Rebekah's Ride

Mechanical Engineering Senior Project

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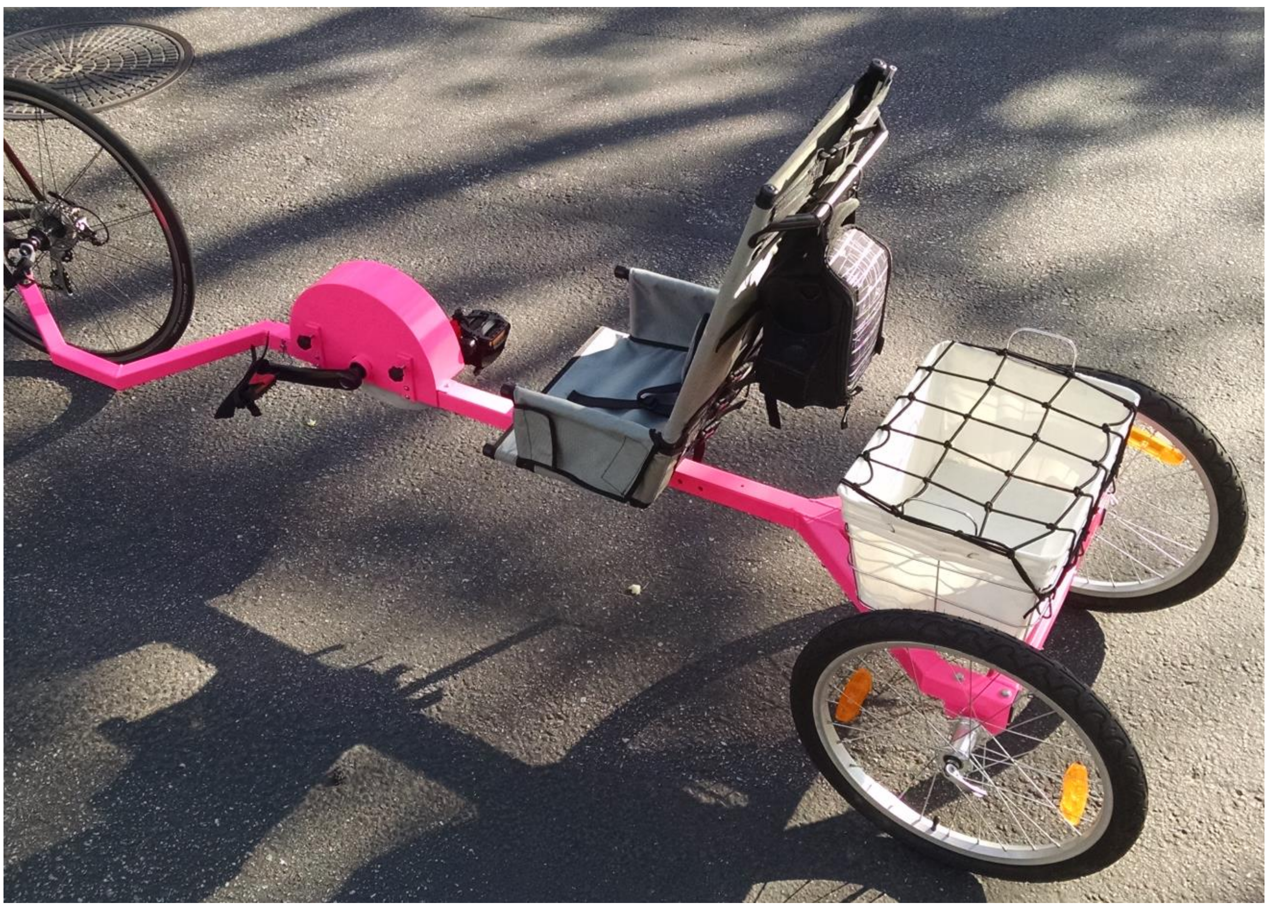

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1.0 Introduction

Our team, Rebekah's Ride, consists of four California Polytechnic State University (Cal Poly), San Luis Obispo mechanical engineering students: Cameron Weinberg, Kelly Perkins, Jacob Hentzler, and Alex Rowson. Drusilla Potts, a Cal Poly kinesiology student assisted our team throughout the project as well. We accepted a design challenge presented by Michael Lara of Special Olympics in the San Luis Obispo region, on behalf of one of their participating families. Rebekah's Ride was advised by Professor Sarah Harding, of the Cal Poly mechanical engineering department.

It was our mission to design and build a bicycle attachment that provides a safe, comfortable, and entertaining ride that can attach to any common bicycle for Rebekah, a 12 year old girl living with cerebral palsy. While she is not confined to a wheelchair, she needs assistance with walking. Rebekah is expected to grow taller, but will most likely remain at a lower weight compared to her peers, as her metabolism is very fast due to cerebral palsy tightening her muscles. The tightening of her muscles also means she has the strength to be capable of pedaling a bike. Rebekah has performed in the Special Olympics in the field of gymnastics. She loves being active and feeling movement.

2.0 Background

The overall goal of our team's background research was to familiarize ourselves with Cerebral Palsy in general and with bicycle trailers that are already on the market. We researched various types of trailers and previous projects by Cal Poly students with similar components to our project. After learning more about the customer requirements, we supplemented our initial research with research on electric motors for bicycles.

2.1 Cerebral Palsy and the Benefits of Exercise

Rebekah is living with cerebral palsy, a disorder of varying severity. Cerebral palsy is a neurological disorder caused by brain injury that results in the impairment of body movement and motor function.[1] The brain trauma that results from cerebral palsy can occur anytime between fetal development and infancy. Not everyone with cerebral palsy is considered to have a disability. Since cerebral palsy is a disorder and not a disease, each case is specific to the individual. Some individuals show very little issues with motor skills and movement, while others are confined to a wheelchair, or struggle with motion on one side of their body. The same is true with the mental capabilities of individuals with cerebral palsy. Usually other underlying developmental brain abnormalities accompany cerebral palsy. [2]

Exercise is very important for human life, including those living with cerebral palsy. The type, and amount of exercise performed varies from individual to individual. Cardio and muscle strengthening of weak muscle groups are extremely important exercises for those with cerebral palsy.[3] Since the severity of cerebral palsy varies so greatly, there is not a directly accessible marketplace for exercise equipment designed specifically for those with cerebral palsy. Types of exercises include the following: arm cycling, stair climbing, chair aerobics, dancing, jogging, leg cycling, exercise bands, rowing, swimming, walking, water aerobics, wheeling (in a wheelchair), yoga, and Tai Chi.[4] Rebekah enjoys bicycling, so the trailer we built is specifically designed to meet her and her mother's needs.

2.2 Types of Bicycles Trailers

There are many different bike attachments that allow parents to bring their children along with them on their bike ride. Parents purchase attachable trailers for their children that are not yet able to ride a bike on their own. These existing devices are not designed to incorporate the size of older children and adults, or they pose safety problems for the rider. Problems and difficulties also arise for the parents before, during, and/or after operation.

Rebekah's parents were originally using the Weehoo iGo Pro Bicycle Trailer (Figure 1). This trailer is just under 30 pounds, contains one wheel, and is made for children up to 52 inches and 65 lbs.[5] The trailer had been a great product for the family, but Rebekah was beginning to surpass these height and weight limits, so she was very uncomfortable during the operation of the trailer. Also, with only one wheel, the trailer is unstable while the towing bike is stopped. On the other hand, having just one wheel provides easier turns than trailers with two or more wheels. In addition, the Weehoo bike trailer is low to the ground, which is a safety hazard for Rebekah's swinging or dangling hands while riding, but it does help keep a low center of gravity.

Figure 1: Rebekah's old bicycle attachment (Weehoo I-Go Pro)
Source: *Weehoo IGo Pro Bike Trailer*[6]

There are desirable details of the Weehoo bike trailer that her mother wanted to see carried over into the new design. The bike trailer has a three-point, over-the-shoulder harness system which allowed Rebekah to stay safely in the seat. The bike trailer is also as narrow as a standard bike, making it ideal for riding through tight spaces and alongside roads. The bike has storage pouches that are not only great for storing needed items, but keep Rebekah's hands away from the back wheel. There are pedals that Rebekah could use to help pedal and exercise; however, most of the time Rebekah lacked a desire to pedal. The new bicycle attachment had to encourage Rebekah to pedal.

Other trailers, such as the WeeRide Co-Pilot (Figure 2), are made to accommodate children ages 4 to 10 years old; however, they lack the safety requirements needed for Rebekah. The bike trailer has a weight limit of 75 lbs.[7] and does not have a secure recumbent seat. The WeeRide Co-Pilot does provides pedaling capability, which is a feature that is desirable for Rebekah.

Figure 2: WeeRide Co-Pilot
Source: WeeRide Co-Pilot[8]

A third type of bike trailer we found was a recumbent canopy bicycle trailer like the Instep Quick N Ez (Figure 3). While this bike has positive aspects like recumbent seats, two foldable wheels that allow the bike attachment to stand on its own, and five-point harnesses, it is obviously made for smaller children. This product, which is designed to carry two children in it, has a maximum carrying weight of 80 lbs.[9] It also does not allow the passenger to pedal and is not narrow enough for Rebekah's mother to easily maneuver between obstacles.

Figure 3: Quick N Ez Bicycle Trailer
Source: Quick N Ez Bicycle Trailer[10]

2.3 Previous Design Work

A search was done on similar past senior projects completed by students at Cal Poly. Although no project was found identical to the one presented to our group, there were a few projects that had components that could possibly be adapted to Rebekah and her mother's requirements. First off, a group that worked on the Adapted Recumbent Bike in 2010 did extensive research on a comfortable recumbent seat for their customer. They found four viable options: the Ventisit for about $100, memory foam for about $20, gel padding, and mini cell foam.[11] The cell foam option was chosen, and was provided by Dr. Kevin Taylor of Cal Poly's kinesiology department. This could have been adapted to specifically fit Rebekah's trailer.

Another interesting project was the Quadricycle in 2010. The group incorporated a hand crank system in addition to a traditional foot crank mechanism.[12] This allowed the user to power the device using their arm motion or leg motion. Since Rebekah is very active, especially with her arms, we looked into a similar design to let her exercise with her upper or lower body. After further understanding the customer requirements, we ruled out the option of having a hand crank system due to the hazards present for Rebekah's active hands.

2.4 Electric Bike Motors

After testing the old bicycle attachment that Rebekah and her mother use, we found that using a chain drive on the bicycle attachment to help push the driving bike would not be necessary. This is because even when Rebekah is pedaling, the added torque is only great enough to feel when going up large hills at a slow speed. A motor on the lead bicycle can add this torque instead. The motor can provide a greater amount of energy to assist Rebekah's mother up the hill. Additionally, Rebekah's mother will not have to worry about stalling the bike when Rebekah decides to stop pedaling. With an electric motor, Rebekah's mother will be able to choose when she desires to use the motor's added power.

There are two types of motor systems that would be feasible on the family's bike that is used to drive the bicycle attachment. The first type, hub motors (Figure 4), are motors that are directly incorporated into the hub of the front or rear wheel. With this type of motor, the correct sized wheel with the motor already on it can be bought and installed within minutes. The other feasible type of motor for the family's bike is a mid-drive motor system. In this system, the motor is mounted near the crank set of the bike. The motor shaft is then connected to the crank set by a belt or chain. This mechanical engagement drives the crank set, which in turns drives the back wheel through the bike's current drive train. A mid-drive motor system can be seen in Figure 5.

Figure 4: Front and Rear Wheel Hub Motors Adapted from: Dual-Drive Sports Ebike[13]

Figure 5: Mid-Drive Motor Attached near Bottom Bracket Source: GNG Gen-2[14]

Both of these motor systems have advantages and disadvantages. A mid-drive motor uses the existing drive train to help the rider choose the gear ratio he or she wants to use. Most hub motors just drive the wheel or wheels that they are joined to, not allowing the rider to choose a desired speed or torque. A mid-drive motor has great weight distribution because it places the motor near the center of gravity of the bicycle, offering more stability than a hub motor system. The mid-drive motors are more efficient, but they are also more expensive. Hub motors are generally quieter, easier to maintain, and don't cause wear on the pedal drivetrain like mid-drive systems do.

3.0 Objectives

As stated earlier, Rebekah loves to go on bike rides with her family. Our primary goal was to design and build a bicycle attachment for Rebekah that provides a safe, comfortable, and entertaining ride that can attach to any common bicycle. With this device, Rebekah will be able to comfortably exercise and enjoy an excursion with her family. After a meeting with Rebekah's mother and Michael discussing requirements and considerations for the device, we developed a list of specifications and functions to meet and exceed their expectations. In this section we will discuss the customer's requirements, a tool used to develop specifications, our final design specifications, and our plan that allowed us to meet those specifications.

After a discussion with Rebekah's mother, we decided that it was not necessary for Rebekah to drive the wheels of her bicycle trailer. The added torque from pedaling in the Weehoo trailer is not great enough to warrant a chain drive from the crank set to the wheels of the trailer. We made this decision after personally riding around in a lead bicycle and having a rider pedal in Rebekah's old trailer. We noticed the effects of the pedaling were only slightly felt by the person on the lead bicycle. Having no chain drive also eliminated possible pinch points and simplified the bike trailer design. Instead of the chain drive on the trailer, a motor outfitted on the lead bicycle gives Rebekah's mother the extra power when she needs it.

The customer requirement and design considerations can be found in the following sections. The customer requirements were elements of the bicycle that were absolutely necessary in our finished design. The design considerations were elements of the attachment that would have made the bike more appealing to our customer. All of the requirements and most of the design considerations can be seen on the final product.

3.1 Customer Requirements

After interviewing our customers we determined the following list of customer requirements:

- The bicycle attachment must be narrow enough to allow safe travel on all types of roads
- The device should be lightweight enough to be transported by any of Rebekah's family members
- The device will be able to hold items securely and safely
- The device should be able to attach to the back of standard bicycles
- The bicycle trailer will encourage Rebekah to pedal
- The device needs to have a turn radius capable of making turns that their current attachment can make
- The device will be adjustable enough to comfortably secure Rebekah as she grows with her age
- The attachment should last at least 4 years through continuous use.
- The device will safely secure Rebekah in a harness
- The device will have a recumbent seat

These requirements were used to make sure we had engineering specifications that accounted for all of the desires of the customer. We used a tool called Quality Function Deployment (QFD) to develop our specifications. The QFD is discussed below.

3.2 Quality Function Deployment

To ensure that all of the requirements listed by Rebekah's mother were included in our design, we created a Quality Function Deployment diagram (Appendix A). Using this diagram, we were able to relate the customer's requirements with engineering specifications. In order to relate the requirements and specifications, we used a weight factor for each of the customer requirements, which describe the importance of each requirement. The QFD then relates each of the customer's requirements to engineering specifications and calculates the overall importance of each specification. This diagram also allows us to see what devices are currently on the market that either meet, or fall short of the customer's requirements or the engineering specifications. This allowed us to determine where other companies with similar devices are performing well and where the performance could be increased for our specific case.

The QFD showed us that the overall size of the bicycle attachment has a very large impact on our customer requirements. The height, length, and width of the attachment made up about 55 percent of the total specification importance. These parameters affected the safety, comfort, and adjustability, among other requirements of the attachment.

In accordance with our QFD, we created a table that relates our engineering specifications with a target, tolerance, risk, and compliance (Table 1). The target is a numerical value that we aimed for in our design and analysis. The tolerance column identifies the specification of the target number. For example, in our table, the tolerance shows us that our target values were all determined based on the extremes (minimum and maximum) of our requirements. Risk is the feasibility that the target or requirement will not be met in our final design. Risk is measured in high, medium, and low (H, M, L) designations.

Compliance is the method of verification that was be used to prove our targets were met. Compliance was evaluated through four different methods of verification: analysis (A), testing (T), similarity to existing designs (S), and inspection (I). Analysis was verified through engineering analysis and modeling. Testing was verified through physical testing of our product. Similarity was verified through current standards and similar existing technologies. Inspection was verified through physically looking at the product.

After more research and another meeting with Rebekah and her mother, we reconsidered a few of our engineering specification values. The values can be seen in Table 1.

Table 1: Engineering Specifications Table

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Max Weight of Device (lbs.)	50 lbs.	Max	H	T
2	Max User Weight (lbs.)	150 lbs.	Max	M	T
3	Max User Height (in.)	66 in.	Max	M	T
4	Max User Width (in.)	18 in.	Max	M	T
5	Max Overall Height of Device (in.)	40 in.	Max	L	I
6	Max Overall Width of Device (in.)	22 in.	Max	H	I
7	Max Overall Length of Device (in.)	90 in.	Max	M	I
8	Zero Reachable Pinch Points (#)	0	Max	H	I
9	Seat movement from prior maximum (+)	+6 in.	Min	L	S,T
10	Time to Learn (min)	10 min	Max	L	T,S
11	Max Number of Components to be Assembled (#)	4	Max	L	I
12	Product Lifetime (years)	7 years	Max	H	A,S
13	Pack Storage ($ft.^3$)	1 $ft.^3$	Min	L	T

The changes made in this table are also reflected in the QFD.

The max user weight was decreased from 200 pounds to 150 pounds. This decision was made because there was already be factors of safety included in our analysis that accounted for a person significantly heavier than 150 pounds.

The max user height was reduced from 70 inches to 66 inches because the possibility of Rebekah growing to be over 66 inches is very small.

The max total width of the device was increased from 18 inches to 22 inches. By making the max width 22 inches (similar to the width of the handlebars of an average bike) we gave ourselves room to make Rebekah's seat as comfortable and as safe as possible. However, after purchasing off the shelf parts for the wheel and axle assembly, we exceeded our max width by just under 2 inches. Exceeding this limit is justified later in the report, in section 6.6.

The max overall length of the bike was originally said to be 96 inches but after additional research we decided that 90 inches would allow for more stability.

The adjustability of the seat was originally designed to be a range of 12 inches, but after reviewing pedaling ergonomics and Rebekah's body dimensions, we decided that a six inch range of seat adjustability was adequate.

Since the critical design review, we realized that there is no reason to have the seat any closer to the pedals than what is the farthest point on the Weehoo trailer. Therefore, we changed the specification to be six inches of adjustability longer than the current location of her Weehoo trailer.

3.3 High Risk Specification Discussion

Previously, our team found four high risk specifications that we identified in Table 1. Our highest risk engineering targets were the following: max weight of the device, max width of the device, pinch points, and product lifetime.

The max weight of the device was originally designated as high risk because of the possibility an electric motor be included in the design. It was decided that the motor would be attached to the lead bicycle rather than our trailer attachment, so the weight of the motor will not be factored into our design. There was still a risk of exceeding the max weight of the device, but it was less likely now that the motor would not be factored in, so the risk was downgraded to medium.

We purchased an axle and wheel assembly from Burley that exceeded our max width specification. We decided to test this to see if it was truly a high risk specification, or if it would be less of a concern for our group. We developed a prototype model that had a track width of 24 inches and tested it behind a bike. We found no issue with this width, and it was still an easy task to keep within the bike lane. More on this topic will be discussed throughout the report.

Having zero reachable pinch points was designated as high risk due to the fact that there are multiple places on a bicycle in which Rebekah could possibly injure herself. We were not as concerned with pinch points that were out of the reach of Rebekah because they would not have posed an immediate threat to her. We needed to make sure that while the bike is in motion, Rebekah could not reach the wheels, ground, pedals, or any other possibly unsafe component with her hands.

The lifetime of the product was the final high risk specification that we identified. The life of the product was dependent on not only our analysis and design, but also on the customer's treatment of the product. We designed our device with this in mind and overbuilt parts that encounter additional wear and stress.

These high risk specifications ended up being all attainable goals with the final product that our team built.

3.4 Design Considerations

In addition to the engineering specifications, we kept many design considerations in mind that we wanted to incorporate through the design process. The original design considerations are listed below.

- Use an electric motor to assist the bike rider up a hill
- Provide tangible positive feedback to Rebekah when she pedals the bike
- Fit in the back of a 2002 Dodge Grand Caravan
- Pink color
- Enough wheels for stability when parked or use a kickstand the deploys when the lead bike is not in motion
- Add suspension to the bike for a more comfortable ride
- Install a device to keep Rebekah's hands in safe positions while still allowing her freedom of movement
- Quick release fasteners for attachment points
- Similar quietness of operation of current attachment used.
- Use a material that is strong, will not rust, and is cost effective.

The electric motor assistance component of the bike is a useful addition to the bicycle trailer. An electric motor will help propel the lead bicyclist and Rebekah up large hills. Hub motor systems are easily adaptable to different bikes and are less expensive the mid-drive systems. They also make the bike look less bulky and provide more than enough power for our customer's intended use.

For selecting a material for the frame of the trailer, three materials were originally considered for the tubing: Aluminum 6061-T6, general 1020 steel, and a 4130 steel alloy. The aluminum chosen is a common aluminum for bike frames. Aluminum is a popular material due to its low weight, high stability, and resistance to corrosion. Of the three selected materials, aluminum is generally the most expensive. The "T6" simply means the aluminum is tempered to make the material stronger. General 1020 steel is just a basic, everyday iron/carbon composition of steel. 4130 steel alloy is commonly referred to as chrome-moly because of its alloying elements, Chromium and Molybdenum that add to its strength.[15] Chrome-moly is stronger than 1020 steel with roughly the same density, so theoretically there is less material needed for the same strength, resulting in a lighter frame than 1020 steel. A decision between cost, strength, and weight was made to optimize our design and will be discussed later.

4.0 Idea Generation

During the ideation phase of the design development process, our team used techniques such as brainstorming, brainwriting, SCAMPER (Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, Rearrange or Reverse), and other methods to bring forth possible solutions to the given problem. Since the bicycle trailer is a complex overall design, we focused on idea generation for individual subcomponents. These subcomponents included the type of bike seat to provide the most comfort to Rebekah, the adjustability of the seat, the method of attaching the bicycle trailer to the lead bicycle, the motivation device to encourage Rebekah to continuously pedal, the number of wheels to be on the trailer and where to place them, and the shape of the frame.

4.1 Brainstorming with Identifying Functions

A simple brainstorming activity our team did included identifying bicycle functions composed of a verb followed by a noun. Our shared verb/noun combinations included ‘protect child’, ‘push pedal’, ‘attach bicycle’, ‘adjust seat’, and ‘stabilize bicycle’. Using ‘protect child’ as an example, we gave ourselves about 3 minutes for each header to come up with as many descriptions of that header as possible. The polished version of this session is shown in Table 2.

Table 2: Brainstorming Table with Identifying Function

Protect Child	Material	Shape/Position
Strap-in	Nylon	Rectangular
Surround	Rubber	Recumbent
Raise	Plastic	Sphere
Block	HDPE/LDPE	Upright
Enclose	Cloth	Suspended
Absorb	Aluminum	Saddle
Flex	Memory Foam	Airfoil
	Cotton	Flat
	Fiber	
	Water	

4.2 In Class Modeling

Exercise is a key aspect to bicycle riding. For those with Cerebral Palsy, exercise is vital to stretch muscles that are ordinarily extremely tight. In one of our lab sections, we modeled ways to help motivate Rebekah to pedal. Some example ideas that we generated included a picture that illuminates that Rebekah can only see when she is pedaling, a mechanical and visual device that would rotate and rise up and down (Figure 6), and music that would play only while Rebekah was pedaling.

Figure 6: Mechanical Motivation Model

A key aspect to the comfort of the trailer is the seat. We considered a few different bike seats including a regular bicycle saddle, a recumbent bike seat, a straight-backed seat, and a design similar to a car seat. We modeled a straight-backed bike seat out of cardboard that can be seen in Figure 7.

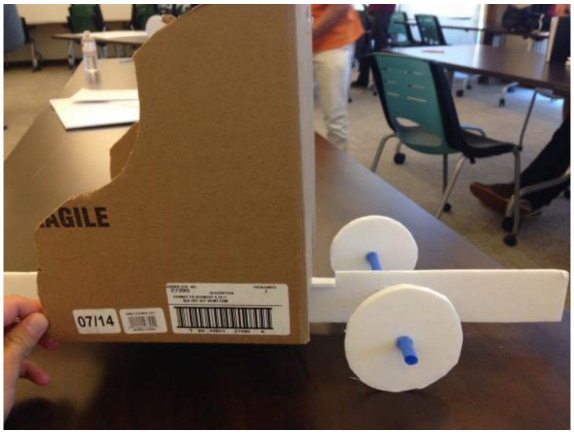


Figure 7: Straight-backed model

4.3 PVC Modeling

Frame consideration for our team was not a high priority to begin with. We agreed that once all of our other subcomponents were decided upon, we could design our frame around those subcomponents. With this being said, we still wanted to have an idea of a few basic frame designs to consider. Three basic frames were created and can be seen in Figure 8. The first is a simple 'T-Beam' design that only has one main beam down the center with the rear hub coming off the back. The second is a 'box frame' design which has 2 main beams that come together in the back for the rear hub. Finally, the third design is a 'Y-Frame' design that has 3 beams down the center all connecting to the rear hub area. Note that these designs were made to scale as close as possible with the PVC fittings that were available. Since only 45 degree bends were available, the Y-Frame design was much wider than would have actually been if we were working with metal, but it still provided an idea of the general shape of the frame.

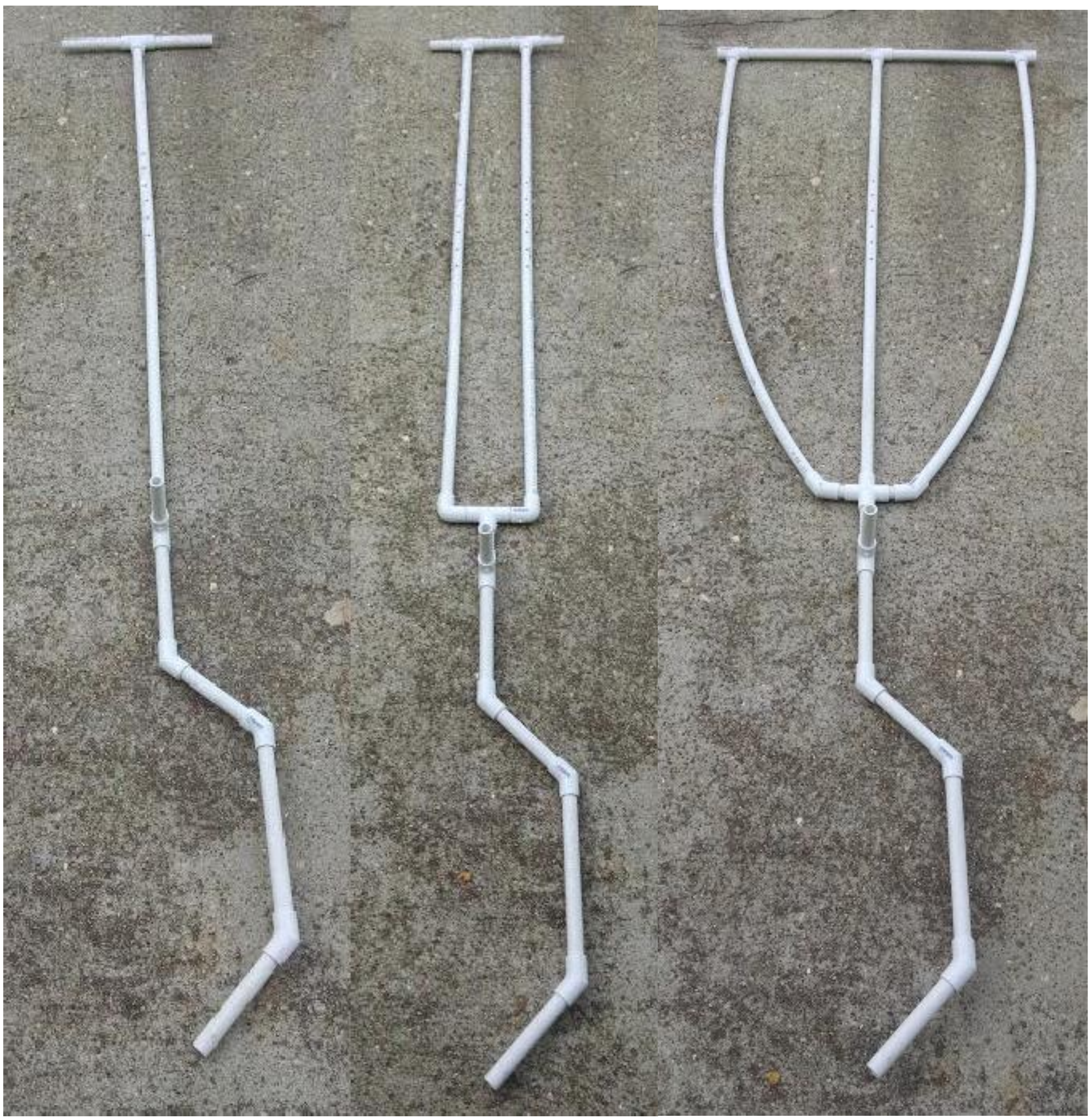


Figure 8: PVC Frames from Left to Right: "T Beam", "Box Frame", "Y- Frame"

4.4 Other Techniques

A lot of our background research was actually implemented for idea generation. Analyzing and comparing various designs already on the market let us make alterations specific to Rebekah. For example, we were stuck on the idea that a seat post attachment was the best option moving forward; however, since we discovered a trailer design similar to that of the one shown in Figure 3, we decided to purchase one on Craigslist to test it out. Turns out from our testing, that the attachment point on the rear hub of the lead bicycle was far superior. After towing this trailer behind one of our personal bicycles, we immediately noticed this trailer was easier for the lead rider. Even with a 175 pound college student riding in the back, the attachment point on the hub had more degrees of freedom, allowing the lead rider to feel more stable on their bicycle.

Another interesting idea generation tool we used was walking backwards while thinking of solutions for the attachment of the trailer to the lead bicycle. This helped stimulate creativity in our minds, and is where we came up with an idea of a 'tow hitch' and 'ball-in-socket' idea to increase the range of motion from the trailer that Rebekah's family uses. This idea was proven correct with our Craigslist trailer experiment as just discussed.

All of the techniques we used for idea generation helped us brainstorm a variety of ideas for solutions to the proposed problem from our customer. With all of these concepts, our next step was to eliminate extraneous ideas and eventually choose a top concept for each subsystem.

5.0 Decision Process

In order to narrow down our concepts for each subsystem, we used a graphical method called design matrices with a weighting system to compare our top few ideas for each subsystem. In a design matrix, the old trailer design along with the new designs are placed in columns, while a list of parameters are placed in rows. Each parameter was given a weight value between one and ten, depending on the importance of the parameter for our customer. The more important parameters were given high valued numbers while the less important parameters were given lower valued numbers. The Weehoo trailer design was set as the datum and for each parameter, each new idea/concept is compared directly to the datum. If the new design is superior to the datum, it receives a "+". If the new design is inferior to the datum, it receives a "-". Finally, if the new design is similar to the datum, it receives a "0". The weight value of the parameter is multiplied by the "+" or "-" designation, and then summed in each column giving each concept a total score. Scores with the highest positive values were considered superior, while scores with the greatest negative values were considered inferior to the datum.

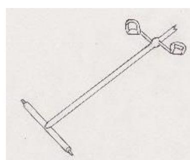
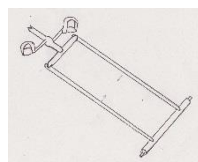
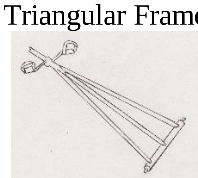
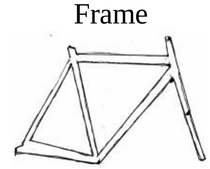
We created six of these decision matrices to decide the final design of the main subcomponents of the bike trailer. We have decision matrices for adjustability, attachment to lead bike, motivation to pedal, seat, wheels, and frame. Each individual decision matrix is shown and discussed in their respective sections below.

5.1 Frame

It was important that the frame allowed for easy adjustment of the seat when necessary. Also, the frame had to be able to handle the max load with a factor of safety added on. The design matrix for frame concepts can be found in Table 3. Initially, it was thought that the two bar design would best suit our requirements.

After getting further into our detailed design, we found that a single bar running down the centerline of the frame would be the best design to incorporate the seat and the wheels that we had selected. Our choice of aluminum as the frame material also led us to make this decision for frame geometry. Specifics will be discussed later in the subcomponent detailed design section (section 6).

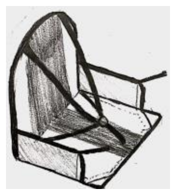
Table 3. Frame Decision Matrix

Parameters	Concepts				
	Weight	One Bar 	Two Bars 	Triangular Frame 	Standard Bike Frame 
Height	3	0	0	0	-
Load Capacity	7	0	+	+	+
Width	7	0	-	-	0
Ease of Creation	5	0	0	0	-
Attaching Adjustable Seat	9	0	+	-	-
Total		0	+9	-9	-10

5.2 Seat

Seat consideration was based mainly on safety for Rebekah. Rebekah's mother strongly urged that the seat keep her safe while riding. Safety and three point harness compatibility proved to be the most important parameters of this decision matrix as seen in Table 4. A slightly recumbent seat proved to be the most successful concept because of its ability to have the required three point harness and to have high side walls to keep Rebekah's hands from reaching the ground and rotating wheels.

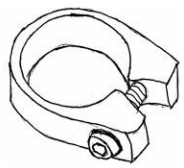
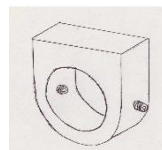
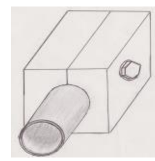
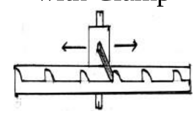
Table 4. Seat Decision Matrix

Parameters	Concepts				
	Weight	Weehoo Seat 	Bike Saddle 	Recumbent Bike Seat With Side Supports 	Car-seat 
Stability	7	0	-	0	+
Comfort	5	0	-	0	-
Finger Safety	9	0	-	+	+
Harness Compatible	8	0	-	0	0
Easy to Use	6	0	+	0	-
Allows User to Move	3	0	+	+	-
Sized for Rebekah	4	0	+	+	0
Total		0	-16	+16	+2

5.3 Adjustability

Seat adjustability is one of the main customer requirements we had because one of the biggest problems with the old trailer is that Rebekah outgrew it. As discussed in our engineering specifications, we wanted the seat to have a range of adjustment of six inches longer than the old Weehoo position. Methods to attach the seat to the frame were explored in this decision matrix which can be found below in Table 5. The most important parameters were 'Strength of Grip' and 'Ease of Use'. It was determined to be imperative that the seat did not come loose at any unintended time. When adjustment was necessary, it should be easy for the customer to loosen the mechanism and adjust the seat as desired. The 'Through Bolt' design proved to be most desirable from our matrix.

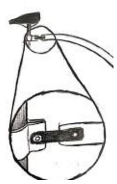
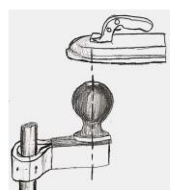
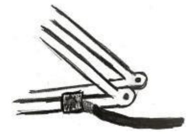
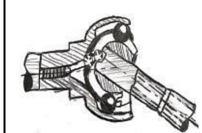
Table 5. Adjustability Decision Matrix

Parameters	Concepts					
	Weight	Quick Release 	Screw Collar 	Set Screw 	Through Bolt or Cotter Pin 	Linear Ratchet with Clamp 
Strength of Grip	9	0	0	-	+	+
Ease to Use	7	0	-	-	-	-
Speed of Use	5	0	-	-	-	0
Durability	7	0	0	-	+	0
Slop	5	0	0	0	+	+
Size	2	0	+	+	0	-
Pinch Points	3	0	+	+	+	-
Cost	6	0	+	+	0	-
Ease of Incorporation	4	0	0	0	-	-
Total		0	-1	-10	+8	-8

5.4 Attachment to Lead Bicycle

The old Weehoo trailer restricted motion from left to right and allowed minimal motion up and down. The new trailer design had to accommodate as many degrees of motion as possible. Since our experience with the old trailer was so negative in this regard, these parameters were the most important for this decision. Another important consideration is the location of attachment to the lead bicycle. This design matrix can be found below in Table 6. Having an arm attach to one side of the frame near the rear hub location was an overwhelmingly superior concept. This concept has since been tested as a prototype, and the results of this matrix are confirmed.

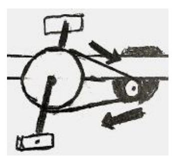
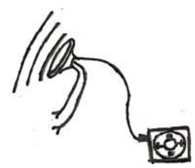
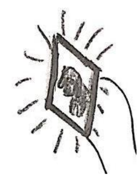
Table 6. Attachment Decision Matrix

Parameters	Concepts					
	Weight	Datum (Seat) 	Tow Hitch(Seat) 	Attachment to Both Sides of Frame 	Attachment to One Side of Frame 	Ball and Socket (Seat) 
Up/Down Motion	7	0	0	0	0	+
Left/Right Motion	7	0	+	-	+	+
Ease of Attachment	6	0	+	0	+	0
Ease of Design	3	0	-	0	0	-
Attachable to Multiple Bikes	4	0	0	0	0	+
Tilt Motion	5	0	0	-	+	+
Durability	6	0	0	+	+	0
Strength of Place Attached	5	0	0	+	+	0
Total		0	+10	+5	+29	+16

5.5 Motivation

A key customer requirement was motivating Rebekah to continuously pedal throughout their family's ride. Since this design consideration is purely based on motivation, the 'fun' parameter was most important to our design matrix which can be found in Table 7. Mechanical systems could prove to be fun for a while, but our team decided that Rebekah would likely grow tired of the same thing over and over. Having her pedaling power a speaker to play music, which she loves, was a great idea to continuously motivate her to keep pedaling throughout their entire trip. Music is something everyone listens to on a daily basis, so Rebekah will not grow tired of hearing her favorite new songs like she would with a mechanical design.

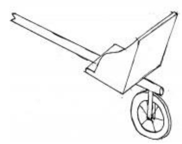
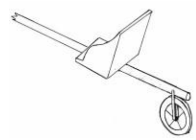
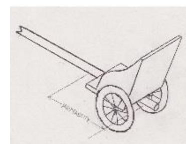
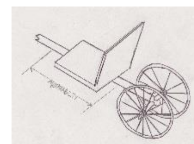
Table 7. Motivation Decision Matrix

Parameters	Concepts					
	Weight	Motivation from Mom 	Motor that Moves Feet 	Moving Mechanical Toy 	Music Player 	Lights Flash 
Cost	3	0	-	-	-	-
Ease to Make	2	0	-	-	-	-
Durability	5	0	-	+	+	+
Long Lasting Effects	8	0	+	0	+	0
Fun	9	0	-	+	+	+
Total		0	-11	+9	+17	+9

5.6 Wheels

The Weehoo trailer only had one wheel, which was not sturdy while riding, especially when coming to a stop at a stoplight or on a hill. Rebekah's mother mentioned that it is very difficult to balance the weight of Rebekah and both bikes when she has come to a stop. This led us to form a design matrix to address this problem. The matrix can be found in Table 8. 'Stability' and 'Safety' were the top two parameters for this matrix because of the stress Rebekah's mother put on both subjects. After completing the matrix, we found that a trailer with two wheels located behind the backrest of the seat is the best concept. A precaution with this design was to be sure that the wheelbase is not wider than an average bicycle's handlebars.

Table 8. Wheels Decision Matrix

Parameters	Concepts				
	Weight	Single Wheel Near Seat 	Single Wheel Behind Seat 	Double Wheels Under Seat 	Double Wheels Behind Seat 
Overall Width	7	0	0	-	-
Overall Length	3	0	-	0	-
Weight	3	0	0	-	-
Stability	10	0	0	+	+
Finger Safety	10	0	+	0	+
Overall Height	2	0	0	0	0
Turning Radius	5	0	-	-	-
Total		0	+2	-5	+2

Using the results from our six design matrices, we came together as a team and discussed the next course of action for our design. Considering our customer requirements, engineering specifications, design considerations, and the results from our design matrices, we narrowed down our choices to our top concepts.

6.0 Final Subcomponent Designs

From the results of the design matrices, we were able to narrow down each subcomponent to one top concept. The individual component designs that we decided would create the best bicycle attachment for Rebekah are discussed below. Each subcomponent discussed is also accompanied by a SolidWorks model and drawing.

Towards the end of the project, we designed a protective shroud to cover the aluminum rotor that is attached to the crank arms of the trailer. Since it was not originally designed with the rest of the trailer, it is not included in detail in any of the following sections. The shroud, and its interface with other components, will be discussed in detail in section 7.5.1 of this report. The solid model of the shroud can be seen in Figure 9.

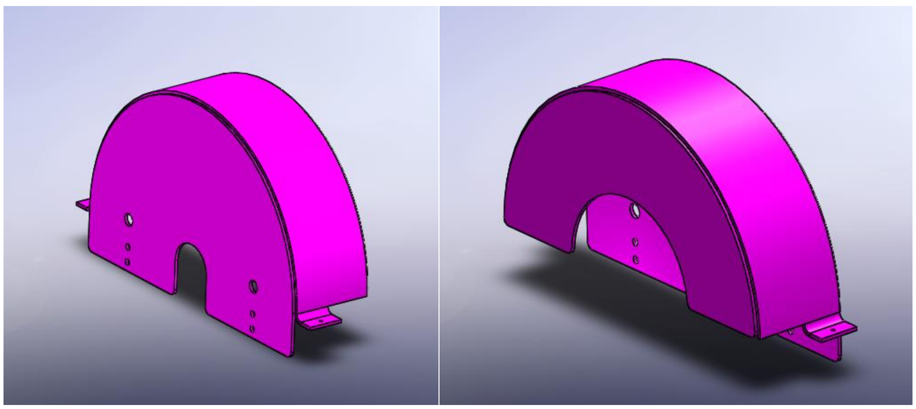


Figure 9. Rotor Shroud Solid Model

6.1 Frame

Initially, according to our matrix, the two bar frame was our chosen best design. The main reasoning for this decision was to eliminate any possibility of the seat attachment point rotating about the round tubing of the frame. Having two bars to mount the seat to would have kept the seat from rotating or tilting. However, since the Preliminary Design Report, we decided to use aluminum square tubing. To see a sketch of our initial idea for the frame, see Appendix B (Figure B1). With the square tubing, we prevented rotation of the seat on the frame without having to use the two bar design. Therefore, we were able to simply use one bar running down the centerline of Rebekah's bicycle trailer. This square aluminum tubing is compatible with the seat, wheels, and attachment to the lead bicycle. It was also easier to weld the pedaling system to the flat surface of the tubing and was easier to weld in general.

1.5 inch square 6061-T6 aluminum with 1/8 inch wall thickness and rounded corners was chosen for the frame to prevent injury with incidental contact to the frame. Tubing was purchased from Precision Machine in San Luis Obispo. The method for choosing these dimensions is discussed in detail later in the Analysis section (section 8.1) of this report. A solid model of the frame design is shown in Figure 10 and the dimensioned drawing for the final frame geometry is provided in Appendix C. The rear horizontal axle section of the frame rests on top of the purchased axle from Burley that is compatible with their quick release wheels (this will be discussed in detail in section 6.6). Holes in the aluminum match the pre-drilled holes provided with the purchased axle. This section is part of our frame to reinforce the axle purchased from Burley and will is secured using four 1/4 inch bolts. Triangular sections were added to prevent any torqueing of the welded center tube and axle tube at the T-joint. There are five 3/8 inch holes in the tubing for seat adjustability that are each spaced one and a half

inches apart from each other. This allowed for 6 inches of adjustability past the old bike dimensions to accommodate Rebekah's future growth. Oxidation and corrosion around the drilled holes in the tubing was not a concern because the frame was made of aluminum instead of steel. The frame was powder coated pink because it is Rebekah's favorite color.

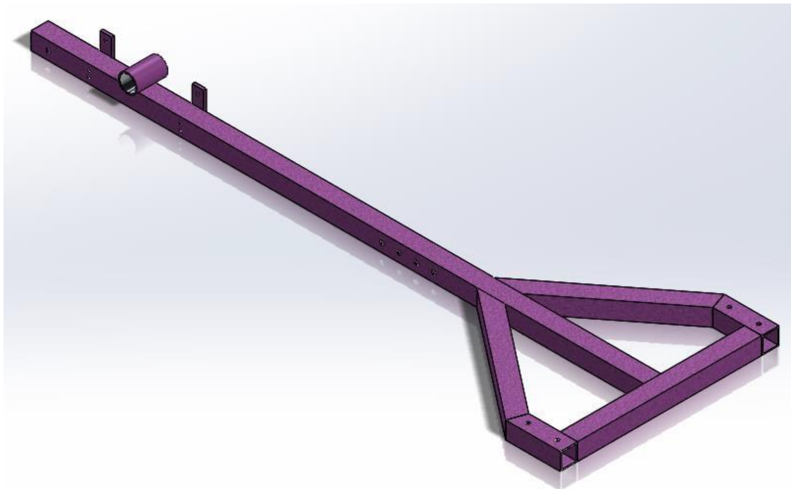


Figure 10. Frame Solid Model

6.2 Seat

We found that a recumbent bike seat with side supports and a three point harness was the most comfortable and the safest seat for Rebekah's bicycle trailer. A sketch of our original idea of the seat can be found in Appendix B (Figure B2). After looking at the possibility of buying seats already manufactured, we realized that there was nothing that fit our safety and ergonomic requirements for Rebekah. Therefore, we decided to design our own frame for the seat, and send it off to have a custom seat stitched with a three point harness system sewn into the seat fabric. The seat and harness dimensions were based off of Rebekah's Weehoo seat, but sized better to fit her current and predicted future dimensions. The solid model of the seat is shown in Figure 11 and the dimensioned drawing of the seat frame is shown Appendix C.

Figure 11. Seat Solid Model

The seat was sent to Chris Gentry at Gentry Welding to be welded according to our dimensions. After this was completed, it was transferred to Mitch's Stitches in San Luis Obispo to have the seat fabricated around the frame. After talking with Mitch and considering his suggestions for our project, we decided to use Cordura fabric, purchased from Quality Stitches in San Luis Obispo, as our material for the seat. This fabric is similar to nylon, is weather resistant, and is durable. The seat was stitched similar to the seat seen in Figure 12 and Figure 13.

Figure 12. Example of TerraTrike Seat[16]

Figure 13. Back of TerraTrike Seat

Harness straps made from Nylon were used with a 3 way split release buckle, purchased from the Strap Works online website, to secure Rebekah in her seat. Specification sheets for these components can be found in Appendix D (Figure D1).

Behind the seat, we affixed a storage basket to the frame. This storage allows Rebekah's family to carry personal items with them on rides. The storage basket includes a bungee net to secure personal belongings within the basket in order to reduce the chance of anything falling out while the bicycle trailer is in motion. The basket was chosen to be large enough to fit a standard sized backpack.

6.3Adjustability

In order to adjust the position of Rebekah's seat as she grows with age, a mechanism had to be designed to hold the seat in a secure and safe position to the frame. With our initial idea of round tubing for the trailer frame, we thought the best design would be a clamp that enclosed the bicycle frame tube with two blocks of metal. There would have been a bolt fastened through a hole in the blocks and the frame. Since we have decided to use a single bar frame with square tubing, these blocks were unnecessary. An initial sketch of this idea is presented in Appendix B (Figure B3).

Our alternate design was similar in nature, but less complex. Two 1/4 inch pieces of aluminum flat stock were welded to the bottom of the seat frame. These flat stock pieces straddle the 1.5 inch square tubing of the frame and have 3/8 inch holes drilled in them to match up with corresponding holes in the frame. A 3/8 inch SAE Grade 8 bolt is placed through the flat stock pieces and the frame tubing, and is secured using a corresponding nut with a split lock washer to hold the joint tight during vibrations caused by everyday use. This design allowed the seat to slide on the frame to be adjusted as Rebekah grows with age. The solid model of the seat attachment design is shown in Figure 14 and the dimensioned drawing is shown in Appendix C.

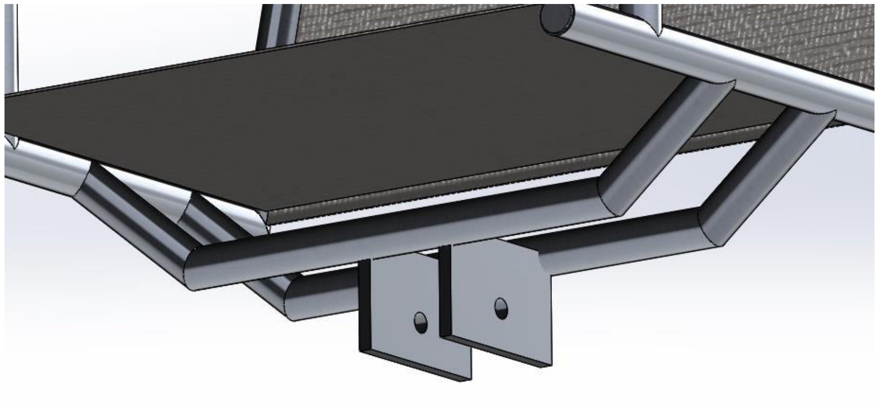


Figure 14. Seat Attachment Solid Model

6.4 Attachment to Lead Bicycle

The best attachment point for securing Rebekah's trailer to the lead bicycle is near the axle of the rear wheel of the leading bike. From our testing, we found that a lower securing site allows for a more stable ride. A sketch of the rough location of the attachment point can be found in Appendix B (Figure B4).

6.4.1 Attachment Device

As stated, attaching to only one side of the wheel allowed for easier turning compared to the old Weehoo model. Our team decided that purchasing this component greatly outweighed the potential time spent and cost of designing and manufacturing the attachment device. Therefore, we purchased the Burley Standard Forged Hitch along with the Burley Flex Connector.

Burley is a well renowned bicycle trailer manufacturer, and their replacement parts can be incorporated to our trailer design. Since these are purchased parts, drawings and specifications are not available to us; however, we do know that the flex connector is compatible with 1 inch inner side dimension of square tubing. To accommodate this requirement, we stepped down our 1.5 inch square tubing for the frame to 1 inch square tubing for the attachment arm of the trailer. The specifics of this joint are discussed below in section 6.4.2. The attachment arm of our trailer has a hole drilled to match the location and the size of the pin that comes with the flex connector from Burley. The standard forged hitch can be easily attached to the lead bicycle by using any standard bike's quick release axle. Simplified solid models of the standard forged hitch and flex connector are provided in Figure 15. A specification sheet with the Burley part number and price can be found in Appendix D (Figure D2) for the standard forged hitch and the flex connector.

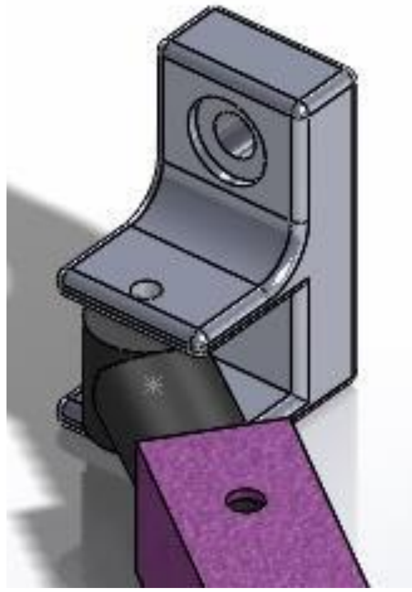


Figure 15. Attachment Point Solid Model

6.4.2 Attachment Arm

The attachment arm serves two purposes in our design: one, to be compatible with the Burley Flex Connector, and two, to allow Rebekah's parents to detach the arm when transporting the trailer. The attachment arm is a 1.25 inch square tube with 1/8 inch wall thickness made of the same aluminum composition as the frame tubing. This gives us an inner dimension of one inch, which is compatible with the Burley Flex Connector. Additionally, the outer dimension is 1.25 inches, which is the dimension of the inner walls of the frame tubing. To attach the arm, it can be placed inside of the frame tubing. A 3/8 inch hole is drilled through both tubes so that a 3/8 inch diameter, 2.5 inch long clevis pin is used to secure the attachment arm inside of the frame tube. The clevis pin is secured with a cotter pin, similar to how a tow hitch is held on to the receiving end on a vehicle. A solid model of this interaction is shown in Figure 16.

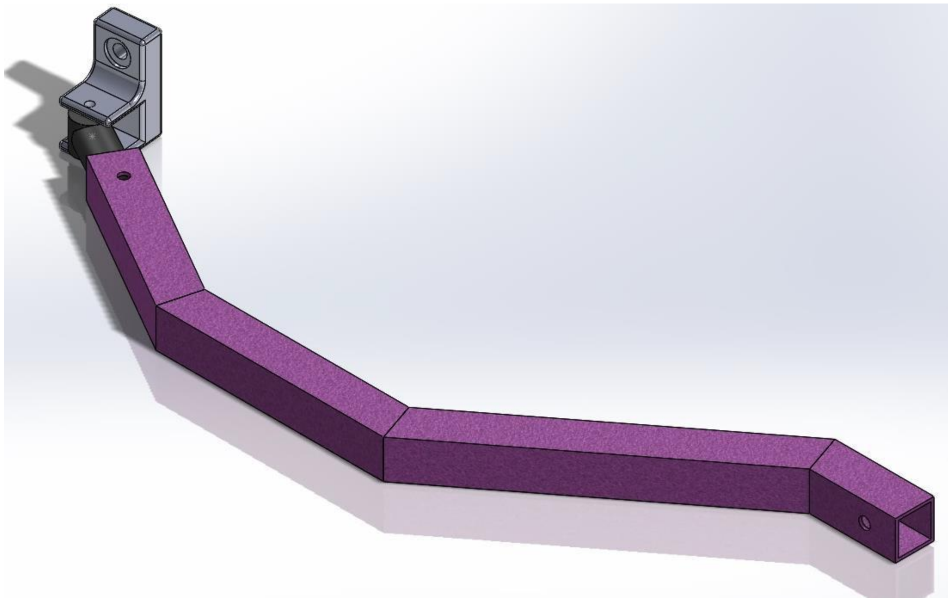


Figure 16. Attachment Arm Solid Model

6.5 Motivation

Rebekah’s pedaling does not contribute to the movement of the bike and is purely for her own exercise. In order to motivate Rebekah to pedal her bike, we decided to have speakers play music as she pedals. This motivation device only plays music when Rebekah is actively pedaling on the bicycle trailer. If Rebekah stops pedaling, then the power will cease and the speaker turn off.

6.5.1 Pedaling System

The pedaling system is built very similar to how regular bicycle pedaling systems are made. A NOVA aluminum bottom bracket shell is welded directly to the top of the frame of the trailer. A Shimano bottom bracket threads into this shell, allowing the spindle to securely spin about a fixed axis perpendicular to the frame. The square tapered spindle interfaces with a Mantra crank set, locking the crank set with the spindle and allowing torque transfer. Weehoo replacement pedals with heel and toe straps are threaded into the end of the cranks. A specification sheet is provided for the pedals in Appendix D (Figure D3). We removed the chain ring attached to the crank set and replaced it with a custom round aluminum plate. This plate will act very similar to a brake rotor. A solid modeling of this system is pictured in Figure 17. The specifications for these parts can be seen in Appendix D (Figures D4 – D6).

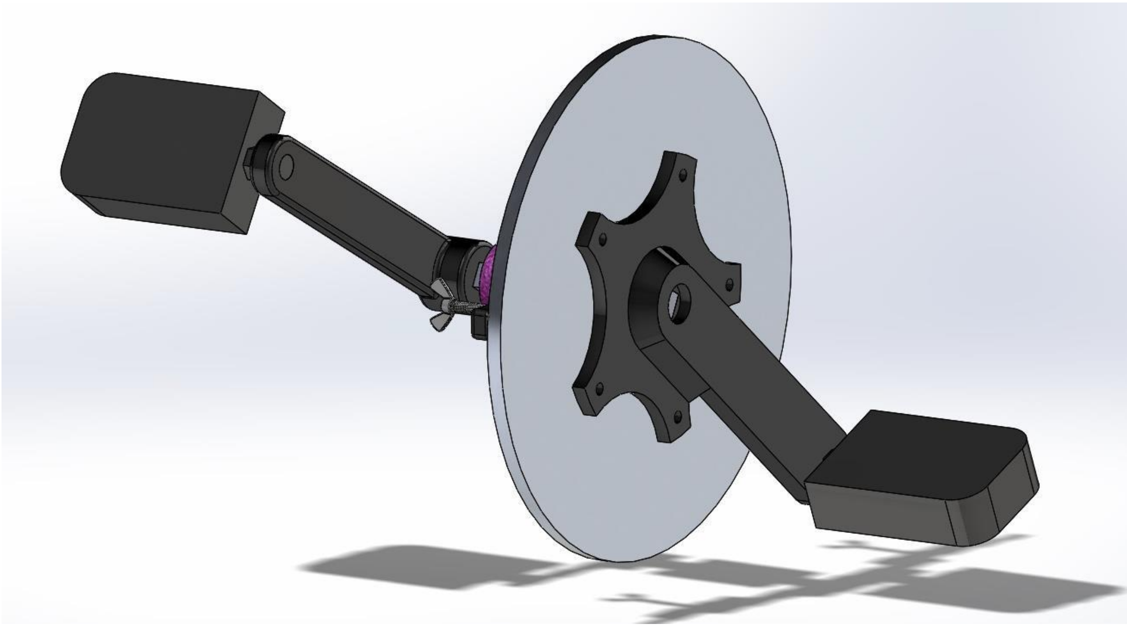


Figure 17. Crankset (Right Side) Solid Model

Providing resistance to Rebekah's pedaling system proved to be a challenge. We looked into many different designs and ideas of how to provide a safe and effective resistance for Rebekah. These designs included direct frictional resistance to the bottom bracket, magnetic resistance on a flywheel, fan/wind motor resistance, and direct frictional resistance on a rotor. We originally thought that magnetic resistance would be the quietest and best option, but it may not provide enough resistance. There is also little research in support of this type of resistance. This led us to choose a system that used bike brake pads on one side of the custom aluminum rotor as the resistance mechanism. We tried multiple variations of this technique with little success. Therefore, we decided to prototype a magnetic system.

The magnetic resistance ended up providing a sufficient amount of resistance for us to move forward with the idea. Since we had to incorporate a protective shroud for the rotating disk anyways (discussed later), it gave us the ability to place magnets on both sides of the aluminum rotor. The exact interface of the entire system is described in detail in Section 7.5.1.

6.5.2 Exercise Motivation

The motivational system design will utilize a hall-effect sensor and a microcontroller. Specifications for both of these components can be found in Appendix D (Figures D7 and D8). A hall-effect sensor is basically a switch triggered by a magnetic field. When the sensor is not in the presence of a magnetic field, the switch is in the off position. Conversely, when the sensor detects a magnetic field the switch is turned to the on position. We originally wanted to place a small round magnet on the left crank arm and secure the hall-effect sensor to the frame of the bike. Every time the crank would pass by the section of the frame with the Hall-Effect sensor, the sensor would be triggered to effectively close a switch for a split second. We ended up deciding to use epoxy to secure a magnet on the aluminum disk instead of the crank arm and then secure the hall-effect sensor on the inside of the rotor shroud. This method triggers the same way as the original plan, but protects the Hall-Effect sensor and magnet from possible damage that could occur outside of the shield. When the switch closes, the signal is sent down the frame of the trailer to a microcontroller board. When the microcontroller senses this switch opening and closing at a set time interval, it sends a small output current to the base of a transistor. The transistor switches the ground of the speakers, turning the speakers on. If Rebekah stops pedaling, the microcontroller will halt the output voltage, turning the

speaker off. A code written to the microcontroller will control all processes in this system. A circuit diagram of the system is shown in Figure 18.

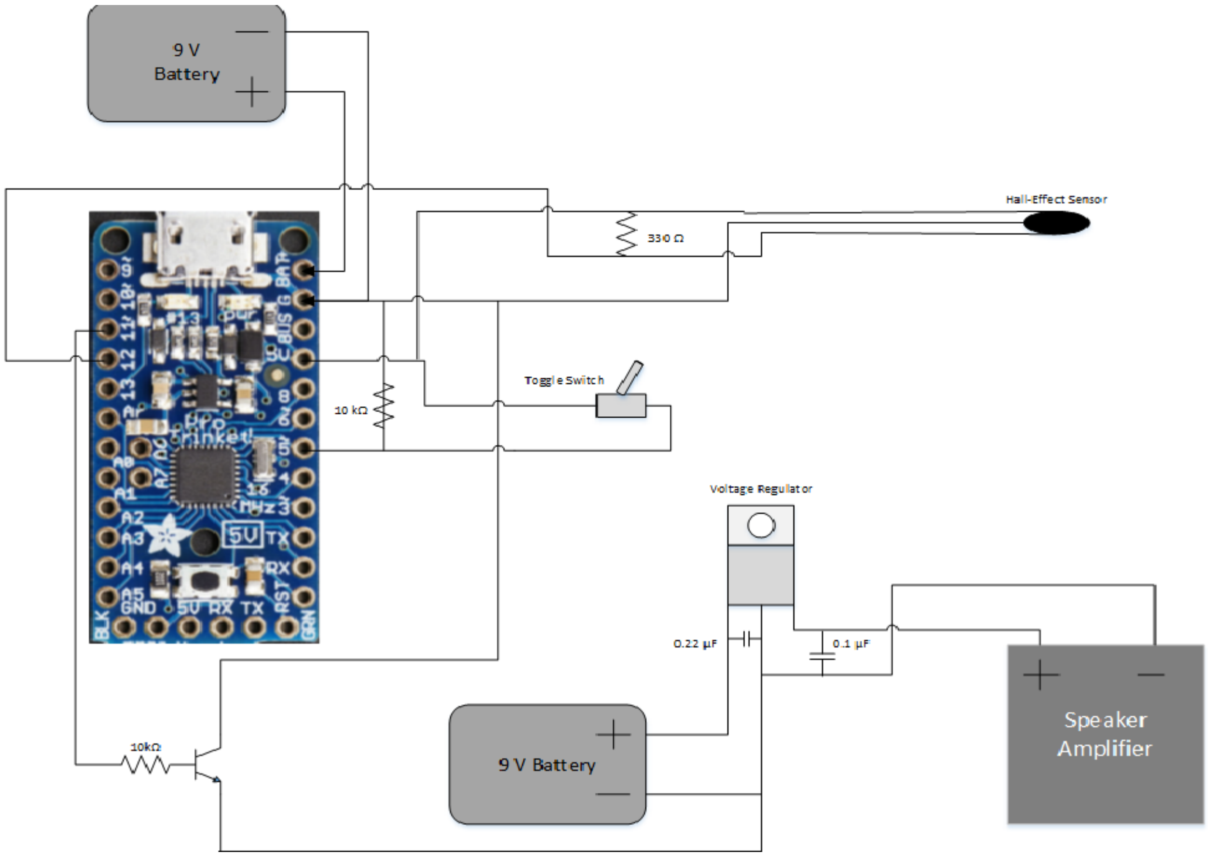


Figure 18. Simple Arduino Circuit Diagram

The speakers are attached by 3.5 mm auxiliary wire to a music player that is constantly playing music from a playlist defined by Rebekah's parents. The 3.5 mm auxiliary wire allows any electronic device with the compatible jack to play music. The speakers were planned to be mounted near the top of the bicycle trailer's seat so Rebekah can hear the music at an appropriate volume.

6.6 Wheels

A bicycle trailer with two wheels is much more stable than a trailer with one wheel. With two wheels, the lead rider does not have to stabilize the entire bicycle system when slowing down or stopping. By positioning the wheels behind the trailer, the overall width of trailer does not have to be compromised in favor of stability. This also helps reduce the possibility of Rebekah getting her hands near the rotating wheels. Our initial sketch of this design can be found in Appendix B (Figure B5).

As discussed in section 6.1, the Burley Axle Tube Assembly along with the Burley Quick Release 20" Wheels were purchased off of the Burley website. Specification sheets with Burley's part number and price are provided in Figure D9 of Appendix D. These two parts function together, and needed to be purchased together. To keep overall trailer width down, we wanted to have a wheel system that was only mounted to the frame on one side of the wheel. This was one of the driving factors for why we selected Burley's quick release wheels. Figure 19 shows a simplified solid model of the axle and wheel assembly (one wheel is transparent to show detail).

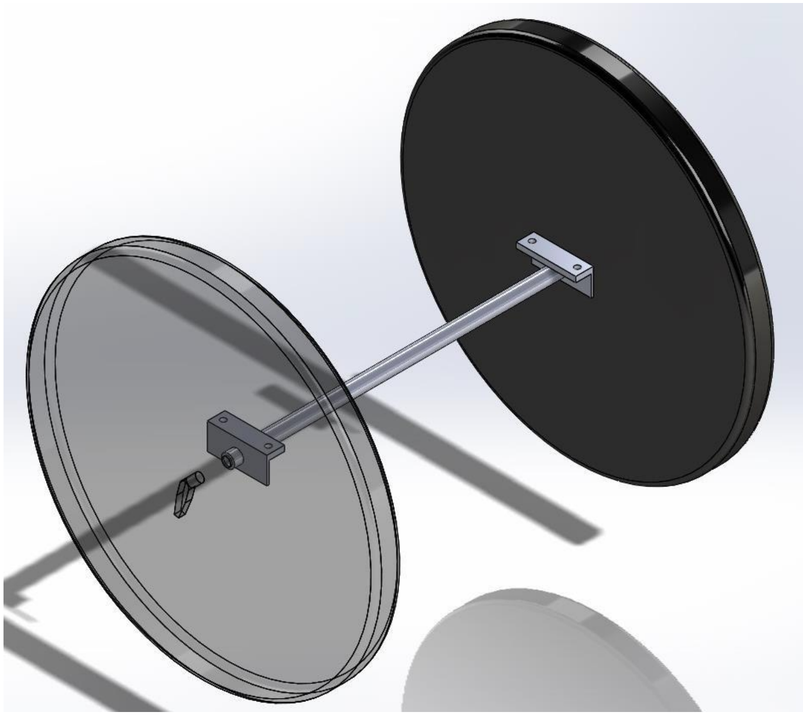


Figure 19. Wheel Assembly Solid Model

An important note for the purchased axle assembly is that when assembled with the wheels, the overall width is 24 inches. This exceeds our design specification of a maximum width of 22 inches. Buying an off the shelf component from a high quality bicycle trailer company like Burley saved our team more time and money than it would have been worth to design our own system, or alter the system that we purchased from Burley. Other interactions between this axle/wheel assembly and the rest of Rebekah's trailer remained unaffected. Therefore, our decision to exceed our maximum width specification by a minor 2 inches is justified by the reasons presented above.

Since the axle assembly and quick release system had to be purchased together, we were only given the option of 16 inch or 20 inch wheels. We chose 20 inch wheels because of the known fact that larger diameter wheels absorb more bumps and chatter that are encountered on any day-to-day ride.

The track width is locked in at 24 inches from the purchased axle assembly. This is an engineered assembly that is in commercial production; therefore, we assumed that their design was acceptable. Additionally, to check the track width and the length of our design, we created a prototype with the same dimensions of our design from a purchased trailer off of Craigslist. This will be discussed in Section 8.4.

6.7 Final Overall Design

Our final system design incorporated all of our top concepts into an integrated bicycle trailer that provides a safe, comfortable, and enjoyable experience for Rebekah and her family. The design of the wheels and frame focuses on stability and strength while the design of the seat and motivation device focuses on comfort and entertainment. This design creates a captivating experience for Rebekah, encouraging her to stay active and enjoy time spent with her family. A sketch of our original design can be found in Appendix B (Figure B6), while our final full assembly solid models can be found in Figures 20 and 21. All assembly and subassembly drawings can be found in Appendix C.

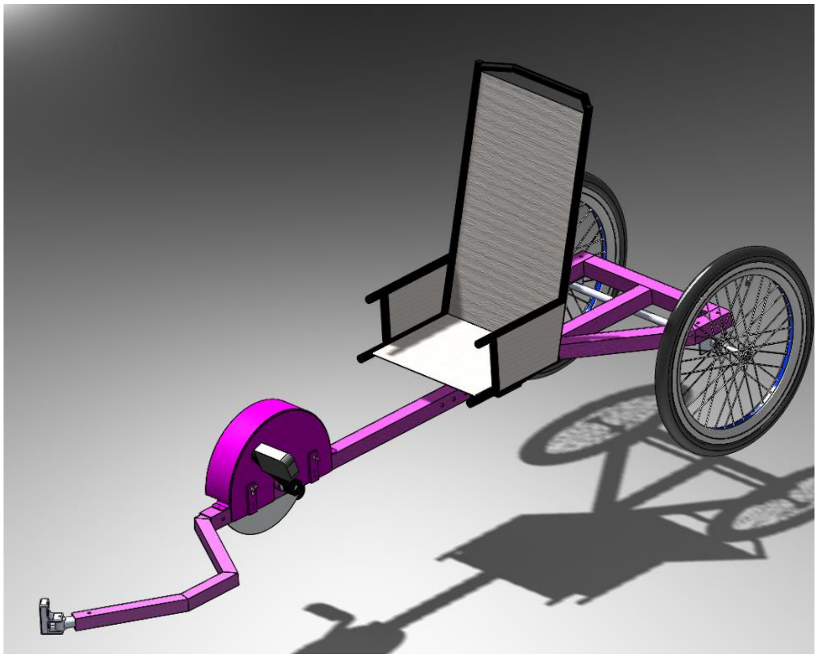


Figure 20. Full Assembly (Left Side)

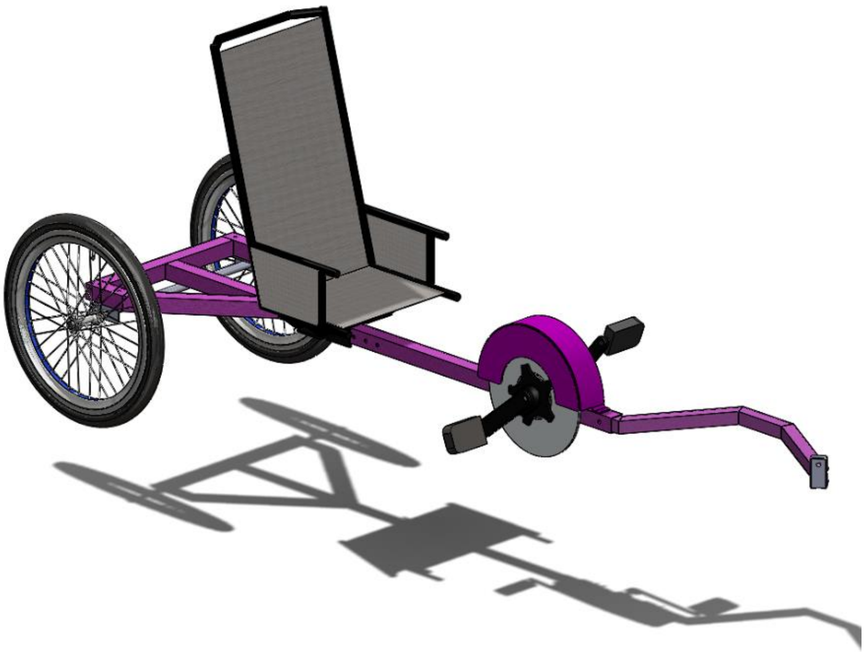


Figure 21. Full Assembly (Right Side)

A predicted cost and weight analysis was done on an individual subassembly level to see the breakdown of the contribution of each subassembly to the total cost and weight of the design. The results are shown below in Table 9.

Table 9. Individual Subassembly Predicted Weight and Cost

Subassembly	Sub-Assembly Name	Sum of Total, With Tax	Sum of Weight (lbs)
0	Miscellaneous	$ 182.24	0.1268
100	Bike Frame	$ 395.28	7.938
200	Seat	$ 634.02	9.7732
300	Wheel System	$ 161.73	6
400	Exercise Motivation	$ 312.53	6.9
500	Attachment to Main Bike	$ 61.04	3.146
600	Personal Storage	$ 49.25	4.75
Grand Total		$ 1,796.09	38.634

As seen above, we predicted that the most expensive and the heaviest subassembly would be the seat. The reason the seat and frame were predicted to be so expensive with respect to the other components is due to the cost of labor that is necessary to complete the designs. The seat required the aluminum frame to be welded and fabric to be sewn around the frame. The frame required the aluminum to be welded and powder coated pink, because it is Rebekah's favorite color and it provides a layer of weather proofing to resist minor damage. A note to keep in mind is that we generously estimated the labor hours for these processes. A complete breakdown of the actual cost of each component in each subassembly is given later in the Cost Analysis and Finance Management section (section 9.0) of this report.

7.0 Product Realization

Once the main manufacturing began to take place, some design changes naturally occurred in the process. The final manufactured product of each subcomponent is discussed below, along with any design changes that had to be incorporated to make the final product functional.

7.1 Frame

The final frame was manufactured very similar to our original final design as seen in section 6.1. The bottom bracket shell was originally designed to sit on top of the frame, but after careful consideration, it was decided that notching a circular hole centered at the top of the frame would allow the bottom bracket shell to be welded more securely. This decision can be seen in Figure 22.


Figure 22. Bottom Bracket Placement

The frame was designed on SolidWorks with 1 1/2 inch square aluminum tubing and a 1/8 inch wall thickness. The metal tubing was purchased from Precision Machine in San Luis Obispo. Each member of the frame was cut to length at the angles specified by the SolidWorks model. Holes were drilled in the frame for the interface with the seat, rotor shroud (discussed in section 7.5.1), attachment, wires, and bottom bracket. The five 3/8 inch holes to allow the seat to be bolted to the frame were drilled down the center of the tube, 1.5 inches apart. Six holes were drilled in the frame to allow the rotor shroud to be secured to the frame. Two 3/16 inch holes were drilled vertically in line with each other on each side of the bottom bracket shell and two more 3/16 holes were drilled on the top of the frame. A 3/8 inch hole was drilled near the front end of the frame to allow a clevis and hitch pin to connect the attachment bar to the frame. Two small holes were drilled in the frame for the Hall-Effect sensor wires to be fed through the frame. Once all of the holes were drilled, the frame was given to Matt Bezkrovny to be welded. After welding, holes were drilled in the back of the frame to allow the wheel axle to be bolted onto the frame exactly perpendicular to the direction of travel. The final welded frame can be seen in Figure 23.


Figure 23. Completed Frame

7.2 Seat

Tubing for the manufacturing of the seat has was ordered through McCarthy Tank and Steel. We used 1/2 inch inner diameter schedule 40 aluminum pipe. This pipe had an outside diameter of 0.85 inches and was readily available to buy through McCarthy Tank and steel. The design of the seat was created on SolidWorks. SolidWorks allowed us to isolate each member of the seat to find the specific angles that needed to be cut. Each tube was notched at the corresponding angles, allowing flush connections to be made. 1/4 inch thick aluminum plate was cut and added to the bottom of the seat frame to provide reinforcement and added welding area for the flanges that serve as our attachment point to the trailer frame. The cut and notched tube and plate was then taken to Gentry Welding in San Luis Obispo and welded in the 3-D orientation seen in Figure 24.

Figure 24. Welded Seat Frame

Once the seat was welded, it was taken to Central Coast powder coating and powder coated black. After the frame was finished, it was taken to Mitch’s Stitches of San Luis Obispo where it was fitted with grey Cordura fabric and black trim. Nylon straps were sewn onto the fabric in three spots to create a 3-point harness with plastic side release buckles and strap adjusters. Nylon straps, adjusters, and buckles were also used to allow the fabric to tighten onto the seat with ease. The final product can be seen in Figure 25.


Figure 25. Completed Seat

7.3 Adjustability

The seat adjustability was accomplished by the 1/4 inch aluminum flange pieces that were welded to the bottom of the seat frame. A 3/8 inch hole was drilled in the center of the flange so that it could be lined up with the corresponding holes drilled in the frame and secured using a 3/8 inch bolt. A close up of the attachment mechanism can be seen in Figure 26.


Figure 26. Seat Attachment to Frame

7.4 Attachment to Lead Bicycle

The attachment arm was designed and fabricated in similar fashion to the frame. 1 1/4 inch square aluminum tubing with a 1/8 inch wall thickness was also purchased at Precision Machine. We chose this size to fit snuggly inside the larger tubing of the frame. The tubing was cut to length at specified angles and given to Matt Bezkrovny to weld. Once welded, a hole was drilled into the attachment arm at each end of the tubing

to interface with the frame on one side and the burley attachment on the other. Figure 27 shows the original attachment arm on the right, and the updated arm on the left. After testing the original arm, we found that the turning radius was compromised when the lead bicycle was turning to the right. The rear wheel of the lead bicycle would make contact with the arm when attempting to turn sharply to the right. This led us to manufacture a new arm that extended further to the left to allow for a tighter turning radius.

Figure 27. Comparison of Attachment Arms (Left is Final Product)

In order to avoid interfering with the bolts that are used to hold the rotor shroud on the frame, the attachment arm needed to be slotted with a 3/16 inch end mill. This allows the attachment arm to slide into the frame and securely attach without interfering with the bolt. The final machined arm with the Burley flex connector is shown in Figure 28.

Figure 28. Final Attachment Arm

7.5 Motivation

The motivational device and pedaling system for the bicycle trailer incorporates a protective shroud, a magnetic resistance system, and electronics to play music while Rebekah pedals. Each of these subcomponents are discussed below.

7.5.1 Protective Shroud

The aluminum rotor poses a potential source of danger for Rebekah when riding the trailer. Therefore, a protective shroud had to be designed to cover it.

The aluminum disk was designed on SolidWorks to fit to the Retrospec Crank Arms that were purchased. The disk was modeled, and CNC code was created in Creo, a solid modeling software. We started with a 12 inch square, 1/4 inch thick aluminum plate and milled it down to the current 11 inch diameter disk with corresponding holes to fit to the Retrospec crank arms. The machining occurred in the IME labs in Building 41 on the Cal Poly campus, shown in Figure 29. The disk is attached to the right crank by chain ring bolts that came with the crank set. Thread locker Red 271 was applied to the bolts to create a permanent seal between the aluminum disk and the right crank.

Figure 29. CNC Machining the Aluminum Rotor

The rotor shroud was designed as a sheet metal part assembly on SolidWorks. 16-gauge mild steel sheet metal was purchased at Ace Hardware in San Luis Obispo. The SolidWorks drawings were printed on the Cal Poly ME lab plotter at a 1:1 scale. The printed drawings were then cut out and taped to the sheet metal. Using the taped drawings as an outline, the sheet metal was scored and marked for cutting. The outlined parts on the sheet metal can be seen in Figure 30.

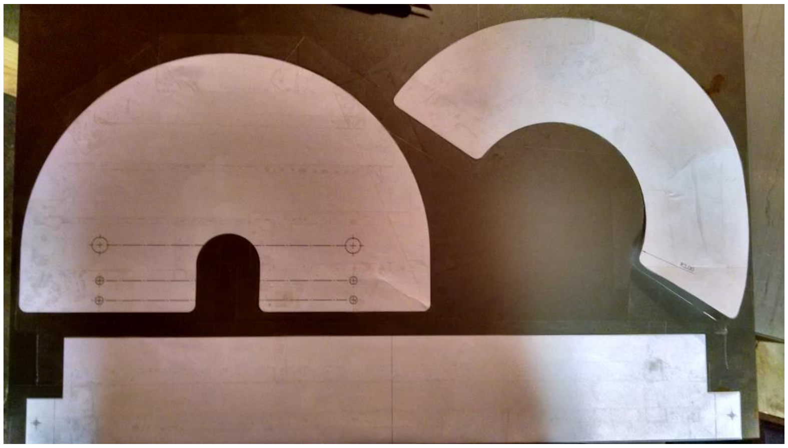


Figure 30. Shroud Templates

Rough cuts using a straight metal shear, 90 degree shear, and circular shear. Then an abrasive wheel and grinding disk were used to smooth out the sheet metal into the desired shapes. The long rectangular section was rolled into a half circle with a slip roll to approximately 13 inches in diameter. A press brake was used to create flanged tabs that help secure the shroud to the frame.

Matt Bezkrovny spot welded the three sheet metal parts together to form the shroud. Holes were drilled on the side of the shroud that sits flush with the frame. These holes match the hole pattern on the frame. Two larger clearance holes were drilled higher to allow the adjustable magnet device to be inserted into the shroud.

To secure the steel shroud to the frame, two 1/4 inch thick aluminum tabs were manufactured. Two holes were drilled in the tabs to match the hole pattern of the steel shroud and the aluminum trailer frame. A third hole was drilled in each tab and was tapped to allow a 1/4-20 inch threaded rod to be threaded into the aluminum. These tapped holes lined up with the clearance holes in rotor shroud. The final shroud with tabs and threaded rod can be seen in Figure 31.

Figure 31. Protective Shroud

7.5.2 Resistance System

The resistance device was designed in conjunction with the rotor shroud. Strong Neodymium magnets were purchased and assembled with the shroud. The magnet stacks involve a 1 inch thick, 1 inch diameter magnet attached to a ½ inch thick, 1 inch square magnet. These one and a half inch stacks are magnetically attracted to milled and tapped 1 inch square steel blocks that connect the threaded rod to the magnets. The 1/4-20 threaded rod passes through a clearance hole in the rotor shroud and is threaded into the tapped hole in the

aluminum tab. A plastic knob is threaded onto the end of the rod with thread locker. This allows for the magnets to be moved closer and farther away from the aluminum rotor inside of the shroud. These stacked magnets are on the left side of the shroud facing forward.

On the opposite side of the shroud, 1 1/2 inch round, 3/8 inch thick magnets are placed on the inside of the right side of the shroud. These magnets are directly across from the magnet stacks described above. The magnetic poles are facing each other so that they attract to each other. This creates a magnetic field between the two sets of magnets and opposes the motion of the aluminum rotor when it spins in between the magnets. Figure 32 shows the magnets placed inside of the shroud and on the threaded rod.

Figure 32. Magnet Placement

After noticing that the sheet metal was deflecting a small amount when the magnetic resistance was in use, the shroud was reinforced with 1/8 inch by 3/4 inch steel stock that was epoxied on the opposite side of the aluminum tabs. The aluminum tabs were also epoxied onto the outside of the shroud. This fortified design will help keep the shroud from deflecting or warping over time. These additions can be seen in Figure 31 as well.

7.5.3 Electronics

The motivational device uses a 5V Adafruit Pro Trinket microcontroller to determine whether or not to play music through the speakers. The Pro Trinket microcontroller uses Arduino software and code. The speakers were removed from their original amplifier and wired to a DROK PAM8403 Mini Power Amplifier Board. All electronics are either soldered to wire or crimped to a disconnect. The disconnects allow for easier removal of each component and easier troubleshooting. Heat shrink, electrical tape, or liquid electrical insulator are all used in order to electrically isolate each component. All of the electronics are enclosed in a black ABS plastic electronics box. The two power sources for the microcontroller and speakers, the microcontroller, and the amplifier are all attached to the inside of the box with Velcro. Holes were drilled in the box to allow access to power switches. The internal and external views of the electronics box is seen in Figure 33.

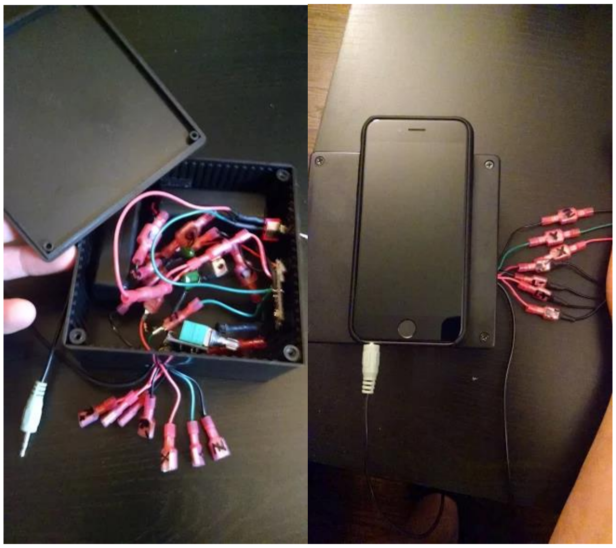


Figure 33. Internal and External Views of Electronics Box

The Hall-Effect Sensor, which sends the signal to the microcontroller, is wired from inside of the rotor shield, through the frame, and up the backside of the seat to the electronics box. The box is placed in a bag that has very small holes cut into the fabric to allow wires in and out of the bag from the Hall Effect Sensor and the speakers. The speakers fit snuggly in the mesh pouches on either side of the bag. The bag is attached at the top of the reverse side of the seat frame using small carabineers.

The power source for the speakers is wired to a 5 volt voltage regulator with two capacitors across the leads. The 5 volt signal then travels to the Mini Power Amplifier Board. This board takes the sound signal from a music player through an auxiliary cord and sends it to the speakers. The ground wire of the amplifier power source is connected to the ground of the whole system including the Adafruit microcontroller and its power source. The microcontroller is connected to the Hall-Effect sensor. When the microcontroller reads the signal from the sensor, it sends an output signal to a transistor. The transistor senses the incoming current and acts as a switch for the system ground wire. When the ground connection is closed, the regulated 5V power is sent to the amplifier, turning on the speakers allowing the music to be played from the auxiliary cord. This entire circuit, wires, speakers, and music playing device are contained in a carrying case that is attached to the back of the trailer seat using small carabiner clips shown in Figure 34. If Rebekah's family wants to bring music to a picnic location, or something similar, all they have to do is detach the wire disconnects and unhook the carabiners.

Figure 34. Electronics Carrying Case (shown unzipped)

7.6 Wheels

The wheel and axle assembly was ordered from the Burley website. The aluminum axle attaches to the bottom of the frame with four 1/4 inch bolts. The holes were carefully drilled perpendicular to the direction of travel of the frame in motion so that the axle will hold the wheels in that plane of motion. The wheels are one sided quick release wheels that interface with the purchased axle assembly. The frame is designed to reinforce the purchased axle assembly. The assembled product is seen in Figure 35.

Figure 35. Assembled Wheel Set

7.7 Final Product

All manufactured components were assembled to create our final product. The frame was powder coated pink by Central Coast Powder Coating and a luggage basket was attached to the rear section of the trailer for storage of personal items during rides.

The trailer was able to fit in a Toyota Camry with the seat, attachment arm, and wheels disassembled. These three components are very easy to assemble and disassemble, and specific instructions for these actions can be found in the User's Assembly Guide in Appendix L. Figures 36 and 37 show various views of the final manufactured bicycle trailer.

Figure 36. Final Product (Side Views)

Figure 37. Final Product (Rear View)

As you can see from Figure 37, the electronic system and speakers are completely enclosed in the carrying case. This case is easily detachable using small carabiner clips. If Rebekah's family decides they want to take the speakers to a picnic, the beach, or anywhere else they may ride to, all they have to do is disconnect the wires from the frame using the convenient disconnects. Additionally, all other necessary items for these kind of rides can be placed close by in the basket.

Our final product is designed according to our original engineering specifications. All specifications were met with exception to the overall width of the device. The reasoning behind this decision is discussed earlier in the report. A complete summary of the main attributes to our final product are shown in Table 10.

Table 10. Summary of Final Product Attributes

Design Specification		Original Designation	Final Actual Designation
Max Weight of Device		50 lbs.	37 lbs.
Max Height of Device		40 in	38 in
Max Width of Device		22 in	24 in
Max Length of Device		90 in	89 in
Seat Adjustment from Prior Max		+6 in	+6 in
Total Cost (with Motor)		$2,477 (Total Budget)	$2,427

The final purchase we made was a motor for the lead bike. Since the trailer and Rebekah will add a lot of extra weight for the bike to tow, a motor was deemed necessary to assist the bike driver up hills and at times when extra torque may be needed. The motor system we chose to outfit the lead bike with was a LEED 10k+ E-Bike Kit. The kit contains a 250 Watt hub motor attached to a front wheel set, a Panasonic 24 volt, 6.4 amp hour lithium-ion battery, a battery charger, a throttle and cable system, a battery bag, and cabling zip ties. Our team will install the kit on the family's bike that they use to take Rebekah on rides. The front wheel of their bike will be replaced with the new motorized wheel, which will be wired to the battery near the back of the bike and to the throttle at the handlebars. This motor set has a range of about 12 miles, can reach a top speed of 15 mph unassisted and weighs less than 8 pounds. This motor should have plenty of power to help the bicycle driver up many of the hills in the Central Coast.

8.0 Analysis

Engineering analysis was done to select the dimensions of tubing necessary for the frame as well as to find the required shear strength for the bolt that is holding the seat to the frame. Braking force, for our original design, and an overall prototype test were performed to gain an idea of the feasibility of certain aspects of our design.

8.1 Frame

Analysis for the frame was initially done with the intention of using round tubing. Since then, our team made the decision that aluminum square tubing was the best material to use for our design. With this in mind, the following analysis for round tubing is discussed because the same process was used to calculate similar values for our final selected material and geometry. The initial analysis was done for a "T-Bar", "Box", and "Y" frame geometry. Since these are irrelevant now, they have been deleted from the report, but can still be found in Appendix E for reference. The basic trend from these calculations is that aluminum is the lightest option, 1020 steel is the heaviest, and that 1020 steel is the cheapest while aluminum is generally most expensive. Our group decided that the fact that aluminum is lighter and does not rust outweighs the extra cost in comparison to steel. The basic frame analysis is discussed below.

By modeling the frame in two dimensions as a simply supported beam on both ends and using material properties obtained from the McMaster Carr website, we found the maximum bending moment created by our assumed max weight of 150 pounds along with a factor of safety of 3. Originally, since we made these calculations with the idea that round tubing would be used for the frame, we used diameters instead of side dimensions. We used the yield strength provided on the McMaster Carr website to select an outer dimension (OD), then we could use this bending moment to find the inner dimension, ultimately giving us the necessary wall thickness (WT) for the round tubing. An example of this calculation is shown in Appendix E. For ease of calculation, we created an Excel spreadsheet (Appendix E) to guess the inputted OD to find the resulting WT.

As explained previously, we used the same procedure described above to calculate the necessary wall thickness with a selected outer side dimension for the square tubing. The Excel spreadsheet was altered to account for the new geometry. An example of this new sheet can be found in Appendix E. Using our design dimensions for the frame, we were able to calculate the total weight of the aluminum frame based on the density.

Using an estimated price of $3 per foot, given to us by McCarthy Tank and Steel, we were able to estimate the total cost of the frame material. A summary of these calculations made in Excel can be found in Table 11, and the entire spreadsheet can be found in Appendix E.

Table 11. Summary of Frame Analysis

Design Parameter	Value
Max Design Weight	150 lbs.
Factor of Safety	3
Outer Dimension Guess	**1.500 in**
Inner Dimension	1.290 in
Wall Thickness	**0.105 in**
McCarthy OD	1.500 in
McCarthy WT	0.125 in
Total Weight	8.250 lbs.

As seen in the bolded values above, with an outer dimension of 1.5in, the necessary WT is 0.105 inches. Therefore, we decided to use a stock size of 1.5 inch square tubing with a WT of 0.125 inches. Yielding of the aluminum tubing should not be an issue with this calculation. Total weight was calculated using an estimated 10ft of tubing to get an idea of the weight of the frame. The exact weights of each subcomponent, including the frame, can be found in Figure 9 in the Final Detail Design section (section 6.7) of this report.

<u>8.2 Bolt Shear Strength</u>

An analysis was completed to check the shear strength of a 3/8 inch bolt under the 150 pound specified load, with the same factor of safety of 3. We used a 3/8-16 SAE Grade 8 bolt and nut to secure the seat to the frame through the holes drilled in the seat flanges and the frame. Using this, for a 150 pound load with a factor of safety of 3, we calculated the required strength for the bolt to be 9,677psi. This sample calculation can be found in Appendix E. The ultimate strength for an SAE grade 8 bolt is 150ksi. Therefore, since the bolt's required strength is much lower than its ultimate strength, the 3/8 inch bolt underneath

Rebekah's seat is strong enough to support our specified load.

8.3 Brake Pad Force

This test was originally completed with the idea in mind that we would be using brake pads as the resistance mechanism. Since then, we tested magnetic resistance in a similar fashion to what is described below. We concluded that magnetic resistance was a better solution, and that is what was implemented to our final design.

A simplified test was done to see if our original design of the rim brake pads resisting the movement of the flywheel attached to the cranks would provide enough force to actually give the rider a workout. The test was set up by having a bike mounted to a stationary bicycle trainer. The trainer has an aluminum disc where the fan is located. We took a brake pad off of another bicycle and simply pressed down on this flywheel while another member pedaled on the bicycle. With just an average amount of force, the friction from the brake pad and flywheel interaction was high enough to effectively stop the rider from pedaling. This result gave us confidence that our design would have been even more superior due to the fact that we would have had two brake pads on a larger diameter flywheel, effectively giving us more stopping torque. A picture from this test can be found in Figure 38.

Figure 38. Brake Pad Testing

8.4 Full Prototype Test

As discussed earlier, our team purchased a bicycle trailer off of Craigslist to alter its dimensions to meet our geometric design specifications. We narrowed the trailer down to an approximate 24 inch track width and about 75 inches in overall length. The goal of this test was to see if making the trailer longer and skinnier would affect its turning radius or the handling capability of the lead rider. After towing each other behind one of our bikes, we found that we could make turns much tighter than any turn that could be made in a bike outfitted with the old Weehoo trailer. We discovered that the turning radius is mainly dependent on the way the trailer is mounted to the lead bicycle. In this case, we had plenty of turning capability. In other words, when we turned the bicycle and trailer assembly on roads and paths that are commonly used

by solo bicycles, we found no interferences between the lead bicycle and the trailer. Also, at higher speeds there was no additional bouncing or wobbling to speak of. These results gave us confidence to continue with our design of having a track width of 24in and an overall length of approximately 75in. An image from the testing can be seen in Figure 39.

Figure 39. Full Prototype Testing

9.0 Cost Analysis and Finance Management

After designing the trailer, we were able to compile a complete list of what we needed in order to build the design. Each component of our design was specified by its price and place of purchase. A cost analysis sheet was created to keep track of total project cost, where to buy material, estimated weight, and estimated shipping times, which can be found in Appendix F. The entire design was broken into subsystems, including individual parts for the subsystems. By having the supplier already specified for each part we were able to minimize the amount of different suppliers used. This allowed us to order our parts in larger orders to cut down on shipping costs. The cost analysis sheet not only summarized what we needed to buy and how much each item cost, but it also helped keep an ongoing list of what had already been purchased in order to track expenses and reimbursements.

The main subassemblies of the bike trailer consisted of the bike frame, the seat, the wheel system, the exercise motivation, the attachment to the lead bicycle, and the personal storage component. A complete breakdown of the purchased components can be found in the spreadsheet in Appendix F.

The bike frame subassembly included the aluminum raw material, welding labor, as well as the powder coating for the frame, totaling at $445.

The seat involved purchasing aluminum raw material, welding labor, fabric to stretch around the seat frame, stitching labor, nylon straps, and buckles. This gave a seat cost of $732.

The wheel system was entirely purchased off the shelf. The axle assembly and two quick release wheel assemblies totaled $160.

The pedaling and motivational systems included pedals, crank arms, a bottom bracket and bottom bracket shell, a custom aluminum resistance rotor, a protective cover for the rotor, magnets, an Arduino microcontroller, speakers, and a power supply. All of these components cost roughly $290.

Attaching the bike trailer to the main bike included raw aluminum material, welding labor, and an off the shelf rear-axle bicycle attachment from Burley costing around $125.

On the rear end of the bike trailer a basket and bungee net were attached in order to provide storage for personal items, which cost about $31. Lastly, other miscellaneous purchases resulted in another $45. The total cost of the entire project, not including the motor, was $1,848. The motor for the lead bicycle costs $579, making our total project cost $2,427. A summary of the expenses is shown in Table 12.

Table 12. Summary of Project Expenses

Subsystem	Cost
Bike Frame	$ 445.00
Seat	$ 731.19
Wheel System	$ 156.38
Exercise Motivation	$ 291.61
Attachment to Main Bike	$ 126.35
Personal Storage	$ 30.97
Miscellaneous (+Motor)	$ 645.08
	$ 2,426.58

A large portion of the expenses were from labor costs for the seat and bike frame. We were able to minimize the welding costs by going through a Cal Poly shop tech, Matt Bezkrovny. San Luis Obispo local businesses were extremely generous when we approached them about the purpose of our project. We were given discounts on most labor and material costs. The local businesses that helped with our project were the following: Precision Machine, Gentry Welding, Central Coast Powder Coating, and Mitch's Stitches.

At the Critical Design Review, our overall expected cost of the project was found to be $1,800 (see Table 9). Since this cost was $300 over the allowed budget of $1,500, we applied for and were granted the CPConnect Project Funding Opportunity grant. Our rewarded grant was $977, making our total project budget $2,477. With these extra funds, we were able to include the motor for Rebekah's mother's bike to make rides easier for her.

We did not commit to buying the bike motor until we were sure our project funds would be able to pay for it. We waited to purchase the bike motor until we tested the complete bicycle trailer with Rebekah and her family, which ensured every possible expense was accounted for besides the bike motor. Prior to purchasing the bike motor, we had $629 remaining in our budget, which allowed us to get a motor rated for 12 miles at $579.

10.0 Build and Test Plan

In order to ensure that none of the individual components will fail and that the bicycle trailer is safe, we created a design manufacturing plan and design verification plan.

10.1 Manufacturing Plan

An updated Gantt Chart highlighting our detailed plan for manufacturing can be found in Appendix G. In order to complete this project in a timely manner we planned to start manufacturing February 12th, after we presented our final design to our sponsor. Many items that could possibly take a long time to ship were purchased early on in the manufacturing process. Tubing for the seat, frame, and attachment arm were sourced and purchased mid-February.

Manufacturing and design adjustments were made along the process. Specific adjustments are discussed in the Project Realization section (Section 7) of this report. We gave ourselves plenty of time to complete each stage of the manufacturing process to give us enough time to make these adjustments as necessary. This helped keep our team on track for the Design Expo on May 29th, 2015.

10.2 Design Verification Plan

We came up with tests to ensure that our final product was acceptable to give to Rebekah and her family. The tests, location of the tests, and test supervisors can be found in the Design Verification Plan and Report (DVPR) in Appendix H. The tests found in the DVPR made sure we checked all possible failure points that were listed in the Design Failure Modes and Effects Analysis (DFMEA) of Appendix I.

We wanted the bike trailer to be as safe as possible for Rebekah so that she and her family could enjoy using the trailer without worrying about any accidents occurring. During the design phase, DFMEA sheets (Appendix I) were filled out in order to target possible points in the design where failure may occur during the use of the product, such as a crack in the material at weak sections or rotating pieces creating danger for Rebekah. DFMEA sheets were created for the seat adjustment system, the attachment bar to the lead bike, the frame of the bicycle trailer, and the pedaling system, the seat, the electrical system, and the wheels. One major concern brought out with the DFMEA was corrosion interfering with the integrity of the bike trailer.

10.2.1 Seat Adjustability

The adjustability mechanism for the seat needed to allow a non-technical person to be able to adjust the seat with ease. Rebekah will get taller as she grows in age and our design for the trailer kept that in mind. The seat will have to be adjusted no more than once or twice a year in order to account for Rebekah's growth. In order for the seat adjustability to be considered adequate, the seat should be able to be adjusted in under 10 minutes using only simple tools. Our seat can be taken apart using only two wrenches. We had 3 test subjects attempt to adjust the seat (excluding ourselves) and each person was able to adjust the seat in under the maximum allowed time. Appendix L is a User's Manual that has pictures for step by step instruction for seat adjustment, among other functions. Additionally, our team will walk through the entire trailer with Rebekah and her family so that they are confident in using it.

It was very important to make sure that the seat's attachment hole could be aligned over each hole drilled into the frame. Unfortunately, the seat cannot slide along the frame as initially planned due to the added thickness of the powder coat. However, the seat can still simply be placed on the frame at the desired distance from the pedals, with the holes still aligned with each other.

10.2.2 Attachment to Lead Bicycle

The attachment device to the lead bicycle needed to be durable. In order to test the attachment strength, we pulled the trailer around with the maximum design weight, 150 pounds. After pulling the trailer over various terrain with the maximum weight, there were no visible signs of permanent deformation or cracking in the attachment arm or Burley Flex Connector. An important note is that the Burley Flex Connector is meant to be replaced about every year. It is designed to be a flexible piece and will degrade over time. Information about this is located in Appendix K, the Maintenance and Troubleshooting Guide.

We also needed to make sure a non-technical person could attach and detach the trailer. All members of the team were able to detach the attachment arm from the lead bike and the attachment arm from the

trailer in under three minutes. The family will be provided a user manual and will be shown how to detach and reattach the attachment arm (see Appendix L).

10.2.3 Bicycle Trailer Frame

Before we created the computer-aided design (CAD) model of the bike, we performed a beam bending analysis for our aluminum tube. The analysis was conducted with the max weight of 150 pounds and a factor of safety of three. With this calculation and our chosen tube thickness, we could sufficiently say that the frame was strong enough to safely transport Rebekah. Due to our budget and time frame, we did not make a prototype with the chosen tube thickness and we did not test our final project to failure.

Our designed frame is longer in length than the family's Weehoo frame. To test maneuverability, we set obstacles 15 feet apart and had the lead bike with the trailer maneuver between them. Figure 40 shows two team members performing this test. The bike was able to maneuver around five obstacles, each 15 feet apart, without hitting any of them. With this test we concluded that the family could safely ride around obstacles that could appear in a bike path.

Figure 40. Maneuverability Test

Another concern we had with our frame was the existence of reachable pinch points. We had Rebekah sit in the trailer and reach for the ground and back wheels. She was unable to touch the ground or the wheels, passing the 'no reachable pinch points' test.

In Table 1, we listed our engineering specifications. In order to test if our trailer met the size specifications, we used a tape measure to measure the length, height, and width. We also used a scale to measure the weight. The trailer weighed 37 pounds, which was less than the max weight of the device specified (50 pounds). The height was measured to be 39 inches, which was less than the max overall height of the device specified (40 inches). The trailer's length is 89 inches, which falls within the maximum specified length of the device (90 inches). The trailer is 24 inches wide, which is four inches wider than initially specified. We have deemed this to be acceptable because the specified trailer width was originally arbitrarily set. A proven, off the shelf wheel set and axle ended up being a more beneficial option than creating a custom wheel set.

10.2.4 Pedaling System

We understand the safety hazards that may present themselves with the resistance pedaling system. Initially, we planned on using brake pads to provide resistance to pedaling. We tested a variety of materials to act as frictional brakes and noticed similar issues with all of them. The biggest issue was that the braking force was not uniform, leading us to look into a magnetic resistance option discussed earlier. Although the

magnets do not provide as much resistance as the frictional brakes tested, they allow a uniform resistance that is silent and does not create heat. Since the magnetic resistance does not use friction as a means of resistance, our pedaling system passes the test of remaining under the temperature of 110 °F, the heat threshold for a safe to touch object.

The pedals needed to be able to hold Rebekah's feet securely in place with no chance of her foot slipping off in motion. We decided that a pedal with an over the top shoe strap and a heel strap would be able to properly and comfortably keep Rebekah's feet on the pedals. To test this, we observed Rebekah riding and pedaling in the bicycle trailer. She was able to pedal constantly without any indication that her feet would ever slip off of the pedals

10.2.5 Seat

The harness needed to protect Rebekah while still remaining comfortable and durable. Rebekah will continue to grow and the bicycle trailer was designed to last her into adulthood. The seat harness was created and stitched on to the seat with this in mind. To test the adjustability of the seat, our team strapped Rebekah at her current size into the seat with the harness. One of our group members happens to have a similar body type to our maximum specified height and weight. We secured this team member into the seat with the harness and found that the harness was adjustable enough to secure our group member as well. Therefore, the harness is proven to be adjustable enough to satisfy our original requirement. We have ridden the bike trailer for a total time of over and hour and have clipped and unclipped the harness 50 times. There is no visible wear on the harness.

10.2.6 Electrical Systems

The electrical motivation system was a very important part of our bicycle trailer. It provides Rebekah with the motivation to pedal and it separates our trailer from all other trailers on the market today. With knowledge of the bag and box that is used to carry all of the electronics, we decided that the system should not be used in rainy conditions. The system should be able to withstand light rainfall because the bag offers a lot of protection from the elements, but it is still not completely waterproof. Riding in foggy or damp conditions will not put the electronics in danger. However, using the trailer in any conditions that involve slick or wet roads is not recommended.

We wanted to make sure that our electrical system was durable. We tested to make sure the speaker system would remain intact if the bike trailer fell over onto its side. Since the speakers are placed on the back side of the seat, they are in a safe position to avoid contact with the ground if the trailer were to be dropped, or topple for any extraordinary reason. Since the trailer can fall on its side and not destroy the electrical system, the system passes its durability test.

To test the electrical system, we made sure to that the Pro Trinket microcontroller successfully turned the speaker on and off. In order to test this, we pedaled the crank set and confirmed that the speakers turned on and remained on during the entirety of the 5 minute test. We verified that when pedaling ceased, the music stopped playing. We tested Rebekah's pedaling speed with the microcontroller to ensure that she could constantly pedal fast enough to keep the music playing. The timing value programmed into the microcontroller was changed to a speed that Rebekah was comfortable with, but still provided adequate exercise for her.

10.2.7 Wheels

The wheels for the bicycle trailer needed to be securely attached to the frame and provide stability to the entire trailer. In order to test the strength of the attachment of the wheels to the frame, we pulled outward from the trailer with a force of 50 pounds and found that the wheels did not dislodge.

We tested the bicycle trailer stability at the same time as the maneuverability tests. While weaving between obstacles placed 15 feet apart, we observed the wheels closely. Both wheels stayed in contact with the ground throughout the test. This test showed us that the trailer can be ridden around objects without the fear of tipping over.

Rebekah's family may encounter a situation in which they will have to take the wheels off of the frame of the trailer. The quick release wheels that were purchased for the trailer allow an adult to remove the wheels in under a minute, but still provide adequate connection strength with the axle when ridden.

11.0 Method of Approach

This project was broken up into many phases. First we gathered information on Rebekah and the issues with her original Weehoo bicycle trailer. Then we generated multiple new designs and evaluated those ideas using techniques like brainwriting, which was discussed earlier. In the first design report we proposed a preliminary design. The preliminary design was later improved upon and we finalized our project design and created drawings or gathered specification sheets for all of our components. The next stage was to actually manufacture the bicycle trailer and purchase the necessary components. Finally we evaluated and tested our manufactured product to ensure that it met the specifications set at the beginning of the project.

As part of the design process flowchart (presented by Professor Schuster at Cal Poly), we started in phase one with specification development and planning. In order to assess our original design problem, we tested Rebekah's old bicycle trailer at different speeds, turning radii, and terrain in order to help us better approach a new bicycle trailer design. With the help of Drusilla Potts, we took measurements of Rebekah's body to ensure that our bicycle trailer's design would accommodate her current and future size. Some of the measurements we took of Rebekah are shown in Figure 41. We personally took all of Rebekah's measurements because standard ergonomics charts may not apply to her. The project proposal was the final result of phase one.

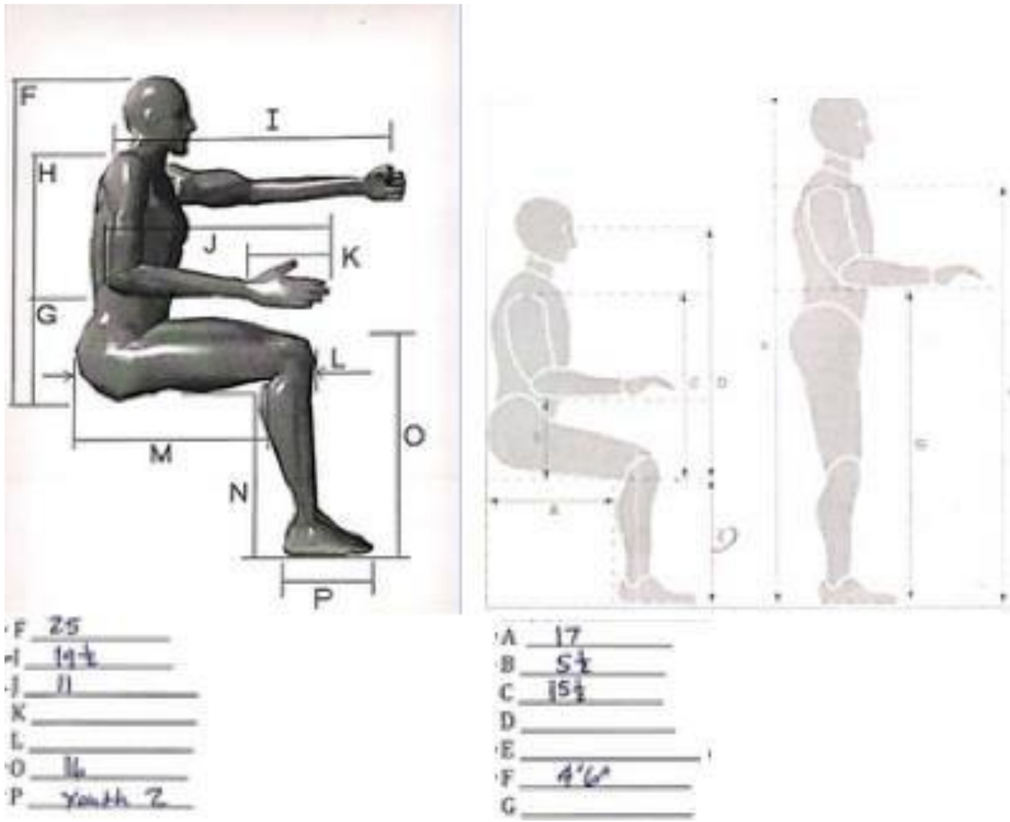


Figure 41: Anthropometric Data of Rebekah
Adapted From: Simple Anthropometric Chart[17]

Phase two involved conceptual design. For this phase, we completed brainstorming and considered many different designs for the bicycle trailer to come up with our final design. Next, we created our final design on SolidWorks. This allowed us to know what parts to order or manufacture in order to assemble the trailer in the next phase. Computer generated models are helpful, but we needed to build a prototype to test. Because of that, we acquired a simple 2-wheel trailer similar to that of Figure 3. We stripped the trailer down to just the frame, wheels, and attachment arm. Since the bicycle was just a simple frame, we were able to use the Cal Poly Machine Shops to prototype our final design.

Additionally, we needed to ensure that our final product would not be a safety hazard to Rebekah or anyone who handles the trailer. To help accomplish this, we filled out a safety checklist shown in Appendix J. In this phase we showed that our design met the customer requirements, finalized all design details, and addressed all foreseen safety hazards. We then were able to move to phase three to develop and manufacture our final design.

Phase three was the product design phase. In this phase we built and tested the bicycle trailer. A few design changes were made after realizing issues with the design. These changes were approved by our sponsor and Rebekah's family. These design changes included the switch from friction resistance to magnetic resistance, the design of a wider attachment arm, and the creation of a rotor shroud to encase the aluminum disk and the magnetic resistance.

Phase three is followed by the production phase. Our team is not going to enter this phase since this trailer was made specifically for use by Rebekah and her family. We delivered the final finished bicycle trailer to the family in the second week of June 2015.

12.0 Management Plan

In order to keep the project on track, a management plan with a timeline of events was created. The management plan includes a list of responsibilities for each group member according to each individual's strengths. All team members contributed to each responsibility, but there was a lead for each part of the project, which is shown by the name associated with the responsibility in Table 12. This procedure was agreed upon by the entire team to be an efficient way to work, in contrast to having a single team leader for the entire project. Each subsection of the project will had a proficient member who was internally motivated and had more interest in the specific responsibilities than the other group members did. Having multiple sub-project leaders allowed the team to eliminate the possibility of a lack of interest in a specific area. This lack of interest can be found in teams with a single team leader. The list of responsibilities and the corresponding leader is shown in Table 13. Milestone dates for the project are shown in Table 14. These dates were provided to assure punctuality for important deliverables and events of the project.

Table 13*:* Leadership Responsibilities

Name	Responsibilities
Alex Rowson	Structural Analysis All subsystem dynamic and static analysis (Microsoft Excel, MATLAB, etc.) Lead manufacturer during manufacturing portion of project
Cameron Weinberg	Research of existing solutions to similar customer requirements Design for Manufacturing and assembly (DFMA) Record all finances and retain all receipts of purchase
Jacob Hentzler	Weekly Status Reports SolidWorks modeling Hand drawings and sketches Electronics Lead
Kelly Perkins	Subsystem prototype test considerations Prepare, record, and produce organized data for each test conducted Background of cerebral palsy and its implications

Alex led the team through engineering analysis for the project. Cameron's manufacturing experience helped with design for manufacturing. Jacob led ideation and modeling of the subsystems and final design. Finally, Kelly was responsible for data collection of all tests she created.

Keeping these strengths in mind, a timeline was established for key dates for the project so that each member was sure to complete key tasks on time. This kept the team on track for the beginning of June deadline.

Table 14: Timeline of Events and Deadlines

Deliverable/Event	Date
~~Project Proposal Report~~	~~10-21-2014~~
~~Preliminary Design Report~~	~~11-18-2014~~
~~Preliminary Design Review~~	~~12-5-2014~~
~~Final Design Report~~	~~2-5-2015~~
~~Critical Design Review~~	~~2-10-2015~~
~~Test Status Presentations~~	~~3-12-2015~~
~~Project Update Memo~~	~~4-10-2015~~
~~Project Hardware/Safety Demo~~	~~4-24-2015~~
~~Senior Design Expo~~	~~5-29-2015~~
Final Project Report	6-5-2015

This list of important dates only includes major deadlines for the project. Items with a strikethrough indicate that date has passed. A more detailed timeline is shown in the computer generated Gantt Chart shown in Appendix G. The Gantt Chart was created using Microsoft Project, and was discussed earlier in the Manufacturing Plan (Section 10.1).

13.0 Conclusion

This was an extremely rewarding project. Our team had its ups and downs throughout this year long project, but seeing the pure joy on Rebekah's face when she saw the final trailer for the first time at Project Expo made every past struggle worth it. Rebekah's excitement and glow drew spectators from other projects over to our location to see the happiness for themselves. It was a moment that photos will never do justice, and is something that each and every one of us will remember for the rest of our lives.

We were incredibly lucky. Our advisor, Sarah Harding, had a saying for Senior Project that she always reminded her teams of: "it's not about the project, it's about the process". This simple saying could not be more accurate for the Rebekah's Ride Team. Thinking of where this project started, and seeing the final result and the impact it had on Rebekah's family was an unforgettable experience. See Figure 42 for a picture of our team with Professor Harding sharing Rebekah's excitement.

Figure 42. Team Picture with Rebekah and Professor Harding

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[17] *Simple Anthropometric Chart*. Digital image. *Mr. Patterson's Website Portal*. Schenectady City School District, n.d. Web. 13 Oct. 2014. <http://www.schenectady.k12.ny.us/users/pattersont/IBDT%20Website/IBTerms.html>.

Appendix A: QFD

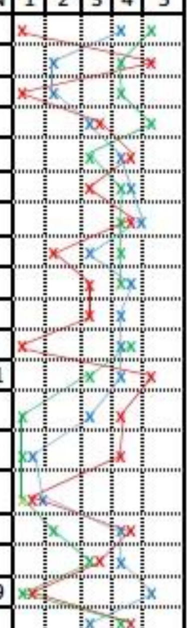
Customer 1: Rebekah's Parents
Customer 2: Rebekah
Customer 3: QL+

Current Product Used: WeeHoo iGo
Competitor 1: WeeRide Co-Pilot
Competitor 2: InStep Quick N EZ Bike Trailer

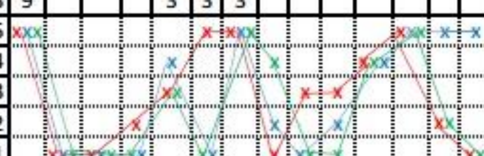
Customer	Grouping	Voices	Item No.	Importance	A: Max Weight of Device (lbs)	B: Max User Weight (lbs)	C: Max User Height (in.)	D: Max User Width (in.)	E: Max Overall Height of Device (in.)	F: Max Overall Width of Device (in.)	G: Max Overall Length of Device (in.)	H: Zero Reachable Pinch Points (#)	I: Handlebar movement from nominal (+/- in.)	J: Seat movement from nominal (+/- in.)	K: Time to Learn (min)	L: Max Number of Components (#)	M: Product Lifetime (yrs)	N: Pack Storage (ft³)
1	Safety	Pinch Points	1	10								9	3	3		3		
1	Safety	Seated Height	2	7			3		9			1						
1	Safety	Bike Stability	3	10	3	3	1	1	9	9	9		1	1	1			
1	Safety	Wheel Spokes	4	2								3						
1	Reliability	Durable	5	7		1										1	9	
1	Reliability	Low Maintenance	6	7		1										1	3	
1	Reliability	Strong through mult.uses	7	7		1										1	9	
1	Comfort	Smooth Ride	8	6	3	3		1	1	3	3		1	1				
1	Comfort	Easy to Use	9	5	1		1	1	3	3	3	1	3	3	9	3		
1	Comfort	Quiet Operation	10	3	1											1		
1	Comfort	Seat / Strap Comfort	11	8			9	9	3	9	3		1	9				
1	Comfort	User Freedom	12	5		3	3	3	3	3	3	1	3	3				1
1	Adjustability	Seat	13	6			1	9		9	9	3	1	9	1			
1	Adjustability	Handlebars	14	2			3		3	3	3	3	9	1	1			
3	Adjustability	Adaptability (future)	15	1					1	1	1	1			3	1	1	
2		Appearance	16	5					3	3	3							
1		Portable	17	4	9				9	9	9					9		
1		Storage	18	2														9
1		Light Weight	19	3	9				3	3	3							
		Targets			50 lbs	200 lbs	78 in.	18 in.	40 in.	22 in.	96 in.	0	3 in.	6 in.	10 min.	4 parts	7 years	1 ft³
		Weighted Importance			119	84	135	162	280	331	283	138	108	204	66	106	148	23
		% Importance			7.26	5.12	8.23	9.9	17.1	20	17.3	8.4	6.6	12	4.02	6.46	9	1.4

Total weighted importance: 1640

Customer Ratings (Bad 1 – 5 Good)



Company Ratings (Good 5 – 1 Bad)



Strong - 9
Medium-3
Weak - 1
Relationship Strength

Appendix B: Sketches of Initial Ideas (Page 1 of 3)

Frame:

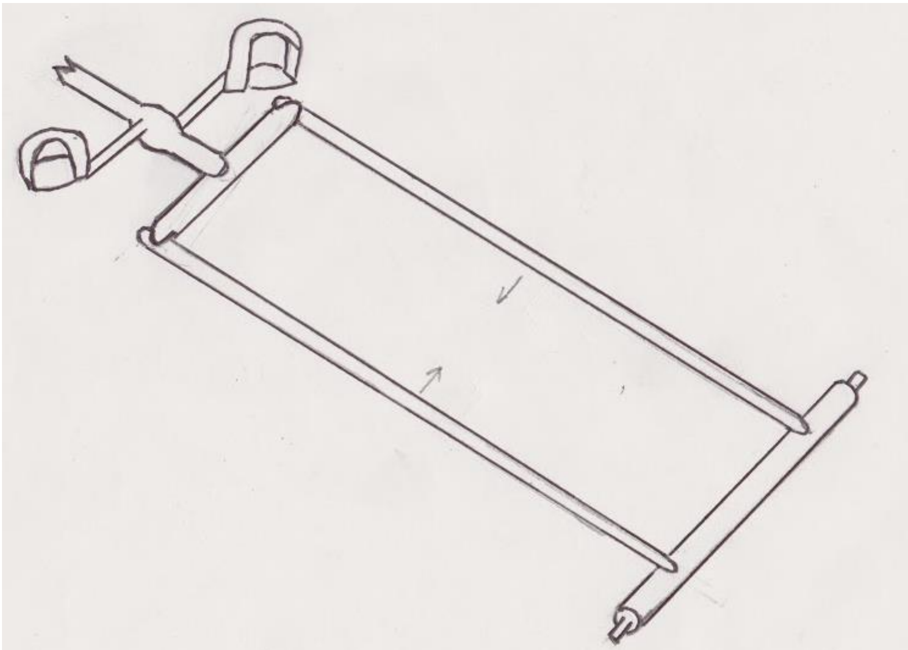


Figure B1. Two Bar

Seat:

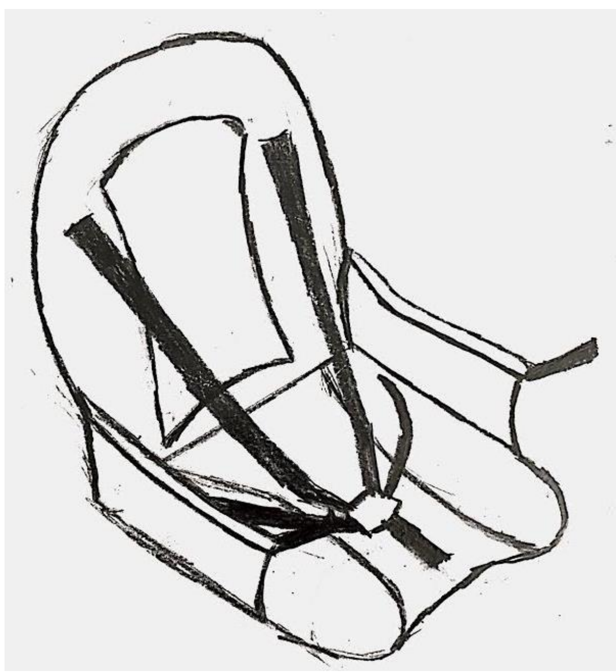


Figure B2. Recumbent Seat with Side Supports

Appendix B: Sketches of Initial Ideas (Page 2 of 3)

Adjustability:

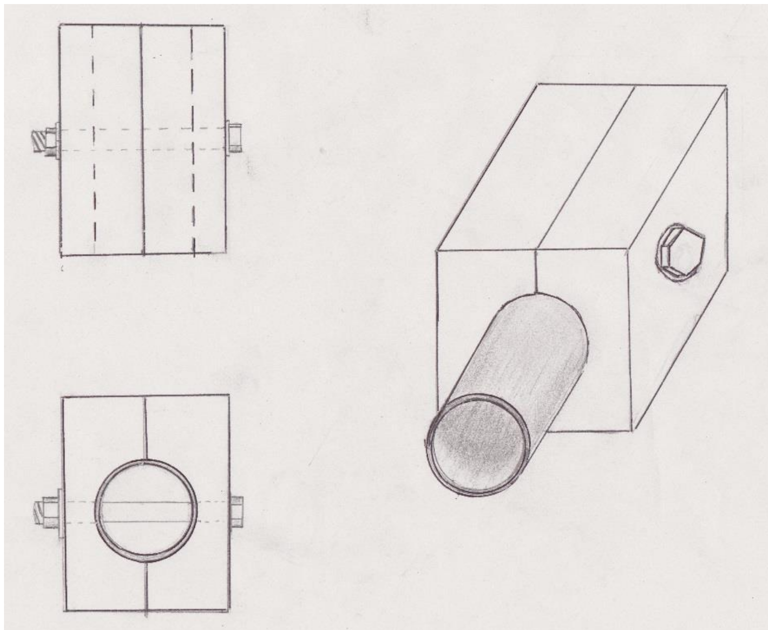


Figure B3. Through Bolt

Attachment:

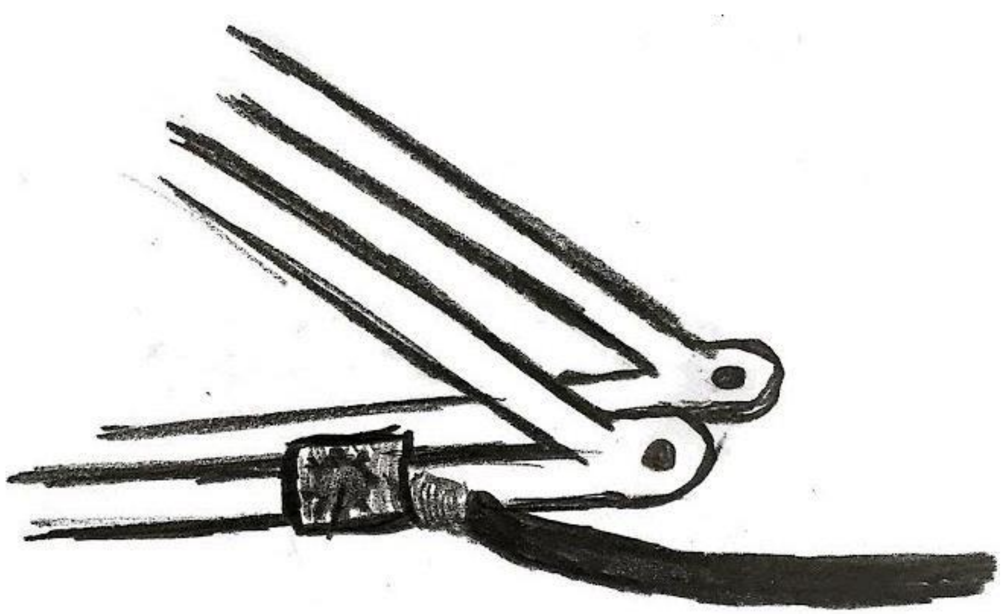


Figure B4. Attachment to One Side of Frame

Appendix B: Sketches of Initial Ideas (Page 3 of 3)

Wheels:

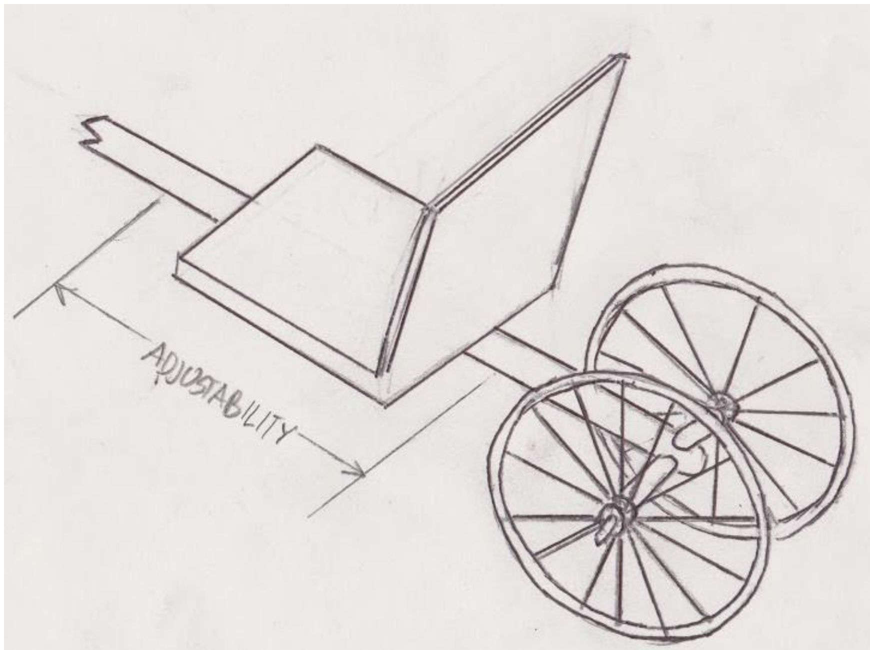


Figure B5. Double Wheels Behind Seat

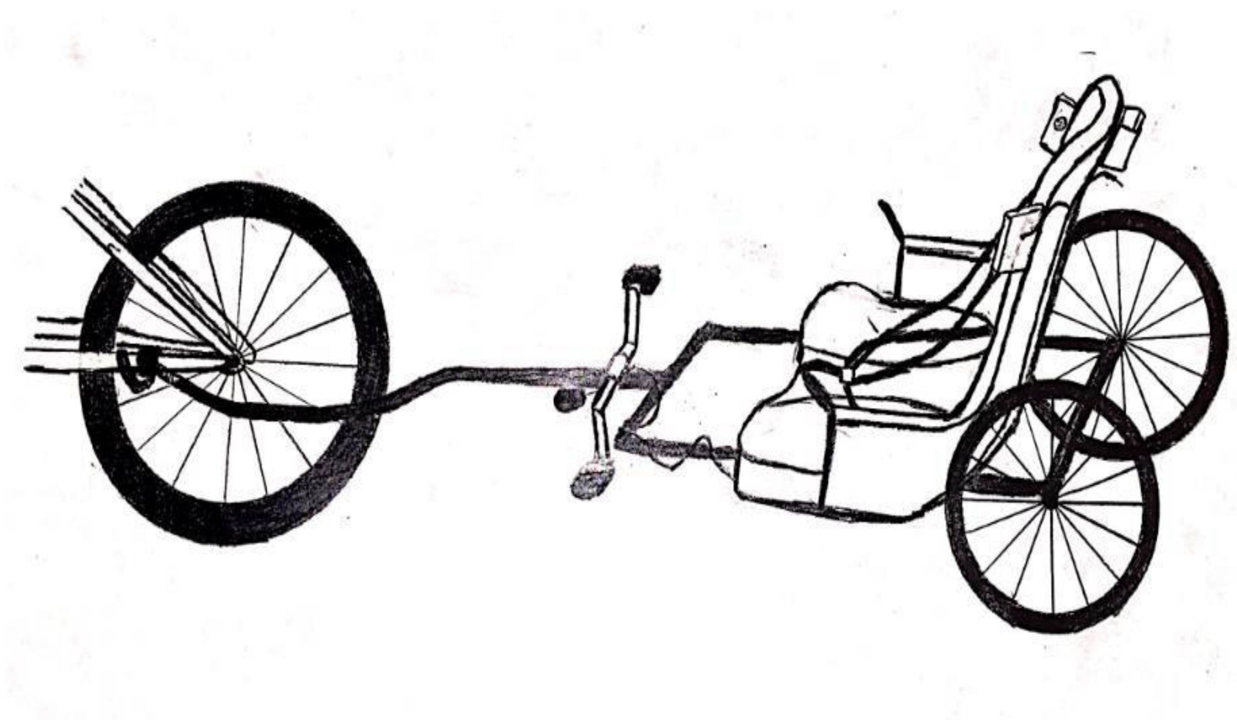
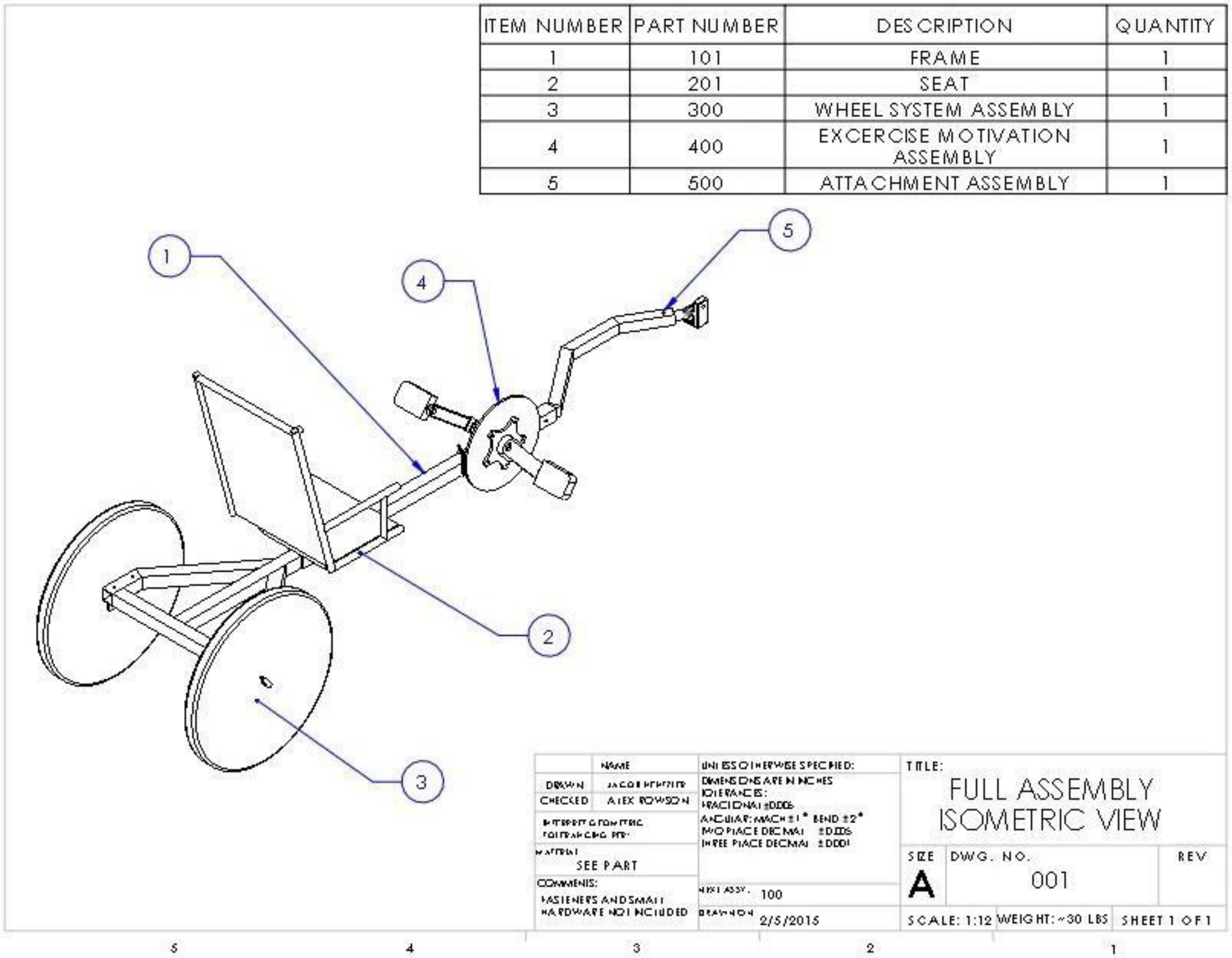


Figure B6. Initial Design



ITEM NUMBER	PART NUMBER	DESCRIPTION	QUANTITY
1	101	FRAME	1
2	201	SEAT	1
3	300	WHEEL SYSTEM ASSEMBLY	1
4	400	EXCERCISE MOTIVATION ASSEMBLY	1
5	500	ATTACHMENT ASSEMBLY	1

Figure C1. Full Assembly Drawing

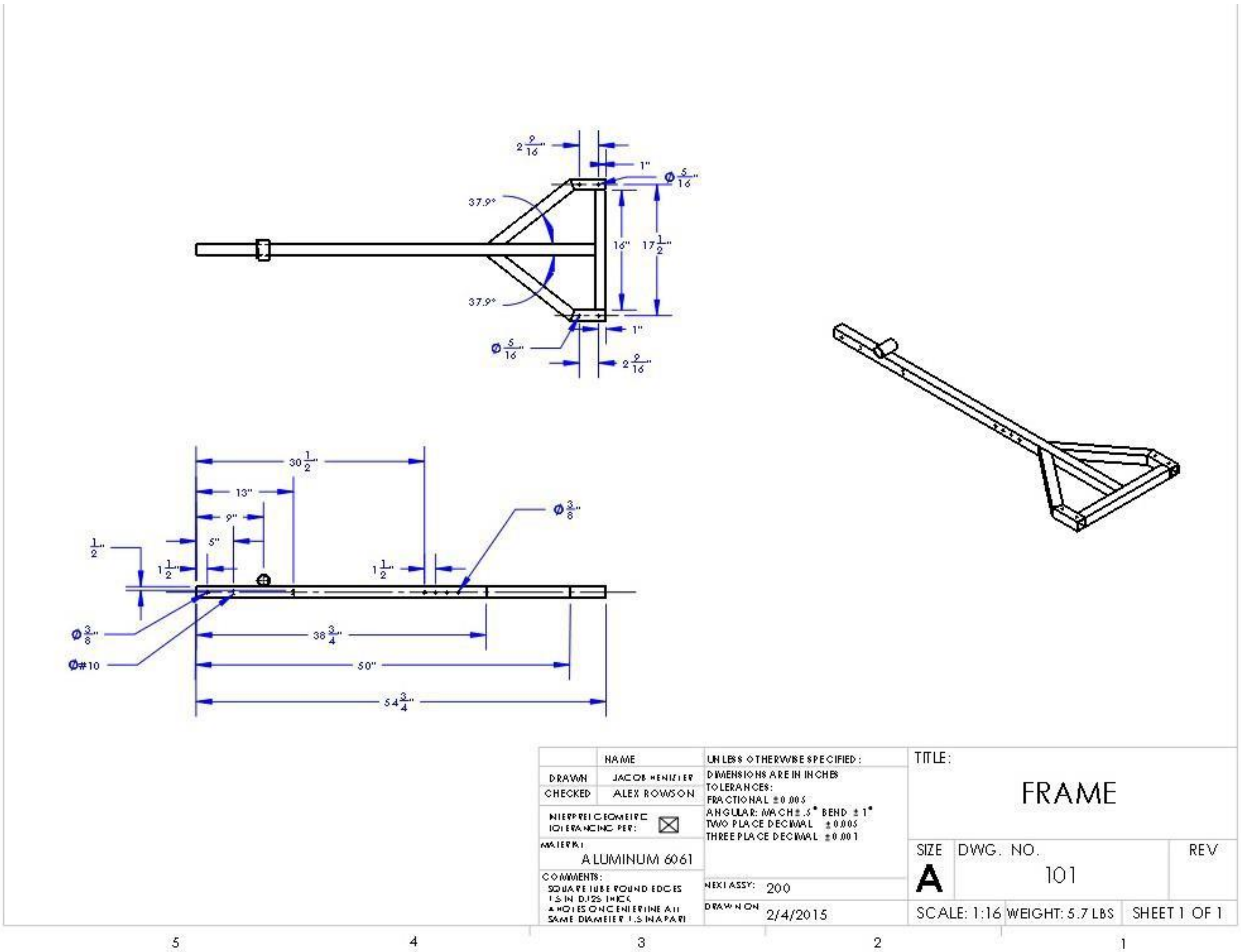


Figure C2. Frame

Appendix C: Detailed Drawings (Page 3 of 8)

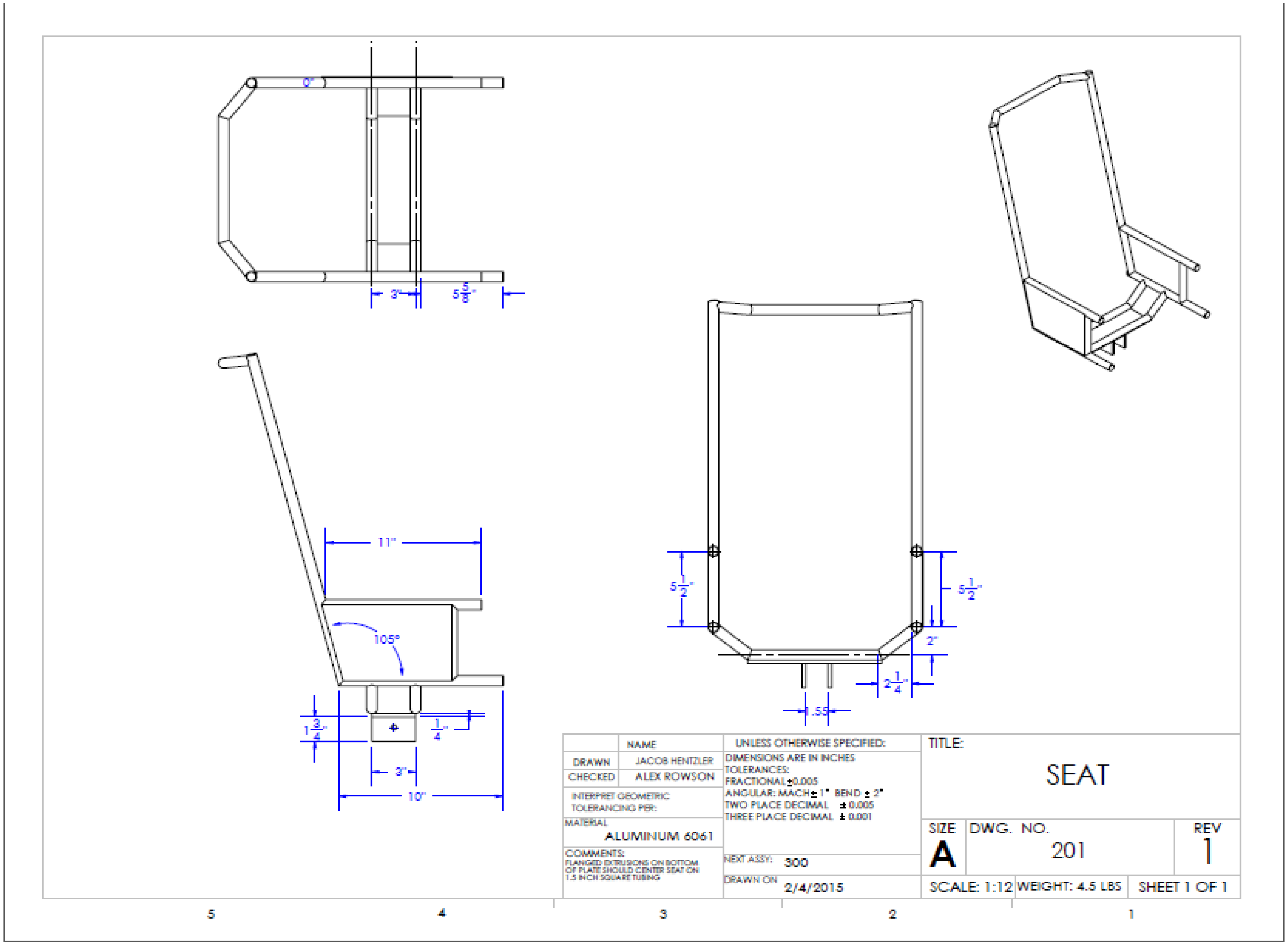


Figure C3. Seat

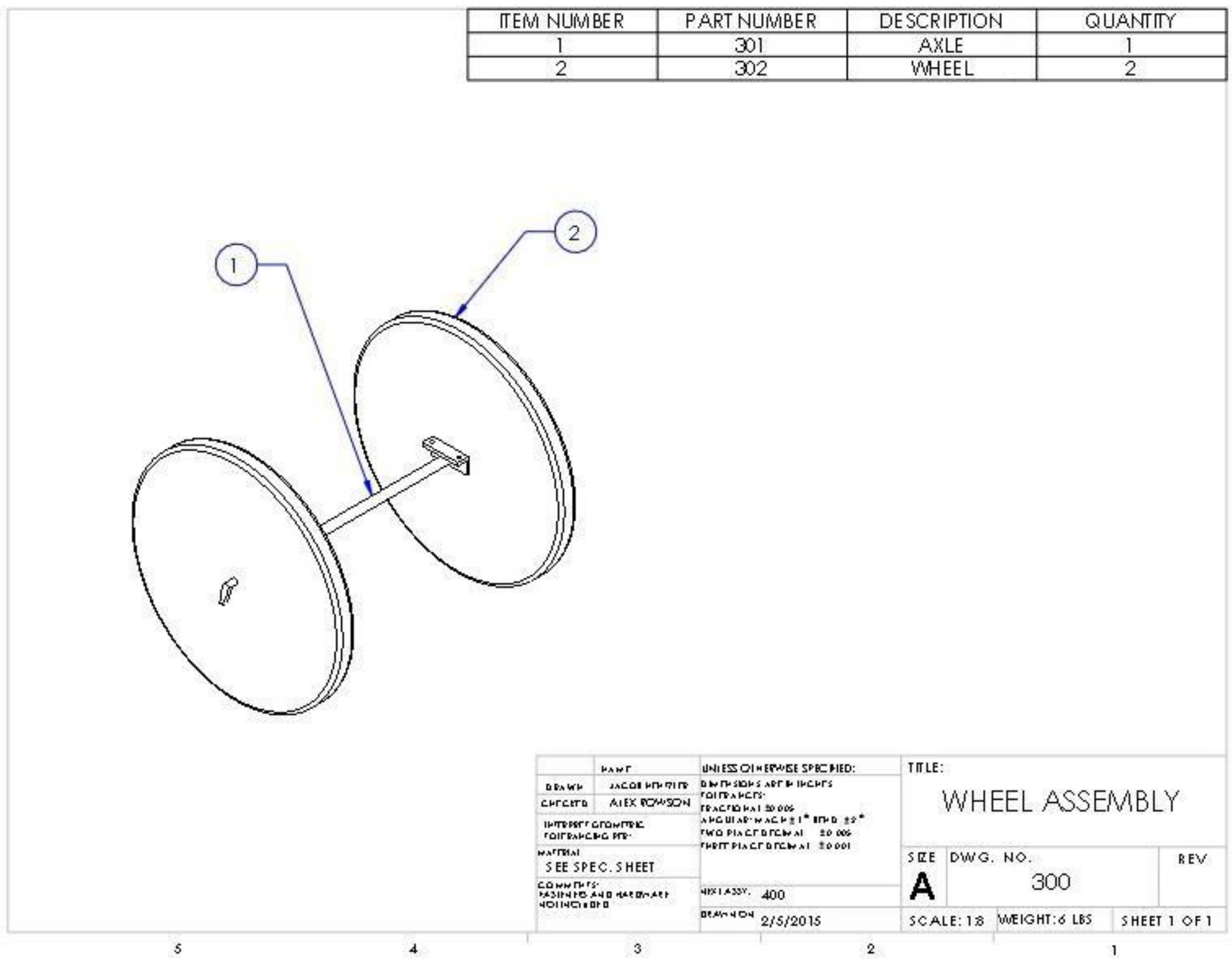


Figure C4. Wheel Assembly Drawing

Appendix C: Detailed Drawings (Page 5 of 8)

ITEM NUMBER	PART NUMBER	DESCRIPTION	QUANTITY
1	401	PLASTIC ADAPTIVE PEDALS	2
2	402	MANTRA CRANK SET	1
3	403	ALUMINUM BRAKE ROTOR	1
4	404	BRAKE PADS	2
5	412	BOTTOM BRACKET SHELL	1
6	413	BOTTOM BRACKET	1

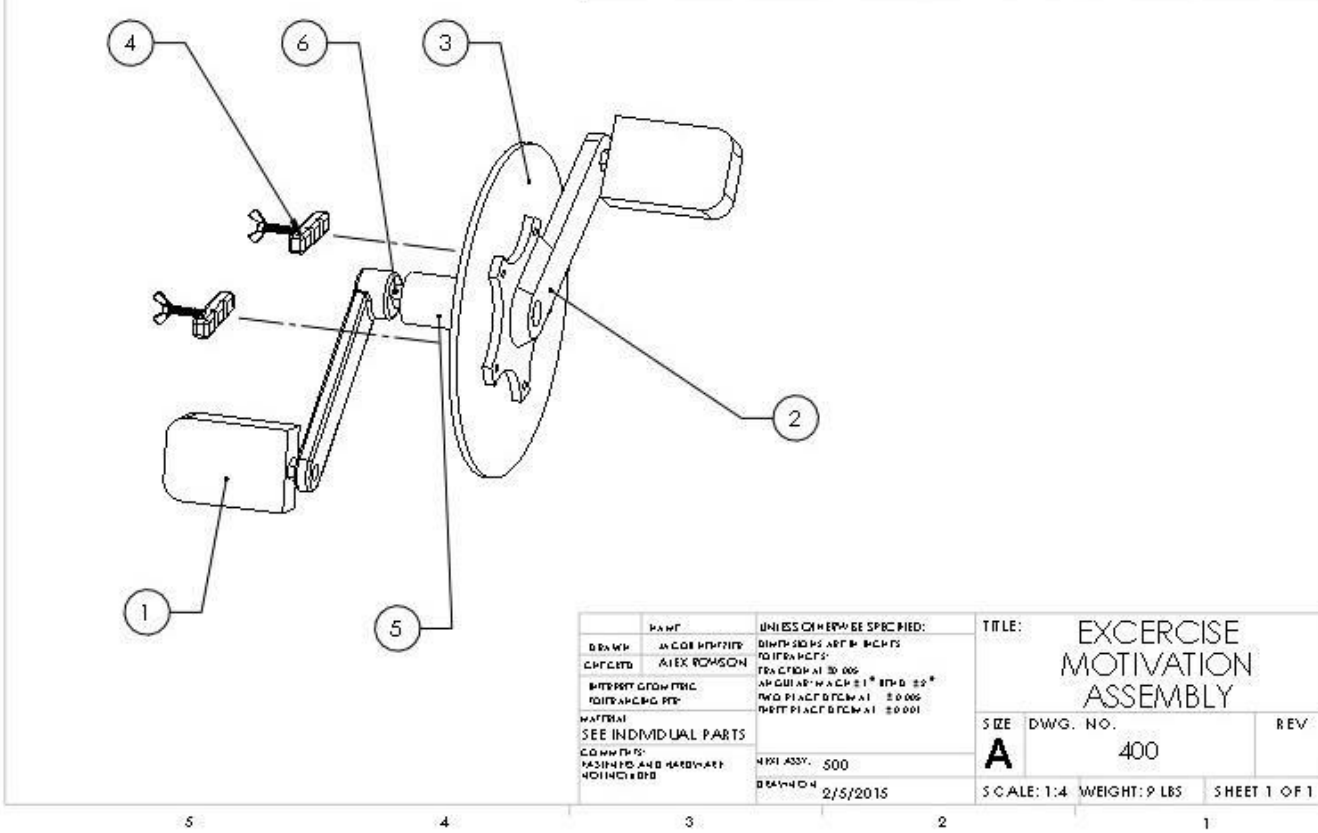


Figure C5. Motivation Assembly Drawing

Appendix C: Detailed Drawings (Page 6 of 8)

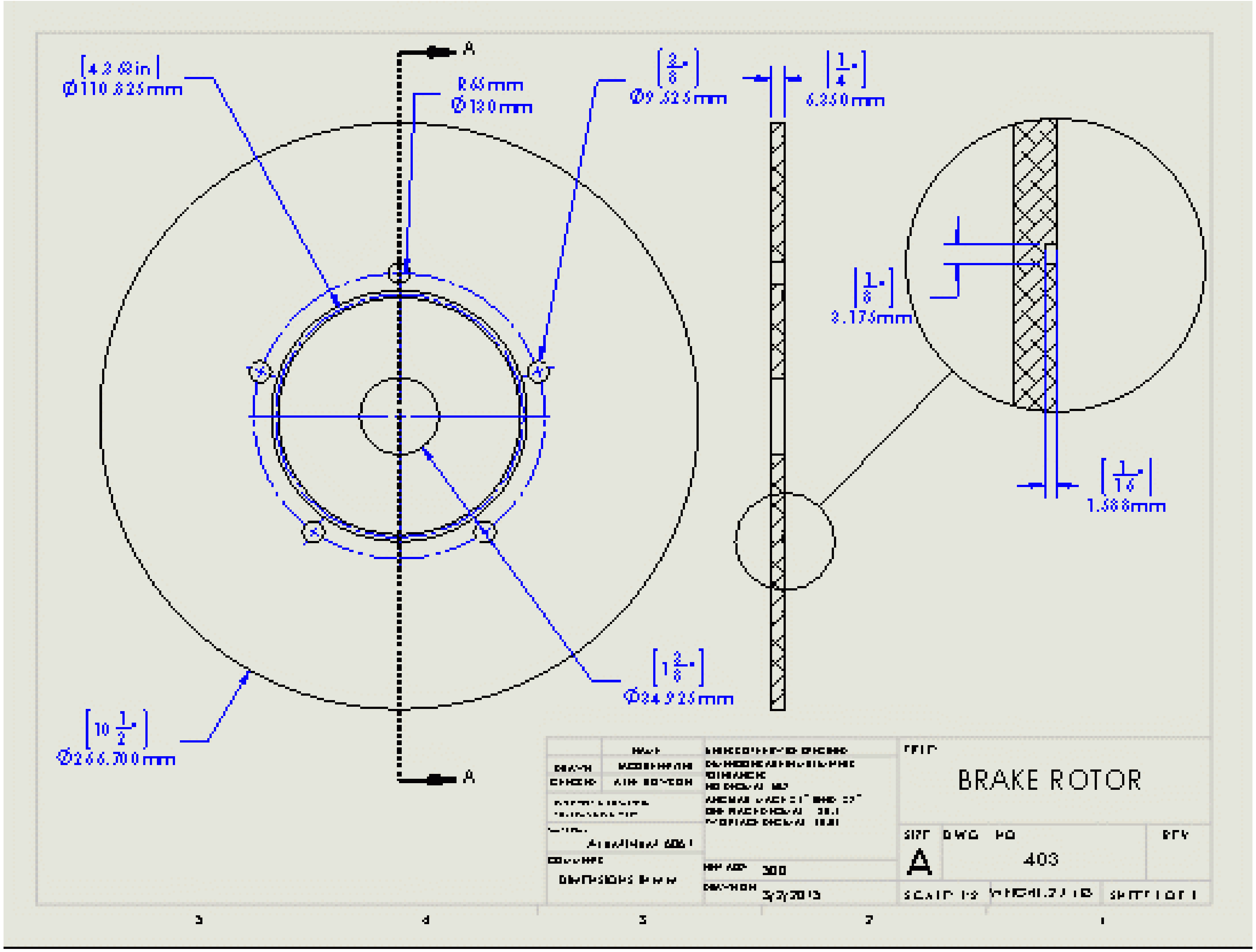


Figure C6. Rotor Drawing

Appendix C: Detailed Drawings (Page 7 of 8)

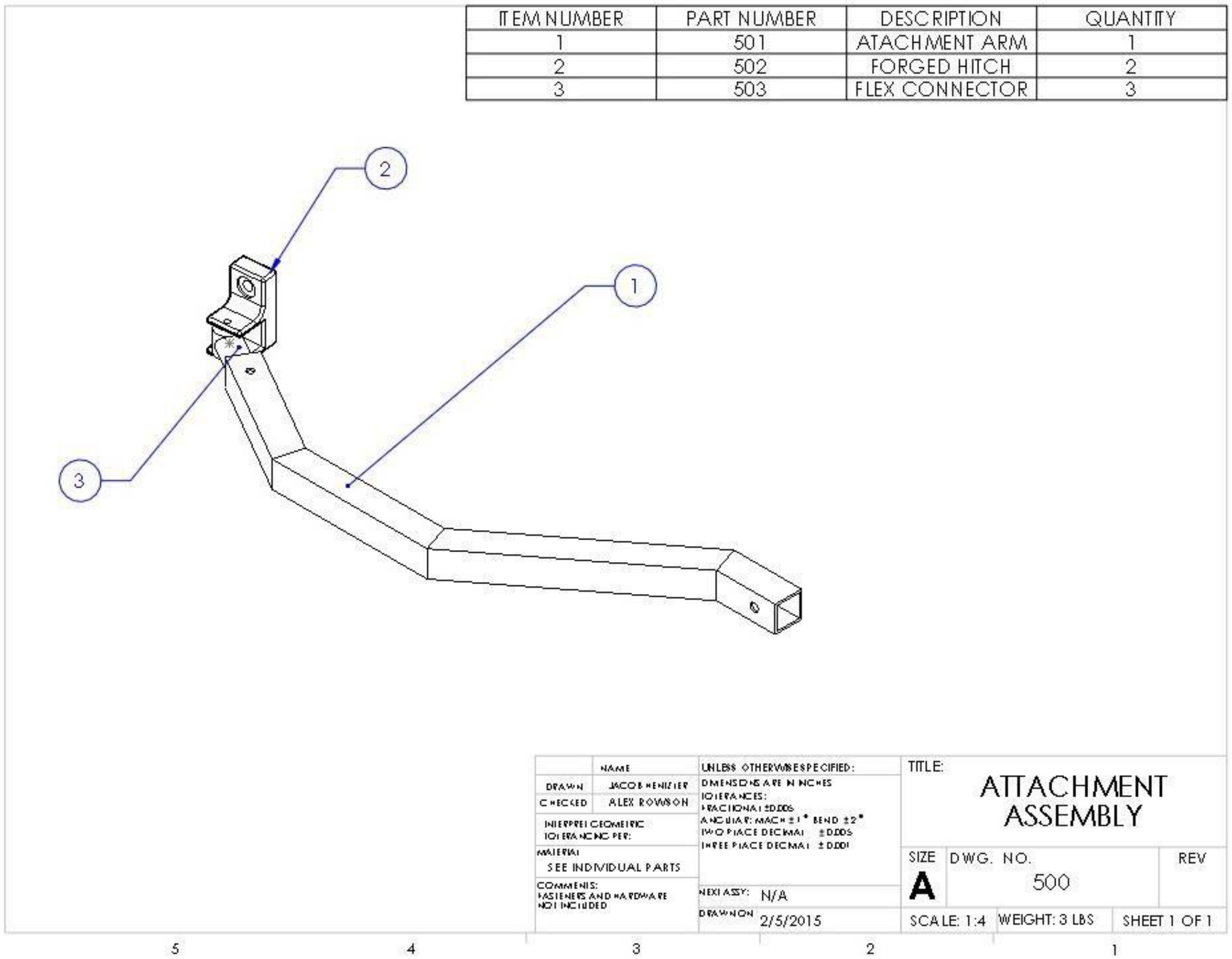


Figure C7. Attachment Assembly Drawing

Appendix C: Detailed Drawings (Page 8 of 9)

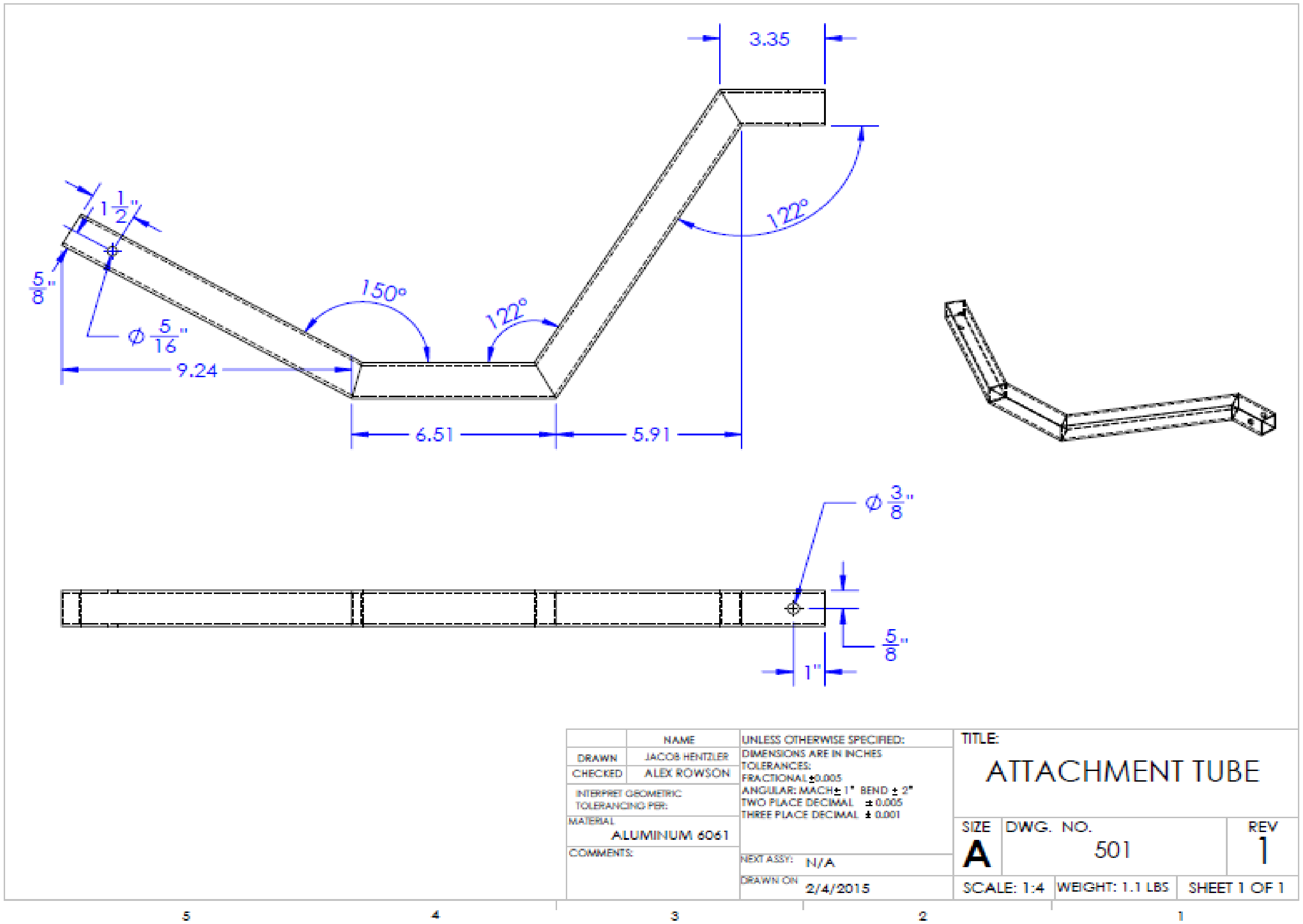


Figure C8. Attachment Arm Drawing

Appendix C: Detailed Drawings (Page 9 of 9)

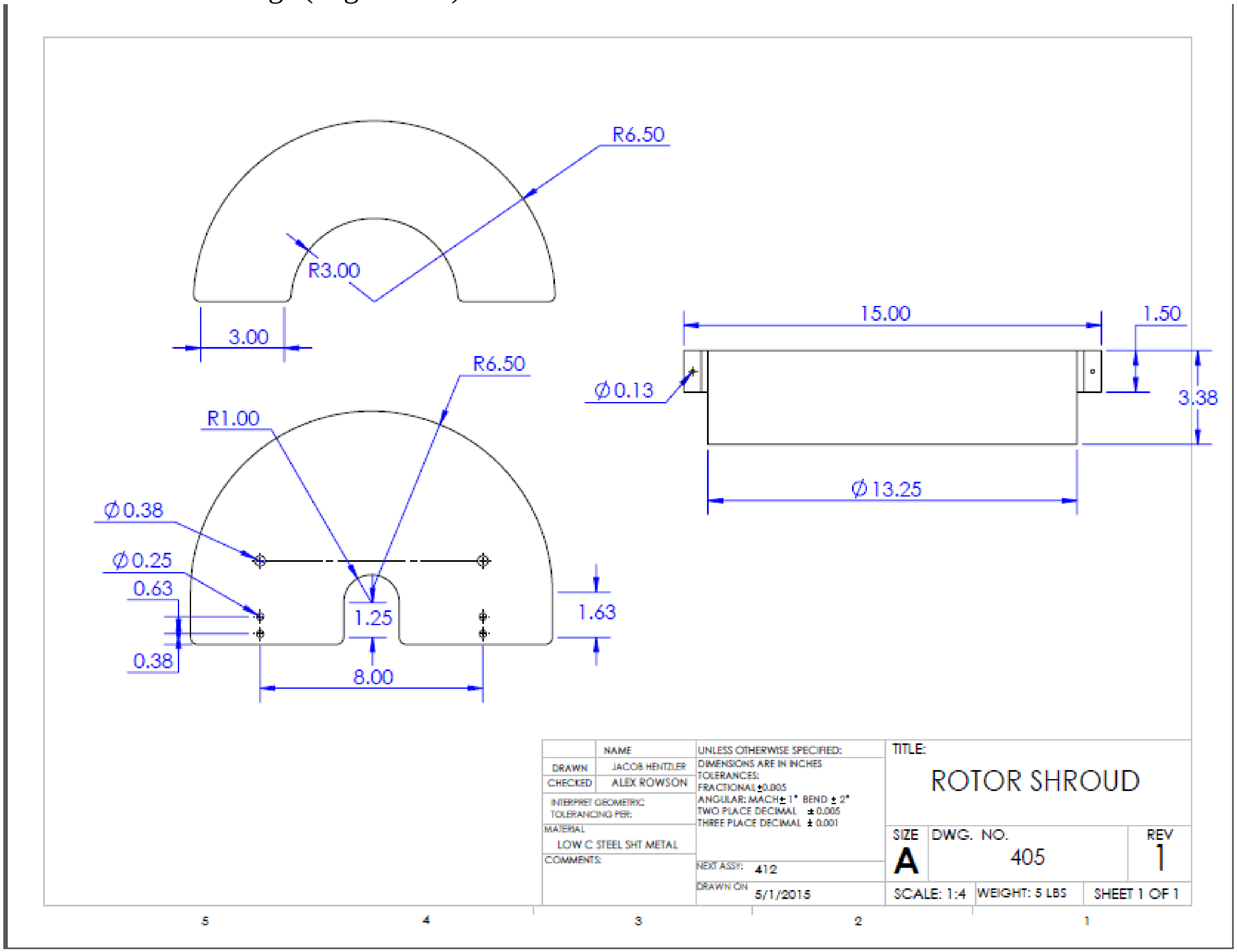
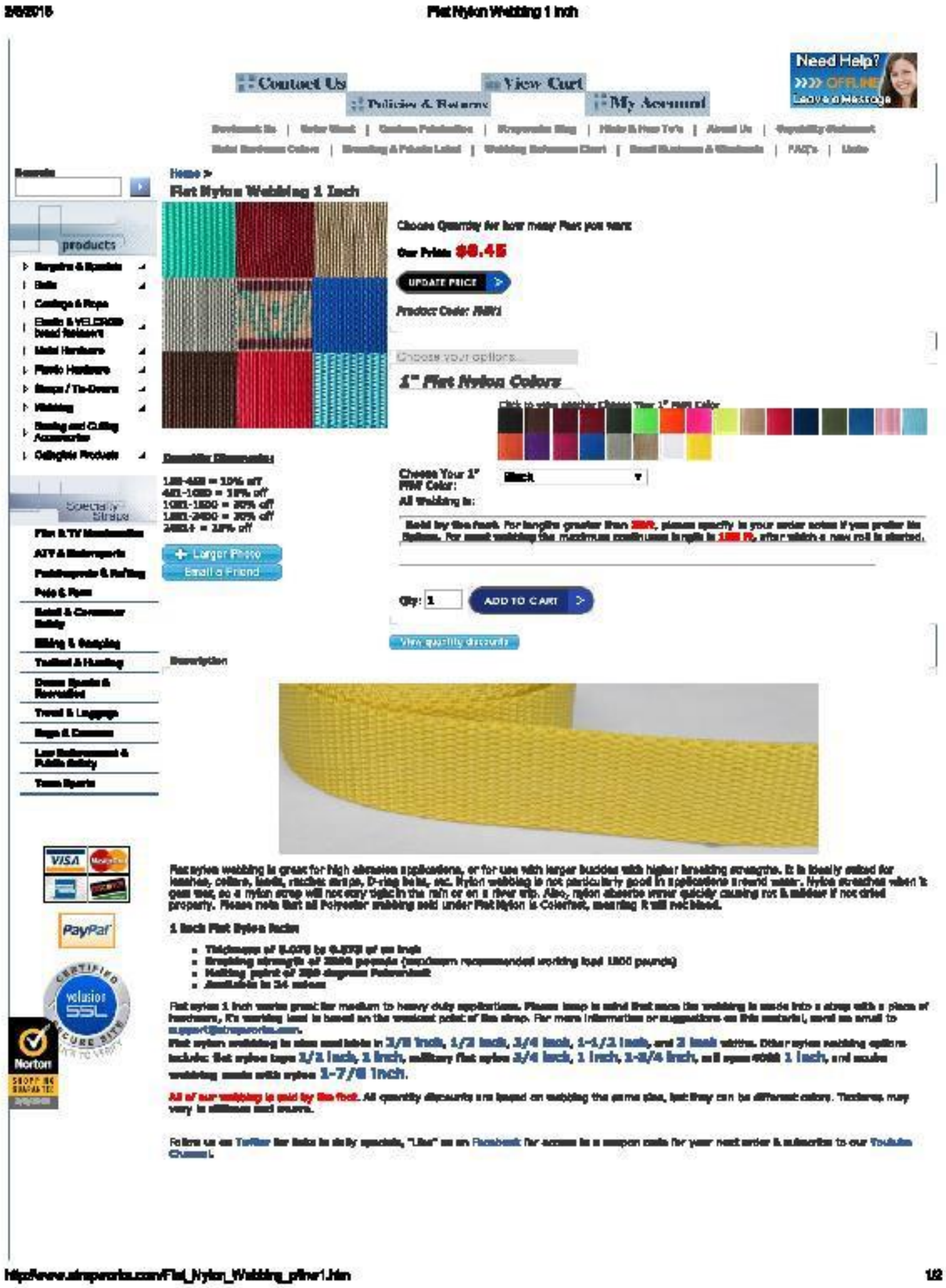


Figure C9. Rotor Shroud Drawing

Appendix D: Specification Sheets (Page 1 of 12)



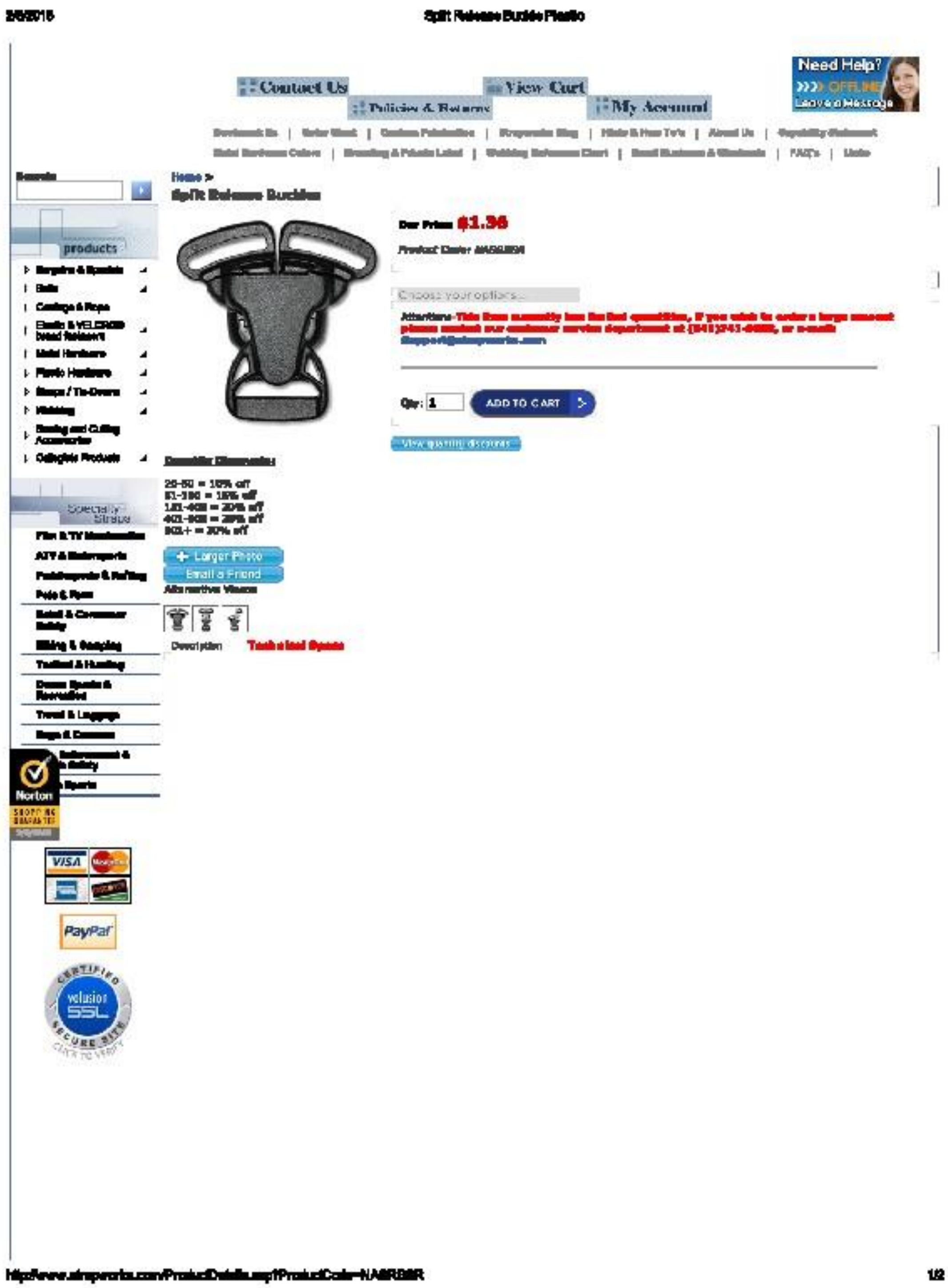


Figure D1. Safety Harness Materials

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Standard Forged Hitch

- Works with disc brake and full suspension
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- Made of forged 6061 T6 aluminum
- Mono-stays require a longer safety strap which can be purchased separately
- Fits both 9.5 mm and 10.5 mm axles
- Does not include Flex Connector

Hitch Guide Video

Installation Video

If you are upgrading from a Classic Hitch to a Standard Forged Hitch, you will also need to purchase a Flex Connector: Part # 950038 (square tow bar) or Part # 950037 (round tow bar).

Flex Connector Guide Video

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Flex Connector for Square Tow Bar

This part connects the trailer to the hitch. It attaches inside the tow bar and locks in place inside the hitch using a retaining pin (Standard Forged Hitch) or bolt and nut (Classic Hitch). This flexible connector can stretch easily to allow user to lay down a bike. See manual for more details.

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Figure D2. Burley Attachment

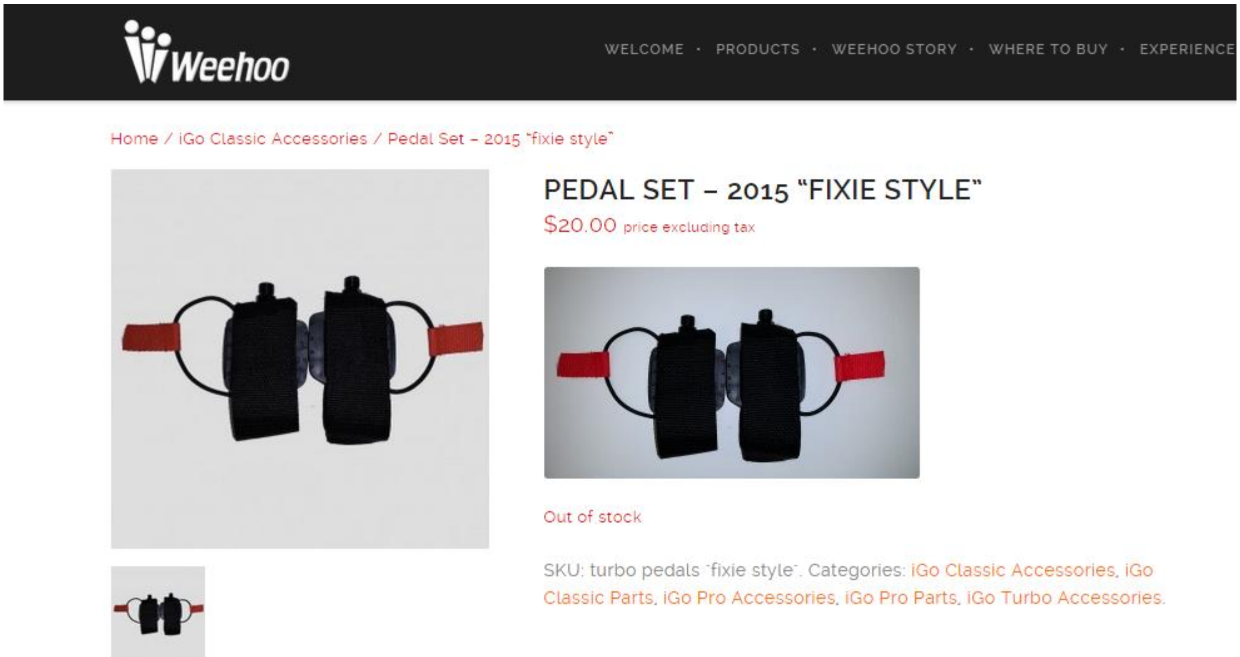

Figure D3. Pedals

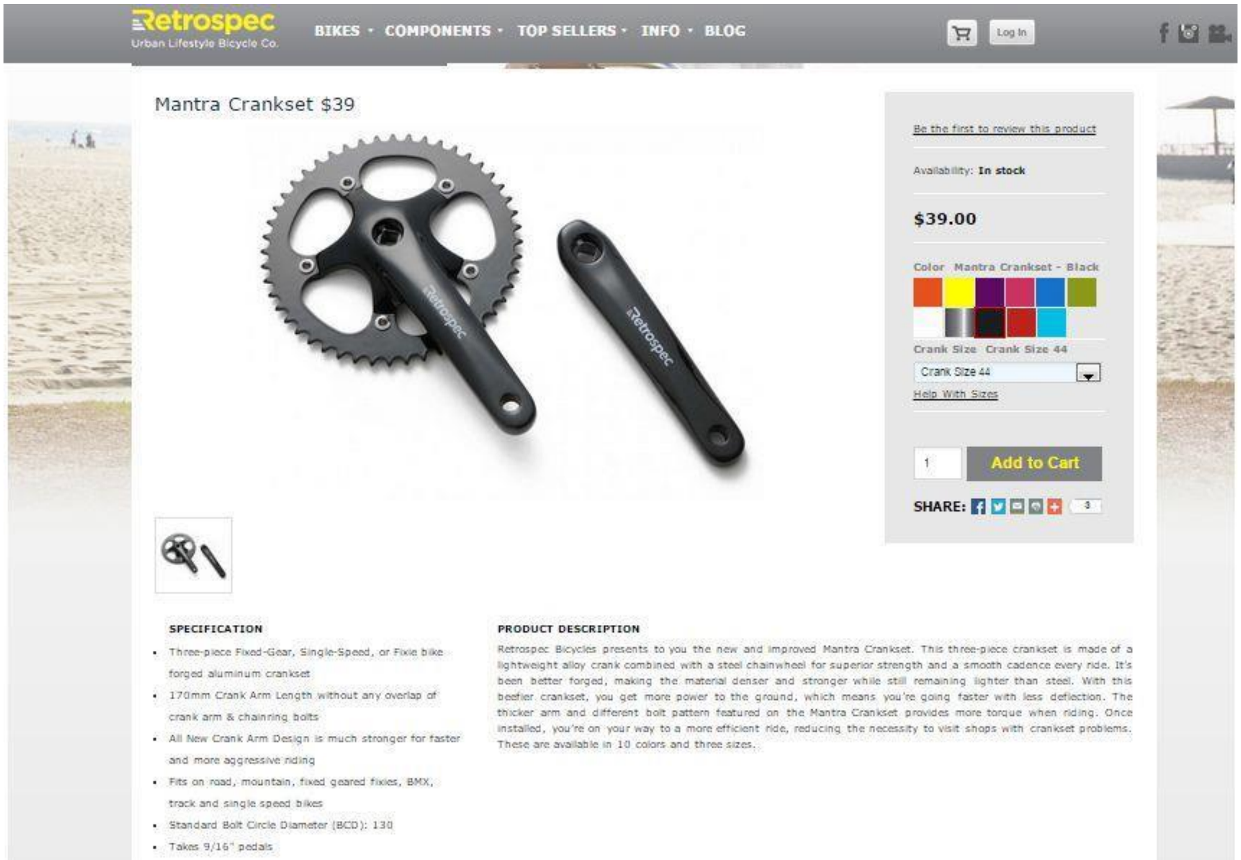

Figure D4. Crankset

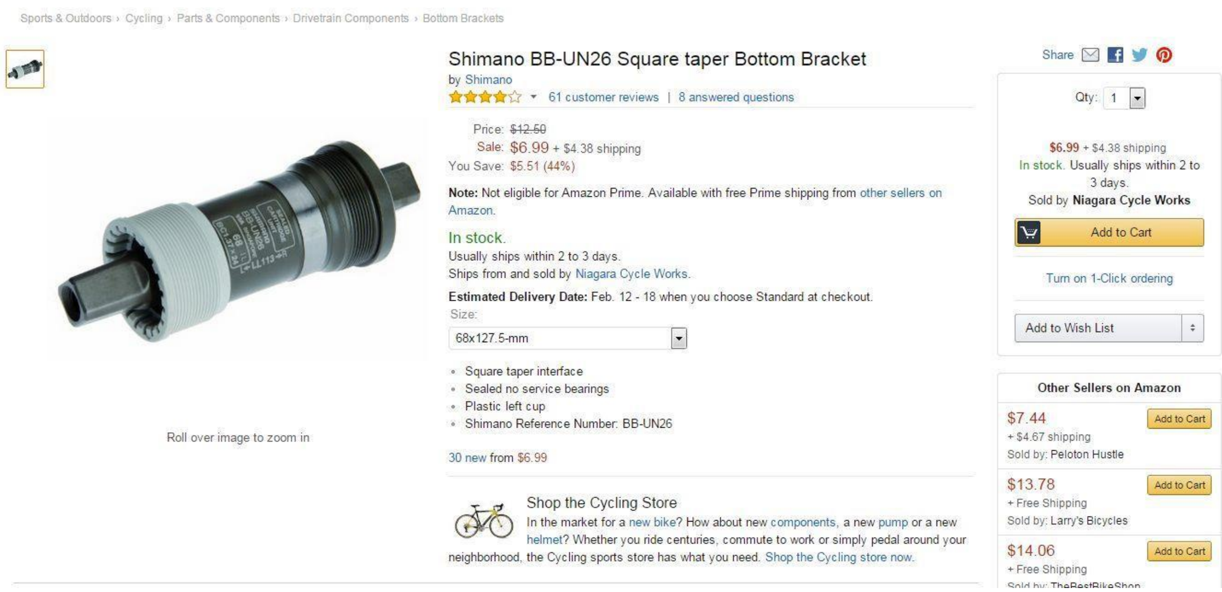

Figure D5. Bottom Bracket

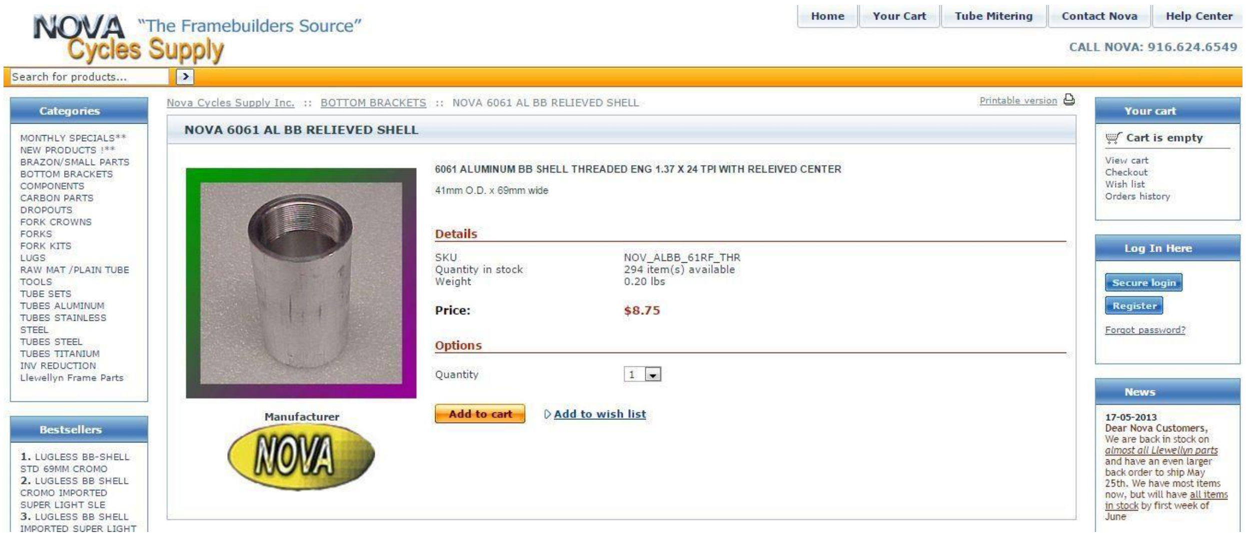

Figure D6. Bottom Bracket Shell

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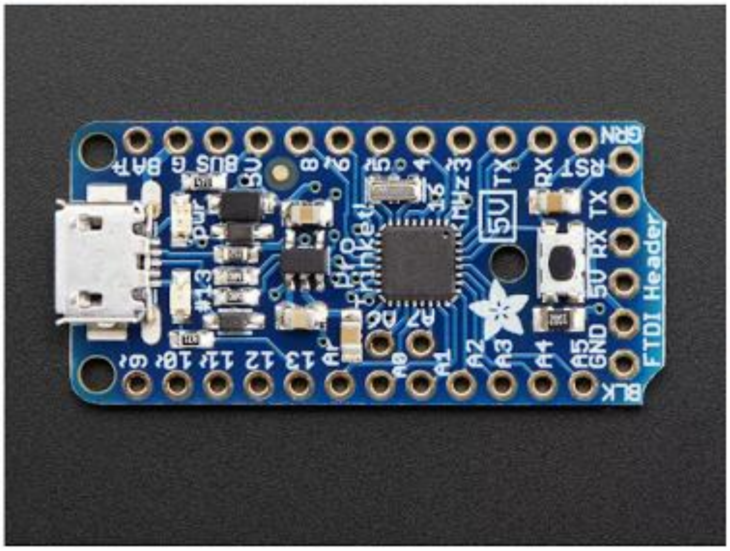

Adafruit Pro Trinket - 5V 16MHz

PRODUCT ID: 2000

$9.95

65 IN STOCK

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Also include 1 x Adafruit Pro Trinket LiIon/LiPoly Backpack Add-On ($4.95)

QTY	DISCOUNT
1-9	$9.95
10-99	$8.96
100+	$7.96

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DESCRIPTION

TECHNICAL DETAILS

LEARN

DESCRIPTION

Trinket's got a big sister in town - the **Pro Trinket 5V**! Pro Trinket combines everything you love about Trinket with the familiarity of the common core Arduino chip, the ATmega328. It's like an Arduino Pro Mini with more pins and USB tossed in, so delicious.

Trinket's a year old now, and while its been great to see tons of tiny projects, sometimes you just need more pins, more FLASH, and more RAM. That's why we designed Pro Trinket, with 18 GPIO, 2 extra analog inputs, 28K of flash, and 2K of RAM.

Like the Trinket, it has onboard USB bootloading support - we opted for a MicroUSB jack this time. We also added Optiboot support, so you can either program your Pro Trinket over USB or with a FTDI cable just like the Pro Mini and friends.

The Pro Trinket PCB measures only 1.5" x 0.7" x 0.2" (without headers) but packs much of the same capability as an Arduino UNO. So it's great once you've finished up a prototype on an official Arduino UNO and want to make the project smaller.

The Pro Trinket 5V uses the Atmega328P chip, which is the same core chip in the Arduino UNO/Duemilanove/Mini/etc. at the same speed and voltage. So you'll be happy to hear that not only is Pro Trinket programmable using the Arduino IDE as you already set up, but 99% of Arduino projects will work out of the box!

For tons more details, check out the Introducing Pro Trinket tutorial

Here's some things you may have to consider when adapting Arduino sketches:

- Pins #2 and #7 are not available (they are exclusively for USB)
- The onboard 5V regulator can provide 150mA output, not 800mA out
- You cannot plug shields directly into the Pro Trinket
- There is no Serial-to-USB chip onboard. This is to keep the Pro Trinket small and inexpensive, you can use any FTDI cable to connect to the FTDI port for a Serial connection. The USB connection is for uploading new code only.
- The bootloader on the Pro Trinket use 4KB of FLASH so the maximum sketch size is 28,672 bytes. The bootloader does not affect RAM usage.

Here's some handy specifications:

- ATmega328P onboad chip in QFN package
- 16MHz clock rate, 28K FLASH available
- USB bootloader with a nice LED indicator looks just like a USBtinyISP so you can program it with AVRdude and/or the Arduino IDE (with a few simple config modifications).
- Also has headers for an FTDI port for reprogramming
- Micro-USB jack for power and/or USB uploading, you can put it in a box or tape it up and use any USB cable for when you want to reprogram.
- On-board 5.0V power regulator with 150mA output capability and ultra-low dropout. Up to 16V input, reverse-polarity protection, thermal and current-limit protection.
- Power with either USB or external output (such as a battery) - it'll automatically switch over
- On-board green power LED and red pin #13 LED
- Reset button for entering the bootloader or restarting the program.
- Works with 99% of existing Arduino sketches (anything that doesn't use more than 28K, and doesn't require pins #2 and #7)
- **Mounting holes! Yeah!**

Figure D7. Adafruit Pro Trinket Microcontroller

Hall effect sensor - US5881LUA

PRODUCT ID: 158

$2.00

IN STOCK

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QTY	DISCOUNT
1-9	$2.00
10-49	$1.75
50+	$1.50

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DESCRIPTION

TECHNICAL DETAILS

DESCRIPTION

Hall effect sensors detect whether a magnet is near. Useful for non-contact/waterproof type switches, position sensors, rotary/shaft encoders. I tried dozens of different hall effect sensors to see which one would work best for the SpokePOV kit (to determine the wheel location) and this one came out on top!

Runs at 3.5V up to 24V. To use connect power to pin 1 (all the way to the left), ground to pin 2 (middle) and then a 10K pull up resistor from pin 3 to power. Then listen on pin 3, when the south pole of a magnet is near the front of the sensor, pin 3 will go down to 0V. Otherwise it will stay at whatever the pullup resistor is connected to. Nothing occurs if a magnet's north pole is nearby (unipolar).

Works fantastic with the high strength magnet Read the datasheet

Read a nice whitepaper from the manufacturer with many ideas and designs for use

TECHNICAL DETAILS

RoHS

Dimensions:

- Length: 1.51mm/0.06in
- Width: 4.08mm/0.16in
- Height: 3.00mm/0.12in
- Weight: 0.1g/0.004oz

Figure D8. Hall Effects Sensor

2/2/2015 ::2004-2013 Axle Tube Assembly, Nomad | Nomad - Burley--BURLEY--

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Item No: 950029

International prices and models will vary.

USD $20.00

Quantity: 1

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2004-2013 Axle Tube Assembly, Nomad

Axle Tube Assembly for 2004-2013 Nomad.

Replacement axle tube.

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Print Page

Item No: 160028

International prices and models will vary.

USD $60.00

Quantity: 1

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2007-2009 20" Alloy Wheel, (07-08) D'Lite, Encore, Honey Bee & Bee

20" alloy spoked quick release wheel with tire, tube, and reflectors.

Compatible with:

- 2007-2008 D'Lite
- 2007-2009 Encore

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Figure D9. Burley Wheel and Axle Assembly

Appendix E. Analysis and Calculations (Page 1 of 8)

Weight and Cost Analysis for a T-Frame

T-Frame (1 Beam)											
Aluminum (6061-T6)				General Purpose Steel (1020)				Steel (4130 Alloy)			
OD (in)	WT (in)	Weight (lb)	Total Cost	OD (in)	WT (in)	Weight (lb)	Total Cost	OD (in)	WT (in)	Weight (lb)	Total Cost
1.250	0.250	6.597	$58.30	1.125	0.188	13.156	$60.07	1.000	0.120	7.886	$68.32
1.500	0.125	**4.536**	$55.71	1.500	0.065	6.966	**$21.15**	1.125	0.083	6.459	$53.82
								1.375	0.049	4.852	$53.67

Weight and Cost Analysis for a Box Frame.

Box Frame (2 Beams)											
Aluminum (6061-T6)				General Purpose Steel (1020)				Steel (4130 Alloy)			
OD (in)	WT (in)	W (lb)	Total Cost	OD (in)	WT (in)	W (lb)	Total Cost	OD (in)	WT (in)	W (lb)	Total Cost
1.000	0.125	5.773	$71.84	1.000	0.120	15.773	$47.27	0.750	0.120	11.292	$114.59
1.250	0.065	4.065	$103.48	1.500	0.049	10.620	**$35.58**	0.875	0.083	9.819	$93.22
1.500	0.049	**3.753**	$123.06					1.000	0.049	6.960	$69.63
								1.125	0.035	5.698	$90.30

Weight and Cost Analysis for a Y-Frame.

Y-Frame (3 Beams)											
Aluminum (6061-T6)				General Purpose Steel (1020)				Steel (4130 Alloy)			
OD (in)	WT (in)	Weight (lb)	Total Cost	OD (in)	WT (in)	Weight (lb)	Total Cost	OD (in)	WT (in)	Weight (lb)	Total Cost
1.000	0.065	**4.811**	$135.49	1.000	0.049	10.440	**$35.63**	0.750	0.065	9.976	$108.75
1.000	0.125	8.659	$107.77					0.875	0.049	9.068	$96.67
1.250	0.065	6.098	$155.23					1.000	0.035	7.567	$110.43

Figure E1: Original Frame Analysis

Max Weight	150	lbs
# Beams	1	
Total Frame Length	84	in
Avg Location of Load (from origin)	52	in
Avg Location of Load (from wheels)	32	in
Factor of Safety	1.5	
Max Moment	2971.429	psi

Aluminum (6061-T6)		
Density	0.1	lb/in^3
Yield Strength	35000	psi
Outer Diameter Guess	1.25	in
Max Bending Radius	0.625	in
Inner Diameter	0.952	in
Wall Thickness	0.149	in
McMaster WT	0.250	in
McMaster OD	1.250	in
Price per 6ft	$ 49.97	
Total Cost	$ 58.30	
Total Weight	6.597	lb
McMaster WT	0.125	in
McMaster OD	1.500	in
Price per 6ft	$ 47.75	
Total Cost	$ 55.71	
Total Weight	4.536	lb

Steel (General Purpose 1020)		
Density	0.283	lb/in^3
Yield Strength	45000	psi
Outer Diameter Guess	1.5	in
Max Bending Radius	0.75	in
Inner Diameter	1.373	in
Wall Thickness	0.064	in
McMaster WT	0.188	in
McMaster OD	1.125	in
Price per 6ft	$ 51.49	
Total Cost	$ 60.07	
Total Weight	13.156	lb
McMaster WT	0.065	in
McMaster OD	1.500	in
Price per 6ft	$ 18.13	
Total Cost	$ 21.15	
Total Weight	6.966	lb

Steel (4130 Alloy)		
Density	0.283	lb/in^3
Yield Strength	70000	psi
Outer Diameter Guess	1.5	in
Max Bending Radius	0.75	in
Inner Diameter	1.422	in
Wall Thickness	0.039	in
McMaster WT	0.120	in
McMaster OD	1.000	in
Price per 6ft	$ 58.56	
Total Cost	$ 68.32	
Total Weight	7.886	lb
McMaster WT	0.083	in
McMaster OD	1.125	in
Price per 6ft	$ 46.13	
Total Cost	$ 53.82	
Total Weight	6.459	lb
McMaster WT	0.065	in
McMaster OD	1.250	in
Price per 6ft	$ 49.83	
Total Cost	$ 58.14	
Total Weight	5.752	lb
McMaster WT	0.049	in
McMaster OD	1.375	in
Price per 6ft	$ 46.00	
Total Cost	$ 53.67	
Total Weight	4.852	lb

Figure E2. Analysis of 1 Bar Frame

Max Weight	150	lbs
# Beams	2	
Total Frame Length	84	in
Avg Location of Load (from origin)	52	in
Avg Location of Load (from wheels)	32	in
Factor of Safety	1.5	
Max Moment	1485.714	psi

Aluminum (6061-T6)		
Density	0.1	lb/in^3
Yield Strength	35000	psi
Outer Diameter Guess	1.5	in
Max Bending Radius	0.75	in
Inner Diameter	1.422	in
Wall Thickness	0.039	in
McMaster WT	0.125	in
McMaster OD	1.000	in
Price per 6ft	$ 30.79	
Total Cost	$ 71.84	
Total Weight	5.773	lb
McMaster WT	0.065	in
McMaster OD	1.250	in
Price per 6ft	$ 44.35	
Total Cost	$ 103.48	
Total Weight	4.065	lb
McMaster WT	0.049	in
McMaster OD	1.500	in
Price per 6ft	$ 52.74	
Total Cost	$ 123.06	
Total Weight	3.753	lb

Steel (General Purpose 1020)		
Density	0.283	lb/in^3
Yield Strength	45000	psi
Outer Diameter Guess	1.5	in
Max Bending Radius	0.75	in
Inner Diameter	1.441	in
Wall Thickness	0.030	in
McMaster WT	0.120	in
McMaster OD	1.000	in
Price per 6ft	$ 20.26	
Total Cost	$ 47.27	
Total Weight	15.773	lb
McMaster WT	0.049	in
McMaster OD	1.500	in
Price per 6ft	$ 15.25	
Total Cost	$ 35.58	
Total Weight	10.620	lb

Steel (4130 Alloy)		
Density	0.283	lb/in^3
Yield Strength	70000	psi
Outer Diameter Guess	1.25	in
Max Bending Radius	0.625	in
Inner Diameter	1.195	in
Wall Thickness	0.028	in
McMaster WT	0.120	in
McMaster OD	0.750	in
Price per 6ft	$ 49.11	
Total Cost	$ 114.59	
Total Weight	11.292	lb
McMaster WT	0.083	in
McMaster OD	0.875	in
Price per 6ft	$ 39.95	
Total Cost	$ 93.22	
Total Weight	9.819	lb
McMaster WT	0.049	in
McMaster OD	1.000	in
Price per 6ft	$ 29.84	
Total Cost	$ 69.63	
Total Weight	6.960	lb
McMaster WT	0.035	in
McMaster OD	1.125	in
Price per 6ft	$ 38.70	
Total Cost	$ 90.30	
Total Weight	5.698	lb

Figure E3. Analysis of 2 Bar Frame

Max Weight	150	lbs
# Beams	3	
Total Frame Length	84	in
Avg Location of Load (from origin)	52	in
Avg Location of Load (from wheels)	32	in
Factor of Safety	1.5	
Max Moment	990.476	psi

Aluminum (6061-T6)		
Density	0.1	lb/in^3
Yield Strength	35000	psi
Outer Diameter Guess	1.25	in
Max Bending Radius	0.625	in
Inner Diameter	1.174	in
Wall Thickness	0.038	in
McMaster WT	0.065	in
McMaster OD	1.000	in
Price per 6ft	$ 38.71	
Total Cost	$ 135.49	
Total Weight	4.811	lb
McMaster WT	0.125	in
McMaster OD	1.000	in
Price per 6ft	$ 30.79	
Total Cost	$ 107.77	
Total Weight	8.659	lb
McMaster WT	0.065	in
McMaster OD	1.250	in
Price per 6ft	$ 44.35	
Total Cost	$ 155.23	
Total Weight	6.098	lb

Steel (General Purpose 1020)		
Density	0.283	lb/in^3
Yield Strength	45000	psi
Outer Diameter Guess	1	in
Max Bending Radius	0.5	in
Inner Diameter	0.903	in
Wall Thickness	0.049	in
McMaster WT	0.049	in
McMaster OD	1.000	in
Price per 6ft	$ 10.18	
Total Cost	$ 35.63	
Total Weight	10.440	lb

Steel (4130 Alloy)		
Density	0.283	lb/in^3
Yield Strength	70000	psi
Outer Diameter Guess	0.875	in
Max Bending Radius	0.4375	in
Inner Diameter	0.794	in
Wall Thickness	0.041	in
McMaster WT	0.035	in
McMaster OD	1.000	in
Price per 6ft	$ 31.55	
Total Cost	$ 110.43	
Total Weight	7.567	lb
McMaster WT	0.065	in
McMaster OD	0.750	in
Price per 6ft	$ 31.07	
Total Cost	$ 108.75	
Total Weight	9.976	lb
McMaster WT	0.049	in
McMaster OD	0.875	in
Price per 6ft	$ 27.62	
Total Cost	$ 96.67	
Total Weight	9.068	lb

Figure E4. Analysis of 3 Bar Frame

Max Weight	150	lbs
# Beams	1	
Total Frame Length	84	in
Avg Location of Load (from origin)	52	in
Avg Location of Load (from wheels)	32	in
Factor of Safety	3	
Max Moment	2971.429	psi
Aluminum (6061-T6)		
Density	0.1	lb/in^3
Yield Strength	35000	psi
Outer Dimension Guess	1.5	in
Max Bending Distance	0.75	in
Inner Dimension	1.290	in
Wall Thickness	0.105	in
McCarthy WT	0.125	in
McCarthy OD	1.500	in
Price per Foot	$ 3.00	
Total Cost	$ 30.00	
Total Weight	8.250	lb

Figure E5. Analysis of 'T-Frame' with Square Tubing

PURPOSE: ANALYSIS OF SIMPLY SUPPORTED ALUMINUM BEAM (6061-T6)

ASSUME: MAX WEIGHT = 150 lbs

SIMPLY SUPPORTED BEAM ON BOTH ENDS

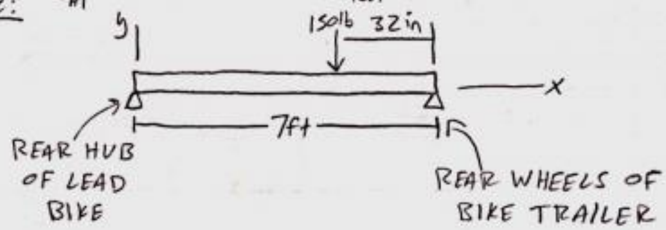
2-DIMENSIONAL BENDING ONLY

$\text{Density}_{Al} = 0.1\ \text{lb/in}^3$ $\text{Density}_{Steel} = 0.238\ \text{lb/in}$

$\sigma_y = 35\ \text{ksi}$ (MECHANICS OF MATERIALS BEER, FERDINAND)

F.O.S. = 1.5

SCHEMATIC:



FOR THE "T-FRAME" MODEL:

ANALYSIS:

$$M_{max} = \frac{(150\,lb)(32\,in)(52\,in)}{84\,in}$$

$$M_{max} = 2971.43\ psi$$

$$\frac{\sigma_y}{F.O.S} = \sigma_{max} = \frac{M_{max}\,c}{I}$$

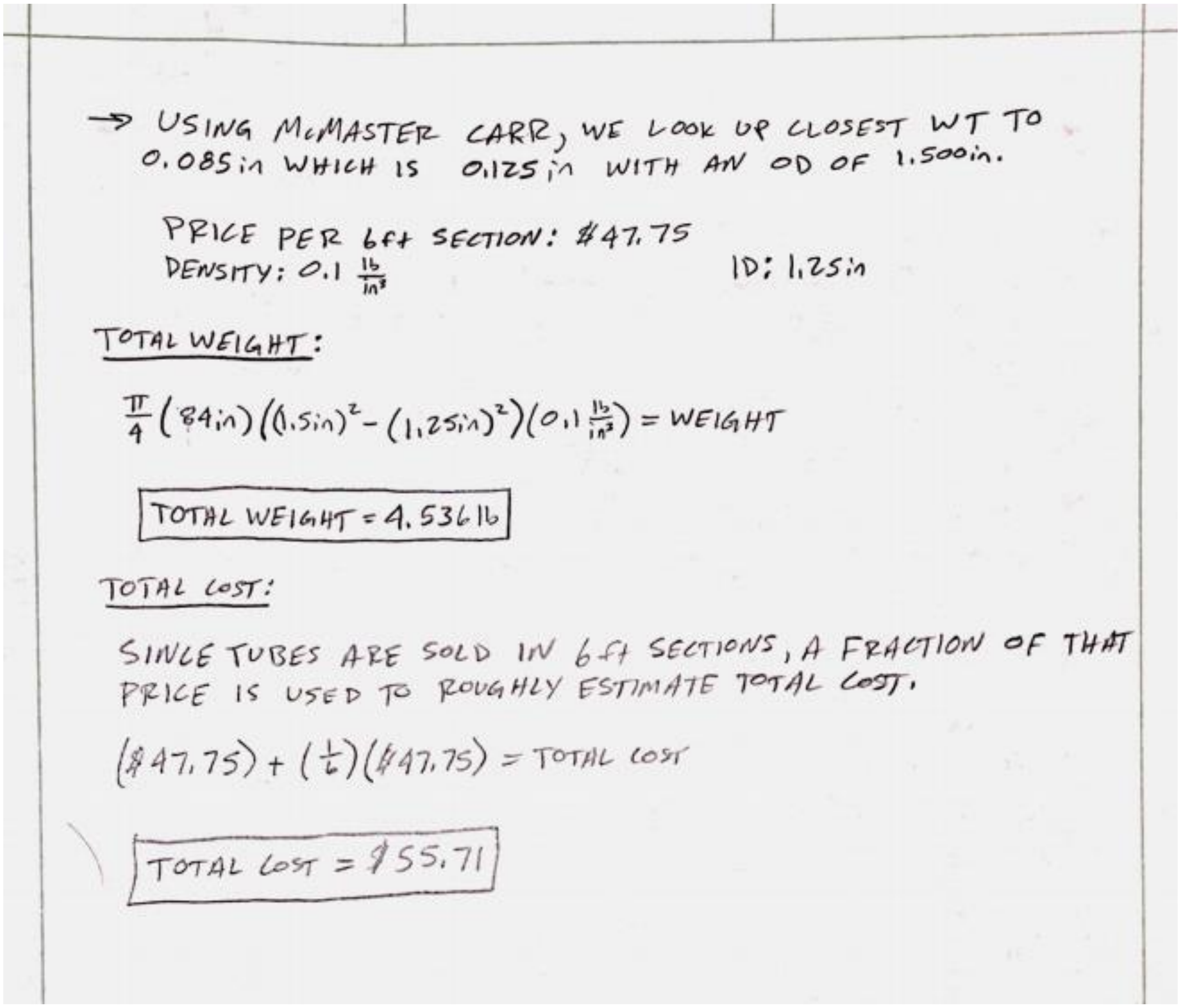
$$\frac{35000\,\frac{lb}{in^2}}{1.5} = \frac{(2971.43\,\frac{lb}{in^2})(0.75\,in)}{\frac{\pi}{64}\left((1.5\,in)^4 - D_i^4\right)}$$

$$\boxed{D_i = 1.329\,in}$$

$$\frac{D_o - D_i}{2} = WT = \frac{1.5\,in - 1.329\,in}{2} \Rightarrow \boxed{WT = 0.085\,in}$$

Figure E6: Analysis of Simply Supported Aluminum Beam

Appendix E: Analysis and Calculations (Page 7 of 8)



→ USING McMASTER CARR, WE LOOK UP CLOSEST WT TO 0.085in WHICH IS 0.125in WITH AN OD OF 1.500in.

PRICE PER 6ft SECTION: \$47.75

DENSITY: $0.1 \frac{lb}{in^3}$ ID: 1.25in

TOTAL WEIGHT:

$$\frac{\pi}{4}(84in)\left((1.5in)^2-(1.25in)^2\right)\left(0.1\frac{lb}{in^3}\right) = WEIGHT$$

TOTAL WEIGHT = 4.536 lb

TOTAL COST:

SINCE TUBES ARE SOLD IN 6ft SECTIONS, A FRACTION OF THAT PRICE IS USED TO ROUGHLY ESTIMATE TOTAL COST.

$$(\$47.75) + \left(\frac{1}{6}\right)(\$47.75) = TOTAL\ COST$$

TOTAL COST = \$55.71

Figure E7: Example Calculation of Total Weight and Cost for Aluminum

Appendix E: Analysis and Calculations (Page 8 of 8)

BOLT SHEAR STRENGTH

PURPOSE: TO MAKE SURE $\frac{3}{8}$"-16 BOLT CAN SUPPORT REBEKAH IN HER SEAT.

ANALYSIS:

$$P = \frac{S_t A}{N}$$

w/ N = FACTOR OF SAFETY = 3

$S_t = 0.6\, S_{ULT}$ = ULTIMATE STRENGTH OF BOLT

(0.6 IS FOR SAFETY DUE TO VARIATIONS IN MATERIAL)

A = CROSS-SECTIONAL AREA

P = LOAD = 150 lbs

AVERAGE STRESS AREA ↓

$$150\,lb_f = \frac{(0.6)(S_{ULT})(0.0775\,in^2)}{3}$$

$S_{ULT} = 9{,}677\,psi$

MIN PROOF STRENGTH = 120 ksi

MIN ULT STRENGTH = 150 ksi

∴ SINCE $S_{ULT_{CALCULATED}} < S_{PROOF}$

THE BOLT PASSES ✓

WE WILL USE A 3/8"-16 GRADE 8 BOLT TO ATTACH THE SEAT.

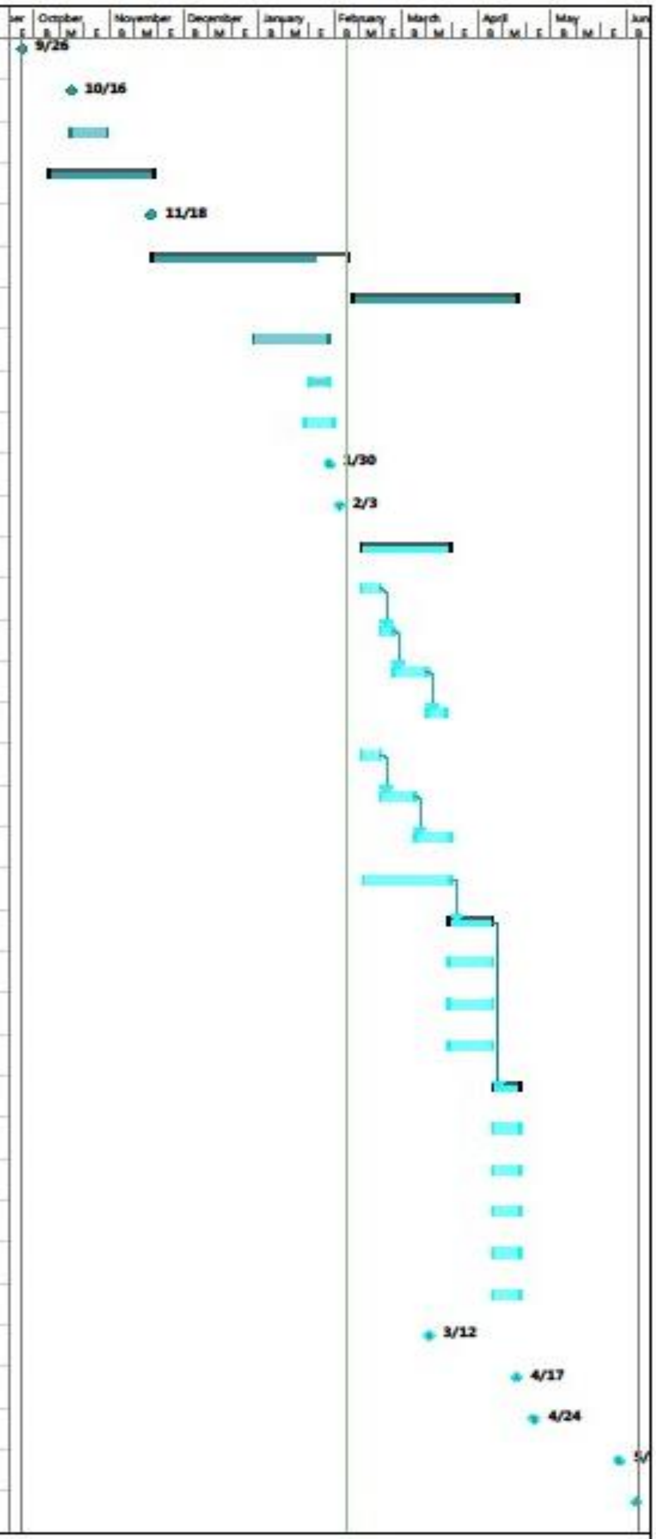
Figure E8. Bolt Shear Strength

Appendix F: Cost Tracking

Parts List and Cost Analysis								
Part #	Item/Labor Details	Material	Shipping (If Applicable)	Labor	Total, With Tax	Materials Company	Labor Company	Shipping Time
100	Bike Frame [$445]	$ 125.00	$ -	$ 320.00	$ -			
101	12' of 1.25" Square Aluminum(0.125" thick) w/ Welding	$ 125.00	$ -	$ 160.00	$ 285.00	McCarthy	Cal Poly Techs	Pickup
102	Powder Coating	$ -	$ -	$ 160.00	$ 160.00		C C Powder Coating	
200	Seat [$731.19]	$ 91.07	$ 21.05	$ 615.00	$ -			
201	20' of 0.82" Aluminum (0.125" thick) w/ Welding	$ 33.20	$ -	$ 180.00	$ 215.86	McCarthy	Gentry	Pickup
202	Cordura black fabric w/ stitching	$ -	$ -	$ 435.00	$ 435.00	Quality Fabrics	Mitch's Stitches	Pickup
203	Single Adjust Side 1" Release Buckles ($0.82 each)	$ 12.30	$ 7.16	$ -	$ 19.46	Strapworks		US Postal First Class
204	Split Release Buckle	$ 1.36	$ -	$ -	$ 1.36	Strapworks		US Postal First Class
205	Seat Belt Buckles	$ 3.40	$ -	$ -	$ 3.40	Strapworks		US Postal First Class
206	1" Black Nylon Straps (10' @ $0.45/ft)	$ 21.95	$ -	$ -	$ 21.95	Strapworks		US Postal First Class
207	Diono Soft Wraps, Black	$ 6.99	$ -	$ -	$ 7.51	Amazon		Prime (2-Day)
209	Rubber Push-in Bumper	$ 11.87	$ 13.89	$ -	$ 26.65	McMaster-Carr		Within a week
210	3/8-16 x 2.5in Bolt	$ -	$ -	$ -	$ -	Fastenal		UPS Ground
211	3/8-16 nut	$ -	$ -	$ -	$ -	Home Depot		Pickup
212	3/8-16 split lock washer	$ -	$ -	$ -	$ -	Home Depot		Pickup
213	3/8-16 washer	$ -	$ -	$ -	$ -	Home Depot		Pickup
300	Wheel System [$156.38]	$ 140.00	$ 16.38	$ -	$ -			
301	Axle	$ 20.00	$ 16.38	$ -	$ 36.38	Burley		Already Here
302	Wheels	$ 120.00	$ -	$ -	$ 120.00	Burley		Already Here
303	5/16-18 x 2.5in Bolt	$ -	$ -	$ -	$ -	Fastenal		UPS Ground
304	5/16-18 nut	$ -	$ -	$ -	$ -	Fastenal		UPS Ground
305	5/16-18 split lock washer	$ -	$ -	$ -	$ -	Home Depot		Pickup
306	5/16-18 washer	$ -	$ -	$ -	$ -	Home Depot		Pickup
400	Exercise Motivation [$291.61]	$ 92.36	$ 28.94	$ -	$ -			
401	WeeHoo Pedals	$ 20.00	$ 5.00	$ -	$ 25.00	WeeHoo		UPS Ground
402	Crankset	$ 35.99	$ -	$ -	$ 38.69	Retrospec		FedEx Ground
403	Brake Rotor (1/4" Aluminum Plate 12"x12")	$ -	$ -	$ -	$ -	OnlineMetals		UPS Ground
404	Kool Stop Dura 2 Threaded Set Triple Compound Pad	$ -	$ -	$ -	$ -	Amazon		Prime (2-Day)
405	Kool Stop Dura 2 Brake Insert (2)	$ -	$ -	$ -	$ -	Amazon		Prime (2-Day)
406	AL-202 HF USB Acoustics	$ 12.59	$ -	$ -	$ 12.59	Amazon		Prime (2-Day)
407	Adafruit Pro Trinket	$ 9.95	$ 4.79	$ -	$ 14.74	Adafruit		UPS Ground
408	Hall effect sensor - US5881LUA	$ 13.83	$ -	$ -	$ 13.83	Amazon&Adafruit		UPS Ground
409	10-24 x 2in bolt	$ -	$ -	$ -	$ -	Home Depot		Pickup
410	10-24 nut	$ -	$ -	$ -	$ -	Home Depot		Pickup
411	10-24 split lock washer	$ -	$ -	$ -	$ -	Home Depot		Pickup
412	6061 Aluminum BB Shell Threaded Eng 1.37 x 24 TPI with Releived Center	$ 8.75	$ 14.77	$ -	$ 23.50	Nova		1-5 Days
413	Shimano BB-UN26 Square Taper Bottom Bracket	$ 6.99	$ 4.38	$ -	$ 11.37	Amazon		Amazon (3 - Day)
414	Sheet Metal for Protection over Resistance Rotor	$ 41.03	$ -	$ -	$ 41.03	Miner's ACE		Pickup
415	Lunchbox to House Speakers and Wiring	$ 11.06	$ -	$ -	$ 11.06	Amazon		Prime (2-Day)
416	Solder Wire	$ 5.95	$ -	$ -	$ 5.95	Adafruit		UPS Ground
417	USB A Jack to 5.5/2.1mm jack adapter [ID:988]	$ 2.95	$ -	$ -	$ 2.95	Adafruit		UPS Ground
418	Battery Pack x 2	$ 7.08	$ -	$ -	$ 7.08	Amazon		Prime (2-Day)
419	Wire Housing HardShell	$ 8.28	$ -	$ -	$ 8.28	Amazon		Prime (2-Day)
420	Hand Knob with Thread Insert	$ 2.90	$ -		$ 2.90	Amazon		Prime (2-Day)
421	Socket Type Snap-Lock Leveling Mount	$ 19.06	$ -		$ 20.86	Amazon		Prime (2-Day)
422	Threaded Rod	$ 2.12	$ -		$ 2.12	Amazon		Prime (2-Day)
423	Magnets	$ 49.66	$ -	$ -	$ 49.66	Amazon		Prime (2-Day)
500	Attachment to Main Bike [$126.35]	$ 59.20	$ -	$ -	$ -			
501	4' of 1.25" Aluminum (0.125" thick)	$ -	$ -	$ 64.00	$ 64.00	McCarthy	Cal Poly Techs	Pickup
502	Standard Forged Hitch	$ 22.00	$ -	$ -	$ 25.15	Amazon		Prime (2-Day)
503	Flex Connector for Square Tow Barx2	$ 37.20	$ -	$ -	$ 37.20	Amazon		Prime (2-Day)
504	3/8 in. x 2 in. Zinc-Plated Universal Clevis Pin	$ -	$ -	$ -	$ -	Home Depot		Pickup
505	3/32" Hitch Pin	$ -	$ -	$ -	$ -	Home Depot		Pickup
600	Personal Storage [$30.97]	$ 29.18	$ -	$ -	$ -			
601	CreativeWare Large Storage Basket	$ 23.81	$ -	$ -	$ 25.60	Amazon		Prime (2-Day)
602	Premium Bike Bungee Cargo Net - X-thick Cord - 6 Hooks	$ 5.37	$ -	$ -	$ 5.37	Amazon		Prime (2-Day)
603	Black Zip-Ties	$ -	$ -	$ -	$ -	Home Depot		Pickup
000	Miscellaneous Expenditures [$645.08]	$ 638.93	$ 6.15	$ -	$ -			
001	Testing	$ -	$ -	$ -	$ -			
002	Motor for Liz	$ 579.00	$ -	$ -	$ 579.00			
003	3/8 in.-16 x 2 in. Zinc-Plated Grade 8 Hex Cap Screws ($0.96 each)	$ -	$ -	$ -	$ -	Home Depot		Pickup
004	#3/8 - 16 Coarse Zinc-Plated Steel Flange Nut ($0.60/bag)	$ -	$ -	$ -	$ -	Home Depot		Pickup
005	Zinc-Plated Split Lock Washers ($0.20 each)	$ -	$ -	$ -	$ -	Home Depot		Pickup
006	3/32" Zinc-Plated External Hitch Pin (2-Piece) ($0.54 each)	$ -	$ -	$ -	$ -	Home Depot		Pickup
007	Stationary Pedal	$ 32.24	$ -	$ -	$ 32.24	Amazon		Prime (2-Day)
008	3/8" Yellow Zinc Grade 8 Flat Washer ($0.84/3)	$ -	$ -	$ -	$ -	Home Depot		Pickup
009	Safety Flag: Pink	$ 16.95	$ 6.15		$ 23.10	Aditude Gear		Priority
010	Coupler Bike Attachment (For testing)	$ 10.74	$ -		$ 10.74	Amazon		Prime (2-Day)
Total		$ 1,259.55	$ 72.52	$ 999.00	$ 2,426.58			

Appendix G: Gantt Chart

ID	Task Name	Duration	Start	Finish
1	Project Selection	0 days	Fri 9/26/14	Fri 9/26/14
2	Meeting With Sponsor	0 days	Thu 10/16/14	Thu 10/16/14
3	Problem Definition	11 days	Thu 10/16/14	Thu 10/30/14
4	**Idea Generation**	**31 days**	**Tue 10/7/14**	**Tue 11/18/14**
11	Preliminary Design Report	0 days	Tue 11/18/14	Tue 11/18/14
12	**Detailed Design**	**59 days**	**Tue 11/18/14**	**Fri 2/6/15**
49	**Electric Motor**	**49 days**	**Mon 2/9/15**	**Thu 4/16/15**
52	Bill of Materials	23 days	Tue 12/30/14	Thu 1/29/15
53	Test Plan	6 days	Thu 1/22/15	Thu 1/29/15
54	CDR Presentation	10 days	Tue 1/20/15	Sat 1/31/15
55	Design Report	0 days	Fri 1/30/15	Fri 1/30/15
56	Critical Design Review	0 days	Tue 2/3/15	Tue 2/3/15
57	**Manufacture**	**27 days**	**Thu 2/12/15**	**Fri 3/20/15**
58	Purchase Frame Tubes	6 days	Thu 2/12/15	Thu 2/19/15
59	Cut Tubes	3 days	Fri 2/20/15	Tue 2/24/15
60	Weld Frame	10 days	Wed 2/25/15	Tue 3/10/15
61	Paint Frame	6 days	Wed 3/11/15	Wed 3/18/15
62	Purchase Seat Frame Tubes	6 days	Thu 2/12/15	Thu 2/19/15
63	Weld Seat	10 days	Fri 2/20/15	Thu 3/5/15
64	Stich Seat Cover	11 days	Fri 3/6/15	Fri 3/20/15
65	Purchase and Delivery	26 days	Thu 2/12/15	Fri 3/20/15
66	**Assembly**	**12 days**	**Fri 3/20/15**	**Mon 4/6/15**
67	Motivational System	12 days	Fri 3/20/15	Mon 4/6/15
68	Peddles and Resistance Device	12 days	Fri 3/20/15	Mon 4/6/15
69	Rest of Trailer	12 days	Fri 3/20/15	Mon 4/6/15
70	**Testing**	**9 days**	**Tue 4/7/15**	**Fri 4/17/15**
71	Test Eletrical Systems	9 days	Tue 4/7/15	Fri 4/17/15
72	Test Wheels	9 days	Tue 4/7/15	Fri 4/17/15
73	Test Adjustabity	9 days	Tue 4/7/15	Fri 4/17/15
74	Test Frame	9 days	Tue 4/7/15	Fri 4/17/15
75	Test Harness	9 days	Tue 4/7/15	Fri 4/17/15
76	Test Status Presentation	0 days	Thu 3/12/15	Thu 3/12/15
77	Project Updated Memo	0 days	Fri 4/17/15	Fri 4/17/15
78	Project Hardware/Safety Demo	0 days	Fri 4/24/15	Fri 4/24/15
79	Senior Design Expo	0 days	Fri 5/29/15	Fri 5/29/15
80	Final Project Report	0 days	Fri 6/5/15	Fri 6/5/15



Page 1

Appendix H: DVP&R Charts (Page 1 of 2)

ME428 DVP&R Format													
TEST PLAN									TEST REPORT				
Item No	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
					Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
Wheels												
1	Wheel attachment strength	Wheels can be pulled at a force of 50 lbs without detaching	Alex	DV	1	B	4/1/2015	4/1/2015	Pass	1	0	
2	Wheel placement and width	Lead bike can maneuver around obstacles placed 15 feet apart without wheels skidding or leaving ground	Alex	DV	5	B	5/15/2015	5/15/2015	Pass	5	0	
Electrical Systems												
3	Physical durability of speakers	No damaged substained from the trailer falling over	Jacob	DV	1	B	5/12/2015	5/12/2015	Pass	1	0	
4	Electrical systems turns on	Pedaling turns on music	Jacob	CV	60	A	3/1/2015	3/1/2015	Pass	60	0	
5	Electrical systems turns off	Music turns off after pedaling stops	Jacob	CV	60	A	3/1/2015	3/1/2015	Pass	60	0	
6	Music is clear during use of bike trailer.	Music stays on, uninterrupted, at Rebekah's pedal speed	Jacob	CV	60	A	5/26/2015	5/26/2015	Pass	60	0	
Attachment to Lead Bike												
7	Durability of attachment	After 30 minutes of riding, there is no visible warping, cracking or permanent deformation	Alex	DV	1	B	5/15/2015	5/15/2015	Pass	1	0	
8	Strength of attachment	Does not come undone when pulling trailer around for 30 min with max weight	Alex	DV	1	B	5/15/2015	5/15/2015	Pass	1	0	
9	Ease of attachment	Attachment arm can be detached from lead bike and trailer in under 3 minutes	Alex	DV	5	B	5/15/2015	5/15/2015	Pass	5	0	

Appendix H: DVP&R Charts (Page 2 of 2)

ME428 DVP&R Format												
TEST PLAN									TEST REPORT			
Item No	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
					Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
Seat & Adjustability												
10	Sliding cability of seat adjustment	Seat can easily slide without scraping or getting stuck	Alex	DV	1	B	5/15/2015	5/15/2015	Fail	0	1	Seat cannot slide due to powder coat. This is considered acceptable though since seat can still be removed and placed over frame
11	Pinch point protection	Rebekah cannot reach the ground or wheels while sitting on the trailer	Kelly	CV	1	A	5/26/2015	5/26/2015	Pass	1	0	
12	Ease of adjjustability	Seat can be adjusted in under 10 minutes	Alex	DV	4	B	5/15/2015	5/15/2015	Pass	4	0	
13	Quality of harness	Harness taken on and off 50 times with no sign of rips or seam tears	Kelly	DV	1	B	5/15/2015	5/26/2015	Pass	1	0	
14	Harness adjustability	Harness can strap in Rebekah at her current size and up to the size of 5'5" person	Project Group	CV	1	A	5/26/2015	5/26/2015	Pass	1	0	
Frame												
16	Weight	Trailer weighs under 50 lbs	Alex	DV	1	B	5/15/2015	5/15/2015	Pass	1	0	
17	Height	Trailer's height is under 40 inches	Alex	DV	1	B	5/15/2015	5/15/2015	Pass	1		
18	Width	Trailer's width is under 22 inches	Alex	DV	1	B	5/15/2015	5/15/2015	Fail	0	1	Deemed acceptable since the initial design width was arbitrarily chosen before parts were bought
19	Length	Trailer's length is under 90 inches	Alex	DV	1	B	5/15/2015	5/15/215	Pass	1	0	
20	Turning capability of elongated prototype	Lead bike can maneuver around obstacles placed 15 feet apart without hitting obstacles or the rider having to put foot on ground	Alex & Jacob	DV	5	B	5/15/2015	5/15/2015	Pass	5	0	
Pedaling												
21	Heat generated by resistance pedaling	Temperature of brake rotor remains less than 110 F after 30 minutes of pedaling	Alex	DV	1	B	5/15/2015	5/15/2015	Pass	1	0	
22	Straps of Pedals	Rebekah's feet remain strapped into the pedals as she rides	Project Group	DV	1	B	5/26/2015	5/26/2015	Pass	1	0	

Appendix I: DFMEA Charts (Page 1 of 5)

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System 1 - Bicycle Trailer
_X_ Subsystem 2 - Adjustment Bracket
___ Component

Design Responsibility:

FMEA Number:

Page 1 of 1

Model Year(s)/Vehicle(s):

Key Date: 12/2/2014

Prepared By: Cameron Weinberg

Core Team: Rebekah's Ride

FMEA Date (Orig.) 12/2/2014 (Rev.) 12/2/2014

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Secures Seat	Scratches paint on frame	Exposed metal undergoes corrosion	7	High friction contact between bracket and frame	5	35	Create smoother sliding surface for adjustment.					
Adjust size		Undesired aesthetic	3		5	15						
	Chatters during use	Undesired noise	2	Too large of tolerance fit	3	6						
		Seat slowly moves from desired setting	3		3	9						

Appendix I: DFMEA Charts (Page 2 of 5)

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System 1 - Bicycle Trailer
_X_ Subsystem 2 - Attachment to Main Bike
___ Component

FMEA Number:

Design Responsibility:

Page 1 of 1

Model Year(s)/Vehicle(s):

Key Date: 12/2/2014

Prepared By: Cameron Weinberg

Core Team: Rebekah's Ride

FMEA Date (Orig.) 12/2/2014 (Rev.) 12/2/2014

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Pulls Bike Trailer	Slips around	Bike trailer unstable	4	Main bike is too small for the attachment mechanism	5	20	Adjust high and low tolerances of attachment to fit 95th percentile of bike frames					
Helps keep bike system stabilized	Attachment Breaks	Bike Trailer Detaches	8	Weak joint	4	32	Increase safety factor in analysis					

Appendix I: DFMEA Charts (Page 3 of 5)

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System 1 - Bicycle Trailer
_X_ Subsystem 2 - Bike Frame
___ Component

Design Responsibility:

FMEA Number:

Page 1 of 1

Model Year(s)/Vehicle(s):

Key Date: 12/2/2014

Prepared By: Cameron Weinberg

Core Team: Rebekah's Ride

FMEA Date (Orig.) 12/2/2014 (Rev.) 12/2/2014

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Supports Trailer Components	Corrosion	Frame falls apart during use	9	Exposed metal due to holes	5	45	Seal all cuts and holes unprotected by paint coat					
Stabilize bike trailer			9	Too thin of a paint coat	8	72						
	Bending	Trailer drags after many uses	6		3	18						

Appendix I: DFMEA Charts (Page 4 of 5)

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System 1 - Bicycle Trailer
_X_ Subsystem 2 - Pedals
___ Component

Design Responsibility:

FMEA Number:

Page 1 of 1

Model Year(s)/Vehicle(s):

Key Date: 12/2/2014

Prepared By: Cameron Weinberg

Core Team: Rebekah's Ride

FMEA Date (Orig.) 12/2/2014 (Rev.) 12/2/2014

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Provides exercise	Pedals lock up and are unable to rotate	Rebekah doesn't get exercise	4	Ungreased axel	2	8						
	Pedal Connection to frame breaks	Rebekah's foot hits the ground	7	Poor welding/rust	2	14						
	Strap holding Rebekah's foot breaks	Rebekah's foot is not attached to anything	5	Bas sewing	4	20						

Appendix I: DFMEA Charts (Page 5 of 5)

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System 1 - Bicycle Trailer
_X_ Subsystem 2 - Seat
___ Component

Design Responsibility:

FMEA Number:

Page 1 of 1

Model Year(s)/Vehicle(s):

Key Date: 12/2/2014

Prepared By: Cameron Weinberg

Core Team: Rebekah's Ride

FMEA Date (Orig.) 12/2/2014 (Rev.) 12/2/2014

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Provides comfort	Rebekah doesn't fit in seat	Rebekah is uncomfortable	7	Seat was designed too small	10	70	Allow room for Rebekah's growth over time					
Supports & secures child	Seat Fabric tears through	Rebekah is exposed to the environment below	3	Poor fabric choice	4	12						
			3	Repeated use	7	21						

Appendix J: Safety Checklist (Page 1 of 2)

ME428/429/430 Senior Design Project 2014-2015

SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

Team: ______________________ Advisor: ______________

Y	N	
×	☐	Do any parts 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 adequately guarded?
☐	×	Does any part of the design undergo high accelerations/decelerations that are exposed to the user?
☐	×	Does the system have any large moving masses or large forces that can contact the user?
☐	×	Does the system produce a projectile?
×	☐	Can the system to fall under gravity creating injury?
☐	×	Is the user exposed to overhanging weights as part of the design?
☐	×	Does the system have any sharp edges exposed?
☐	×	Are there any ungrounded electrical systems in the design?
☐	×	Are there any large capacity batteries or is there electrical voltage in the system above 40 V either AC or DC?
×	☐	Is there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids when the system is either on or off?
☐	×	Are there any explosive or flammable liquids, gases, dust, or fuel in the system?
☐	×	Is the user of the design required to exert any abnormal effort and/or assume a an abnormal physical posture during the use of the design?
☐	×	Are there any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	×	Will the system generate high levels of noise?
×	☐	Will the product be subjected to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc. that could create an unsafe condition?
☐	×	Is it easy to use the system unsafely?
☐	×	Are there any other potential hazards not listed above? If yes, please explain on the back of this checklist.

For any "Y" responses, add a complete description on the reverse side. DO NOT fill in the corrective actions or dates until you meet with the mechanical and electrical technicians.

Appendix J: Safety Checklist (Page 2 of 2)

Description of Hazard	Corrective Actions to be Taken	Planned Completion Date	Actual Completion Date
The bicycle trailer has rotating wheels that could be a potential pinch point.	Place the wheels far enough behind the bike so they are not a safety hazard.	5/15	
The trailer could topple over if someone is reckless.	Use a two wheel design in order to prove stability. Instruct users of proper bicycle trailer use.	5/15	
A battery is used to power the speakers.	Keep the battery in water proof storage.	5/15	
The bicycle trailer could possibly be used in foggy conditions	Advise the rider to check the weather before going on rides. Provide the trailer with proper lights and flags.	5/15	

Attachment Arm

The Burley Square Flex Connector is depicted below. The piece that connects the trailer to the lead bicycle is made of a durable, flexible material. Due to this fact, the long, cylindrical piece is meant to flex to absorb bumps and move with the lead bicycle.

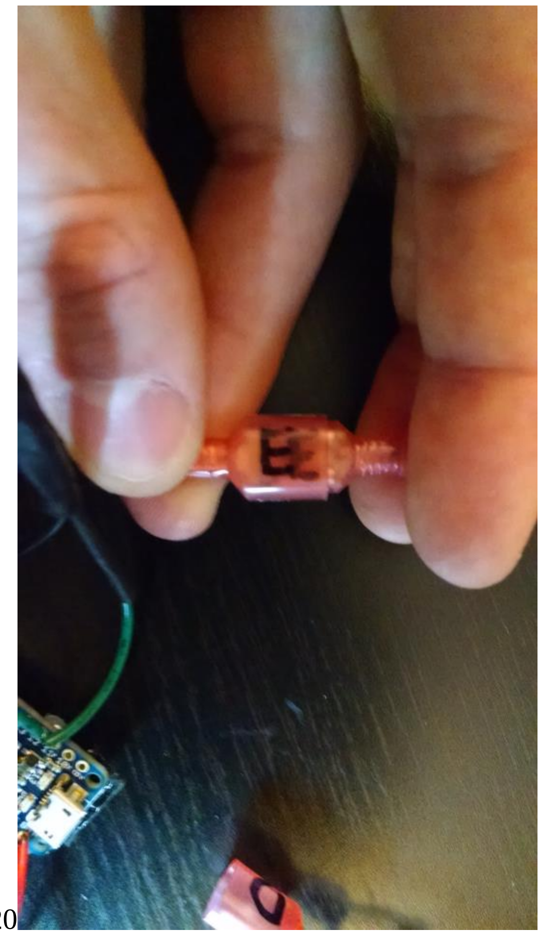
ATTENTION: Since there is repeated flexing in this piece, IT MUST BE CHECKED FOR ANY ISSUES regularly. It is suggested to check the piece every few rides to ensure there are no cracks or other impurities developing in the flex connector.

It is necessary to replace this item AT LEAST once every year to prevent any damage to the lead bicycle or the trailer. The replacement "Burley Square Flex Connector" (Burley part #950038) can be found on the Burley website, Amazon, and many other retailers for about $20. Be sure to search for the square flex connector, since Burley has a similar attachment piece for round tube frames.

Music System

The motivational music system works by a magnetic triggering system that is located on the disc that is attached to the pedals of the bicycle trailer. If the music system ever stops playing, follow these troubleshooting steps in order:

1) Turn both battery packs off, count for three seconds, and turn the battery packs back on again
2) Repeat Step 1 with a 10 second count.
3) Assure both power packs are turned on and flip the toggle switch to play music constantly. If music plays, skip to Step 10. If it does not play, continue to step 4.
4) Open up the electronic box, keeping track of the small screws than hold the lid on.
5) Check all off the wire disconnect junctions and be sure they are fully pushed together. These disconnects are present so that the entire motivational system can be detached from the bike when not in use. Be sure that all letters correspond with each other as seen in the figures below (i.e. X matches with X, A matches with A)

[20]


6) The Adafruit microcontroller should have a green light constantly on. If there is a red light, solid or blinking, repeat step 2 until the red light is no longer on. (It may take a few moments for the red light to disappear after turning on the microcontroller.)
7) Check all connections to make sure no metal terminals are shorting each other (metal touching another terminal or bare wire that should not be in contact).

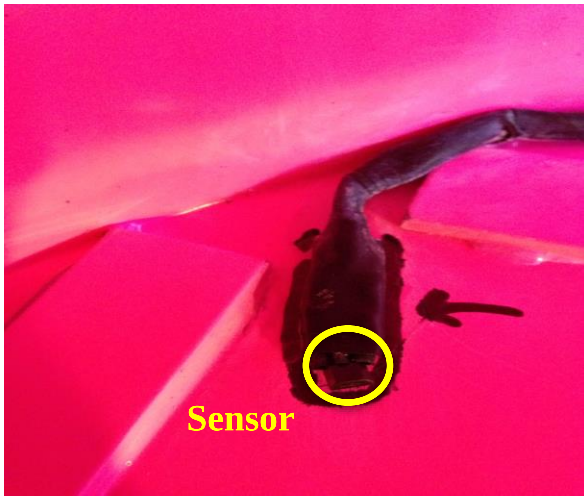
8) If the Adafruit microcontroller green light is not on, replace the battery pack that is not attached to the voltage regulator.

9) Replace the battery in the power pack attached to the voltage regulator with a new 9V battery

10) Check that the magnet is still secured to the disc that is attached to the pedals. If no magnet is present, any 1/8” thick magnet a half inch in diameter or larger can be used as a replacement (sold at Home Depot or any hardware store). Secure flush with outer edge of disc with an adhesive such as JB Weld or a two part epoxy.

11) Follow the procedure to remove the protective shroud from the frame of the trailer, which can be found in the Assembly Guide. Once the shroud is removed and magnets are removed, check to see that the Hall Effects Sensor is still secured in the top of the protective shroud.

12) The sensor may be dislodged from the shroud (there is a black outline of where the sensor should be). If this is the case, lightly sand the inside of the shroud where the sensor is to be secured (the black outlined area). Apply superglue to the underside of the electrical tape that is wrapped around the sensor leads. Carefully press the sensor and tape onto the surface within the black outline as flat as possible. Add more superglue to the sides of the wire that lead to the top of the shroud. Be sure that the superglue creates a good connection between the wiring and the shroud surface.

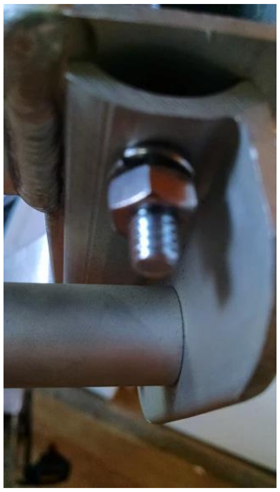


Wheels

Required Parts:
Burley Nomad Axle Tube Assembly (Part #: 950029)
1/4” by 2 1/2" bolts (4)
1/4” nuts (4)
1/4” washer (4)
1/4” split lock washer (4)
Burley 20” Wheel (2) (Part #: 160028)

Align the Burley Nomad Axle Tube Assembly to the corresponding holes in the custom trailer frame.
Place 1/4” bolt and washer through hole (x4).

Insert split lock washer on opposite side of bolt, then tighten bolt down securely.



Insert Burley 20” wheel axle into the Burley Nomad Axle Assembly until inside of wheel axle is flush with the axle tube assembly.

Tighten the quick release lever on the Burley wheel set.

NOTE: This will be a tight junction; it is what holds the wheel onto the axle assembly. DO NOT attempt to loosen or tighten the nut on the opposite side of the quick release lever. It is factory set and should not be adjusted.

The final assembled wheels on the frame should look like the picture below.

Pedaling System

<u>Required Parts:</u>
Standard bottom bracket
Chain ring bolts (5)
Crank arm (2)
Custom aluminum rotor
Crank bolts (2)
Weehoo pedals (2)

Thread in bottom bracket to the bottom bracket shell on the frame. The threads on the bottom bracket should thread into the RIGHT side of the frame if you were to stand on the frame and face forward, in the direction of travel. Next, thread the loose cap on the LEFT side of the frame (facing forward).

NOTE: This requires the use of a bottom bracket tool.

NOTE: the RIGHT side threads (the threads attached to the bottom bracket) are reverse threads (clockwise = loosen) while the LEFT side threads (plastic ring) are normal threads (clockwise = tighten).

Place custom rotor onto the crank arm.

Secure using five chain ring bolts using an Alan wrench.

NOTE: Use a thread locker such as Loctite Threadlocker Red when fastening these bolts to ensure they do not come loose during use.

Press crank arm WITHOUT the custom rotor over the LEFT side of the bottom bracket (facing forward). Secure using crank bolt threading into the bottom bracket. This does not have to be tightened forcefully, but should be snug.

Press crank arm WITH the custom rotor over the RIGHT side of the bottom bracket (facing forward). Secure using crank bolt threading into the bottom bracket. This does not have to be tightened forcefully, but should be snug.

Thread the RIGHT pedal into the RIGHT crank arm (facing forward). The pedals have an “R” or “L” designation on the face of the threaded post of the pedal. Secure tightly using a crescent or pedal wrench. Repeat for the LEFT side pedal.

NOTE: The right pedal is normal threaded (clockwise = tighten) while the left pedal is reverse threaded (clockwise = loosen).

Magnetic Resistance System

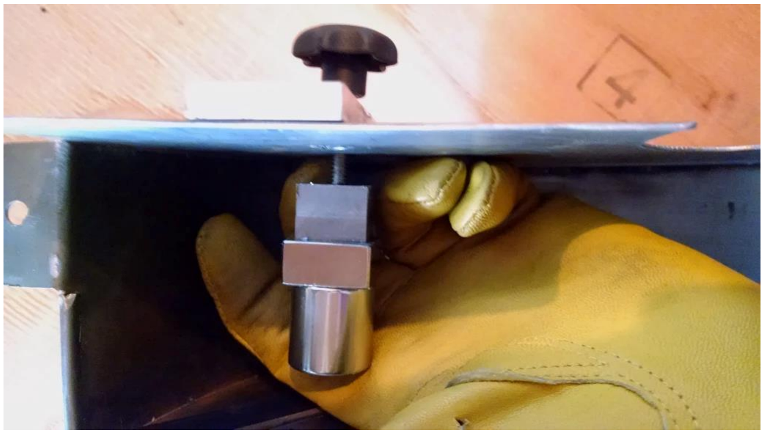
Required Parts:
Custom protective shroud
1 1/2" by 3/8” thick magnet (2)
1” by 1” thick magnet (2)
1” by 1” by 1/2" thick magnet (2)
Custom threaded steel block (2)
1/4" – 20 (diameter – threads per inch) threaded rod with plastic handle (2)

Thread rod with plastic handle through top hole in protective shroud (x2).

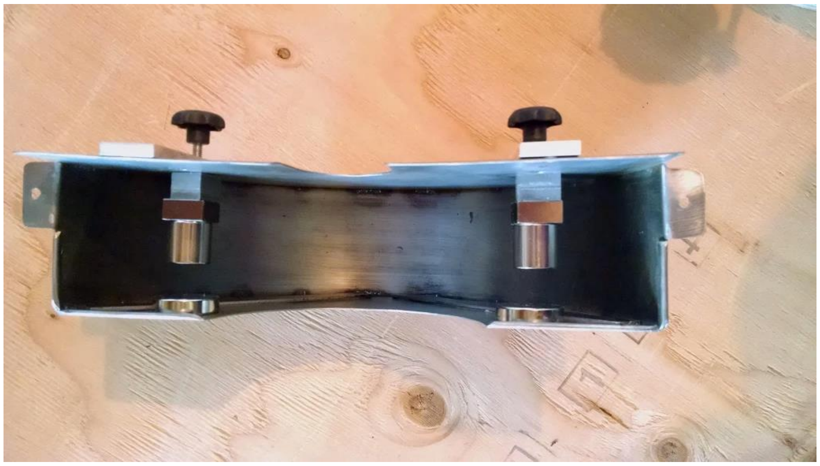
CAUTION! The magnets used in this system are EXTREMELY powerful and should be handled with extreme care. Use thick gloves when handling. Be sure to keep any electronics or magnetic material (Aluminum is NOT magnetic, steel IS magnetic) a safe distance away when handling the magnets.

With the 1”x1” square magnet and the 1”x1” cylindrical magnet stacked on the custom threaded steel block, thread the handle into the custom steel block until tight.

NOTE: the magnet will naturally want to attract to the steel protective shroud, so use caution when removing/placing these magnets.



The final assembled magnets in the protective shroud will look similar to the picture shown below.



Protective Shroud

Required Parts:
Custom protective shroud
#8 by 2” long bolts (2)
#8 by 2 1/2" long bolts (4)
#8 washers (6)
#8 split lock washers (6)
#8 nuts (6)

Place protective shroud over the rotor. Be mindful of the location of the magnets in the shroud when it is lowered over the aluminum disk. It is easiest to place the shroud on the frame when the crank on the aluminum disk is in the downward position, as seen in the picture below.

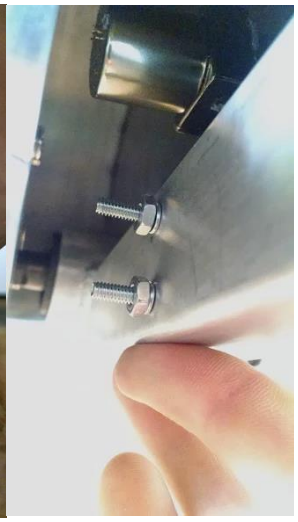
Locate the front and rear tabs on the protective shroud and line up the holes in the shroud with the corresponding holes in the frame. Insert a #8 by 2” long bolt (shorter of the two types of bolts) and washer into the front tab. Repeat for the rear tab.

Locate the four holes on the lower LEFT side of the protective shroud (facing forward). Insert two #8 by 2 1/2" long bolts (longer bolts) and washers through the forward holes so the end of the threaded portion of the bolt is towards the rotor. Repeat for the side rear two holes.

Place #8 lock washer then nut on each of the previously placed six #8 bolts.

CAUTION! Use extreme caution when using metal tools to tighten bolts as they are close to the magnets.

Tighten the four side bolts firmly. Tighten the two top tab bolts snugly (no need to over tighten these, they help with placement of the shroud over the rotor).

The final assembled protective shroud will look similar to the images below.


Seat

<u>Required Parts:</u>
Custom seat frame with fabric
3/8” by 2 1/2” bolt
3/8” nut
3/8” washer
3/8” split lock washer
Safety flag

The seat’s fabric tightness may be adjusted by tightening or loosening the straps that run down the back of the seat. The entire seat fabric may be removed and washed, if desired.

Place the seat over the trailer frame and line up the hole in the bottom of the seat with the desired hole in the frame. Each hole is 1 1/2" from the next to allow for adjustability.

Place the 3/8” bolt and washer through the seat and frame holes.

Place the 3/8” split lock washer then nut on the opposite side and tighten firmly.

Insert the safety flag to the receiver located near the upper RIGHT of the seat (facing forward). The final assembled seat will look similar to the image below.

NOTE: The electronics bag clips to the top tube on the rear of the seat frame using two carabiner clips.

Attachment Arm

<u>Required Parts:</u>
Custom attachment arm
3/8” clevis pin
Cotter pin
Burley Square Flex Connector (Part #: 950038)
Burley Standard Forged Hitch (Part #: 960041)

Insert the slotted end of the custom attachment arm to the trailer frame. Be sure that the attachment arm extends out to the LEFT (facing forward).

Place the 3/8” clevis pin through the attachment arm and frame hole and insert cotter pin to secure in place.

Insert the Burley square flex connector piece into the end of the custom attachment arm so that the rounded end is inserted first.

Place the given bolt through the safety strap hole from top to bottom of the attachment arm.

Place safety clip ring on the bottom of the attachment arm so it is flush with the frame. Next, place the split lock washer then nut on the bolt, and tighten down firmly.

NOTE: Be sure that the safety clip ring is extending FORWARD or LEFT (facing forward). It is pictured to the LEFT in the image below.

When attaching to lead bicycle, place cylindrical portion of the flex connector into the Burley standard forged hitch (located on lead bicycle rear axle). Place pin through the top of the Burley standard hitch and flex connector and secure with clip.

NOTE: Be sure to place the pin in the hitch from top to bottom, NOT bottom to top. If placed incorrectly, the connection could come loose during operation.

Loop safety strap around rear chain stay portion of lead bicycle frame and clip to bottom safety clip ring (see picture above).

Final Assembly

Appendix M: Electronics List

1: Adafruit Pro Trinket 5V (https://learn.adafruit.com/downloads/pdf/introducing-pro-trinket.pdf)

1: DROK® Ultra Small 5V Car Audio Amplifier Mini Power Amplifier (090155) (http://www.alldatasheet.com/datasheet-pdf/pdf/246505/PAM/PAM8403.html)

1: Addicore 5V 1.5A Positive Voltage Regulator L7805CV (http://www.st.com/web/en/resource/technical/document/datasheet/CD00000444.pdf)

1: NPN Transistor 2N2222 (https://cdn.sparkfun.com/datasheets/Components/General/P2N2222A-D.PDF)

1: 3144 Hall Effect Sensor (http://www.mpja.com/download/a3144eul.pdf)

1: 0.1 μF Polyester-Film Capacitor

1: 0.22 μF Polyester-Film Capacitor

2: 10KΩ Resistor

1: 330Ω Resistor

1: Toggle Switch

2: 9 V Battery Holder with switch

2: 9 V Batteries

Gardner Bender 15-151M Fully Insulated Male Disconnects

Gardner Bender 15-151F Fully Insulated Female Disconnects

22 gauge stranded wire (green, red, black)