endeavor. On the note of manufacturability, carbon fiber shows yet another weakness. Carbon fiber is the most difficult material to design for and manufacture. The amount of man hours that are used for carbon fiber layups are massive. And the final area of concern is the ability to repair the material. There exists no means to repair cracked carbon fiber other than layering more carbon on top, which is a very poor fix. These weaknesses pushed us to quickly decide against carbon for the frame material.

Aluminum was the next material that was considered. The Human Powered club has not had much experience working with aluminum as a frame material. Aluminum however does have advantages that would lend it well to being used on the frame. Aluminum's strength to weight ratio is outstanding, and although it is relatively soft, it is a homogeneous material with no directional strength limitations like carbon. Unlike carbon aluminum can be welded; however, welding aluminum is a difficult form of the art which requires heat treating after. Cal Poly does not have an oven large enough to heat treat a full frame, therefore, the work would need to be shipped to an external company. Aluminum can be repaired by welding it which is a significant advantage when compared to carbon.

Appendix D: Applicable Standards from ASME, Formula SAE, and Baja SAE Rules

This appendix details a listing of applicable industry codes, standards, and regulations.

ASME HPV Rules [18]

1. Safety
    a. The safety of participants, spectators, and the general public will override all other considerations. Any event can be delayed, terminated prematurely, or canceled if the Head Judge determines it necessary.
    b. Each vehicle must demonstrate that it can come to a stop from a speed of 25 km/hr in 6.0 m, can turn within an 8.0 m radius, and demonstrate stability by traveling for 30 m in a straight line at a speed of 5 to 8 km/hr.
    c. Each vehicle must have a braking system with properly designed brakes on the front most wheel at a minimum. If multiple forward wheels are used each wheel must have its own brake.
    d. All vehicles must include a rollover protection system (RPS) that protects all drivers in the vehicle in the event of an accident.
    e. All drivers of all vehicles in all events will always be secured to their vehicle by safety harnesses with lap and shoulder belts (4 or 5-point harnesses) that the vehicle is in motion. The safety harness must be attached to the RPS or a structural member in the RPS.
    f. All surfaces of the vehicle (exterior and interior) must be free from sharp edges and protrusions, and other hazards.
    g. All participants must wear fully enclosed shoes, appropriate clothing, and properly fitting helmets with fastened straps that meet Consumer Product Safety Commission (CPSC) Safety Standard.
    h. All drivers will log no less than 30 minutes of riding experience in their vehicle prior to the competition.
    i. A competition official shall oversee tests of each vehicle's ability to meet the braking, turning, and forward motion requirements.
    j. Modifications to vehicles between events of the competition must not compromise the safety of the vehicle. The competition officials reserve the right to remove, from the competition, any vehicle that is judged to be unsafe by any metric.

ASME HPV Loading Cases [18]

1. Rollover Protection System (RPS) Load Cases
    a. The RPS system shall be evaluated based on two specific load cases – a top load representing an accident involving an inverted vehicle and a side load representing a vehicle fallen on its side. In all cases the applied load shall be reacted by constraints at the safety harness attachment points; simulating the reaction force exerted by the rider in a crash.
    b. Top Load: A load of 2670 N per driver/stoker shall be applied to the top of the roll hoop(s), directed downward and towards the rear of the vehicle at an angle of 12° from the vertical, and the reactant force must be applied to the seat belt, seat, or roll hoop

attachment point and not the bottom of the roll hoop (unless the bottom is the attachment point). Note that there may be one roll hoop for the driver and another roll hoop for the stoker which will result in each RPS having an applied load of 2670 N, or the driver and stoker can both be protected by a single roll hoop which will result in the RPS having an applied load of 5340 N. The roll hoop is acceptable if 1) there is no indication of permanent deformation, fracture, or delamination on either the roll hoop or the vehicle frame, 2) the maximum elastic deformation is less than 5.1 cm and shall not deform such that contact with the driver's helmet, head or body will occur.

c. Side Load: A load of 1330 N per driver/stoker shall be applied horizontally to the side of the roll hoop at shoulder height, and the reactant force must be applied to the seat belt, seat, or roll hoop attachment point and not the other side of the roll hoop. Note that there may be one roll hoop for the driver and another roll hoop for the stoker which will result in each RPS having an applied load of 1330 N, or the driver and stoker can both be protected by a single roll hoop which will result in the RPS having an applied load of 2670N. The roll hoop is acceptable if 1) there is no indication of permanent deformation, fracture or delamination on either the roll hoop or the vehicle frame, 2) the maximum elastic deformation is less than 3.8 cm and shall not deform such that contact with driver's helmet, head occurs.

Loads and their points of application are shown in Figure 109.

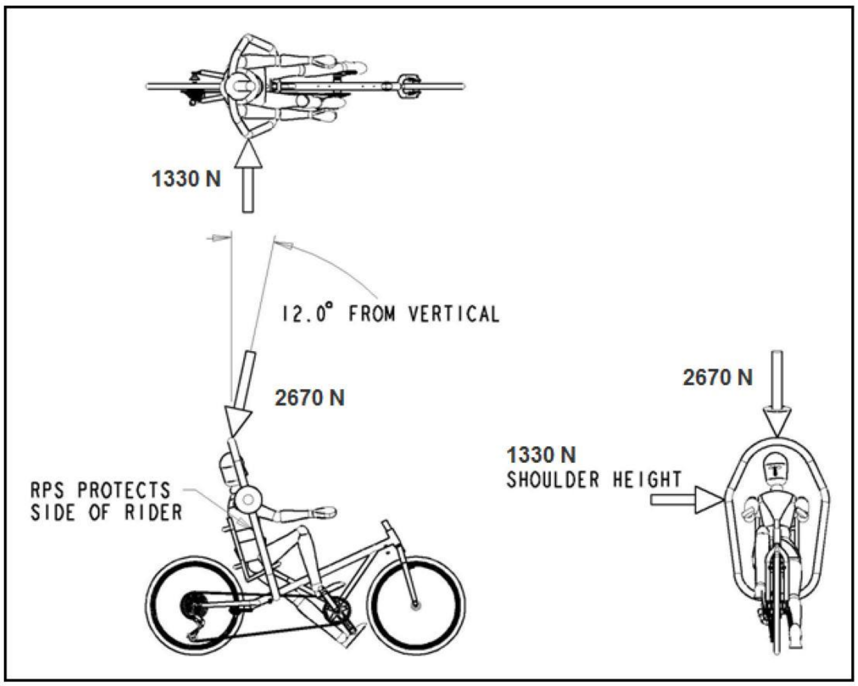


Figure 109. Example of proper RPS (rollover protection system) design and side and top load case applications [18].

SAE Safety Standards [19]

1. RRH – Rear Roll Hoop

   The RRH, as shown in Figure 111, is a planar structure behind the driver's back that defines the boundary between the front-half and rear-half of the roll cage. The driver and seat must be entirely forward of this panel. The RRH is substantially vertical but may incline by up to 20 deg. from vertical. The vertical members of the RRH may be straight or bent and are defined as beginning and ending where they intersect the top and bottom horizontal planes. The vertical members must be continuous tubes (i.e. not multiple segments joined by welding). The vertical members must be joined by ALC and BLC members at the bottom and top (see Figure 110). ALC and BLC members must be continuous tubes or adhere to Section 2. Butt Joints. Lateral Connections (LC) members cannot have a bend; however, they can be a part of a larger, bent tube system. ALC, BLC, and RRH members must all be coplanar.

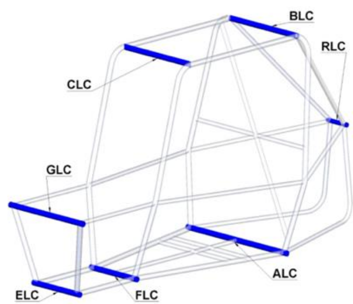


Figure 110. General frame schematic showing lateral connections.

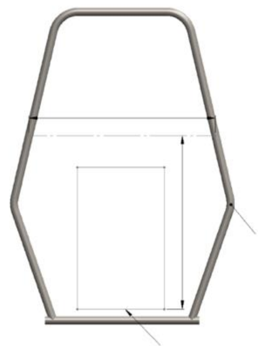


Figure 111. General rear roll hoop schematic.

2. Butt Joints
   a. Requirement

      Roll cage element members which are made of multiple tubes, joined by welding, must be reinforced with a welding sleeve. Many roll cage elements are required to be continuous tubes and may not be made of multiple pieces. Tubes which are joined at an angle need not be sleeved.
   b. Size

      Sleeves must be designed to fit tightly on the inside of the joint being reinforced. External sleeves are not allowed. Sleeves must extend into each side of the sleeved joint, a length of at least two times the diameter of the tubes being reinforced and be made from steel at least as thick as the tubes being reinforced.
   c. Welding

      The general arrangement of an acceptable sleeved joint is shown in Figure 112. A butt weld and four (4) rosette welds are required. Two (2) rosette welds are required each tube piece. Rosette welds are to be made in holes of a minimum diameter of 16 mm (0.625 in.). A minimum of 102 mm (4.0 in.) of linear weld is required to secure the sleeve inside the joint, including the butt joint and the rosette welds.

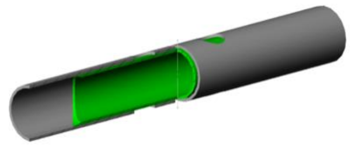


Figure 112. Interior of acceptable sleeved joint.

3. SIM – Side Impact Members
   The two Side Impact Members (SIM), shown in Figure 113, define a horizontal mid-plane within the roll cage. These members are joined to the RRH and extend generally forward, at least as far as a point forward of every driver's toes, when seated in normal driving position. The forward ends of the SIM members are joined by a lateral cross member, DLC. The DLC may be omitted if the GLC provides adequate protection for the driver's toes.

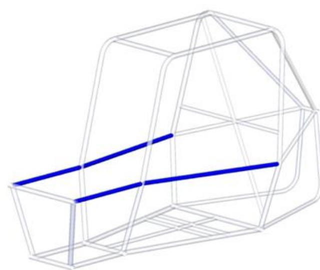


Figure 113. General frame schematic showing side impact members.

4. USM – Under Seat Member

The USM, shown in Figure 114, must be positioned in such a way to prevent the driver from passing through the plane of the LFS in the event of seat failure.

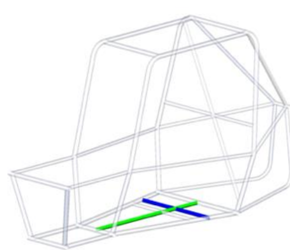


Figure 114. General frame schematic showing under seat member.

5. Welding Process Check

Each person who makes any welded joint on any of the vehicle's roll cage elements must personally make two welding samples (defined below), using the same materials and processes as used in the roll cage element welds. Welding samples must be made from the same tube

Sample 1: Destructive Testing

A 90-degree joint, the leg length is unrestricted (Figure 115). This joint must be destructively tested causing the joint to fail in the base material (as opposed to the weld metal). The testing method is free- either tensile or bending failure may be induced; however, the peak stress must be located at the weld. In the case of bending failure, take care that the largest bending moment is located at the weld.

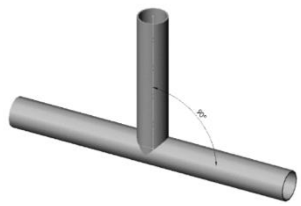


Figure 115. Weld sample for destructive testing.

Sample 2: Destructive Inspection

Two tubes joined at a 30-degree angle with a length of at least 150 mm (5.9 in.) from the center of the joint (Figure 116). The sample must be sectioned along the length of tube to reveal adequate and uniform weld penetration.

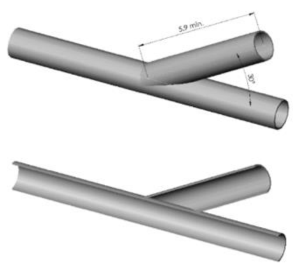


Figure 116. Weld sample for destructive inspection.

6. Driver Clearance
   a. Vertical Space

      The driver's helmet shall have 152 mm (6 in.) minimum clearance from any two points among those members that make up to top of the roll cage.
   b. Sharp Edges

      The entire vehicle, including the roll cage shall have no exposed sharp edges which might endanger the driver, track workers, or people working around the vehicle while the vehicle is in any attitude (static, dynamic, inverted, etc.).
7. Driver Restraint
   a. Function

      The driver restraint system shall function to safely and securely hold the driver within the envelope of the vehicle's roll cage. The driver restraint system shall also quickly and completely disengage when required to allow the driver a minimum egress time. The driver restraint system, shown in Figure 68, consists of a safety harness, arm restraints, and the vehicle's seat. The driver restraint system shall be fully functional and properly worn whenever the driver is seated in the vehicle.

b. Driver Harness
The driver harness shall consist of a 5-point (or more) system comprised of two shoulder belts (left and right), two lap belts (left and right), and one or more anti-submarine belts all joining at a single, central buckle (disconnect point). Figure 117 shows a schematic of a five-point harness. The anti-submarine belt serves to positively locate the buckle and prevent the driver from riding under the lap belts.

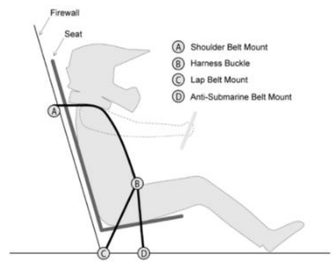


Figure 117. Driver harness schematic.

c. Release Mechanism
All belts in the driver harness must join to a single, central, metal-to-metal, lever-type, quick-release buckle. Cam-Lock, and other enclosed buckles susceptible to jamming from small debris (such as sand particles) are explicitly prohibited. The release mechanism (buckle) shall be protected against accidental unfastening from a direct pull, rollover or slide along the side.

d. Shoulder Belts
The shoulder harness shall be of the over-the-shoulder type. Only separate shoulder straps are permitted. “Y”-type shoulder straps are explicitly prohibited.

e. Positioning, Vertical
The shoulder belt mounting point, point (A) in Figure 118, shall be positioned no higher than vertically level with each driver’s shoulders, and no lower than 102 mm (4.0 in.) vertically below each driver’s shoulders.

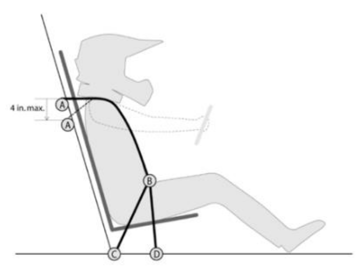


Figure 118. Driver harness schematic showing mounting points.

f. Positioning, Lateral
The lateral spacing of the shoulder belts shall be between 178 mm (7.0 in.) and 229 mm (9.0 in.) when measured center-to-center. See Figure 119. Lateral position of the shoulder belts along their mounting tube must be restrained by a structure other than the firewall.

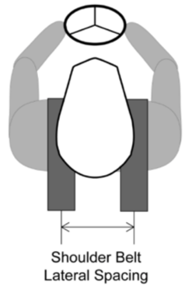


Figure 119. Lateral spacing between shoulder belts.

g. Attachment

The shoulder belts shall be looped and secured around a straight, horizontal tube welded within the plane of the RRH. Provisions for lateral position restraint shall be provided. Firewall material is not acceptable for lateral position restraint. See Figure 120 for details.

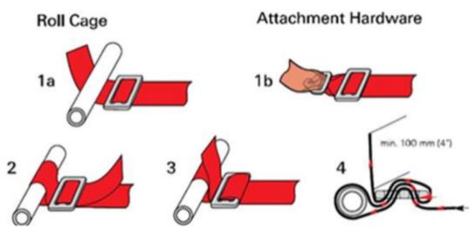


Figure 120. Proper attachment of driver harness to frame.

8. Eye Protection
    a. Type

    All drivers shall wear motocross-style goggles with a full-circumference elastic band that wraps completely around the driver's helmet. "Quick Straps" or other quick-release systems are explicitly prohibited.
9. Clothing
    a. Gloves

    Drivers shall wear gloves to protect their hands. Durable, abrasion resistant gloves are required.
    b. Shoes

    Drivers shall wear socks and shoes.
    c. Upper Garments

    Drivers shall wear a fire-resistant shirt. The shirt must have a factory label showing an SFI rating, FIA rating, NFPA 2112 rating, or other fire-resistant rating.
    d. Lower Garments

    Drivers shall wear long pants made of natural materials such as cotton, denim, etc. Drivers may also wear fire resistant pants having an SFI, FIA, NFPA 2112, or other fire-resistant rating.
    e. Combustible Material

    Jerseys, gloves, socks or other garments made from nylon or any other synthetic material which will melt or combust when exposed to open flame or extreme heat, are explicitly prohibited from use during competition.

Appendix E: IHPVA Rules and Regulations

This appendix details a listing of Battle Mountain competition rules and regulations.

International Human Powered Vehicle (IHPVA) Vehicle Requirements [12]

1. Power
   a. Vehicles must be driven solely by human power.
   b. Non-human power sources (batteries, solar cells, etc.) are permitted only for powering sensors, displays, communication equipment and lights.
   c. Control devices, cooling fans, powered aerodynamic devices, etc., may not be powered from non-human sources.
2. Energy Storage
   a. No device which stores energy over more than one input power cycle (e.g., one leg stroke), or which releases energy under control of the operator, may be used in any event except the road race, or speed events longer than one mile.
   b. Energy storage devices are permitted in these events provided no energy is stored before the start of the event (no chemical, electrical, kinetic, potential, or other form.)
3. Brakes
   a. All vehicles must have a brake system.
4. Control
   a. All vehicles must be controlled by the rider(s), with the single exception of that necessitated by the standing start. (see 5. Flying Start a.)
5. Flying Start
   a. The vehicle may be moving before entering the timed portion of the course. During launch of the vehicle from a stationary position, the vehicle may be assisted by no more than 3 persons per single rider vehicle. Assistants may push the vehicle, but assistance is limited to the first 15 meters of vehicle travel. All launch assistants must be on foot and cannot use anything other than their hands (or gloves) to touch the vehicle while it is in motion. Roller skates are specifically prohibited.
6. Integrity
   a. No vehicle may discard any part after beginning motion.
   b. Any external devices that are not integral to the vehicle and are temporarily affixed to provide stability or assistance while starting are prohibited (launch carts, push sticks, etc.)
7. Geometry
   a. Vehicle geometry may not be alterable during use except for steering purposes; i.e. sails or moving control surfaces specifically intended to enhance the sailing characteristics of the vehicle are not permitted.
8. Rider
   a. The vehicle shall contain only one person.
   b. No change of riders or removal of riders is permitted during a race.
9. Wind Speed
   a. 1.66 m/s max wind speed in any direction for a legal record run.

10. Safety
    a. All riders shall wear helmets during all competition.
    b. Helmets must meet the standards of a nationally accredited testing facility of an IHPVA member country. The burden of proof of meeting these requirements resides with the competitor.
    c. Vehicles may be disqualified from competition due to inadequate braking capability, lack of stability, poor visibility, presence of dangerous protrusions, or other unsafe design features.
    d. Vehicles deemed unsafe may be flagged off the course by event officials.
11. Safety Recommendations
    a. Install a red flashing light or reflective tape somewhere on the back of your bike.
    b. Encircle the rider-area of your bike with the extra protection of strong and abrasive-resistant composites.
    c. Purchase a set of radios for communication with the rider.

Battle Mountain Rules and Procedures [12]

1. Course
    a. The Rt. 305 course has a five-mile run-up with a 200-meter trap followed by 2/3 of a mile deceleration zone to the catch area.
2. Records
    a. This event will run under the IHPVA Competition Rules. Speed records are sanctioned by the IHPVA. Classes are divided by gender, number or riders, age groups, and a subclass for multitrack vehicles.

Battle Mountain Chase Vehicle Rules [17]

1. Chase Vehicle Rules
    a. Only one chase vehicle allowed per bike.
    b. There must be enough people in the chase vehicle to catch the bike on the road (two people minimum.)
    c. Chase vehicles will have a chase official onboard with radio and flare to communicate any problems with the bike to race control and other chase vehicles.
    d. Moving bikes in the right lane and chase vehicles in the left lane.
    e. Mechanical problems and accidents: Non-moving bikes and chase vehicles on the left, as close to the fence as possible. If a downed bike is on the right, park chase vehicle to far left and assist in moving bike and rider to far right.
    f. Chase vehicles must never pass normally moving bikes. Stay behind a minimum of 100 meters. Failure to stay this distance behind your bike will result in a disqualification of that run, even though it was the chase vehicle driver’s fault.
    g. Passing is extremely dangerous. Chase vehicles should be aware of the bikes following them, particularly if the chase vehicle is moving slowly and is at risk of being overtaken. If this situation occurs, both the leading bike and chase vehicle “are having a problem” and should have moved to the left lane, and off of the road.
    h. If there is any problem, turn on your flashers to warn oncoming bikes and chase vehicles.

i. If a following chase vehicle sees that their rider is going to overtake another chase vehicle, the chase vehicle should radio to the leading chase vehicle and tell it to hold its line. Bikes may pass on the right or stay behind and follow depending on where they are on course.

2. Course Rules
    a. Start – Turn on your car/truck headlights.
    b. On course – The chase official should continually check his mirrors and communicate on the radio to be aware of the position of the following bike and chase vehicle.
    c. Timing area – When you approach the timing area, slow down to 45 mph. Stay at least 200m behind the bike.
    d. Bridge – At the bridge turn off your headlights to help the catch team see the bikes.
    e. Catch area - Slow down! Do not pass your bike before it is caught. Pull directly into the parking area all of the way past the gate. Bikes can arrive within seconds of one another. The catch team will handle the bike. Catch vehicle helpers will have time to get back and assist the rider out of the bike. Use caution, the catch area is very busy; there are bikes, riders, team members, media and spectators who may not be paying close attention.

Appendix F: Photos of Battle Mountain 2018

This appendix contains photos taken of competing bikes at Battle Mountain 2018, taken by Kyra Schmidt.

Figure 121. Kevlar fairing protector on IUT Annecy's vehicle.

Figure 122. Frame for Eta Prime.

Figure 123. Rear triangle on Van Vugt.

Figure 124. Wheel spacer device on Varna.


Figure 125. Front fork on TU Delft's vehicle.

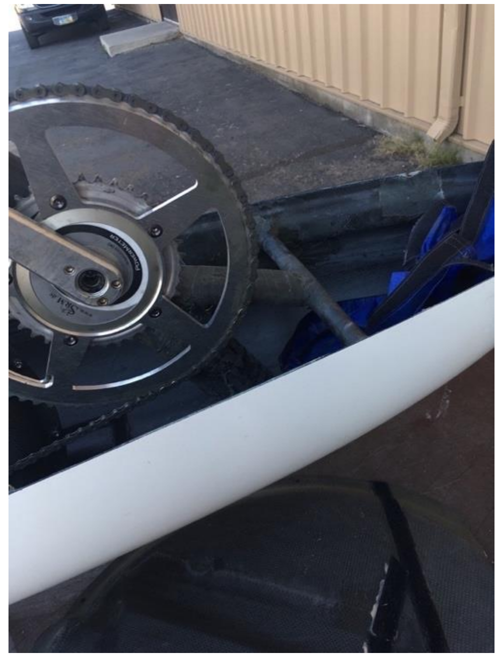


Figure 126. Front support on Varna.

Appendix G: Physical Parameters of Patterson Control Model

This appendix contains Table 25 which outlines the physical parameters of the Patterson Control Model.

Table 25. Physical parameters of the Patterson Control Model.

Physical Parameter	Representative Variable	Units
Wheelbase – horizontal distance between axles	a	meters
Horizontal distance from rear axle to center of gravity	b	meters
Vertical distance from ground to center of gravity	h	meters
Longitudinal radius of gyration	kx	meters
Head tube angle – measured from vertical	beta	degrees
Fork offset – perpendicular distance between steering axis and axle	s	meters
Front wheel radius – vertical distance from ground to axle	Rt	meters
Total mass of bike and rider	m	kg
Handlebar radius – perpendicular distance from center of head tube to end of handlebars	Rh	meters

Appendix H: Notes from Meeting about Old Battle Mountain Chassis

This appendix contains notes from a meeting with George Leone about old chassis.

Primal 2 Notes:

- 3-4 crashes, after that seemed more unstable at high speeds (perhaps the wheels or something else got out of true)
- it was harder to start from stopped than Primal 1
- inefficient drive
- rider wanted a more reclined position, could be more responsive at high speeds
- max speed: 70+ mph

Primal 1 Notes:

- more upright (easier to ride and start)
- built like an ASME bike
- wheelbase was too short (feels twitchy)
- the rider liked riding the bike
- max speed: 65 mph

Zeta Notes:

- Tom Amick built as a time trial bike
- No fairing
- Raced at the velodrome and at time trials

Appendix I: Customer Needs and Wants

This appendix contains Table 26 which outlines the customer needs and wants.

Table 26. Customer Needs and Wants.

Needs	Wants
Support the rider under normal riding conditions, protect the rider under crash loads	Rider comfort
Ability to reach speeds of 61.2 MPH, to break American Collegiate Record	Cost-effective frame design
Be stable at speeds over 60 mph	Lightweight
Custom frame tailored to chosen rider	Easy to manufacture
Provide mounting points for all other subsystems, such as drivetrain, fairing, seat, etc.	Ease of maintenance
Have low frontal area, ability to be integrated with aerodynamic elements	
Structural roll hoop	
Allow rider to produce high power output	
Available to race at Battle Mountain 2019	
Adheres to Battle Mountain race technical specifications as well as safety specification set by Dr. Mello and Jim Gerhardt	

Appendix J: House of Quality

This appendix contains the House of Quality generated through the QFD process.

Correlations	
Positive	+
Negative	–
No Correlation	

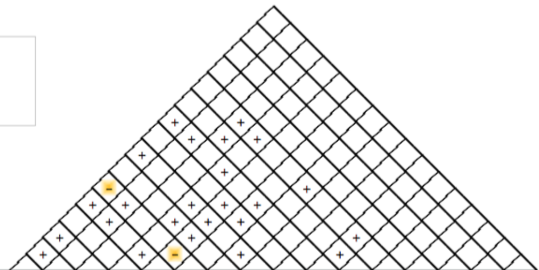
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

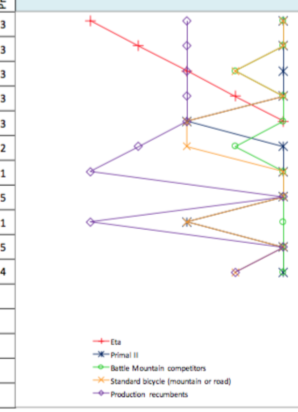
QFD House of Quality

Project: Framed

Revision Date: 10/17/18



Row #	Weight Chart	Relative Weight	HPV Club	Rider	Cal Poly	Mentors	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Speed	Frontal area	Rider power	Frequency	Cost	Weight	Instability Peak	High Speed Sensitivity (50+ mp	Integration with bicycle compo	Crash Loading	Side Loading	Rider Loads					Eta	Primal II	Battle Mountain competitors	Standard bicycle (mountain or	Bonneville speed competitors	Production recumbents	Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products						
	WHO: Customers							Direction of Improvement	▲	▼	▲	▲	▼	▼	▲	▲	◇														
1		9%	8	8	7	8	9	Reach speeds of 61.2 MPH	●	●	●	○	○	●	●	●	●	▽	▽	○					5	5	5	1	5	3	1
2		7%	8	6	4	8	9	Low frontal area	●	●	▽	▽	○	○	○	▽	▽	▽	▽	▽					5	5	5	1	5	3	2
3		9%	10	10	4	8	9	Allow rider to produce high power	●	▽	●	▽	○	○	○	●	●	▽	▽	●					5	4	4	5	1	3	3
4		10%	10	10	7	8	9	Ready to race at Battle Mountain	●	▽	●	○	▽	▽	●	●	●	●	●	●					5	5	5	1	1	3	4
5		7%	10	4	6	6	9	Cost effective	○	○	○	○	●	●	▽	○	▽	▽	▽	▽					3	5	3	5	1	3	5
6		7%	8	8	4	5	9	Lightweight	●	○	○	▽	●	●	○	▽	▽	▽	▽	▽					5	4	3	5	1	2	6
7		8%	10	10	3	7	9	Custom fit to rider	○	●	●	▽	○	○	●	○	○	▽	▽	○					5	5	5	1	4	1	7
8		7%	10	7	3	7	9	Mounting points for subsystems	○	▽	○	▽	▽	▽	▽	●	●	○	○	▽					5	5	5	5	5	5	8
9		11%	10	10	8	9	9	Structural roll bar	▽	▽	▽	●	○	○	▽	●	▽	●	●	●					3	5	3	1	5	1	9
10		12%	10	10	10	10	9	Complies with BM safety and rules	▽	▽	▽	●	▽	▽	▽	●	▽	●	●	○					5	5	5	5	1	5	10
11		12%	10	10	10	10	9	Rider safety	○	▽	▽	●	▽	▽	●	●	●	●	●	●					5	5	4	4	4	4	11
12		0%																													12
13		0%																													13
14		0%																													14
15		0%																													15
16		0%																													16



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	≥ 61.2 MPH	475 in^2	≥ 1000 W / 5s	< 15 Hz	< $1500	40 lbs	15 mph	Low	PASS							
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9				
	Technical Importance Rating	509.8	326.6	434.5	427.7	305	359.3	460.1	690.1	494.9	470	470	490.4				
	Relative Weight	9%	6%	8%	8%	6%	7%	8%	13%	9%	9%	9%	9%				
Curr. Products	#REF!																
	Eta	5	5	5	5	3	5	5	5		5	5					
	Primal II	5	5	4	5	5	4	5	5	5	5	5					
	Battle Mountain competitors	5	5	4	5	3	3	5	5	3	5	4					
	Standard bicycle (mountain or road)	1	1	5	1	5	5	1	5	1	5	4					
	Bonneville speed competitors	5	5	1	1	1	1	4	5		1	4					
	Production recumbents	3	3	3	3	3	2	1	5	1	5	4					
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix K: Concept Models

This appendix contains photos and descriptions of concept models created by the team during a rapid prototyping session. Photos were taken by Brendon Morey.

Figure 127 shows a frame with one under member. There is bracing that comes up from the bottom under the roll hoop, which comes straight down. The front wheel is smaller than the rear, and there is one triangulation to the wheel.

Figure 127. Frame with one under member.

Figure 128 is another frame with one under member, as well as side bracing and side impact foam. The roll hoop tapers in from the shoulders and contains impact foam near the rider's head. There are two rear triangle triangulation members.

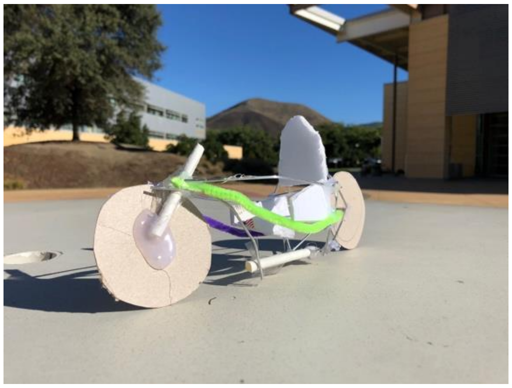


Figure 128. Frame with one under member, side bracing, and impact foam.

Figure 129 shows a sleeker design. This frame has long tubes bent instead of welded. There is a roll hoop and shoulder area roll hoop. There are two members on the bottom and side for bracing.

Figure 129. Frame with tube bends instead of welding.

Figure 130 shows a frame with bracing that comes around the bottom and side, with impact foam along sides & back. There are no negative bends in roll hoop and the two wheels would be the same size.

Figure 130. Frame with bottom and side bracing and side and back impact foam.

The last model, shown in Figure 131, was designed to resemble the frame of Primal 2 by George Leone. It has a Roll hoop that is connected to the rear axle, a side hoop that comes up from the floor, and one member along the bottom.

Figure 131. Frame resembling Primal 2.

Appendix L: Concept Prototype

This appendix contains photos of the process and test results from the concept prototype manufacturing, taken by Keyanna Henderson.

Process

Figure 132. Hot worked bending on homemade die.

Cold worked, outer diameter = 1”, thickness = 0.058”

Figure 133. Cold worked bending on shop jig showing this tube was bent to 100°.

Figure 134. Bent tube showing failure by deformation.

Cold worked, outer diameter = 1.25”, thickness = 0.049”

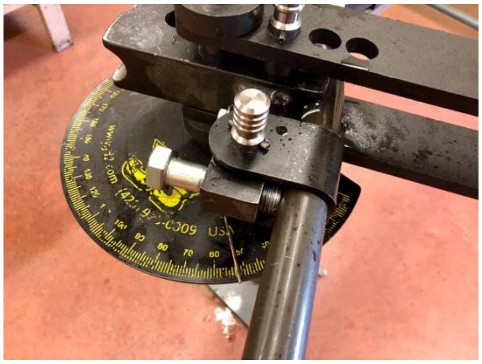


Figure 135. Cold worked bending on shop jig showing this tube was bent to 55°.

Figure 136. Bent tube showing failure by crinkling.

Hot worked, outer diameter = 1.25”, thickness = 0.049”

Figure 137. Hot Worked bending on homemade die.

Figure 138. Bent tube showing no failure.

Hot worked, outer diameter = 1.25”, thickness = 0.049”

Figure 139. Hot Worked bending on homemade die.

Figure 140. Bent tube showing failure by crinkling.

Hot worked, outer diameter = 1”, thickness = 0.049”

Figure 141. Hot Worked bending on homemade die.

Figure 142. Bent tube showing failure by deformation.

Appendix M: Design Hazard Checklist

This appendix contains the Design Hazard Checklist.

Team: Framed Advisor: Eileen Rossman

Y	N	
✓	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
✓	☐	2. Can any part of the design undergo high accelerations/decelerations?
✓	☐	3. Will the system have any large moving masses or large forces?
☐	✓	4. Will the system produce a projectile?
✓	☐	5. Would it be possible for the system to fall under gravity creating injury?
☐	✓	6. Will a user be exposed to overhanging weights as part of the design?
☐	✓	7. Will the system have any sharp edges?
☐	✓	8. Will any part of the electrical systems not be grounded?
☐	✓	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	✓	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	✓	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
✓	☐	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
✓	☐	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	✓	14. Can the system generate high levels of noise?
☐	✓	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
✓	☐	16. Is it possible for the system to be used in an unsafe manner?
☐	✓	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

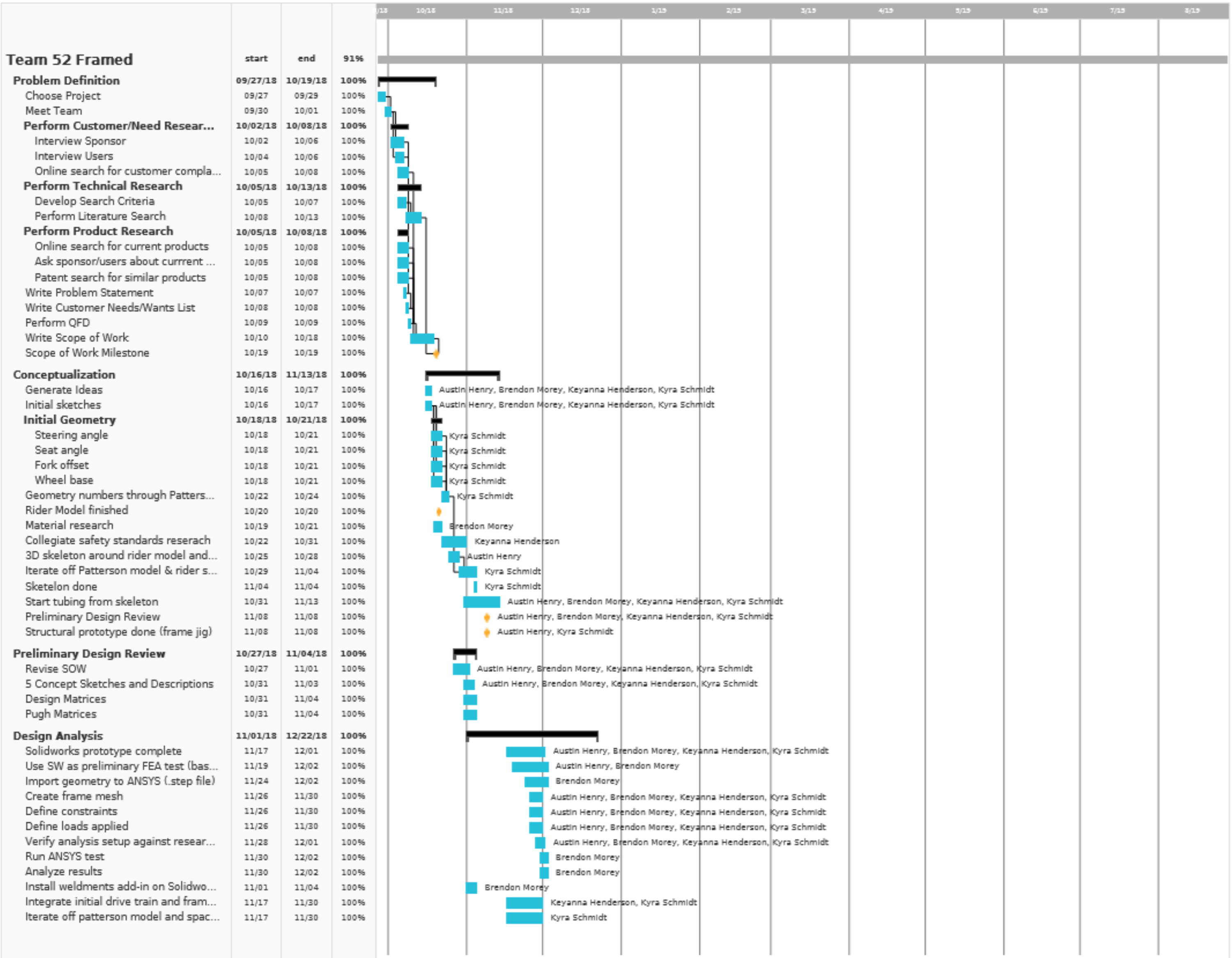
For any hazards checked "Y" for yes, please see Table 27 on the next page for individual descriptions, corrective actions to be taken, and the date to be completed on.

Table 27. Description of Hazards and Planned Corrective Actions.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Hazardous shearing and cutting, pinch points, and shear points could present themselves during the manufacturing of the frame.	Team members will be properly educated on the dangers of the pinch points and other hazards that are present in the manufacturing of the bicycle. The senior members and safety officers of the club will be the leaders of these trainings.	January – April 2019	January 26 – April 20
The frame will undergo very high accelerations and decelerations during testing and racing.	The rider will be wearing safety gear such as a helmet and a five-point harness. Also, there will be foam padding to protect the rider against the framing.	June – September 2019	
The system itself will be a large moving mass. When being ridden/raced, the frame will experience large drag forces and possibly forces due to wind.	The frame will be covered by a carbon fiber, fiberglass, and Kevlar fairing that will serve as the aerodynamic component and as the protection against abrasions in the event of a sliding crash.	June – September 2019	
Because the bike will be two wheeled, it is unstable on its own when upright. Therefore, the frame can easily fall due to gravity when not running at high enough speeds.	The rider will have extensive training time on the frame. The team will assist the rider in starting the vehicle for the first 15m of the course. The vehicle stability dynamics have been optimized by using the Patterson Control model to achieve the most stable bike geometry.	Battle Mountain September 2019 (date TBD)	
The user of the bike will exert a very large amount of energy during the race to move the bike at high speeds. He will be in a recumbent position that uses abdominal muscles in addition to leg muscles to power the bike.	The rider will be conditioned and fully trained in the bike in preparation for the competition. There will be an air intake that feeds the rider fresh air by use of a mask.	Battle Mountain September 2019 (date TBD)	
There is a possibility of exposure of hazardous materials to the team during manufacturing.	Proper safety techniques will be followed, and the team will be compliant with Cal Poly Shop safety standards.	January – April 2019	January 26 – April 20
The system could be used in an unsafe manner if the rider is not properly trained and comfortable operating the vehicle.	The rider will be trained on a version of a recumbent bicycle provided by Lightning Bikes. Once he is comfortable with the dynamics of riding a recumbent bike, he will begin the training of riding the competition bicycle.	Battle Mountain September 2019 (date TBD)	

Appendix N: Gantt Chart

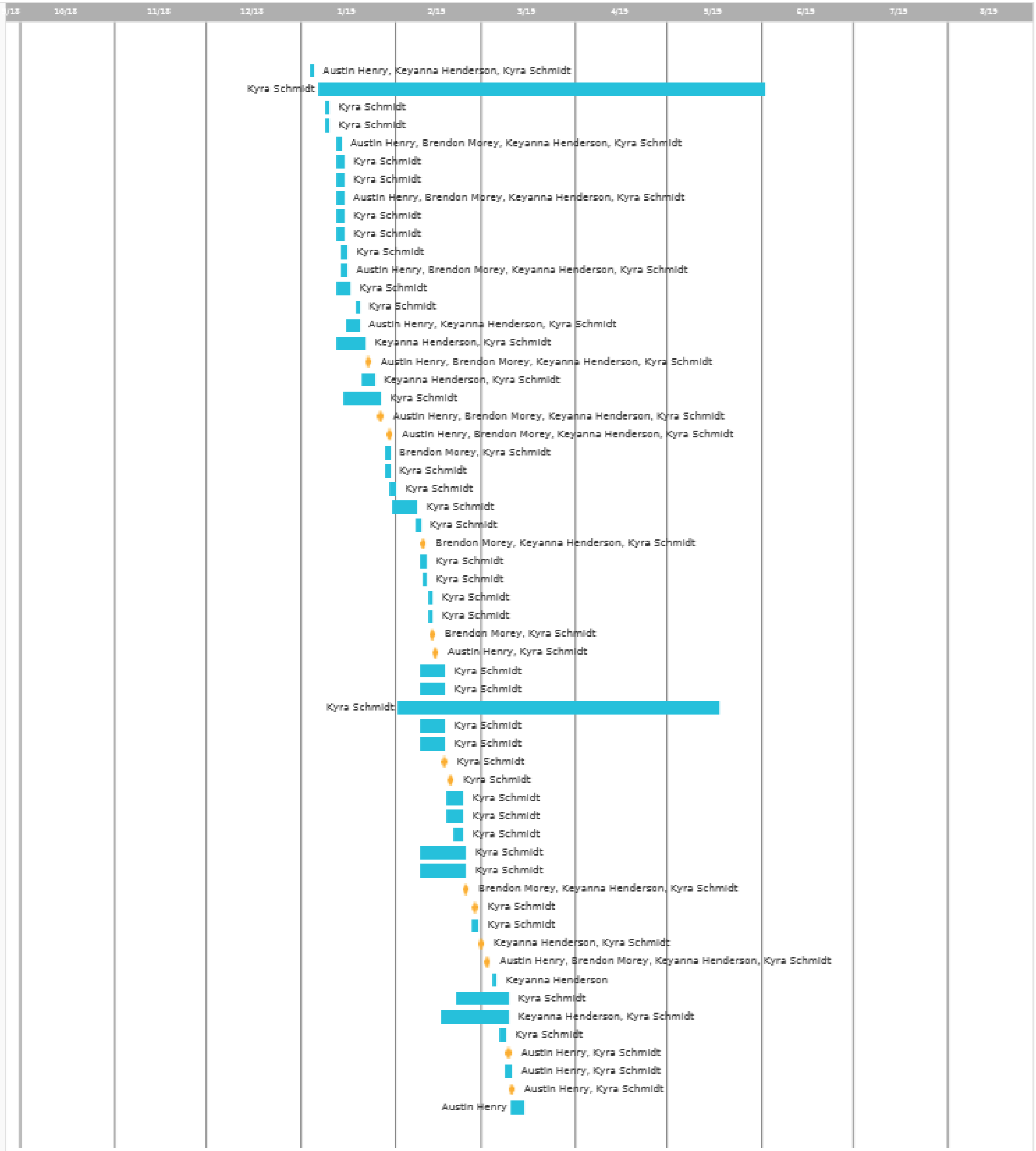
This appendix contains the final, overall Gantt Chart.



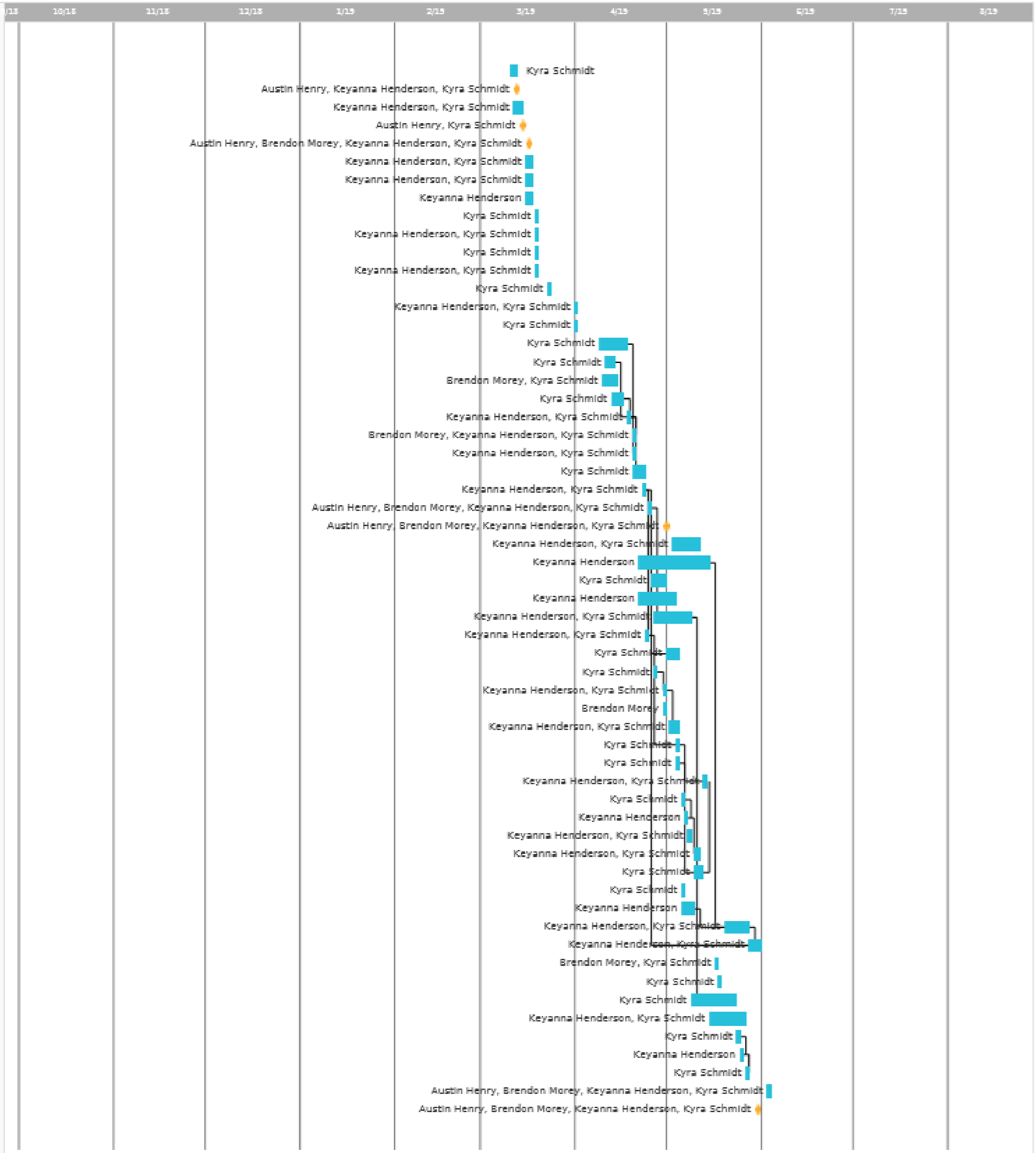
Task	Start	Finish	% Complete	Resources
Get all subsystems mounting points...	11/17	12/02	100%	Keyanna Henderson
Get rider pedal circle and leg circle	11/17	11/27	100%	Kyra Schmidt
Derive tiller steering for handling	11/19	12/02	100%	Kyra Schmidt
Reach out to Alex about tube bendi...	11/17	11/30	100%	Kyra Schmidt
Rider testing for final side positionin...	11/11	11/11	100%	Kyra Schmidt
Make roll bar around rider frontal pi...	11/17	11/30	100%	Austin Henry
Meet with Bike Builders regarding fo...	11/27	11/27	100%	Keyanna Henderson, Kyra Schmidt
Concept for frame jig	11/17	12/02	100%	Austin Henry
Model for frame jig	11/21	12/02	100%	Austin Henry
Discuss current handling findings wi...	11/26	11/30	100%	Kyra Schmidt
Rigorously go through CAD and cha...	11/17	12/02	100%	Brendon Morey, Kyra Schmidt
Add in frontal impact member	11/17	11/30	100%	Kyra Schmidt
Check patterson model inputs	11/25	11/30	100%	Kyra Schmidt
Rider testing under load	11/25	11/30	100%	Kyra Schmidt
Assemble fork and frame in CAD	12/02	12/04	100%	Brendon Morey, Kyra Schmidt
Create ISO standard safety require...	11/26	12/02	100%	Austin Henry
Check hip width for getting in/out of...	11/26	11/30	100%	Kyra Schmidt
Check clearances with knees for side...	11/26	11/30	100%	Kyra Schmidt
Get stiffness requirements from driv...	11/24	11/30	100%	Brendon Morey, Keyanna Henderson, Kyra Schmidt
Building the testing jig	11/24	12/02	100%	Austin Henry, Kyra Schmidt
Testing jig for final rider positioning	12/12	12/12	100%	Kyra Schmidt
Physical gauges around Josh for ride...	12/12	12/12	100%	Kyra Schmidt
Verify with Philwood hubs on dimens...	12/20	12/20	100%	Kyra Schmidt
Rider testing with high sensitivity bi...	12/12	12/12	100%	Kyra Schmidt
Finalize loading values for FEA	12/02	12/07	100%	Austin Henry
Finalize loading locations for FEA	12/02	12/07	100%	Kyra Schmidt
Verify hub dimensions for rear triang...	12/13	12/13	100%	Kyra Schmidt
Analyze with CAD and verify fork an...	12/19	12/22	100%	Kyra Schmidt
Finish first stage frame jig cad	12/19	12/22	100%	Kyra Schmidt
Finish second stage frame jig cad	12/19	12/22	100%	Austin Henry
Jig feasibility recommendations from...	12/19	12/22	100%	Austin Henry, Kyra Schmidt
Detail Design	**11/12/18**	**05/25/19**	**100%**	
Select fasteners	11/12	11/22	100%	Austin Henry, Kyra Schmidt
Interim Design Review	12/04	12/04	100%	Austin Henry, Brendon Morey, Eileen Rossman, Keyanna Henderson, Kyra Schmidt
Critical Design Review Club	01/12	01/12	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Source steerer	12/20	12/20	100%	Kyra Schmidt
Source fork blades	12/20	12/20	100%	Kyra Schmidt
Source headset	12/01	12/08	100%	Kyra Schmidt
Design front dropouts	12/05	12/20	100%	Kyra Schmidt
Design rear dropouts	12/18	12/18	100%	Kyra Schmidt
Source head tube	11/23	11/23	100%	Kyra Schmidt
Source frame tubing material	12/01	12/01	100%	Brendon Morey, Kyra Schmidt
Finalize fork offset, headtube angle,...	12/21	12/21	100%	Kyra Schmidt
Finalize bend radii based on benders...	12/18	12/18	100%	Kyra Schmidt
Finalize bend radii, minimum straigh...	12/28	12/28	100%	Kyra Schmidt
Design seat mounting	12/28	12/28	100%	Kyra Schmidt
Bottom member final design, for sea...	12/27	12/27	100%	Kyra Schmidt
Rear triangle brake mounting memb...	01/11	01/11	100%	Kyra Schmidt
Top and middle side support design	11/25	11/25	100%	Keyanna Henderson, Kyra Schmidt
Truss members	12/01	12/01	100%	Austin Henry, Brendon Morey
Mid drive truss members	11/26	11/26	100%	Brendon Morey, Kyra Schmidt
Final bike component compatibility ...	01/11	01/11	100%	Kyra Schmidt
Design harness mounting	01/05	01/05	100%	Brendon Morey, Keyanna Henderson
Design/ source mid drive bosses and...	12/26	12/26	100%	Kyra Schmidt
Source stock for dropouts	11/27	11/27	100%	Kyra Schmidt
Source stock for frame jigs	01/05	01/05	100%	Kyra Schmidt
Create excel documenting total of all...	01/01	01/01	100%	Kyra Schmidt

Create excel documenting all parts t...	01/01	01/01	100%	Kyra Schmidt
Cost analysis	01/09	01/09	100%	Kyra Schmidt
Document minimum lengths of tubi...	01/03	01/03	100%	Kyra Schmidt
Out of plane tubing detailed drawin...	01/06	01/06	100%	Kyra Schmidt
Make individual part files of each tu...	01/06	01/06	100%	Kyra Schmidt
Create planes in part files and save ...	01/06	01/06	100%	Kyra Schmidt
Small cut indexes in CAD for miters ...	01/06	01/06	100%	Kyra Schmidt
Final parts drawings for all frame tu...	01/06	01/16	100%	Kyra Schmidt
Final parts drawings for all 1st stage...	01/16	01/23	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Final parts drawings for all 2nd stag...	01/16	01/23	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Final parts drawings for fork jig	01/16	01/23	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Assembly drawings of fork	01/06	01/06	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Assembly drawing of frame	01/07	01/07	100%	Kyra Schmidt
Assembly drawing of frame jig 1	01/07	01/16	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Assembly drawing of frame jig 2	01/07	01/15	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
BOM frame	01/11	01/14	100%	Kyra Schmidt
BOM fork	01/11	01/14	100%	Kyra Schmidt
BOM frame jig 1	01/11	01/14	100%	Austin Henry, Kyra Schmidt
BOM frame jig 2	01/11	01/14	100%	Austin Henry
BOM fork jig	01/11	01/14	100%	Kyra Schmidt
Layout drawing for stage 1 jig	01/11	01/14	100%	Kyra Schmidt
Layout drawing for stage 2 jig	01/11	01/14	100%	Kyra Schmidt
Finalize brake mounting members	01/11	01/14	100%	Kyra Schmidt
Finalize seat mounting members	01/11	01/14	100%	Kyra Schmidt
Verify custom made fixtures with wo...	01/09	01/09	100%	Kyra Schmidt
Create Solidworks drawing template ...	12/18	12/21	100%	Keyanna Henderson
Choose harness to purchase	12/18	12/21	100%	Keyanna Henderson
Choose foam to purchase and mount...	01/01	01/08	100%	Keyanna Henderson, Kyra Schmidt
Finalize Frame Jig CAD	01/01	01/11	100%	Austin Henry, Kyra Schmidt
Frame Safety Testing Design	01/01	01/25	100%	Austin Henry
Discuss and finalize boundary condit...	01/14	01/15	100%	Brendon Morey
Re input boundary conditions for ea...	01/15	01/16	100%	Brendon Morey
Re run all FEA simulations	01/17	01/18	100%	Brendon Morey
Hand calcs for BB support beam	01/14	01/18	100%	Keyanna Henderson
Hand calcs for steerer	01/14	01/18	100%	Austin Henry
Side support pillar frame jig redesign...	01/15	01/16	100%	Kyra Schmidt
Ask for advice re jig pillar first stage...	01/14	01/15	100%	Kyra Schmidt
Discuss mid drive mounting potentia...	01/14	01/18	100%	Kyra Schmidt
Meet with drivetrain for final loading...	01/14	01/18	100%	Brendon Morey, Keyanna Henderson, Kyra Schmidt
Recap meeting with Jim G. about C...	01/14	01/18	100%	Kyra Schmidt
Redesign mid drive fixturing based ...	01/17	01/20	100%	Kyra Schmidt
Finalize tubing OD's and wall thickn...	01/17	01/18	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Critical Design Review Senior Project	01/15	01/15	100%	Brendon Morey, Kyra Schmidt
Mesh convergence plot	01/15	01/15	100%	Brendon Morey
Resource GA stock	01/15	01/15	100%	Kyra Schmidt
Potential donations for steel	01/15	01/15	100%	Kyra Schmidt
Meeting with Jim G via mid drive mo...	01/15	01/15	100%	Brendon Morey, Keyanna Henderson, Kyra Schmidt
Re size top plates in frame jig for m...	01/15	01/15	100%	Kyra Schmidt
Meet with Jim C via layout and scribi...	01/18	01/18	100%	Kyra Schmidt
Meet with Jim G to go over mitering...	01/16	01/16	100%	Kyra Schmidt
Left hand out of plane bend tubing d...	01/16	01/20	100%	Kyra Schmidt
Follow up thank you to Advance Tube	01/16	01/16	100%	Kyra Schmidt
Discuss handling with Dr. Patterson	04/15	04/22	100%	Kyra Schmidt
Meeting with Dr. Patterson	05/04	05/04	100%	Kyra Schmidt
Discuss tiller steering approx with Dr...	05/13	05/25	100%	Kyra Schmidt
Manufacturing	**01/04/19**	**06/03/19**	**100%**	
Manufacturing & Test Review	02/28	02/28	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt

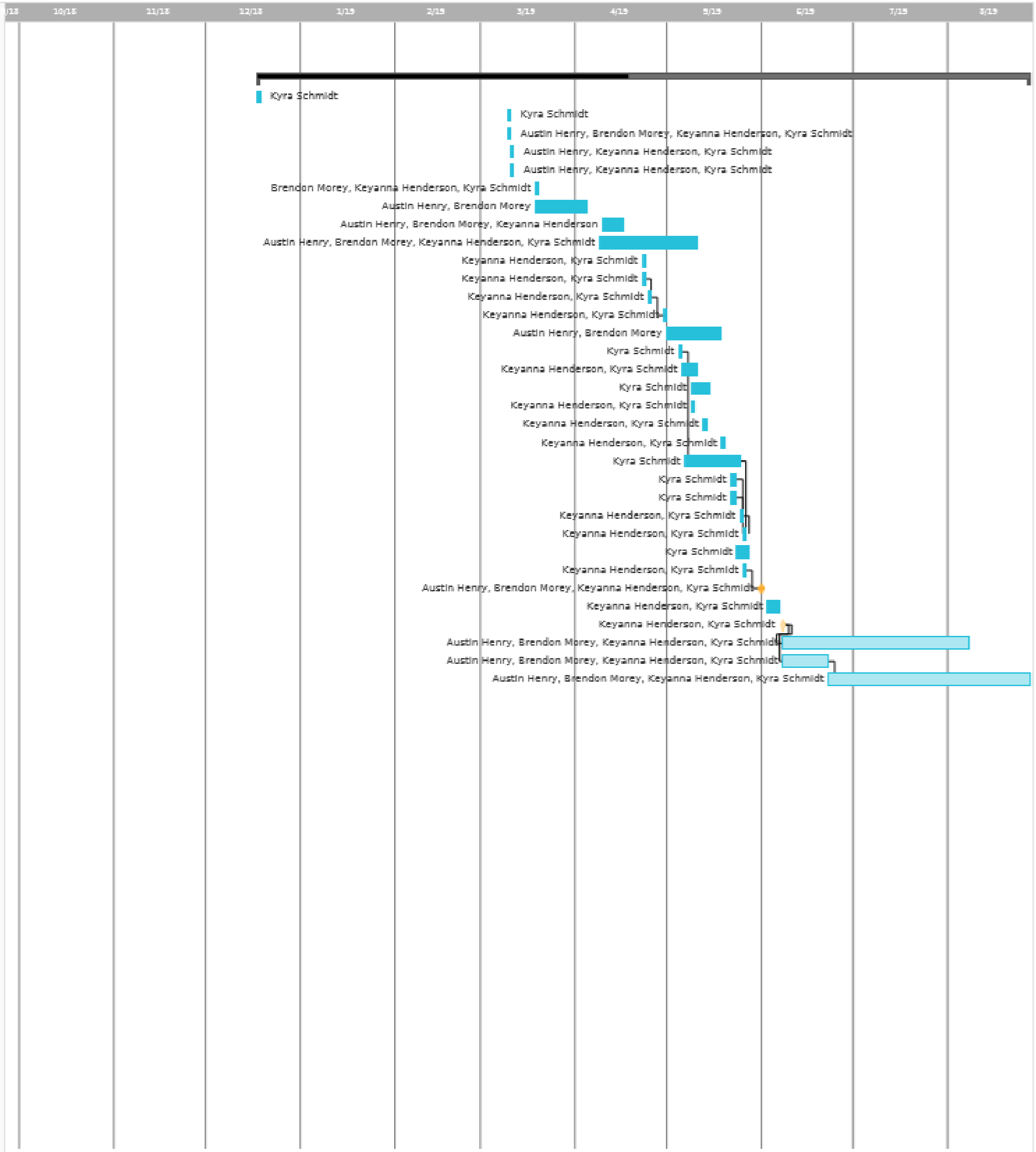
Task	Start	End	%	Resources
Concept Prototype	01/04	01/04	100%	Austin Henry, Keyanna Henderson, Kyra Schmidt
Plan build day schedule (repeating)	01/07	06/01	100%	Kyra Schmidt
Acquire 4" radii bender that can do	01/09	01/09	100%	Kyra Schmidt
Get Jim G.'s opinion of indexing plan	01/09	01/09	100%	Kyra Schmidt
Plan who is creating which drawings	01/13	01/13	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Plan critical parts and milestones	01/13	01/14	100%	Kyra Schmidt
Meeting with Gerrity for CNC tooling	01/13	01/14	100%	Kyra Schmidt
Meeting with Advance Tube	01/13	01/14	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Machine rear drop outs	01/13	01/14	100%	Kyra Schmidt
CAM front drop outs	01/13	01/14	100%	Kyra Schmidt
Purchase stock for frame jig	01/14	01/15	100%	Kyra Schmidt
Build Day (2/2)	01/14	01/15	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Book CNC machines	01/13	01/16	100%	Kyra Schmidt
Acquire rest of frame jig stock from ...	01/19	01/19	100%	Kyra Schmidt
Finalize detail drawings of all jig par...	01/16	01/19	100%	Austin Henry, Keyanna Henderson, Kyra Schmidt
Purchase: silver pencil, emory cloth ...	01/13	01/21	100%	Keyanna Henderson, Kyra Schmidt
Final decision on in house or out of ...	01/22	01/22	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Finalize detail drawings of all bent t...	01/21	01/24	100%	Keyanna Henderson, Kyra Schmidt
Plan order of CNC parts to be made	01/15	01/26	100%	Kyra Schmidt
Build Day (1/26)	01/26	01/26	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Build Night (1/29)	01/29	01/29	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Get water jet parts water jet	01/29	01/29	100%	Brendon Morey, Kyra Schmidt
Machine front dropouts	01/29	01/29	100%	Kyra Schmidt
Write manufacturing plan	01/30	01/31	100%	Kyra Schmidt
Organize and keep track of purchas...	01/31	02/07	100%	Kyra Schmidt
Get bike builder's fork jig	02/08	02/08	100%	Kyra Schmidt
Build Day (2/9)	02/09	02/09	100%	Brendon Morey, Keyanna Henderson, Kyra Schmidt
Decide what parts can be shared wi...	02/09	02/10	100%	Kyra Schmidt
Logistics meeting for club deadlines	02/10	02/10	100%	Kyra Schmidt
Clamp/ tac jig to table and ensure le...	02/12	02/12	100%	Kyra Schmidt
Print out miters for fork blades	02/12	02/12	100%	Kyra Schmidt
Build Night (2/12)	02/12	02/12	100%	Brendon Morey, Kyra Schmidt
Build Night (2/13)	02/13	02/13	100%	Austin Henry, Kyra Schmidt
Move bender to hangar	02/09	02/16	100%	Kyra Schmidt
Test of indexing miters with current...	02/09	02/16	100%	Kyra Schmidt
Finalize detail drawings of all miters...	02/02	05/17	100%	Kyra Schmidt
Move baja welding table to in front o...	02/09	02/16	100%	Kyra Schmidt
Level welding table	02/09	02/16	100%	Kyra Schmidt
Build Day (2/16)	02/16	02/16	100%	Kyra Schmidt
Build Day (2/18)	02/18	02/18	100%	Kyra Schmidt
Locate all tac'd components on jig	02/18	02/22	100%	Kyra Schmidt
Locate all bolted/ snugged compone...	02/18	02/22	100%	Kyra Schmidt
Rear triangle plotted miters unwrap...	02/20	02/22	100%	Kyra Schmidt
Acquire long stock from Aircraft Spr...	02/09	02/23	100%	Kyra Schmidt
Miter method testing and tool figure...	02/09	02/23	100%	Kyra Schmidt
Build Day (2/23)	02/23	02/23	100%	Brendon Morey, Keyanna Henderson, Kyra Schmidt
Build Night (2/26)	02/26	02/26	100%	Kyra Schmidt
Finalize purchasing documentation ...	02/26	02/27	100%	Kyra Schmidt
Build Night (2/28)	02/28	02/28	100%	Keyanna Henderson, Kyra Schmidt
Build Day (3/2)	03/02	03/02	100%	Austin Henry, Brendon Morey, Keyanna Henderson, Kyra Schmidt
Purchase EVA impact foam	03/05	03/05	100%	Keyanna Henderson
Pick up bent tubes from Advance Tu...	02/21	03/09	100%	Kyra Schmidt
Test most aggressive degrees of be...	02/16	03/09	100%	Keyanna Henderson, Kyra Schmidt
Index out of plane bent tubes	03/07	03/08	100%	Kyra Schmidt
Build day (3/9)	03/09	03/09	100%	Austin Henry, Kyra Schmidt
Miter side supports	03/09	03/10	100%	Austin Henry, Kyra Schmidt
Build day (3/10)	03/10	03/10	100%	Austin Henry, Kyra Schmidt
Break tac and rotate top side suppor...	03/11	03/14	100%	Austin Henry



Index mid drive supports	03/11	03/12	100%
Build night (3/12)	03/12	03/12	100%
Drill and miter mid drive supports	03/12	03/14	100%
Build night (3/14)	03/14	03/14	100%
Build day (3/16)	03/16	03/16	100%
Remove frame from 1st stage jig	03/16	03/17	100%
Remove 1st stage jig from welding t...	03/16	03/17	100%
Grind welding table flat	03/16	03/17	100%
Layout and scribe all 2nd stage jig l...	03/19	03/19	100%
Get 2nd stage jig on welding table in...	03/19	03/19	100%
Tac 2nd stage jig to welding table	03/19	03/19	100%
Place frame on 2nd stage jig	03/19	03/19	100%
Place frame back on 1st stage jig for...	03/23	03/23	100%
Re-miter top side support	04/01	04/01	100%
Re-miter left mid drive truss	04/01	04/01	100%
Rear triangle full welded	04/09	04/17	100%
Side supports full welded	04/11	04/13	100%
Miter brake mounting (rear triangle)	04/10	04/14	100%
Full weld bottom bracket support	04/13	04/16	100%
Re set up 2nd stage jig	04/18	04/18	100%
Miter straight bottom members	04/20	04/20	100%
Drill holes in bottom members	04/20	04/20	100%
Bent bottom member + holes	04/20	04/23	100%
Full weld bottom members	04/23	04/23	100%
Bend bent truss members	04/25	04/25	100%
Confirmation Prototype Sign off	04/30	04/30	100%
Size and cut foam	05/03	05/11	100%
Cut and sew velcro	04/22	05/14	100%
Fit with seat in bosses	04/26	04/30	100%
Purchase harness and submit reimb...	04/22	05/03	100%
Miter side truss members	04/27	05/08	100%
Face and ream headtube (with bike ...	04/24	04/24	100%
Purchase and install crown race	05/01	05/04	100%
Contact George about layup plate	04/27	04/27	100%
Prep (sizing, cutting) for fiberglass l...	04/30	04/30	100%
Finish harness mount tabs	04/30	04/30	100%
Fiberglass stiffener layup x2	05/02	05/04	100%
Assemble headset in headtube	05/04	05/04	100%
Purchase race seat	05/04	05/04	100%
Assemble fork in headset w/ wheel ...	05/13	05/13	100%
Cut out bottom bracket shell	05/06	05/06	100%
Re miter bb support	05/07	05/07	100%
Re-set up jig for welding new bb	05/08	05/08	100%
Weld in new bb shell	05/10	05/11	100%
Press on race seat	05/10	05/12	100%
Final okay from Jim G and Dr. Mello ...	05/06	05/06	100%
Cut fiberglass to size	05/06	05/09	100%
Attach velcro and foam to fiberglass	05/20	05/27	100%
Mount foam in bike	05/28	05/31	100%
Place wheel in rear triangle	05/17	05/17	100%
Drill holes and locate bosses in fork,...	05/18	05/18	100%
Full weld truss members	05/09	05/23	100%
Full weld bosses	05/15	05/26	100%
Portable frame jig - design	05/24	05/24	100%
Portable frame jig - cut material	05/25	05/25	100%
Portable frame jig - weld	05/27	05/27	100%
Locate harness mount tabs with seat...	06/03	06/03	100%
Final frame sign off	05/30	05/30	100%



Testing	**12/18/18**	**08/27/19**	**48%**
Josh on rider testing jig	12/18	12/18	100%
Get info on height of frame outside f...	03/10	03/10	100%
Test fit 1 with Josh and side supports...	03/10	03/10	100%
Remove frame from jig for testing	03/11	03/11	100%
Set up jig over josh on rider testing j...	03/11	03/11	100%
Second test fit with side supports in f...	03/19	03/19	100%
Write destructive testing procedures	03/19	04/04	100%
Roll bar testing- crush test	04/10	04/16	100%
Operators manual finalized	04/09	05/10	100%
Test fit, Josh getting into the bike wi...	04/23	04/23	100%
Test fit, Josh in bike with seat mold ...	04/23	04/23	100%
Test fit, with shoulder & leg truss m...	04/25	04/25	100%
Test fit with Josh and bent truss me...	04/30	04/30	100%
Analyze load testing data and put in ...	05/01	05/18	100%
Email Prof Kean about using the rad...	05/05	05/05	100%
Destructive weld testing	05/06	05/10	100%
Inspect weld tests, Kevin William ins...	05/09	05/14	100%
Test with Josh and seat and fork and...	05/09	05/09	100%
Test with Josh and seat and vision s...	05/13	05/13	100%
Weigh bike	05/19	05/19	100%
Figure out if need special fixtures, h...	05/07	05/24	100%
Excel doc for calc CG from lab results	05/22	05/23	100%
Excel doc for calc Rx from lab results	05/22	05/23	100%
Find experimental CG according to ...	05/25	05/25	100%
Swing the final frame to figure out a...	05/26	05/26	100%
Uncertainty analysis for experimenta...	05/24	05/27	100%
Test fit with Josh, with final drivetrai...	05/26	05/26	100%
Project Expo	05/31	05/31	100%
Test with Josh and foam	06/03	06/06	100%
Chassis Rideable (still need: braking,...	06/07	06/07	0%
Testing Josh starting bike	06/08	08/07	0%
Testing with Josh riding bike- low sp...	06/08	06/22	0%
Testing Josh at airport- higher speeds	06/23	08/27	0%



Appendix O: Purchasing Excel Documents

This appendix contains purchasing excel documents.

Purchasing excel is for all frame components is shown below.

Part	Part # (if applicable)	Stock Description	Link/ Source	Amount total (quantity, feet, etc.)	Minimum lengths needed (if applicable)	Unit Cost	Total Cost	Purchased? (Y/N)	When purchased	Recieved? (Y/N)	When recieved/ projected date recieved	How purchased?	Who purchased?
Head Tube	n/a	n/a	http://www.paragonm	1	n/a	$38.00	$38.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Roll Bar manufacture	04-A01-001-FRAME-RollhoopUpper	see Roll Bar tubing	Advance Tube	1	n/a	$0.00	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Advance Tube Bent tubing stock	04-A01-001-FRAME-RollhoopUpper; 04-A01-001-FRAME-RollhoopLower; 04-A01-001-FRAME-BottomBracketSupport; 04-A01-001-FRAME-TopSideSupport; 04-A01-001-FRAME-MiddleSideSupport	4130 TUBE: 1", 1.25", 1.5" OD x .035", .049"	Advance Tube	1	n/a	$410.75	$410.75	Y	Feb 2019	Y	March 2019	By team & reimbursment	Kyra
Roll Bar harness mount	04-A01-001-FRAME-RollhoopHarnessMountBar	4130 TUBE: 1"ODx.035"	https://www.aircrafts	2	2 ft	$4.75	$9.50	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Bottom Bracket support manufacture	04-A01-001-FRAME-BottomBracketSupport	see Bottom Bracket support cantilever tubing	Advance Tube	1	n/a	$0.00	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Side supports manufacture	04-A01-001-FRAME-TopSideSupport; 04-A01-001-FRAME-MiddleSideSupport	4130 TUBE: 1"ODx.035"	Advance Tube	4	n/a	$0.00	0	Y	Jan 2019	Y	March 2019	By team & reimbursment	Kyra
Bottom Support tubing	04-A01-001-FRAME-BottomMemberBent	4130 TUBE: .875"ODx.049"	https://www.aircrafts	4	4 ft	$5.40	$21.60	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-BottomMemberAngled	4130 TUBE: .875"ODx.035"	https://www.aircrafts	4	2 ft	$3.90	$15.60	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-BottomMemberHorizontalHarnessMount	4130 TUBE: .875"ODx.035"	https://www.aircrafts	1	1 ft	$3.90	$3.90	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Trusses (not including mid drive mounting)	04-A01-001-FRAME-ShoulderTrussSupport	4130 TUBE: .875"ODx.035"	https://www.aircrafts	4	2 ft	$3.90	$15.60	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-BentTruss	4130 TUBE: .875"ODx.035"	https://www.aircrafts	2	1 ft	$3.90	$7.80	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-StraightTrussRear	4130 TUBE: .875"ODx.035"	https://www.aircrafts	2	1 ft	$3.90	$7.80	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-StraightTrussMid	4130 TUBE: .875"ODx.035"	https://www.aircrafts	3	3 ft	$3.90	$11.70	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-StraightTrussFront	4130 TUBE: .875"ODx.035"	https://www.aircrafts	2	2 ft	$3.90	$7.80	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Rear dropouts	04-A01-002-REARDROPOUTS	4130 RND: 1.375"DIAx12"	Bike Builders Donati	1	n/a	0	0	Y	Dec 2018	Y	Dec 2018	By team & reimbursment	Kyra
Rear Triangle	04-A01-001-FRAME-RearTriangleInnerLower	4130 TUBE: .75"ODx.035"	https://www.aircrafts	3	3 ft	$3.65	$10.95	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-RearTriangleOuterLower	4130 TUBE: .75"ODx.035"	https://www.aircrafts	3	3 ft	$3.65	$10.95	Y	Feb 2019	Y	March 2019	By team & reimbursment	Kyra
	04-A01-001-FRAME-RearTriangleUpper	4130 TUBE: .75"ODx.035"	https://www.aircrafts	4	2 ft	$3.65	$14.60	Y	Feb 2019	Y	March 2019	By team & reimbursment	Kyra
Mid drive bosses	04-A01-004-MIDDRIVEBOSS	1018 RND: .5"DIAx12"	IMS	1	n/a	$1.79	$1.79	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra

Part	Part # (if applicable)	Stock Description	Link/ Source	Amount total (quantity, feet, etc.)	Minimum lengths needed (if applicable)	Unit Cost	Total Cost	Purchased? (Y/N)	When purchased	Recieved? (Y/N)	When recieved/ projected date recieved	How purchased?	Who purchased?
Cantilever for fairing	04-A01-001-FRAME-FairingSupport	4130 TUBE: 1"ODx.035"	https://www.aircrafts|	2	2 ft	$4.75	$9.50	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Mid drive mounting	04-A01-001-FRAME-MidDriveTruss	4130 TUBE: .875"ODx.035"	https://www.aircrafts|	4	2 ft	$3.90	$15.60	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Bosses for seat mounting	04-A01-005-SEATBOSS; 04-A01-007-SEATBOSSLONG	1018 RND: .5"DIAx12"	IMS	2	n/a	$1.79	$3.58	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Tab for harness mounting	04-A01-006-HARNESSTABS	Steel 13 ga: 4" x 4"	IMS	1	n/a	$12.46	$12.46	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Bolt for harness mounting	n/a	7/16-20 x 1.25"	Ace	1	n/a	$2	$2	N	March 2019	N	March 2019	By team & reimbursment	
Racing Harness	n/a	n/a	https://www.summitr	1	n/a	$0	0	Y	March 2019	Y	March 2019	By team & reimbursment by MESFAC	Keyanna
EVA Impact foam (side members)- 1" thick	n/a	24 mm	https://tntcosplaysupply.com/product/extra-thick-eva-foam/	2	n/a	$9.95	$19.90	Y	March 2019	Y	March 2019	By team & reimbursment	Keyanna
EVA Impact foam (adhesive backed)	n/a	4 mm	https://tntcosplaysupply.com/product/adhesive-backed-eva-foam/	1	n/a	$5.95	$5.95	Y	March 2019	Y	March 2019	By team & reimbursment	Keyanna
Hook and loop velcro for wraparound and panels	n/a	1" x 30'	https://www.mcmaster.com/9273k34	1	n/a	$37.18	$37.18	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Fiberglass load distribution memebers for shoulder area	n/a	4 oz 30" x 36" e-glass weave	The Craft	2	n/a	$12	$24	Y	March 2019	Y	March 2019	By team & reimbursment	Team
Spray adhesive	n/a	n/a	https://www.amazon.	1	n/a	$12	$12	N	March 2019	N	March 2019		
Resin, Hardner, Bagging, etc.	n/a	n/a	Club: will use materials purchased by club already for fairing, etc.	n/a	n/a	0	0	Y	March 2019	Y	March 2019	By team & reimbursment	Team
Copper tubing brush	n/a	n/a	Home Depot	1	n/a	$5	$5	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
320 grit Emery cloth	n/a	n/a	Home Depot	1	n/a	$15	$15	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Extra frame stock	04-A01-001-FRAME-FairingSupport	4130 TUBE: 1"ODx.035"; .875"ODx.035"	https://www.aircrafts|	2	2 ft	$4.75	$9.50	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Back ordered stock + more extra stock	n/a	4130 TUBE: various	https://www.aircrafts|	n/a	n/a	n/a	$140.66	Y	April 2019	Y	April 2019	By team & reimbursment	Kyra
Sheet Cost	$900.17												
Overall Cost	$1,971.71												

Purchasing excel for all Frame Jig components.

Stage 1	Stage 2											
Part	**Part # (if applicable)**	**Stock Description**	**Link/ Stock Source**	**Amount**	**Unit Cost**	**Total Cost**	**Purchased? (Y/N)**	**When purchased**	**Recieved? (Y/N)**	**When recieved/ projected date recieved**	**How purchased?**	**Who purchased?**
Dummy rear hub	04-A03-010-DUMMYREARHUB	6061 RND: 1.25"DIAx5"	IMS	1	$5	$5	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Jig pillar	04-A03-001-JIG_PILLAR	Steel 4x4: .25" wallx24"	Rose Float	1	$0.00	$0.00	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Jig base	04-A03-001-JIG_BOTTOM	Steel 4x4: .25" wallx88"	Rose Float	1	$0	$0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Tube blocks 1.25"	04-A03-002-TUBE_BLOCK_1.25	n/a	George Leone	3	$0.00	$0.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Tube blocks 1"	04-A03-002-TUBE_BLOCK_1.0	n/a	George Leone	1	$0.00	$0.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Bottom Bracket Plug	04-A03-004-BB_PLUG	6061 RND: 2"DIAx5"	IMS	1	$11	$11	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Conical Spacers (Head tube)	04-A03-007-CONICAL_PLUG	6061 RND: 2"DIAx5"	IMS	1	$7	$7	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
All thread (head tube)	04-A03-005-HEAD_TUBE_ROD	1/2-20 ALL THREADx36"	Ace	1	$6.99	$6.99	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Nuts for 1/2 All thread	n/a	1/2-20 Nuts	Ace	8	$0.30	$2.40	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Washers for above nuts (do we need these?)	n/a	1/2" Warshers	Ace	1 pack	$8.49	$8.49	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
#10-32 bolts for Tube blocks and plate for jig pillar	n/a	#10-32x1.5"	Ace	12	$1.19	$14.28	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
3/8 Washers	n/a	3/8" washers	Ace	1 pack	$7.29	$7.29	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
3/8" Bolts	n/a	3/8-24 X 0.75"	Ace	1 pack	$33.99	$33.99	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Front Plate	04-A03-003-FRONT_PLATE	Steel 1/4" PLT: 12"x7"	From inside top plate	2	0 (will be from top plate)	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Top Plate	04-A03-008-TOP_PLATE	Steel 1/4" PLT: 16"x21"	IMS	1	$67.00	$67.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Head tube mounts (plate distance spacer)	04-A03-006-HEAD_TUBE_MOUNT; 04-A03-006-HEAD_TUBE_MOUNT_SPACER	6061 RND: 1"DIAx24"	IMS	1	$15	$15	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Mid Drive Spacers	04-A03-009-MID_DRIVE_SPACER	6061 RND: 1"DIAx6"	IMS	1	$5	$5	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Top Side Support Pillar	04-A03-013-PILLARTOPSIDESUPPORT	Steel 2x2: .125" wallx24"	Sea train	1	0	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra

Stage 1	Stage 2											
Part	**Part # (if applicable)**	**Stock Description**	**Link/ Stock Source**	**Amount**	**Unit Cost**	**Total Cost**	**Purchased? (Y/N)**	**When purchased**	**Recieved? (Y/N)**	**When recieved/ projected date recieved**	**How purchased?**	**Who purchased?**
Middle Side Support Pillar	04-A03-011-PILLARMIDSIDESUPPORT	Steel 2x2: .125" wallx24"	Sea train	1	0	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Fairing Cantilever Riser	04-A03-012-FAIRINGCANTILEVERSPACER	Steel 2x3: .125" wallx24"	HAAS Cutoffs	1	0	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Plate for jig pillar	04-A03-016-PILLAR_BASE	Steel PLT: .25" thick, 8"x6"	Steel Bridge	1	$0.00	$0.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Plate for inside jig pillar	04-A03-014-JIGPILLARPLATE	Steel PLT: .25" thick, 3.5"x3.5"	Steel Bridge	1	$0.00	$0.00	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Bolts for jig pillar blate inside thing	n/a	#10-32x1"	Ace	1	$0.95	$0.95	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Dummy bolts for rear dropouts	n/a	M8x1.25x40mm	Ace	4	$0.95	$3.80	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Bolts for tube blocks	n/a	M5x.8x35mm	Ace	4	$1.19	$4.76	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Brendon
Roll bar riser	04-A04-006-ROLL_BAR_POST	Steel 2x2: .125" wallx24"	Rose Float	2	0	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Roll bar riser plate	04-A04-006-ROLL_BAR_POST	Steel PLT: .25" thick, 4"x4"	Steel Bridge	2	0	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Tube blocks for bottom member	04-A03-002-TUBE_BLOCK_0.875	n/a	http://www.paragonmachineworks.com/ft4006-tube-block.html	2	$12.83	$25.66	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Center support	04-A04-003-CENTER_SUPPORT	Steel 4x4: .125" wallx24"	IMS	1	$28	$28	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Roll bar plug	04-A04-005-ROLL_BAR_PLUG2	6062 RND: 1.5"DIAx5"	IMS	1	$10	$10	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Sheet Cost	$256.61											

Purchasing excel for all Fork components.

Part	Part # (if applicable)	Stock Description	Link/ Stock Source	Amount	Unit Cost	Total Cost	Purchased? (Y/N)	When purchased	Recieved? (Y/N)	When recieved/ projected date recieved	How purchased?	Who purchased?
Front dropouts	04-A02-003-FRONTDROPOUTS	4130 PLT: 3/4"x6"x2"	https://www.mcmaster	2	$17.95	$35.90	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Fork Steerer	04-A02-004-STEERTUBE	n/a	https://www.cycle-fram	1	$10.60	$10.60	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Fork blades	04-A02-006-FORKBLADELEFT; 04-A02-007-FORKBLADERIGHT	n/a	https://www.cycle-fram	2	$24.00	$48.00	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Head set	n/a	n/a	https://www.chainreac	1	$45.51	$45.51	Y	Feb 2019	Y	Feb 2019	By team & reimbursment	Kyra
Fork tensioner bosses	04-A02-005-FORKBOSS	n/a	https://www.cycle-fram	2	$1.69	$3.38	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Crown race	n/a	n/a	Amazon	1	$12	$12	Y	April 2019	Y	April 2019	By team & reimbursment	Kyra
Race seat	n/a	n/a	Nova	1	$21	$21	Y	May 2019	N	May 2019	By team & reimbursment	Kyra
Sheet Cost	$176.39											

Purchasing excel for all Fork jig components.

Part	Part # (if applicable)	Stock Description	Link/ Stock Source	Amount	Unit Cost	Total Cost	Purchased? (Y/N)	When purchased	Recieved? (Y/N)	When recieved/ projected date recieved	How purchased?	Who purchased?
Dummy front axel	04-A03-011-DUMMYFRONTAXLE	6061 RND: 1.25"DIAx5"	IMS	1	0	0	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Sheet Cost	$0											

Purchasing excel for all testing components.

Part	Part # (if applicable)	Stock Description	Link/ Stock Source	Amount	Unit Cost	Total Cost	Purchased? (Y/N)	When purchased	Recieved? (Y/N)	When recieved/ projected date recieved	How purchased?	Who purchased?
Roll bar testing	n/a	n/a	n/a	n/a	n/a	$300	Y	Nov 2018	Y	Nov 2018	By team & reimbursment	Kyra
Bend testing/ miter testing	n/a	4130 TUBE: 1"ODx.035"	https://www.aircraftsp	10	$4.75	$47.50	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Bend testing/ miter testing	n/a	4130 TUBE: .875"ODx.035"	https://www.aircraftsp	10	$3.90	$68.00	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Weld testing	n/a	4130 TUBE: 1"ODx.035"	https://www.aircraftsp	0	$4.75	$0.00	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Roll Bar test manufacture	04-A01-001-FRAME	see Roll Bar tubing	Advance Tube	1	$0.00	0	Y	Jan 2019	Y	Feb 2019	By team & reimbursment	Kyra
Sheet Cost	$415.50											

Purchasing excel for all tooling.

Tool	Link/ Source	Amount	Unit Cost	Total Cost	Purchased?	When purchased	Recieved?	When recieved/ projected date recieved	How purchased?	Who Purchased?
Angle Rotation Gauge	https://www.trick-toc	1	$98.97	$98.97	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Soft jaws for rear dropouts	One Way Industrial	1	$16	$16	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
1/2" Rougher	https://www.amazon	1	$18	$18	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
1/2" Finisher	https://www.ebay.cc	1	$39.36	$39.36	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
3/16" Finisher	https://www.amazon	1	$12.71	$12.71	Y	Jan 2019	N	Lost in mail, never recieved	By team & reimbursment	Kyra
1/8" Chamfer	https://www.ebay.cc	1 (pack of 5)	$22	$22	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Soft jaws for front dropouts	One Way Industrial	1	$16	$16	Y	Jan 2019	Y	Jan 2019	By team & reimbursment	Kyra
Sheet Cost	$223.04									

Appendix P: Parts to Make Excel Documents

This appendix contains an excel documenting all the components to be made in house, broken down by process or operation.

Parts to bend, miter, grind, drill, weld, etc.:

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)		
Part	**Part # (if applicable)**	**Stock Description**	**Ops to do**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Notes**
Race seat	n/a	n/a	press	1	Y	70	
Head tube	n/a	n/a	face; ream; press head set	1	Y		
Steerer	04-A02-004-STEERTUBE	n/a	cut; miter; weld	1	Y		
Right fork blade (viewed from the rider's perspective)	04-A02-007-FORKBLADERight	n/a	cut; miter; drill; weld	1	Y		
Left fork blade (viewed from the rider's perspective)	04-A02-006-FORKBLADELeft	n/a	cut; miter; weld	1	Y		
Bend testing	n/a	4130 TUBE: .875"ODx.035"	cut; bend	1	Y		
Weld testing	n/a	4130 TUBE: 1"ODx.035"	cut; miter; weld	2	Y		
Top Side Support Pillar	04-A03-013-PILLARTOPSIDESUPPORT	Steel 2x3: .125" wallx24"	cut; grind fish eye, tac	2	Y		
Middle Side Support Pillar	04-A03-011-PILLARMIDSIDESUPPORT	Steel 2x3: .125" wallx24"	cut; grind fish eye, tac	2	Y		
Top Plate	04-A03-008-TOP_PLATE	Steel 1/4" PLT: 16"x21"	drill; ream	2	Y		
Front Plate	04-A03-003-FRONT_PLATE	Steel 1/4" PLT: 13"x6"	water jet	2	Y		
Fairing Cantilever Riser	04-A03-012-FAIRINGCANTILEVERSPACER	Steel 2x3: .125" wallx24"	cut	1	Y		
Roll bar riser	04-A04-006-ROLL_BAR_POST	Steel 2x2: .125" wallx26"	cut; drill; weld	2	Y		
Roll bar riser base plate	04-A04-006-ROLL_BAR_POST	Steel PLT: .125" thick, 4"x4"	water jet	2	Y		
Bottom bracket support pillar	04-A04-004-BB_SUPPORT	Steel 4x4: .125" wallx16"	cut; drill	1	Y		

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)		
Part	**Part # (if applicable)**	**Stock Description**	**Ops to do**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Notes**
Roll bar hoop	04-A01-001-FRAME-RollhoopUpper	4130 TUBE: 1.25"ODx.049"	cut; miter; weld	1	Y		
Roll bar bottom dude	04-A01-001-FRAME-RollhoopLower	4130 TUBE: 1.25"ODx.035"	cut; drill; weld	1	Y		
Seat/ harness mount support	04-A01-001-FRAME-RollhoopHarnessMountBar	4130 TUBE: 1"ODx.035"	cut; miter; weld	1	Y		
Seat/ chain stays left	04-A01-001-FRAME-RearTriangleOuterLower; 04-A01-001-FRAME-RearTriangleInnerLower; 04-A01-001-FRAME-RearTriangleUpper	4130 TUBE: .75"ODx.035"	cut; miter; weld	3	Y		
Seat/ chain stays right	04-A01-001-FRAME-RearTriangleOuterLower; 04-A01-001-FRAME-RearTriangleInnerLower; 04-A01-001-FRAME-RearTriangleUpper	4130 TUBE: .75"ODx.035"	cut; miter; weld	3	Y		
Top side support left	04-A01-001-FRAME-TopSideSupport	4130 TUBE: 1"ODx.035"	bend; cut; miter; weld	1	Y		
Top side support right	04-A01-001-FRAME-TopSideSupport	4130 TUBE: 1"ODx.035"	bend; cut; miter; weld	1	Y		
Middle side support left	04-A01-001-FRAME-MiddleSideSupport	4130 TUBE: 1"ODx.035"	bend; cut; miter; weld	1	Y		
Middle side support right	04-A01-001-FRAME-MiddleSideSupport	4130 TUBE: 1"ODx.035"	bend; cut; miter; weld	1	Y		
Bottom support straight angled members	04-A01-001-FRAME-BottomMemberAngled	4130 TUBE: .875"ODx.035"	cut; miter; drill; weld	2	Y		
Bottom support small hoizontal member	04-A01-001-FRAME-BottomMemberHorizontalHarnessMount	4130 TUBE: .875"ODx.035"	cut; weld	1	Y		
Bottom support bent member	04-A01-001-FRAME-BottomMemberBent	4130 TUBE: .875"ODx.049"	bend; cut; miter; drill; weld	1	Y		

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)		
Part	**Part # (if applicable)**	**Stock Description**	**Ops to do**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Notes**
Straight truss members left	04-A01-001-FRAME-StraightTruss1; 04-A01-001-FRAME-StraightTruss2; 04-A01-001-FRAME-StraightTruss3	4130 TUBE: .875"ODx.035"	cut; miter; weld	3	Y		
Straight truss members right	04-A01-001-FRAME-StraightTruss1; 04-A01-001-FRAME-StraightTruss2; 04-A01-001-FRAME-StraightTruss3	4130 TUBE: .875"ODx.035"	cut; miter; weld	3	Y		
Bent truss members left	04-A01-001-FRAME-BentTruss; 04-A01-001-FRAME-ShoulderTrussSupport	4130 TUBE: .875"ODx.035"	bend; cut; miter; weld	2	Y		
Bent truss members right	04-A01-001-FRAME-BentTruss; 04-A01-001-FRAME-ShoulderTrussSupport	4130 TUBE: .875"ODx.035"	bend; cut; miter; weld	2	Y		
Middrive support left	04-A01-001-FRAME-MidDriveTruss	4130 TUBE: .875"ODx.035"	bend; drill; cut; miter; weld	1	Y		
Middrive support right	04-A01-001-FRAME-MidDriveTruss	4130 TUBE: .875"ODx.035"	bend; drill; cut; miter; weld	1	Y		
Bottom bracket support	04-A01-001-FRAME-BottomBracketSupport	4130 TUBE: 1.5"ODx.049"	cut; miter; weld	1	Y		
Fairing cantilever	04-A01-001-FRAME-FairingSupport	4130 TUBE: 1"ODx.035"	cut; miter; weld	1	N		mitered
Bosses Full Welded	n/a	n/a	weld	9	N		95% ish
Harness mount tabs	04-A01-006-HARNESSTABS	Steel .090" PLT: 4" x 4"	water jet; weld	2	N		water jet
Roll bar hoop test	04-A01-001-FRAME-RollhoopUpper	4130 TUBE: 1.25"ODx.049"	cut; miter; weld	1	Y		
Roll bar bottom dude test	04-A01-001-FRAME-RollhoopLower	4130 TUBE: 1.25"ODx.035"	cut; drill; weld	1	Y		
Seat/ harness mount support test	04-A01-001-FRAME-RollhoopHarnessMountBar	4130 TUBE: 1"ODx.035"	cut; miter; weld	1	Y		
Weld testing 90	n/a	4130 TUBE: 1.25"ODx.035"	cut; miter; weld	1	Y		

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)		
Part	**Part # (if applicable)**	**Stock Description**	**Ops to do**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Notes**
Weld testing 30	n/a	4130 TUBE: 1.25"ODx.035"	cut; miter; weld	1	Y		
Jig for holding frame off welding table	n/a	Steel 2x2: .125" wallxvarious sizes"	cut; weld	1	Y		

Parts to make from composites, etc.:

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)			
Part	**Part # (if applicable)**	**Stock Description**	**Machine/ Process Needed**	**Ops Needed**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Notes**
EVA foam padding	n/a	14" x 18"	n/a	cut	2	N	20	
Fiberglass 45	n/a	45: 17" x 80"	Fiberglass layup	layup; cut; adhere; drill	2	Y		
Fiberglass 90	n/a	90: 17" x 40"	Fiberglass layup	layup; cut; adhere; drill	2	Y		
Peal ply	n/a	20" x 165"	Fiberglass layup	cut	1	Y		
Perf	n/a	20" x 165"	Fiberglass layup	cut	1	Y		
Breather	n/a	20" x 165"	Fiberglass layup	cut	1	Y		
Vac bag	n/a	23" x 170"	Fiberglass layup	cut	1	Y		
Plastic	n/a	20" x 170"	Fiberglass layup	cut	2	Y		
Velcro Mounting-alignment	n/a	Adhesive back velcro	n/a	cut; adhere	4	N		
Velcro Mounting- wrap	n/a	Plain back velcro	Sewing machine	cut; sew	4	N		

Parts to CNC machine:

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)	
Part	**Part # (if applicable)**	**Stock Description**	**Machine Needed**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**
Rear dropouts	04-A01-002-REARDROPOUTS	4130 RND: 1.375"DIAx12"	mill	4	Y	10
Rear dropouts softjaws	n/a	soft jaws	mill	1	Y	
Front dropouts	04-A02-003-FRONTDROPOUTS	4130 PLT: 2"x4.2"x6.2"	mill	4	Y	
Front dropouts softjaws	n/a	soft jaws	mill	1	Y	

Parts to manual machine:

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)			
Part	**Part # (if applicable)**	**Stock Description**	**Machine Needed**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Total Parts to Make Overall**	**Notes**
Seat mount bosses long	04-A01-007-SEATBOSSLONG	1017 RND: .5"DIAx5"	lathe	2	Y	36	136	
Seat mount bosses	04-A01-005-SEATBOSS	1018 RND: .5"DIAx7"	lathe	3	Y			
Mid drive mount bosses	04-A01-004-MIDDRIVEBOSS	1018 RND: .5"DIAx12"	lathe	6	Y			
Dummy front axel	04-A03-011-DUMMYFRONTAXLE	6061 RND: 1.25"DIAx5"	lathe	1	Y			
Bottom Bracket Plug	04-A03-004-BB_PLUG	6061 RND: 2.5"DIAx5"	lathe	2	Y			
Conical Spacers (Head tube)	04-A03-007-CONICAL_PLUG	6061 RND: 2.5"DIAx5"	lathe	2	Y			
Dummy rear hub	04-A03-010-DUMMYREARHUB	6061 RND: 1.25"DIAx5"	lathe	1	Y			
Head tube mounts	04-A03-006-HEAD_TUBE_MOUNT	6061 RND: 1"DIAx10"	lathe & mill	2	Y			
Head tube mount spacer	04-A03-006-HEAD_TUBE_MOUNT_SPACER	6061 RND: 1"DIAx10"	lathe	1	Y			
Mid Drive Spacers	04-A03-009-MID_DRIVE_SPACER	6061 RND: 1"DIAx10"	lathe	4	Y			
Jig base	04-A03-001-JIG_BOTTOM	Steel 4x4: .125" wallx90"	mill	1	Y			
Jig pillar	04-A03-001-JIG_PILLAR	Steel 4x4: .125" wallx24"	mill	1	Y			
Jig pillar plate	04-A03-014-JIGPILLARPLATE	Steel PLT: .25" thick, 3.5"x3.5"	water jet, mill	1	Y			
Jig pillar base plate	04-A03-016-PILLAR_BASE	Steel PLT: .25" thick, 8"x6"	water jet, mill	1	Y			

fork	frame	testing	jigging (stage 1)	jigging (stage 2)	jigging (fork)			
Part	**Part # (if applicable)**	**Stock Description**	**Machine Needed**	**Quantity Needed**	**Fully Finished? (Y/N)**	**Total Parts to Make**	**Total Parts to Make Overall**	**Notes**
Roll bar plug	04-A04-005-ROLL_BAR_PLUG2	6062 RND: 1.5"DIAx5"	lathe	2	Y			
Tube blocks .875"	04-A03-002-TUBE_BLOCK_0.875_BOTTOM	n/a	mill	2	Y			
Center riser	04-A04-003-CENTER_SUPPORT	Steel 4x4: .125" wallx8"	mill	1	Y			
Tube blocks 1.25"	04-A03-002-TUBE_BLOCK_1.25_BOTTOM	n/a	mill	3	Y			

Appendix Q: Setup Sheet from Front and Rear Dropouts CAM

This appendix contains the set-up sheet from machining the rear and front dropouts on the CNC mill. Shows tools, feeds and speeds, set-ups, and tool paths used.

Setup Sheet for Program 1001

Job Description: Setup1

Document Path: 04-A01-002-REARDROPOUTSactualreal v14

Setup

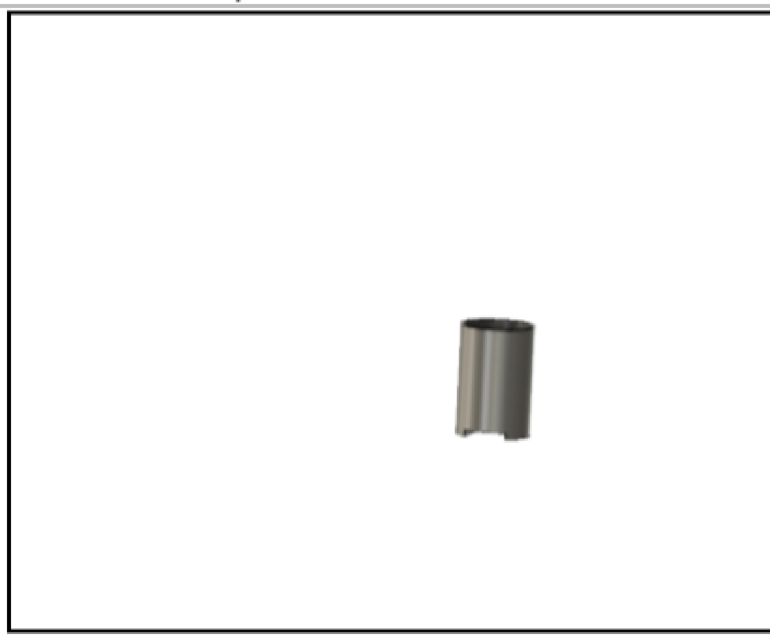
WCS: #0

Stock:
DX: 34.92mm
DY: 34.92mm
DZ: 63.5mm

Part:
DX: 34.92mm
DY: 34.92mm
DZ: 51.82mm

Stock Lower in WCS #0:
X: -17.46mm
Y: -17.46mm
Z: -57.66mm

Stock Upper in WCS #0:
X: 17.46mm
Y: 17.46mm
Z: 5.84mm



Total

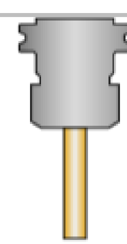
Number Of Operations: 12
Number Of Tools: 7
Tools: T1 T2 T3 T4 T5 T6 T30
Maximum Z: 95.78mm
Minimum Z: -58.17mm
Maximum Feedrate: 659.742mm/min
Maximum Spindle Speed: 12000rpm
Cutting Distance: 5018.49mm
Rapid Distance: 1097.62mm
Estimated Cycle Time: 24m:42s

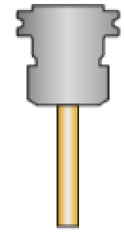
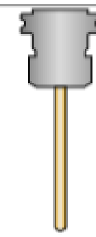
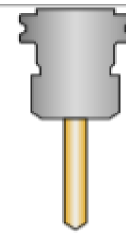
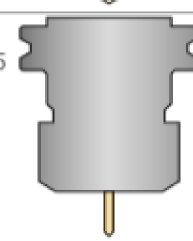
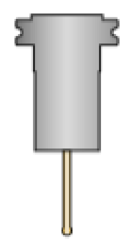
Tools

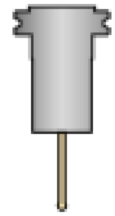
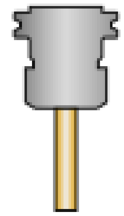
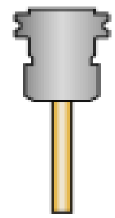
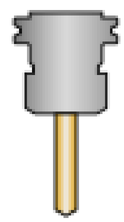
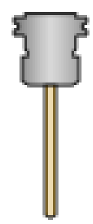
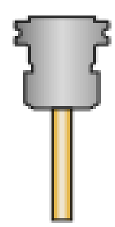
T1 D1 L1
Type: flat end mill
Diameter: 12.7mm
Length: 63.5mm
Flutes: 4
Description: 1/2" HSS rougher 4130

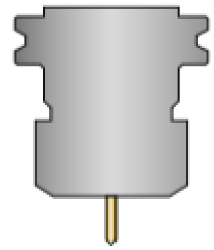
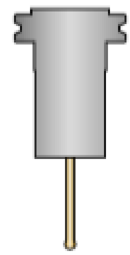
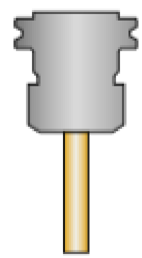
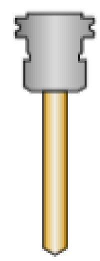
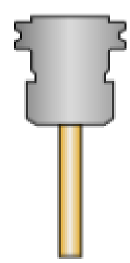
Minimum Z: 0.76mm
Maximum Feed: 80.613mm/min
Maximum Spindle Speed: 688rpm
Cutting Distance: 1163.01mm
Rapid Distance: 191.93mm
Estimated Cycle Time: 14m:28s (58.6%)

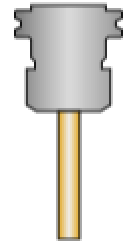
Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35



T2 D2 L2 Type: flat end mill Diameter: 12.7mm Length: 76.2mm Flutes: 4 Description: 1/2" flat finisher carbide 4130	Minimum Z: -18.92mm Maximum Feed: 659.742mm/min Maximum Spindle Speed: 2597rpm Cutting Distance: 3542.02mm Rapid Distance: 361.58mm Estimated Cycle Time: 5m:41s (23%)	Holder: Maritool CAT40-ER32-2.35 Vendor: Maritool Product: CAT40-ER32-2.35	
T3 D3 L3 Type: drill Diameter: 9mm Tip Angle: 118° Length: 117mm Flutes: 2 Description: 9mm drill bit	Minimum Z: -58.17mm Maximum Feed: 87.621mm/min Maximum Spindle Speed: 2597rpm Cutting Distance: 63.54mm Rapid Distance: 307.35mm Estimated Cycle Time: 47s (3.2%)	Holder: Maritool CAT40-ER32-2.35 Vendor: Maritool Product: CAT40-ER32-2.35	
T4 D4 L4 Type: spot drill Diameter: 12.7mm Tip Angle: 118° Length: 63.5mm Flutes: 4 Description: 1/2" spot drill	Minimum Z: -2.54mm Maximum Feed: 414.985mm/min Maximum Spindle Speed: 2597rpm Cutting Distance: 7.54mm Rapid Distance: 39.22mm Estimated Cycle Time: 2s (0.1%)	Holder: Maritool CAT40-ER32-2.35 Vendor: Maritool Product: CAT40-ER32-2.35	
T5 D5 L5 Type: drill Diameter: 19mm Tip Angle: 118° Length: 133.2mm Flutes: 2 Description: 19mm carbide drill	Minimum Z: -5.21mm Maximum Feed: 93.585mm/min Maximum Spindle Speed: 2597rpm Cutting Distance: 43.22mm Rapid Distance: 126.84mm Estimated Cycle Time: 29s (2%)	Holder: Maritool CAT40-ER32-2.35 Vendor: Maritool Product: CAT40-ER32-2.35	
T6 D6 L6 Type: chamfer mill Diameter: 3.17mm Taper Angle: 45° Length: 15.88mm Flutes: 4 Description: 1/8" chamfer	Minimum Z: -3.25mm Maximum Feed: 254mm/min Maximum Spindle Speed: 12000rpm Cutting Distance: 199.15mm Rapid Distance: 70.69mm Estimated Cycle Time: 1m:0s (4%)	Holder: Maritool CAT40-ER32-2.35 Vendor: Maritool Product: CAT40-ER32-2.35	
T30 D30 L30 Type: probe Diameter: 6mm Corner Radius: 3mm Length: 53mm Flutes: 1 Comment: Stock Haas Probe Vendor: Renishaw Product: OMP40-2	Minimum Z: -6.5mm Maximum Feed: 0mm/min Maximum Spindle Speed: 12000rpm Cutting Distance: 0mm Rapid Distance: 0mm Estimated Cycle Time: 0s (0%)	Holder: Renishaw Probe OMP40-2 Vendor: Renishaw Product: OMP40-2	

Operation 1/12 Description: Probe1 Strategy: Probe WCS: #0 Tolerance: 0.01mm	Maximum Z: 60.84mm Minimum Z: -6.5mm	**T80 D30 L30** Type: probe Diameter: 6mm Corner Radius: 3mm Length: 53mm Flutes: 1 Comment: Stock Haas Probe Vendor: Renishaw Product: OMP40-2	
Operation 2/12 Description: Face2 Strategy: Facing WCS: #0 Tolerance: 0.01mm Maximum stepdown: 2.54mm Maximum stepover: 10.16mm	Maximum Z: 20.84mm Minimum Z: 0.76mm Maximum Spindle Speed: 688rpm Maximum Feedrate: 80.613mm/min Cutting Distance: 387.32mm Rapid Distance: 61.49mm Estimated Cycle Time: 4m:49s (19.5%) Coolant: Flood	**T1 D1 L1** Type: flat end mill Diameter: 12.7mm Length: 63.5mm Flutes: 4 Description: 1/2" HSS rougher 4130	
Operation 3/12 Description: Face3 Strategy: Facing WCS: #0 Tolerance: 0.01mm Maximum stepover: 10.16mm	Maximum Z: 20.84mm Minimum Z: 0mm Maximum Spindle Speed: 2597rpm Maximum Feedrate: 659.742mm/min Cutting Distance: 190.87mm Rapid Distance: 34.4mm Estimated Cycle Time: 18s (1.2%) Coolant: Flood	**T2 D2 L2** Type: flat end mill Diameter: 12.7mm Length: 76.2mm Flutes: 4 Description: 1/2" flat finisher carbide 4130	
Operation 4/12 Description: Drill1 Strategy: Drilling WCS: #0 Tolerance: 0.01mm	Maximum Z: 20.84mm Minimum Z: -2.54mm Maximum Spindle Speed: 1532rpm Maximum Feedrate: 414.985mm/min Cutting Distance: 7.54mm Rapid Distance: 39.22mm Estimated Cycle Time: 2s (0.1%) Coolant: Flood	**T4 D4 L4** Type: spot drill Diameter: 12.7mm Tip Angle: 118° Length: 63.5mm Flutes: 4 Description: 1/2" spot drill	
Operation 5/12 Description: Drill2 Strategy: Drilling WCS: #0 Tolerance: 0.01mm	Maximum Z: 20.84mm Minimum Z: -58.17mm Maximum Spindle Speed: 862rpm Maximum Feedrate: 87.621mm/min Cutting Distance: 63.54mm Rapid Distance: 307.35mm Estimated Cycle Time: 47s (3.2%) Coolant: Flood	**T3 D3 L3** Type: drill Diameter: 9mm Tip Angle: 118° Length: 117mm Flutes: 2 Description: 9mm drill bit	
Operation 6/12 Description: 2D Contour1 Strategy: Contour 2D WCS: #0 Tolerance: 0.01mm Stock to Leave: 0mm Maximum stepdown: 1.91mm Maximum stepover: 12.06mm	Maximum Z: 20.84mm Minimum Z: -3mm Maximum Spindle Speed: 2597rpm Maximum Feedrate: 659.742mm/min Cutting Distance: 435.2mm Rapid Distance: 202.66mm Estimated Cycle Time: 52s (3.5%) Coolant: Flood	**T2 D2 L2** Type: flat end mill Diameter: 12.7mm Length: 76.2mm Flutes: 4 Description: 1/2" flat finisher carbide 4130	

Operation 7/12 Description: 2D Chamfer1 WCS: #0 Tolerance: 0.01mm Stock to Leave: 0mm	Maximum Z: 20.84mm Minimum Z: -3.25mm Maximum Spindle Speed: 12000rpm Maximum Feedrate: 254mm/min Cutting Distance: 199.15mm Rapid Distance: 70.69mm Estimated Cycle Time: 1m:0s (4%) Coolant: Flood	**T6** D6 L6 Type: chamfer mill Diameter: 3.17mm Taper Angle: 45° Length: 15.88mm Flutes: 4 Description: 1/8" chamfer	
Operation 8/12 Description: Probe2 Strategy: Probe WCS: #0 Tolerance: 0.01mm	Maximum Z: 95.78mm Minimum Z: 23.89mm	**T30** D30 L30 Type: probe Diameter: 6mm Corner Radius: 3mm Length: 53mm Flutes: 1 Comment: Stock Haas Probe Vendor: Renishaw Product: OMP40-2	
Operation 9/12 Description: Face4 Strategy: Facing WCS: #0 Tolerance: 0.01mm Maximum stepdown: 2.54mm Maximum stepover: 10.16mm	Maximum Z: 55.78mm Minimum Z: 32.89mm Maximum Spindle Speed: 688rpm Maximum Feedrate: 80.613mm/min Cutting Distance: 775.69mm Rapid Distance: 130.44mm Estimated Cycle Time: 9m:39s (39.1%) Coolant: Flood	**T1** D1 L1 Type: flat end mill Diameter: 12.7mm Length: 63.5mm Flutes: 4 Description: 1/2" HSS rougher 4130	
Operation 10/12 Description: Drill3 Strategy: Drilling WCS: #0 Tolerance: 0.01mm	Maximum Z: 55.78mm Minimum Z: -5.21mm Maximum Spindle Speed: 409rpm Maximum Feedrate: 93.585mm/min Cutting Distance: 43.22mm Rapid Distance: 126.84mm Estimated Cycle Time: 29s (2%) Coolant: Flood	**T5** D5 L5 Type: drill Diameter: 19mm Tip Angle: 118° Length: 133.2mm Flutes: 2 Description: 19mm carbide drill	
Operation 11/12 Description: Bore1 Strategy: Bore WCS: #0 Tolerance: 0.01mm Stock to Leave: 0mm	Maximum Z: 55.78mm Minimum Z: -5.21mm Maximum Spindle Speed: 2597rpm Maximum Feedrate: 659.742mm/min Cutting Distance: 2334.73mm Rapid Distance: 80.6mm Estimated Cycle Time: 3m:33s (14.4%) Coolant: Flood	**T2** D2 L2 Type: flat end mill Diameter: 12.7mm Length: 76.2mm Flutes: 4 Description: 1/2" flat finisher carbide 4130	

Operation 12/12		**T2** D2 L2	
Description: 2D Contour2	Maximum Z: 15mm	Type: flat end mill	
Strategy: Contour 2D	Minimum Z: -18.92mm	Diameter: 12.7mm	
WCS: #0	Maximum Spindle Speed: 2597rpm	Length: 76.2mm	
Tolerance: 0.01mm	Maximum Feedrate: 659.742mm/min	Flutes: 4	
Stock to Leave: 0mm	Cutting Distance: 581.22mm	Description: 1/2" flat finisher carbide 4130	
Maximum stepdown: 2.54mm	Rapid Distance: 43.92mm		
Maximum stepover: 12.06mm	Estimated Cycle Time: 58s (3.9%)		
	Coolant: Flood		

Setup Sheet for Program 1001

Job Description: Setup1

Document Path: 04-A02-003-FRONTDROPOUTS v53

Setup

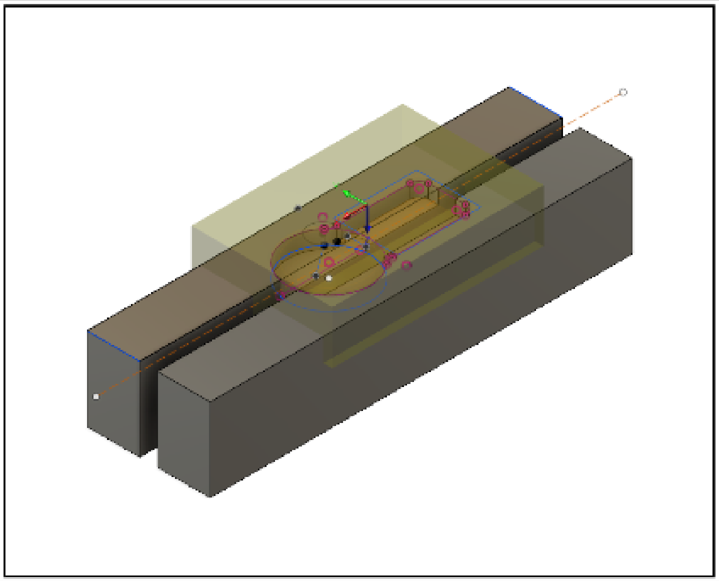
WCS: #0

Stock:
- DX: 76.2mm
- DY: 50.8mm
- DZ: 19.05mm

Part:
- DX: 57.34mm
- DY: 29.5mm
- DZ: 12.27mm

Stock Lower in WCS #0:
- X: -38.1mm
- Y: -25.4mm
- Z: 0mm

Stock Upper in WCS #0:
- X: 38.1mm
- Y: 25.4mm
- Z: 19.05mm



Total

Number Of Operations: 9
Number Of Tools: 6
Tools: **T1 T2 T3 T4 T5 T6**
Maximum Z: 34.05mm
Minimum Z: -0.46mm
Maximum Feedrate: 1000.001mm/min
Maximum Spindle Speed: 12000rpm
Cutting Distance: 2378.2mm
Rapid Distance: 354.46mm
Estimated Cycle Time: 22m:32s

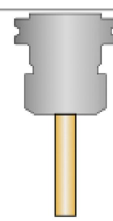
Tools

T1 D1 L1

Type: flat end mill
Diameter: 12.7mm
Length: 63.5mm
Flutes: 4
Description: 1/2" HSS rougher 4130

Minimum Z: 10.29mm
Maximum Feed: 80.613mm/min
Maximum Spindle Speed: 688rpm
Cutting Distance: 1317.94mm
Rapid Distance: 91.76mm
Estimated Cycle Time: 17m:32s (77.8%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35



T2 D2 L2

Type: flat end mill
Diameter: 12.7mm
Length: 76.2mm
Flutes: 4
Description: 1/2" flat finisher carbide 4130

Minimum Z: 15.78mm
Maximum Feed: 659.742mm/min
Maximum Spindle Speed: 2597rpm
Cutting Distance: 682.78mm
Rapid Distance: 86.73mm
Estimated Cycle Time: 1m:5s (4.8%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35

T3 D3 L3

Type: drill
Diameter: 9mm
Tip Angle: 118°
Length: 117mm
Flutes: 2
Description: 9mm drill bit

Minimum Z: -0.46mm
Maximum Feed: 87.621mm/min
Maximum Spindle Speed: 2597rpm
Cutting Distance: 22.51mm
Rapid Distance: 46.51mm
Estimated Cycle Time: 16s (1.2%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35

T4 D4 L4

Type: spot drill
Diameter: 12.7mm
Tip Angle: 118°
Length: 63.5mm
Flutes: 4
Description: 1/2" spot drill

Minimum Z: 15.73mm
Maximum Feed: 414.985mm/min
Maximum Spindle Speed: 2597rpm
Cutting Distance: 6.32mm
Rapid Distance: 30.32mm
Estimated Cycle Time: 1s (0.1%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35

T5 D5 L5

Type: flat end mill
Diameter: 4.76mm
Length: 50.8mm
Flutes: 4
Description: 3/16" HSS flat

Minimum Z: 9.78mm
Maximum Feed: 1000.001mm/min
Maximum Spindle Speed: 2597rpm
Cutting Distance: 183.67mm
Rapid Distance: 33.79mm
Estimated Cycle Time: 51s (3.8%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35

T6 D6 L6

Type: chamfer mill
Diameter: 3.17mm
Taper Angle: 45°
Length: 15.88mm
Flutes: 4
Description: 1/8" chamfer

Minimum Z: 15.53mm
Maximum Feed: 254mm/min
Maximum Spindle Speed: 12000rpm
Cutting Distance: 164.97mm
Rapid Distance: 65.34mm
Estimated Cycle Time: 47s (3.5%)

Holder: Maritool CAT40-ER32-2.35
Vendor: Maritool
Product: CAT40-ER32-2.35

Operations

Operation 1/9

Description: Face1
Strategy: Facing
WCS: #0
Tolerance: 0.01mm
Maximum stepdown: 3.81mm
Maximum stepover: 12.06mm

Maximum Z: 34.05mm
Minimum Z: 17.56mm
Maximum Spindle Speed: 688rpm
Maximum Feedrate: 80.613mm/min
Cutting Distance: 461.13mm
Rapid Distance: 25.22mm
Estimated Cycle Time: 5m:44s (25.4%)
Coolant: Flood

T1 D1 L1

Type: flat end mill
Diameter: 12.7mm
Length: 63.5mm
Flutes: 4
Description: 1/2" HSS rougher 4130

Operation 2/9
Description: Face4
Strategy: Facing
WCS: #0
Tolerance: 0.01mm
Maximum stepover: 12.06mm

Maximum Z: 34.05mm
Minimum Z: 17.05mm
Maximum Spindle Speed: 2597rpm
Maximum Feedrate: 659.742mm/min
Cutting Distance: 461.64mm
Rapid Distance: 25.73mm
Estimated Cycle Time: 42s (3.1%)
Coolant: Flood

T2 D2 L2
Type: flat end mill
Diameter: 12.7mm
Length: 76.2mm
Flutes: 4
Description: 1/2" flat finisher carbide 4130

Operation 3/9
Description: Drill1
Strategy: Drilling
WCS: #0
Tolerance: 0.01mm

Maximum Z: 34.05mm
Minimum Z: 15.73mm
Maximum Spindle Speed: 1532rpm
Maximum Feedrate: 414.985mm/min
Cutting Distance: 6.32mm
Rapid Distance: 30.32mm
Estimated Cycle Time: 1s (0.1%)
Coolant: Flood

T4 D4 L4
Type: spot drill
Diameter: 12.7mm
Tip Angle: 118°
Length: 63.5mm
Flutes: 4
Description: 1/2" spot drill

Operation 4/9
Description: Drill3
Strategy: Drilling
WCS: #0
Tolerance: 0.01mm

Maximum Z: 34.05mm
Minimum Z: -0.46mm
Maximum Spindle Speed: 862rpm
Maximum Feedrate: 87.621mm/min
Cutting Distance: 22.51mm
Rapid Distance: 46.51mm
Estimated Cycle Time: 16s (1.2%)
Coolant: Flood

T3 D3 L3
Type: drill
Diameter: 9mm
Tip Angle: 118°
Length: 117mm
Flutes: 2
Description: 9mm drill bit

Operation 5/9
Description: 2D Contour1
Strategy: Contour 2D
WCS: #0
Tolerance: 0.01mm
Stock to Leave: 0mm
Maximum stepover: 12.06mm

Maximum Z: 34.05mm
Minimum Z: 15.78mm
Maximum Spindle Speed: 2597rpm
Maximum Feedrate: 659.742mm/min
Cutting Distance: 79.63mm
Rapid Distance: 27mm
Estimated Cycle Time: 9s (0.7%)
Coolant: Flood

T2 D2 L2
Type: flat end mill
Diameter: 12.7mm
Length: 76.2mm
Flutes: 4
Description: 1/2" flat finisher carbide 4130

Operation 6/9
Description: Horizontal1
Strategy: Horizontal
WCS: #0
Tolerance: 0.01mm
Stock to Leave: 0mm
Maximum stepover: 12.06mm

Maximum Z: 34.05mm
Minimum Z: 15.78mm
Maximum Spindle Speed: 2597rpm
Maximum Feedrate: 659.742mm/min
Cutting Distance: 141.51mm
Rapid Distance: 34mm
Estimated Cycle Time: 13s (1%)
Coolant: Flood

T2 D2 L2
Type: flat end mill
Diameter: 12.7mm
Length: 76.2mm
Flutes: 4
Description: 1/2" flat finisher carbide 4130

Operation 7/9 Description: 2D Contour2 Strategy: Contour 2D WCS: #0 Tolerance: 0.01mm Stock to Leave: 0.51mm Maximum stepdown: 2.54mm Maximum stepover: 12.06mm	Maximum Z: 34.05mm Minimum Z: 10.29mm Maximum Spindle Speed: 688rpm Maximum Feedrate: 80.613mm/min Cutting Distance: 856.81mm Rapid Distance: 66.54mm Estimated Cycle Time: 11m:48s (52.4%) Coolant: Flood	**T1** D1 L1 Type: flat end mill Diameter: 12.7mm Length: 63.5mm Flutes: 4 Description: 1/2" HSS rougher 4130	
Operation 8/9 Description: 2D Contour5 Strategy: Contour 2D WCS: #0 Tolerance: 0.01mm Stock to Leave: 0mm Maximum stepover: 4.52mm	Maximum Z: 34.05mm Minimum Z: 9.78mm Maximum Spindle Speed: 1833rpm Maximum Feedrate: 1000.001mm/min Cutting Distance: 183.67mm Rapid Distance: 33.79mm Estimated Cycle Time: 51s (3.8%) Coolant: Flood	**T5** D5 L5 Type: flat end mill Diameter: 4.76mm Length: 50.8mm Flutes: 4 Description: 3/16" HSS flat	
Operation 9/9 Description: 2D Chamfer1 WCS: #0 Tolerance: 0.01mm Stock to Leave: 0mm	Maximum Z: 34.05mm Minimum Z: 15.53mm Maximum Spindle Speed: 12000rpm Maximum Feedrate: 254mm/min Cutting Distance: 164.97mm Rapid Distance: 65.34mm Estimated Cycle Time: 47s (3.5%) Coolant: Flood	**T6** D6 L6 Type: chamfer mill Diameter: 3.17mm Taper Angle: 45° Length: 15.88mm Flutes: 4 Description: 1/8" chamfer	

Generated by Fusion 360 CAM 2.0.5350 02/07/2019 16:49:38

Appendix R: Rider Testing Measurements

This appendix contains Table 28, containing measured values from second round of rider testing.

Table 28. Measurements from second round rider testing with physical gauges

Dimension Description	**Current CAD**	**Rider Measurements (to change CAD to)**
Outside of knees, directly down from knees at highest point	15.5”	17.5”
Shoulders	17”	18”
Shins closest to knees, 20” back from bottom bracket	16.88”	17.25”

Legs top down view:

8.5” back from bottom bracket: 16.75”
12” back from bottom bracket: 16.75”
19.5” back from bottom bracket: 17.25”

Roll hoop:

Shoulders: 17”
Hip width: 14.5”

Appendix S: Failure Model and Effects Analysis

This appendix contains the failure mode and effects analysis (FMEA).

Team:

Date: (orig)

System / Function Syste m / Function+A2:Q 16	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Severity	Occurence	Detection	RPN
Fork / provide mounting point for front wheel	incorrect spacing or axial alignment for dropouts	wheel-frame interface is not achieved	6	1) innaccurate manufacturing	1) frame jigging	2	CAD	4	48	run CAD add on testing	Team 2/5	Jig was successfully and accurately manufacturing. As of now should provide solid mounting for wheels.	3	1	2	6
Fork / provide rider with means to steer bike	headset or bearing failure	rider is not able to steer well	7	1) material defect 2) off shelf component defect	1) proper component selection/specs	4	proper specifications	7	196	current product research	Kyra 1/31	A zero stack headset was chosen and purchased. A low profile and bearings will allow for smooth, reliable steering. The part will be inspected once it is in the team's possession.	2	1	3	6
Side support / protect the rider's internal organs	support breaks, crumples, or does not absorb impact	a) rider is injured during crash or rollover b) side support is damaged beyond use	9	1) manufacturing issues 2) material defects 3) weld failure	1) FEA 2) hand calculations	2	FEA	3	54	construct PVC model and perform load tests	Brendon 2/3	Multiple runs with different boundary locations have been performed in Ansys and show that the frame will perform to specs.	4	2	3	24
Bottom support / support the rider's weight	too much deflection	potential for fatigue failure	8	1) poor design 2) poor material selection	1) FEA 2) material testing	6	FEA	3	144	construct PVC model and perform load tests	Brendon 2/3	Multiple runs with different boundary locations have been performed in Ansys and show that the frame will perform to specs.	4	2	3	24
Bottom support / provide mounting point for fairing	mounting not secured to frame or gets sheared off	fairing becomes disconnected	9	1) material defect 2) improper assembly 3) poor fastening choices	1) material testing	4	torque specifications	5	180	construct PVC model	Austin 3/9					
Roll hoop / protect the rider's head	roll hoop sizing is incorrect or deforms	a) rider's head does not fit properly inside roll hoop b) roll hoop fails to protect rider's head during crash or rollover	9	1) poor design 2) inaccurate rider measurements 3) material failure	1) FEA 2) CAD	4	CAD	4	144	construct PVC model and test fit on Josh	Keyanna 3/9					
Rear wheel stays / provide mounting point for rear wheel	incorrect dropout placement or not secured well	wheel-frame interface is not achieved	6	1) poor design 2) improper assembly	1) torque specs for fasteners	8	CAD jig	3	144	frame jig	Team 2/5	Jig was successfully and accurately manufacturing. As of now should provide solid mounting for wheels.	3	2	3	18
Front connecting tube / provide mounting point for bottom bracket	too much deflection, deformation, or weld failure	potential for frame damage and or rider injury	8	1) poor welding 2) poor design	1) CAD 2) proper material selection throught FEA	8	FEA CAD	2	128	get drivetrain calculations and design with high factor of safety	Brendon 2/3	Multiple runs with different boundary locations have been performed in Ansys and show that the frame will perform to specs.	4	3	2	24
Front connecting tube / provide mounting point for fairing	too much deflection or incorrect alignment	fairing is not secured and becomes loose or detaches	9	1) poor design 2) poor material selection	1) design extra support members	6	CAD	4	216	get drivetrain calculations, design with high factor of safety, and build in SolidWorks	Keyanna 1/15	Frame and frame connection to fairing was constructed in SolidWords against the rider model, validating the design.	3	2	2	12
Front connecting tube / provide mounting point for mid-drive	too much deflection or incorrect alignment of threaded inserts	drivetrain failure	6	1) poor design 2) poor material selection 3) improper assembly	1) frame jigging	6	FEA	3	108	get drivetrain calculations, design with high factor of safety, and build in SolidWorks	Brendon 2/3	Multiple runs with different boundary locations have been performed in Ansys and show that the frame will perform to specs.	4	3	3	36
Head tube / provide mounting point for fork	incorrect head tube angle	bike becomes unstable	8	1) inaccurate jigging 2) Patterson control model miscalculation	1) CAD 2) Patterson Control Model iterations	4	Patterson CAD	3	96	frame jig	Kyra 1/15	The Patterson Model was re-run with the design parameters presented in CDR and the output values improved. The design is also supported in a SolidWorks assembly integrating other subsystems.	3	2	3	18
Seat / support the rider and offer rider comfort	seat is uncomfortable	a) rider experiences discomfort or pain b) rider does not perform well	5	1) poor material selection 2) lack of padding 3) poor design	1) padding on seat	8	mold-making	5	200	use foam padding to soften carbon and have Josh try it out and see what he likes	Team 3/9					
Seat / provide mounting point for bottom support	mounting failure	seat is not secure	4	1) improper assembly 2) improper fastening 3) poor fastener selection/sizing	1) proper component selection/specs 2) proper fastener sleection	6	FEA CAD	2	48	size fasteners with high factor of safety	Kyra 1/15	Mounting locations for the seat were designed and verified in SolidWorks and fasteners were selected that will secure the seat and not fail under loads	2	4	2	16

Framed FMEA for CDR

Page 1 of 1

Revision Date: 2/3/2019

Appendix T: Design Verification Plan

This appendix contains the design verification plan (DVPR).

Senior Project DVP&R

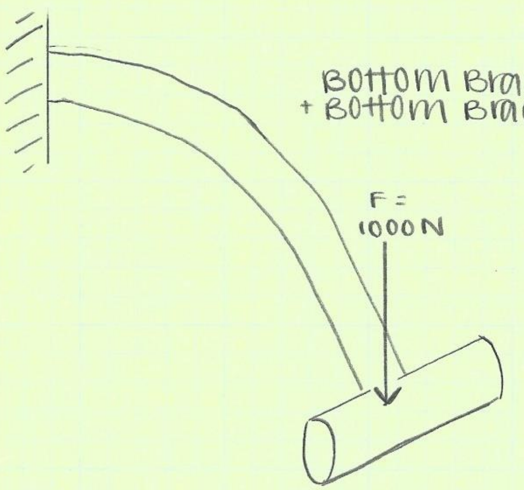
Date: 5/31/19	Team: Framed	Sponsor: George Leone	Description of System: Designing the frame, manufacturing procedure, and testing procedure for the 2019 Cal PolyHPV Club.	DVP&R Engineer: Keyanna Henderson

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	Speed	Speed is ultimately a specification of the entire bike, however the frame is a large factor of it. When the bike is complete the club will perform a speed test using a Garmin that will be borrowed from another club.	Minimum of 62 mph	Keyanna	FP	1	Sys	6/1/2019	9/1/2019	Not yet tested	n/a	n/a	Will test once bike is completed
2	Weight	Weight will be measured when the frame is complete. We will be using a scale borrowed from FSAE.	Maximum of 40 lb	Keyanna	FP	1	Sub	5/28/2019	5/28/2019	22 lbs	1	0	Head set and impact foam taken to add negligible weight.
3	Deflection Under 1200 lbf Vertical Load to Roll Hoop	A test fixture will be built to fit and contain the roll hoop structural prototype and the mechanical engineering department's servo-hydraulic load frame will apply a 5350 N vertical load.	Maximum of 0.25 in	Austin	SP	1	C	3/18/2019	3/25/2019	0.141 in	1	0	Roll Hoop performed as expected. FEA results were confirmed.
4	Deflection Under 600 lbf Side Load to Roll Hoop	Another roll hoop structural prototype will be used for this test, which will also be performed on a test fixture containing the roll hoop while the load frame applies a 2700 N horizontal load.	Maximum of 0.25 in	Austin	SP	1	C	3/18/2019	3/25/2019	0.066 in	1	0	Roll Hoop performed as expected. FEA results were confirmed.
5	Center of Gravity	The final frame's center of gravity will be calculed, using the same procedure as the Mass Properties Lab from ME 441 Single Track Vehicle Design.	Maximum of 0.55 m vertical	Kyra	FP	5	Sys	5/28/2019	5/28/2019	0.493 m	1	0	Test includes frame, drivetrain, and rider. Fairing not included.
6	Radius of Gyration	The finalized frame will be swung using the radius of gyration testing jig for the Single Track Vehicles class. An average of 5 tests will be used to calculate the final value.	Minimum of 0.29 m	Kyra	FP	5	Sys	5/28/2019	5/28/2019	0.35 m	1	0	Test includes frame, drivetrain, and rider. Fairing not included.
7	Weld Integrity- Visual Inspection	A 30° test sample of the thinnest wall thickness used on the final vehicle will be sectioned to reveal uniform and adequate weld penetration. A safety technician from the Mechanical Engineering Department will judge the sample.	Judgement of welding technician, Kevin Williams	Kyra	SP	1	C	5/8/2019	5/10/2019	Pass	1	0	Full penetration at both ends of joint. Minimal burn through given thin tubing (still acceptable sample). Approved by Kevin Williams.
8	Weld Integrity- Destructive Testing	A 90° test sample of the thinnest wall thickness used on the final vehicle will be destructively tested to cause the joint to fail at the base metal.	Failure at base metal, judgement of welding technician, Kevin Williams	Kyra	SP	1	C	5/8/2019	5/10/2019	Pass	1	0	Heat affected zone rip. Failed as expected. Approved by Kevin Williams.

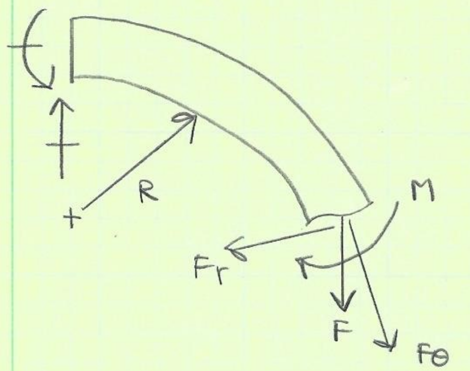
Appendix U: Hand Calculations and FEA Verification Set Up for Bottom Bracket Deflection

This appendix contains hand calculations verifying FEA results.

1/3



→ Approximated as curved beam in bending with constant radius



$R = 0.342\ m$
$A = 4.9 \times 10^{-6}\ m^2$
$I = 2.45 \times 10^{-8}\ m^4$

$E = 2.05 \times 10^{11}\ N/m^2$
$G = 8 \times 10^{10}\ N/m^2$
$C = 2.0$

→ calculate deflection using strain energy and Castigliano's method

$$U_1 = \int \frac{M^2 R}{2EI} d\theta$$

$$U_2 = \int \frac{F_\theta^2 R}{2AE} d\theta$$

$$U_3 = -\int \frac{M F_\theta}{AE} d\theta$$

$$U_4 = \int \frac{C F_r^2 R}{2AG} d\theta$$

$$U = U_1 + U_2 + U_3 + U_4$$
$$= \int \frac{M^2 R}{2EI} d\theta + \int \frac{F_\theta^2 R}{2AE} d\theta - \int \frac{M F_\theta}{AE} d\theta + \int \frac{C F_r^2 R}{2AG} d\theta$$

$$\delta = \frac{\partial U}{\partial F} = \int \frac{R}{EI}\left(M \frac{\partial M}{\partial F}\right) d\theta + \int \frac{F_\theta R}{AE}\left(\frac{\partial F_\theta}{\partial F}\right) d\theta$$
$$- \int \frac{1}{AE} \frac{\partial (M F_\theta)}{\partial F} d\theta + \int \frac{C F_r R}{AG}\left(\frac{\partial F_r}{\partial F}\right) d\theta$$

$M = FR\sin\theta$ $\qquad \frac{\partial M}{\partial F} = R\sin\theta$

$F_\theta = F\sin\theta$ $\qquad \frac{\partial F_\theta}{\partial F} = \sin\theta$

$MF_\theta = F^2 R\sin^2\theta$ $\qquad \frac{\partial (MF_\theta)}{\partial F} = 2FR\sin^2\theta$

$F_r = F\cos\theta$ $\qquad \frac{\partial F_r}{\partial F} = \cos\theta$

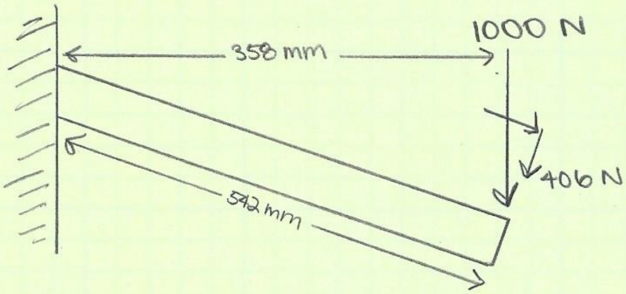
→ integrate from 0 to $\pi/2$ for approximation

$$\delta = \frac{FR^3}{EI}\int_0^{\pi/2} \sin^2\theta\, d\theta + \frac{FR}{AE}\int_0^{\pi/2} \sin^2\theta\, d\theta$$
$$- \frac{2FR}{AE}\int_0^{\pi/2} \sin^2\theta\, d\theta + \frac{CFR}{AG}\int_0^{\pi/2} \cos^2\theta\, d\theta$$
$$= \frac{\pi F R^3}{4EI} + \frac{\pi F R}{4AE} - \frac{\pi F R}{2AE} + \frac{\pi C F R}{4AG}$$
$$= \frac{\pi F R^3}{4EI} - \frac{\pi F R}{4AE} + \frac{\pi C F R}{4AG}$$

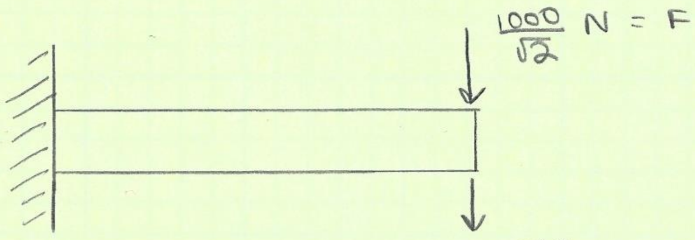
→ Plug in values

$$\delta = \frac{\pi(1000\text{ N})(0.342\text{ m})^3}{4(2.05\times10^{11}\text{ N/m}^2)(245\times10^{-8}\text{ m}^4)}$$
$$- \frac{\pi(1000\text{ N})(0.342\text{ m})}{4(1.44\times10^{-4}\text{ m}^2)(2.05\times10^{11}\text{ N/m}^2)}$$
$$+ \frac{\pi(2.0)(1000\text{ N})(0.342\text{ m})}{4(1.44\times10^{-4}\text{ m}^2)(8\times10^{10}\text{ N/m}^2)}$$
$$= 0.0125\text{ m}$$

$$\boxed{\delta = 6.29\text{ mm}}$$



→ Further approximation using straight beam supported at one end at an angle



→ calculate deflection using beam tables

$$\delta = \frac{FL^3}{3EI}$$

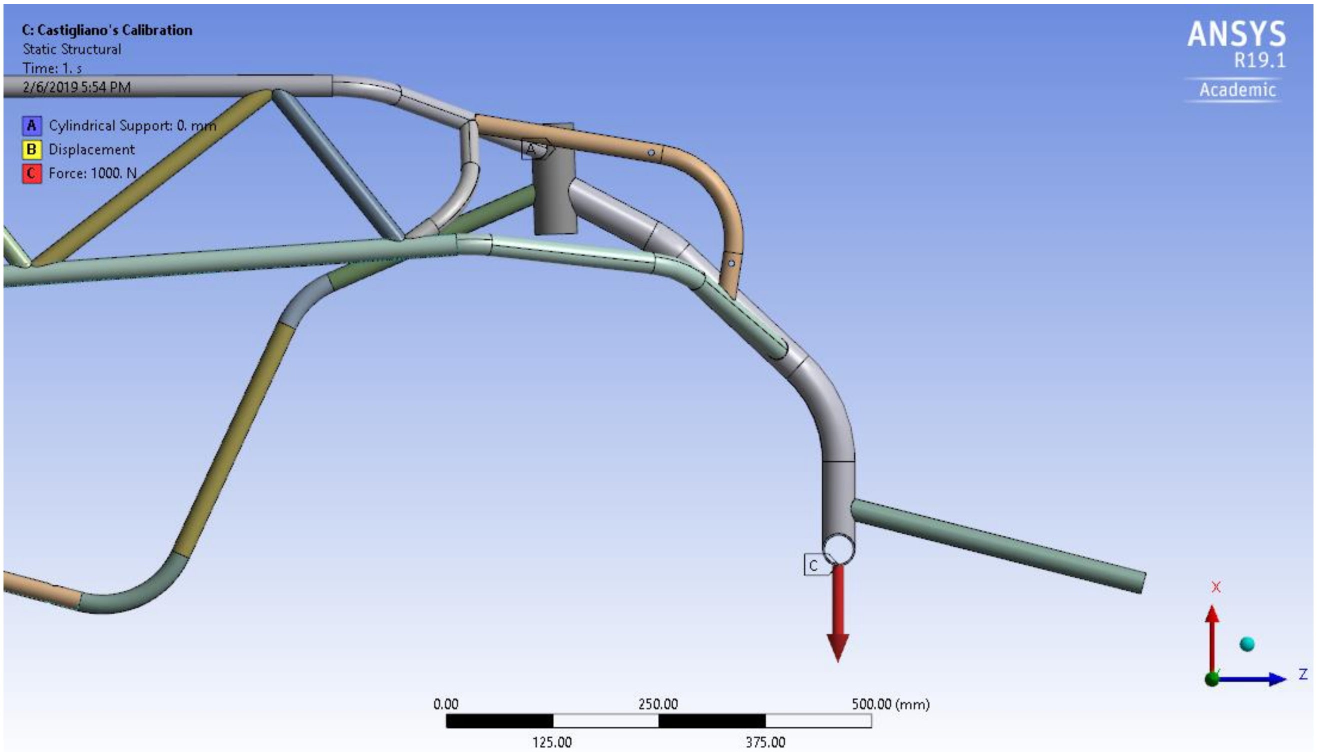
$$= \frac{(1000/\sqrt{2}\ N)(0.542\ m)^3}{3(2.05\times10^{11}\ N/m^2)(2.45\times10^{-8}\ m^4)}$$

$$= 0.00747\ m$$

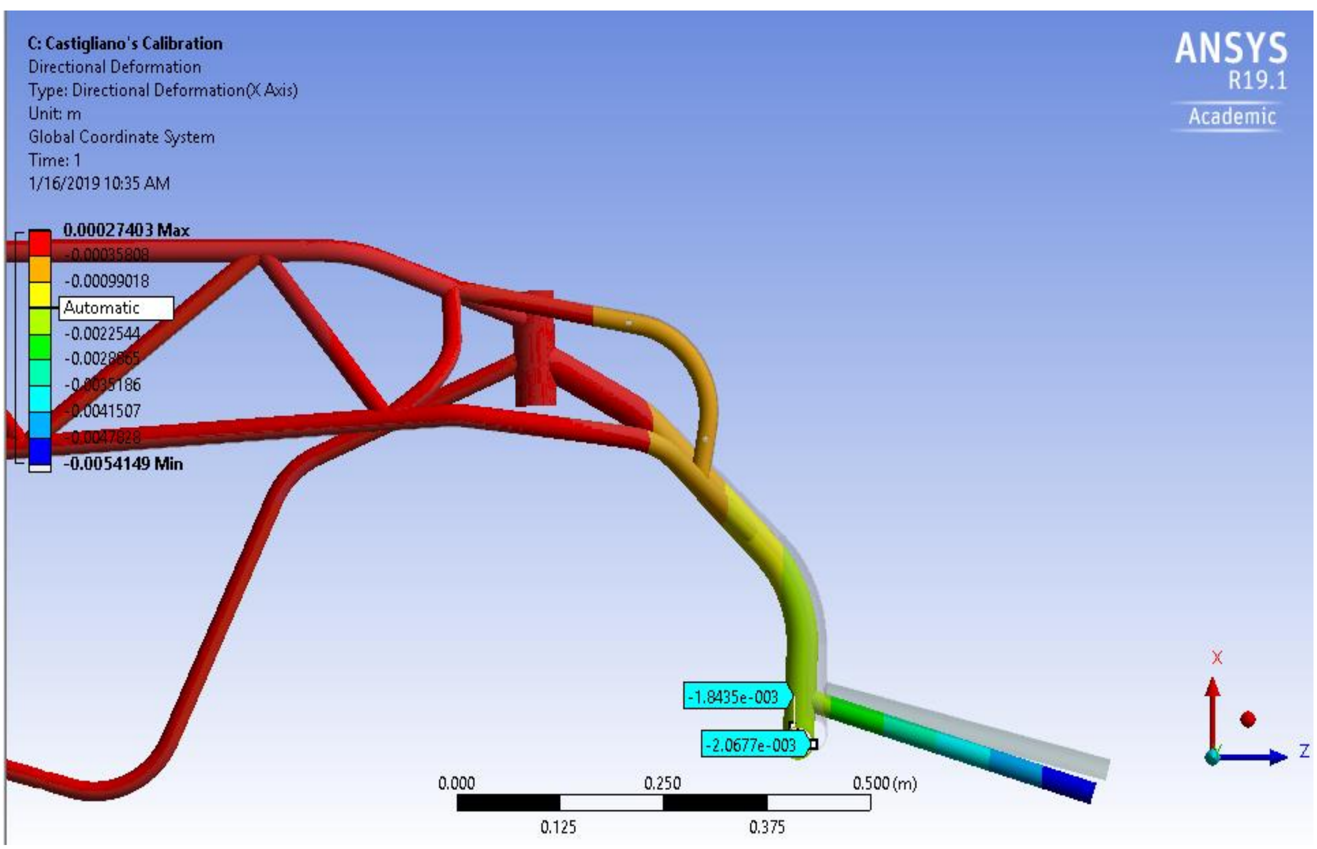
$$\boxed{\delta = 7.5\ mm}$$

∴ Because this calculation is a further approximation, we expect this deflection value to be slightly larger than the curved beam in bending calculation.

Castigliano's Calibration Setup

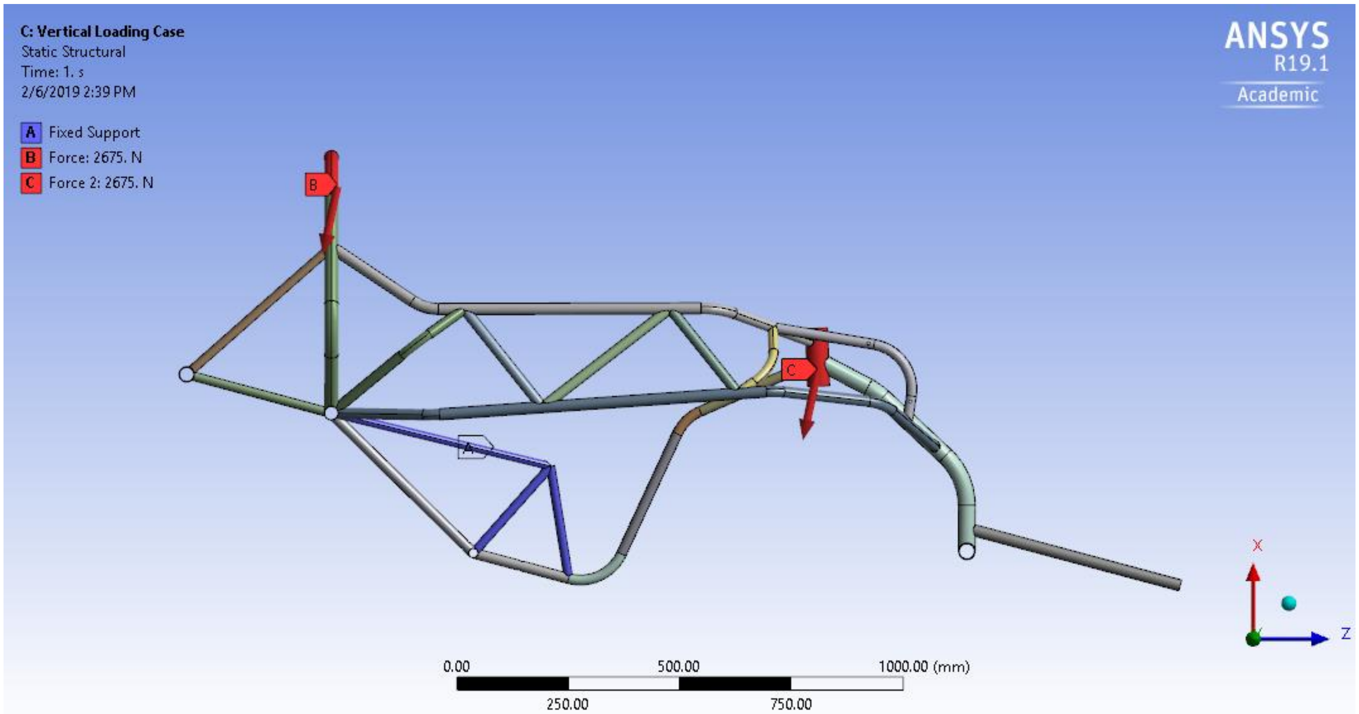


Castigliano's Calibration Deformation Results

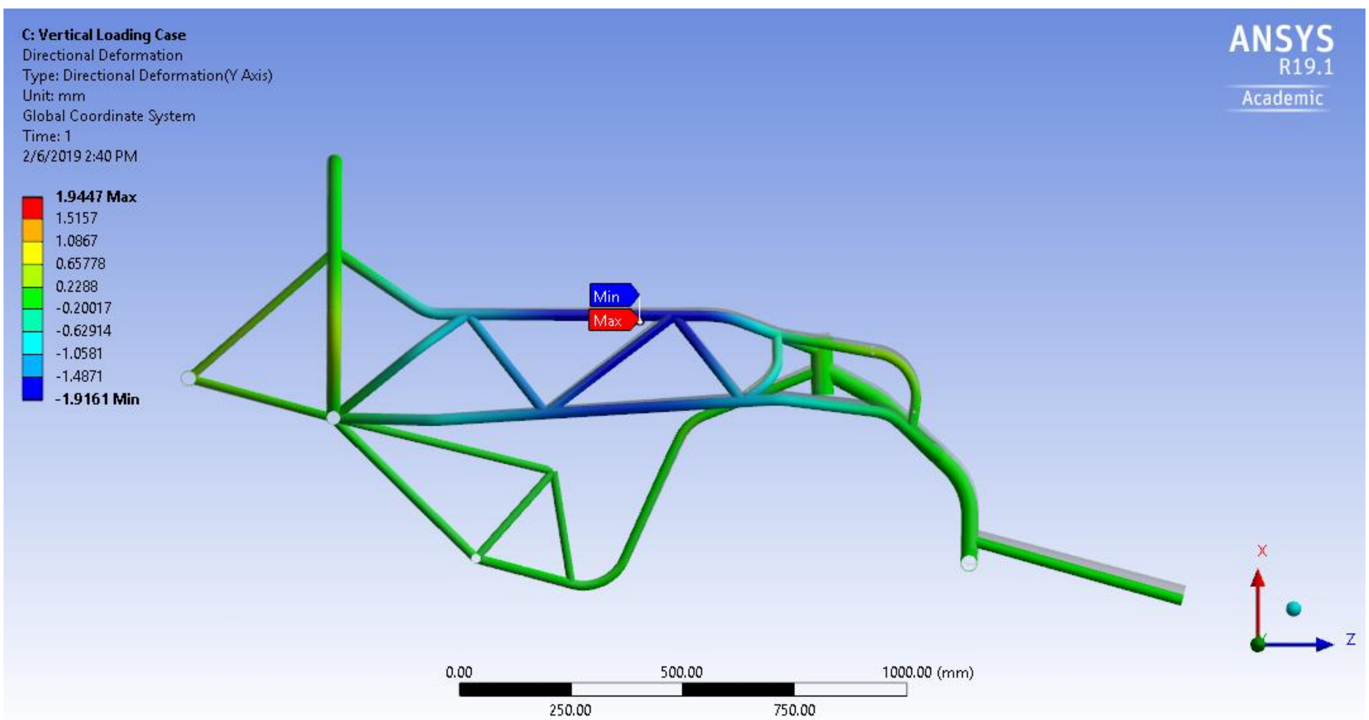


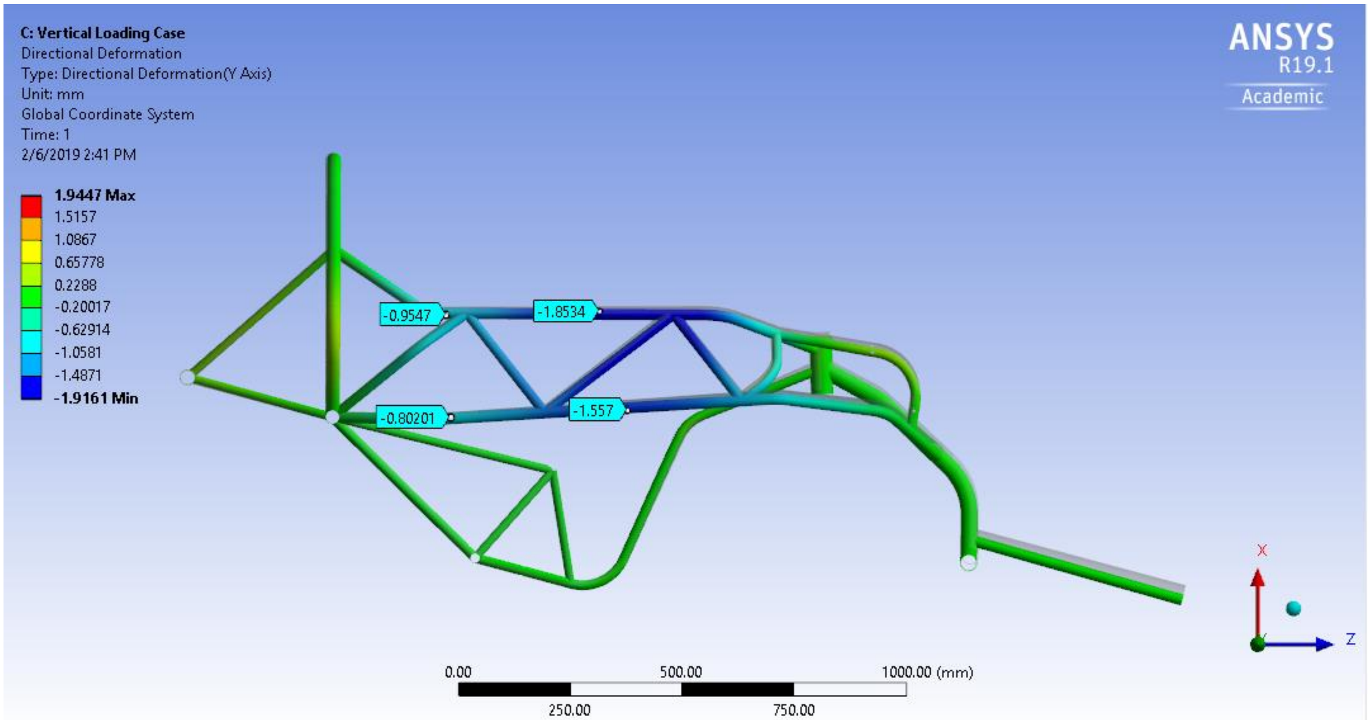
Appendix V: Vertical Loading FEA Setup

This appendix contains vertical loading FEA setup.



Results

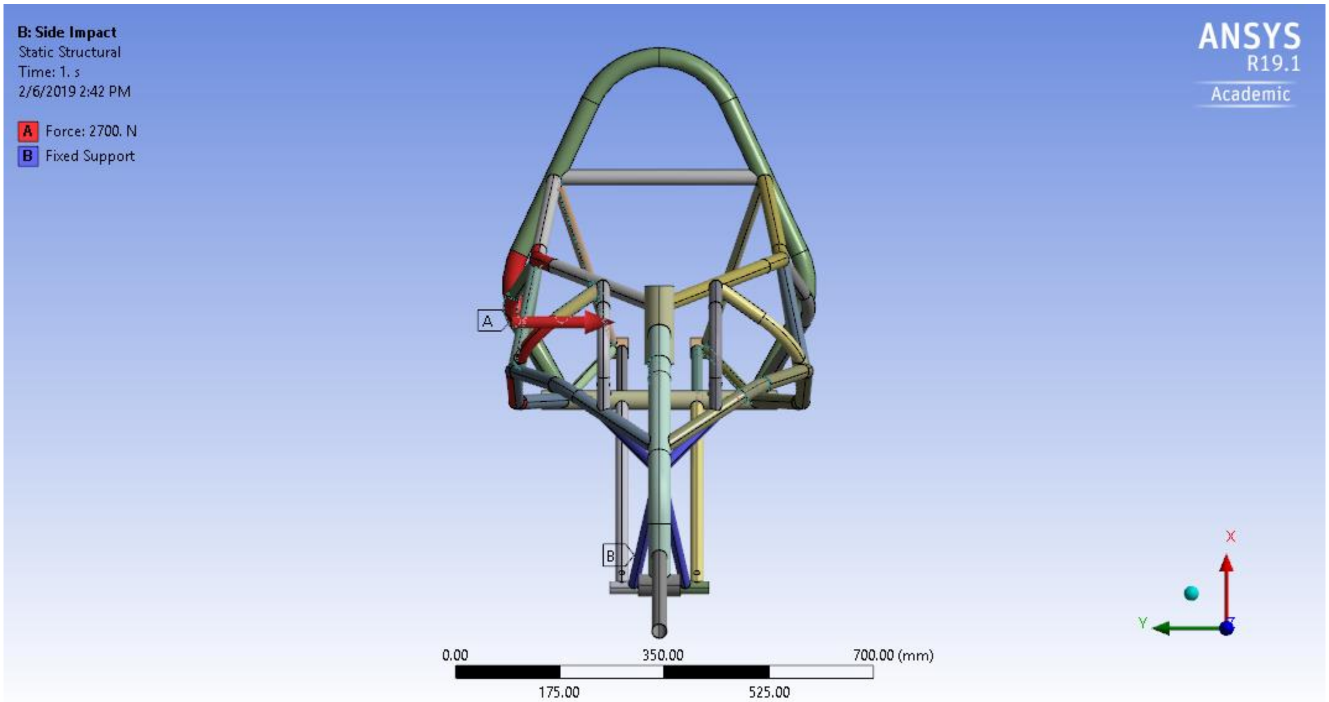


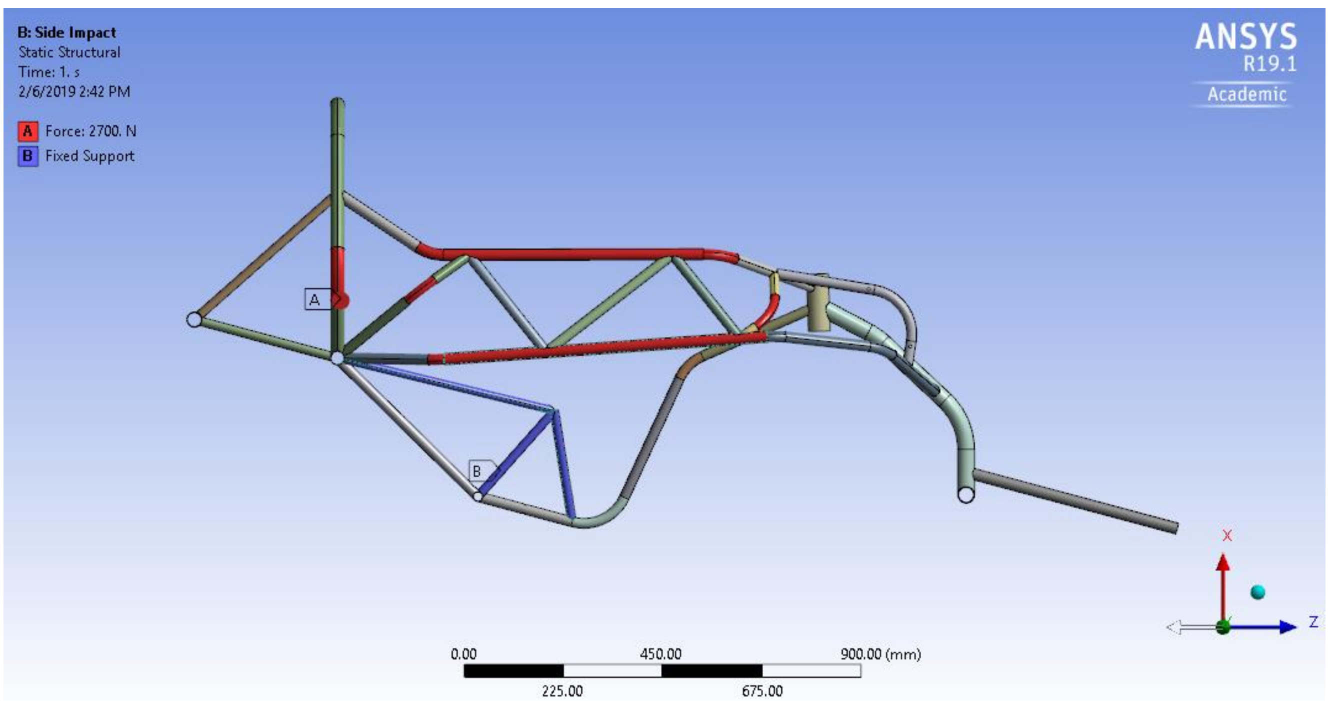


C: Vertical Loading Case
Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1
2/6/2019 2:41 PM
1.9447 Max
1.5157
1.0867
0.65778
0.2288
-0.20017
-0.62914
-1.0581
-1.4871
-1.9161 Min
-0.9547
-1.8534
-0.80201
-1.557
ANSYS
R19.1
Academic
0.00
500.00
1000.00 (mm)
250.00
750.00

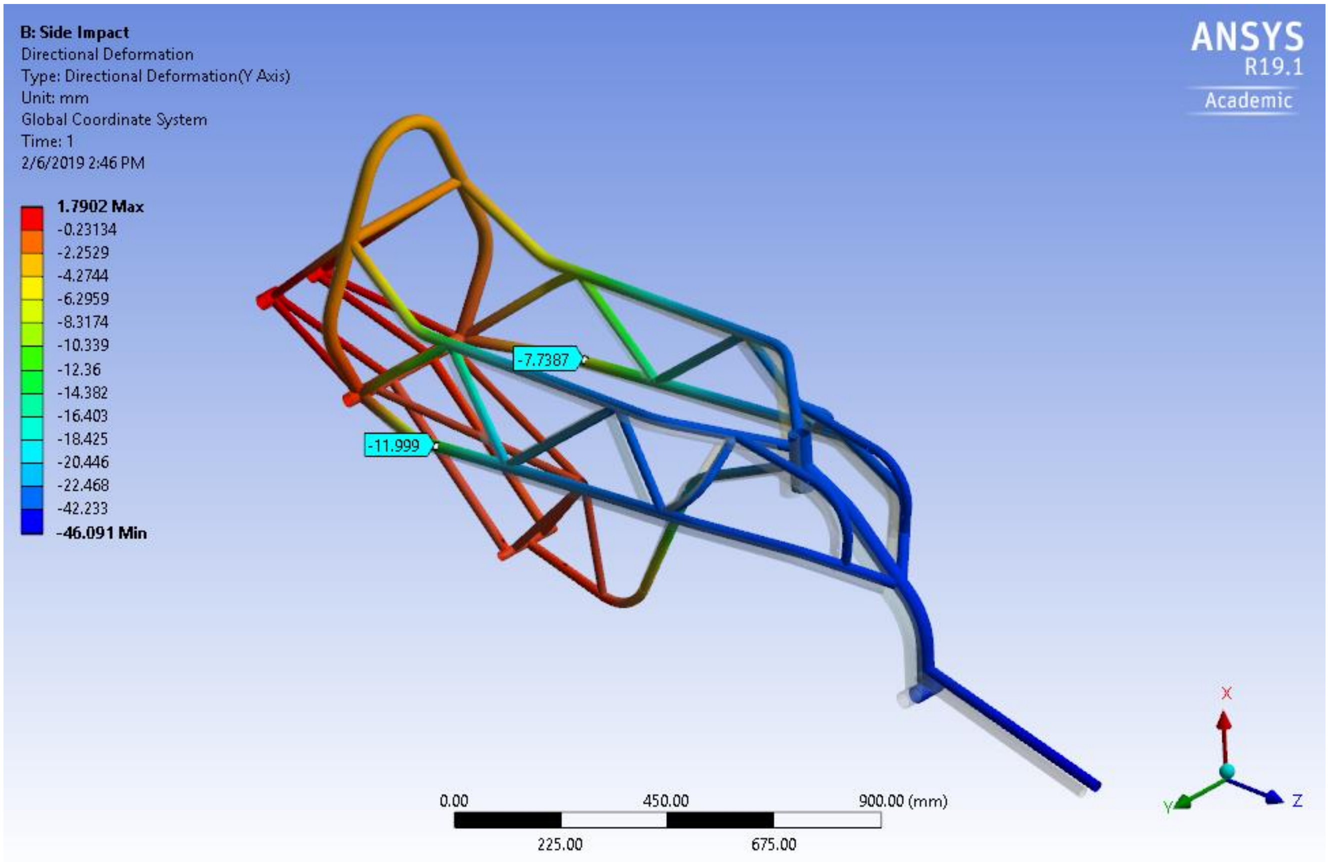
Appendix W: Side Loading FEA Setup

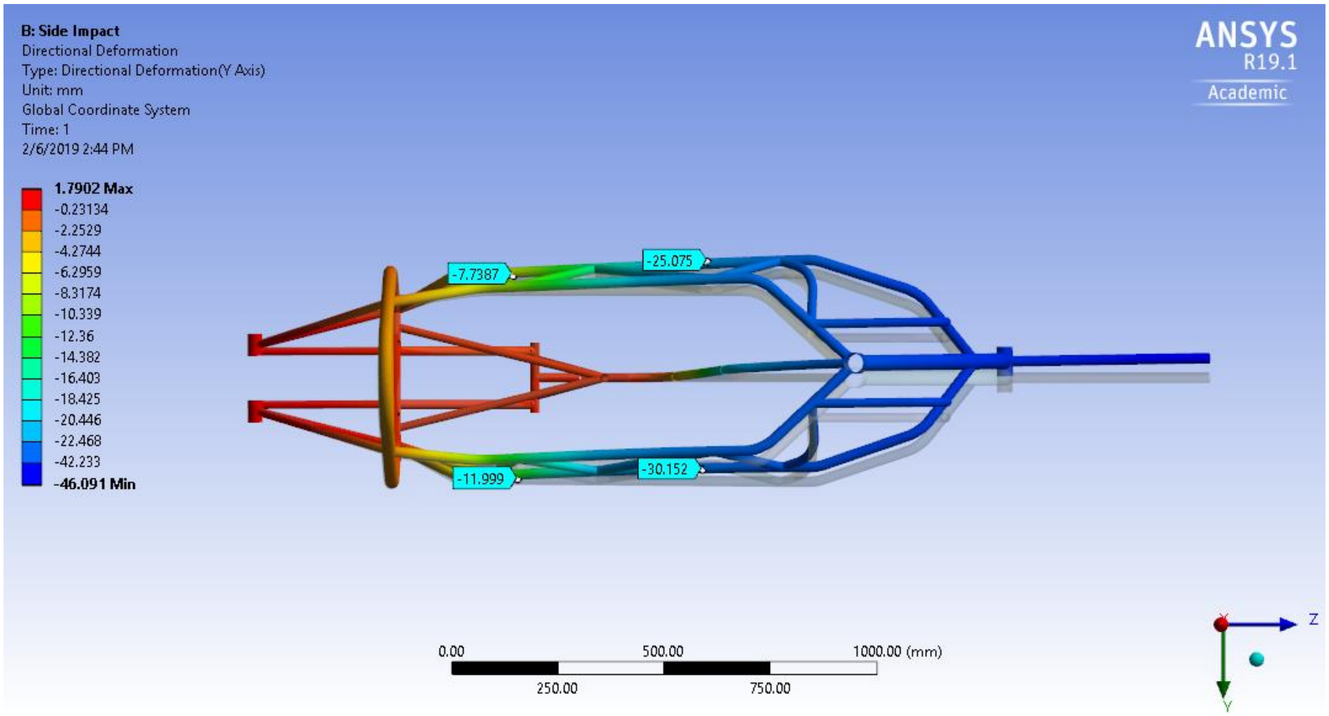
This appendix contains side loading FEA setup.





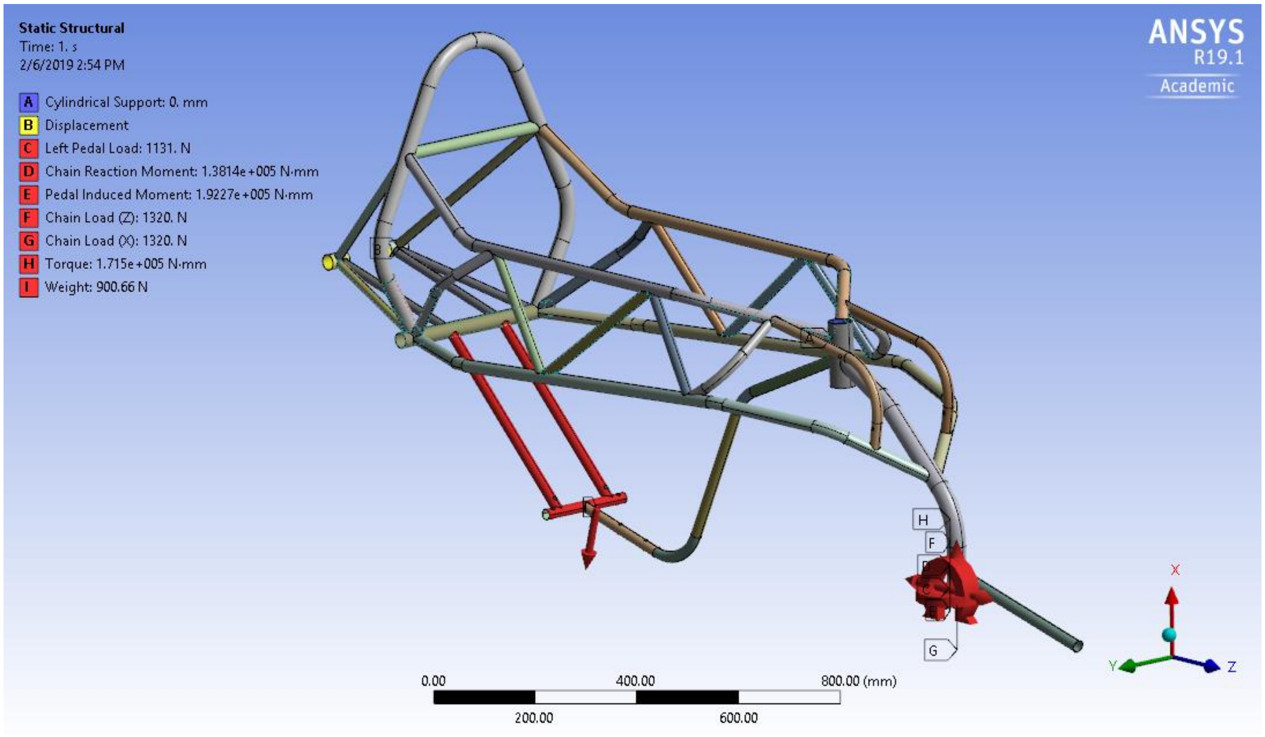
Results


B: Side Impact
Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1
2/6/2019 2:46 PM
1.7902 Max
-0.23134
-2.2529
-4.2744
-6.2959
-8.3174
-10.339
-12.36
-14.382
-16.403
-18.425
-20.446
-22.468
-42.233
-46.091 Min
ANSYS
R19.1
Academic
-7.7387
-11.999
0.00
450.00
900.00 (mm)
225.00
675.00
X
Y
Z

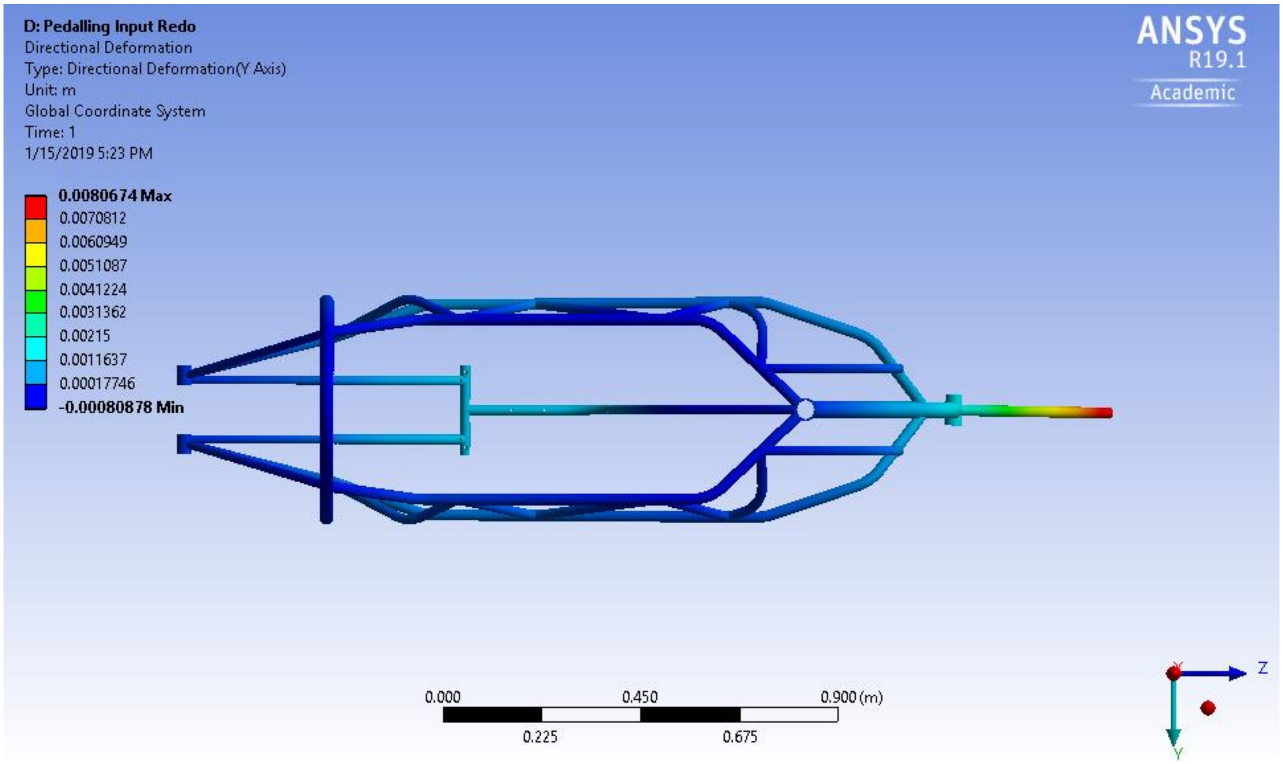

B: Side Impact
Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1
2/6/2019 2:44 PM
1.7902 Max
-0.23134
-2.2529
-4.2744
-6.2959
-8.3174
-10.339
-12.36
-14.382
-16.403
-18.425
-20.446
-22.468
-42.233
-46.091 Min
ANSYS
R19.1
Academic
-7.7387
-25.075
-11.999
-30.152
0.00
500.00
1000.00 (mm)
250.00
750.00
Z
Y

Appendix X: Pedal-Input Loading FEA Setup

This appendix contains the FEA set up for pedal-input loading.



Results

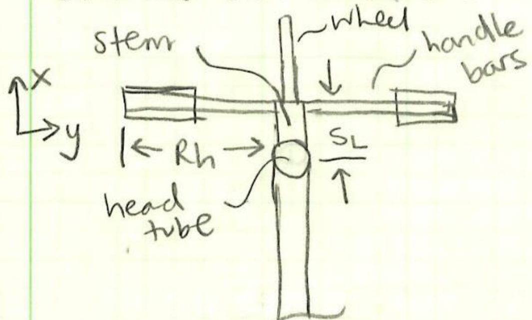


Appendix Y: Tiller Steering Approximation Derivation for Patterson Control Model

This appendix contains hand calculations for approximating the handlebar radius on a “tiller steering” recumbent as the stem length.

TILLER STEERING APPROXIMATION

standard diamond frame approx:



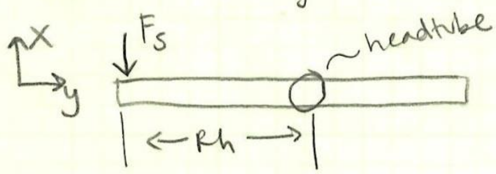
R_h = handle bar radius

S_L = stem length

Top view: diamond frame

For diamond frame, $R_h >> S_L$

Thus, S_L is negligible. In Patterson Control Model, R_h is used to calculate a moment about the head tube given a steering force input.

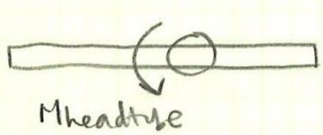


F_s = steering force input

R_h = handlebar radius

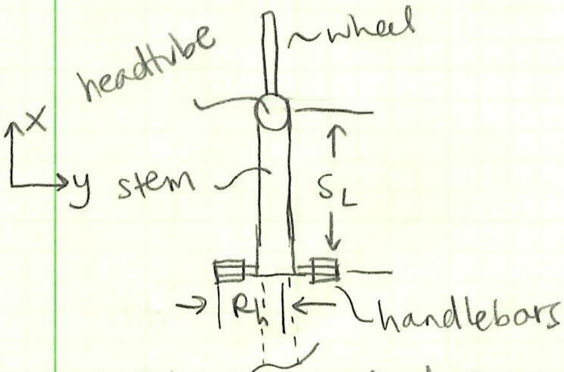
$$M_{headtube} = R_h * F_s$$

*idealized with no stem length



TILLER STEERING APPROXIMATION cont'd

Recumbent with short handlebar approx:

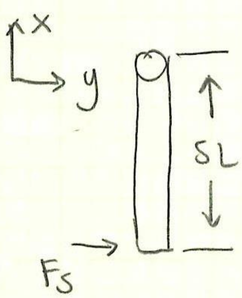


R_h = handle bar radius
S_L = stem length

Top view: recumbent frame

For recumbent with short handle bars (as is typical of Battle Mountain bikes and is true for the Cal Poly bike), $S_L >> R_h$.

Thus, R_h is negligible. To calculate an equivalent moment about the headtube given a steering force input ($M_{headtube}$), S_L must be subsituted for R_h.



F_S = steering force input.
Due to the short handle bars & long stem ("tiller"), the steering force input is perpendicular to a standard bicycle.

S_L = stem length

$M_{headtube} = S_L * F_S$ * idealized with no handle bar radius

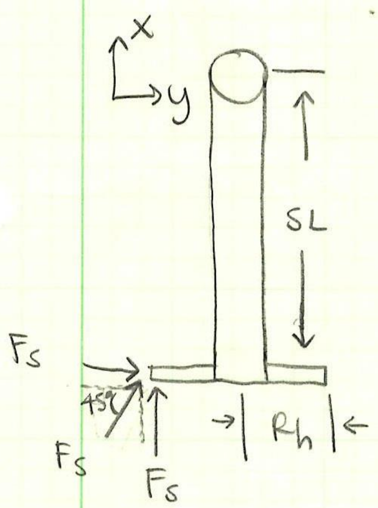
2

TILLER STEERING APPROXIMATION cont'd

Conclusions:

The handle bar radius is used to calculate a final value for sensitivity. To get a more valid prediction for recumbent handling with a tiller steering system, handle bar radius must be substituted with stem length.

R_h (input to model) = stem Length (S_L)



Approximations.

If R_h is small:

> If F_S is $\langle 0, F_s \rangle$, the $M_{headtube}$ is the same as if $R_h = 0$

> If F_s is $\langle F_s \sin 45, F_s \cos 45 \rangle$, the $M_{headtube}$ will be:

$+(F_s \sin 45 * S_L)_z + [-(F_s \cos 45 * R_h)]$

This value will be smaller than $+(F_s * SL)_z$

> If F_S is $\langle F_S, 0 \rangle$, the $M_{headtube}$ will be:

$-(F_S * R_h)_z$

If $R_h < SL$, this value will be smaller than $+(F_s * S_L)_z$

<u>Thus</u>, if take $R_h = S_L$, will always get <u>largest</u> approximation for $M_{headtube}$.

3

Appendix Z: Operator's Manual

This appendix contains the operator's manual for use of the frame. It provides instructions for the user and bystanders to conduct a pre-check and harness strap in, Battle Mountain procedures for launch, general ride (under specified conditions), catch, and emergency extraction. It also details procedures for testing days.

9.1 Pre-Check

NOTE: Prior to any use of the frame that involves a rider in the seat, ample time should be allotted to perform a pre-check that verifies that critical components are in place and members are structurally sound.

The pre-check acts as a checklist that should be 100% completed before the rider gets into the seat. Should any factors not pass this initial inspection, the test or ride will be suspended until the issue is mitigated and the pre-check is passed.

1. Bottom Support Member Bosses

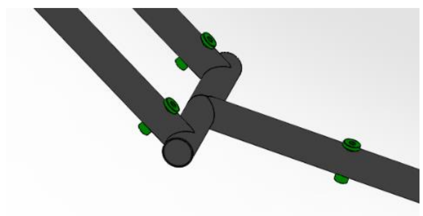


Figure 143. Bottom member support bosses.

Figure 143 shows the three bosses that are welded in the bottom support members. To verify that the bosses are in place and secure, gently push and pull on the tops to confirm that there is no movement. Verify that the welds securing the bosses in the tubes are intact. The two bosses on the parallel tubes are used to mount the lap belts. Verify that belts are correctly and securely mounted on the bosses by tugging on them.

☐ Bottom support member bosses

2. Bottom Support Member Tabs

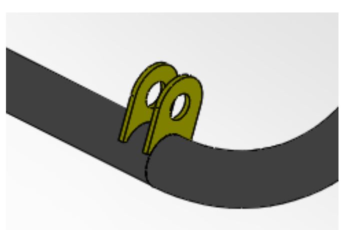


Figure 144. Bottom member mounting tabs.

Figure 144 shows the tabs that are used to mount the anti-submarine belt in the bottom support member. Gently pull and push the tabs in each direction to confirm there is no movement. Verify that the welds securing the tabs to the tube are intact. Verify that the belt is correctly and securely mounted on the tabs by tugging on it.

☐ Bottom support member tabs

3. Roll Hoop Bosses

Figure 145. Roll hoop bosses.

Figure 145 shows the bottom member of the roll hoop where the shoulder belts will be mounted using the wraparound method. To verify that the harness mounting and the harness itself is secure, pull on each belt to ensure they are tight in the length adjustment brackets.

☐ Roll Hoop Bosses

4. Damage to Entire Frame

Conduct a visual inspection of the entire frame to check for any damage that may have resulted in deformation, deflection, or pinch and shear points. If it is possible that something will hinder or harm the rider's body when entering or sitting, it should be addressed.

☐ Damage to Entire Frame

9.2 Harness Strap-In and Release

NOTE: The harness strap-in and release process is one that the rider should be extremely familiar with prior to riding the vehicle. They should be able to both secure and release themselves quickly and independently in the event of an emergency.

9.2.1 Strap-In

1. Bring over the left lap belt that has the tongue part of the latch, as shown in Figure 146.

Figure 146. Strap-in step 1.

2. Bring down the left shoulder belt and slide the latch tongue through, as shown in Figure 147.

Figure 147. Strap-in step 2.

3. Bring up anti-submarine belt and slide the latch tongue through, as shown in Figure 148.

Figure 148. Strap-in step 3.

4. Bring down the right shoulder belt and slide the latch tongue through, as shown in Figure 149.

Figure 149. Strap-in step 4.

5. Bring over the right lap belt with the latch mechanism and hook and secure it onto the tongue, as shown in Figure 150.

Figure 150. Strap-in step 5.

6. The latch mechanism should be assembled and secure, appearing as in Figure 151.

Figure 151. Assembled latch mechanism.

9.2.2 Release

1. Lift up the hook on the right lap belt to release the lock and allow all belts to slide off the tongue, as shown in Figure 152.

Figure 152. Release step 1.

2. The latch mechanism should be released, appearing as in Figure 153.

Figure 153. Released latch mechanism.

9.3 Battle Mountain Procedures

The procedures for the vehicle and frame use at Battle Mountain are detailed below.

9.3.1 Launch

NOTE: The team shall verify that there are trained team members or trained members of the race catch team present at catch before launching the vehicle.

This procedure requires 4-6 trained team members and the vehicle's rider.

Roll the vehicle into the starting line queue in the order specified by the pre-race meeting. Have the rider enter the vehicle when they are comfortable, but not later than at least 3 vehicles back from the starting line.

Have two trained team members, one on each side (left and right) of the bike, support the vehicle from the fairing outside the roll hoop and outside the front of the side supports. Have two other trained team members, one on each side (left and right) of the bike, assist the rider into entering the vehicle.

With the fairing door removed, the rider will stand on the seat of the vehicle to enter. He will then crouch down and rotate his shoulders, so he is perpendicular to the long axis of the vehicle. Once his shoulders clear the top side supports, he will rotate into position, facing forward in the bike. He will then sit down, and extend his legs to reach the pedals underneath both the top and middle side supports, and clip in. The final seated position is shown in Figure 154.

Figure 154. Rider in vehicle prior to putting on door, Battle Mountain 2018.

Two other trained team members should be standing by with water and shade, as needed. The door shall then be slid into the correct alignment on the vehicle and firmly latched. Two trained team members, one on each side (left and right) of the bike, will tape over the door seams as shown in Figure 155.

Figure 155. Bikes getting taped, at Battle Mountain 2018.

When it is time for the team's rider to launch, roll the vehicle with the rider up to the first set of starting lines. There are many start lines, all marked 15m apart, extending down the first part of the course. Thus, if a bike is dropped, the team can simply move up to the next set of 15m lines and attempt to start again.

Once the team is given the start call, they have 2 minutes (120 seconds, per Battle Mountain regulation) to successfully launch their rider into sole control of the vehicle.

NOTE: Only two team members can have tactile contact with the vehicle during launch, per Battle Mountain regulation.

Two (maximum) trained team members, one on each side (left and right) of the bike, will stabilize the bike from falling over at a dead stop. When the start signal is noted, the rider will be relayed this information via the rider's radio. The rider will begin pedaling and as the bike begins to move forward the two team members will continue to move alongside it and stabilize it left and right. Then will inform the rider of leaning and other corrections as needed. This process is shown in Figure 156.

Figure 156. Team members running alongside a launched vehicle, Battle Mountain 2018.

NOTE: The team shall have a maximum of 15m, or roughly 50 feet, in which they can have tactile contact with the vehicle, per Battle Mountain regulation. If longer contact is maintained, the run will not be recognized as a valid run for records.

The team will continue stabilizing the bike throughout the 15m launch zone. Once the second line (located 15m in front of the previous launch line) on the ground is passed, all team members must no longer have contact with the bike. All hands must be off the vehicle, and the team members shall withdraw and enter the chase car.

NOTE: At NO point during the launch process (once the rider is pedaling off the first start line), shall team members be allowed to push or otherwise contribute to the forward movement of the vehicle, per Battle Mountain regulation.

9.3.2 Race Riding

NOTE: At NO point may a chase car pass any moving bike.

This procedure requires 2 trained team members and the vehicle's rider.

At least two dedicated chase vehicle team members will be present, one driving the vehicle and the other operating the rider communication radio. The team members from launch will also be in the chase vehicle to move to catch.

During racing at Battle Mountain, all vehicles shall stay confined to the right side of the road. The chase car shall stay on the left side of the road.

NOTE: The chase car may not get closer than 100m to any moving bike.

Each distance from the finish line is marked with a flag. The distance listed on the flags is distance to the FINISH LINE, shown in Figure 157. Thus, the flag labeled 200m is the START of the time traps. The finish line is marked with banner flags.

Figure 157. The Glowworm, tandem recumbent record holder, finishing a run.

If at any point an issue arises, the rider will notify (if possible) the team via the rider's two-way radio. They will then pull off the course to the far right.

9.3.3 Catch

This procedure requires 4-6 trained team members and the vehicle's rider.

After the 200m speed traps, the rider will have roughly 1 mile to cool down. The catch zone, denoted by large banner flags, is roughly 40-50 feet long. The rider will enter the catch zone, denoted with banner flags, coasting at under 10mph. The rider will feather the brakes to slow and stop.

As the vehicle enters the catch zone, 2 - 4 trained members will position themselves on either side (right and left) of the vehicle. The team members should radio the rider and apply some force (i.e., slap) the fairing to warn the rider the catch team has support of his vehicle.

When the vehicle slows, the catch team will reach out hands to stabilize the bike as it continues to slow down. When the vehicle comes to a complete stop, two trained team members will support the vehicle from falling on its side. Two other trained members will remove the tape from the fairing door seam and slide the door off.

Figure 158. Door removed, Primal 2.

It shall be the first goal of the catch team to ensure the rider is in good health.

The door shall be handed off to another trained member, and the rider questioned to assure he is lucid. Two other members will assist the rider in unclipping, standing up, and getting out of the vehicle with the other two members keeping the bike upright. The rider will then move to the trainer inside the chase vehicle to warm down, and the team members shall remove the vehicle from the road. This is shown in Figure 158.

NOTE: Since there are vehicles launched every two minutes, it shall be the goal of the team to remove the rider and vehicle from the road as quickly and efficiently as possible.

9.4 Emergency Extraction of Rider

In the event of a crash or rider emergency, there shall be a way to safely remove the rider from the enclosed bike. The rider will be wearing a helmet and a safety harness; therefore, his immediate extraction from the vehicle may be impeded. In the event of a crash, the team will contact the rider via the two-way radio to assess his condition and ask safety protocol questions. Prior to any riding of the bike, the rider will be fully trained to remain in the vehicle and await the arrival of emergency personnel in a crash scenario. This training will allow the first responders to safely remove the rider in an effort to preserve a potential spinal injury case. To remove the rider from the bike, the team or first responders will remove the taping that seals the fairing. Then, the front of the fairing will be removed, and the rider will be exposed. Next, the rider will be instructed to remain still while the safety personnel evaluate him and proceed to carefully extract him from the vehicle.

In the event of a crash during rider testing, the club members present will be responsible for properly aiding the rider. Therefore, team members and rider will be trained prior to conducting any event of testing. This will ensure that each party involved knows exactly what to do to keep the rider's safety paramount. During the testing phase, the rider will not always be enclosed in the fairing, so rider extraction techniques will vary. When the fairing is not installed around the rider, the speed at which the rider is allowed to ride is limited to below 30mph.

To aid in rider and safety personnel training, a table general crash protocols based on the type of crash incurred as seen in Table 29 below.

Table 29**.** Procedures for rider and safety personnel for each crash type

Crash Type	Protocol	Priority Personnel
Tip-over (low speed)	1. Contact rider for status 2. If responds in affirmative, upright the vehicle 3. If hurt, proceed with rider's instruction	1. Team Members (if no First Responders Present) 2. First Responders
Rollover or Sliding	1. Contact rider for status 2. If responsive, continue communication and give instruction to remain still 3. Carefully remove fairing (if installed) 4. Stabilize rider's neck to ensure safe extraction 5. Proceed to remove rider from bike	1. First Responders 2. Team Members

9.5 Testing Procedures

Test riding the Human Powered Vehicle will need at least five in order to run. The first step in preparing for a ride is passing the pre-check. A copy of the club's pre ride check can be seen below, in 9.6 Pre- Test Check List. The first section of this checklist involves checking environmental factors. These environmental factors include wind, length of run, condition of road, debris present on road, traffic, and the interaction between the light and the vehicle's vision system. If necessary, measures should be taken to mitigate risks associated with unsafe conditions; removing debris, marking obstacles, and directing traffic are examples of these measures. Once all of these factors have been evaluated and deemed acceptable by the team, the next check is to check the bike setup.

Before the rider is allowed to start a practice run the bike must be inspected. There are eight subsystems that must be checked and prepped in order to start a ride, these include: frame, drivetrain, fairing, braking, breathing, vision, steering, and wheels. The frame subsystem specifically requires visual inspection of all of the welds and joints and an inspection of the racing harness.

After establishing that the vehicle and track are safe, the team must ensure that the personal on site know their responsibilities. If riding will be longer than 0.25 miles, a chase vehicle will be used to help assist the rider in the event of a mid-ride emergency. This chase vehicle must be equipped with a first aid kit and at least one individual trained in first aid. This vehicle must also be equipped with a two-way radio to help communicate with the rider. Communication, driving, and passing procedures will all be verbally clarified before the vehicles start their run

The launch and catch teams must also be made aware of their responsibilities. The launch team will help the rider into the vehicle, ensure that the rider remains cool before the run, and also close the vehicle door before the vehicle launches if riding with a fairing. The launch team is also responsible for starting the bike. This involves holding the bike upright before the run gets underway and running with the bike during the start as the vehicle is rather unstable at low speeds. Once the vehicle 'outruns' the launch team, their responsibilities end.

The catch team is the team responsible for stopping the bike and helping the rider exit the vehicle. The first of these responsibilities is the more critical of the two. It involved signaling the rider to let him know when and how hard to brake and then actually catching the vehicle as it comes to a stop. This team must make sure that they are supporting the fairing at or near the roll hoop so as to avoid damaging the fairing. Once the vehicle is caught, it is the responsibility of the catch team to remove the door as quickly as possible and help the rider exit the vehicle. This exit will me more important on longer rides and hotter days as he will likely have trapped quite a lot of heat inside of the frame.

In order to ride the Human Powered Vehicle at speeds higher than 30 miles per hour a number of requirements must first be met. Firstly, the vehicle must have been proven road worthy by passing the pre-check. Next, environmental factors must be evaluated. These environmental factors include wind, length of run, condition of road, debris present on road, traffic, and the interaction between the light and the vehicle's vision system. Once all of these factors have been evaluated and deemed acceptable by the team then regular riding can commence.

Before the rider is allowed to start a practice run on a non-competition raceway there must also be measures taken to prep the road to be tested on. The first of these is to visually inspect the road for foreign object debris (FOD). This will be done by a team of two individuals driving along the road at less than 10 miles per hour and visually checking for FOD. If there is any FOD found along the road then it will be removed by the individual who is not driving.

The pre-test checklist is shown below, in 9.6 Pre-Test Check List.

9.6 Pre-Test Check List

9.6.1 Environmental Conditions

- Visibility
  - Verify that there is at least one mile of visibility through the air
  - Verify that the camera is functional and surface is clean
  - Verify that all individuals not riding are wearing reflective safety vests
- Road Conditions
  - Verify either on foot or on a bicycle that there is no debris larger than 2” in diameter
  - Mark any large potholes on the road with cones
- Traffic
  - Ensure that traffic is stopped while riding on open roads
- Weather
  - Verify that wind is kept to a safe level while riding
  - Verify that the heat index present at the location of riding is under 100

9.6.2 Bike Setup

- Frame
  - Visually inspect frame for damages including cracks, deformations, or scratches
  - Ensure that all racing harness bolts are tight and secure

- Drivetrain
  - Ensure that all drivetrain bolts and fasteners are tight and secure
  - Shift drivetrain to check for unusual noises and/or behaviors
  - Place drivetrain in lowest gear
  - Ensure that appropriate pedals are being used

- Fairing
  - Ensure that all fairing bolts and fasteners are tight and secure
  - Visually inspect fairing for damage including cracks or deformations

- Braking
  - Ensure that all braking bolts and fasteners are tight and secure
  - Check that brake lever feels firm and has an appropriate amount of travel
  - Rotate the rear wheel and check that there is no brake rub present
  - Visually inspect rotors and pads for cleanliness

- Breathing
  - Check that the breathing system connections are secure at the mask and at the fairing
  - Visually inspect breather hose for cracks or leaks

- Vision
  - Ensure that all vison fasteners and electrical connections are tight and secure
  - Visually inspect wiring for frays, entanglement, and improper routing
  - Check camera functionality through display screens
  - Visually inspect cameras for debris, moisture, and other obstructions

- Clean the windows if necessary, using anti-fog cleaner

- Steering
  - Ensure that all steering bolts and fasteners are tight and secure
  - Check steering lockout to ensure that front wheel does not contact the fairing
  - Check adjustment of handlebar length and angle

- Wheels and Tires
  - Ensure that all axle bolts and fasteners are tight and secure
  - Visually inspect tires and wheels for damage or oils/chemicals
  - Check that tire pressure is at an appropriate level.

9.6.3 Chase Vehicle

- First Aid
  - Ensure that chase vehicle is equipped with first aid kit
  - Ensure that one individual in chase team is first aid certified

- Communications
  - Check two-way radios for battery life and range
  - Go over radio communications phrases and procedures with rider and radio operator

- Driver
  - Go over emergency passing procedures with rider and chase vehicle driver
  - Ensure that the driver is aware that he is always to maintain a 50-100 meter following distance behind the rider
  - Ensure that drives headlights and high beams are on to increase visibility

Appendix AA: Testing Procedure for Experimentally Determining Center of Gravity and Radius of Gyration

The following is the testing procedure used to find center of gravity and radius of gyration. This is the same procedure as used in ME 441 Single Track Vehicle Design at Cal Poly. These tests were completed in the final frame with Josh, the chosen rider, strapped into the final vehicle's seat.

2) Locating the Center of Mass or CG or Center of Gravity: Please measure it at 5 D values, to get an average value and standard deviation.

Last week, most of the geometric dimensions were measured from a few bicycles, but correct application of any of the stability models (Lowell & McKell, and soon the Patterson Control Model) requires knowledge of the mass properties. For this, the following variables will be used (see next page):

A	Wheelbase
B	c.g. location ahead of the rear wheel contact point, i.e. the x-coordinate of the c.g.
h	height of the c.g. in the upright position, i.e. the z-coordinate of the c.g.
B	steering axis inclination
e	front axle offset
T	road trail
r_h	handlebar radius
r_f	front wheel radius
r_r	rear wheel radius
I_x	Roll Moment Inertia, i.e. mass moment of inertia about the x-axis
$r_{p\text{-}rail}$	distance from the swing pivot to the swing rail (not a bicycle parameter but required)

Wheelbase and C.G. Location

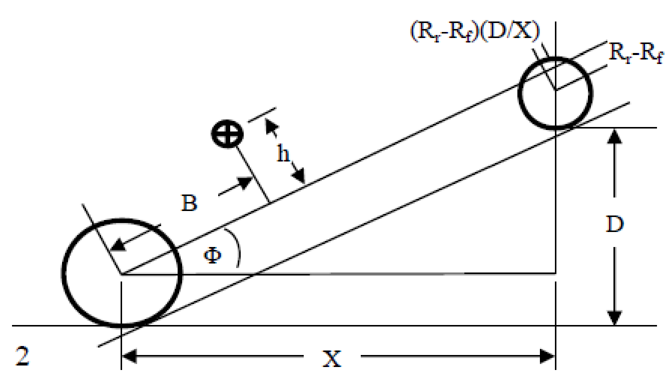
Measure the horizontal distance or wheelbase between the axles. This can be performed by eye or drop a weighted line from each axle and measure the distance on the floor.

Weigh the bike/rider. Record the total weight as well as the weights on the front and rear wheels.

$$B = A\frac{W_{Fwheel}}{W_{Total}} \quad (1)$$

Raise the front scale a small distance (D) with the provided block. Measure the horizontal distance between the axles (X) as before for the wheelbase. The bike/rider is now tilted upward at an angle

$$\tan\phi = \frac{D}{X} \quad (2)$$



We now have a right triangle with the angle φ at the rear axle. If the wheels are of equal diameter then the hypotenuse (Hyp) of the triangle formed by X and D is the wheel base A. If the wheels are not of equal diameter then

$$Hyp = A + \left(R_{lower} - R_{upper}\right)\tan\phi$$

$$Hyp = A + \left(R_{lower} - R_{upper}\right)\left(\frac{D}{X}\right) \tag{3}$$

Now we can find the height of the c.g. above the rear axle. For equal diameter wheels Hyp is equal to the wheel base A. For, wheels not of equal diameter use the value of Hyp calculated using equ (3).

$$h_{cg/ra} = \frac{\left(B - Hyp\left(\frac{N_f}{W_t}\right)\right)}{\left(\frac{D}{X}\right)} \tag{4}$$

Where N_f is the normal force or weight on the front wheel measured with the front wheel elevated. The height of the c.g. above the ground is.

$$h = h_{cg,ra} + r_r \tag{5}$$

3) Determining the Roll Moment of Inertia of the Rider/Bicycle: Please measure it 5 times, to get an average value and standard deviation.

Mass Properties – Roll Moment of Inertia

Moments of inertia can be measured with swing or twist tests where the period of the rotational or swing motion is measured and the moment of inertia about the rotational axis calculated by

$$I = \frac{T^2 mgr_{cm}}{4\pi^2} \tag{6}$$

Where,

- I = moment of inertia of the system about the axis of rotation
- T = period of the motion
- m = mass of the system
- g = acceleration due to gravity
- r_{cm} = distance from the pivot or axis to center of mass of the system

To determine the roll moment of inertia of the bike and rider we will swing the bike and rider in an assembly with a known moment of inertia about the axis of rotation. The total mass moment of inertia is the summation of all moments of inertia about a common axis

$$I_t = I_{swing} + I_{bike/rider about pivot} \tag{7}$$

However, the moment of inertia in equation (7) is the roll moment of inertia about the swing axis. The roll moment of inertia of the bike about the center of mass of the bike rider system can be determined from using the parallel axis theorem

$$I_t = I_{swing} + \left(I_{bike/rider} + mr^2\right) \tag{8}$$

Therefore,

$$I_{bike/rider} = I_t - I_{swing} - mr^2 \tag{9}$$

Where,

r = distance from the pivot to the center of mass of the bike rider system

(note: you will need to record the distance from the swing pivot to the rail to determine r)

Remember that this yields the roll moment of inertia about the center of mass of the bike rider system.

Also, some characteristics of the swing from John Fabijanic:

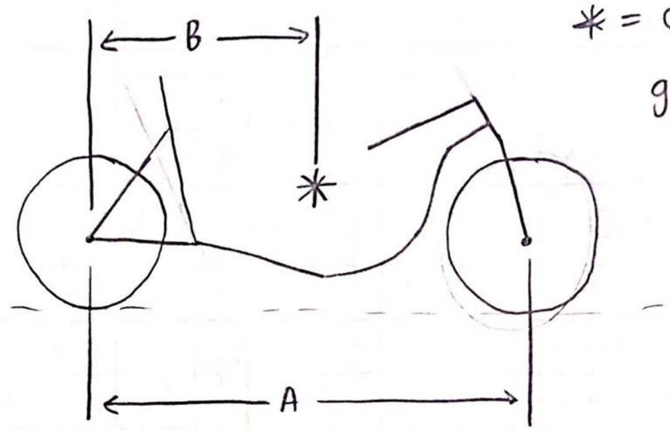
Swing		
Io swing	*33.91*	slug ft2
r swing pivot to swing c.g.	*3.692*	ft
r pivot to rail	*5.375*	ft
W swing	*63.5*	lb

Appendix AB: Center of Gravity Hand Calculations and Schematics

This appendix contains hand calculations for experimentally determining center of gravity.

CENTER OF GRAVITY CALCULATIONS/SCHEMATICS

GIVEN:



* = center of gravity

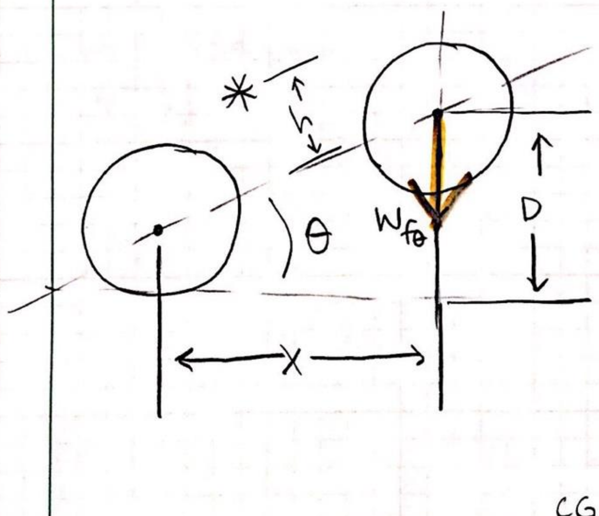
Horizontal distance from rear axel to C.G. (B):

$$B = \frac{A\ W_{front}}{W_{total}}$$

B = dist rear axel to CG horizontal

A = wheel base

D = height ground to front axel when bike inclined at angle θ



X = horizontal distance b/w axels when bike inclined at angle θ

$W_{fθ}$ = weight of front of bike when inclined at angle θ

h = vertical distance CG to axel height

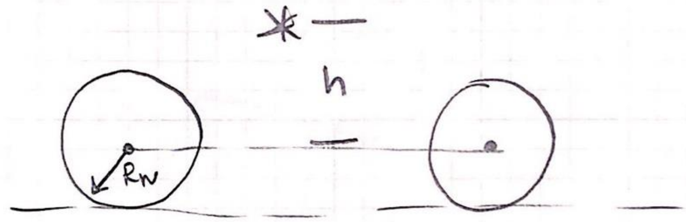
1

CENTER OF GRAVITY CONT'D

→ From class:

$$h = \frac{B - A\left(\frac{W_{f0}}{W_{total}}\right)}{\frac{D}{X}}$$

Know position above axels, add wheel radius to find height from ground



Height (vertical distance) of CG above ground:

$$h_g = h + R_w$$

Unit analysis:

$$B\,[ft] = \frac{[ft]\,[lbf]}{[lbf]} \quad ✓$$

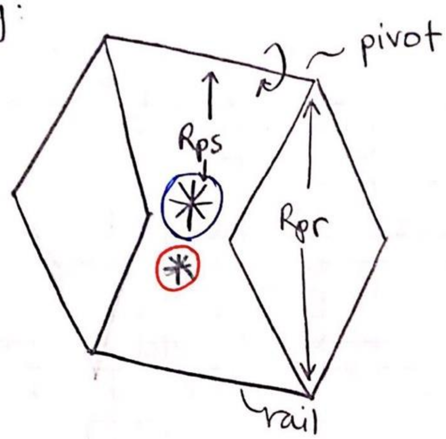
$$h\,[ft] = \frac{[ft] - [ft]\,\frac{[lbs]}{[lbs]}}{\frac{[ft]}{[ft]}} \quad ✓$$

Appendix AC: Radius of Gyration Hand Calculations and Schematics

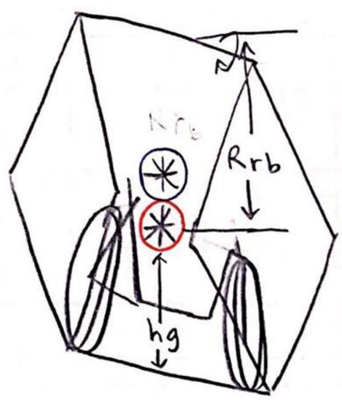
This appendix contains hand calculations for experimentally determining radius of gyration.

RADIUS OF GYRATION CALCULATIONS

Swing:



Note:
all references to "bike" are to bike + rider system.



R_{ps} = dist. pivot to CG of swing

R_{pr} = dist. pivot to rail

h_g = CG bike from ground

R_{rb} = dist. pivot to CG bike

$$R_{rb} = R_{pr} - h_g$$

1

RADIUS OF GYRATION CALCULATIONS

GIVEN:

$$I_{bs} = \frac{T^2 m_{total}\, g\, r_{sys}}{4\pi^2}$$

I_{bs} = Mass moment of inertia of bike <u>and</u> swing <u>about</u> swing's pivot

$m_{total} = m_{bike} + m_{swing}$

r_{sys} = dist. pivot to <u>equivalent CG</u> of bike + swing

$$r_{sys} = \frac{\Sigma m_i y_i}{m_{total}} = \frac{m_{swing} R_{ps} + m_{bike} R_{rb}}{m_{total}}$$

g = acceleration due to gravity

T = period of swings

I_{swing} = mass moment of inertia of <u>swing</u> <u>about</u> swing's pivot

THUS,

$$I_{bs} = I_{swing} + I_{bike} \quad \left[\text{about swing's pivot}\right]$$

→ But, want I_{bike} about <u>bike's</u> <u>center</u> of <u>gravity</u>

By Parallel Axis thereom:

$$I_{bs} = I_{swing} + I_{bike\,cg} + m_{bike}(R_{rb})^2$$

(I_{bs} ← measure; I_{swing} ← given; $I_{bike\,cg}$ ← find; $m_{bike}(R_{rb})^2$ ← measure)

2

RADIUS OF GYRATION CALCULATIONS

solve for $I_{bike\,cg}$

By definition:

$$k_x = \sqrt{\frac{I_{bike\,cg}}{m_{bike}}}$$

k_x = radius of gyration, Patternson Model Input

Unit analysis:

$$I_{bs}\,[lbm \cdot ft^2] = \frac{[\cancel{s^2}][lbm][ft/\cancel{s^2}][ft]}{4\pi^2}$$

$$= [lbm \cdot ft^2] \quad ✓$$

$$k_x\,[ft] = \sqrt{\frac{[\cancel{lbm} \cdot ft^2]}{[\cancel{lbm}]}}$$

$$= \sqrt{[ft^2]}$$

$$= [ft] \quad ✓$$

3

Appendix AD: Center of Gravity Testing- Measurements and Results

This appendix contains testing results and excel calculations for determining center of gravity. It also contains uncertainty analysis for center of gravity measurements.

Mass Properties of HPV Frame – May 2019

These values are calculated with the frame, the rider, and the drivetrain. The fairing is not included. Height of scales off is ground: 2.5".

Horizontal Position of Center of Gravity

See picture to right for variable representations

Measured Values

	Variable	Measurement	Units	Measurement Tool	Uncertainty	(Uncertainty/Measurement)^2
Wheelbase	A	4.708333333	ft	Park Tool tape measure	0.00260417	3.05917E-07
Weight front	Wf	151	lbf	Longacre Racing scale	0.5	1.09644E-05
Weight total	Wtot	250	lbf	Longacre Racing scale	0.5	0.000004
Radius of Wheel	Rw	1.072916667	ft	Park Tool tape measure	0.00260417	5.89122E-06

Calculated Values

	Variable	Value	Units	Root Sum Square Uncertainty
Hor. Dist. Rear Axle to CG	B	2.843833333	ft	0.003907729
	Bm	0.8668004	m	

Vertical Position of Center of Gravity

Average of 5 measurements taken to find final height of CG. Inclined at 5 different angles.

Measured Values - Round 1

	Variable	Measurement	Units	Measurement Tool	Uncertainty	(Uncertainty/Measurement)^2
Angle of inclination	theta1	20.66104163	degrees	Calculated value (n/a)	n/a	
Hor. Dist. Rear axel to front axel	X1	4.8125	ft	Park Tool Tape measure	0.00260417	2.92817E-07
Ver. Dist. Front axel to ground	D1	1.697916667	ft	Park Tool Tape measure	0.00260417	2.35237E-06
Weight front at angle theta	Wftheta1	146	lbf	Calculated value (n/a)	n/a	
Weight rear at angle theta	Wrtheta1	104	lbf	Longarce Racing scale	0.5	2.31139E-05

Calculated Values - Round 1

	Variable	Value	Units	Root Sum Square Uncertainty
Ver. Dist. CG above axel height	h1	0.26690184	ft	0.00615178
Ver. Dist. CG above ground	hg1	1.339818507	ft	

Measured Values - Round 2

	Variable	Measurement	Units
Angle of inclination	theta2	23.00782992	degrees
Hor. Dist. Rear axel to front axel	X2	4.770833333	ft
Ver. Dist. Front axel to ground	D2	1.864583333	ft
Weight front at angle theta	Wftheta2	138	lbf
Weight rear at angle theta	Wrtheta2	112	lbf

Calculated Values - Round 2

	Variable	Value	Units
Ver. Dist. CG above axel height	h2	0.626445065	ft
Ver. Dist. CG above ground	hg2	1.699361732	ft

Measured Values - Round 3

	Variable	Measurement	Units
Angle of inclination	theta3	25.48087219	degrees
Hor. Dist. Rear axel to front axel	X3	4.625	ft
Ver. Dist. Front axel to ground	D3	1.989583333	ft
Weight front at angle theta	Wftheta3	137	lbf
Weight rear at angle theta	Wrtheta3	113	lbf

Calculated Values - Round 3

	Variable	Value	Units
Ver. Dist. CG above axel height	h3	0.612921466	ft
Ver. Dist. CG above ground	hg3	1.685838133	ft

Measured Values - Round 4

	Variable	Measurement	Units
Angle of inclination	theta4	26.76017152	degrees
Hor. Dist. Rear axel to front axel	X4	4.604166667	ft
Ver. Dist. Front axel to ground	D4	2.072916667	ft
Weight front at angle theta	Wftheta4	136	lbf
Weight rear at angle theta	Wrtheta4	114	lbf

Calculated Values - Round 4

	Variable	Value	Units
Ver. Dist. CG above axel height	h4	0.627462312	ft
Ver. Dist. CG above ground	hg4	1.700378978	ft

Measured Values - Round 5

	Variable	Measurement	Units
Angle of inclination	theta5	29.09991324	degrees
Hor. Dist. Rear axel to front axel	X5	4.5625	ft
Ver. Dist. Front axel to ground	D5	2.21875	ft
Weight front at angle theta	Wftheta5	135.5	lbf
Weight rear at angle theta	Wrtheta5	114.5	lbf

Calculated Values - Round 5

	Variable	Value	Units
Ver. Dist. CG above axel height	h5	0.600279343	ft
Ver. Dist. CG above ground	hg5	1.673196009	ft

Average vertical Position of CG above ground	hgavg	1.619718672	ft
	hgm	0.493690251	m

Appendix AE: Uncertainty Analysis Hand Calculations

This appendix contains hand calculations for center of gravity uncertainty analysis.

UNCERTAINTY ANALYSIS

→ center of gravity calculations

$$u, \text{uncertainty} = \sqrt{\left[\frac{U_{meas_1}}{Meas_1}\right]^2 + \left[\frac{U_{meas_2}}{Meas_2}\right]^2 + \dots + \left[\frac{U_{meas_n}}{Meas_n}\right]^2}$$

For horizontal dist. rear axle to CG:

$$B = A\frac{W_f}{W_{tot}}$$

$$U_B = \sqrt{\left[\frac{U_{Wf}}{W_f}\right]^2 + \left[\frac{U_{Wtot}}{W_{tot}}\right]^2 + \left[\frac{U_A}{A}\right]^2}$$

For vertical dist. ground to CG:

$$h_g = h + R_w$$

where

$$h = \frac{B - A\left(\frac{W_{f\theta}}{W_{total}}\right)}{\frac{D}{X}}$$

where

$$W_{f\theta} = W_{tot} - W_{r\theta}$$

$$U_{h_g} = \sqrt{\left[\frac{U_B}{B}\right]^2 + \left[\frac{U_{RW}}{RW}\right]^2 + \left[\frac{U_A}{A}\right]^2 + \left[\frac{U_{Wtot}}{W_{tot}}\right]^2 + \left[\frac{U_{Wr\theta}}{W_{r\theta}}\right]^2 + \left[\frac{U_D}{D}\right]^2 + \left[\frac{U_X}{X}\right]^2}$$

(U_B/B) from above

1

Appendix AF: Radius of Gyration Testing- Measurements and Results

This appendix contains testing results and excel calculations for determining radius of gyration.

Mass Properties of HPV Frame May 2019

These values are calculated with the frame, the rider, and the drivetrain. The fairing is not included.

Longitudinal Radius of Gyration about Center of Gravity

Given Values: Swing

	Variable	Value	Units
I about pivot	Io,old	33.91	slug*ft^2
I about pivot converted	Io	1091.902	lbm*ft^2
Vert. dist. Pivot to swing CG	Rps	3.692	ft
Vert. dist. Pivot to rail	Rpr	5.375	ft
Swing Weight	Ws	63.5	lbf

Measured Values

Average of 5 measurements taken to find final period. Time to swing 10 times measured.

	Variable	10 swings time 1	10 swings time 2	10 swings time avg	1 swing time	Units
Period 1	T1	22.69	22.7	22.695	2.2695	sec
Period 2	T2	23.13	22.55	22.84	2.284	sec
Period 3	T3	22.93	22.65	22.79	2.279	sec
Period 4	T4	22.73	22.6	22.665	2.2665	sec
Period 5	T5	22.83	22.61	22.72	2.272	sec
Avg Period	Tavg			22.742	2.2742	sec

Calculated Values: Isystem

Calculates roll moment of inertia about center of mass of bike+rider+swing system. System refers to the swing+rider&bike.

	Variable	Value	Units
Rider and Bike Weight	Wrb	250	lbf
Rider and Bike Mass	Mrb	250	lbm
Swing Mass	Ms	63.5	lbm
Mass Total (swing, rider, bike)	Mtot	313.5	lbm
Gravity	g	32.2	ft/s^2
Vert. dist. Pivot point to cg of bike+rider	Rrb	3.755281328	ft
Equivalent cg of bike+rider+swing	Rsys	3.742463579	ft
Roll M.o.I. about cg of system	Isys	4949.354632	lbm*ft^2

Calculated Values: md^2 for PAT

Calculates the md^2 term to translate M.o.I. about the bike's cg to M.o.I. of the bike about the swing's pivot point.

	Variable	Value	Units
md^2	mdd	3525.534463	lbm*ft^2

Calculated Values: Ibike,rider

Calculates roll moment of inertia about center of mass of bike+rider system. This is then used in the final radius of gyration calculation.

	Variable	Value	Units
Roll M.o.I. about cg of bike+rider	Ib	331.918169	lbm*ft^2

Calculated Values: Rx

Calculates radius of gyration about center of mass of bike+rider system. This is then used as an input to the Patterson Control Model.

	Variable	Value	Units
Radius of Gyration about Longitudinal Axis	Rx	1.152246795	ft
	Rx	0.351204823	m

Appendix AG: Detail Drawings

The following four pages include the indented bill of materials including all drawings. The following pages are a compilation of all detail drawings and assembly drawings for the Human Powered Vehicle Frame project.

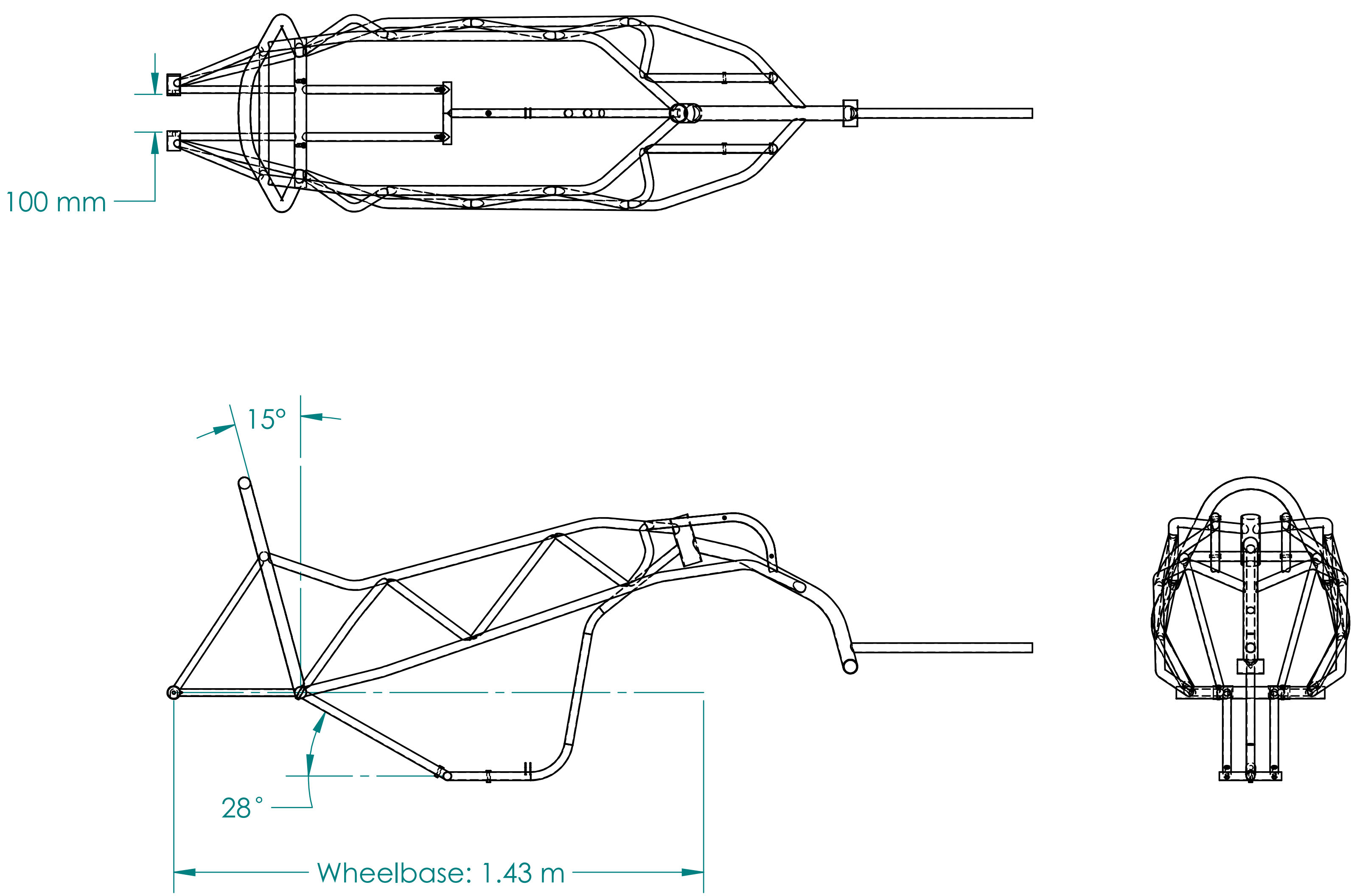
Indented Bill of Material (BOM)
Framed

Assembly Level	Part Number	Description Lvl0	Lvl1	Lvl2	Vendor	Qty	Cost	Ttl Cost
0	04-A05-001	Final Assy						
1			Frame Jig 1					
2	04-A03-004			Bottom Bracket Plug	IMS	2	11	22
2	04-A03-007			Conical Spacers (Head Tube)	IMS	1	7	7
2	04-A03-010			Dummy Rear Hub	IMS	2	5	10
2	04-A03-006			Head Tube Mounts	Steel Bridge	2	0	0
2	04-A03-006			Head Tube Mount Spacer	IMS	1	15	15
2	04-A03-009			Mid Drive Spacers	IMS	4	5	20
2	04-A03-001			Jig Base	Rose Float	1	0	0
2	04-A03-001			Jig Pillar	Rose Float	1	0	0
2	04-A03-014			Jig Pillar Plate	IMS	1		0
2	04-A03-016			Jig Pillar Plate Base Plate	Steel Bridge	1	0	0
2	04-A03-002			Tube Blocks 1.25"	George	3	0	0
1			Frame Jig 2					0
2	04-A04-005			Roll Bar Plug	IMS	2	10	20
2	04-A03-002			Tube Blocks 0.875"	Paragon	2	12.83	25.66
2	04-A04-006			Roll Bar Riser	Rose Float	2	0	0

2	04-A04-006		Roll Bar Riser Base Plate	Steel Bridge	2	0	0
2	04-A04-004		Bottom bracket support pillar	IMS	1	15	15
2	04-A04-003		Center riser	IMS	1	28	28
1		Fork Jig					0
2	04-A03-011		Dummy Front Axel	IMS	1	0	0
1		Frame					0
2	04-A01-005		Seat mount bosses	IMS	5	1.79	8.95
2	04-A01-004		Mid drive mount bosses	IMS	4	1.79	7.16
2	4130 Tube		Roll bar hoop	AirCraft Spruce	1	316	316
2	4130 Tube		Roll bar bottom dude	AirCraft Spruce	1		0
2	4130 Tube		Seat/ harness mount support	AirCraft Spruce	1		0
2	4130 Tube		Seat/ chain stays left	AirCraft Spruce	3		0
2	4130 Tube		Seat/ chain stays right	AirCraft Spruce	3		0
2	4130 Tube		Top side support left	AirCraft Spruce	1		0
2	4130 Tube		Top side support right	AirCraft Spruce	1		0
2	4130 Tube		Middle side support left	AirCraft Spruce	1		0
2	4130 Tube		Middle side support right	AirCraft Spruce	1		0

2	4130 Tube	Bottom support straight angled members	AirCraft Spruce	2		0
2	4130 Tube	Bottom support small hoizontal member	AirCraft Spruce	1		0
2	4130 Tube	Bottom support bent member	AirCraft Spruce	1		0
2	4130 Tube	Straight truss members left	AirCraft Spruce	3		0
2	4130 Tube	Straight truss members right	AirCraft Spruce	3		0
2	4130 Tube	Bent truss members left	AirCraft Spruce	2		0
2	4130 Tube	Bent truss members right	AirCraft Spruce	2		0
2	4130 Tube	Middrive support left	AirCraft Spruce	1		0
2	4130 Tube	Middrive support right	AirCraft Spruce	1		0
2	4130 Tube	Bottom bracket support	AirCraft Spruce	1		0
2	4130 Tube	Fairing cantilever	AirCraft Spruce	1		0
2	Steel .090"	Harness mount tabs	IMS	2	12.46	24.92
2	04-A01-002	Rear dropouts	Bike Builders	4	0	0
2	n/a	EVA foam padding	TNT Cosplay	2	9.95	19.9
2	n/a	Foam stiffener	TNT Cosplay	2	5.95	11.9

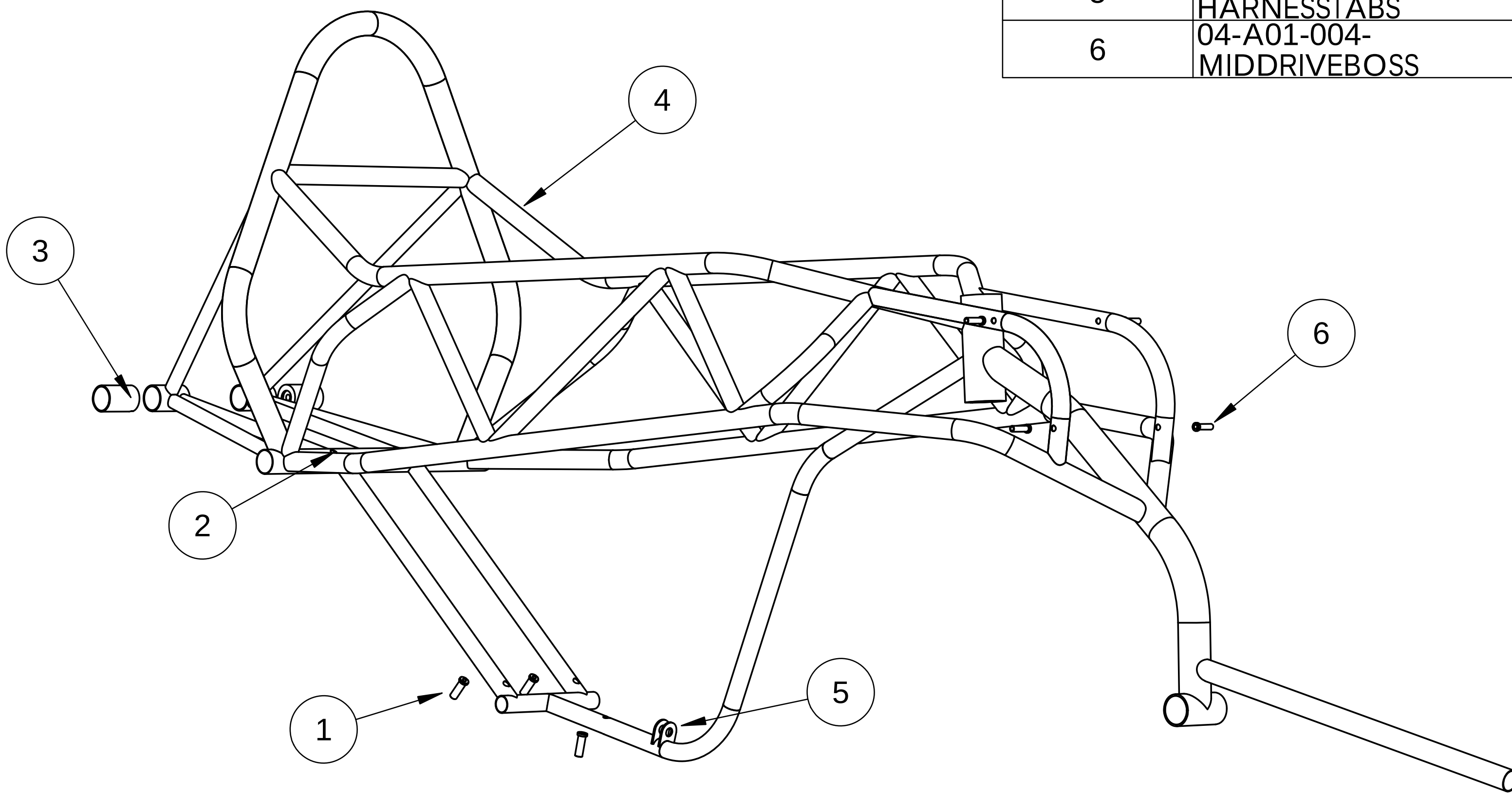
		Velcro Mounting-wrap				
2	n/a		McMaster	4	37.18	148.72
1		Fork				0
2	n/a	Head tube	Paragon	1	38	38
2	n/a	Steerer	NOVA	1	10.6	10.6
2	n/a	Right fork blade	NOVA	1	24	24
2	n/a	Left fork blade	NOVA	1	24	24
2	04-A02-003	Front dropouts	McMaster	2	17.95	35.9
	Total Parts			**90**		
	Total Cost					**832.71**



Drawn By:	KYRA SCHMIDT	TITLE: A04-05-001-FRAMEASSEMBLY	REV 00	
Start Date:	1/7/19			SCALE: 1:17 | MATERIAL: 4130 Steel | 1 OF 1

Cal Poly Human Powered San Luis Obispo

ITEM NO.	PART NUMBER	QTY.
1	04-A01-005-SEATBOSS	3
2	04-A01-007-SEATBOSSLONG	2
3	04-A01-002-REARDROPOUTS	2
4	04-A01-001-FRAME	1
5	04-A01-006-HARNESSTABS	2
6	04-A01-004-MIDDRIVEBOSS	4



Cal Poly Human Powered San Luis Obispo

Drawn By:	KEYANNA HENDERSON
Checked By:	KYRA SCHMIDT
Start Date:	1/31/19

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:

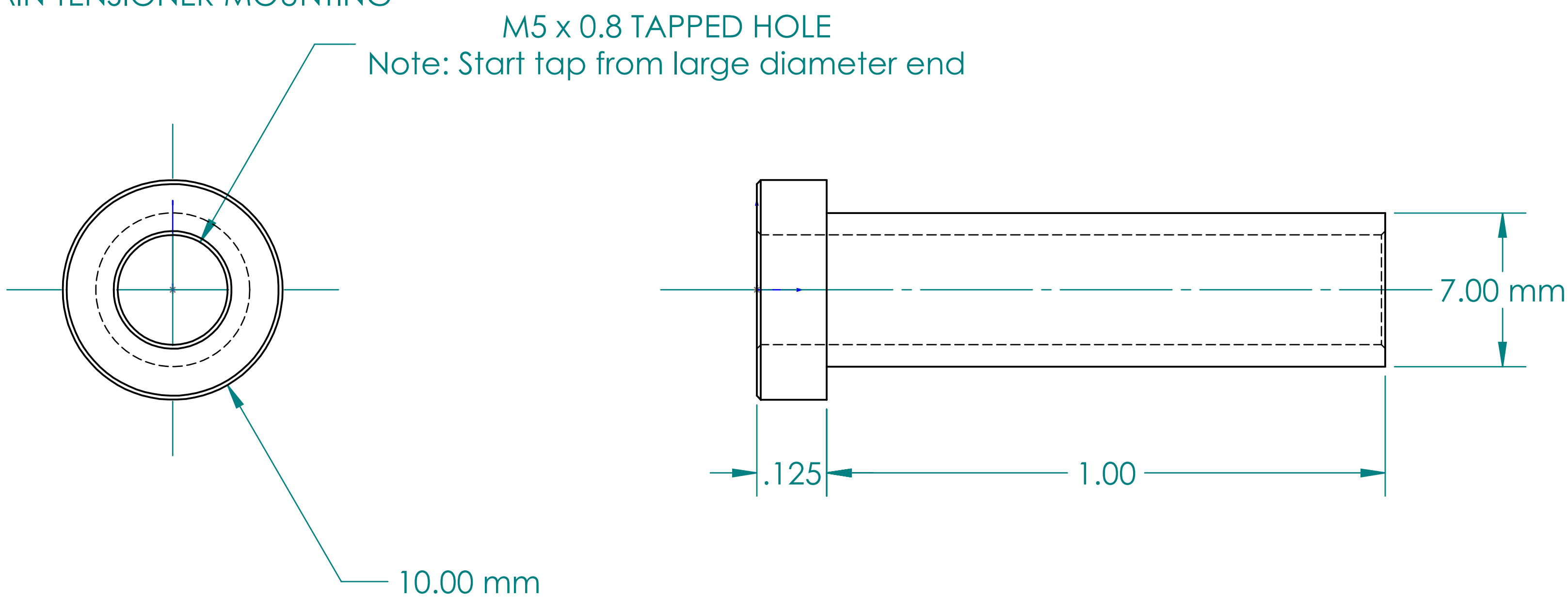
04-A05-001-FRAMEONLYASSEMBLY

REV 00

SCALE: 1:8 | MATERIAL: 4130 STEEL | 1 OF 1

NOTE:
ALL METRIC DIMENSIONS DESIGNATED WITH "mm"
ALL METRIC TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED:
XX.XX ± 0.10
XX.X ± 1

6 REQUIRED;
4 for MID DRIVE MOUNTING
2 for CHAIN TENSIONER MOUNTING

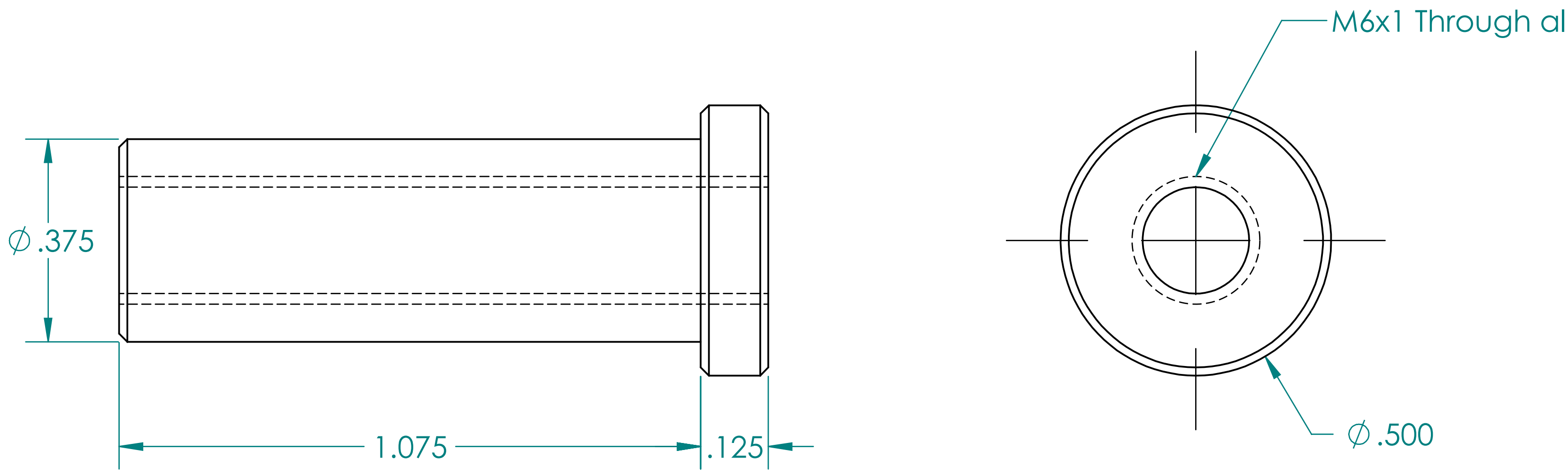


		UNLESS OTHERWISE SPECIFIED:			
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-004-MIDDRIVEBOSS		REV 00
Drawn By:	KYRA SCHMIDT				
Checked By:	KEYANNA HENDERSON				
Start Date:	1/16/18		SCALE: 3:1	MATERIAL: 1018 STEEL	1 OF 1

Cal Poly
Human Powered
San Luis Obispo

NOTE:
Break all sharp edges

QUANTITY: 2

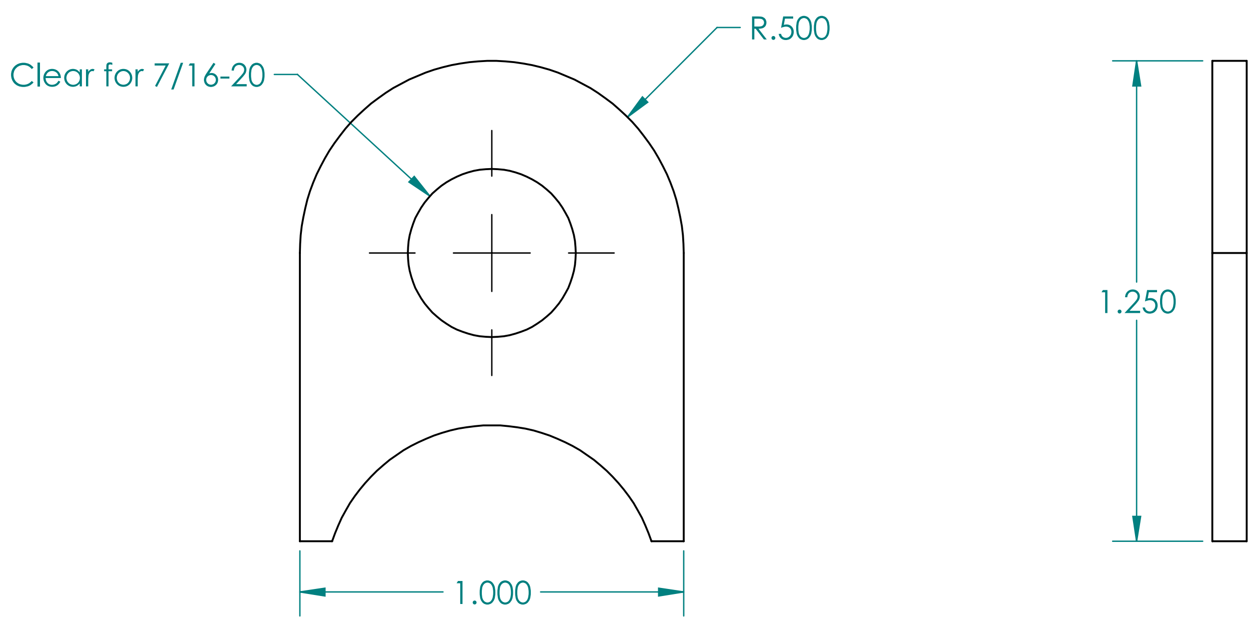


Cal Poly Human Powered San Luis Obispo		UNLESS OTHERWISE SPECIFIED:	
Drawn By:	KEYANNA HENDERSON	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-005-SEATBOSS
Checked By:	KYRA SCHMIDT		REV 00
Start Date:	1/31/19		SCALE: 3:1 · MATERIAL: 4130 STEEL · 1 OF 1

Note: Outside profile and hole locations defined by model to be waterjet.
Hole final dimensions to be drilled post water jet operation.

Stock: 13 GA Steel Plate

Quantity: 2

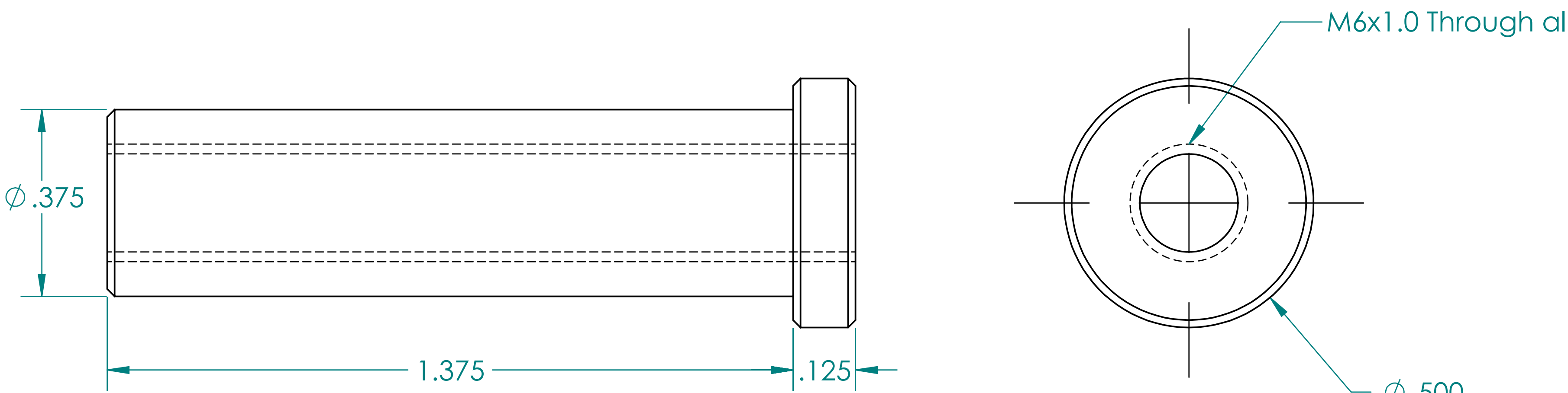


		UNLESS OTHERWISE SPECIFIED:			
Drawn By:	KEYANNA HENDERSON	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-006-HARNESSTABS		REV 00
Checked By:	KYRA SCHMIDT				
Start Date:	1/31/19		SCALE: 2:1	MATERIAL: 4130 STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo

NOTE:
Break all sharp edges

QUANTITY: 2



Drawn By:	KEYANNA HENDERSON
Checked By:	KYRA SCHMIDT
Start Date:	1/31/19

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-007-SEATBOSSLONG

REV: 00

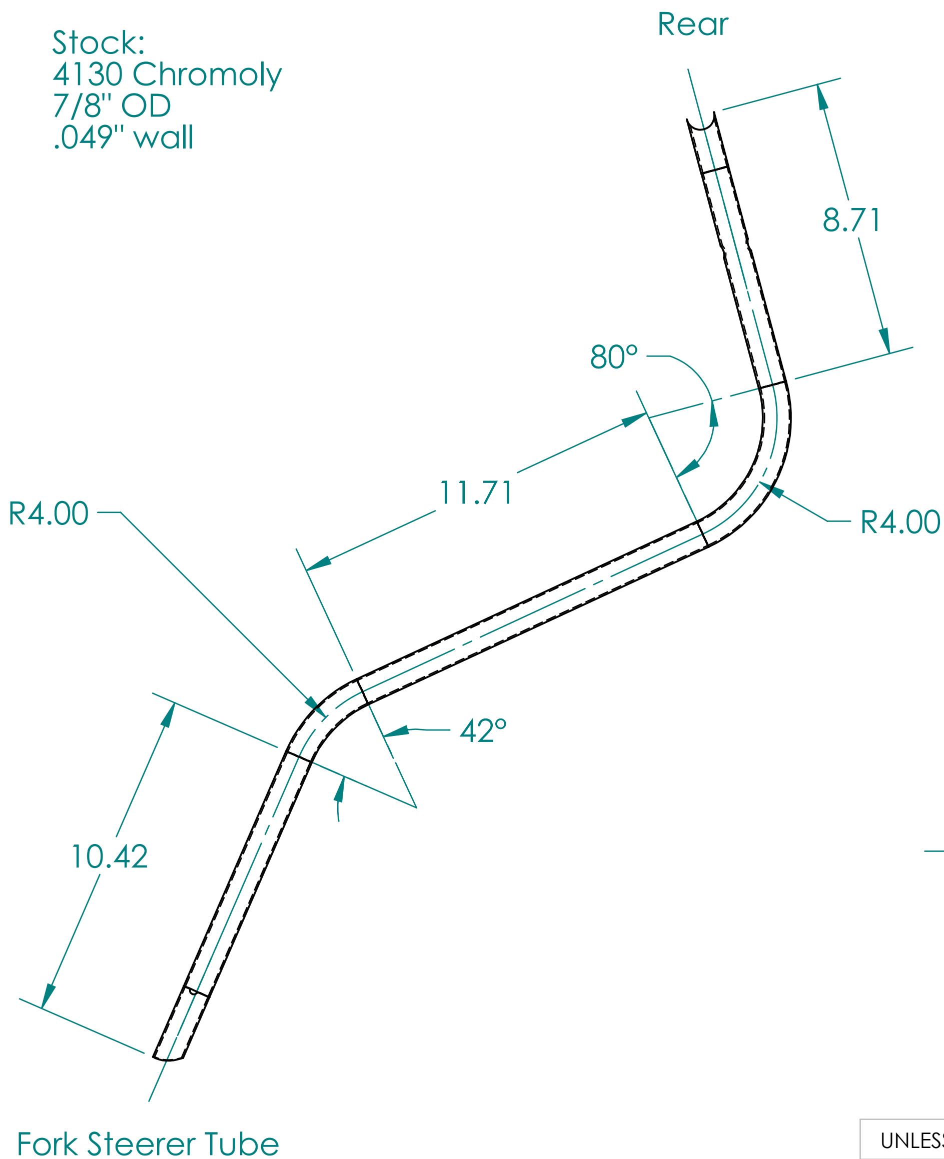
SCALE: 3:1

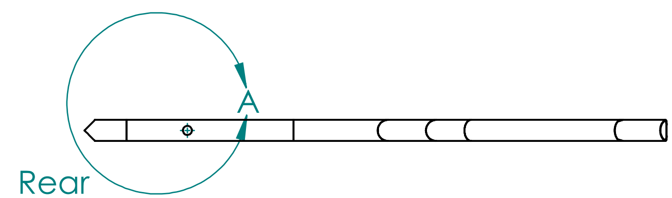
MATERIAL: 4130 STEEL

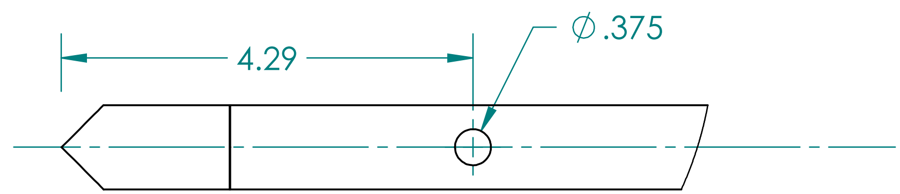
1 OF 1

Cal Poly Human Powered San Luis Obispo

Stock:
4130 Chromoly
7/8" OD
.049" wall



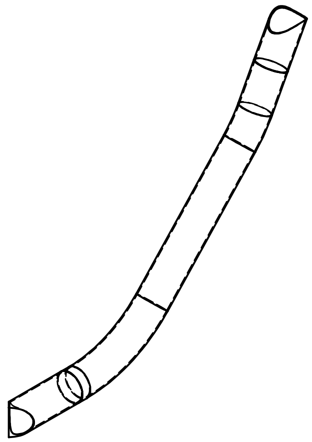




DETAIL A
SCALE 1 : 2

Cal Poly
Human Powered
San Luis Obispo

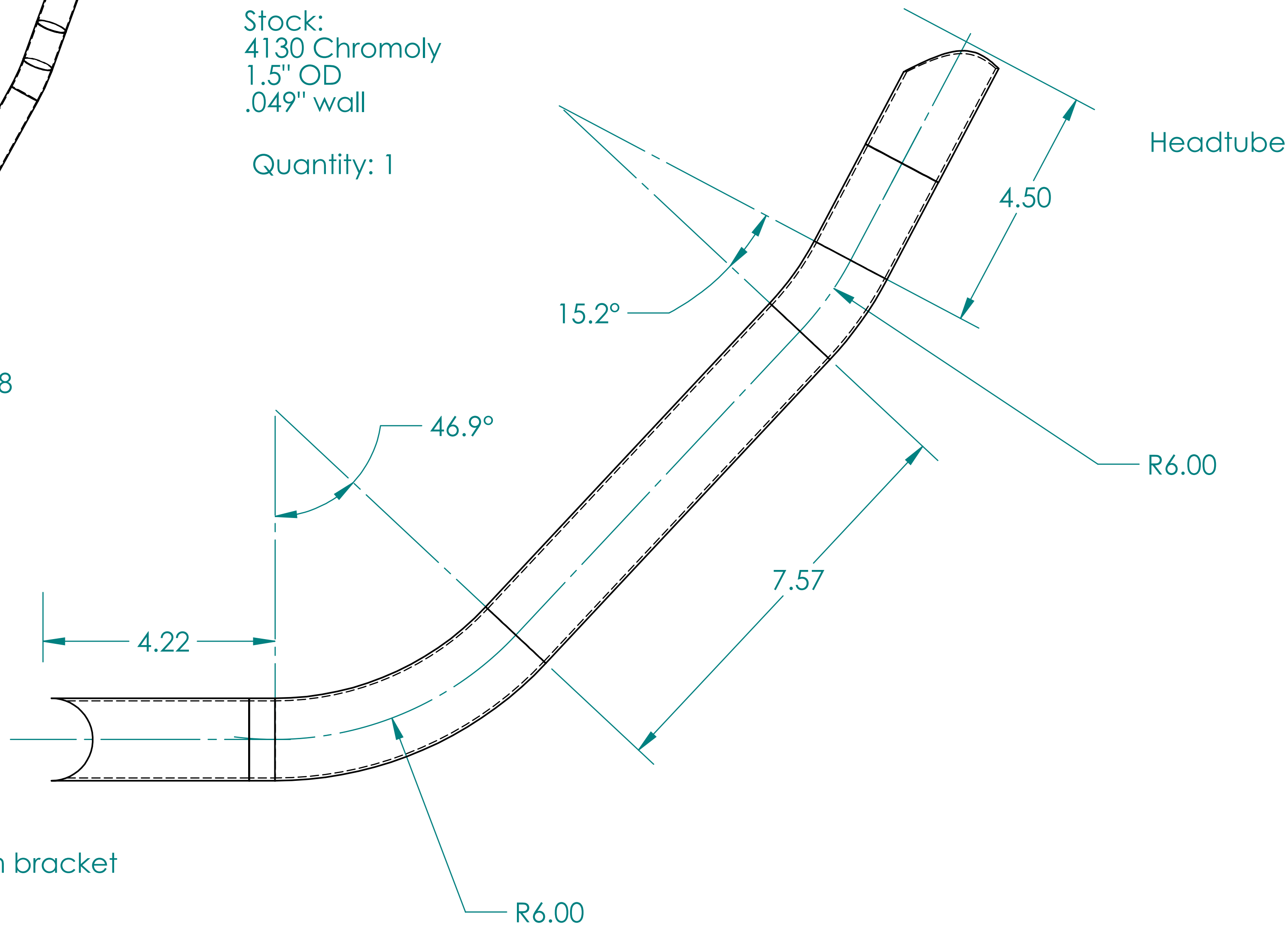
Drawn By:	KEYANNA HENDERSON	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-BottomBentSupport	REV 00
Checked By:	KYRA SCHMIDT		SCALE: 1:6 / 4130 STEEL	1 OF 1
Start Date:	1/31/19			



SCALE: 1:8

Stock:
4130 Chromoly
1.5" OD
.049" wall

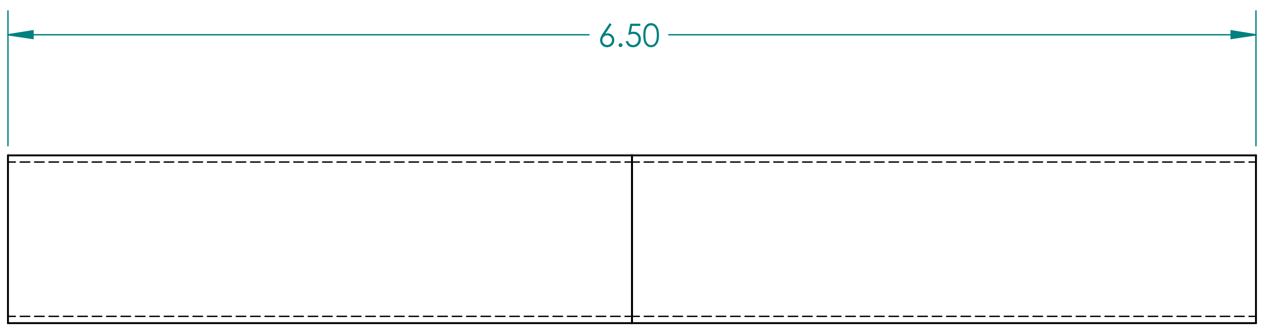
Quantity: 1



		UNLESS OTHERWISE SPECIFIED:		
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-BottomBracketSupport	REV 00
Drawn By:	KYRA SCHMIDT			
Start Date:	1/13/18		SCALE: 1:4 / MATERIAL: 4130 STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo

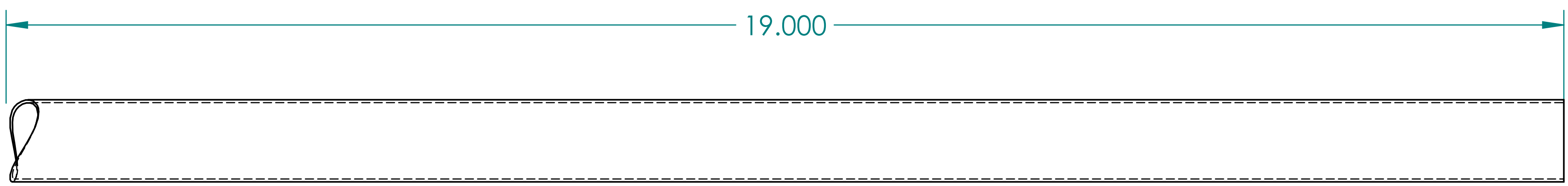
Stock:
4130 Chromoly
.875" OD
.035" wall



Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KEYANNA HENDERSON	UNLESS OTHERWISE SPECIFIED:	TITLE: 04-A01-001-FRAME-BottomHorizontal		REV 00
Checked By:	KYRA SCHMIDT	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC			
Start Date:	1/31/19		SCALE: 1:1	MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
1" OD
.035" wall



Cal Poly Human Powered
San Luis Obispo

Drawn By:	KEYANNA HENDERSON
Checked By:	XXXXXX
Start Date:	1/31/19

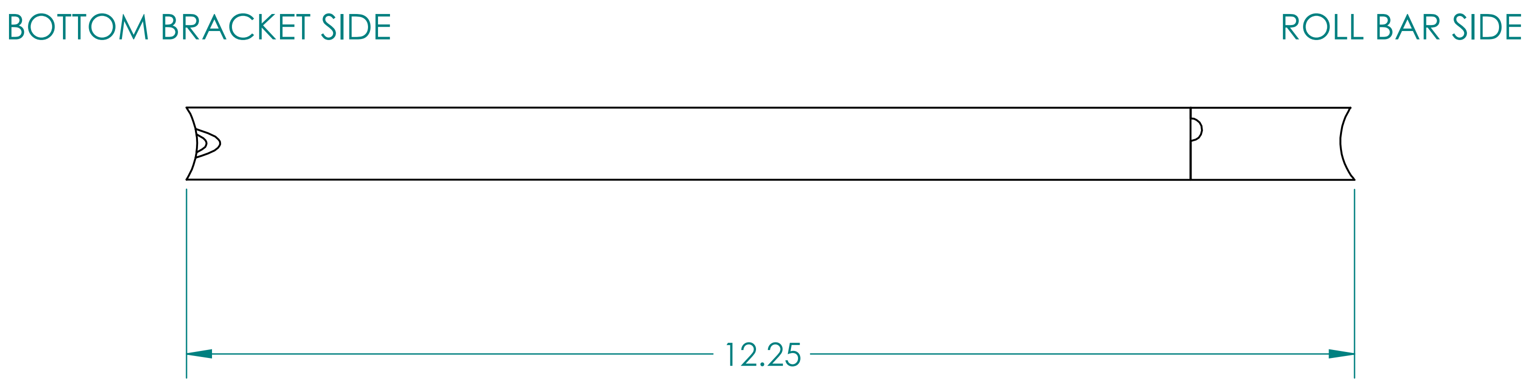
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-FairingSupport		REV 00
SCALE: 1:2	MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
3/4" OD
.035"

Note: Miters showin in miter drawing. Overall rough cut lenth same of righ and left sides

QTY: 2



Drawn By:	AUSTIN HENRY	UNLESS OTHERWISE SPECIFIED:	
Checked By:	XXXXXX	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-RearTriangleLowerInnerRight
Start Date:	1/30/2019		REV 00
			SCALE: 1:2
			MATERIAL: 4130 STEEL
			1 OF 1

Cal Poly Human Powered San Luis Obispo

Stock:
4130 Chromoly
3/4" OD
.035"

Note: Miters showin in miter drawing. Overall rough cut lenth same of righ and left sides

QTY: 2

ROLL BAR SIDE

BOTTOM BRACKET SIDE

Cal Poly Human Powered San Luis Obispo

Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

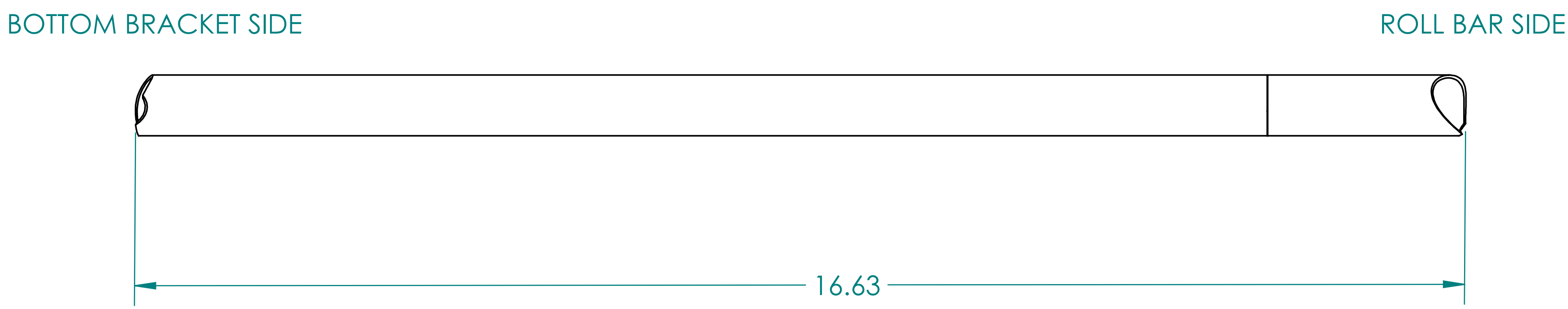
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-RearTriangleLowerOuterRight		REV 00
SCALE: 1:2	MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
3/4" OD
.035"

Note: Miters showin in miter drawing. Overall rough cut lenth same of righ and left sides

QTY: 2



Cal Poly Human Powered San Luis Obispo

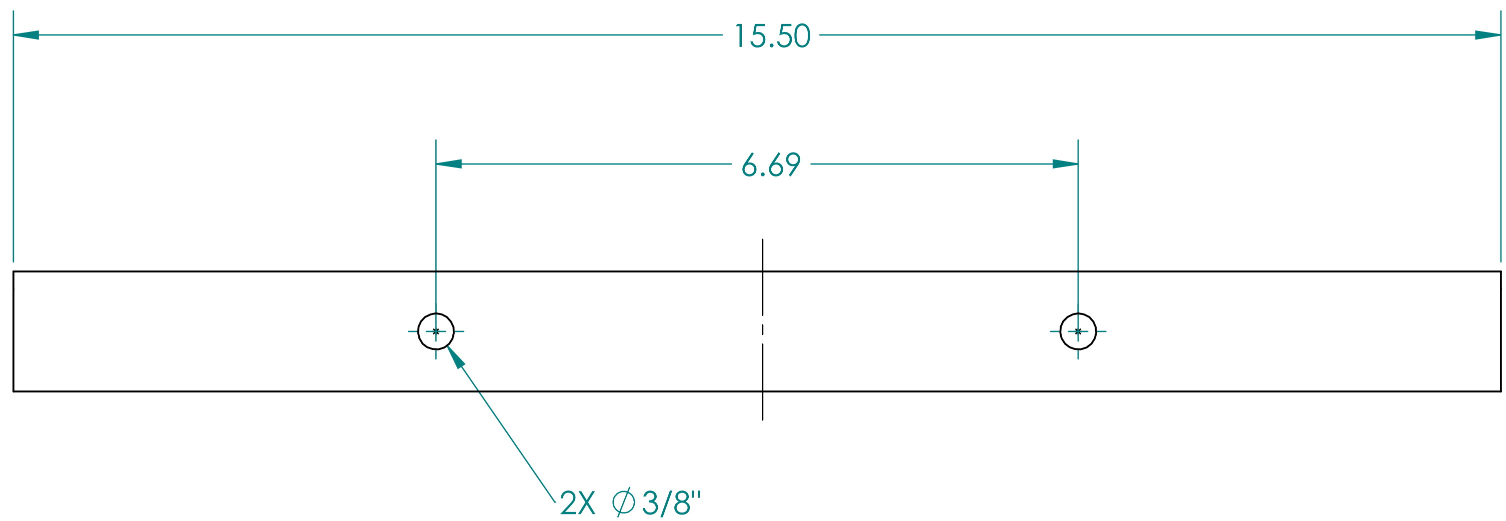
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-RearTriangleUpperRight		REV 00
SCALE: 1:2	MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
1.25" OD
.035"

PART IS SYMETRICAL ABOUT CENTERLINE



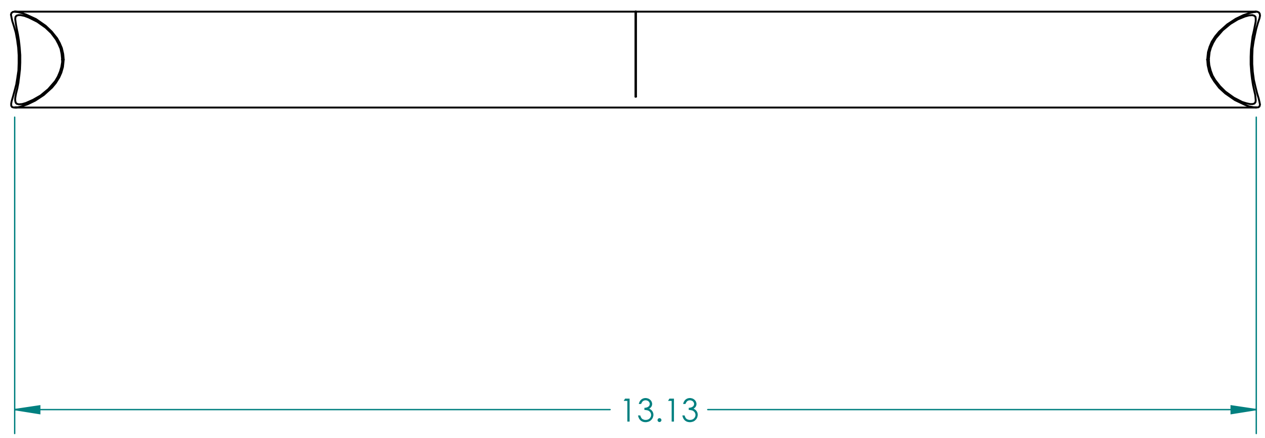
Cal Poly Human Powered San Luis Obispo

Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-RollBarHorizontalLower		REV 00
SCALE: 1:2	MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
1" OD
.035"



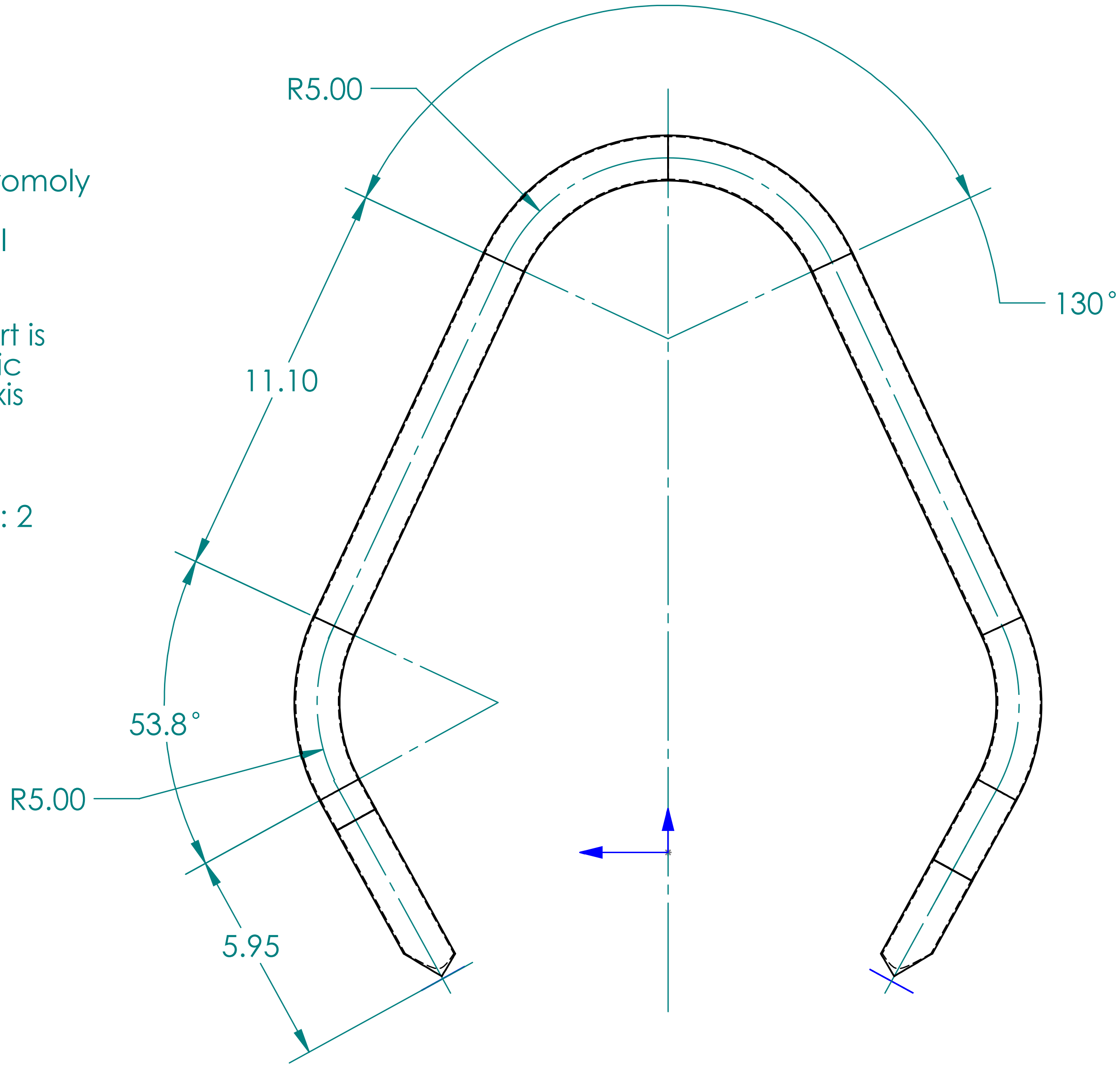
Cal Poly Human Powered San Luis Obispo

Drawn By:	AUSTIN HENRY	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-RollBarHorizontalUpper	REV 00
Checked By:	XXXXXX			
Start Date:	1/30/2019		SCALE: 1:2 / MATERIAL: 4130 STEEL	1 OF 1

Stock:
4130 Chromoly
1.25" OD
.035" wall

Note: Part is symmetric about axis shown.

Quantity: 2



Cal Poly
Human Powered
San Luis Obispo

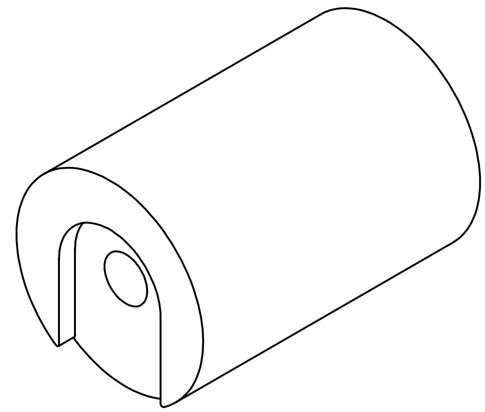
Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/21/19

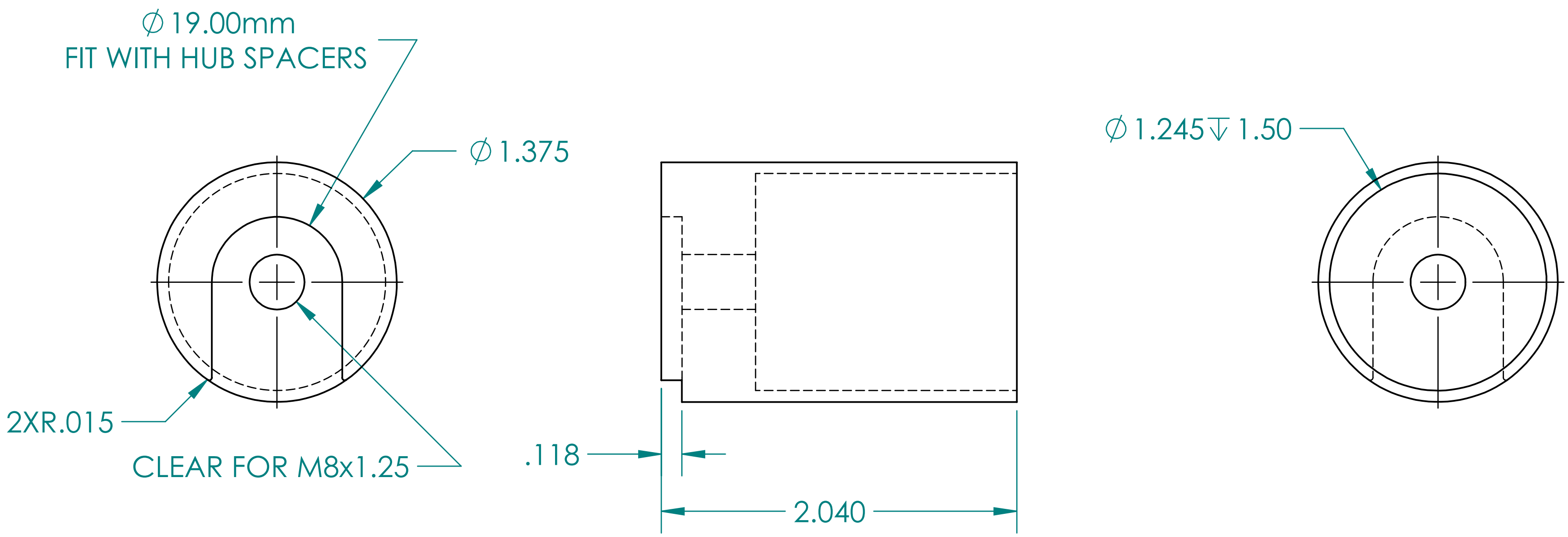
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-RollhoopUpper		REV 00
SCALE: 1:5	MATERIAL: 4130 STEEL	1 OF 1

NOTE:
ALL METRIC DIMENSIONS DESIGNATED WITH "mm".
ALL METRIC TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED:
XX.XX ± 0.10
XX.X ± 1

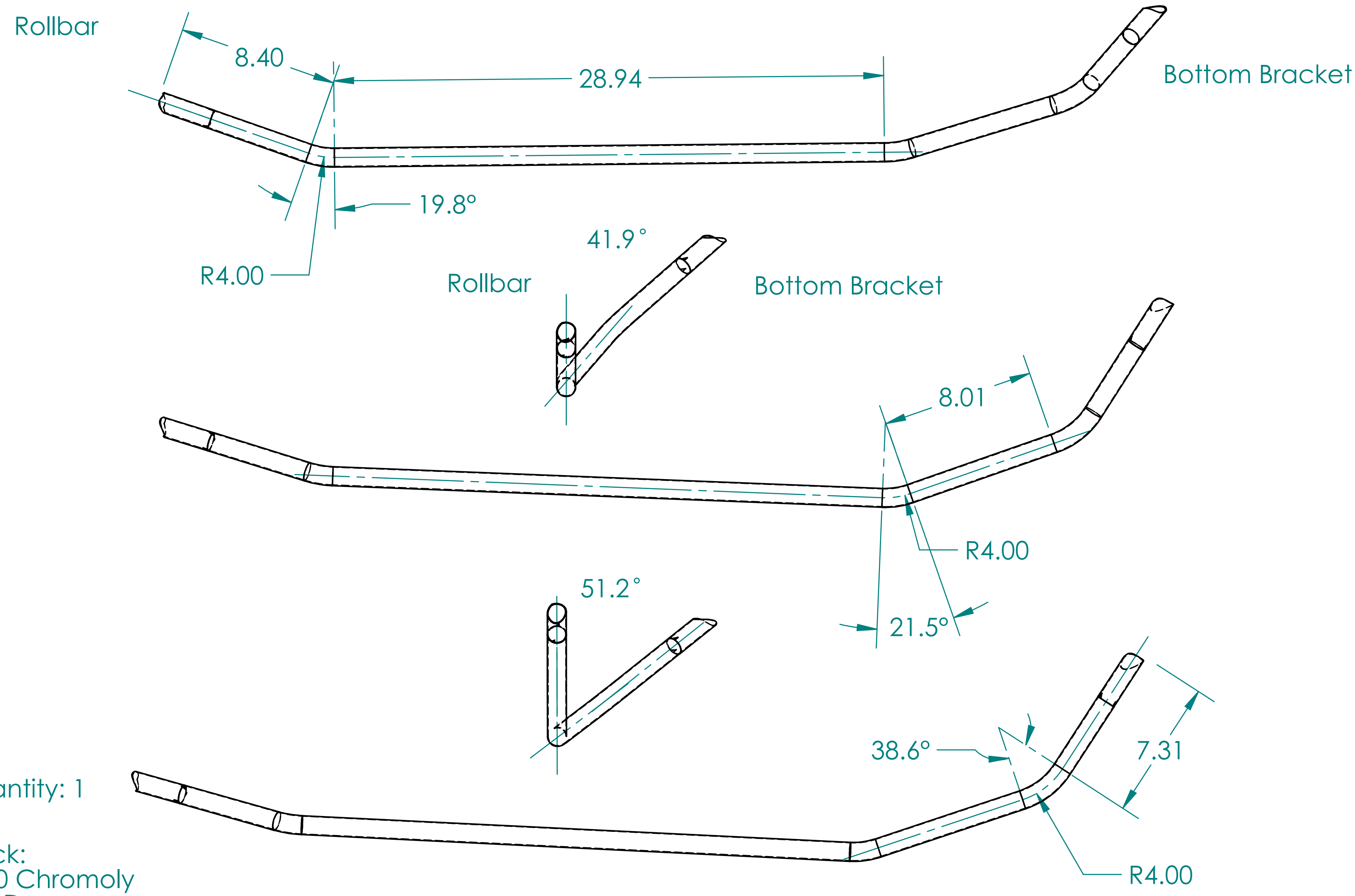
4 REQUIRED





Cal Poly Human Powered San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-002-REARDROPOUTS		REV 00
Start Date:	12/31/18		SCALE: 1:1	MATERIAL: 4130 Steel	1 OF 1



Quantity: 1

Stock:
4130 Chromoly
1" OD
.035"

Drawn By:	KYRA SCHMIDT
Checked By:	Chris Scarborough
Start Date:	1/27/19

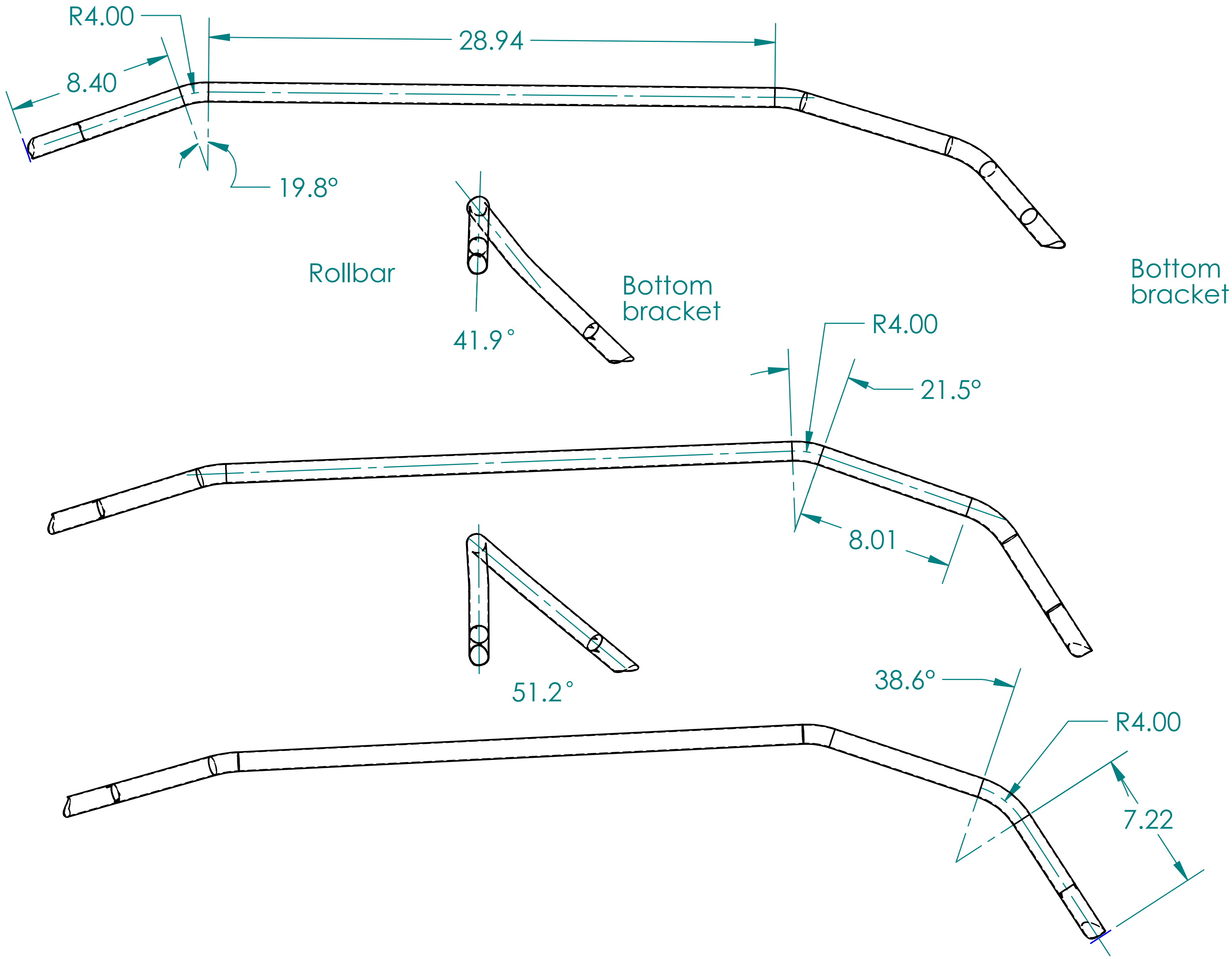
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±1°
TWO PLACE DECIMAL: ±0.035
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A01-001-FRAME-MiddleSideSupportLeft

REV 00

SCALE: 1:8 | MATERIAL: 4130 STEEL | 1 OF 1

Cal Poly Human Powered San Luis Obispo



Quantity: 1

Stock:
4130 Chromoly
1" OD
.035"

Cal Poly Human Powered San Luis Obispo

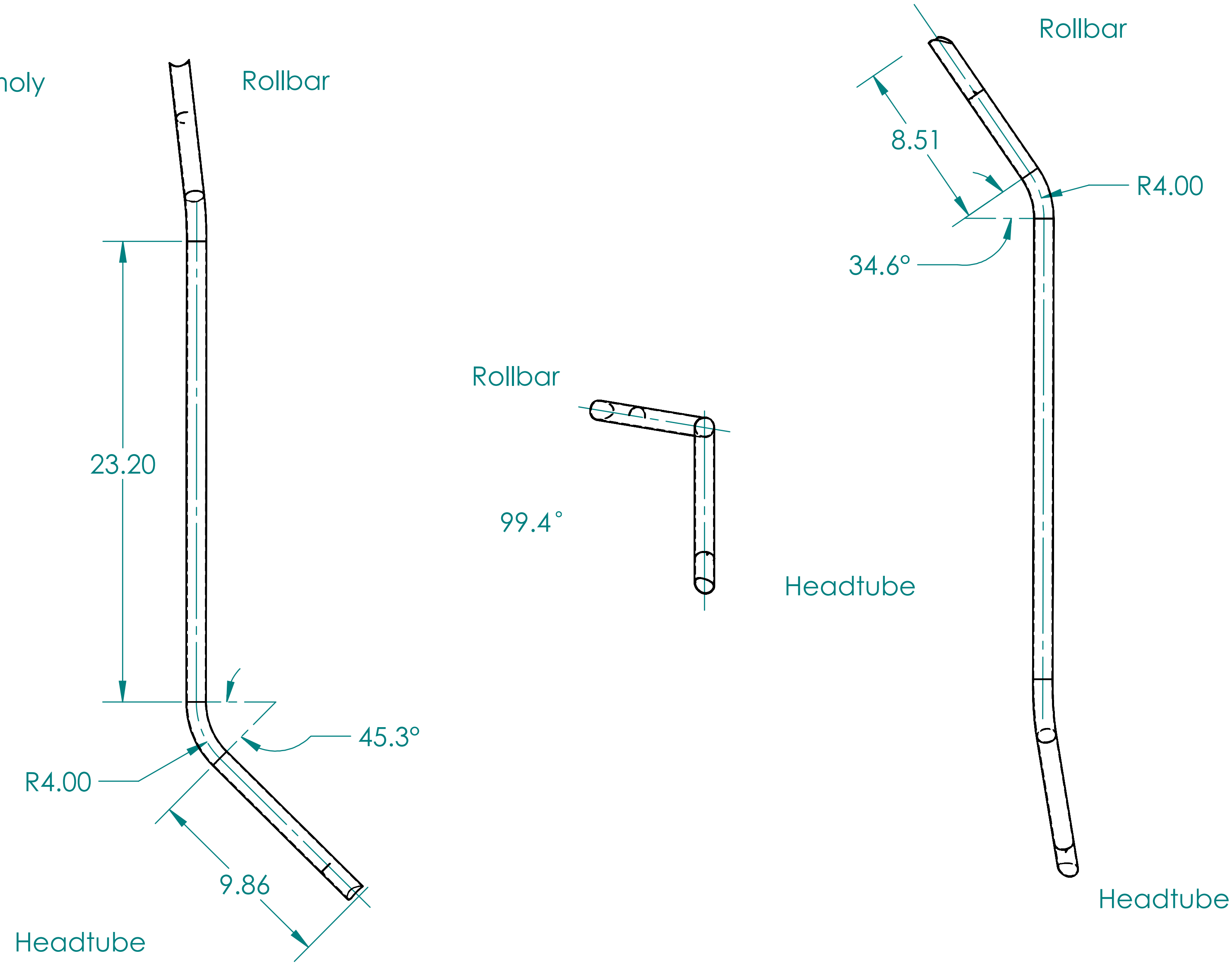
Drawn By:	KYRA SCHMIDT
Start Date:	1/5/18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: A01-001-FRAME-MiddleSideSupportRight		REV 00
SCALE: 1:8	MATERIAL: 4130 Steel	1 OF 1

Stock:
4130 Chromoly
1" OD
.035" wall

Quantity: 1

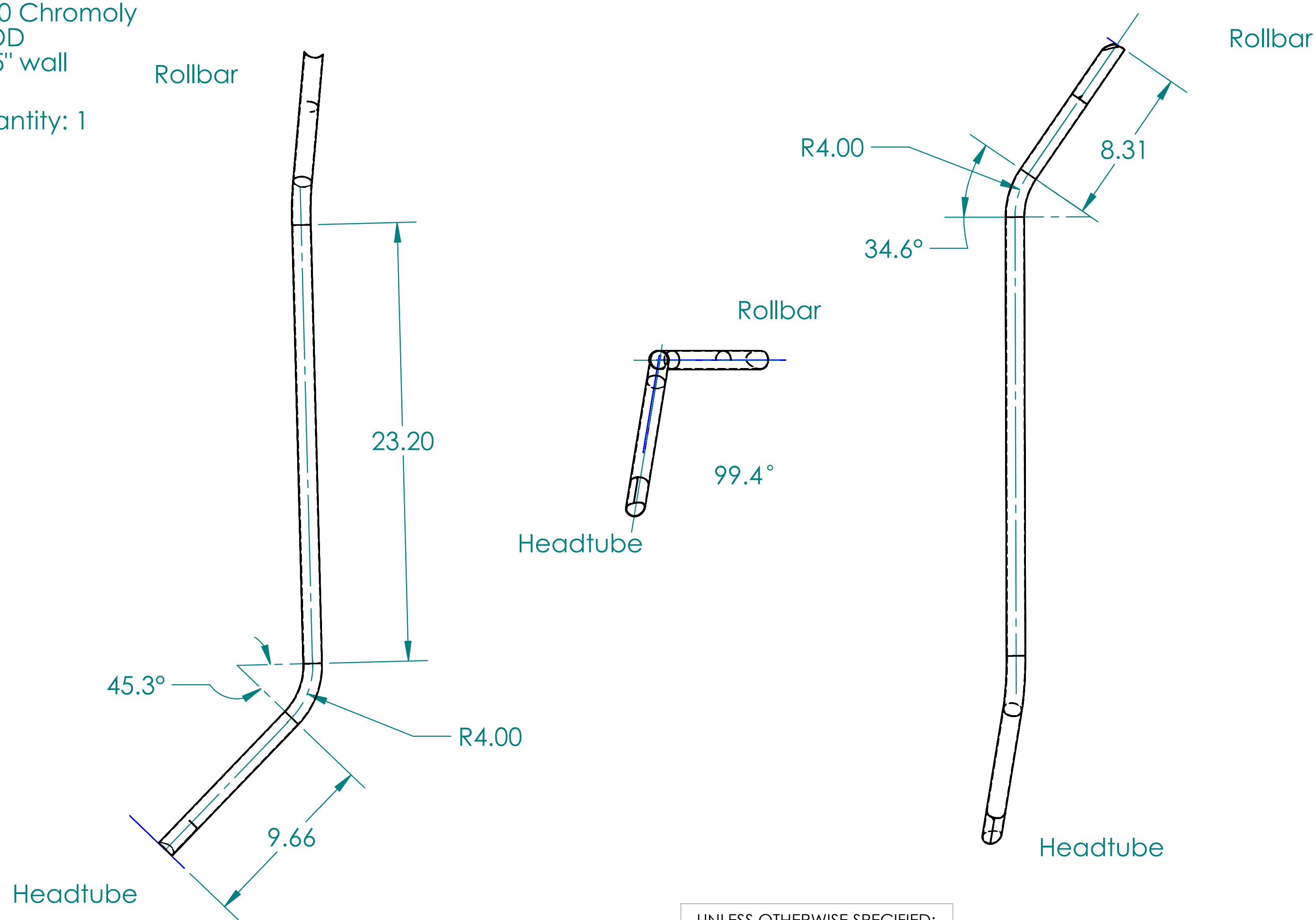


Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±1° TWO PLACE DECIMAL: ±0.035 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-TopSideSupportLeft		REV 00
Checked By:	Chris Scarborough				
Start Date:	1/20/19		SCALE: 1:8	MATERIAL: 4130 STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo

Stock:
4130 Chromoly
1" OD
.035" wall

Quantity: 1



Cal Poly Human Powered San Luis Obispo

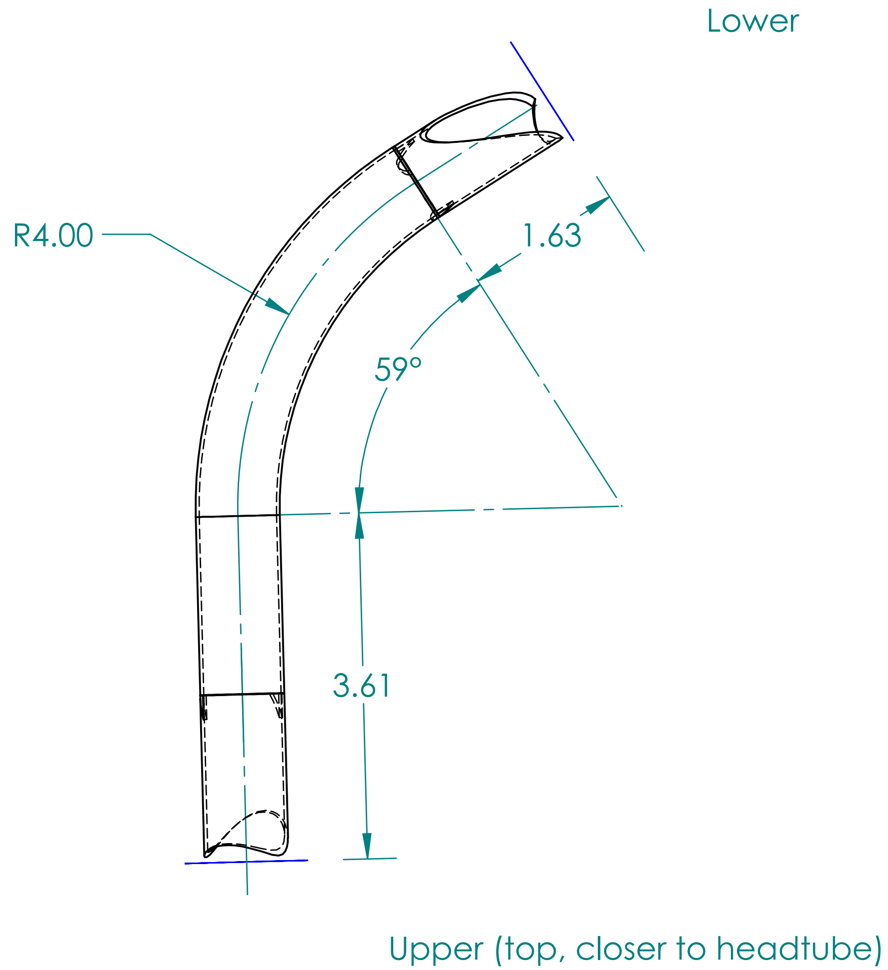
Drawn By:	KYRA SCHMIDT
Start Date:	1/20/19

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±1°
TWO PLACE DECIMAL: ±0.035
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A01-001-FRAME-TopSideSupportRight

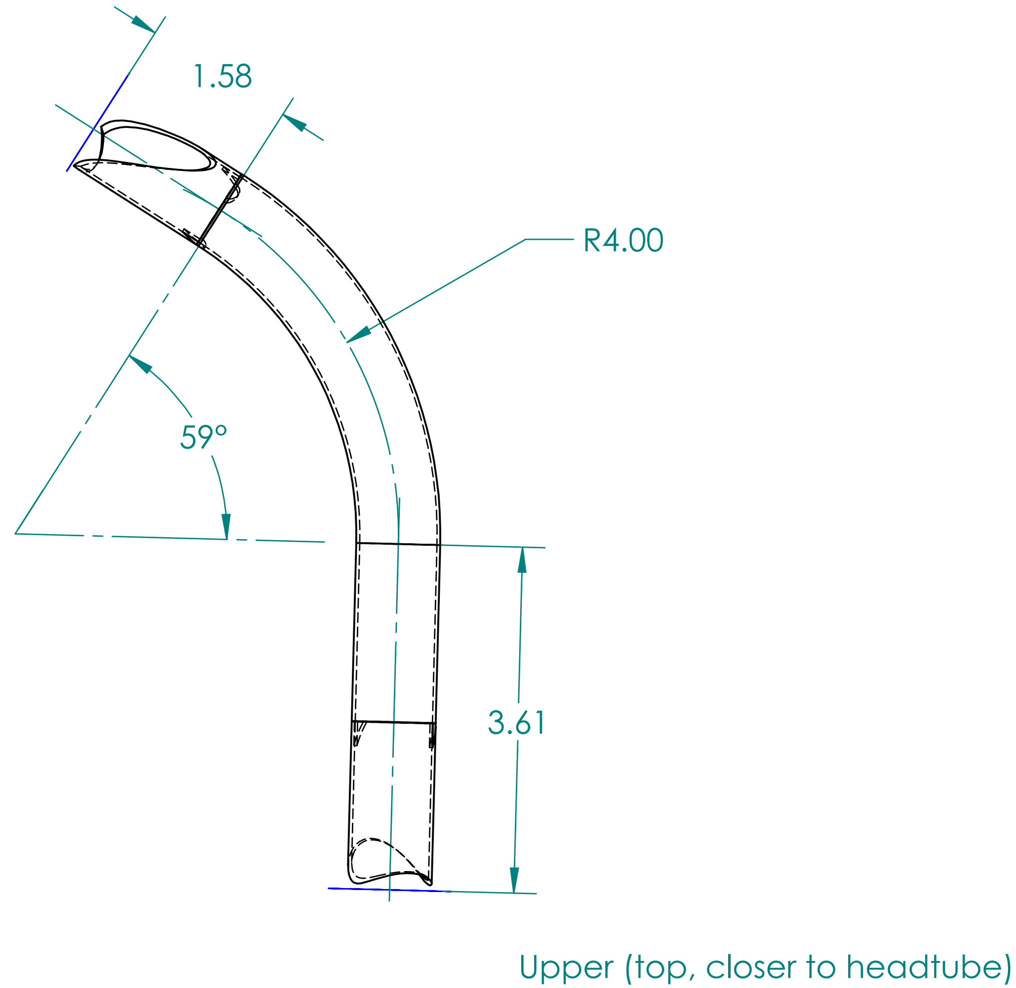
REV 00

SCALE: 1:8 | MATERIAL: 4130 STEEL | 1 OF 1



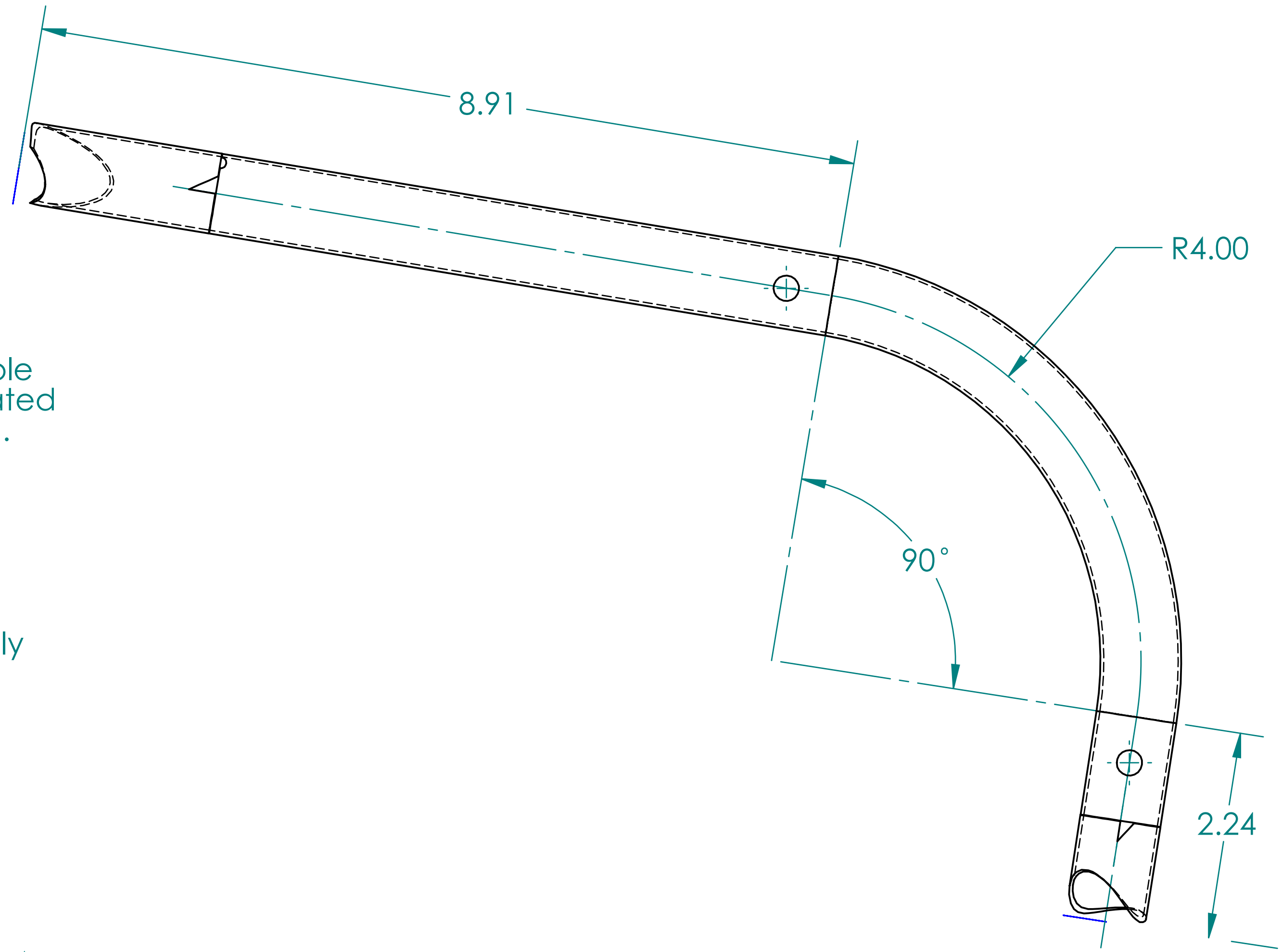
Stock:
4130 Chromoly
7/8" OD
.035" wall

Cal Poly Human Powered San Luis Obispo		UNLESS OTHERWISE SPECIFIED:		
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A01-001-FRAME-BentTrussLeft	REV 00
Drawn By:	KYRA SCHMIDT			
Checked By:	XXXXXX			
Start Date:	1/30/19		SCALE: 1:2 / MATERIAL: 4130 STEEL	1 OF 1



Cal Poly Human Powered San Luis Obispo	Drawn By: KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: A01-001-FRAME-BentTrussRight; REV 00
	Start Date: 1/5/18		SCALE: 1:2; MATERIAL: 4130 Steel; 1 OF 1

Headtube
(rear)



Front

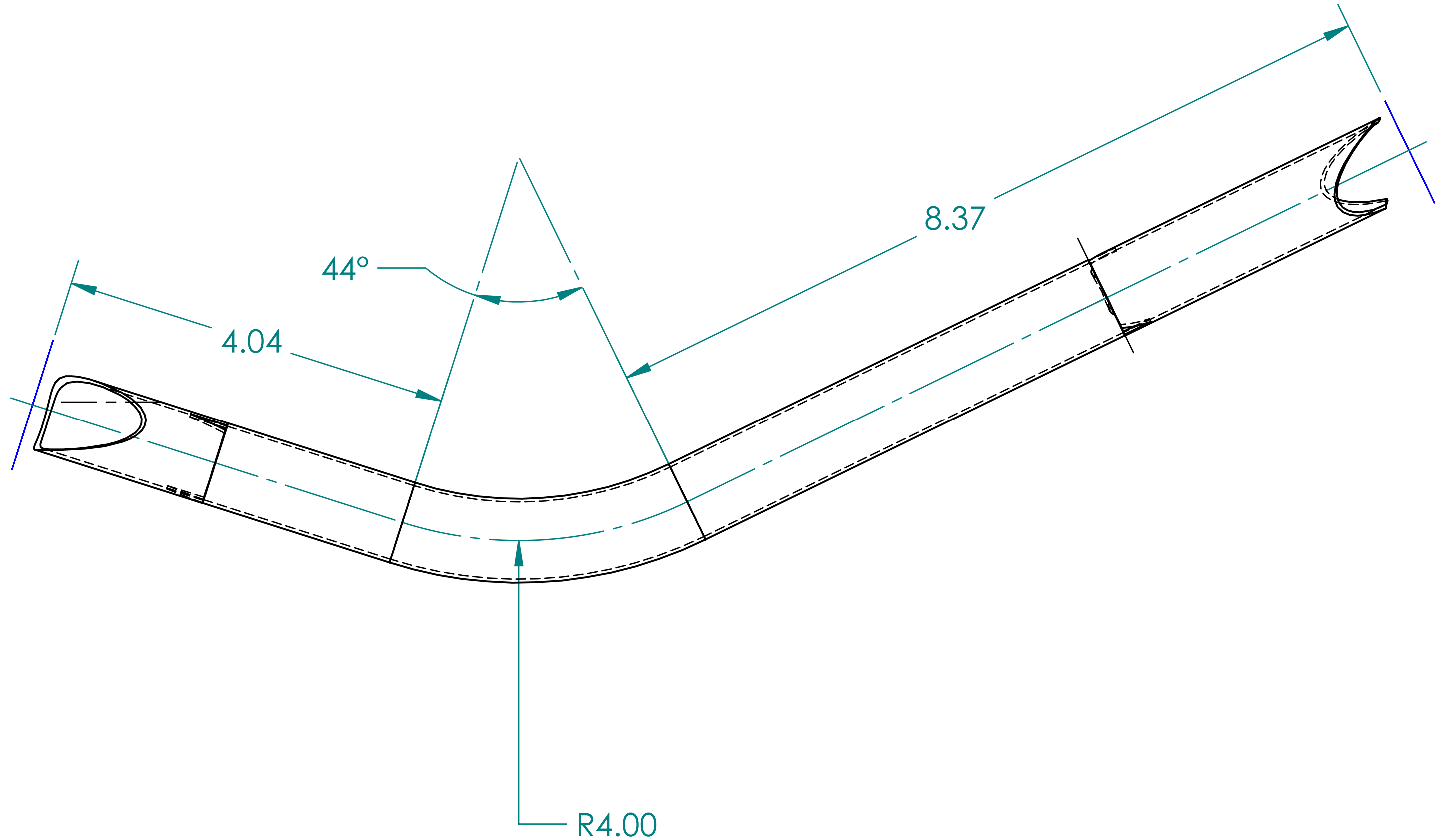
Note: Final hole
positions located
with frame jig.

Stock:
4130 Chromoly
7/8" OD
.035" wall

SCALE: 1:4

Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: A01-001-FRAME- MidDriveTrussRight	REV 00
Start Date:	1/5/18		SCALE: 1:2 / MATERIAL: 4130 Steel	1 OF 1



Drawn By:	KYRA SCHMIDT		
Checked By:	XXXXXX		
Start Date:	1/30/18		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A01-001-FRAME-ShoulderTrussSupportLeft

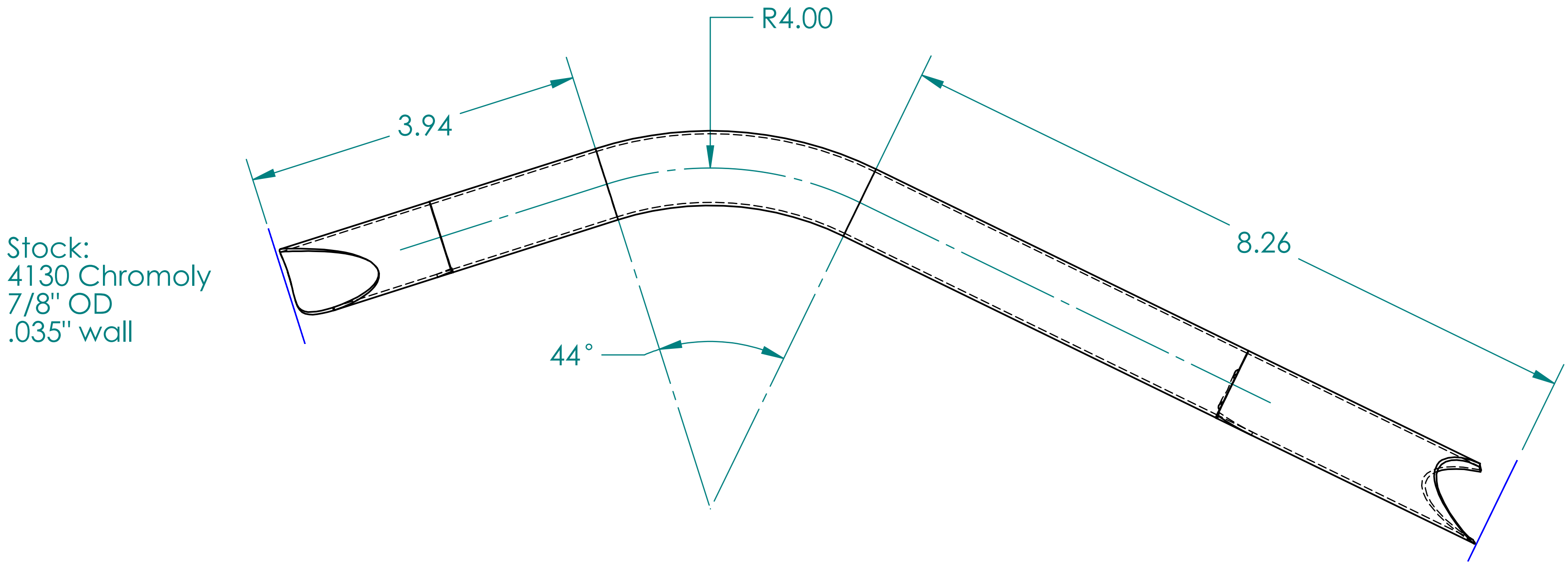
REV 00

SCALE: 1:2

MATERIAL: 4130 STEEL

1 OF 1

Cal Poly Human Powered San Luis Obispo

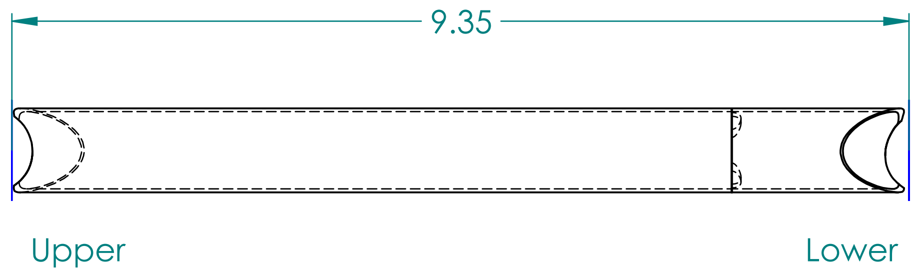


Cal Poly Human Powered San Luis Obispo	Drawn By: KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: A01-001-FRAME-ShoulderSupportTrussRight		REV 00
	Start Date: 1/5/18		SCALE: 1:2	MATERIAL: 4130 Steel	1 OF 1

Note: Miters shown in miter drawings. Overall rough cut length same for right and left sides.

QUANTITY: 2

Stock:
4130 Chromoly
7/8" OD
.035"



Drawn By:	KYRA SCHMIDT	
Start Date:	1/5/18	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

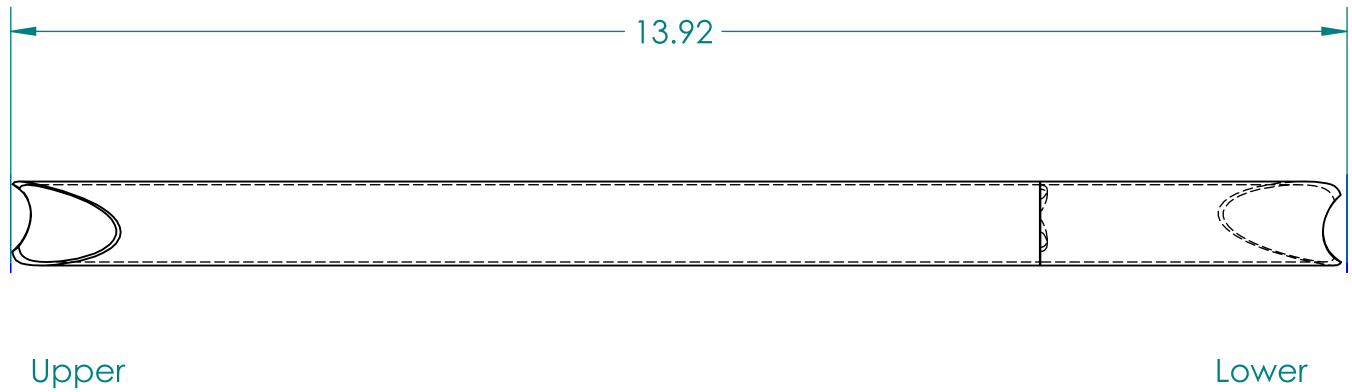
TITLE:		REV
04-A01-001-FRAME-StraightTrussFrontRight		00
SCALE: 1:2	MATERIAL: 4130 Steel	1 OF 1

Cal Poly Human Powered San Luis Obispo

Note: Miters shown in miter drawings.
Overall rough cut length same for right and left sides.

QUANTITY: 2

Stock:
4130 Chromoly
7/8" OD
.035"



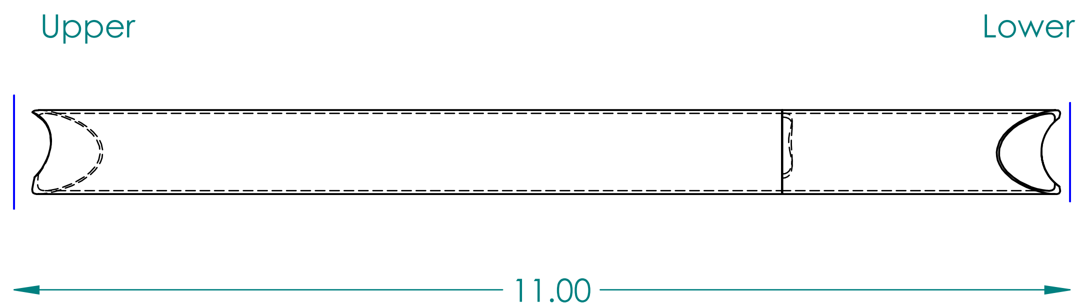
Cal Poly Human Powered San Luis Obispo

Drawn By: KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: A01-001-FRAME-StraightTrussMidRight		REV 00
Start Date: 1/5/18		SCALE: 1:2	MATERIAL: 4130 Steel	1 OF 1

Note: Miters shown in miter drawings. Overall rough cut length same for right and left sides.

QUANTITY: 2

Stock:
4130 Chromoly
7/8" OD
.035" wall

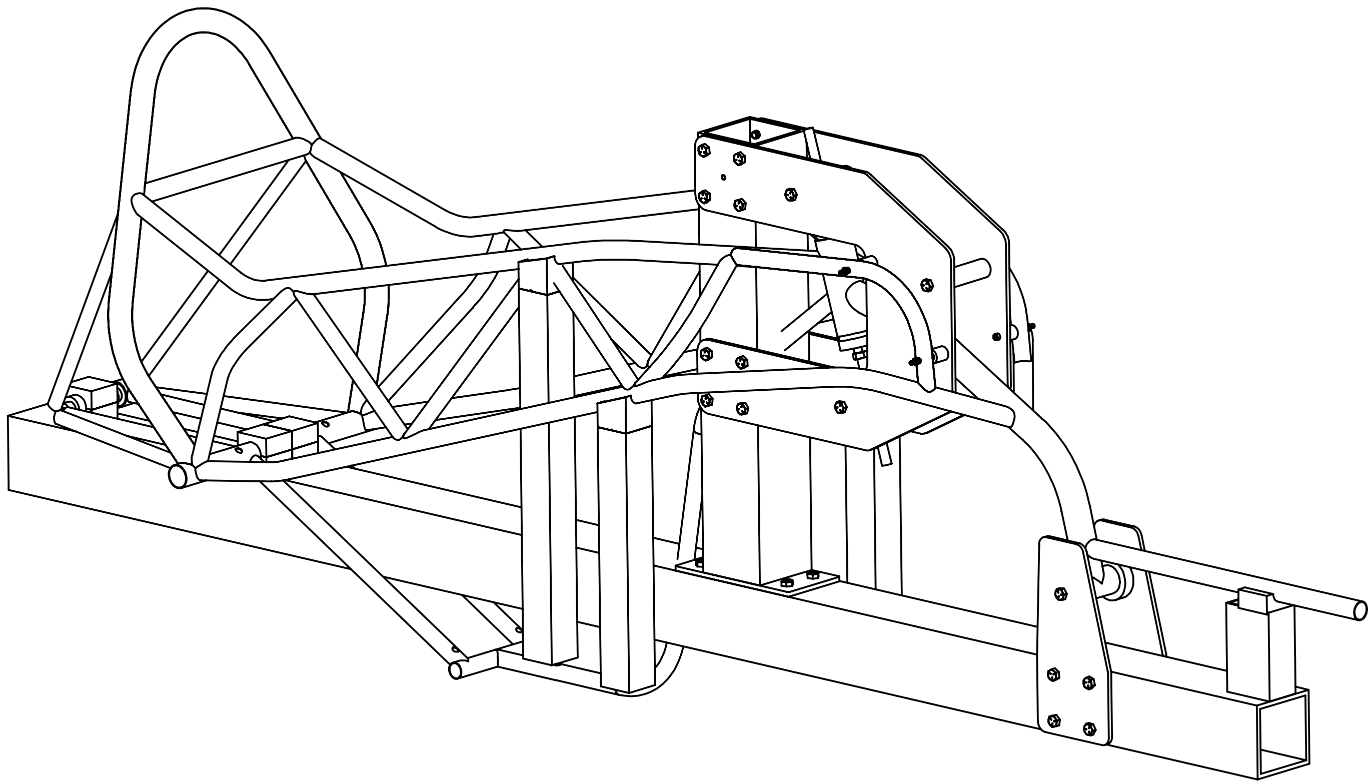


Cal Poly Human Powered San Luis Obispo

Drawn By:	KYRA SCHMIDT
Start Date:	1/5/18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:		REV
04-A01-001-FRAME-StraightTrussRearRight		00
SCALE: 1:2	MATERIAL: 4130 Steel	1 OF 1



ITEM NO.	SUB ASSEMBLY	DESCRIPTION
1	FRAME	FRAME WELDMENT
2	BASE	PARTS TO BE TACKED TO WELDING TABLE
3	REAR END	REAR TRIANGLE FIXTURING
4	PILLAR	PARTS ATTAHED TO PILLAR
5	FRONT END	FRONT END FIXTURING

Cal Poly
Human Powered
San Luis Obispo

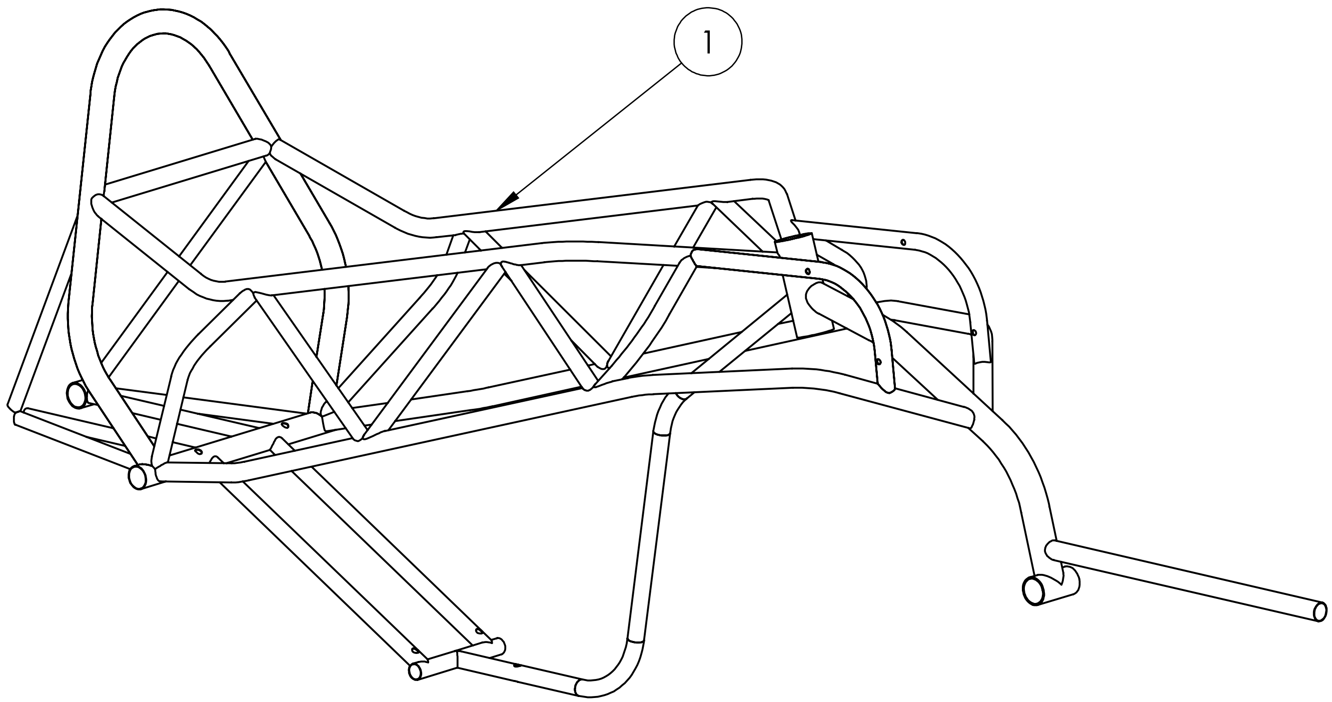
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/19

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-FRAME_JIG_ASSEMBLYNEW

REV
00

SCALE: 1:10
MATERIAL: XXXXXX
1 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	04-A01-001-FRAME	FRAME WELDMENT	1

Cal Poly
Human Powered
San Luis Obispo

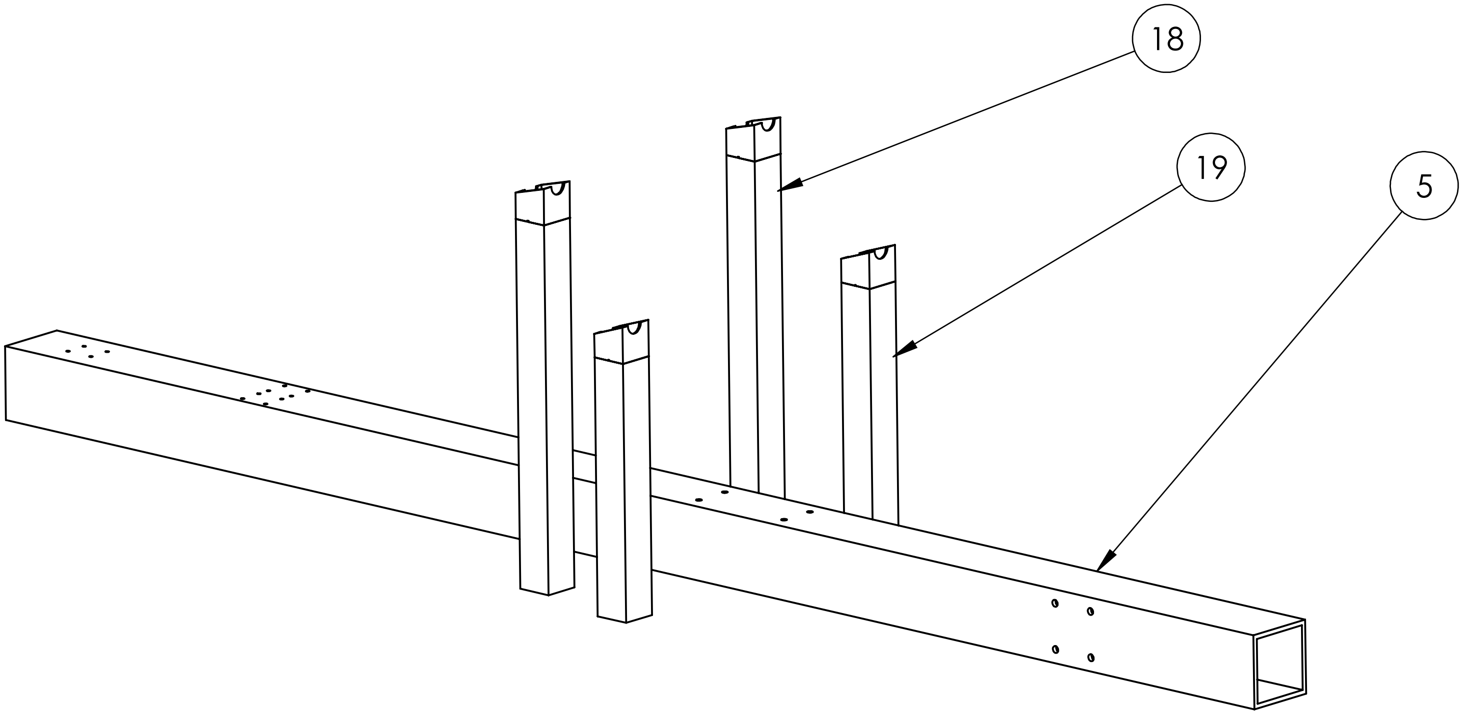
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-FRAME_JIG_ASSEMBLYNEW

REV
00

SCALE: 1:10 | MATERIAL: XXXXXX | 2 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	04-A03-001-JIG_BOTTOM	4 X 4 STEEL JIG BASE	1
18	04-A03-013-PILLARTOPSIDESUPPORT	TOP SIDE SUPPORT PILLAR	2
19	04-A03-011-PILLARMIDSIDESUPPORT	MID SIDE SUPPORT PILLAR	2

Cal Poly Human Powered San Luis Obispo

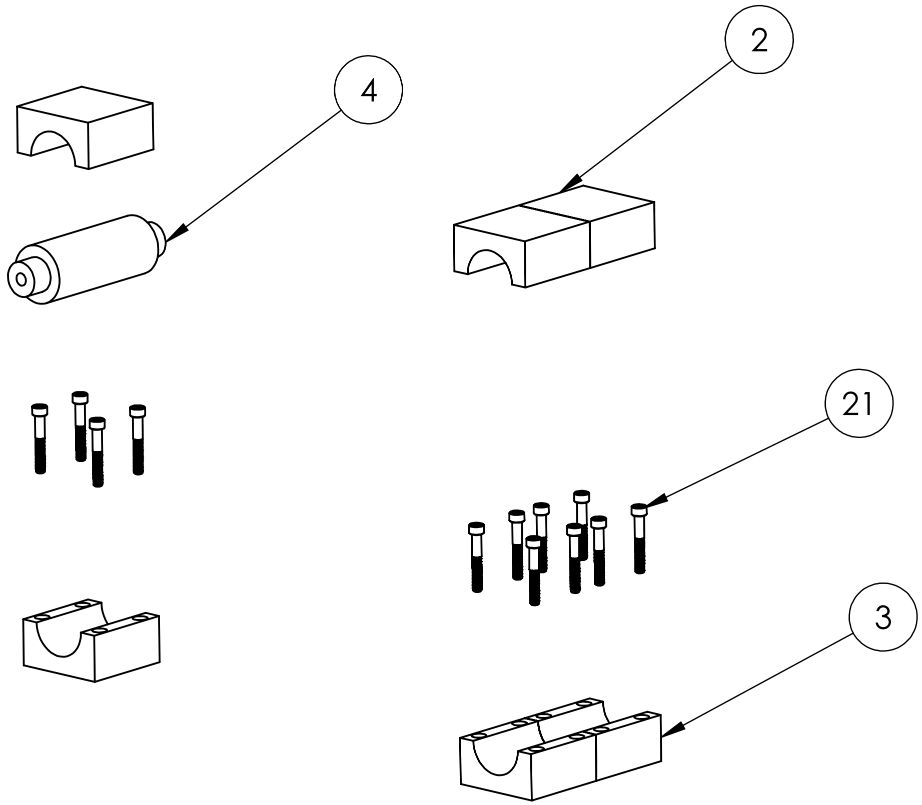
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-FRAME_JIG_ASSEMBLYNEW

REV
00

SCALE: 1:10
MATERIAL: XXXXXX
3 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	04-A03-002-TUBE_BLOCK_1.25	TUBING BLOCK TOPS	3
3	04-A03-002-TUBE_BLOCK_1.25BOTTOM	TUBING BLOCK BOTTOMS	3
4	04-A03-010-DUMMYREARHUB	REAR HUB SPACER	1
21	90128A948	FASTENERS	12

Cal Poly Human Powered San Luis Obispo

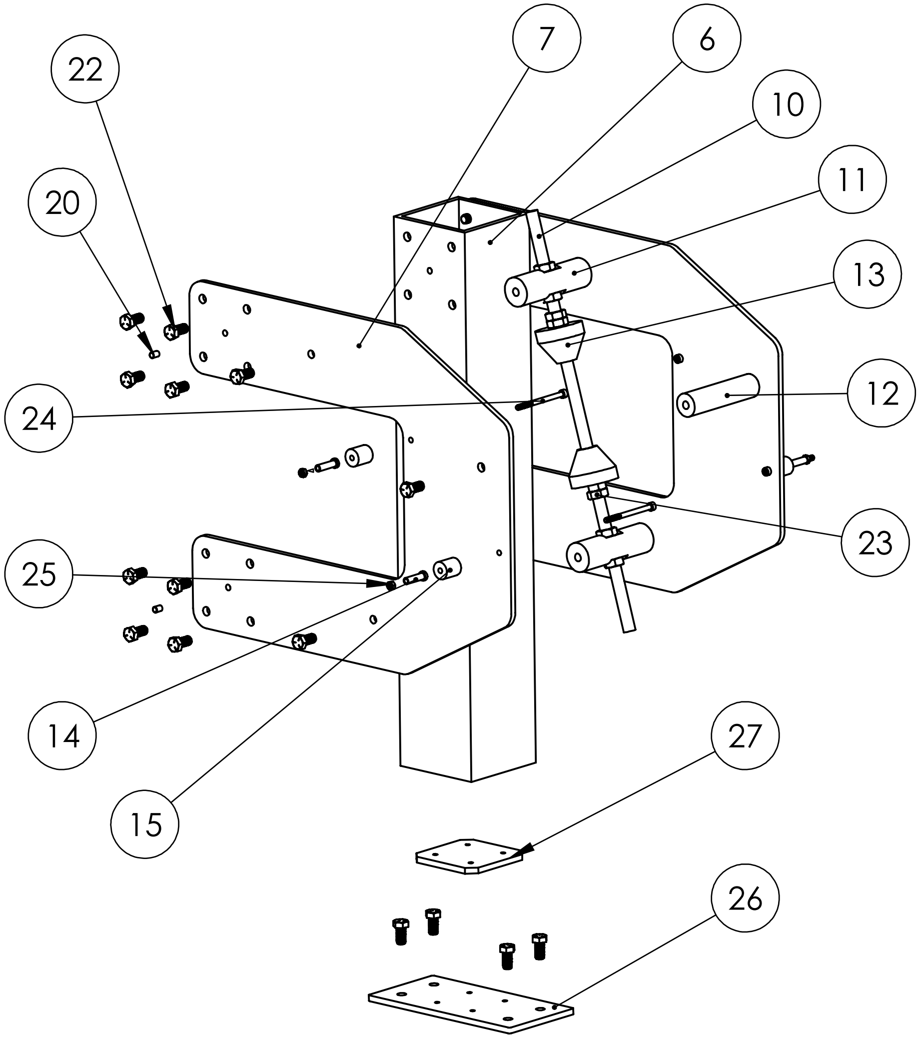
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-FRAME_JIG_ASSEMBLYNEW

REV 00

SCALE: 1:4 | MATERIAL: XXXXXX | 4 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
6	04-A03-001-JIG_PILLAR	MAIN SUPPORT	1
7	04-A03-008-TOP_PLATE	SUPPORT PLATE	2
10	04-A03-005-HEAD_TUBE_ROD	1/2-13 THREADED ROD	1
11	04-A03-006-HEAD_TUBE_MOUNT	HEAD TUBE LOCATING SPACER	2
12	04-A03-006-HEAD_TUBE_MOUNT_SPACER	RIDGIDITY SPACER	1
13	04-A03-007-CONICAL_PLUG	HEAD TUBE PLUG	2
14	04-A01-004-MIDDRIVEBOSS	MID-DRIVE BOSS	4
15	04-A03-009-MID_DRIVE_SPACER1	MID-DRIVE SPACER	4
20	04-A03-015-DOWELPIN	LOCATING DOWEL PIN	4
22	92865A622	3/8 - 24 SPACERS	36
23	94846A525	1/2 -13 NUTS	8
24	91290A272	M5 FASTENERS	4
25	92497A300	M5 NUTS	4
26	04-A03-016-PILLAR_BASE	JIG PILLAR BASE	1
27	04-A03-014-JIGPILLARPLATE	JIG PILLAR WELDED PLATE	1

Cal Poly Human Powered San Luis Obispo

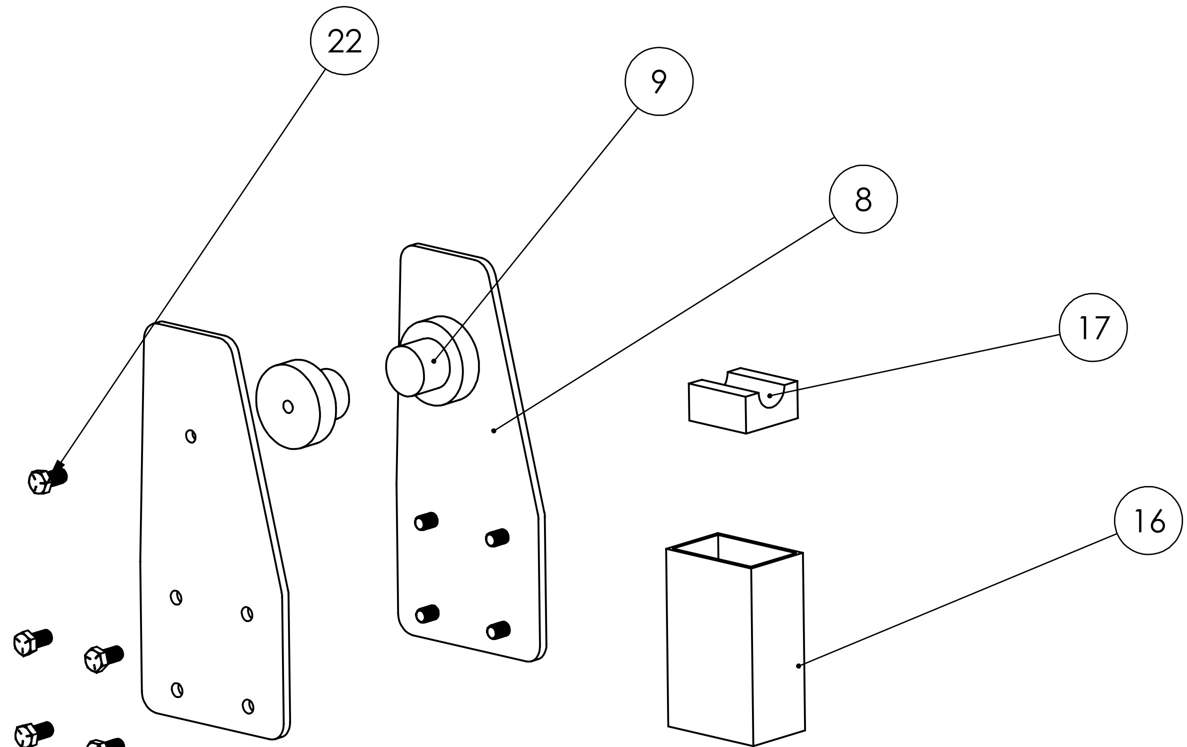
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-FRAME_JIG_ASSEMBLYNEW

REV 00

SCALE: 1:8 | MATERIAL: XXXXXX | 5 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	04-A03-003-FRONT_PLATE	FRONT LOCATION PLATE	2
9	04-A03-004-BB_PLUG	BOTTOM BRACKET PLUG	2
16	04-A03-012-FAIRINGCANTILEVERSPACER	CANTILEVER HEIGHT SPACER	1
17	04-A03-002-TUBE_BLOCK_1.0	CANTILEVER TUBE BLOCK	1
22	92865A622	3/8-24 FASTENERS	36

Cal Poly Human Powered San Luis Obispo

Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/29/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-FRAME_JIG_ASSEMBLYNEW

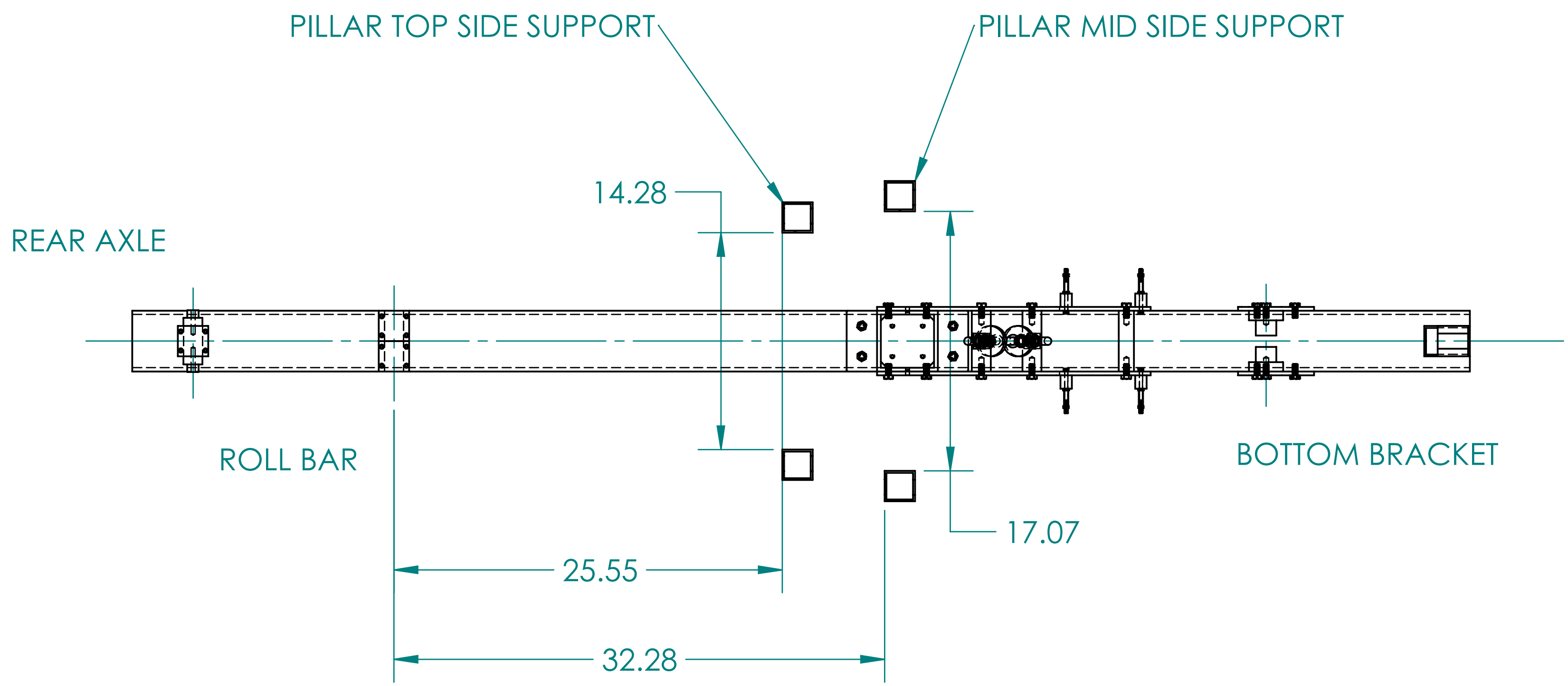
REV 00

SCALE: 1:5

MATERIAL: XXXXXX

WELDING TABLE LAYOUT

Note: Pillar Side Supports (4) will be tac'd to table. Jig base will be clamped to end of table and tac'd on other side.
Jig base will be leveld. Welding table will be leveled.

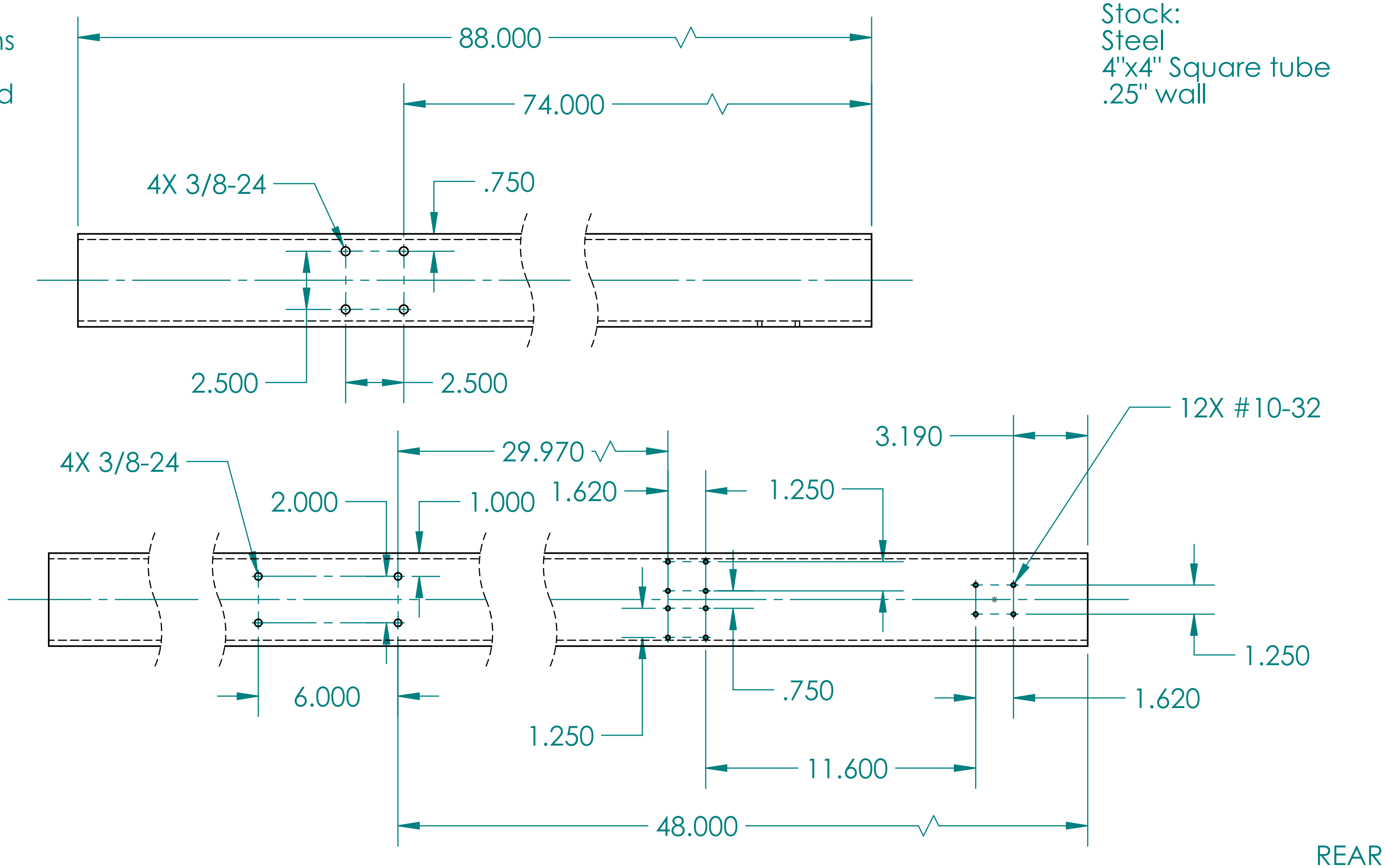


Cal Poly Human Powered San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-FRAME_JIG_ASSEMBLYNEW	REV 00
Checked By:	XXXXXX		SCALE: 1:12	MATERIAL: n/a
Start Date:	1/30/19			7 OF 7

Note: Hole locations and dimensions the same on left and right sides

Stock:
Steel
4"x4" Square tube
.25" wall



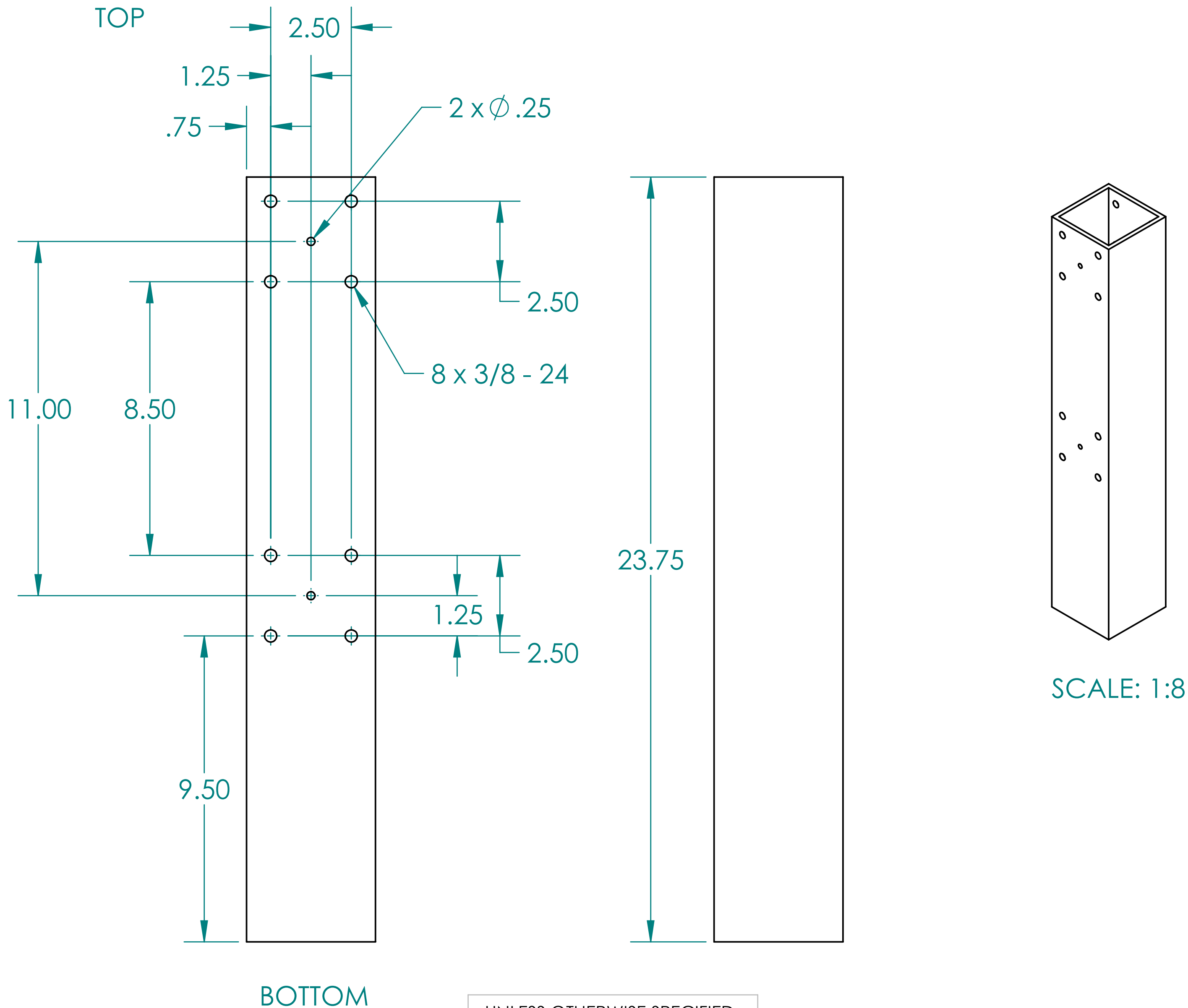
Cal Poly Human Powered San Luis Obispo	Drawn By:	KYRA SCHMIDT	
	Checked By:	KEYANNA HENDERSON	
	Start Date:	1/24/19	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-001-JIG_BOTTOM		REV 00
SCALE: 1:20	MATERIAL: STEEL	1 OF 1

Stock:
Steel
4"x4" Square tube
.25" wall

NOTE: All hole dimensions and positions same for right and left sides



Drawn By:	Keyanna Henderson
Checked By:	Kyra Schmidt
Start Date:	1/24/19

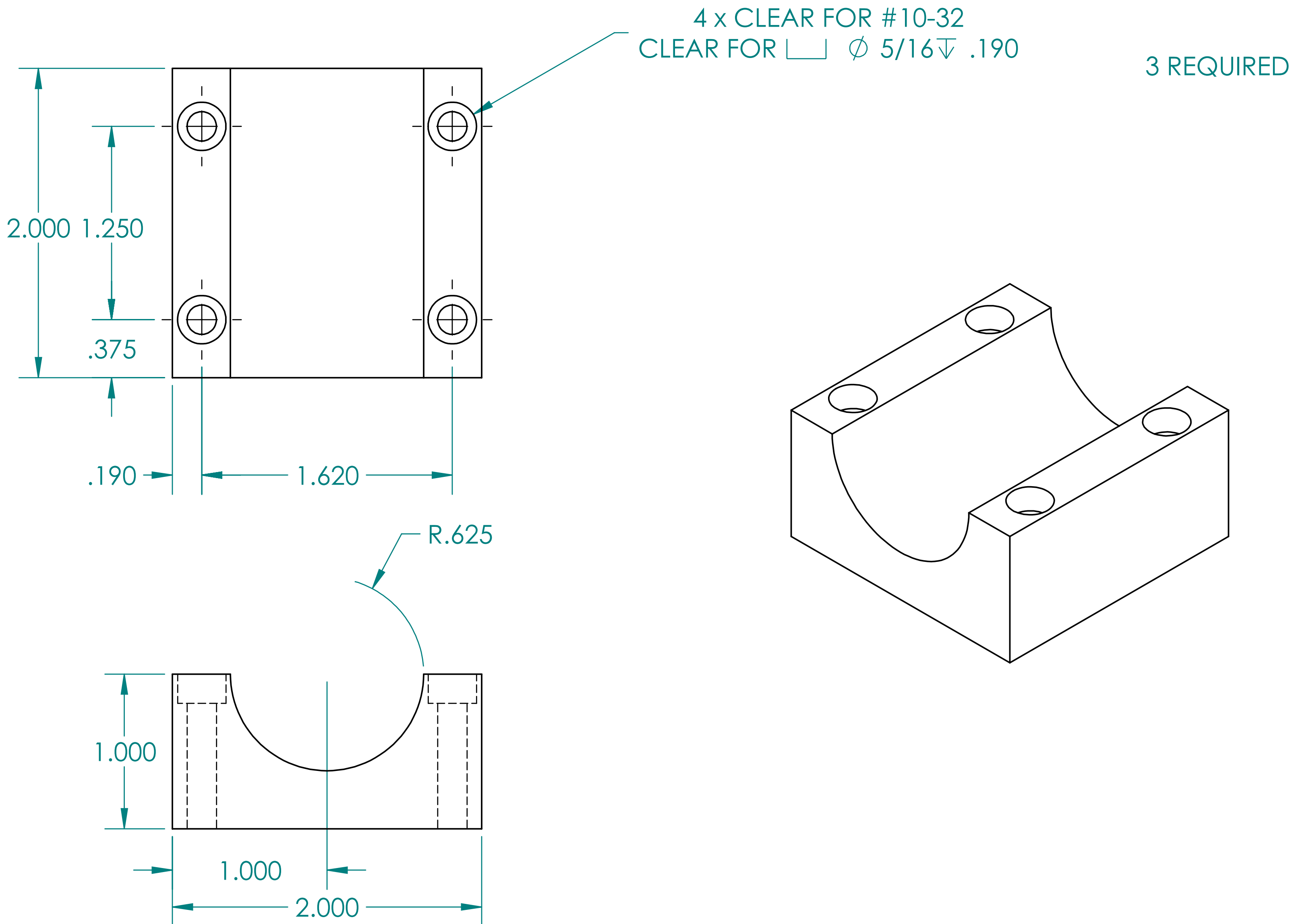
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-001-JIG_PILLAR

REV
00

SCALE: 1:5
MATERIAL: Steel
1 OF 1

Cal Poly Human Powered San Luis Obispo



Cal Poly Human Powered San Luis Obispo

Drawn By:	KEYANNA HENDERSON
Checked By:	KYRA SCHMIDT
Start Date:	1/24/19

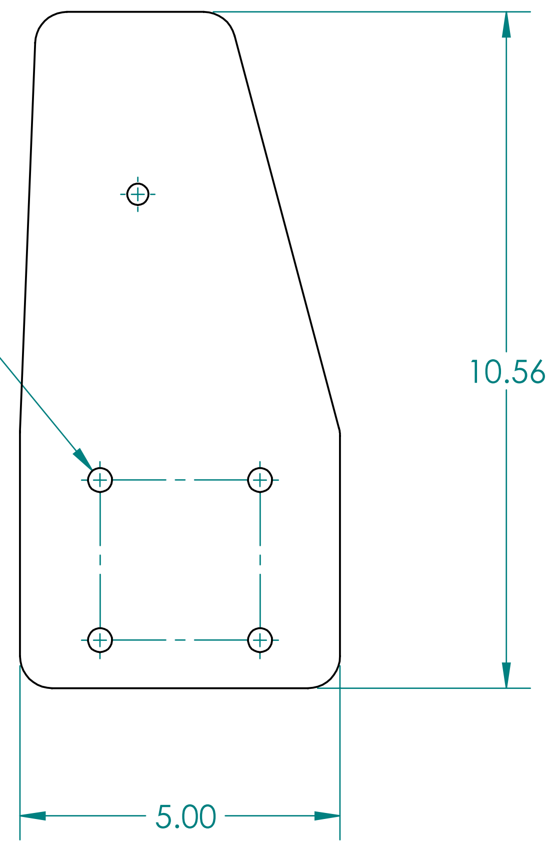
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A03-002-
TUBE_BLOCK_1.25BOTTOM

REV
00

SCALE: 1:1
MATERIAL: ALUMINUM
1 OF 1

Note: Outside profile and hole locations defined by model to be waterjet.
Hole final dimensions to be drilled post water jet operation.



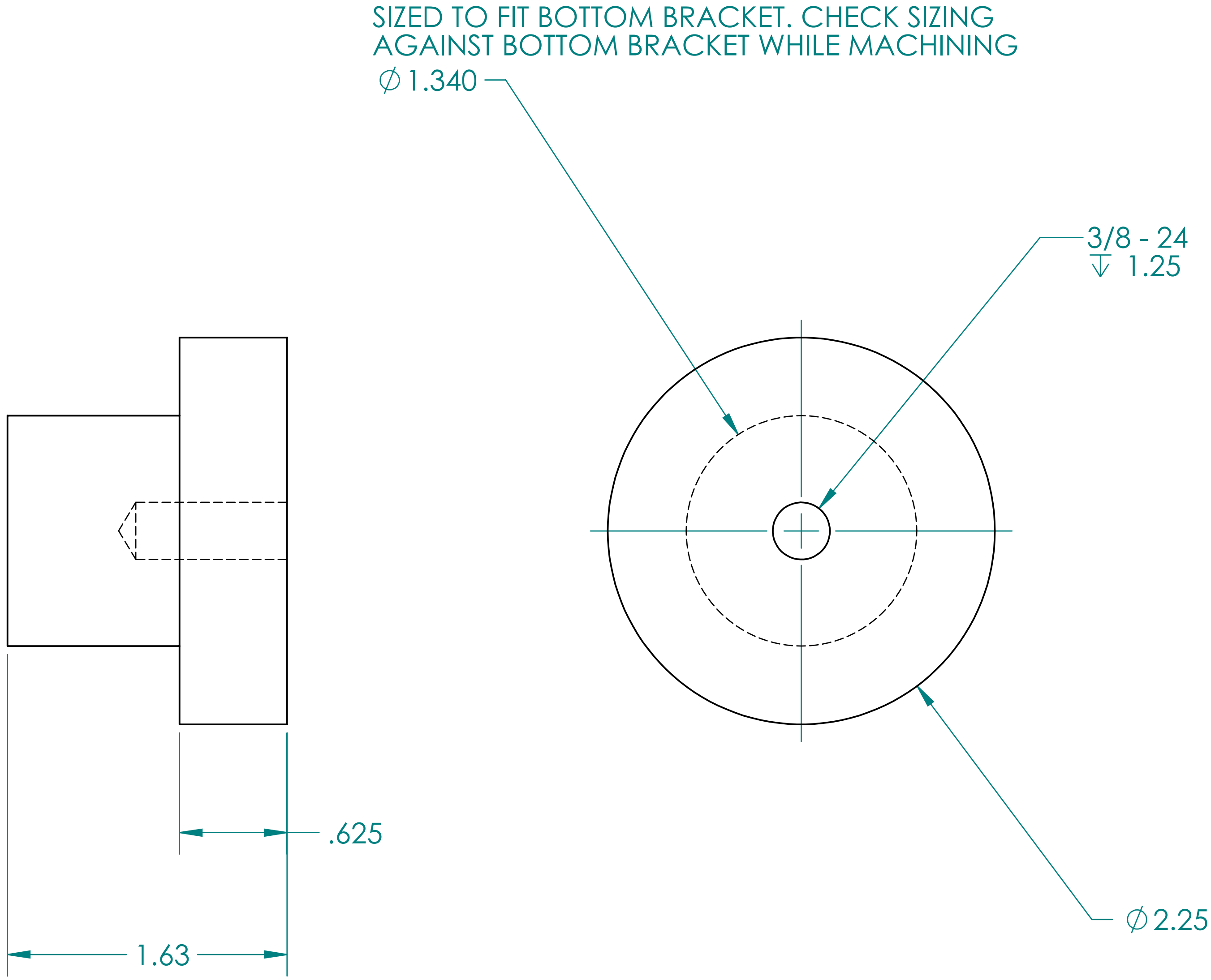
2 REQUIRED

Stock:
Steel
12"x7" Plate
.25" thick

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-003-FRONT_PLATE
Checked By:	KEYANNA HENDERSON		REV 00
Start Date:	1/21/19		SCALE: 1:3 · MATERIAL: STEEL · 1 OF 1

Cal Poly Human Powered San Luis Obispo

QUANTITY: 2

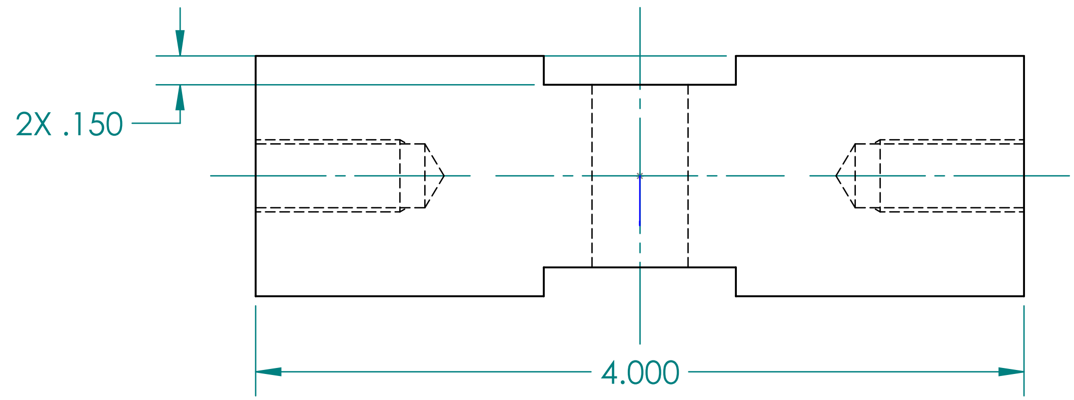


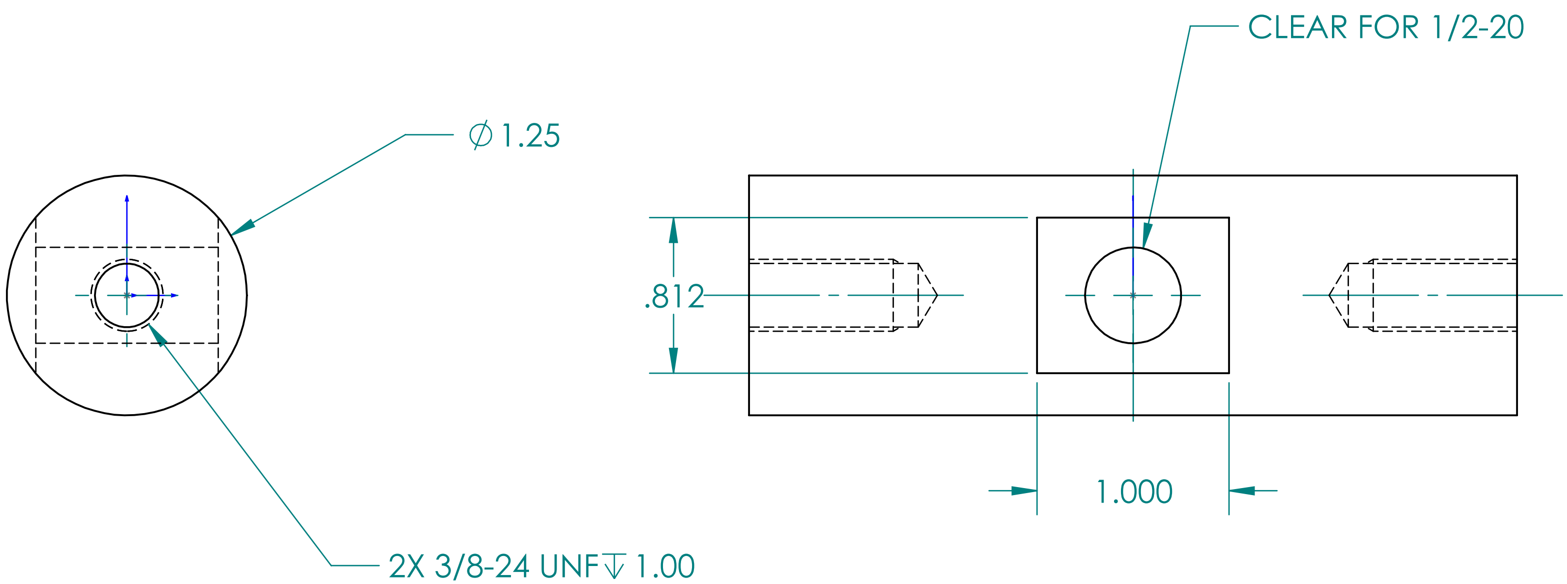
Drawn By:	AUSTIN HENRY	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: BB PLUG	REV 00
Checked By:	KYRA SCHMIDT		SCALE: 1:1	MATERIAL: ALUMINUM
Start Date:	1/22/19			1 OF 1

Cal Poly Human Powered San Luis Obispo

2 REQUIRED

Note: Make Head Tube Mounts and Head Tube Mount Spacer as close to same length as possible.
All holes bottoming tapped.

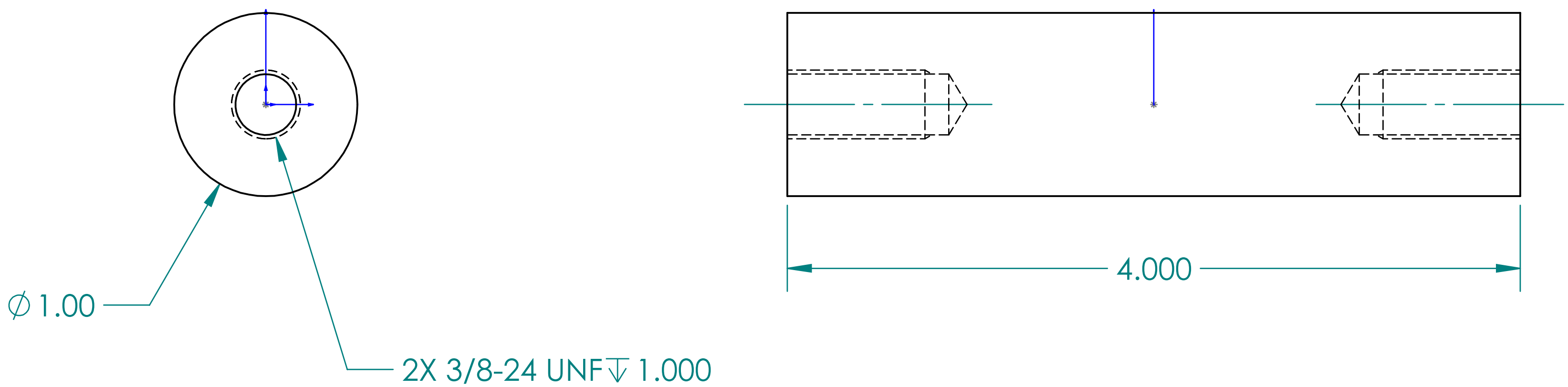




Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-006-HEAD_TUBE_MOUNT		REV 00
Checked By:	KEYANNA HENDERSON				
Start Date:	1/16/19		SCALE: 1:1	MATERIAL: 6061 ALUMINUM	1 OF 1

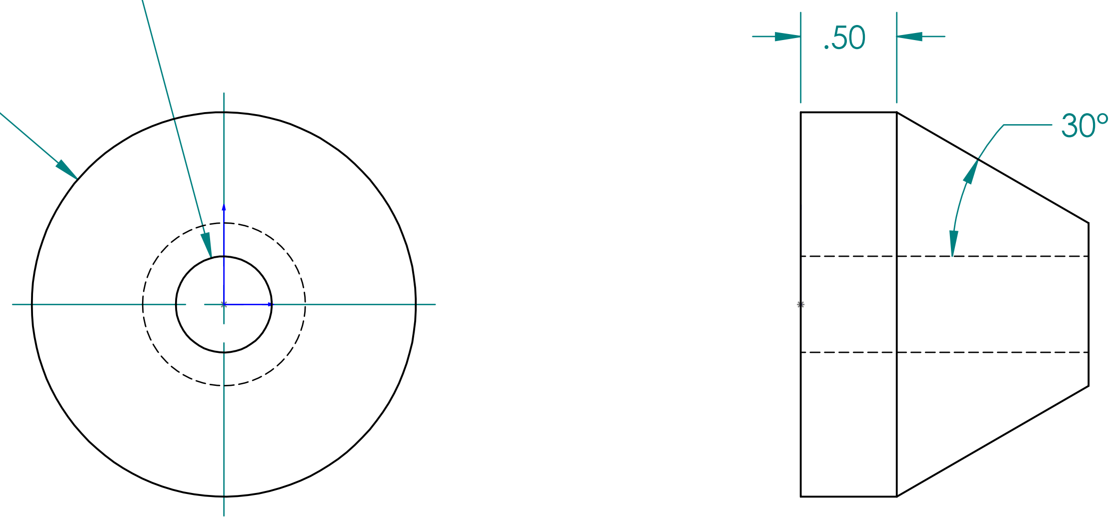
Cal Poly Human Powered San Luis Obispo

Note: Make Head Tube Mounts and Head Tube Mount Spacer as close to same length as possible.
All holes bottoming tapped.



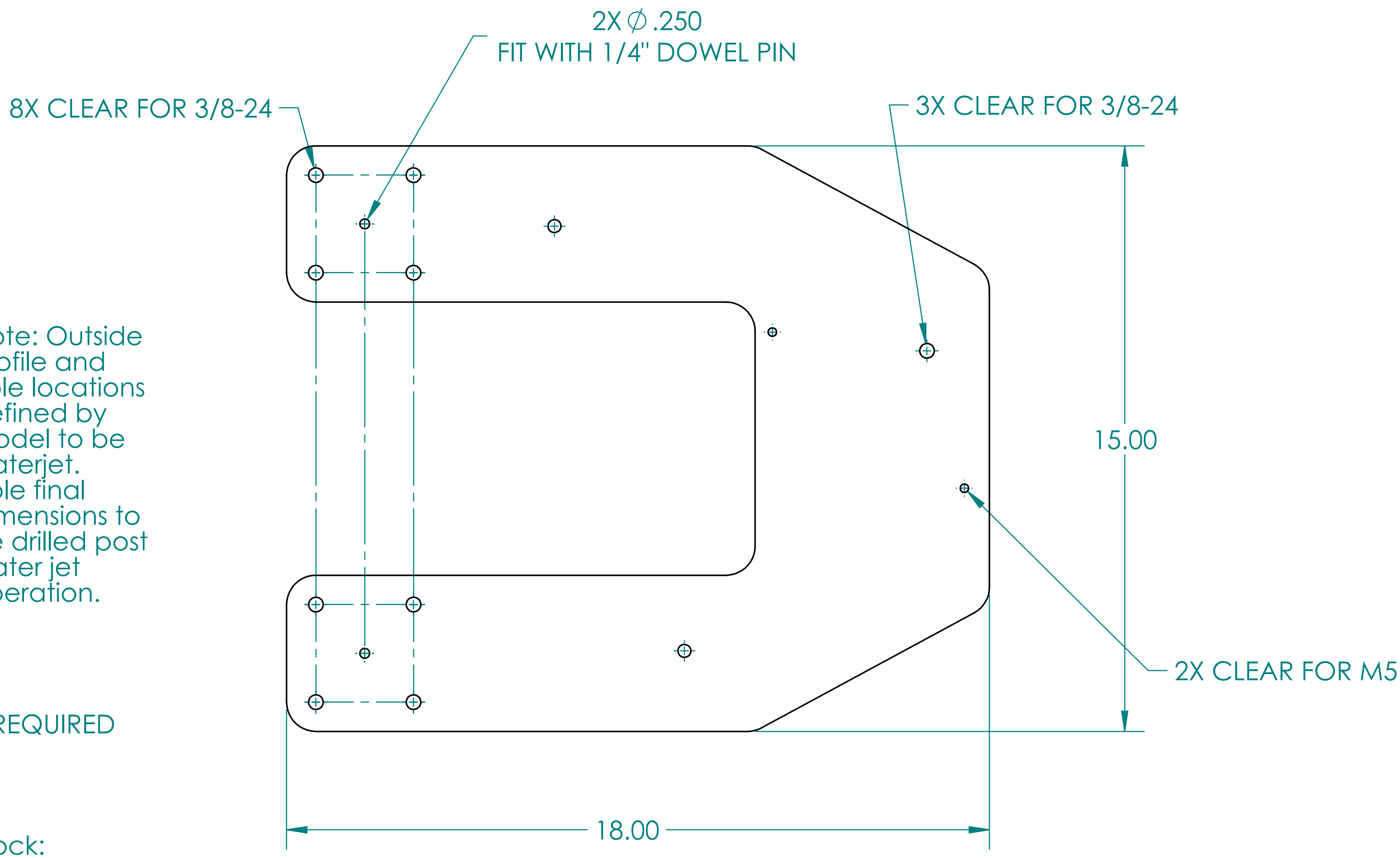
Cal Poly Human Powered San Luis Obispo

		UNLESS OTHERWISE SPECIFIED:		
		DIMENSIONS ARE IN INCHES	TITLE:	REV
Drawn By:	KYRA SCHMIDT	TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2°	04-A03-006-HEAD_TUBE_MOUNT_SPACER	00
Checked By:	KEYANNA HENDERSON	TWO PLACE DECIMAL: ±0.05		
Start Date:	1/16/19	THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	SCALE: 1:1 / MATERIAL: 6061 ALUMINUM	1 OF 1



Drawn By:	AUSTIN HENRY	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-007-CONICAL_PLUG
Start Date:	1/22/19		REV 00
		SCALE: 2:1	MATERIAL: 6061 ALUMINUM
			1 OF 1

Cal Poly Human Powered San Luis Obispo



Note: Outside profile and hole locations defined by model to be waterjet. Hole final dimensions to be drilled post water jet operation.

2 REQUIRED

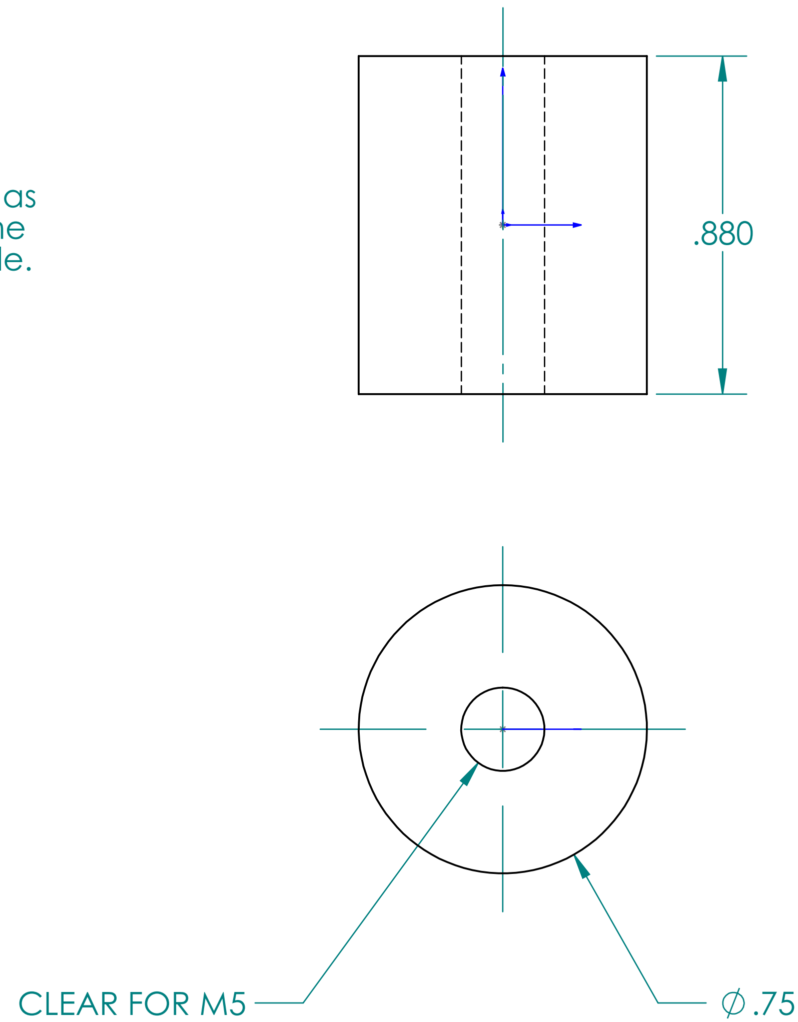
Stock:
Steel
18"x15" Plate
.25" thick

Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-008-TOP_PLATE		REV 00
Checked By:	XXXXXX				
Start Date:	1/20/19		SCALE: 1:4	MATERIAL: STEEL	1 OF 1

4 REQUIRED

Note: Makeall 4 as close to the same length as possible.



Cal Poly Human Powered San Luis Obispo

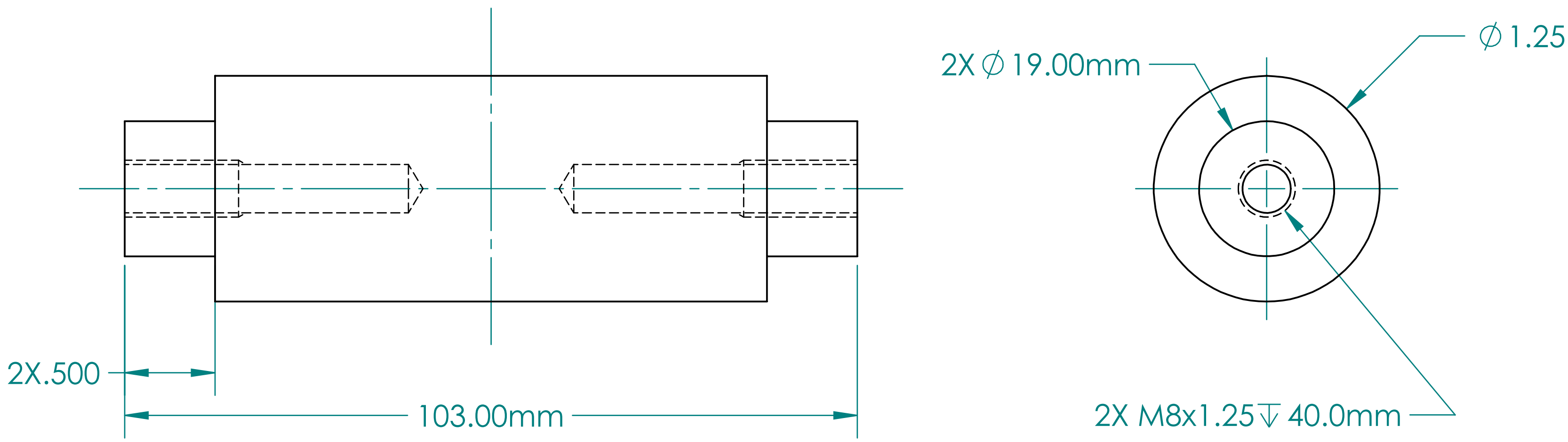
Drawn By:	KYRA SCHMIDT
Start Date:	1/16/19

UNLESS OTHERWISE SPECIFIED:

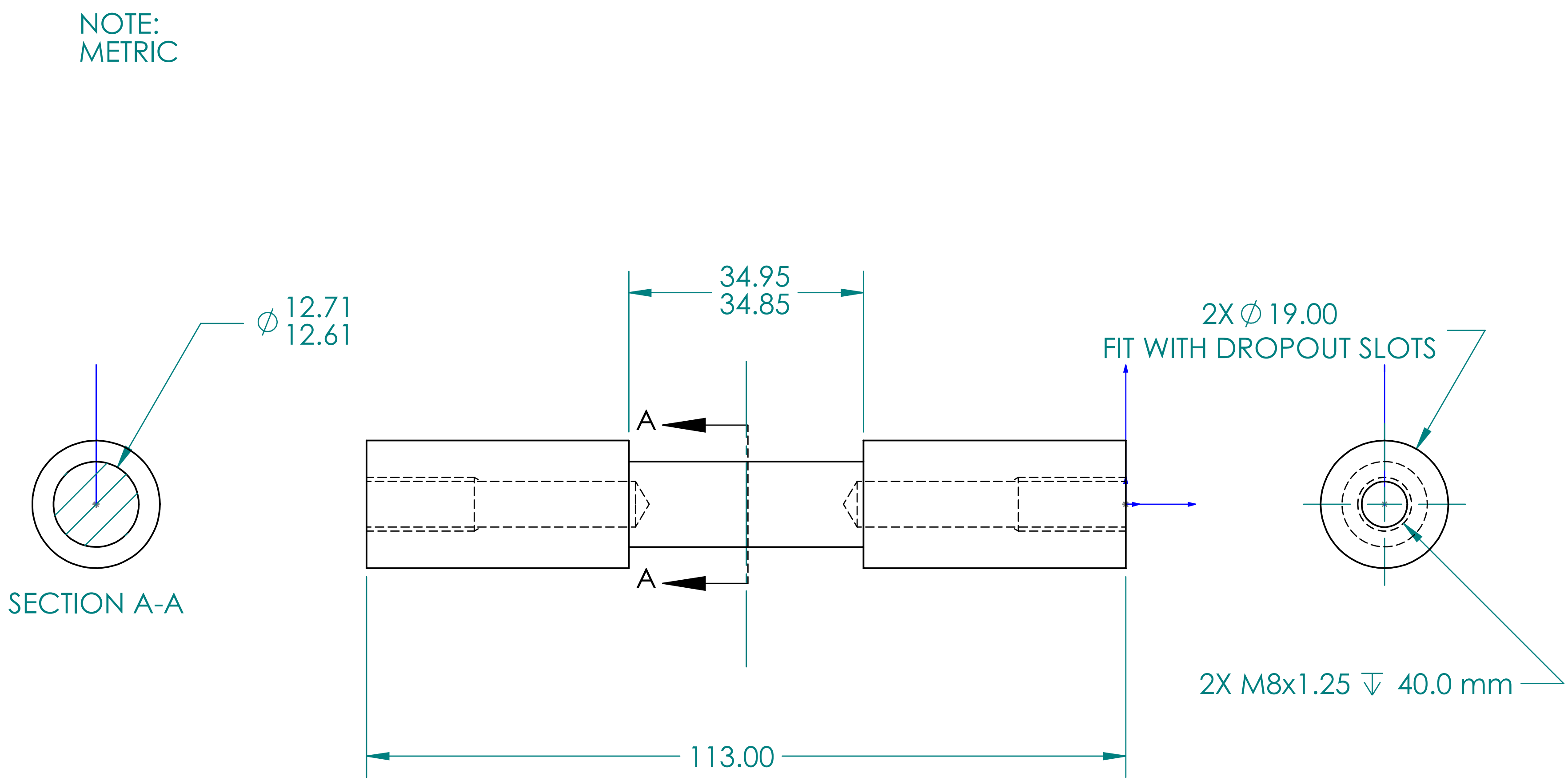
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-009-MID_DRIVE_SPACER1		REV 00
SCALE: 2:1	MATERIAL: 6061 ALUMINUM	1 OF 1

NOTE:
ALL METRIC DIMENSIONS DESIGNATED WITH "mm".
ALL METRIC TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED:
XX.XX ± 0.10
XX.X ± 1



Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-010-DUMMYREARHUB	REV 00
Start Date:	1/1/18		SCALE: 1:1 / MATERIAL: 6061 Al	1 OF 1



Cal Poly Human Powered San Luis Obispo

Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/20/19

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS.
TOLERANCES:
ONE PLACE DECIMAL: ±1
TWO PLACE DECIMAL: ±0.10
TOLERANCING PER: MMC

TITLE:
04-A03-011-DUMMYFRONTAXLE

REV 00

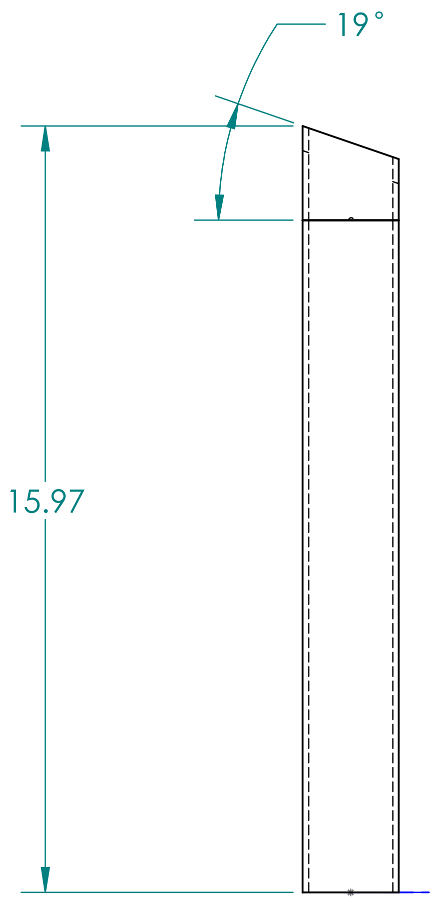
SCALE: 1:1

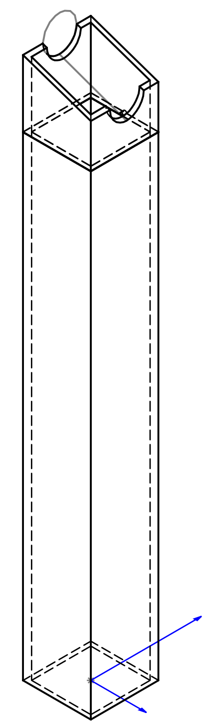
MATERIAL: 6061 ALUMINUM

1 OF 1

2 REQUIRED

Stock:
Steel
2"x2" Square tube
.125" wall

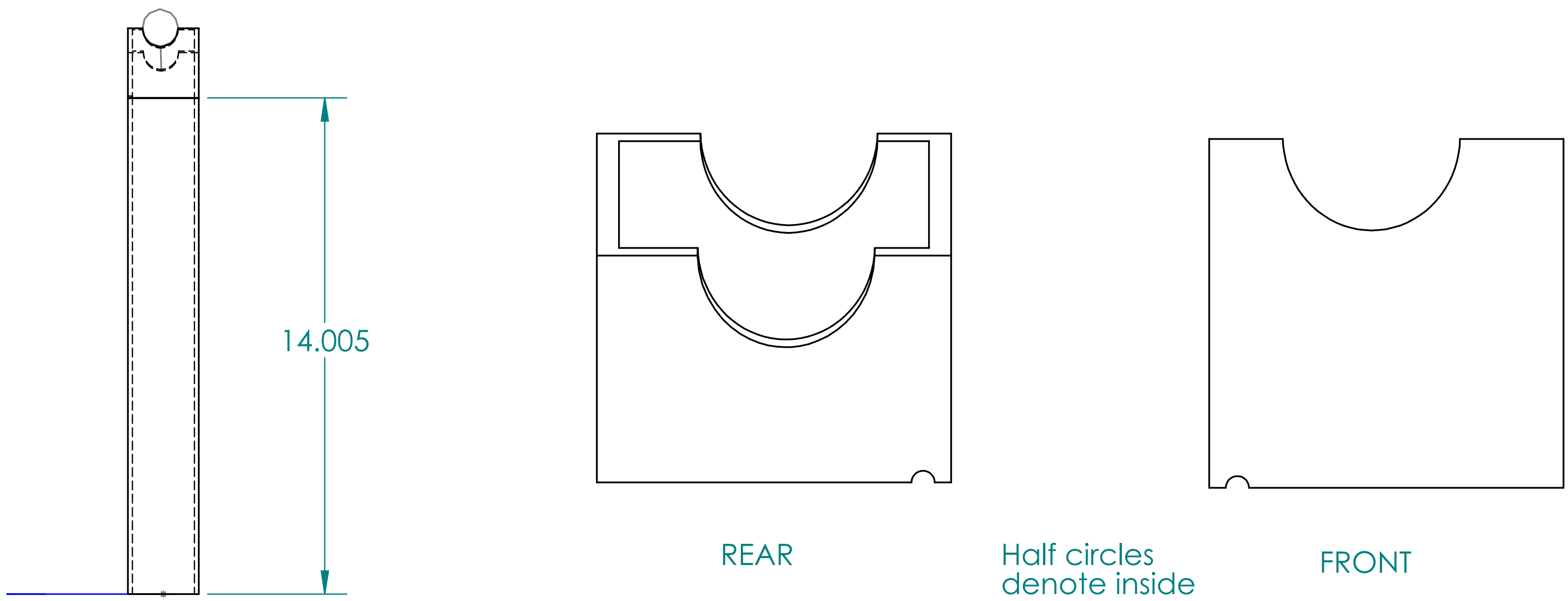




Note: Miters shown in miter drawing

Cal Poly Human Powered San Luis Obispo	Drawn By: KYRA SCHMIDT Start Date: 1/16/19	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-011-PILLARMIDSIDESUPPORT REV 00 SCALE: 1:4 MATERIAL: STEEL 1 OF 1

LEFT SIDE



SCALE: 1:5

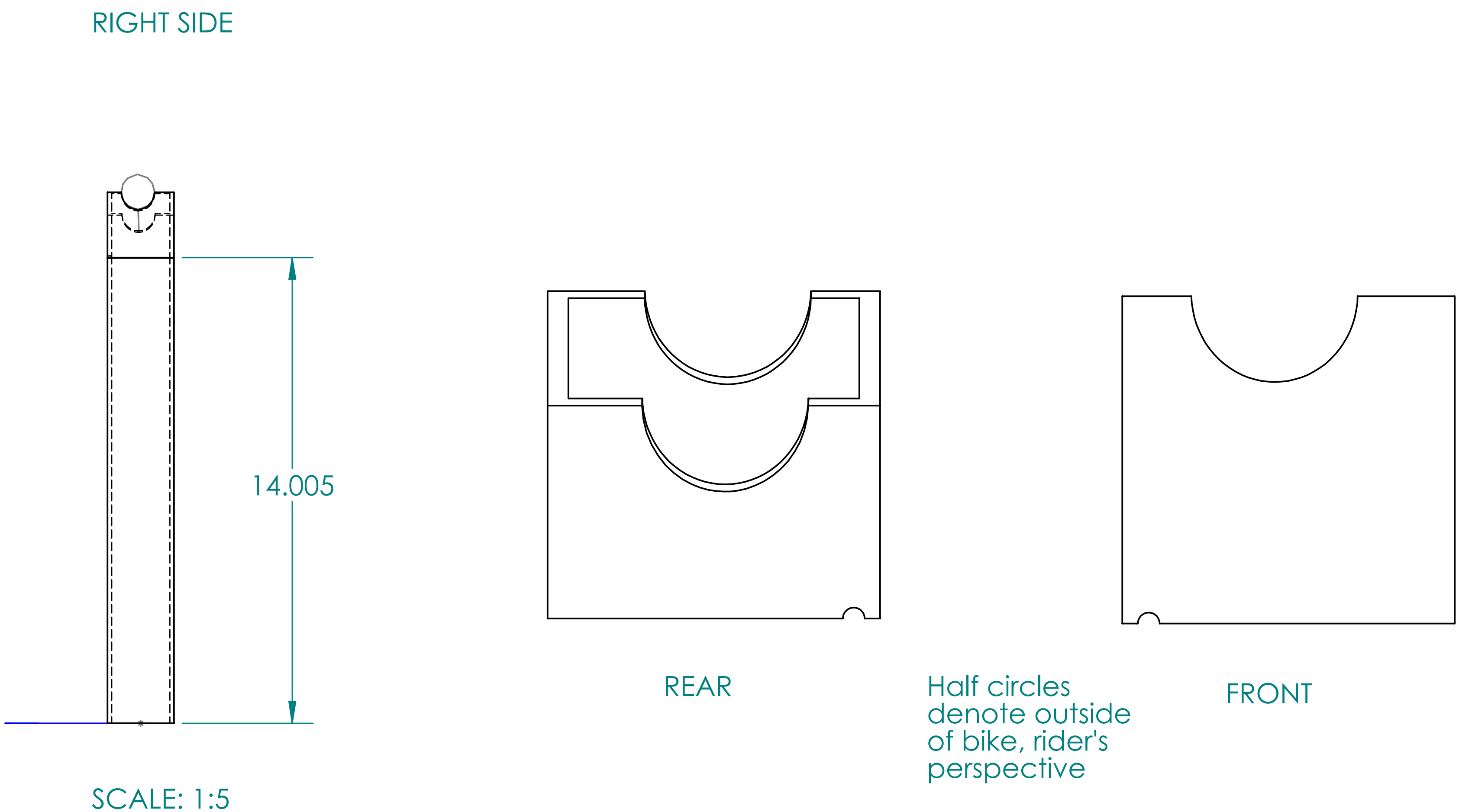
REAR

Half circles denote inside of bike, rider's perspective

FRONT

Cal Poly Human Powered San Luis Obispo

		UNLESS OTHERWISE SPECIFIED:		
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-011-PILLARMIDSIDESUPPORT-mitersLEFT	REV 00
Drawn By:	KYRA SCHMIDT			
Start Date:	1/17/19		SCALE: 1:1 / MATERIAL: STEEL	1 OF 1



Drawn By:	KYRA SCHMIDT
Start Date:	1/17/19

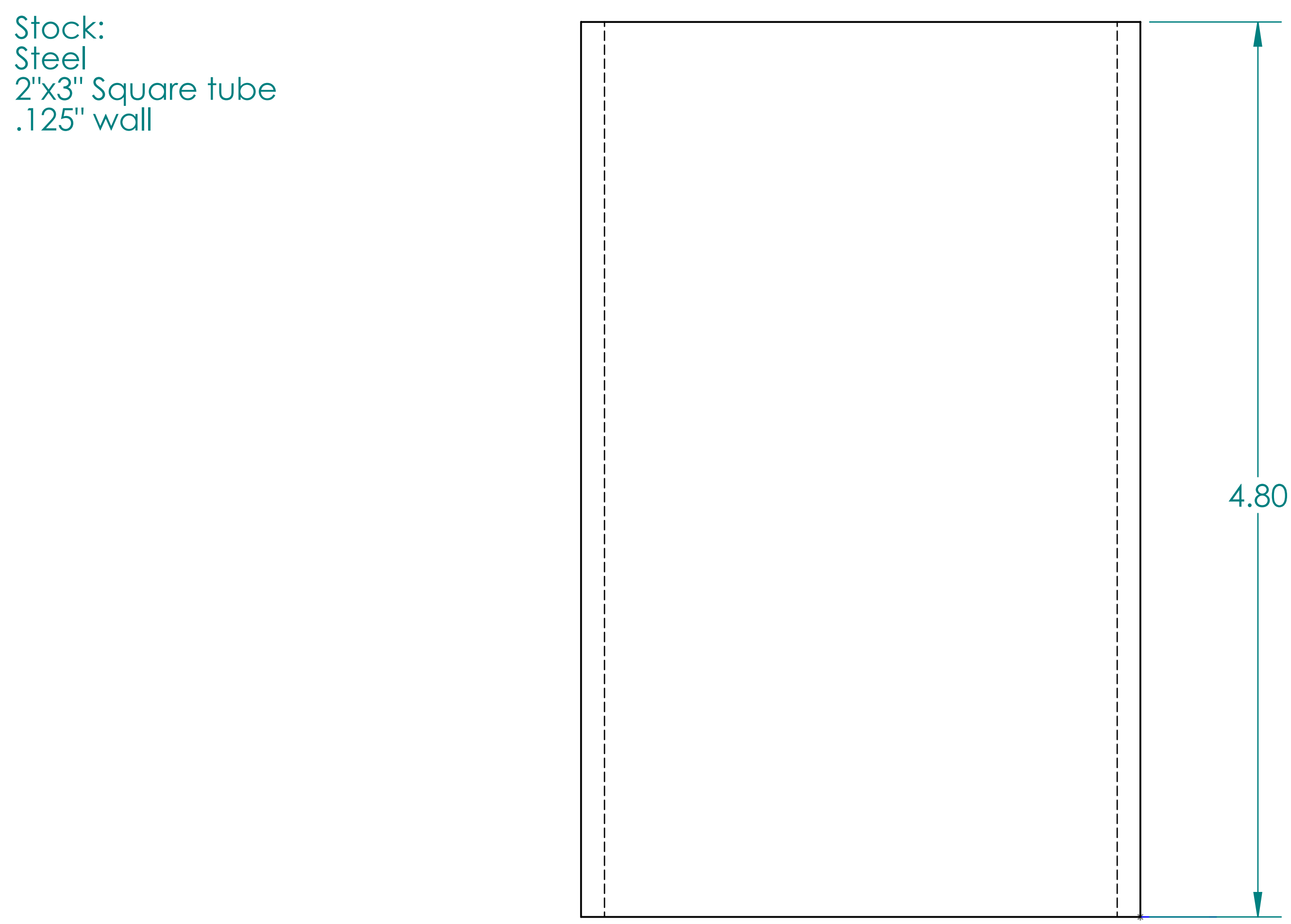
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-011-PILLARMIDSIDESUPPORT-RIGHT-miters

REV 00

SCALE: 1:1 | MATERIAL: STEEL | 1 OF 1

Cal Poly Human Powered San Luis Obispo

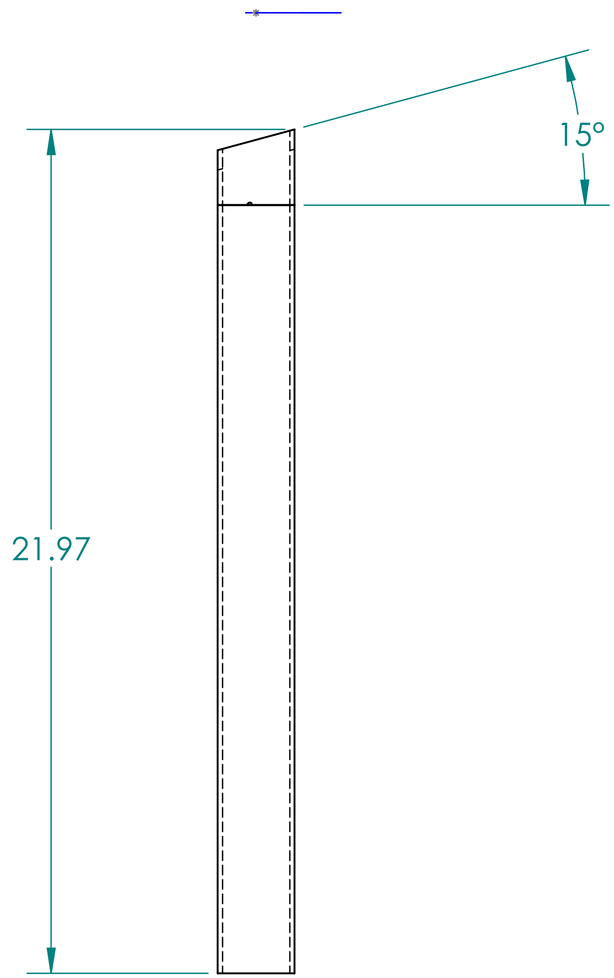


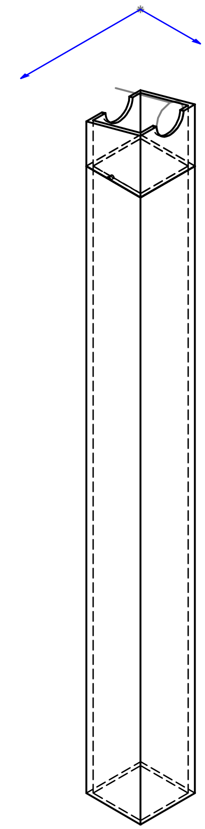
Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-012-FAIRINGCANTILEVERSPACER
Checked By:	XXXXXX		REV 00
Start Date:	1/21/19		SCALE: 1:1 / MATERIAL: STEEL / 1 OF 1

Cal Poly Human Powered San Luis Obispo

2 REQUIRED

Stock:
Steel
2"x2" Square tube
.125" wall

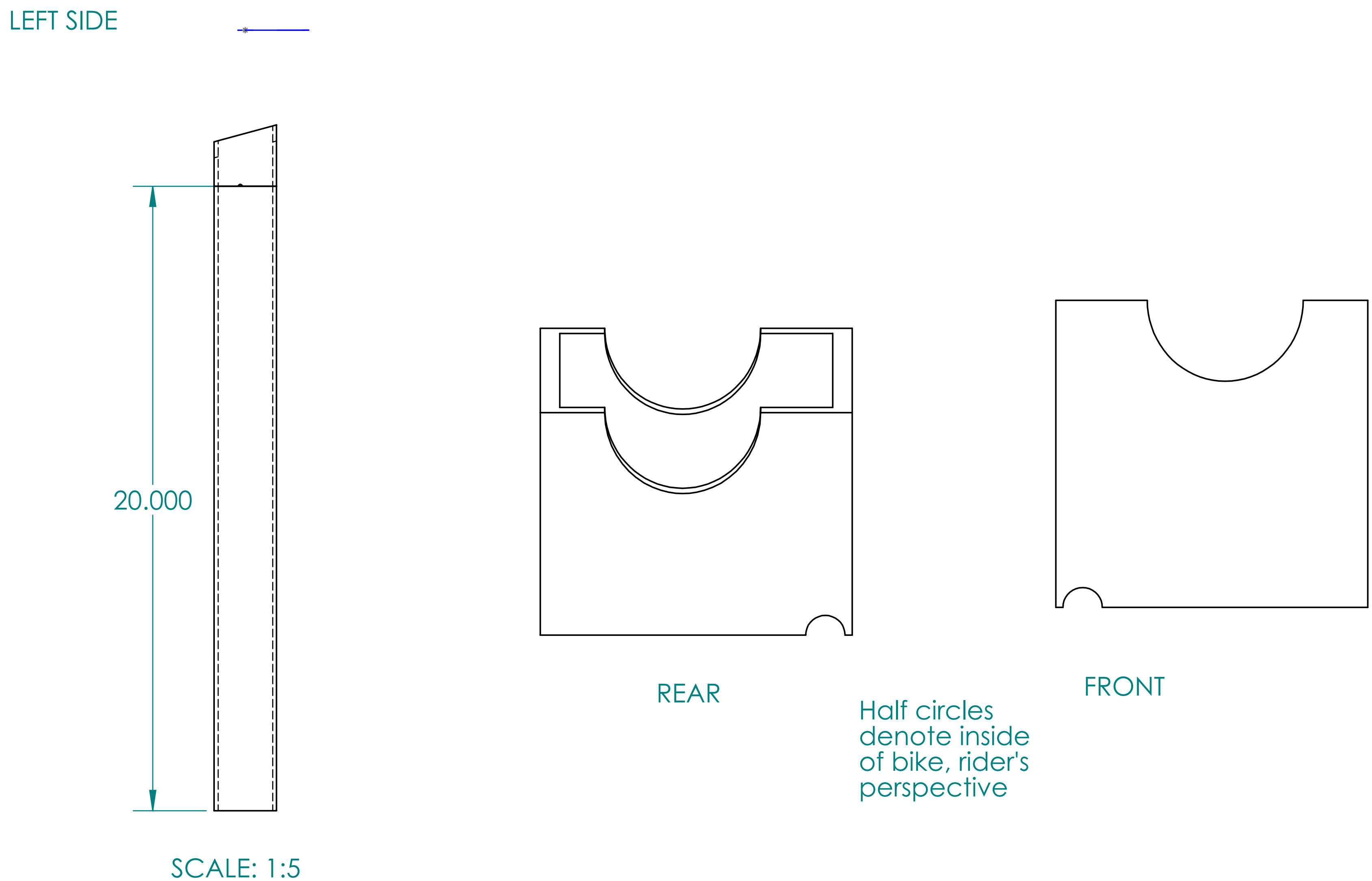




Note: Miters shown in miter drawing

Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-013-PILLARTOPSIDESUPPORT		REV 00
Checked By:	XXXXXX				
Start Date:	1/20/19		SCALE: 1:5	MATERIAL: STEEL	1 OF 1



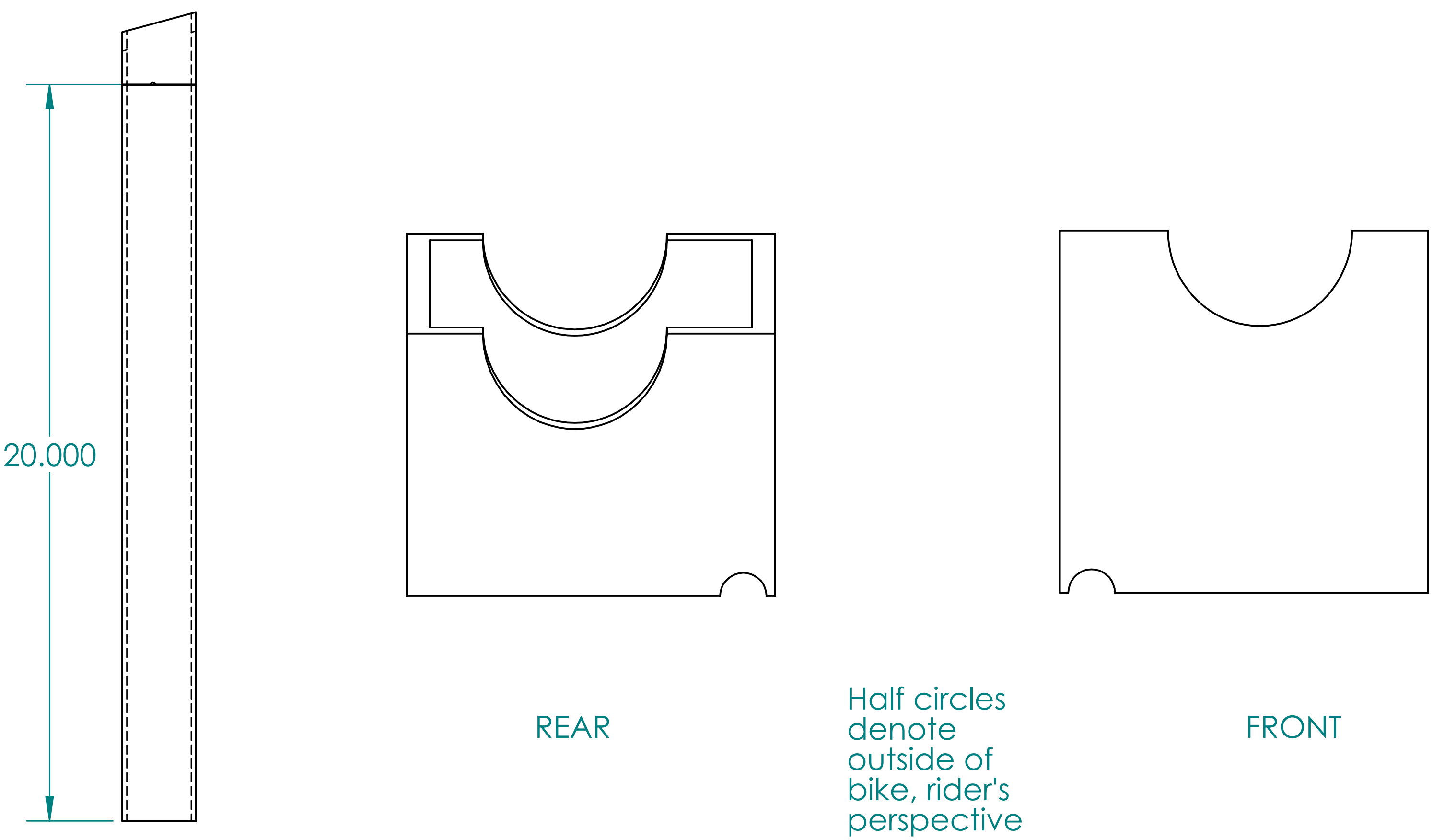
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/20/19

TITLE:		REV
04-A03-013-PILLARTOPSIDESUPPORT-mitersLEFT		00
SCALE: 1:1	MATERIAL: STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo

RIGHT SIDE



REAR

Half circles denote outside of bike, rider's perspective

FRONT

SCALE: 1:5

Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/20/19

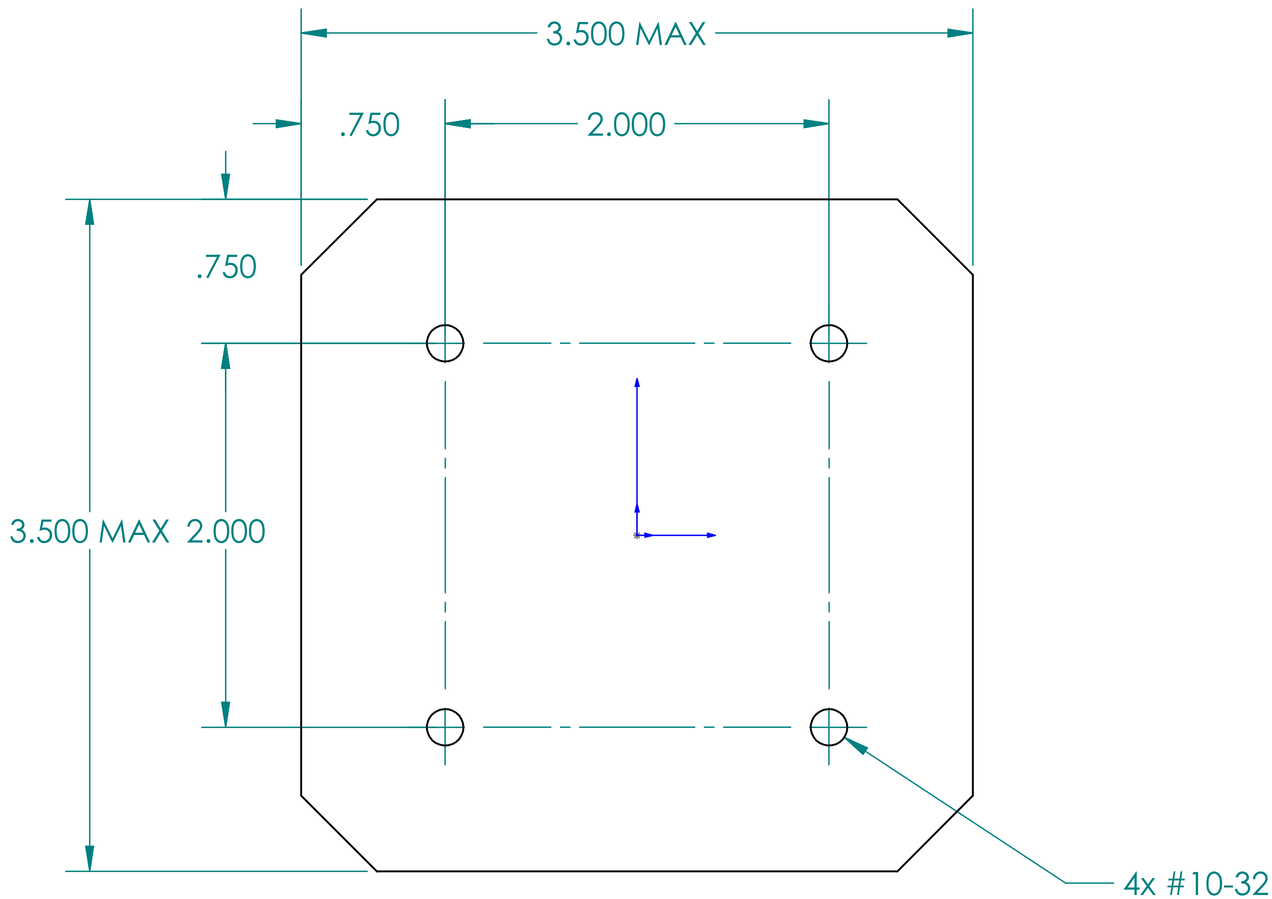
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-013-PILLARTOPSIDESUPPORT-mitersRIGHT		REV 00
SCALE: 1:1	MATERIAL: STEEL	1 OF 1

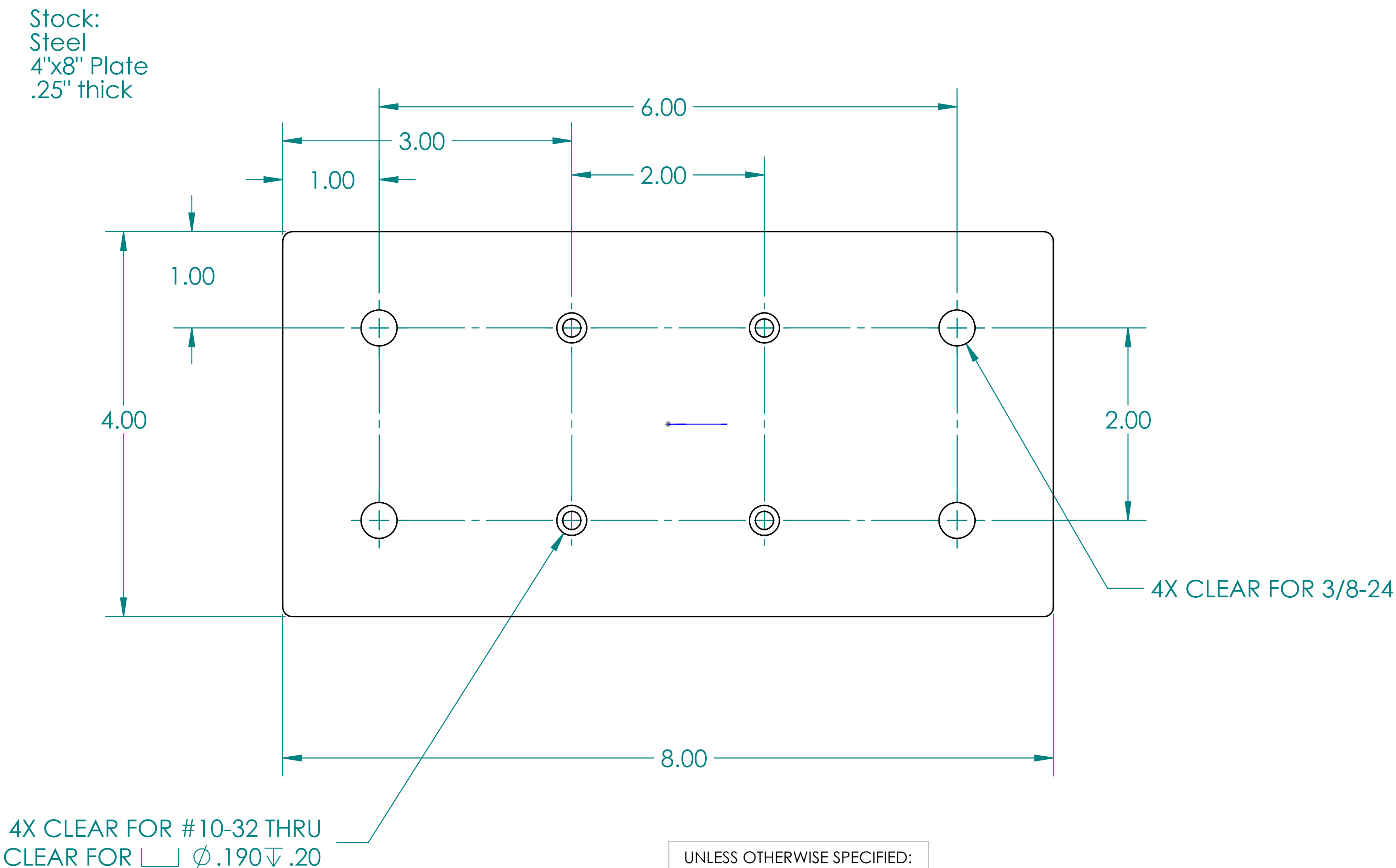
Stock:
Steel
4"x4" Plate
.25" thick

Note: Sand all corners down by at least 9/32" .750



		UNLESS OTHERWISE SPECIFIED:		
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A03-014- JIGPILLARPLATE	REV 00
Drawn By:	KYRA SCHMIDT			
Checked By:	XXXXXX			
Start Date:	1/20/19		SCALE: 1:1 / MATERIAL: STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo



Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/19/19

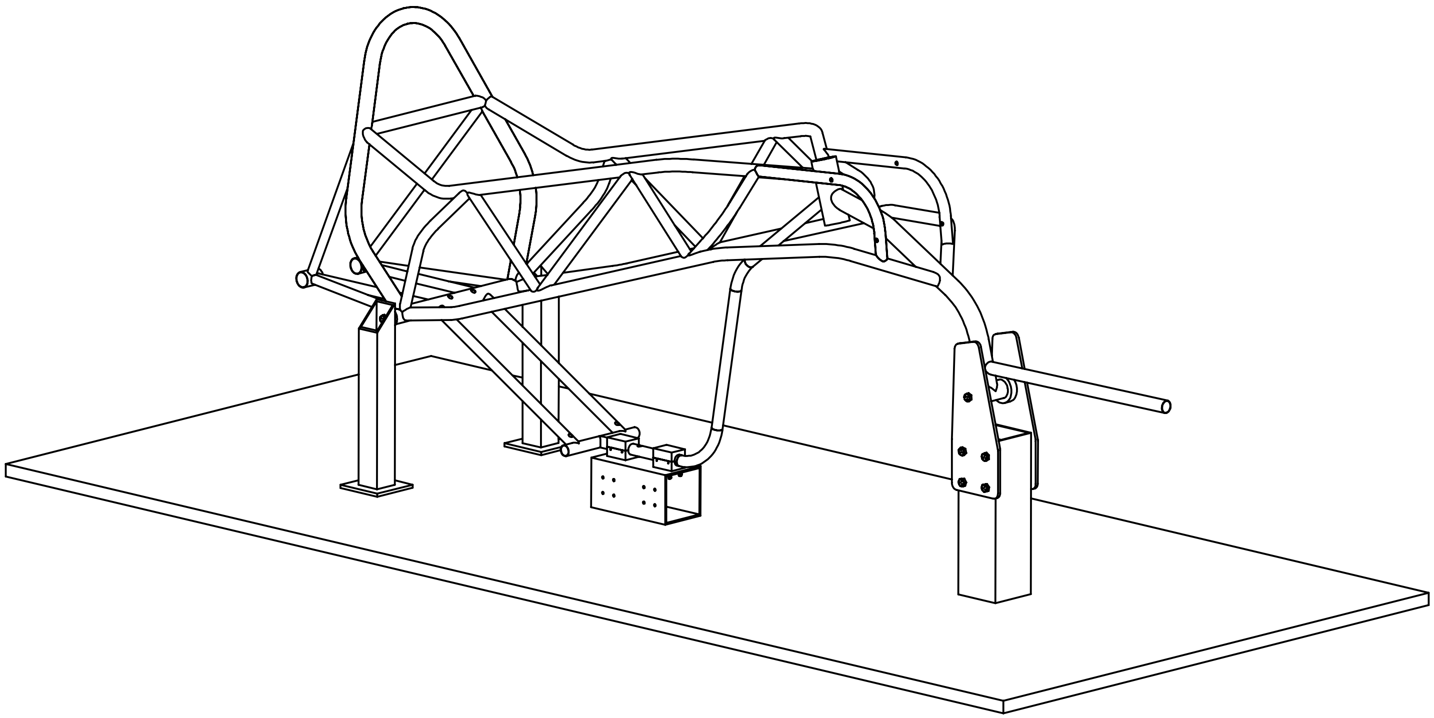
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-016-PILLAR_BASE

REV 00

SCALE: 2:3 | MATERIAL: STEEL | 1 OF 1

Cal Poly Human Powered San Luis Obispo



ITEM NO.	SUB ASSEMBLY	DESCRIPTION
1	TABLE AND FRAME	WELDING TABLE
2	FRONT END	BOTTOM BRACKET SUPPORT
3	REAR END	ROLL HOOP SUPPORT

Cal Poly Human Powered San Luis Obispo

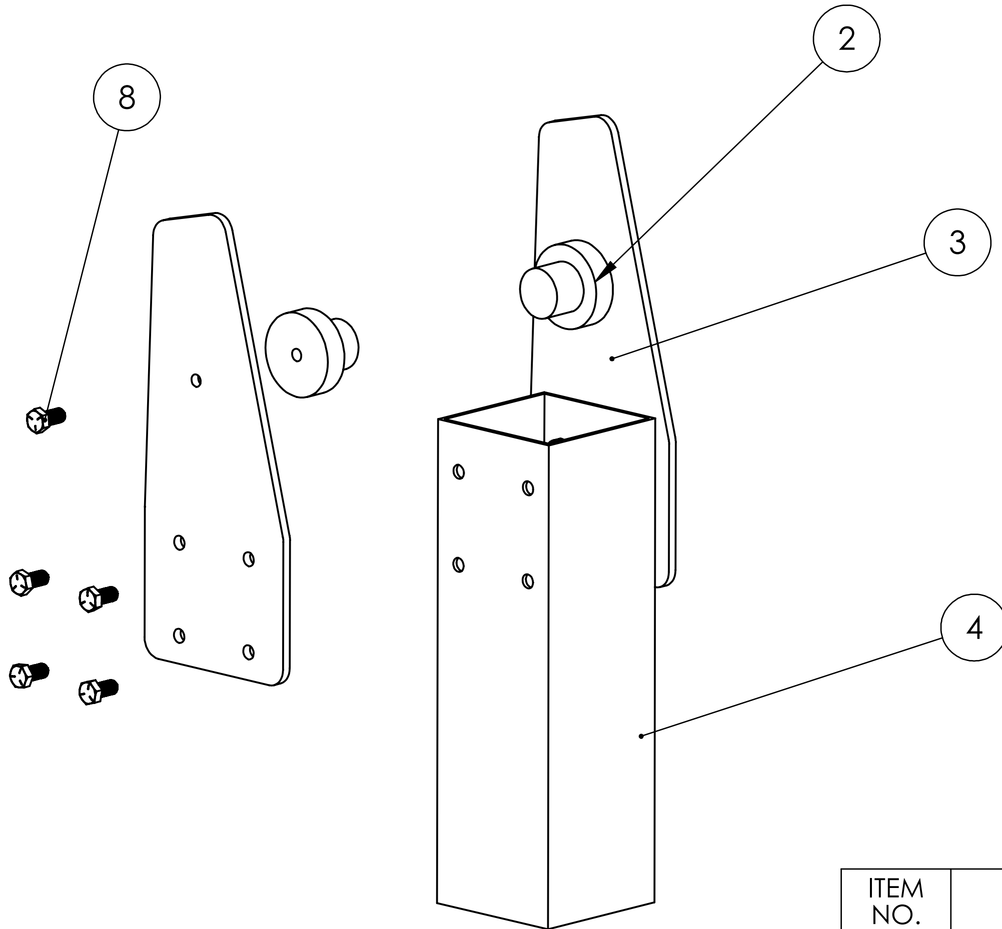
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A04-FRAME_JIG_ASSEMBLY_2ND

REV 00

SCALE: 1:15 | MATERIAL: XXXXXX | 1 OF 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	04-A03-004-BB_PLUG	BOTTOM BRACKET PLUG	2
3	04-A03-003-FRONT_PLATE	BOTTOM BRACKET SUPPORT PLATE	2
4	04-A04-004-BB_SUPPORT	BOTTOM BRACKET SUPPORT	1
8	92865A622	3/8-24 FASTENERS	12

Cal Poly Human Powered San Luis Obispo

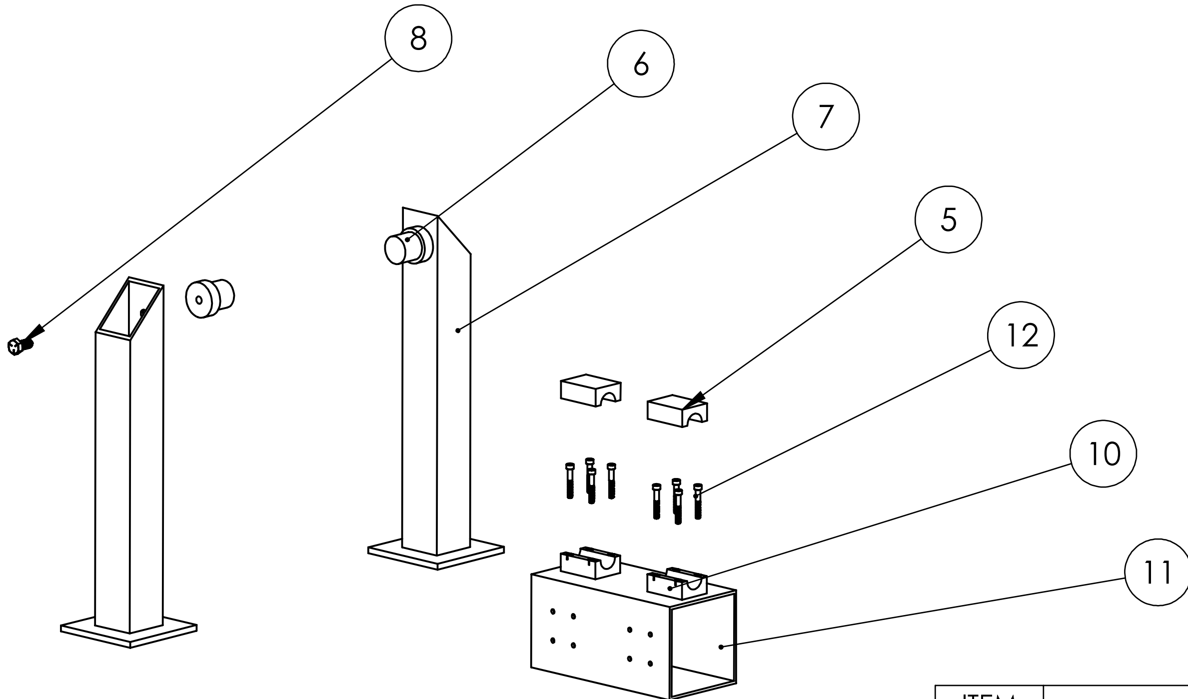
Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A04-FRAME_JIG_ASSEMBLY_2ND

REV 00

SCALE: 1:5 | MATERIAL: XXXXXX | 3 OF 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	04-A04-002-TUBE_BLOCK_0.875	UPPER TUBE BLOCK	2
6	04-A04-005-ROLL BAR PLUG2	ROLL BAR END PLUG	2
7	04-A04-006-ROLL_BAR_POST	ROLL BAR SUPPORT POST	2
8	92865A622	3/8-24 FASTENERS	12
10	04-A03-002-TUBE_BLOCK_.875BOTTOM	LOWER TUBE BLOCK	2
11	04-A04-003-CENTER_SUPPORT	TUBE BLOCK SUPPORT	1
12	90128A948	10-32 FASTENERS	8

Cal Poly Human Powered San Luis Obispo

Drawn By:	AUSTIN HENRY
Checked By:	XXXXXX
Start Date:	1/30/2019

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

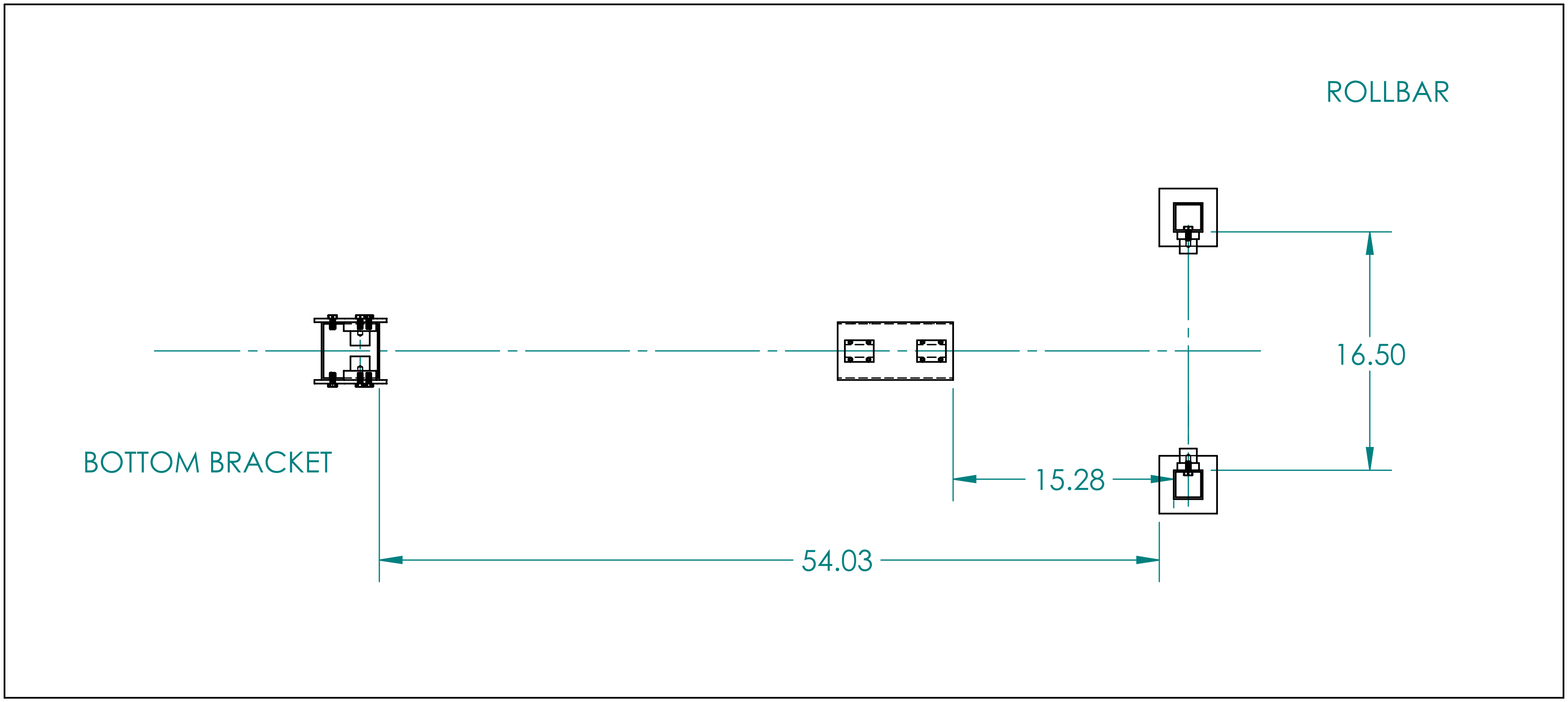
TITLE: 04-A04-FRAME_JIG_ASSEMBLY_2ND

REV 00

SCALE: 1:8 | MATERIAL: XXXXXX | 4 OF 5

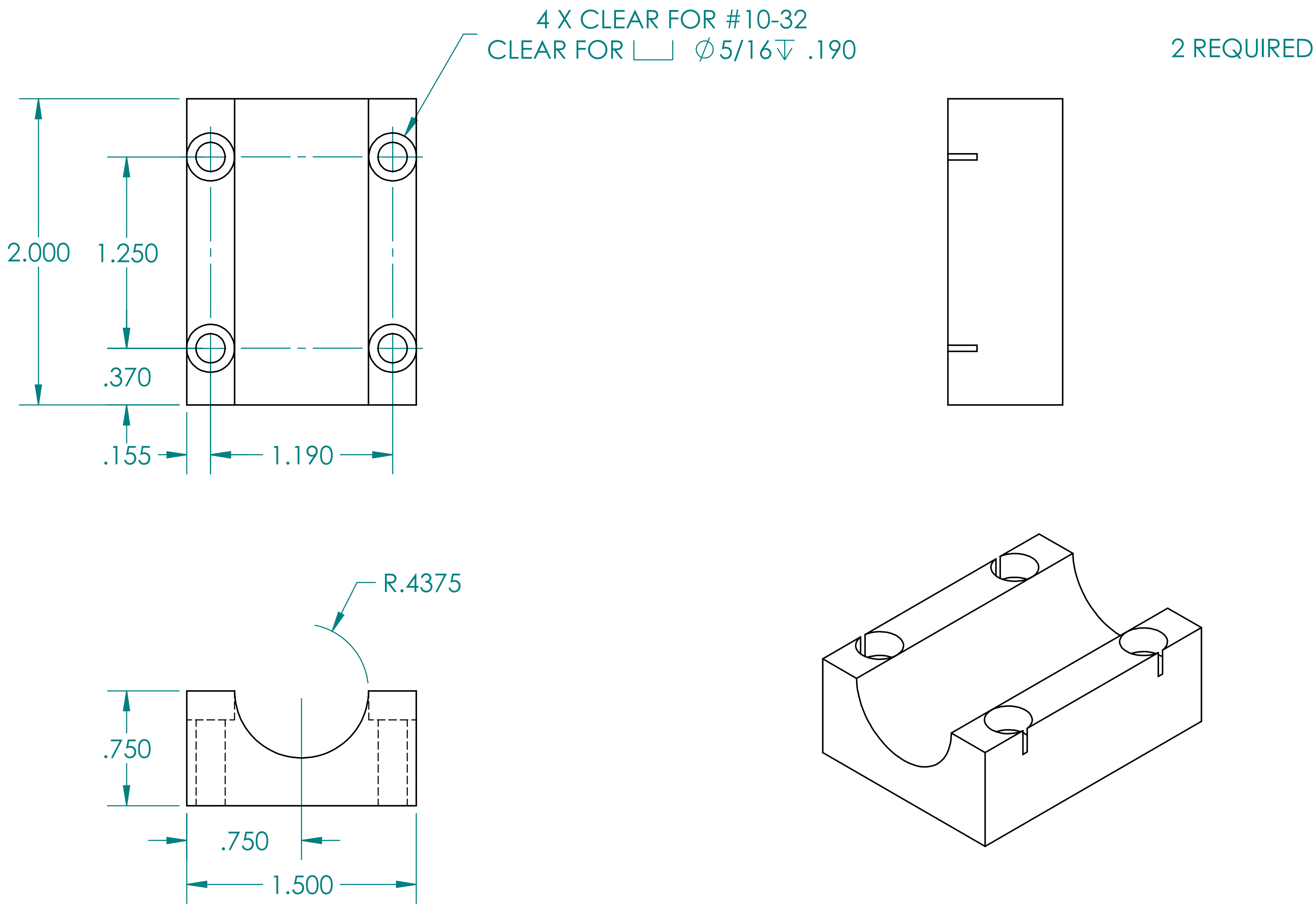
WELDING TABLE LAYOUT

Note: Center Support and Bottom Bracket Support Pillar will be tac'd to table. Roll bar posts will be clamped or tac'd to table. Frame will be elevated sufficiently such that wheels can be fit.



Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A04-FRAME_JIG_ASSEMBLY_2ND	REV 00
Checked By:	XXXXXX		SCALE: 1:12	MATERIAL: n/a
Start Date:	1/30/19			5 OF 5

Cal Poly Human Powered San Luis Obispo



Drawn By:	KEYANNA HENDERSON
Checked By:	KYRA SCHMIDT
Start Date:	1/24/19

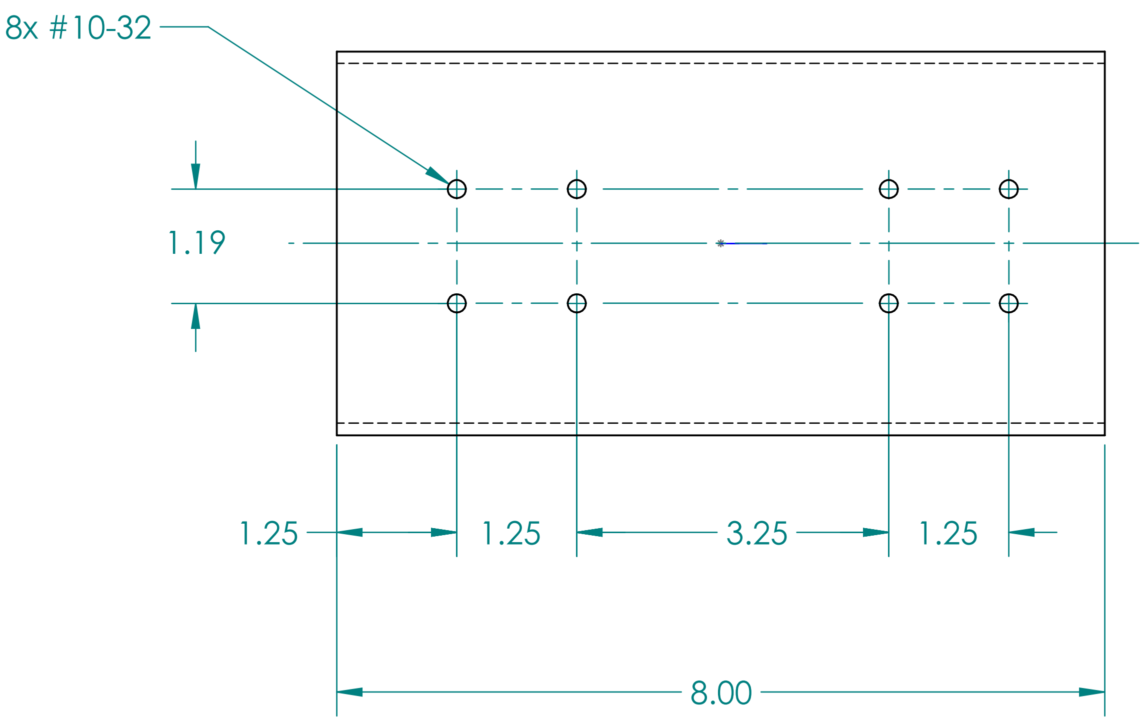
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A03-002-TUBE_BLOCK_.875BOTTOM		REV 00
SCALE: 1:1	MATERIAL: ALUMINUM	1 OF 1

Cal Poly Human Powered San Luis Obispo

Stock:
Steel
4"x4" Square tube
.125" wall

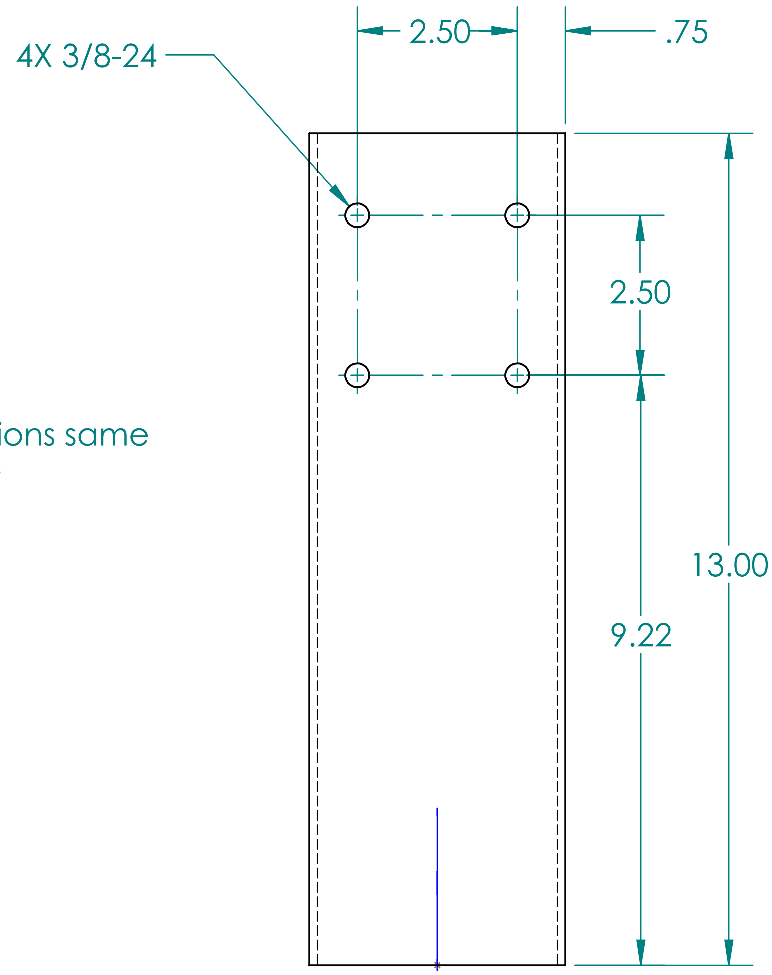


		UNLESS OTHERWISE SPECIFIED:	TITLE:	REV
Drawn By:	KYRA SCHMIDT	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	04-A04-003- CENTER_SUPPORT	00
Checked By:	XXXXXX			
Start Date:	1/30/19		SCALE: 1:2 / MATERIAL: STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo

Stock:
Steel
4"x4" Square tube
.125" wall

NOTE: All hole
dimensions and positions same
for right and left sides



Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/21/19

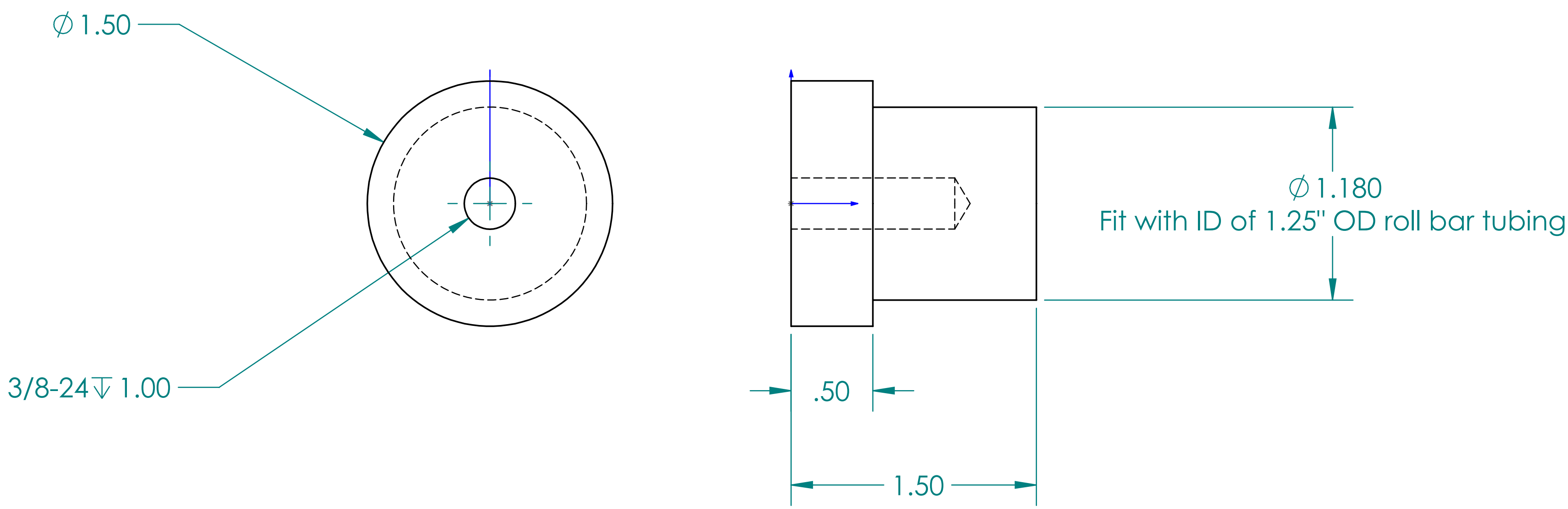
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE:
04-A04-004-BB_SUPPORT

REV
00

SCALE: 1:3
MATERIAL: STEEL
1 OF 1

QUANTITY: 2

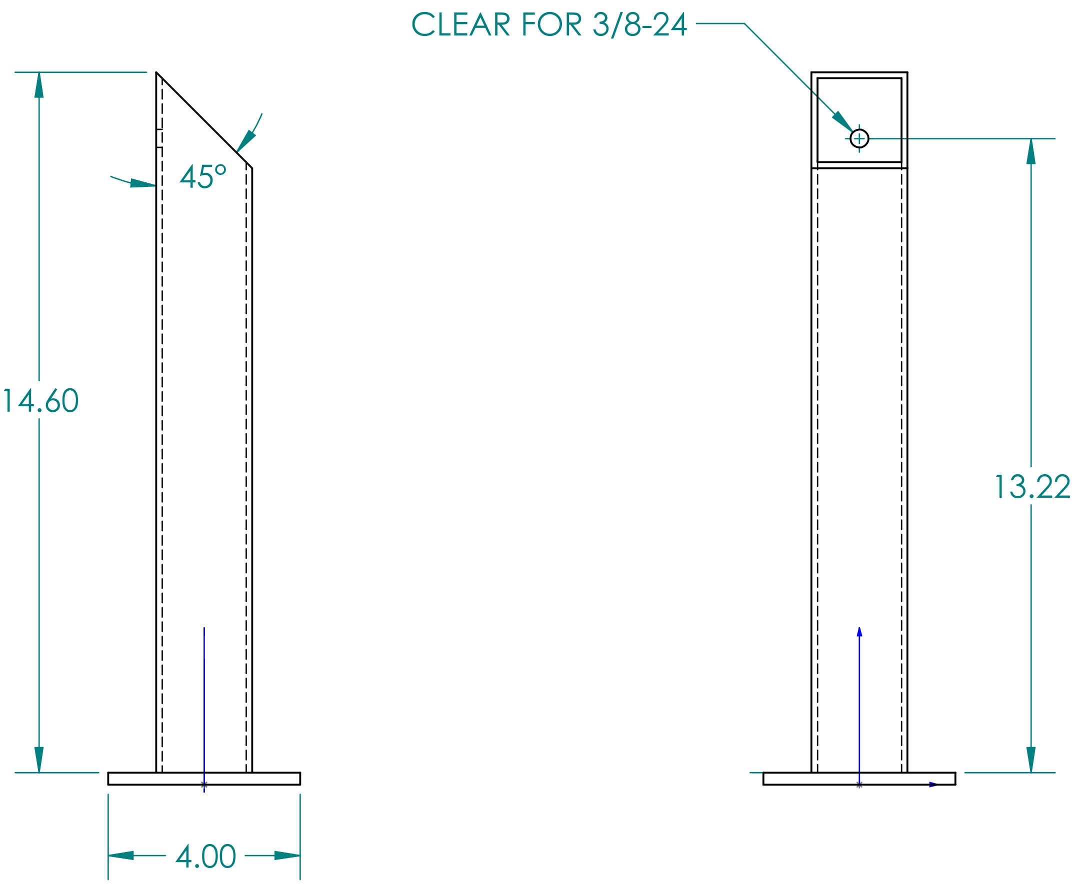


Cal Poly Human Powered San Luis Obispo

Drawn By:	KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A04-005-ROLL BAR PLUG2		REV 00
Checked By:	XXXXXX				
Start Date:	1/30/19		SCALE: 1:1	MATERIAL: 6061 ALUMINUM	1 OF 1

Note: Assembly of 2x2 steel tube and 1/4" steel plate.
Tube will be tac'd to center of plate.

QUANTITY: 2



Drawn By:	KYRA SCHMIDT
Checked By:	XXXXXX
Start Date:	1/30/19

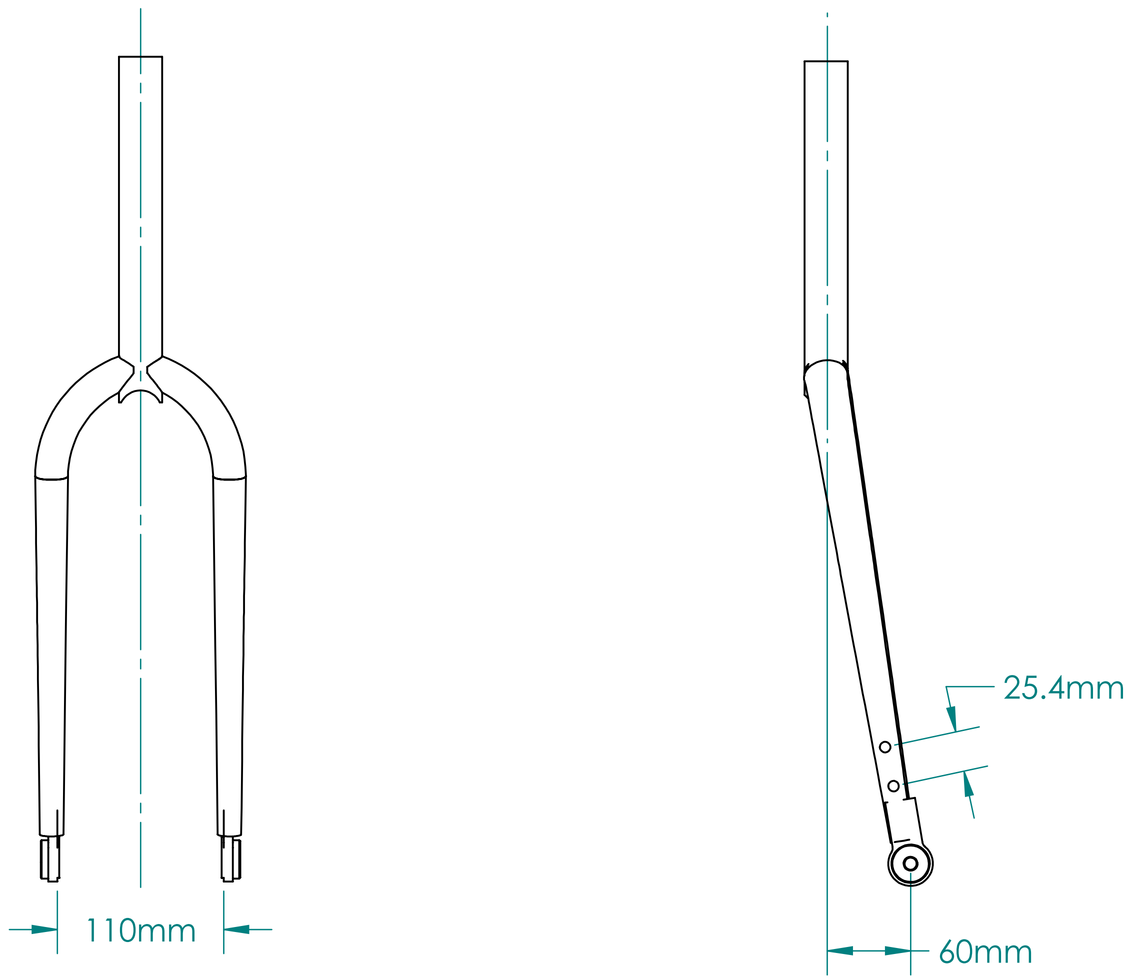
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A04-006-ROLL_BAR_POST		REV 00
SCALE: 1:4	MATERIAL: STEEL	1 OF 1

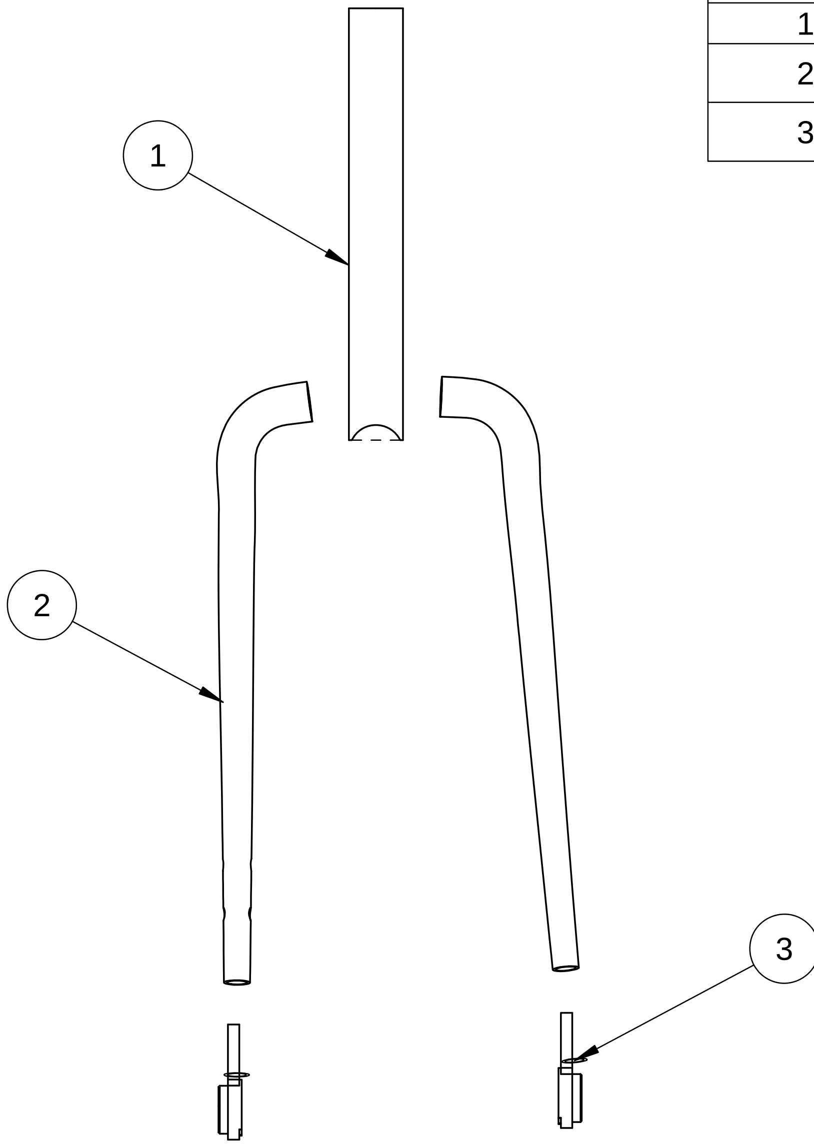
Cal Poly Human Powered San Luis Obispo

HEADTUBE ANGLE:
73° off horizontal



Drawn By:	KYRA SCHMIDT	TITLE: 04-A02-001-FORKASSEMBLY	REV 00			
Start Date:	1/1/19			SCALE: 1:5	MATERIAL: 4130 Steel	1 OF 1

Cal Poly Human Powered San Luis Obispo



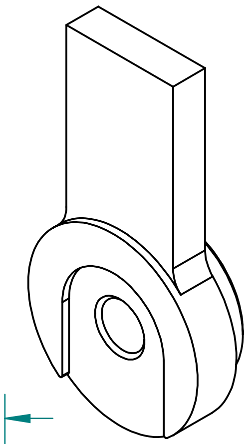
ITEM NO.	PART NUMBER	QTY.
1	04-A02-004-STEERTUBE	1
2	04-A02-002-FORKBLADE	3
3	04-A02-003-FRONTDROPOUTS	2

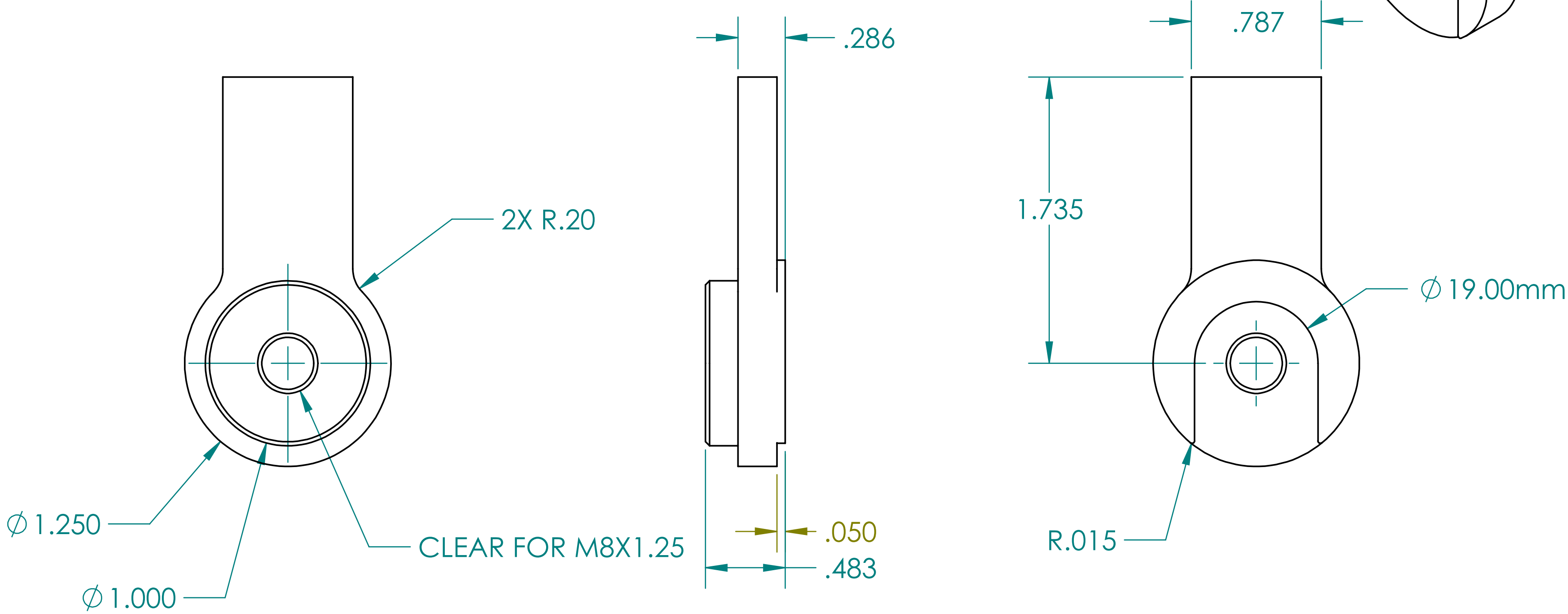
Cal Poly Human Powered San Luis Obispo

Drawn By:	KEYANNA HENDERSON	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A02-001-NEWFORKASSEMBLY	REV 00
Checked By:	XXXXXX		SCALE: 1:4	MATERIAL: 4130 STEEL
Start Date:	1/31/19			1 OF 1

NOTE:
ALL METRIC DIMENSIONS DESIGNATED WITH "mm".
ALL METRIC TOLERANCES ARE AS FOLLOWS UNLESS OTHERWISE SPECIFIED:
XX.XX ± 0.10
XX.X ± 1

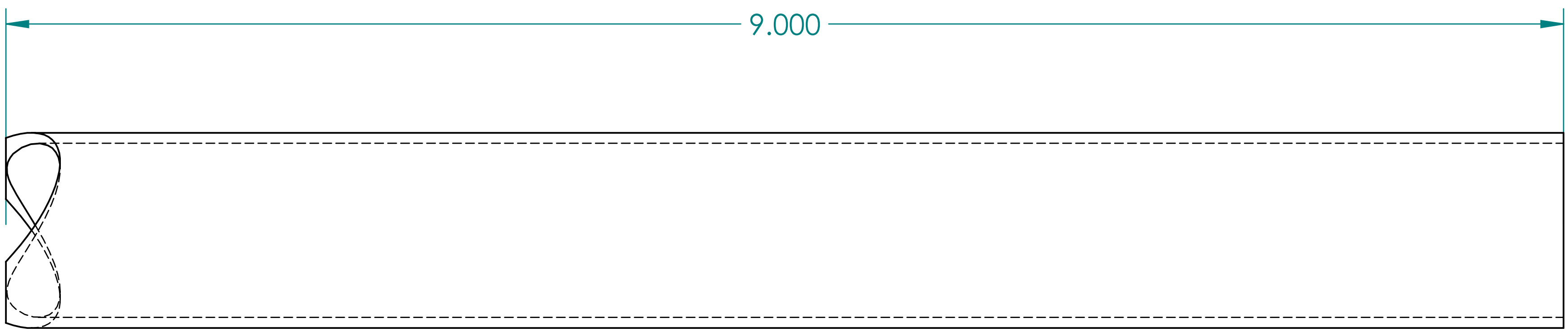
2 REQUIRED





Cal Poly Human Powered San Luis Obispo	Drawn By: KYRA SCHMIDT	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A02-003-FRONTDROPOUTS	REV 00
	Start Date: 12/31/18		SCALE: 1:1 / MATERIAL: 4130 Steel	1 OF 1

Stock:
4130 Steel
1.126" OD
.061" wall



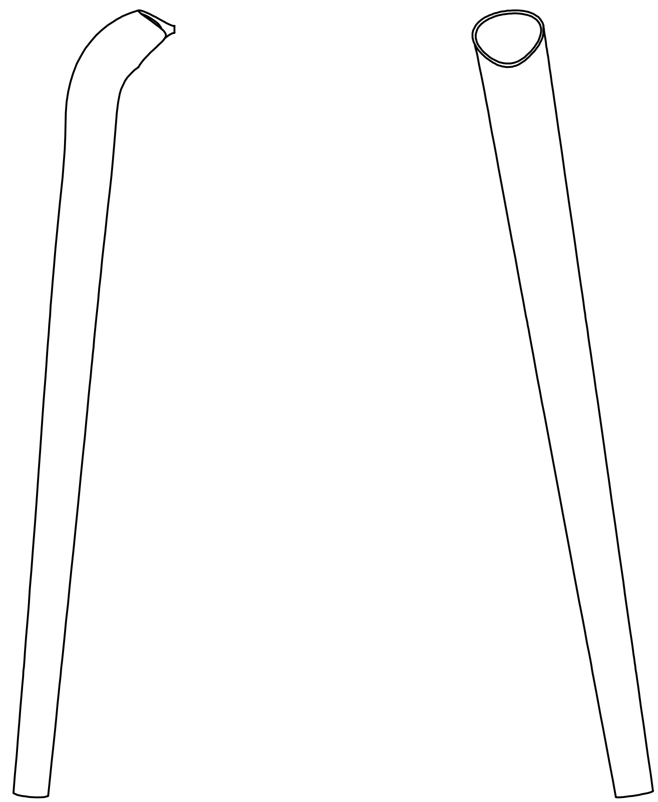
Cal Poly
Human Powered
San Luis Obispo

Drawn By:	KEYANNA HENDERSON	UNLESS OTHERWISE SPECIFIED:	TITLE: 04-A02-004-STEERTUBE	REV 00
Checked By:	XXXXXX	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	SCALE: 1:1 — MATERIAL: 4130 STEEL	1 OF 1
Start Date:	1/31/19			

NOTE:
Blade is 12.46" in length
Final dimensions determined by chain tensioner

Blades sourced from NOVA Cycles Supply:
NOVA CRMO 25MM ROAD UNICROWN CX
Retro FORKBLADES

Miters not shown



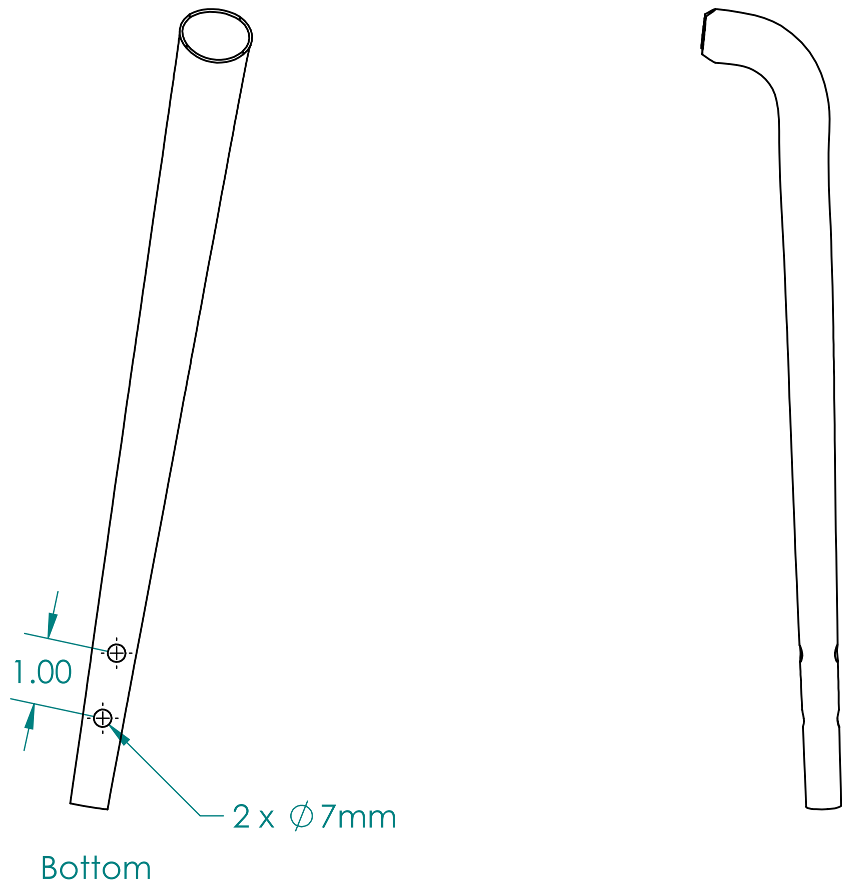
Cal Poly Human Powered San Luis Obispo

Drawn By:	KEYANNA HENDERSON	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ±1/8 ANGULAR: BEND ±2° TWO PLACE DECIMAL: ±0.05 THREE PLACE DECIMAL: ±0.005 TOLERANCING PER: MMC	TITLE: 04-A02-006-FORKBLADERight	REV 00
Checked By:	KYRA SCHMIDT		SCALE: 1:3	MATERIAL: 4130 STEEL
Start Date:	1/31/19			1 OF 1

NOTE:
Blade is 12.46" in length
Bottom hole is roughly 1.38" from bottom face
Final dimensions determined by chain tensioner

Blades sourced from NOVA Cycles Supply:
NOVA CRMO 25MM ROAD UNICROWN CX
Retro FORKBLADES

Miters not shown



Drawn By:	KEYANNA HENDERSON
Checked By:	KYRA SCHMIDT
Start Date:	1/31/19

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/8
ANGULAR: BEND ±2°
TWO PLACE DECIMAL: ±0.05
THREE PLACE DECIMAL: ±0.005
TOLERANCING PER: MMC

TITLE: 04-A02-007-FORKBLADELeft		REV 00
SCALE: 1:3	MATERIAL: 4130 STEEL	1 OF 1

Cal Poly Human Powered San Luis Obispo