TEAM JOSEPH’S BIKE TRAILER

Final Design Review

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SPONSOR: MICHAEL LARA

Keely Thompson
kthomp25@calpoly.edu
Curtis Wathne
cwathne@calpoly.edu
Ryan Meinhardt
rmeinhar@calpoly.edu
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Abstract

This final design report shows the results of this senior project’s design process of creating a custom bike trailer for Team Joseph. As done in the Scope of Work, Preliminary Design report, and Critical Design report, current products, relevant technologies, and American Society for Testing and Materials (ASTM) standards are fully researched and benchmarked to aid in the design selection process. Customer requirements are looked at and developed into engineering specifications. A detailed design was created for CDR to show to Team Joseph, and manufacturing and testing plans were laid out. This final design report adds the final design revisions made to the trailer, details from the manufacturing process, and testing results.
Joseph is a 23-year-old man with a form of Cerebral Palsy known as spastic quadriplegia. Cerebral palsy is the result of brain damage while a child’s brain is under development. It affects muscle and motor control; spastic quadriplegia is a severe form where limited muscle function causes all four limbs of the person to be very stiff. The stiffness is caused by muscles being constantly engaged [1]. Joseph is consistent with the condition and is also nonverbal, unable to walk, and has an intellectual impairment. He is five feet tall and about 75 pounds. Despite his size, Joseph is quite strong, especially with his legs. His right femur has displaced from the hip socket, causing the joint to be very sensitive. Due to his hip dysplasia, his right leg is also about two inches shorter than his left leg. Despite his conditions, Joseph is happiest and most comfortable with motion and the wind in his face. He participates in triathlon events in which he rides in a trailer during the bike leg of the race.

Team Joseph is a dedicated group of individuals that make it possible for Joseph to participate in triathlons. The team is led by his father, John, and includes members of both the community and the San Luis Obispo chapter of Special Olympics Southern California.

This senior project team consists of three fourth year mechanical engineering students; Keely Thompson, Curtis Wathne, and Ryan Meinhardt. Ms. Thompson will be managing the seat and harness. Mr. Wathne will manage the attachment and rotation mechanisms. Mr. Meinhardt will handle the frame and structural analysis.

The goal of this project is to replace his current trailer. Despite being made for people with special needs, it is worn out and lacks a seat that sufficiently meets his physical and safety requirements. This project is to design, manufacture, and test a purpose-built bicycle trailer for Joseph and Team Joseph. Specifically, Joseph needs extra padding around his right hip and femur due to his dislocated hip as well as extra support for his head and neck due to poor neck control.
2 Background

This section details the results from meeting with Team Joseph, a review of currently existing bike trailers, relevant bike trailer technology, and industry standards for bike trailers. Current trailers were benchmarked in order to get an idea of standard frame styles, weights, materials, and other features. Technologies were analyzed to see what companies do with regards to braking, attaching, and incorporating safety features. Applicable industry standards are given to show the testing requirements our trailer will have to pass to be deemed acceptable. No further background research was completed since CDR (February 2018).

2.1 Sponsor Interviews

To further develop an understanding of the needs the bike trailer needs to fulfill, interviews were conducted with members of Team Joseph, including the project sponsor Michael Lara, Joseph’s dad John Cornelius, Team Joseph Member Jeff Cenoz, and Joseph Cornelius himself. The team brought Joseph’s jogger with them to highlight the successes and things to improve from that project. From the meeting, it was determined that they do not believe their current Wike Bike trailer is sufficient for Joseph due to the lack of cushioning and roll-over protection system. The trailer also handles poorly causing the cyclist to feel as if the trailer is surging back and forth.

It was determined that their first and foremost concern for a new bike trailer is safety. This includes keeping Joseph comfortable during riding and protected in the unfortunate event of a crash. This requires an effective seat and harness to keep him in place as well as a robust frame with a roll-over protection system. While they use this trailer for racing triathlons, they emphasized that they are not concerned nearly as much about speed and performance. The full set of notes from the customer interview can be seen in Appendix A.

2.2 Existing Products

This section reviews various types of bike trailers. Trailers were chosen to highlight as many relevant aspects of bike trailers as possible. Some of them are not designed to carry people or even attach to bikes. However, they highlight other aspects that we will implement into our trailer, such as seats specifically for Joseph or unique attachment mechanisms.
Pros:
- Seat customization
- Weather protection
- Collapsible
- Lightweight
- Carries larger passengers
- Easy attachment to bike

Cons:
- Not robust
- Normal (current) seat not made for Joseph
- No braking mechanism
- Insufficient crash safety features

Figure 2.2.1. Wike Bike Trailer
This trailer has been specifically designed for riders with special needs. Specifically, it allows for larger riders (up to 125lbs and 64in tall). The seat is removable and Wike will input a car seat if the user is more comfortable with that. The full weather protection system is retractable which allows for easy loading and unloading. It is also collapsible allowing for easy transport. It weighs 34lbs and is made out of steel.

Pros:
- Easy attachment with parking brake
- Weather protection
- Adjustable suspension
- Lightweight and large payload

Cons:
- High CG (designed to go off road)
- Seats are inadequate for Joseph

Figure 2.2.2. Burley Cub Trailer
The Burley Cub bike trailer, a general bike trailer used for transporting children, cargo, or both. Most notably, it has a parking brake, adjustable suspension, weather protection, and an elastic attachment mechanism that allows the bike to fall without the trailer tipping. It is also relatively lightweight for its robust design, coming in at 37lbs. It is made out of 6061 Aluminum.
Figure 2.2.3. BOB Ibex Trailer
A trailer designed specifically for all terrain cargo hauling. It requires a custom quick release that mounts the trailer on both sides of the rear triangle of the bike. It also utilizes a single wheel meaning it rotates with the bike during turning. Certain models have a suspension mechanism that allows the trailer to go on offroad trails. It is made out of 4130 chromoly steel.

Pros:
- Attaches to both sides of bike
- Possible suspension
- Relatively high carrying capacity for size

Cons:
- Single rear wheel
- Not made for carrying people

Figure 2.2.4. Joseph’s Jogger
The jogger currently used by Team Joseph. It has a well-designed seat that gives the necessary support for Joseph, specifically his hips and head as well as a strong foot platform that he can push against. The seat will need more padding to deal with the increased bumps associated with biking. It also lacks any sort of weather protection. Since it is a jogger, it has a third wheel with a disk brake and adjustable handlebars for the runner. The frame, made out of 4130 chromoly steel is overbuilt leading to a weight of over 45lbs [2].

2.3 Existing Technologies

This section highlights relevant bike trailer technology. The issues we focused on analyzing were the attachment and decoupling mechanism, braking, and harness/restraints as these issues already have technology we can draw from in designing our trailer. We investigated technologies from both currently available bike trailers as well as other products that incorporate these features.
(a) Nylon strap leashes are a common feature on low end trailers. While they will keep the stroller from rolling away, they apply no braking force.

(b) This linkage parking brake design is common on all levels of bike trailers as it is very simple to construct and use. It is very similar to the braking mechanisms used on wheelchairs or caster wheels.

(c) Hub engaged parking brakes are only available on high end bike trailers. They often feature a foot lever that allows for easy engagement. It is also the most robust braking mechanism; however, it is a more complicated construction design.

(d) Surge brakes are commonly incorporated on trucking rigs to help brake the trailer during long descents. They automatically engage the brakes on the trailer when the velocity of the trailer is greater than the velocity of the towing vehicle.
(a) This harness is specifically designed for passengers with special needs. It has two padded layers that overlap making it highly adjustable and comfortable for passengers of all sizes.

(b) This harness is simple in design and adjustable. Though it lacks comfort padding, it would serve Joseph well because it would not obstruct his feeding tube in the middle of his abdomen.

(c) This harness is simple in design but lacks comfort. Its centralized torso harness may interfere with Joseph’s feeding tube, however it has great adjustability and crotch support.

(d) While this is not a harness, this personal floatation device’s geometry could provide great support for the whole torso. Its open design would not interfere with Joseph’s feeding tube. It is also heavily padded.
Figure 2.3.3. Bike Decoupling Mechanisms

(a) This wheel bearing system would not be practical for the wheels of the trailer, however its design with the hub, bearings, and upright/axle could be used to create a rotational joint. This would allow the trailer to remain on two wheels and the bike lean left or right. Built for dynamic loads of vehicles, this system can handle radial and axial loads.

(b) The BOB trailer forks attach to both sides of the quick release, thus reducing the torque applied to the quick release and frame of the bike. However, due to the dual sided attachment, this design requires a custom, longer quick release. Sold individually, these items could be the link between the bikes of Team Joseph and Joseph’s trailer and would make replaceable parts easily available.

(c) Burley trailers use a Flex Connector which is an elastomeric connection that completes the joint between the bike and trailer. The elastic properties of the flex connector allow for the bike to rotate 180 degrees (as if it were falling) without the trailer tipping. This is useful in the event of a crash as the rider in the trailer should stay upright. It needs to be replaced every 3-5 years due to fatigue stresses.
Figure 2.3.4. Attachment Mechanisms

(a) Dual sided attachment mechanisms, such as the BOB trailer forks, require a custom quick release axle. The trailer has dropouts that sit over the extended shoulders of the quick release.

(b) Burley’s Travoy seatpost attachment is a 2 piece clamping mechanism allows the mechanism to attach to seatposts of different diameters. There is a vertical axis of rotation that allows the bike to turn easily. The design also utilizes Burley’s Flex Connector (see Figure 3.3.3.c) that allows for yaw in the case of the bike tipping over.

(c) The most common trailer attachment mechanism incorporates a bracket that allows the bike’s standard quick release axle to screw on over the top of it. The trailer is attached through the vertically aligned holes, allowing for left and right rotation during turning.

2.4 Industry Standards

There are currently two documents that deal with the safety and testing of bike trailers. ASTM F1975-15 [3] details the safety testing for trailers attached at the rear axle, including a drop and tip over test. ASTM F2917-12 [4] has similar procedures for trailers that are attached via the seat post of the bike.
3 Objectives

The objectives section details the scope of the project, starting with what Joseph and Team Joseph need and want in a bike trailer. These are transformed into engineering specifications to benchmark the success of our trailer design. The scope of the project is analyzed to determine what elements of the project we can control. The only changes since CDR have been to the specifications table in section 3.5.

3.1 Problem Statement

Joseph is a young man with Cerebral Palsy who loves participating in triathlon events. In the cycling event, he is towed in a bike trailer tailored to riders with special needs. However, his trailer is worn out and lacking desired safety features. Joseph and his team need a purpose-built bike trailer that allows him and his team to safely and easily participate in bike rides. The trailer should protect Joseph in the event of a crash, provide weather protection, and accommodate his physical needs for a comfortable ride.

3.2 Boundary Diagram

The boundary diagram begins with a diagram of the bike, trailer, and riding surface. Elements within the blue dashed line are elements that we can control in this project – namely, this is the trailer, seat, and any attachment mechanisms. Elements touching the dashed line will have a heavy influence on the design of the trailer but cannot be controlled by us; for the trailer these are the bike and the riding surface. Any elements outside the line may have an effect on the trailer but are not considered within the scope of this project.

Figure 3.2.1. Boundary Diagram for Team Joseph’s Bike Trailer.
3.3 Customer Requirements and Wants

As previously discussed and shown in Attachment A, the team met with Team Joseph to determine what they require out of the bike trailer as well as what would be nice if it were included.

Customer Requirements:
1. Support and align Joseph’s body (especially his hips and neck)
2. Have a robust rollover protection system
3. Include a harness that comfortably restrains Joseph in the event of a crash
4. Make the ride for Joseph as smooth as possible (minimize bumps)
5. Be versatile between all bikes used
6. No reachable pinch points
7. Be easily transportable in the bed of a truck
8. Be weatherproof and protect Joseph from sun and rain

Customer Wants:
1. Set up and loading possible with only one person
2. Keep the trailer upright even in the case of a bike crash
3. Be able to easily repair flat tires and do routine maintenance
4. Match Team Joseph’s colors
5. Have a quick attachment mechanism
6. Minimize play in attachment mechanism
7. Be lightweight for easy riding

3.4 Quality Function Deployment

We used a Quality Function Deployment (QFD) (Appendix B) to determine the importance of customer requirements and the corresponding engineering specifications. The table compares each customer desire/requirement to an engineering measurement with a correlation rating. The correlation ratings are 9:strong, 3:moderate, 1:light, and blank for no correlation. These correlations are multiplied by the importance of the requirement to Team Joseph (ranked on a scale from 1-5) and used to determine how important each measurement is. For example, a requirement from Team Joseph is that the trailer needs to be sturdy and safe in the event of a crash. A measurement that is strongly correlated to this is the factor of safety on the frame, so the rating is a 9. This was then multiplied by an importance factor of 5, as safety is of high importance to Team Joseph. This study showed that our most important measures were safety elements – factors of safety on the frame and the stability of the bike under turning, while our least important measures dealt with the overall size of the trailer.

There were certain customer requirements that did not go into the QFD. These were requirements that had pass/fail criteria – such as having a seat that fit Joseph correctly or the ability to mount to Team Joseph’s bikes. While these are critically important to designing a successful trailer, a trailer design that does not achieve these requirements were not considered in the ideation process and cannot be ranked against other ideas.
### 3.5 Engineering Specifications

#### Table 3.5.1. Engineering Specifications

<table>
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<th>Spec #</th>
<th>Specification Description</th>
<th>Target</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
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<tr>
<td>1</td>
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<td>500lbs</td>
<td>Min</td>
<td>L</td>
<td>A,T</td>
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<tr>
<td>2</td>
<td>Frame Factor of Safety</td>
<td>2</td>
<td>Min</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>Stability</td>
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<td>Min</td>
<td>M</td>
<td>A,T</td>
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<td>4</td>
<td>Bike decoupling</td>
<td>180deg</td>
<td>Min</td>
<td>M</td>
<td>T,S</td>
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<td>5</td>
<td>Pinch points</td>
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<td>Max</td>
<td>L</td>
<td>I</td>
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<td>6</td>
<td>Quick attachment</td>
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<td>Max</td>
<td>L</td>
<td>T</td>
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<td>7</td>
<td>No play in attachment</td>
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<td>45”</td>
<td>Max</td>
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<td>I</td>
</tr>
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</table>

A = Analysis  
T = Test  
I = Inspection  
S = Similarity between other projects

Since CDR, 4 specifications have changed. Due to budget and time concerns with upholstery, the rain cover is not being made, so specification 12 is not being tested. Specifications 13, 14, and 15 have been updated to match better measurements made of the transportation vehicles.

The only high-risk spec we have is the weight requirement. Team Joseph have said they do not care much about the weight of the trailer, yet we believe that we need to keep the trailer as light as possible in order to keep riding feasible. The trailers we researched all came in under 40lbs, which is the goal we have set. However, the seat for Joseph to will be much heavier than the seats currently available in trailers due to Joseph’s needs. Due to this, we put extra effort into designing a frame and attachment mechanism that are as lightweight as possible in order to offset the weight of the seat.

Specifications were tested using a variety of approaches. Restraint force was ensured by selecting a harness with the correct rating as well as modeling the harness-frame attachment in FEA and ensuring the frame and attachment points do not fail. Frame static and fatigue factor of safeties were determined in the design phase before manufacturing the trailer. Stability was initially determined analytically with the location of the center of mass and the geometry of the trailer (with a rider in it); it was an iterative process to ensure the final design does not roll. Testing was performed similar to ASTM F2917-12 standards, on a 45-degree incline. The bike decoupling was based mainly of existing products; its design ensures that the bike can rotate and pivot free of the trailer. Physical testing was done to show that the bike can rotate freely of the trailer. Pinch points were determined with a rider in the trailer; the rider used every degree of motion possible in attempt to locate one. Attaching the trailer to a bike was timed multiple times. Play in the trailer (forwards/backwards motion) was measured with a dial indicator rigidly attached to the trailer and touching the rear bike wheel; with the bicycle stationary, the trailer was pushed towards and pulled away from the bike in order to read the movement. Weighing the complete trailer was done with a hanging scale. Removing a wheel was timed multiple times to ensure any one can remove the wheel. The
degree of sun protection was determined using a light source lined up horizontally with a participant’s eyes to ensure a setting sun will not shine in Joseph’s eyes. If the rain resistance was installed on the trailer, it would have been tested as per water ingress test IPX4 [5]. Dimensions of the trailer were measured using traditional tools.
4 Concept Design Development

This section details the design development and selection stage of the design process. This begins with the ideation processes and results, then idea refinement, and finally the Pugh and decision matrices that were used to select the top designs. Prototyping of the best ideas and CAD modeling of the top concepts are shown to highlight the designs that will be analyzed moving forward. These were the concept designs used for PDR in November 2017 and no new concept development has occurred since then. Final designs beginning in section 5 used these as a starting point for analysis and testing.

The main concepts analyzed in this section are the bike to trailer attachment, seat attachment, harness, and braking mechanism as these are the areas our team will have to design and analyze. For these, there are ideation/brainstorming results, Pugh matrices, and decision matrices. Other areas of the trailer, namely the frame, weather protection system, and seat are also analyzed, however not in the same depth as they have to be designed specifically around the other elements of the trailer (the case for the frame and weather protection system) or the design is being taken from another product (in the case of the seat, which is primarily being taken from Joseph’s jogger).

4.1 Concept Selection and Results

After the ideation/brainstorming process, the most feasible ideas were chosen to be analyzed as potential solutions for the bike trailer. These feasible ideas were then placed in Pugh matrices to be compared to a benchmark product, in our case, this was the trailer Team Joseph uses currently. Ideas that did not score well in this analysis and were deemed either unfeasible or insufficient were discarded. The remaining ideas were placed in weighted decision matrices to determine the best concepts. Weight factors (on a scale of 1 [low importance] to 5 [high importance]) were determined based on Team Joseph’s requirements (namely safety) and feasibility for our team (able to analyze the design and manufacture). Full decision matrices for the attachment mechanism, harness, and seat attachment can be seen in Appendix C.

The top idea or ideas from the decision matrices were chosen for further analysis in the future. Ideas that scored very closely led our team to believe that we could not confidently make a decision between several top designs without further engineering analysis or testing. For the attachment mechanism, a Bicycle Bob style fork and a single arm hitch were chosen. For the harness, a restraint vest was chosen, with the attachment style of either clips or Velcro to be decided on. For the seat attachment, the lawn chair style straps with Velcro or an isolated plate were further analyzed.

4.1.1 Attachment Mechanism

The attachment mechanism between the bike and trailer body is a critical part of the overall system. It translates power to the trailer and gives the bicyclist one more degree of freedom than the trailer. One of the requirements for the trailer is that it must not roll (or lean) like the bike pulling it. Both the bike and trailer will be able to yaw (turn) and pitch (adjust to a change in slope). The attachment mechanism must minimize slop in its structure as well; common complaints with “flex connector” style trailers are that the trailer can oscillate back and forth relative to the bike due to the harmonic power delivery of a bike. Four competing designs came out of our ideation process.
Design 1: Trailer Fork
This design makes use of a trailer fork similar to the trailer forks on Bob Gear Yak and Ibex trailers. It attaches to the bike by the Bob Gear quick release, which has rotating surfaces that allow the bike and trailer to pitch relative to each other. Behind the dropout and wheel are the pivots for yaw and roll, respectively.

Design 2: Seat Post Clamp
Numerous trailers on the market utilize a clamp that attaches to the seat post of a bicycle. While this design is strong and it keeps the linkage aligned with the centerline of a bike, it is not as compatible when compared to dropout-style attachments. It also has the possibility of slipping around the seat post.

Design 3: Single Arm Hitch, Pivots Behind Bike Axle
Similar to a trailer fork, this design utilizes one arm that is routed up the non-drive side of the bicycle and attaches through the existing rear axle. The axis for pitch is right next to the rear wheel of the bike as well, which minimizes forces on it when the road changes slope. It utilizes one pin instead of two when compared to the trailer fork but has the possibility to induce more stress on the bike itself.

Design 4: Single Arm Hitch, Pivots at Bike Axle
The difference from Design 3 is that the axis for roll and yaw are right next to the rear axle of the bike. Because of the different location the actual arm connecting the bike to the trailer must curve outward to allow for turning (yaw). This design is also quite complex and compact since all of the degrees of freedom are so close to each other.

Two leading designs came out of the selection process for the attachment mechanism. The two are the trailer fork, similar to the Bob Gear bike trailers, and the single arm linkage. Both designs have three degrees of freedom that do not interfere with the dynamics of maneuvering a bike, which can be seen below in Figure 4.1.1.
Both the trailer fork and single arm linkage allow the bike to lean, turn, and experience a change in slope relative to the trailer. Both attach to the rear axle of a road bike. The trailer fork utilizes a Bob Gear quick release, which is a simple purchase and install on any quick release style bike wheel. The single arm linkage uses the existing quick release, which goes through the attachment system. Pins through each of the trailer fork dropouts will hold the trailer down on the Bob Gear quick release if this design is chosen. One pin, that will double as the axis for pitch (slope changes) will secure the single arm to the hinge on the existing dropout.

4.1.2 Harness

While the harness fit and strength is crucial to Joseph's safety, his comfort in the harness is also critical. The harness will attach to the frame of the trailer to ensure its security in the event of a crash. A padded five-point harness design will be used. After ideation, two harness designs were developed.

Design 1: Padded strapped five-point harness
This design is comprised of padded, adjustable straps that are arranged to avoid Joseph's feeding tube. The straps will connect using a series of buckles. This is the simplest harness design and provides the most adjustability.

Design 2: Padded Velcro vest
This harness design also provides four points of contact to the frame, but gives full contact across Joseph's upper body. The vest wraps and closes using Velcro eliminating any potential pinch points associated with buckles. The vest can either be shortened or have a hole cut into it so that it doesn't rub on Joseph's feeding tube.
4.1.3 Seat Support and Attachment

While the seat ensures that Joseph is comfortable and secure, how the seat is attached to the frame is a non-explicit form of safety and restraint in the event of a crash. Joseph’s current bike trailer makes use of a simple bench seat. Because of this, an assortment of pads and blankets are used to better support Joseph. How the seat attaches to the frame for his new trailer is a possibility to increase comfort and safety. Four leading ideas arose from the ideation process, drawing from a range of sources like stretchers to Joseph’s Jogger.

Design 1: Strap Array
This design follows the design of Joseph’s Jogger and has the style of a strapped lawn chair. A series of fabric belts will be routed between frame members that create the surface for the seat pads to Velcro to. The belts will be secured with metal strap adjusters and Velcro will ensure there are no loose ends. The seat pads themselves will attach to the straps with Velcro contact surfaces.

Design 2: Integrated Hoops in Seat Covers
Since the pads will be custom made, the means of mounting them to a tube frame could be built into their covers. Though this idea is ideal for two parallel tubes, it would be hard to integrate into the trailer with the required seat geometry for Joseph. If one of the pads wore out, it would also be costly to replace due to the custom upholstery work required.

Design 3: Stretcher Style
Similar to a stretcher, this design creates a fabric surface that the seat pads would rest on. It is similar to Design 1 and could be seen as one wide strap creating the support surface. The fabric would wrap around tubes in the frame and secure with Velcro on the underside. Velcro on top of the surface would secure the seat pads.

Design 4: Isolated Bench Seat
This design improves upon the simple design already in use in Joseph’s current trailer. The bench seat is isolated from frame with rubber standoffs, or dampers. This design is similar to that of body mounts used in automobiles and can provide extra means of comfort for Joseph. Like several of the other designs, the seat pads would be secured to the isolated bench seat panels with Velcro.

Of these design ideas, a decision matrix determined the leading concept. The strap array was determined to provide the best in terms of static and dynamic comfort, the ease and strength of attaching the seat, and durability. This concept was also chosen to support and attach the seat in Joseph’s jogger and has been proven to be strong, reliable, and comfortable.
4.1.4 Parking Brake

The parking brake system is what will lock the trailer in place when the bike is not moving or is detached. This will allow for the rider to get off their bike and not worry about it starting to roll away, helping the rider load or unload Joseph easily and by themselves. The current trailer used by Team Joseph does not incorporate any sort of braking mechanism, making the loading and unloading process a difficulty for one person. These ideas were shown to Team Joseph and a decision was made with their input to have a kickstand.

Design 1: Wheelchair brakes
This braking mechanism utilizes brakes commonly found on wheelchairs that use a rod, usually coated in a rubber or rubber-like material that is pressed against the wheel to prevent it from rolling. Each wheel usually locks independently. These brakes could be purchased off the shelf before installing onto the trailer.

Design 2: Hub Lock Mechanism
The hub lock mechanism is a braking system currently used by many bike trailers currently available on the market today. There is generally a single lever and linkage mechanism that pushes a plate outward against the hub causing it to lock. The plate either locks via friction or pushes a pin into a hole in the hub. While these are commonly used in bike trailers, they cannot be purchased separately and therefore must be designed by our team.

Design 3: Kickstand
The kickstand will support the front portion of the trailer and can be flipped down when the trailer needs to be supported and stopped. A rubberized material on the bottom of the kickstand will function as a brake, utilizing friction with the ground.
4.1.5 Seat

The seat design of the trailer is crucial for Joseph's comfort and support. Since the seat of the jogger was highly successful, we simply modified its design for the trailer. No changes were made to angle of Joseph's upper body and hips. The biggest difference between the jogger and trailer seats is that the trailer seat will raise his ankles onto the plane of his hips, effectively straightening Joseph's legs to a gentler bend. This allowed us to lower the entire seat which lowers the CG, thus increasing the stability of the trailer. This change in leg angle also required an angle change on the leg booster to keep his leg tangent with edge of the seat. Changes in the seat can be seen below in Figure 4.1.2. The trailer seat also has more padding under his hips and around his shoulders to support him better at the higher speeds that the trailer will be traveling at. Note this is the seat design for the PDR presentation and has since been iterated. Please see Section 5.1.3 for the final design.

![Figure 4.1.2. The modified seat geometry and angles. The trailer seat is in black, the jogger seat is in blue.](image)

4.1.6 Weather Protection

The weather protection system used on the trailer was designed to follow similar systems used by nearly every covered bike trailer. This would consist of clear, flexible plastic in front of Joseph attached to fabric that is attached to the frame of the trailer. The plastic would allow for Joseph to see out of the trailer while simultaneously being protected from any rain. The fabric would provide a more durable mount to the trailer frame and allow cockpit to ventilate.
4.1.7 Frame

At PDR, the frame had been designed to show the connection and interaction of all the other mechanisms. The basic shape of the trailer was chosen with our intuition to support the loading we expect to see. The design was iterated through FEA to meet the desired factors of safety for normal riding conditions and in the event of a rollover crash. While this conceptual design trailer is overbuilt, it was a sound basis for iterations performed to meet safety factor requirements and reduce the weight of the frame.

4.2 Concept Models and Analysis

Two prototypes were made to analyze the performance of the chosen attachment mechanisms. While in theory the 3 degrees of freedom provided by the attachment mechanisms will allow for full rotation of the bike while the trailer can remain stationary, this does not always hold true in practice. These models were used to validate our speculation.

A scaled trailer fork design was built out of foam core, and included the 3 rotation parts, a bike wheel, and a fixed stand to represent the trailer. The wheel was free to rotate as it would be if it were attached to a bike. Our team was able to rotate the bike wheel a full 180 degrees in terms of leaning, and was able to turn and pitch freely as well. This indicates that the mechanism was able to provide the necessary rotation for Team Joseph. The trailer fork model can be seen below in Figure 4.2.1.

A full scale single arm design was built utilizing PVC for the arm, steel to house the rotation pieces, and bearings to allow for rotation. Model was then connected to a Cannondale CAAD10 road bike. The trailer
end of the attachment arm was held fixed by a team member to simulate the trailer sitting in place. Again, the bike was able to rotate in the 3 directions it needs to rotate in to provide for turning, leaning, and pitching, indicating that the design is feasible in practice.

![Figure 4.2 PVC prototype of single arm design.](image)

### 4.3 Detailed Description of Joseph’s Bike Trailer

Two leading configurations were selected for further development and analysis. The difference between the two are in the dynamic attachment linkage between the trailer and the bike as seen in Figure 4.3.1 below. Both designs allow for the same degrees of freedom and meet the dynamic riding characteristic requirements of Team Joseph. The seat is the modified seat from Joseph’s Jogger, which better supports Joseph’s body. The harness (not shown) is a 5-point harness with two straps over the shoulders, a waist strap (two points), and a strap between the legs that fully restrains Joseph. Like Joseph's jogger, the seat is supported with series of straps that attach directly to the frame and seat through loops on the back of the cushions. The combination of the seat and straps ensures that bumps and road vibrations will be absorbed. The trailer uses 20-inch wheels, the same as Joseph’s Jogger’s wheels. This allows Team Joseph to swap out wheels easily if one of the vehicles gets a flat.
Of the various braking mechanisms that were considered, a simple kickstand with a rubber foot serves Team Joseph and the trailer best. It allows Joseph to be in the trailer while it is not attached and enables one person to attach the trailer to a bike; perfect for John to easily take his son out for a ride. Other design features include a chromoly steel tube construction; this material is the preferred material for steel bikes and tube frames due to its great characteristics in strength, durability, welding and machining. The frame and attachment linkage are powder coated red to match the Team Joseph color theme and to give the trailer a durable finish. The weather protection (not shown) is similar to a tent fly; it will be transparent, allowing Joseph to get a full visual experience when riding. It will protect Joseph from rain and any spray coming off the rear wheel of the bike. The weather protection is removable because Joseph loves the wind in his face when there is no rain.

Since safety is the main priority, this section of the report (done for PDR) and design process has focused on the seat and seat support, harness, frame, brake and attachment mechanism. These features have a direct impact on the safety of Joseph when he is in the trailer. For the layout of the trailer and more detailed diagrams, refer to Appendix D.

4.4 Discussion of Risks and Concerns

While this project was relatively straight forward, there were a few risks and concerns that came up through the preliminary design process with the primary concern being the attachment to the bike. While either attachment mechanism chosen would have been built to the desired factor of safety, we were concerned that the designs would prematurely fatigue the quick release axles on Team Joseph's bikes. To ensure that Team Joseph will receive a bike trailer that does not stress out their bikes, we performed testing of a standard quick release under the loads expected due to each designs. Please see Section 5.2.1 for the test set-up and results that were used to help determine the final choice between the single arm attachment and trailer fork designs.

Due to the nature of the project, there are also inherent risks and hazards that come with Joseph’s Bike Trailer. Three main hazards were brought to light by the Safety Hazard Checklist and Risk Assessment, as seen in Appendix E and F respectively. The first hazard is that there are rotating wheels within close
proximity to Joseph that he could get his hand or arm caught in. To avoid this, wheel fenders fully prevent Joseph from reaching the wheels and spokes when he is secured in the trailer. The second risk is improper use of the trailer. Not every rider has experience riding with a trailer and could ride too aggressively, putting Joseph at risk of injury. To avoid putting Joseph in danger, riders will be encouraged to ride carefully. The trailer was designed to have a low center of gravity and a wide enough track width to right itself after leaning 45°. The final hazard is that of weather exposure. To ensure that the trailer is safe to use in all conditions, rain protection will come as an attachable accessory. Components that are prone to corrosion will be powder coated and users will be encouraged not expose the trailer to corrosive environments (like the beach) or store the trailer wet. This will ensure the trailer will last and can stand up to all types of riding conditions for years to come.

A major challenge for both our team as well as the Joseph’s Jogger team was finding a qualified and reliable upholstery service to make the seat cushions. The Joseph’s Jogger senior project team had a stressful and frustrating ordeal just getting the seat finished in time for the project expo. To avoid the same situation and ensure the seat is done in a timely and professional manner, a new upholstery service was chosen.
5 Final Design

This section details the final design of the bicycle trailer. Section 5.1 describes the overall design and component design of the attachment mechanism, seat, and frame. Sections 5.2 describes the analysis and design developments that lead to the final design for each component. A final drawing package can be seen in Appendix G.

5.1 Functional Description
The final trailer design meets all of Joseph’s physical needs and allows the bike to ride and turn as normal. The three main systems consist of the bike attachment system, the frame, and the seat. The sections below describe each of the main subsystems. The full assembly can be seen below in figure 5.1.1.

5.1.1 Attachment Mechanism
The bike attachment mechanism, called the trailer fork, allows for three degrees of rotation and serves as a sturdy link between the bike and trailer. The trailer fork dropouts rest on a Bob Gear quick release and
is secured down by a pin on the underside of both dropouts. Each bike in Team Joseph's fleet can have a Bob Gear quick release, allowing for a standardized attachment to every bike. The quick release and trailer fork dropouts allow the bike to pitch up and down with changes in the surface slope. Behind the wheel are the roll and turn pivots. These pivots and their locations allow for the lean-to-turn control of a bike while keeping the trailer upright. The trailer fork design can be seen below in Figure 5.1.2. Please see Section 5.2.1 for a detailed description of the analysis and testing used to develop the final design.

Figure 5.1.2. The trailer fork assembly. Bob Gear Quick release not shown.

5.1.2 Frame

The frame makes up the structural portion of the trailer as well as defining the geometry for Joseph’s body. It includes a roll bar and other support that provide protection for Joseph in the event of a crash or rollover. It also has sturdy footrest consisting of support tubes and a carbon fiber sandwich plate that will support the foam portion of the footrest that Joseph pushes on. The tubing around the plate also is utilized as the mounting location for the trailer fork. Custom 20in thru axle wheels mount onto the hubs that protrude from the frame via stub axles and are locked in with a pin. Support tubes are included to help deal with the forces associated with hitting bumps in the road. Fenders mount to the frame to prevent Joseph from getting his hand caught in the spokes or in the wheel while riding. They will also help to prevent water from being thrown forward by the tire while riding in the rain. The frame with fenders and footplate can be seen in Figure 5.1.3. Please see Section 5.2.2 for a detailed description of the finite element analysis used to develop the final design as well as design updates since CDR.
5.1.3 Seat

The seat provides the comfort and support that Joseph needs. As described in Section 4.1.5 the seat design is very similar to that of the jogger. It maintains the same hip angle and general dimensions, but it extends his legs to allow for a lower trailer CG to improve the safety of the design. The depth of the headrest was increased to allow Joseph to wear a helmet while he is riding in the trailer. The thickness and firmness of all of the cushions were increased to help dampen bumps when travelling at a higher speed. Please see Section 5.2.3 for a detailed description of the research and testing used to develop the final design as well as updates since CDR.
5.2 Analysis & Design Development

Preliminary designs were iterated through testing and analysis to meet the project specifications. The following sections describe the processes used in developing the final designs for the attachment mechanism, frame, and seat.

5.2.1 Attachment Mechanism

As discussed in Section 4.1.1, there were two leading designs for the attachment mechanism. Prototypes were developed and testing was performed to decide between the trailer fork and single arm attachment mechanism designs. Through this testing, the trailer fork design was selected, and finite element analysis and calculations were used to size the tubing, bushings, and bearings.

The first test performed to decide between the single arm and trailer fork attachment mechanism designs was testing the strength and rigidity of quick releases. With the single arm pivot design, there was a possibility of stressing out the quick release; if the attachment mechanism harmed the stock components of a bike, then it is not a sound design. To test a standard 5mm quick release, a cantilever beam was fastened to a pipe with a 5mm hole running through it. This setup mimicked the quick release being clamped to the side of a bike’s dropouts. The cantilever beam setup and single arm pivot design can be seen in Figure 5.2.1.
A bucket with 35lbs of water was hung 16in away from the quick release to simulate the reaction force the turning hinge would experience during the beginning of a turn. As seen in Figure 5.2.1, the load applied deformed the quick release substantially. Figure 5.2.2 shows deformation between the beam, made of a sturdy aluminum extrude and steel plate, and the test jig that simulated the bike dropouts. This deformation caused the quick release to behave like a spring, voiding its ability to satisfy the design goal of being rigid. This was caused by the quick release stretching inside of the test jig just like it would stretch between the dropouts of a bike.

With the visible deflection of the beam and gap at the dropouts, the quick release test showed that a standard quick release would not hold up to the dynamic forces of towing a trailer with the single arm pivot design. Even if it was strong enough to endure the fatigue, the amount of flex this connection provides is unacceptable.
To alleviate the deflection, a shorter design was created and prototyped, as shown in Figure 5.2.3. Creating the structural prototype of the shortened single arm pivot design was very beneficial to the direction of the overall trailer design as it proved that all the degrees of freedom worked. Using a children’s bicycle trailer, the prototype was attached to the frame, loaded up with metal weights, and ridden. Compared to the flex connector that was originally on the trailer, which also mounted to the left side of the bike, the single arm pivot design was rigid and created a smooth riding dynamic. There were no oscillations or play in the attachment.

![Figure 5.2.3. The shortened single arm pivot design and structural prototype.](image)

While the shorter design also inherently reduced the stress on the quick release by moving the roll and turn axes forward and shortening the effective lever arm, this design had several shortcomings. Since the roll axis was offset to one side of the bike, when leaning the bike, the trailer would rotate left and right. While there was no play in the attachment itself, this rotation was felt by the rider in a slight surging riding characteristic. The right hand turning radius was also limited by wheel clearance with the bend in the single arm.

Alternatively, the trailer fork design is more robust and only slightly more time consuming to attach than the single arm pivot design. The reason why the single arm pivot was preferred was because of its simplicity and ease of attachment, however, it was proven to be unreliable and resulted in undesirable riding characteristics. By placing the turn and lean rotations in line with the rear wheel of the bicycle, the handling of the trailer was greatly improved.

By using the Bob Gear quick release, the trailer fork offers a non-intrusive mounting attachment point for the trailer. Each bike of the Team Joseph fleet would be required to purchase a BOB gear quick release. Between the combined results of the quick release test and the structural prototype, it was decided that the trailer fork is the superior design.

Bob Gear also sells their own trailer forks; however, these are designed for a single wheeled trailer. The turn axis is not perpendicular with the ground, giving a stability characteristic only relevant to a single wheeled trailer in line with the bike. The Bob Gear trailer fork also uses plastic bushings, which will wear quicker with a heavier trailer like Joseph’s.
Due to the geometry limitations of the Bob Gear trailer fork, the bike trailer will feature its own custom trailer fork. The trailer fork will always be a part of the trailer and is built to last.

The trailer fork is made of chromoly steel and high strength components. Chromoly steel was selected for the tubes and metal parts because of its strength, machinability, and ease of welding. An exploded view of the trailer fork can be seen below in Figure 5.2.5.
Each component was analyzed by itself to determine the appropriate size and material. The critical components can be seen listed below in Table 5.2.1:

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Required Strength</th>
<th>Size</th>
<th>Strength Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1101</td>
<td>Hub Bearings</td>
<td>1,550 lbf radial, 115 lbf axial (speed bump case)</td>
<td>40mm OD, 17mm ID, 17.5 mm wide</td>
<td>1,950 lbf static (combined radial/thrust)</td>
</tr>
<tr>
<td>1106</td>
<td>7/16-20 Bolt-Hub</td>
<td>115lb axial, 75 lbf shear (pulling the trailer)</td>
<td>7/16-20 x 3.5in Grade 8</td>
<td>150,000 psi tensile strength (22,500 lbf)</td>
</tr>
<tr>
<td>1105</td>
<td>3/8-24 Bolt-turn axis</td>
<td>60 lbf shear (pulling the trailer)</td>
<td>3/8-24 x 6.5in Grade 8</td>
<td>150,000 psi tensile strength (16,500 lbf)</td>
</tr>
<tr>
<td>1107</td>
<td>Brass Bushing-turn axis</td>
<td>595 lbf radial, 165 lbf axial (speed bump case)</td>
<td>0.500in OD, 0.375in ID, 0.750in length</td>
<td>830 lbf radial, 420 lbf thrust, at 120 rpm</td>
</tr>
</tbody>
</table>

Calculations for determining the size of the components can be seen in Appendix H. The most critical components are the bearings in the hub unit, which gives the bike the ability to lean. The pair of bearings and the pair of bushings must resist the moment created by the weight of the trailer on the quick release; this is called the tongue weight. With an over-estimated 50 lbf of tongue weight on the quick release, the worst case scenario was determined to be when the trailer hits a speed bump. Hitting a speed bump increases the tongue weight to 165 lbf. The bearings and bushings were determined to be the weakest point; once these were sized, other parts were sized for assembly fit and checked for strength. Table 5.2.1 shows that the bolts holding the pivots together are significantly stronger than required. When sizing the components, processes and assembly was taken into consideration; the slightly larger components allow for an easy assembly by hand. Larger parts will also last; since this is a custom trailer, Team Joseph wants a low maintenance, built-to-last trailer.

For the fork tubes, the same 0.5 x 0.065in 4130 chromoly tubing was used as on parts of the frame. The dropouts of the trailer fork are made of 3/16" 4130 chromoly plates; this thickness mates well with the dropouts on the Bob Gear quick release. A loading case of the trailer fork can be seen below in Figure 5.2.6. Since the desired factor of safety was not reached, triangular gussets were added in the areas of high stress to achieve the desired factor of safety of 2.
Between the appropriately sized bearings, bushings, hardware, and fork materials, the trailer fork should provide Team Joseph with many years of riding.

5.2.2 Frame

All metal used on the frame is 4130 chromoly steel for the tubing, tabs, and hubs. The axles and fenders are 6061 Aluminum. These materials were chosen for their ease of manufacturing, specifically welding and machining. These steel alloys have the best strength compared to manufacturability and are a standard in the bike industry. The steel and aluminum are powder coated to create a corrosion resistant frame. The frame was designed initially to provide the correct body position for Joseph. Tube diameters and thicknesses were chosen similar to Joseph’s Jogger and to standard sizes on bike frame. A finite element model of the frame was created to analyze it. From this analysis, it was determined that tube thickness could be reduced from 0.065” (used in the Jogger) to 0.030”. This corresponds to a frame weight savings of 46%. From the results, the frame geometry was also refined, removing tubes that were not adding to the stiffness or strength of the frame.

Two main loading conditions were considered. The first included the weight of Joseph and the seat (100lbs downward), a 1g pull force from the trailer (115lbs forward), an impact from a speedbump at both axles (396lbs up and 190 lbs back, as was analyzed by an old senior project/ Human Powered Vehicle report), and a force modeling a push from Joseph on the footrest (150lbs forward). This is the worst-case loading condition that the trailer can expect to see regularly, and a FS of at least 2 is desired.

Figure 5.2.6. A finite element analysis of the trailer fork frame.
Despite this, since the hubs are substantially shorter than the rest of the tubes compared to their thickness, they cannot be appropriately modeled as beam elements. To deal with this, a full mesh was created on the structure surrounding the hub (the full model was not analyzed to save computing time). Fillets were also added between tubes to represent the welds. No significant change to the factor of safety was shown.

The second loading condition simulates a rollover crash scenario. A 300lb impact force was applied to the rollbar at the angle it would hit in a rollover crash. This force was based on the 300lb horizontal force requirement for the Human Powered Vehicle competition, as the frame hits the ground in a roughly horizontal orientation in a rollover crash. Results can be seen in Figure 5.2.8.
The footrest was cut from a carbon fiber sandwich panel that was previously part of a Cal Poly Human Powered Vehicle trike. The panel consists of three plies of Toray T300 twill on either side of a 0.25'' Nomex honeycomb core. While the core itself adds minimal strength, it increases the distance between the laminates thus increasing the moment of inertia of the plate and therefore increasing the bending stiffness, which is what will help to resist Joseph’s pushing.

Since CDR, there have been several frame design changes due to manufacturing difficulties and safety concerns. Instead of mounting the axles onto an angled support on the side triangles, they were mounted to the upright tubes at the back of the trailer. This was largely due to the difficulty in manufacturing the angled supports. The angle at which the supports were mounted required very steep miters and were near impossible to jig for welding. Through FEA, it was determined that the angled supports were unnecessary and that attaching the axles to the upright tubes still provided a factor of safety of more than 2 under normal riding conditions.

The original fender design was three inner plies of carbon fiber Toray T300 twill and two outer plies of a Kevlar-Carbon weave donated by the Human Powered Vehicles club. The addition of the Kevlar plies was intended to improve the safety of the fenders in the event of a crash since Kevlar does not have the same splintering failure mode that carbon fiber does. However, we still had safety concerns about the carbon fiber due to its explosive failure method. Since carbon fiber is not strong in compression and the fenders would be the first part of the trailer to hit the ground in the event of a rollover crash, we determined that aluminum was a better material choice to ensure Joseph's safety. In the event of a crash, the aluminum fenders would simply bend and could easily be replaced. Thus, the fenders were fabricated using 0.095in thick aluminum sheet bent into an L-channel.
Previous designs included a kickstand that mounted to the lowest front tube of the trailer to allow John to load Joseph into the trailer without any assistance, keep the trailer from rolling away when parked, and protect the powder coat finish of the front tube. However, the kickstand and its mounting tab would have had to extend below the lowest tube by about 1.5in leaving only about 3in of clearance. This meant the trailer would not be able to clear the standard speedbump which is about 3.5in tall. To relieve this clearance problem the kickstand was traded for a thick rubber sleeve along the lowest front tube. The rubber sleeve will still allow John to load Joseph independently, keep the trailer still when parked, and protect the lowest front tube. The rubber sleeve will not keep the trailer completely horizontal, but the front of the trailer will only have to be lifted about 4in when attaching to the bike and there should be very minimal weight on the front of the trailer.

5.2.3 Seat & Weather Protection

While the trailer and jogger's seats are dimensionally very similar, one major difference between the two is the fabrics and foams utilized. The jogger's seat covers were made from waterproof canvas and mesh where Joseph sits. However, since the mesh isn't waterproof, the entire seat cover was lined in a waterproof silk film. This silk film is not breathable and thus made the foam heat retentive. The seat covers for the bike trailer will be made completely from polyurethane laminate fabric. It is a waterproof, durable, and breathable fabric which is commonly used for cloth diapers or changing pad covers so it's also very soft. Using a single fabric will be simpler to upholster and this fabric choice allows the foam to breathe and release heat. SLO Sail and Canvas proposed the addition of a thin, washable, removable mesh pad to go over the top of the seat, but it was not delivered by SLO Sail and Canvas with the rest of the seat. If needed, this can be pursued at a later date. The seat covers are fully washable and removable, so the covers can be laundered or even replaced if needed.

The jogger used both latex and high resilience foam cushions. HR foam is half the density of latex, and therefore, half the weight. It is also very supportive and distributes pressure well. The material degrades very slowly and will last at least ten years [6]. Although HR foam doesn't distribute heat as well as latex foam [7]. The breathable fabric decreases the heat retention of the cushions as compared with the jogger's seat.

All the foams were sourced through and cut by SLO Sail and Canvas. Due to the weight savings and net heat retention reduction, the trailer's cushions were fabricated using HR foam as a base. A layer of polyester batting was placed over the top of the foam to help fill out all the seat covers and give a full look. For load bearing cushions such as the base seat cushions and footrest, a layer of 1/8" thick closed cell foam in between the foam and batting layers was designed to help distribute the loads. However, upon receiving the completed seat, the closed cell foam layer was not added. All ride testing was completed without the seat and the straps alone provided a comfortable ride. We believe that the cushions will be very comfortable for Joseph even without the closed cell foam layer. Since the trailer will travel at much higher speeds than the jogger and will thus likely result in a bumpier ride, the thickness of the base cushions was increased by an inch to increase Joseph's comfort. A firmer HR foam (36 ILD vs. 18 ILD) compared to the jogger was also used to better support Joseph.

As discussed in Section 4.1.5, the seat used the same hip angle and dimensions as the jogger's seat, but extended Joseph's legs to decrease the center of gravity of the trailer. Although the seat design is similar to the jogger's seat, there are several key differences including harness routing capabilities, material and foam selection, and improvements to increase the comfort of the seat. This required several iterations due
to input from professors, upholsterer's, Joseph's dad, and test fits. Figure 5.2.9 shows the difference between the PDR and CDR designs.

![Figure 5.2.9. Comparison between PDR seat (blue dashed lines) and updated seat design.](image)

The height of the hip cushions was reduced to give Joseph more shoulder room. This change will also allow the harness to pass between the cushions, as shown in Figure 5.2.10, rather than cutting a slot through the cushions as done in the jogger. This will improve the fit of the harness, simplify the upholstery required, and increase the longevity of the cushions. As discussed during the PDR presentation, Team Joseph requested a 5-point harness rather than a 4-point harness to prevent Joseph from sliding underneath the waist strap. Thus, the trailer has a G-Force Camlock harness from Summit Racing. This harness is made of 2in wide nylon webbing, has a camlock for easy buckling, and is highly adjustable. There is also a 2in wide nylon strap that can be used to restrain Joseph's legs.

![Figure 5.2.10. Seat assembly with harness.](image)

All the cushions are connected to each other with Velcro, as shown in Figure 5.2.11(a). The headrest and base seat cushion will be directly attached to the frame by a series of 2in wide polyester straps just like the jogger seat, as shown in Figure 5.2.11(b). Attaching the cushions to the straps rather than a rigid plate gives some suspension to the seat, much like the give of the seat of a lawn chair. The breaking strength of a single 2in wide strap is 5500 lbs and polyester webbing is 5 times as durable as nylon webbing [8]. Between the seat and headrest, there are 15 straps which is very redundant in terms of strength but is
necessary to fully support the cushions and keep the seat cushions from shifting. The original design incorporated 13 straps, but we added two more straps during the test fit to prevent the seat from sagging. The hip cushions and footrest will also be held in place by the fenders and footplate respectively.

We performed a test fit with Joseph in which we attached the straps to the frame and placed the foam on top. This was done to ensure that the seat design fit Joseph well before the upholstery was started and to aid in routing the harness. We trimmed 1" off the thickness of the footrest cushion to allow for Joseph's legs to extend comfortably. We also decided to split the top and bottom of the bent seat cushion to allow the submarine strap of the harness to route between them, as shown in Figure 5.2.12. Rather than mounting the harness using tabs, we decided to loop the harness around the frame tubing as specified in racing specifications.
Since some of Team Joseph's races and training rides will be several hours long, sun protection for Joseph is required. The sun canopy is comprised of a replacement stroller sun canopy purchased from Chicco. These sun canopies are designed for extended weather exposure and easily replaced if needed. A sun canopy extension is also included to increase the angle of protection for Joseph. This extension will also be useful to keep a rain protection system out of Joseph's face if that is pursued in the future.

The team races and trains in all weather conditions, so a rain protection system was designed. However, weather protection will no longer be included in the final product due to seat upholstery manufacturing delays and budget restrictions. The design for the rain protection system is still discussed, so if weather protection is desired, Team Joseph can pursue this further with SLO Sail and Canvas or a different company of their choice. Since the trailer is much longer than standard strollers or bike trailers, it needs a custom rain cover. The proposed design was a lightweight, removable rain cover that would attach to the frame using Velcro tabs like those seen on tent rainflies. All the materials discussed below can be sourced, sewn, and patterned by SLO Sail and Canvas. The proposed design featured a windshield made from clear, UV resistant vinyl to give Joseph full visibility. Even UV resistant vinyl degrades over time, so the rain protection must be removable to protect the materials from UV exposure as much as possible. To prevent condensation on the inside of the rain cover, the sides were proposed to be made from a high-end waterproof breathable fabric from Patagonia. SLO Sail and Canvas proposed the addition of small plastic vents to further increase the breathability. SLO Sail and Canvas does not have seam sealing capabilities, but Mountain Air has seam sealant if seam leakage is a concern. It may be possible for the rain cover to be patterned to fit both the jogger and trailer.

5.3 Discussion of Safety, Maintenance, and Repair

The trailer is meant to last for many triathlon seasons and bike rides. Safety has been a top priority throughout the project, and the design reflects this. John and Team Joseph are also looking for a low maintenance bike trailer.

The trailer has multiple features that make it as safe as possible for Joseph. The frame features a roll bar that extends past his head. The seat adheres to his posture needs and supports his whole body; he is secured by a 5-point racing harness as well. The trailer has a wide wheelbase and a low center of gravity, thus increasing stability when turning. Wheel fenders prevent Joseph from contacting spinning wheels as well.

The bike trailer is designed to be low maintenance. Using standardized bike components for the wheels will ensure that the trailer rolls for many miles. The trailer fork utilizes sturdy bearings and bushings; should these wear, they are easily replaced due to the design of the assembly and are standard sizes. The frame and trailer fork tubes are designed to be the last parts that would need replacing. Should any component break or show signs of wear, Team Joseph is encouraged to contact the senior project team member for advice for a repair. Since the metal components are all made of chromoly, the trailer could easily be repaired by one of the senior project team members or a welding/machining service. The seat and components that mount the seat are all modular; if a cushion or strap wears out, the drawings are available and it can be easily remade.

5.4 Cost Analysis

To fund the project, a GoFundMe campaign was created. Named “Ride with Joseph,” this campaign page outlines who Joseph is, what Team Joseph is, and the project to build Joseph a custom bike trailer. It has a
goal of $4,000, and as of June 1, 2018, it has leveled off at $2,504. This goal was created before it was
known the metal would be donated. It also aims high; any remaining funds will go to the Cornelius family
to support Joseph and Team Joseph and to get them signed up for future triathlons.

5.4.1 Materials and Components

The raw materials for the frame and trailer fork consist mainly of Chromoly steel tubing, Chromoly bar
and round stock, and hardware. The metal for the trailer was donated; with the approval from Team
Joseph on the final design, the bill of materials for the metal was sent to the donator. This allowed
budgeting to go towards purchasing quality hardware, bearings, wheels, and services. The sum of
materials, excluding the metal, is $305. This can be seen in Appendix I. The metal donation summed to
$540.

5.4.2 Seat & Sun Protection

The majority of the seat materials including foam, Velcro, and strapping was sourced through SLO Sail
and Canvas. All of these were included in their rough seat build estimate. The polyurethane laminate
fabric was sourced through Wazoodle and cost $117. The sun shade will be purchased through Chicco for
$43, and an add-on visor was purchased for $25 through Amazon. The 5-point harness was purchased to
secure Joseph to the seat. The harness is a G-Force Camlock racing harness, which offers an easy way to
get Joseph in and out of the trailer; it cost $105 through Summit Racing.

5.4.3 Services

Multiple services were required to complete the bike trailer. These services are out of the abilities of the
senior project team's resources, and therefore they had to be outsourced to businesses. Fortunately, the
required services can be found locally in San Luis Obispo.

5.4.3.1 Seat

The seat was upholstered by SLO Sail and Canvas for $970 including foam, straps, Velcro, and zippers.

5.4.3.2 Powder Coating

The frame and trailer fork assembly were powder coated by Central Coast Powder Coating in San Luis
Obispo. After verifying the trailer’s functionality, the parts were disassembled and sent out for powder
coating. The powder coat for the frame and trailer components cost a total of $240.

5.4.3.3 Wheel building

Due to the use of strong 20mm thru-axles and 20in rims, the wheels had to be laced by hand. 20in wheels
do not come standard with through axle hubs; since through axles are necessary to mount the wheels to
the frame, this service must be outsourced. The wheels were built by Art's Cyclery for a total of $420
including parts and labor.
6 Manufacturing

6.1 Manufacturing Timeline

Below, Figure 6.1 shows the order in which the bike trailer was manufactured, including outsourced parts and assembly.

![Team Joseph's Bike Trailer Manufacturing Process Diagram]

Figure 6.1.1. Complete manufacturing plan for bike trailer

6.2 Trailer Fork and Frame

Tubes for the frame and trailer fork were manufactured first. The tubes were cut 2in longer than required with a band saw. Once every tube stock was cut to size, a mill was used to miter the 1in diameter tubes. Tubes that were 0.5in in diameter required no mitering. The 1in tubes were placed in the vice and the head of the mill was set at the desired angle; a 1in roughing end mill made the miter cuts (a 1in hole saw would have worked as well). The mitering setup can be seen below in Figure 6.2.1.
Figure 6.2.1. A 1in diameter tube being mitered with a 1in roughing end mill.

Once all of the 1in tubes were mitered, the 0.5in tubes were ground down to the correct length and angle using a metal belt sander and angle finder. Once every tube for the frame was made, the ends of each one were prepared by sanding any surface rust or patina off, wiped clean with a rag, and dried with compressed air. The end of a ready-to-weld tube can be seen below in Figure 6.2.2.

Figure 6.2.2. The end of a tube after sanding and deburring.

Tubes that had a tube miter attaching to its surface received a small vent hole. Every vent hole will be covered up by the mitered tube, as if the longitudinal centerline of the mitered tube makes the location of the vent hole. The vent holes in the tube joints allow the whole frame to breathe and circulate air; a slight
patina will form instead of trapped moisture creating a rust hole in the future. An example of a vent hole can be seen below in Figure 6.2.3

Figure 6.2.3. An example of a drilled vent hole.

With all of the tubes prepared and the vent holes drilled, the frame was tacked together. The frame was tacked together as two halves, with the final welding occurring at the knee joint. The rectangular foot and back rests were tacked first, as these are planar features by themselves. Large clamps and a 90° metal block were used to fixture the foot and back rests. The shin tubes were then tacked onto the foot rest perpendicular. The seat-back angle was then formed with the back rest, thigh tubes, and respective triangulation. The middle knee joint was then elevated above the welding table and tacked, as seen in Figure 6.2.4 below.

Figure 6.2.4. Left: the back rest as a planar feature being fixtured.

With the whole frame tacked together, every angle and length was double checked. With each dimension confirmed, every tacked joint was then fully welded. Next the foam was checked for fitment with Joseph. The only modification was reducing the height of the foot rest pad by 1 in, allowing Joseph to extend his legs slightly more. The foam fitment can be seen below in Figure 6.2.5.
While the frame was being tacked together, components for the trailer fork and axles were built simultaneously. The 20mm aluminum axles, axle receiving tubes, and the turning hinge were turned on a lathe to ensure tight fitment. The hub body and bearing caps were machined on a lathe as well. The turning hinge was milled from a solid steel billet. Several of the parts made on a lathe can be seen below in Figure 6.2.6.

The 0.5in diameter tubes for the trailer fork were cut to length and bent using a 2in radius bending die. To ensure the angles were correct, a 1:1 scale drawing of the fork tubes was created and the tubes were checked for the correct angle and length. Slots for the dropouts were milled in the long end of each of the four fork tubes. Dropouts were milled out of 0.190in thick chromoly plate. A jig was created to ensure proper alignment of the dropouts, tubes, and turning hinge. The jig consisted of a dropout spacer, and a wood panel to hold the spacer and the steering tube at the correct distance and orientation. The whole assembly was clamped to a welding table and held in place as shown in Figure 6.2.7 below:
The trailer fork was welded as much as possible in its fixture. Welding distorts the overall shape, so the aluminum dropout spacer was always in place, even when out of the clamps and wood spacer.

Since the axles do not mount to the same, continuous tube, it is imperative that the wheels mounts are concentric and the same elevation. Concentric and level axles will produce minimal rolling resistance, extend tire life, and will make the trailer sit straight up. To ensure the axles are lined up, a sliding jig was created out of two 80/20 extrude beams as seen below:
As seen in Figure 6.2.8 above, the 20mm bolts are what locate the rails relative to each other. Each rail has a 90° mount going to the alignment bolts; the 90° mounts of one rail are perpendicular to the other 90° mounts of the other rail. This setup constrains the axle mount tubes in all three directions when clamped to the frame. The tubes were tacked and wheels were temporarily installed to measure the toe-in/out and camber angles. There was less than a millimeter difference when measuring the leading and trailing edges of the rim, yielding a toe-out angle of less than 0.5° between both wheels. The camber was negative and of equal magnitude. The tacks were further welded and alignment was checked again. Overall the tow-in/out and camber were measured three times before the tubes were fully welded to the frame. Vertical triangulation was added to the frame as well for extra stiffness.

The hub body was attached to the frame with a road bike wheel in the trailer fork. The trailer fork was leveled and the hub body was tacked in place, starting with the bottom and top 1in tubes, then the left and right 0.5in tubes. Before the lateral 0.5in tubes were tacked in place, the alignment of the hub body was confirmed to be in line with the frame and the ground clearance was checked with the road bike wheel and trailer fork installed. The lateral 0.5in tubes were tacked on, and the almost complete trailer frame/fork assembly was tested for fitment with a road bike, as seen in Figure 6.2.9 below:
With the ground clearance and alignment clear, the rest of the welds were completed. Time spent welding on the hub body and the other joints was distributed, as to keep the temperature of the hub body down and minimize possible distortion for the bearing surfaces.

A total of 8 tabs were welded on the frame. Four tabs are in the four corners of the foot rest, which the actual foot rest plate will mount to. The triangulation bars for the back rest and thigh tubes receive a tab at each end. The fenders will mount to the left and right pairs of tabs.

The fenders were made from 6061 aluminum plates that was 0.09in thick. Each fender was made from a 12in x 24in plate. A 90° bend was located 5.5in parallel from one of the 24in edges. Unfortunately, both fenders showed major signs of cracking when the 90° bend was formed. To fix this, the outside and inside corners of the bend were welded over. The fenders were then sanded smooth to remove any sharp imperfections and get them ready for powder coating as seen in Figure 6.2.10 below.
6.3 Seat

The seat was upholstered by SLO Sail and Canvas. An initial foam fit check was completed with Joseph sitting in the frame before the cushions before any fabric was cut. The frame wheels and trailer fork was not needed for this preliminary fit check, but all of the structural components that Joseph comes in contact were completed. During this fit check, we also routed the harness and located the shoulder tube used to mount the harness. We made several slight seat design modifications as discussed in Section 5.1.3. The final seat upholstery was completed on May 29th by SLO Sail and Canvas and immediately installed in the trailer.
7 Design Verification Plan

This section highlights the key tests were completed after manufacturing of the trailer. Refer to Appendix J for a complete list of all tests and Appendix K for the DVP&R matrix.

7.1 Seat

An initial fit check was performed with Joseph sitting in the frame on top of raw foam. This allowed us to make any geometry changes before the expensive seat upholstery is started. The foot cushion had 1 in of thickness cut off of it based on the results of this test. We also routed the harness and decided to connect the harness directly to the frame tubes rather than tabs.

The polyurethane laminate was tested for waterproofness before incorporating it in the seat covers. The fabric repelled all water that was poured on it, meeting our specifications.

7.2 Weather Protection

A simple sun canopy test was performed with Ms. Thompson sitting in the trailer to ensure that the rider’s face is completely shaded. A removable canopy extension was added to the permanent sun shade for use at dawn and dusk hours when the sun is lower in the sky.

7.3 Frame

The testing performed on the trailer consisted of a ride test, as well as a measurement of key dimensions (length, width, height), and weighing it. The ride test will simply be to connect the trailer to a bike, put a known weight in the trailer (around 110lbs – simulating the weight of a Joseph and a seat which was not available at the time of testing), and to ride it on the road to ensure it can handle all riding conditions (bumps, turning, etc). Since there is only time to build a single trailer for Team Joseph, crash testing will not be performed (as is required by ASTM standards) and FEA results will be trusted. Dimensions and weight will be provided to Team Joseph as a reference.

7.4 Trailer Fork

As was tested with the structural prototype, the trailer underwent testing to ensure that the bike can rotate in all degrees of rotation with respect to the trailer.

7.5 Testing

Seven tests were developed and conducted. These tests aim to evaluate the dynamic functionality and verify the physical construction of Joseph’s bike trailer. The procedures can be seen in Appendix J.

7.5.1 Trailer Stability and Tip-Over Test

This test evaluated the angle at which the trailer will tip. The specification to be met is that the trailer must be able to right itself after a 45° roll angle. To do this, the trailer was tilted while the bike was held
upright. The position was found when the bike was almost self-balancing (the onset of tipping), and the angle was recorded. A magnetic base angle finder was used to measure the angle.

Table 7.5.1. Results from Trailer Tip-Over Test

<table>
<thead>
<tr>
<th>Trial</th>
<th>Tipover angle [°]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57.1</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>2</td>
<td>58.1</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>3</td>
<td>57.8</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>4</td>
<td>53.6</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>5</td>
<td>56.6</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>6</td>
<td>56.2</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>Average</td>
<td>56.6</td>
<td></td>
</tr>
</tbody>
</table>

After an uncertainty analysis shown in Appendix L, the average tip-over angle is 56.6°±7.0°. This value is more than the requirement of 45°, with the lowest expected tip angle being 49.5°. The setup can be seen in Figure 7.5.1 below:

Figure 7.5.1. Trailer at the position when it would no longer right itself.
7.5.2 Bike Roll-Over Verification

This test ensures that the trailer can stay upright, even if the bike is not. It is a simple pass/fail test; the result can be seen below in Figure 7.5.2:

![Figure 7.5.2. Full rotation of a bike and the unaffected trailer.](image)

As seen in Figure 7.5.2, the bike is completely tipped to its side, and the only impact on the trailer is that the front edge is touching the ground. The trailer does not tip over in the event of the bike tipping.

7.5.3 Trailer Attachment Time Test

The trailer attachment time test evaluated the time it takes to completely attach the trailer to the bicycle. The trailer and bicycle were apart and at rest on the ground; the timer starts when the user touches the trailer and ends when the trailer is ready to safely roll away. The goal is that it can be safely and completely attached in less than 1 minute. The results of three trials can be seen below in Table 7.5.2, which shows that it is very quick to set up the trailer with a single person. No uncertainty analysis is performed as the data is not normally distributed – the time to attach decreases each trial as the user gets more experience.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Attachment Time [s]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>19.3</td>
<td>Trailer is easy to attach.</td>
</tr>
<tr>
<td>Average</td>
<td>22.4</td>
<td></td>
</tr>
</tbody>
</table>
7.5.4 Longitudinal Play in the Trailer Fork Evaluation

This test evaluated the amount of longitudinal play in the trailer fork attachment mechanism. The measurement determines how “rigid” the connection is. Ideally there is no play, allowing for a smooth transition between braking and accelerating. The target is no more than 0.050in of play. The results can be seen below in Table 7.5.3

<table>
<thead>
<tr>
<th>Trial</th>
<th>Play in hub [in]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.013</td>
<td>Almost no play</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The average longitudinal play in the trailer fork was 0.016in±0.010in. This is meets the less than 0.050” specification, as the max expected play is 0.026in. The test setup can be seen below in Figure 7.5.3.

Figure 7.5.3. Dial indicator setup for measuring play across hub.
7.5.5 Trailer Weight and Size

Using a bathroom scale and tape measure, the trailer’s final weight and size will be determined. The goal weight for the trailer is no more than 40 lbs; the size target is less than 70in in length, 40in in width, and 45in in height. The actual dimensions of the trailer are 63in in length, 33.75in in width and 40in in height. The results for weight can be seen in Table 7.5.4.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Holder weight [lbs]</th>
<th>Combined Weight [lbs]</th>
<th>Trailer weight [lbs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>2</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>3</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
</tbody>
</table>

An uncertainty analysis showed no deviation in the measurements, so the only uncertainty comes from the resolution of the scale, with the total uncertainty being ±0.1lbs, due to uncertainties in the holder weight and combined weight.

The weight of the trailer exceeds the design specification of 40lbs. This is because the weight of seat components, wheels, and trailer fork components were somewhat unknown until they were purchased. While this is heavier than what the trailer ideally is, Team Joseph has said they are not overly concerned about weight, and this weight is not unreasonable. If this project were to be done again, weight reduction measures could be taken with regards to purchased components – especially those dealing with the wheels and trailer fork components. However, this would increase the cost of the trailer.

7.5.6 Wheel Removal and Installation Time Test

This time trial evaluated the time and ease at which the trailer’s wheels can be removed and installed. The target time to remove a wheel is 30 seconds; the target time to install a wheel is 30 seconds as well. The average time is 8 seconds, much less than the target. No uncertainty is provided as the data is not normally distributed as the user gets more experienced and faster with each install. The results can be seen in Table 7.5.5 below:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Attachment Time [s]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.11</td>
<td>left, remove</td>
</tr>
<tr>
<td>2</td>
<td>11.34</td>
<td>left, install</td>
</tr>
<tr>
<td>3</td>
<td>4.61</td>
<td>right, remove</td>
</tr>
<tr>
<td>4</td>
<td>9.96</td>
<td>right, install</td>
</tr>
<tr>
<td>Average</td>
<td>8.00</td>
<td></td>
</tr>
</tbody>
</table>
7.5.7 Sun Protection Angle Test

This test evaluates the effectiveness of the sun shade system, specifically when the sun would be rising or setting. 90° of protection means that even at sunrise or sunset, Joseph’s eyes won’t receive any glare. The results can be seen below in Figure 7.5.4

![Figure 7.5.4. The shade angle provided by the sun protection system.](image)

As seen in Figure 7.5.4 above, the trailer and its shade do provide shade for a setting and rising sun. Ms. Thompson’s face is completely hidden from the sun at any angle.

7.5.8 Ride Testing

To ensure the handling qualities of the trailer are sufficient for everyday riding, the trailer was attached to a Specialized Venge road bike and ridden. Initially this was done without a seat (it was not yet complete at the time of testing) or rider. This test showed very smooth handling qualities under turning and leaning of the bike. Ms. Thompson and Mr. Wathne each sat in the trailer and were towed by Mr. Meinhardt. With a rider in the trailer, it handles similarly to trailers that were test ridden in the design development stage. Ms. Thompson noted that the ride was much smoother for the rider, with much less lateral swaying than a single arm attachment design. The combined result that the trailer feels similar to the bike rider compared to other commercially available trailers and that the ride is smoother to the passenger proves that our design provides good handling characteristics and will be easily usable by Team Joseph.
8 Project Management

This section details the overall design process that was followed throughout the year. A table of the key deliverables (design reviews, prototyping deadlines, testing times, etc).

8.1 Design Process

As was documented in this report, the design process started with intensive background research on current bike trailers and industry standards. We also analyzed the successful jogger used by Team Joseph. Concept designs were developed based on this research, including the building and testing of prototypes of the attachment mechanism. A CAD model was made showing the initial designs of the frame, seat, and attachment mechanism. Analysis was performed in FEA and with physical tests to further refine the design, which led to the creation of the final model. Testing procedures were developed based on the tests that were listed in the Design Verification Plan section. Final manufacturing started in March, starting with the cutting and mitering of tubes and the machining of metal parts. After manufacturing, testing took place to ensure that all previously specified requirements were met. The completed trailer was delivered to Team Joseph at the senior project expo.

Two main deviations from this design plan arose. The first was the time delay that arose in the manufacturing of the seat by SLO Sail and Canvas. This set back the final assembly of the trailer. Testing also had to be performed with representative weights (sandbags) to model the seat and rider. Also, due to time and budget constraints, the weather protection could not be manufactured before the delivery of the trailer to Team Joseph.

8.2 Table of Key Deliverables

Table 8.2.1 shows the dates of key deliverables that this senior project followed. The dates were specified by the Cal Poly ME senior project course syllabus. Our team has had internal deadlines for the project as well; these were determined throughout the course to assist in achieving the course deliverables. The use of a Gantt Chart was employed to oversee progress, set goals, and keep the project on schedule. The Gantt Chart can be seen in Appendix M.

<table>
<thead>
<tr>
<th>Due Date</th>
<th>Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/16/17</td>
<td>Preliminary Design Review (PDR)</td>
</tr>
<tr>
<td>1/16/18</td>
<td>Interim Design Review</td>
</tr>
<tr>
<td>1/23/18</td>
<td>Build Structural Prototype</td>
</tr>
<tr>
<td>2/6/18</td>
<td>Critical Design Review (CDR)</td>
</tr>
<tr>
<td>3/1/18</td>
<td>Start manufacturing</td>
</tr>
<tr>
<td>3/13/18</td>
<td>Manufacturing &amp; Test Review</td>
</tr>
<tr>
<td>4/19/18</td>
<td>Assembly</td>
</tr>
<tr>
<td>4/26/18</td>
<td>Hardware/Safety Demo</td>
</tr>
<tr>
<td>5/3/18</td>
<td>Start testing</td>
</tr>
<tr>
<td>6/1/18</td>
<td>Project Expo</td>
</tr>
</tbody>
</table>
8.3 Unique Techniques

To analyze the riding dynamics of a single arm design, the team purchased an inexpensive trailer that had a single arm with flex connector. Ride testing was then performed with the team members, and it was noticed that there was a large amount of side to side lag. When testing with the single arm that was made as part of the structural prototype, the lag was still present, although considerably less with the mechanical mechanism. Through the structural prototyping phase, our team built a model of the single arm design (as specified previously). The force on the quick release was analyzed with a bucket of water weighing roughly 35lbs to 40lbs). Since it was deemed infeasible, the trailer fork was selected as the better option.
9 Conclusion

This report has shown the full design process for Team Joseph’s Bike Trailer. The culmination of this project is a high quality, custom bike trailer for Joseph. This final design report shows the final design as well as the testing results proving the trailer meets or exceeds all the defined specifications. This report has been given to Team Joseph at the Cal Poly ME Senior Project Exposition as well as a user’s manual and the trailer itself (in Appendix N).

9.1 Lessons Learned & Recommendations

If desired, a rain cover and removable seat pad may be further pursued. Please refer to Section 5.2.3 for information about these designs.

If the fenders need to be replaced, rather than bending them they should simply be welded together at a right angle. The bending radius required was too tight and caused cracking which was then repaired by welding over the bend.

One key lesson learned in this project was to set clear expectations and make defined contracts with vendors, specifically about deadlines and details required. This would have eliminated the delay in seat manufacturing allowing us to test earlier and improved the quality of the delivered product.
10 References


Appendix A: Customer Interview Notes

Overall Impressions:
- Michael, Jeff, John, Joseph are incredibly passionate people.
- Blow away by what they do and very excited to start working with them

Questions/ Responses:
- Road Conditions
  - Tarmac only.
  - Joseph does not like bumps
- Bumps/ potholes
  - Currently solved by cramming extra foam in trailer (at least 3”)
  - Suspension probably not necessary
- Loading
  - In/ out by John (or any 1 person)
  - Butt first, then position hips
  - Ideally make easier for one person, could add wheelchair brakes/ 3rd wheel
- Priorities:
  - Don’t care about competitiveness/ speed
- Seat:
  - Current position/ angles good, back almost vertical, legs straight in current trailer, pads on footrest, pads for hips and butt, could add for shoulders.
- safety:
  - Roll bar, clamshell like harness or front pad, sidebars to enclose Joseph, padding around hips and head, possibly add shoulder area pads.
  - Note feeding tube around belly button. Need to avoid.
- Weather:
  - Rain/shine. Retractable weather protection, only used during inclement weather
- Types of bikes:
  - Multiple. All road. Aim for universal between standard road bikes.
- Other Notes:
  - Joes weighs between 75-80lbf.
  - Pushes with a lot more force on footrest
  - Match Team Joseph colors of red and yellow
## Appendix B: QFD

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Appendix C: Decision Matrices

### Attachment Mechanism Decision Matrix

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<tr>
<th>Weight Factor</th>
<th>Quick/Easy Attachment</th>
<th>Versatility Between Bikes</th>
<th>Ease of Manufacture</th>
<th>Easy to Service</th>
<th>Allows Bike to Roll (Lean)</th>
<th>Allows Bike to Yaw (Turn)</th>
<th>Allows Bike to Pitch</th>
<th>Little Longitudinal Play</th>
<th>Low Stress on Bike</th>
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<tr>
<td>Single Arm Hitch, (pivot behind wheel)</td>
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<tr>
<td>Single Arm Hitch, (pivot at axle)</td>
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<td>Wike Bike Trailer (Datum)</td>
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### Harness Decision Matrix

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<tr>
<th>Weight Factor</th>
<th>Clear of Feeding Tube</th>
<th>Groin Support</th>
<th>No Pinch Points</th>
<th>Does Not Constrict</th>
<th>Effectiveness in Crash</th>
<th>Distributes Forces</th>
<th>Easy Load/Unload</th>
<th>Ease of Manufacture</th>
<th>Durability</th>
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<td>Roller Coaste...</td>
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<td>Restraint Vest, Strapped (PFD Style)</td>
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<td>Restraint Vest, Velcro (PFD Style)</td>
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## Seat Attachment Decision Matrix

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<th>Weight Factor</th>
<th>Lawn Chair Straps, Velcro</th>
<th>Seat Covers Incorporate Frame Tubes</th>
<th>Hammock Style, Velcro</th>
<th>Isolated Plate, Velcro</th>
<th>Bench Seat with Assorted Padding (Datum)</th>
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<td><strong>Static Comfort</strong></td>
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<td><strong>Ease of Manufacture</strong></td>
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<td><strong>Padding Stability (no movement)</strong></td>
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Appendix D: Concept Layout Drawings

Preliminary Design: Single Arm Attachment Configuration
Preliminary Design: Trailer Fork Attachment Configuration
Preliminary Design: Single Arm Attachment Mechanism

- Hub body attaches to frame
- Pitch (slope change) axis pin release
- Roll (lean) axis
- Yaw (turn) axis
- Thru hole for quick release
Exploded View: the Preliminary Design of Trailer
Preliminary Design: Trailer Fork Mechanism
Appendix E. Safety Hazard Checklist

DESIGN HAZARD CHECKLIST

Team: Team Joseph’s Bike Trailer      Advisor: Sarah Harding      Date: 11/7/17

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 “Y” responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.
<table>
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<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
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<td>Rotating wheels are possible pinch points</td>
<td>Spokes will be covered with a disk and/or fender so Joseph cannot reach the wheel.</td>
<td>May 3, 2018</td>
<td>May 5, 2018</td>
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<tr>
<td>Trailer will be used in all weather conditions</td>
<td>The frame of the trailer and any exposed components will be powder coated to prevent corrosion. The interior of the trailer will be protected with a waterproof cover.</td>
<td>May 3, 2018</td>
<td>May 20, 2018</td>
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<tr>
<td>It is possible for the trailer to be handled unsafely if the biker does not slow down around corners or brake early.</td>
<td>A user manual will be provided with correct user techniques.</td>
<td>May 3, 2018</td>
<td>May 29, 2018</td>
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# Appendix F. Risk Assessment

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<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment Severity</th>
<th>Risk Level</th>
<th>Risk Reduction Methods / Control System</th>
<th>Final Assessment Severity</th>
<th>Risk Level</th>
<th>Status / Responsible</th>
<th>Comments / Reference</th>
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<tr>
<td>1-1</td>
<td>Team Joseph normal operation</td>
<td>excessive force / exertion in operation</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>On-going [Delay]</td>
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<tr>
<td>1-2-1</td>
<td>Team Joseph load / unload trailer</td>
<td>mechanical pinch point attachment, wheel installation</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Negligible</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
<td>On-going [Delay]</td>
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<tr>
<td>1-2-2</td>
<td>Team Joseph load / unload trailer</td>
<td>lifting / bending / twisting poor lifting technique near loading trailer or Joseph</td>
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<td>Likely</td>
<td>Negligible</td>
<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
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<td>1-2-3</td>
<td>Team Joseph load / unload trailer</td>
<td>material handling / excessive weight trailer is too heavy</td>
<td>Serious</td>
<td>Remote</td>
<td>Negligible</td>
<td>Serious</td>
<td>Remote</td>
<td>Negligible</td>
<td>On-going [Delay]</td>
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<td>1-3-1</td>
<td>Team Joseph mishap / bike crash</td>
<td>excessive force / impact from incorrect or improper riding condition</td>
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<td>Remote</td>
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<td>Serious</td>
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<td>Negligible</td>
<td>On-going [Delay]</td>
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<td>2-1-1</td>
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<td>Moderate</td>
<td>Remote</td>
<td>Negligible</td>
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<td>2-1-2</td>
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<td>Remote</td>
<td>Negligible</td>
<td>Serious</td>
<td>Remote</td>
<td>Negligible</td>
<td>On-going [Delay]</td>
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<td>Risk Level</td>
<td>Risk Reduction Methods / Control System</td>
<td>Final Assessment Severity Probability</td>
<td>Risk Level</td>
<td>Status / Responsible / Comments / Reference</td>
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<td>Joseph riding in trailer</td>
<td>mechanical, drawing in, trapping, entanglement, hands on spokes</td>
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<td>Fenders</td>
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<td>Remote</td>
<td>On-going [Daily] Ryan, Keely</td>
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<td>Joseph riding in trailer</td>
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<td>Medium</td>
<td>Fenders</td>
<td>Moderate</td>
<td>Remote</td>
<td>On-going [Daily] Ryan, Keely</td>
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<tr>
<td>3-1-3</td>
<td>Joseph riding in trailer</td>
<td>ergonomics / human factors, posture, seat geometry</td>
<td>Moderate Unlikely</td>
<td>Medium</td>
<td>similar seat geometry</td>
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<td>Remote</td>
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<td>3-1-4</td>
<td>Joseph riding in trailer</td>
<td>ergonomics / human factors, bike crash, poor riding conditions or sudden jarring movement from Joseph</td>
<td>Serious Likely</td>
<td>High</td>
<td>padded foam, restraints</td>
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<td>Remote</td>
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<td>3-1-5</td>
<td>Joseph riding in trailer</td>
<td>ventilation / confined space, rear cover too close to face</td>
<td>Minor Very Likely</td>
<td>Medium</td>
<td>rain cover not close to face</td>
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<td>Remote</td>
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<td>Joseph riding in trailer</td>
<td>ventilation / confined space, lack of fresh air, poor ventilation through rear cover</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
<td>breathable material</td>
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<td>Unlikely</td>
<td>On-going [Daily] Keely</td>
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## Appendix G: Final Drawing Package

### Bill of Materials:

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<th>Part Number</th>
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<td>1300</td>
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<td>Seat Service, Foam, Zippers, &amp; Straps SLO Sail and Canvas 1000 1 1000</td>
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<td>Seat cushion upper 41 Foam, Polyester Herringbone, Velcro, Zippers SLO Sail and Canvas 1000 1 1000</td>
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<td>PART NUMBER</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
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<td>TRAILER FORK</td>
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<tr>
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<td>1200</td>
<td>FRAME</td>
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<tr>
<td>3</td>
<td>1300</td>
<td>SEAT</td>
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1101 Bearings

- Trade Number: 3203-2RS
- Dimensions:
  - Outer Diameter: 40 mm (+0.000, -0.011)
  - Width: 17 mm (+0.000, -0.008)
  - Inside Diameter: 17.5 mm (+0.000, -0.012)

Part Number: 8828T314
Angular-Contact Ball Bearing
1102 Locking Nut
1105 Bolt

Thread length may vary from 1 1/4" to 1 9/16" in length.

3/8"-24 Thread

0.375"

6 1/2"

1/4"

9/16"

Hex

McMasterr-Carr

PART NUMBER 91257A472

High-Strength Steel Cap Screw-Grade 8
1106 Bolt

5/8” Hex

19/64”

3 1/2”

Thread length may vary from 1 1/8” to 1 1/2” in length.

0.4375”

7/16”-20 Thread

PART NUMBER 91257A705

High-Strength Steel
Cap Screw-Grade 8
1107 Bushing

- Diameter: 0.502" +0.001 -0.000
- Thickness: 0.376" +0.001 -0.000
- Length: 3/4" ±0.01
- Width: 1/16"
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.XX ± 0.015
X.XXX ± 0.005

Material: 4130 Steel
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.xxx = 0.008
X.xxx = 0.003

Material: 4130 Steel
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.XXX = 0.008
X.XXX ± 0.003

Material: 4140 Steel
MATERIAL: 4140 STEEL

ALL DIMENSIONS IN INCHES
TOLERANCES:

XXX = 0.003
XX = 0.008
X = 0.010
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.XXX = 0.008
X.XXX = 0.003

MATERIAL: 4130 STEEL

Ø 1.000 X 0.035 WALL

2.25 METER LENGTH
All dimensions in inches
Tolerances:
X:XX = 0.008
X:XXX = 0.003

Completion of: 4130 Steel

Material: 4130 Steel

Dimension: 0.100

Wall thickness: 0.035

2.41 meter length

2.200

0.100
1120 Shoulder Screw
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<td>Footrest Support Tubes</td>
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<td>4</td>
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<td>Shin Tubes</td>
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<td>Thigh Tubes</td>
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<tr>
<td>15</td>
<td>1215</td>
<td>Rubber Bump Guards</td>
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DUE TO 3D GEOMETRY OF THE TUBE, IT WILL BE CUT TO LENGTH AND HAND GROUND TO FIT INTO FRAME.
TUBE IS 0.50INX0.065IN THICK
QUANTITY = 4
HOLE IS CLEARANCE FOR A #10 SOLT
QUANTITY = 4.
HOLE IS CLEARANCE FOR A #10 BOLT.
WELD TO FRAME TANGENT TO OUTSIDE OF TUBES.
0.25 THICKNESS IS ESTIMATED BASED ON CORE USED.
LAYUP SCHEDULE
[0.45,0, CORE 0.45,0]
SLOTS FOR TUBES WILL BE HANDCUT TO ENSURE FIT WITH FRAME
MAKE FROM 24"X12"X0.070" AL PLATE
BEND TO 90°.
TRIM TRIANGULAR EDGES TO MATCH FRAME.
QUANTITY = 2
Part No. 1215  Rubber Bump Guard

Part No. 1216  Hub FT OR8 MT3100

Part No. 1217  Sun Rhyno Lite 20in Rim
Part No. 1219

Goodyear Folding Bead BMX Bike Tire, 20" x 2.125"

Goodyear

Goodyear Folding Bead BMX Bike Tire, 20" x 2.125"

- 4.4 stars • 25 customer reviews | 18 answered questions

List Price: $44.88
Price: $9.04 | prime • FREE One-Day
Delivered tomorrow for FREE with qualifying orders over $35. Details
You Save: $35.84 (40%)
Get $70 off instantly. Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card.

In Stock.
Get it tomorrow, Feb. 10. Order within 22 hrs 42 mins and choose One-Day Shipping at checkout. Details
Ships from and sold by Amazon.com. Gift-wrap available.

Color: Black

- Foldered bead 20-inch tire
- Fits rims 1.5-2.125 inch
- For BMX, freestyle, or other 20-inch bikes

Used & new (3) from $8.14 | prime
Report incorrect product information.

Part No. 1220

Bell Universal Inner Tube

Bell Sports Cycle Products

Bell Universal Inner Tube

- 4.3 stars • 955 customer reviews | 64 answered questions

List Price: $42.89
Price: $3.77 | prime • Free shipping for Prime members when buying this Add-on Item. Details
You Save: $39.12 (70%)
Get $70 off instantly. Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card.

In Stock.
Get it tomorrow, Feb. 10. Add it to a qualifying order within 22 hrs 40 mins and choose One-Day Shipping at checkout. Details
Ships from and sold by Amazon.com. Gift-wrap available.

Size:

- High quality inner tubes
- Full range of all major tube sizes
- Mold cured rubber for consistent side wall—prevents high pressure blow outs
- Valve size/Type: 35mm Schrader
- Wheel size: 20" x 1.75-2.25"
GLUE THIS SIDE TO TOP OF SEAT CUSHION BASE
WITH LONGER SIDE ON OUTSIDE OF THE SEAT

SOLIDWORKS Educational Product. For Instructional Use Only.
NOTE: FOAM SEAT CUSHION BASE PIECES TO BE GLUED TOGETHER. SUBASSEMBLY DIMENSIONS SHOWN. SEE DRAWINGS FOR 1301-2-1 & 1301-2-2 FOR COMPONENT DIMENSIONS. USE SAME FOAM TYPE AS THE REST OF THE SEAT CUSHIONS. ALL CUSHIONS ARE 2" THICK. SEW 2" WIDE STRAPPING TO UNDERSIDE OF CUSHION ACCORDING TO 1306A AND 1306B.
GLUE THIS SIDE TO SEAT CUSHION BASE WITH THE 22" SIDE ON THE TOP.
NOTE: TOLERANCE = 1/4"

2 - 1.5" X 3.5" VELCRO ONLY ON BOTTOM OF HEADREST TO ATTACH TO SEAT CUSHION

2 - 1.5" WIDE POLYESTER STRAPPING LINES SHOW STITCHING LOCATIONS TO ALLOW STRAPS TO PASS UNDERNEATH
NOTE: TOLERANCE = 1/4"

NOTE: 2 - 1.5" X 3" & 1 - 1.5" X 6" VELCRO TO ATTACH TO SEAT CUSHION
FOR 1304-1: SEW VELCRO ON RIGHT SIDE IN SHOWN ORIENTATION
FOR 1304-2: SEW VELCRO ON LEFT SIDE IN SHOWN ORIENTATION

MATERIAL: POLYURETHANE LAMINATE
VELCRO AND FOAM PROVIDED BY
SLO SAIL AND CANVAS

Cal Poly Mechanical Engineering

Drawn By: KEELY THOMPSON

1304

Title: HIP CUSHION

Net Asb: 1300

Date: 2/8/18

Scale: 1:2

Chkd. By: CURTIS WATKINS
NOTE: 1.5" WIDE POLYESTER STRAPPING
MATERIAL PROVIDED BY SLO SAIL AND CANVAS
MUST WRAP AROUND FRAME TO ATTACH SEAT
MUST INCORPORATE BUCKLE AND D-RING FOR SECURING STRAP AND SEAT REMOVAL

19.00

1.50

2X R0.50
LOOPEED STRAPS THAT ATTACH CUSHIONS TO FRAME [ALREADY MADE]

STRAPPING SEWN ONTO HEADREST CUSHION TO CONNECT LOOPEED STRAPS TO CUSHION
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<th>Part Number: 1306</th>
<th>Description: Polyester strapping</th>
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<td>Cost: Included in cost of seat upholstery</td>
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Part Number: 1307  Description: Polyurethane laminate fabric
Vendor: Wazoodle  Cost: $60 ($12/yard)
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<th>Part Number: 1308</th>
<th>Description: 5-point camlock harness</th>
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<td>Vendor: Summit Racing</td>
<td>Cost: $150</td>
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Part Number: 1309  
Description: Stroller sun canopy  
Vendor: Chicco  
Cost: $35
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<tr>
<th>Part Number: 1310</th>
<th>Description: Rain cover (vinyl and Gore-Tex)</th>
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<tbody>
<tr>
<td>Vendor: SLO Sail and Canvas</td>
<td>Cost: Included in cost of seat upholstery</td>
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</table>
Appendix H: Analysis

Bearing and bushing analysis:

Tongue weight: 50 lbf
Distance from quick release to hub and bearings: 19 inches

Worst case scenario: Hitting speed bump hard at 10mph
10mph=14.667 ft/s

Dimensions of bump (assumed to be triangle):
4 inches high
18 inch base
Half of base: 9 inches

Slope= arctan(4/9)=24 degrees
Hypotenuse of triangle= sqrt(4^2+9^2)= 9.85 inches
V_{vertical}= (14.667 ft/s)(sin(24 deg))= 6.0 ft/s

Time taken to go up bump: (4/12 ft)/(6 ft/s)=0.056 seconds

\[ \frac{dV}{dt} = \frac{6-0 \text{ ft/s}}{0.056 \text{ seconds}} = 108 \text{ ft/s}^2 \]

with this simple calculation, the acceleration is 3.3 times that of gravity, thus the 50 lbf tongue weight increases to 165 lbf when striking a speed bump.

Moment at bearings= (200lbs)(16in)=2640 lbf-in
The bearings are spaced 1.78 inches apart, thus the force on each bearing is
\[ F_{bearing} = \frac{2640 \text{ lbf-in}}{1.78 \text{ in}} + 50\text{lbs} \]
\[ F_{bearing}=1550 \text{ lbs. radial} \]
\[ F_{bearing}=115 \text{ lbs. axial (pulling)} \]

Using a similar process for the bushings:
\[ F_{bushing}=(165 \text{ lbf})(16.5\text{ in})(5 \text{ in}) + (115/2 \text{ lbf from pulling on each bushing}) \]
\[ F_{bushing}=595 \text{ lbf radial} \]
\[ F_{bushing}=165 \text{ lbf radial} \]
### Appendix I: Budget Sheet

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<td>Nuts, bolts, bearings, and bushings</td>
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<tr>
<td>Bike Components and Service</td>
<td>Tires, rims, wheels; wheel building</td>
<td>$420</td>
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<tr>
<td>Seat Service</td>
<td>Headrest, seat cushion, pads, and straps through SLO Sail and Canvas</td>
<td>$970</td>
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<tr>
<td>Fabric</td>
<td>Polyurethane laminate fabric</td>
<td>$117</td>
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<td>Harness</td>
<td>5-point harness</td>
<td>$105</td>
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<td>Weather Protection</td>
<td>Sun canopy ordered online and rain protection through SLO Sail and Canvas</td>
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<td>Powder Coat</td>
<td>Powder coat done at Central Coast Powder Coating</td>
<td>$240</td>
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<tr>
<td>Metal</td>
<td>4130 Chromoly Tubes, billets, and plates</td>
<td>$540 (Donated)</td>
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<td>Total</td>
<td>-</td>
<td>$2,225</td>
</tr>
</tbody>
</table>
Appendix J. Test Procedures

Test 1: Stability - Trailer Tip-Over Test
This test will evaluate the angle at which the trailer will tip. The specification to be met is that the trailer must be able to right itself after a 45 degree roll angle.

Location: ME Department machine shops on a flat surface

Equipment:
- 75 lbs total of assorted weight plates
- Magnetic base angle finder
- Rope or zip-ties

Target: Must right itself from a 45 degree roll

Specification: 3

Procedure:
1. Attach the trailer to the bike. Ensure the trailer fork dropouts are secured down with the attached pins.
2. Orient the bike upright and lock the brakes with zip-ties or rope.
3. Place 75 lbs in the seat of the trailer to simulate Joseph's weight.
4. Attach an electronic angle finder to a horizontal cross-member using its magnetic base. The top of the roll bar or the foot rest are both suitable locations. Zero the angle finder once it is securely attached to the frame.
5. Lift one side of the trailer by the wheel axle; observe that the trailer can right itself after reaching a 45 degree roll angle. Record the maximum angle achieved.
6. Repeat 5 times per side for a total of 10 recorded rollover angles for repeatability and analysis.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Measurement</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57.1</td>
<td>R side</td>
</tr>
<tr>
<td>2</td>
<td>58.1</td>
<td>R side</td>
</tr>
<tr>
<td>3</td>
<td>57.8</td>
<td>R side</td>
</tr>
<tr>
<td>4</td>
<td>53.6</td>
<td>L side</td>
</tr>
<tr>
<td>5</td>
<td>56.6</td>
<td>L side</td>
</tr>
<tr>
<td>6</td>
<td>56.2</td>
<td>L side</td>
</tr>
</tbody>
</table>
Test 2: Bike Rollover Test
This test will ensure that the trailer can stay upright, even if the bike is not.
Location: A flat surface.
Equipment: N/A
Target: Bike must lay down to the left and right; 180 degrees minimum of rotation
Specification: 4
Procedure:
   1. Attach the trailer to the bike. Ensure the trailer fork dropouts are secured down with the attached pins.
   2. Roll the bike to the ground, allowing it to completely lay over. Complete for both sides to ensure the trailer stays upright.

Notes: works.
**Test 3: Quick Attachment Time of Trailer**

This test will evaluate the time it takes to completely attach the trailer to the bicycle.

**Location:** A flat surface

**Equipment:**
- Stopwatch

**Target:** Less than 1 minute

**Specification:** 6

**Procedure:**
1. Separate the bicycle and trailer apart on the ground; both must be at rest and hands off.
2. At the start of a timer, one person must attach the trailer to the bicycle.
3. The stop of the timer will be when the rider is ready to safely roll away.
4. Repeat the attachment process for a total of 3 trials to evaluate the time it takes to attach the trailer.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>19.3</td>
<td></td>
</tr>
</tbody>
</table>
**Test 4: Longitudinal Play in the Trailer Fork**

This test will evaluate the amount of longitudinal play in the trailer fork attachment mechanism. This measured quantity will determine how "rigid" the connection is; ideally there is no play, allowing for a smooth transition between braking and accelerating.

**Location:** ME Department machine shops on a flat surface

**Equipment:**
- Dial indicator
- Magnetic base
- Rope or zip-ties
- Bicycle

**Target:** No more than 0.05 inches of play

**Specification:** 7

**Procedure:**
1. Attach the trailer to the bike. Ensure the trailer fork dropouts are secured down with the attached pins.
2. Orient the bike upright and lock the brakes with zipties or rope. Ensure the rear tire is properly inflated.
3. Mount a magnetic based dial indicator to the frame of the bike trailer; orient the dial indicator so its probe is engaged with the rear wheel of the stationary bicycle. Record the precision of the dial indicator.
4. Pull the trailer frame away from the stationary bicycle; zero the dial indicator. This is the position the trailer would assume when accelerating.
5. With the dial indicator zeroed, push the trailer frame towards the bicycle and record the movement in the dial indicator. Pushing the trailer towards the bike simulates the loading and position of the trailer when under braking conditions.
6. Repeat at least 10 times to evaluate the repeatability and the results of the test.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Measurement</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.015</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.015</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.012</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>.017</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.015</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>.018</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.012</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>.013</td>
<td>Mostly not play – more deflection of frame</td>
</tr>
</tbody>
</table>

Precision of Dial Indicator .001
Test 5: Trailer Weight and Size  
**Location:** Flat surface with access to a bathroom scale  
**Equipment:**  
- Bathroom scale  
- Tape measure  

**Target:** Less than 40 lb; less than 60” length, 30” wide, 40” tall  
**Specification:** 8, 13, 14, 15  

**Procedure:**  
1. Weigh the designated lifter(s) on a bathroom scale and record  
2. The lifter(s) will pick up the whole trailer and stand on the scale; record  
3. Weigh the trailer a total of 3 times, preferably with 3 different lifters  
4. Use the tape measure the measure the final prototype.  

<table>
<thead>
<tr>
<th>Lifter Weight (lbs)</th>
<th>Combined Weight (lbs)</th>
<th>Difference (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>172</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>172</td>
<td>225.6</td>
<td>53.6</td>
</tr>
</tbody>
</table>

**Width:** 33.75"  
**Length:** 63" w/o wheels: 56.6"  
**Height:** 40"
Test 6: Wheel Removal/Install Time Test
This test evaluates the time and ease at which the trailer’s wheels can be removed and installed.
Location: A flat surface
Equipment: N/A
Target: Remove the wheel in under 30 seconds; install the wheel in under 30 seconds
Specification: 10
Procedure:
1. Attach the trailer to a bike on a horizontal surface.
2. With the trailer at rest, remove one of the wheels; the timer starts as the operator touches the trailer and ends when the wheel is completely off and the trailer is rested on the ground.
3. With the trailer and wheel on the ground, install the wheel; the timer starts as the operator touches the trailer/wheel and ends when the trailer is ready to roll away.
4. Remove and install each wheel once, for a total of 4 trials; they should all be similar times.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.11s</td>
<td>Left, remove</td>
</tr>
<tr>
<td>2</td>
<td>11.34s</td>
<td>Left, install</td>
</tr>
<tr>
<td>3</td>
<td>4.61s</td>
<td>Right, remove</td>
</tr>
<tr>
<td>4</td>
<td>9.96s</td>
<td>Right, install</td>
</tr>
</tbody>
</table>
Test 7: Sun Protection Angle Test
This test evaluates the effectiveness of the sun shade system, specifically when the sun is setting or rising.

Location: ME Department machine shops with access to a flashlight or setting/rising sun

Equipment:
- Light source: setting/rising sun or flashlight

Target: The sun shade protects the area where Joseph’s head rests from a vertical and horizontal light source

Specification: 11

Procedure:
1. Attach the trailer to a bike on a horizontal surface
2. Shine light (or mid-day) directly above the trailer vertically; ensure the sun cover provides shade for mid-day riding
3. Shine light (or setting sun) horizontally at the front of the trailer; ensure the sun cover shades the head space for afternoon/evening riding

Notes: Good.
## Senior Project DVP&R

**Date:** 5/17/18  
**Team:** Joseph's Bike Trailer  
**Sponsor:** Michael Lara  
**Description of System:** Bike Trailer  
**DVP&R Engineer:** Ryan Meinhardt

### TEST PLAN

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Specification #</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
<th>Test Stage</th>
<th>SAMPLES</th>
<th>TIMING</th>
<th>TEST RESULTS</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Restraint Force</td>
<td>500lbs</td>
<td>KT</td>
<td>FP</td>
<td>1</td>
<td>Comp</td>
<td>11/3/2017</td>
<td>11/3/2017</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Frame factor of safety check in FEA</td>
<td>2 min</td>
<td>RM</td>
<td>FP</td>
<td>1</td>
<td>Sub</td>
<td>1/18/2018</td>
<td>1/31/2018</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Frame tipover test. Roll frame to 45 degrees and ensure it rights itself</td>
<td>45 degree minimum</td>
<td>RM</td>
<td>FP</td>
<td>1</td>
<td>Sys</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Bike decoupling test. Roll bike to ground in both directions (180 degrees total) and ensure trailer does not tip.</td>
<td>180 degree minimum</td>
<td>CW</td>
<td>SP,FP</td>
<td>1</td>
<td>Sub</td>
<td>1/18/2018</td>
<td>1/25/2018</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Checking for no pinch points</td>
<td>0</td>
<td>RM</td>
<td>FP</td>
<td>1</td>
<td>Sys</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Quick attachment of trailer. Trailer needs to be attached or disconnected from bike in less than 1 min.</td>
<td>1 min</td>
<td>CW</td>
<td>FP</td>
<td>1</td>
<td>Sub</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Checking play in attachment</td>
<td>.05in max</td>
<td>CW</td>
<td>FP</td>
<td>1</td>
<td>Sub</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Weighing of trailer</td>
<td>40lbf</td>
<td>All</td>
<td>FP</td>
<td>1</td>
<td>Sys</td>
<td>5/30/2018</td>
<td>5/30/2018</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Fatigue factor of safety</td>
<td>2</td>
<td>CW</td>
<td>FP</td>
<td>1</td>
<td>Sub</td>
<td>2/1/2018</td>
<td>2/14/2018</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>Checking time to remove wheel from frame</td>
<td>30s</td>
<td>RM</td>
<td>FP</td>
<td>1</td>
<td>Comp</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>Checking sun protection of visor</td>
<td>90deg</td>
<td>KT</td>
<td>FP</td>
<td>1</td>
<td>Comp</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>Rain protection check - spraying with water</td>
<td>IPX4 standards</td>
<td>KT</td>
<td>FP</td>
<td>1</td>
<td>Comp</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>13</td>
<td>13,14,15</td>
<td>Size of device</td>
<td>40inx70inx45in</td>
<td>All</td>
<td>FP</td>
<td>1</td>
<td>Sys</td>
<td>5/29/2018</td>
<td>5/29/2018</td>
</tr>
<tr>
<td>14</td>
<td>Other</td>
<td>Checking quick release for deflection under single side loading</td>
<td>40lbf</td>
<td>CW</td>
<td>SP</td>
<td>1</td>
<td>Sub</td>
<td>1/18/2018</td>
<td>1/18/2018</td>
</tr>
</tbody>
</table>
Appendix L. Uncertainty Analysis of Test Results

Tipover Test:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Tipover angle [°]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57.1</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>2</td>
<td>58.1</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>3</td>
<td>57.8</td>
<td>Tipped to right</td>
</tr>
<tr>
<td>4</td>
<td>53.6</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>5</td>
<td>56.6</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>6</td>
<td>56.2</td>
<td>Tipped to left</td>
</tr>
<tr>
<td>Average</td>
<td>56.6</td>
<td></td>
</tr>
</tbody>
</table>

P 0.99
a 0.005
n 6
v 5
s 1.618229485
t 4.032
stat u 7.04748286
resolution 0.1
total u 7.047660226
low 49.5
high 63.6
<table>
<thead>
<tr>
<th>Trial</th>
<th>Play in hub</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.013</td>
<td>Little play</td>
</tr>
</tbody>
</table>

Average: 0.016

P: 0.990
a: 0.005
n: 10
v: 9
s: 0.002983287
t: 3.25
stat u: 0.010168917
resolution: 0.001
total u: 0.010181202
low: 0.006
high: 0.026
Weight Test:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Holder weight [lbs]</th>
<th>Combined Weight [lbs]</th>
<th>Trailer weight [lbs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>2</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
<tr>
<td>3</td>
<td>172.0</td>
<td>225.6</td>
<td>53.6</td>
</tr>
</tbody>
</table>

average 53.6
s 0
u 0.070710678
hi 53.7
low 53.5
Appendix M: Gantt Chart
<table>
<thead>
<tr>
<th>Task Description</th>
<th>Start Date</th>
<th>End Date</th>
<th>Work Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Harness Support Beams</td>
<td>20/04</td>
<td>23/04</td>
<td>100%</td>
</tr>
<tr>
<td>Mount footplate and fenders</td>
<td>30/04</td>
<td>05/05</td>
<td>100%</td>
</tr>
<tr>
<td>Weld wheel stubs</td>
<td>09/05</td>
<td>13/09</td>
<td>100%</td>
</tr>
<tr>
<td>Weld wheel stubs</td>
<td>24/04</td>
<td>30/04</td>
<td>100%</td>
</tr>
<tr>
<td>Sunshade Mounts</td>
<td>01/05</td>
<td>05/05</td>
<td>100%</td>
</tr>
<tr>
<td>Powdercoated frame</td>
<td>02/05</td>
<td>05/05</td>
<td>100%</td>
</tr>
<tr>
<td>Purchase and Install Hardware</td>
<td>21/06</td>
<td>25/06</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Fork Manufacturing</strong></td>
<td>22/03/18</td>
<td>23/04/18</td>
<td>100%</td>
</tr>
<tr>
<td>Miter Tubes</td>
<td>12/04</td>
<td>12/04</td>
<td>100%</td>
</tr>
<tr>
<td>Machine Billets</td>
<td>22/03</td>
<td>21/04</td>
<td>100%</td>
</tr>
<tr>
<td>Assemble Mechanism</td>
<td>26/04</td>
<td>20/06</td>
<td>100%</td>
</tr>
<tr>
<td>Weld</td>
<td>21/04</td>
<td>22/04</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Seat Manufacturing</strong></td>
<td>22/09/18</td>
<td>31/05/18</td>
<td>100%</td>
</tr>
<tr>
<td>Cut foam and sew strips</td>
<td>22/06</td>
<td>12/06</td>
<td>100%</td>
</tr>
<tr>
<td>Check Seat Foam fit</td>
<td>13/06</td>
<td>15/06</td>
<td>100%</td>
</tr>
<tr>
<td>Route harness</td>
<td>12/04</td>
<td>15/04</td>
<td>100%</td>
</tr>
<tr>
<td>Upholster seat cushions</td>
<td>16/04</td>
<td>20/06</td>
<td>100%</td>
</tr>
<tr>
<td>Install seat and harness</td>
<td>31/06</td>
<td>31/06</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td>08/05/18</td>
<td>27/05/18</td>
<td>100%</td>
</tr>
<tr>
<td>Tip-over test</td>
<td>22/05</td>
<td>21/05</td>
<td>100%</td>
</tr>
<tr>
<td>Brake rotation test</td>
<td>22/05</td>
<td>21/05</td>
<td>100%</td>
</tr>
<tr>
<td>Wheel removal test</td>
<td>22/05</td>
<td>21/05</td>
<td>100%</td>
</tr>
<tr>
<td>Brake attachment</td>
<td>22/05</td>
<td>21/05</td>
<td>100%</td>
</tr>
<tr>
<td>Measuring play in attachment</td>
<td>22/05</td>
<td>21/05</td>
<td>100%</td>
</tr>
<tr>
<td>Fit check with Joseph</td>
<td>05/06</td>
<td>05/06</td>
<td>100%</td>
</tr>
</tbody>
</table>
Appendix N. User’s Manual

Before loading Joseph:
- Check that tires are pumped to 10 psi under the max pressure specified on the tire.
- Check that all straps to secure seat are tight.
- Check that the hub mechanism is tight by ensuring that the dot on the tightening nuts are aligned.
- Check that the leash between the trailer and the attachment mechanism is secure and not tangled.

Before riding:
- Check that the pins on the attachment mechanism are in place on the bottom side of the Bob Gear quick release.
- Check that the harness straps are tightened properly and camlock is locked.
Damage repair:

- Seat, Strapping, or Rain Cover
  - SLO Sail and Canvas
    - Slosailandcanvas@yahoo.com
    - (805) 479-6122
    - 645 Tank Farm Rd G, San Luis Obispo, CA 93401

- Frame or Attachment Mechanism
  - Gentry Welding & Fabrication
    - gentrywelding@sbcglobal.net
    - 805.544.4130
    - 733 Buckley Road Unit D San Luis Obispo, CA 93401

- Wheels
  - Art's Cyclery
    - info@artscyclery.com
    - (800) 626-3440
    - 181 Suburban Rd, San Luis Obispo, CA 93401

Replacement:

- Quick release axle
  - BOB gear

- Sun Cover
  - Chicco Bravo Replacement Canopy

- Sun Cover Extension
  - https://www.amazon.com/gp/product/B00CB9DKZU/ref=oh_aui_detailpage_o01_s00?ie=UTF8&th=1

- Harness
  - Summit Racing
    - https://www.summitracing.com/parts/gfr-7570bk

- Wheel components
  - Rims: https://www.amazon.com/SunRingle-Rhyno-Holes-Black-Schrader/dp/B001C6BPF0/ref=pd_sbs_468_8?_encoding=UTF8&pd_rd_i=B001C6BPF0&pd_rd_r=VANHX97K0MRQXYY1F79B&pd_rd_w=wrbWX&pd_rd_wg=OXBaR&psc=1&refRID=VANHX97K0MRQXYY1F79B
  - Hubs: https://www.amazon.com/HUB-FT-OR8-MT3100-36x110x20mmTA/dp/B004E3PADG
  - Tires: https://www.amazon.com/Continental-Ride-Trekking-Bicycle-700x32/dp/B01MECUJIF2/ref=sr_1_1?ie=UTF8&qid=1522776394&sr=8-1&keywords=continental+ride+tour
  - Tubes: https://www.amazon.com/dp/B00WFSNL9W/ref=twister_B00WJZATLY?_encoding=UTF8&psc=1
Use Instructions

Wheel removal & installation

Removal:
1. Unclip and remove axle pin
2. Remove axle and wheel from frame by pulling on the wheel
3. Separate the axle and wheel if desired

Installation:
1. Insert axle through hub of wheel. Make sure the direction of the tread matches the left or right side of the trailer and axle. The bolt pattern should be closest to the frame.
2. Install the axle and wheel into the frame. Align the axle so the “L” or “R,” for left or right side, is upright and can be easily read.
3. Install and clip the axle pin.
Sun cover adjustment
The sunshade parts are standard stroller parts. The black, base sunshade can simply be pulled forward or collapsed. The red sunshade extension is stretched over the base sunshade and attached to the trailer with a buckle running underneath the frame and S-hooks looped around the vertical tubes near the headrest. The extension angle can be changed by simply stretching the extension into its desired location. The extension can also easily be removed if it's not needed.

Seat installation & removal
1. Feed the straps through the loops on the back of the base and upper seat cushions and headrest.
2. Attach the straps to the frame and tighten the straps.
3. Velcro the footrest, thigh, and leg booster cushions in place.

Harness operation
1. Ensure that each strap is securely fastened to the frame
2. Ensure that the straps are routed with no twists.
3. Place Joseph in the seat and engage the cam-lock. Adjust each strap so he is secure, but not over-constrained.

Tire pressure
1. Pump the tires to around 10 psi under the max pressure specified on the tire using a Schrader valve tire pump.